# SUBSISTENCE STRATEGIES AND PLANT DOMESTICATION DURING THE NEAR EASTERN NEOLITHIC TRANSITION

**Dissertation**

der Mathematisch-Naturwissenschaftlichen Fakultät
der Eberhard Karls Universität Tübingen
zur Erlangung des Grades eines
Doktors der Naturwissenschaften
(Dr. rer. nat.)

vorgelegt von
Alexander Weide
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# Danksagung

Eine wissenschaftliche Arbeit – und ganz besonders eine Dissertation – ist nicht der Verdienst einer einzigen Person. Nicht nur die reine Möglichkeit eine solche Arbeit durchführen zu können, sondern auch ihre Ausrichtung und endgültige Form, gehen auf eine Vielzahl an Anregungen und hilfreiche Kommentare zurück, die ich in den letzten dreieinhalb Jahren von Kollegen und Freunden erhalten habe. Da die Liste an Menschen, die mich in dieser Zeit begleitet haben, unendlich lang ist, kann hier natürlich nur einer Auswahl persönlich gedankt werden, was mir hoffentlich verziehen wird.

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## Abstract

The present dissertation project focuses on the reconstruction of plant-based subsistence practices at the aceramic Neolithic site of Chogha Golan in the foothills of the central Zagros Mountains of Iran. A team of the Tuebingen-Iranian Stone Age Research Project (TISARP) excavated two trenches at the site in 2009 and 2010, recovering abundant inorganic and organic remains for studying the site's occupation history. Radiocarbon dating soon made clear that Chogha Golan was first settled during the 12th millennium and occupied until ca. 9,600 cal BP. Major goals therefore include the study of subsistence strategies through time and the comparison of the local socioeconomic record with regional and supra-regional developments. In building upon previous analyses, I studied macrobotanical remains from the mid-sequence (~10,600 cal BP) to the final settlement phase. This period is of major importance for investigating Near Eastern agricultural origins, because morphologically domesticated plants appeared throughout the Levant and central Anatolia between ca. 10,700 and 10,200 cal BP. At Chogha Golan, chaff remains of non-shattering emmer wheat only appeared towards 9,800 cal BP, marking the beginnings of crop cultivation at the site. A major question thus focuses on possible resource management strategies prior to the adoption of emmer wheat. A high abundance of wild grasses, including wild barley (*Hordeum spontaneum*), *Aegilops* sp., wild oats (*Avena* spp.) and many other medium to large-seeded taxa, characterize the complete sequence. In light of the long occupation history and the continuous exploitation of these wild grasses, the active management of local grasslands likely assured the long-term use of these important food resources before emmer was cultivated. These results resemble patterns from many other sites in the Zagros arc, highlighting the importance of wild grasses for local pre-agricultural subsistence strategies. This is in contrast with patterns from the Levantine corridor, where Early Holocene groups heavily focused on a few wild cereal species, which they presumably cultivated for approximately 1,000 years before morphological domestication traits became fixed. This protracted domestication process has often been interpreted from an economic and environmental perspective, but I suggest a significant influence of the slow development of social organizations to be responsible for these patterns. With an emphasis on the emergence of households and individual ownership systems, I suggest that only private food storage allowed a group of cultivators to maintain a selection chain that eventually gave rise to domesticated plants. In this perspective, the social organization of a community is of crucial importance to understand patterns in the emergence of plant cultivation and domestication, which we must integrate in the available explanatory frameworks.

# Zusammenfassung

Die vorliegende Dissertation untersucht die pflanzenbasierten Subsistenzwirtschaft auf der frühneolithischen Fundstelle Chogha Golan am Fuße des zentralen Zagrosgebirges im Iran. Ein Team des „Tuebingen-Iranian Stone Age Research Project" (TISARP) führte 2009 und 2010 Ausgrabungen auf dem Tell durch, welche umfangreiches Material zur Untersuchung der lokalen Siedlungsgeschichte erbrachten. Radiokarbondatierungen machten schnell klar, dass die Siedlung vom 12. Jahrtausend bis ca. 9.600 v.H. besiedelt war. Die wichtigsten Fragestellungen zielen daher auf die langfristige Subsistenzentwicklung und ihre regionale und überregionale Bedeutung ab. Aufbauend auf frühere Studien habe ich makrobotanisches Material aus der oberen Hälfte der Stratigrafie ab ca. 10.600 v.H. untersucht. Dieser Zeitraum ist von zentraler Bedeutung für die Erforschung des frühen Ackerbaus, da zwischen ca. 10.700 und 10.200 v.H. die ersten domestizierten Getreide in der Levante und in Zentralanatolien auftauchten. Am Chogha Golan datieren die frühesten Reste domestizierten Emmers auf ca. 9.800 v.H., weshalb die Untersuchung vorangegangener Subsistenzstrategien und möglicherweise des aktiven Förderns wilder Pflanzengesellschaften in den Fokus rückten. Die Pflanzenreste der kompletten Stratigrafie sind von einem hohen Anteil an Wildgräsern gekennzeichnet, die u.a. Wildgerste (*Hordeum spontaneum*), Walch (*Aegilops* sp.) und wilden Hafer (*Avena* sp.) beinhalten. Diese diversen Wildgräser wurden wahrscheinlich gezielt gefördert, wenn auch nicht kultiviert, um eine stabile Nahrungsgrundlage über mehrere Jahrtausende sicherzustellen. Ähnliche Muster sind von mehreren anderen Fundstellen aus dem Zagrosgebirge bekannt und demonstrieren, dass Wildgräser eine hohe Bedeutung für lokale Subsistenzstrategien hatten. Dies steht im Kontrast zur Levante, wo frühholozäne Gruppen auf die Nutzung und wohl auch Kultivierung weniger Wildgetreidearten fokussiert waren. Trotz der zahlreichen Hinweisen auf Wildgetreidekultivierung dauerte es aber noch mindestens 1000 Jahre bis die ersten morphologisch domestizierten Getreide auftauchten. Diese zeitliche „Verzögerung" wird meist mit einem Fokus auf agronomische und ökologische Faktoren erklärt, wohingegen ich in dieser Dissertation die Wichtigkeit sozialer Faktoren betone. Mit einem Schwerpunkt auf der Herausbildung von *households* und dem Entstehen privater Eigentumssysteme schlage ich vor, dass frühe Ackerbauern erst mit dem Übergang zur privaten Lagerung von Getreideernten die Möglichkeit hatten, einzelne Domestikationsmerkmale zu selektieren. Diese Perspektive macht klar, dass die Entwicklung sozialer Normen einen entscheidenden Einfluss auf das Entstehen domestizierter Pflanzen gehabt hat, was in den Erklärungsmodellen zum Ursprung des Ackerbaus viel stärker berücksichtigt werden muss.

# List of Publications and Personal Contributions

## Published Articles

1) **Weide, A.**, Riehl, S., Zeidi, M., Conard, N.J., 2017. Reconstructing subsistence practices: taphonomic constraints and the interpretation of wild plant remains at aceramic Neolithic Chogha Golan, Iran. Vegetation History and Archaeobotany 26, 487-504. *(Appendix A)*

2) **Weide, A.**, Riehl, S., Zeidi, M., Conard, N.J., 2018. A systematic review of wild grass exploitation in relation to emerging cereal cultivation throughout the Epipalaeolithic and aceramic Neolithic of the Fertile Crescent. PLoS ONE 13(1): e0189811. *(Appendix B)*

## Submitted Manuscripts

3) **Weide, A.** The significance of social change for understanding patterns in Near Eastern cereal domestication. Under review for Paléorient. *(Appendix C)*

## Personal Contribution

For articles 1 and 2, I was responsible for the data collection, analyses, interpretations and writing of the manuscripts. Simone Riehl supervised the studies and the laboratory work and reviewed the articles before submission. Mohsen Zeidi and Nicholas J. Conard excavated the site, recovered the archaeobotanical material and also reviewed the articles before submission. Article 3 represents a theoretical approach to the Neolithic transition and was reviewed before submission by S. Riehl.

# Chapter 1

# Introduction and Goals of Study

## Domestication and the Neolithic Transition in the Near East

Vere Gordon Childe (1936) coined the transition to the Neolithic in the Near East as an essentially economic revolution - the beginnings of food production - made possible by the domestication of plants and animals. Ever since, scholars investigating the Neolithic transition have focused on locating and timing the emergence of domesticates and on reconstructing the concurrent cultural development. While the leading questions of *where*, *when* and *how* equally shaped research projects, scholars took up very different positions on *why* domestication occurred. In the various models put forward since the 1960s, climatic and environmental factors are interwoven with population growth, technological innovations and societal factors. Among the huge number of explanatory frameworks, the most influential ones can broadly be divided into "push" and "pull" scenarios. The former view the adoption of agriculture as a response to resource shortages due to climate change and/or population growth (Pumpelly 1908; Childe 1936; Binford 1968; Flannery 1969; Cohen 1977; Bar-Yosef and Belfer-Cohen 1989, 2002; McCorriston and Hole 1991; Bar-Yosef and Meadow 1995; Rosenberg 1998; Hillman *et al.* 2001; Winterhalder and Kennett 2006; Darabi 2012), whereas the latter view opportunistic human behavior and technological innovations in favorable resource zones as major factors that pulled humans down the pathway to cultivation and domestication (Braidwood R. and Howe 1960; Smith 2007, 2011a; Zeder 2009, 2012a; Zeder and Smith 2009). Arguing within frameworks that reject external stress as a major trigger for the Neolithic transition, many authors concentrated on the social and cognitive factors of the domestication process (Bender 1978; Wilson 1988; Hayden 1990, 2009; Hodder 1990; Cauvin 2000; Watkins 2004; Schmidt 2006; Dietrich *et al.* 2012). These socio-cultural hypotheses do not put much emphasis on explaining the domestication of plants and animals from an ecological or technological perspective. They perceive domestication as the outcome of deeper changes in human social relations or the human mind, sometimes with a religious connotation, which has been profoundly criticized (e.g. Rollefson 2001; Abbo and Gopher 2017).

In light of such diverse approaches to explain the Neolithic transition, most current models reject single prime-movers while emphasizing the entanglement of social, cognitive, demographic, economic and environmental factors on the road to domestication (Benz 2000, 2004; Verhoeven 2004; Byrd 2005; Zeder 2009, 2011a; Sterelny and Watkins 2015; Watkins 2016; Hodder 2017). Consequently, our understanding of the Neolithic transition in the Fertile Crescent has been profoundly changed. Childe's economic and scientific revolution, by implication a sudden and radical event, developed into a protracted, multi-leveled and geographically diffused process (Willcox 2002, 2005; Gebel 2004; Nesbitt 2004; Fuller *et al.* 2011; 2012a, b; Zeder 2009, 2011b). Most of these overarching models put domestication at the very end of the long Neolithization process, starting in the Early Epipalaeolithic (Tab. 1), and apply its traditional definition of accumulating morphological, physiological and behavioral change in plant and animal species under increasing human influence on the reproduction cycle. Definitions of domestication, however, have a diverse history and are debated until today.

**Table 1.** Chrono-cultural sequence of the Near Eastern Neolithic.

| Levantine sequence[a] | $^{14}$C dates (ka cal BP) | Zagros sequence[b] | $^{14}$C dates (ka cal BP) |
|---|---|---|---|
| Epipalaeolithic | | Epipalaeolithic | |
| *Early* | 23 - 18 | *Zarzian* | ~ 17 - 11.7 |
| *Middle* | 18 - 14.6 | | |
| *Late* | 14.6 - 12/11.7 | | |
| Pre-Pottery Neolithic (PPN) | | Neolithic | |
| *PPNA* | 12/11.7 - 10.7 | *Early/aceramic Neolithic* | 11.7 - 9 |
| *Early PPNB* | 10.7 - 10.2 | *Later/Pottery Neolithic* | 9 - 5.5 |
| *Middle PPNB* | 10.2 - 9.5 | | |
| *Late PPNB* | 9.5 - 8.5 | | |

[a] after Byrd (2005), Asouti and Fuller (2012).
[b] after Olszewski (2012), Nashli and Matthews R. (2013).

In a series of recent articles, Zeder (2006, 2012b, 2015) revisited traditional concepts of plant and animal domestication and provides a universal definition without focusing on specific species or situations. According to her model, domestication represents a continuum of increasing interdependency between a human and a plant or animal species, where both partners benefit from the mutual character of the domesticatory relationship. This definition echoes the concepts of e.g. Rindos (1984) or Harris (1989, 1996a, b) and emphasizes the evolutionary character of domestication as being a process, not a status. Since this definition views domestication as beneficial for both partners, Zeder refers to human intention and the ability to spontaneously modify and transmit socially learned behavior for differentiating between domestication and other mutual relationships, e.g. between fungus-growing ants and their fungi (Zeder 2006, 2012b). Moreover, this component of the definition also addresses the issue of conscious selection and the exertion of control over the domestic species.

In his comprehensive study of the variation among plants and animals under domestication, Darwin (1868) recognized that selection for domestication traits can be conscious or unconscious. Conscious selection refers to the directed breeding of a population with the aim of achieving a deliberate goal. It presupposes that the human partner has an understanding of domestication and the selection process. In contrast, unconscious selection refers to automatic effects on a plant or animal population subjected to different selection pressures after they entered a domesticatory relationship with humans (Zohary D. 2004: 5). Factors that induce automatic selection include the replacement of a population from its original habitat, the associated change in ecological conditions and the specific harvesting or culling practices (Harlan et al. 1973; Hillman and Davies 1990; Zohary D. et al. 1998; Zohary D. 2004). Both kinds of selection certainly complemented each other, but disagreement still exists among scholars to which extent the domestication process of plants was initiated and driven by conscious or unconscious selection (Abbo and Gopher 2017).

Due to the fact that animal domestication involves taming and often fencing, scholars focusing on animals have a tendency to understand the domestication process as obtaining control over the managed individuals (Reed 1959; Bökönyi 1989; Ducos 1989; Meadow 1989; Clutton-Brock 1994; Vigne 2011). In this perspective, Price (1999) puts a major emphasis on behavioral aspects in animal domestication, which are only accompanied much later by morphological change. Accordingly, research on caprine domestication in the Taurus-Zagros arc has recognized a considerable time gap of at least 1,000 years between selective hunting strategies focusing on young males and the herding of morphologically wild animals (Peters et al. 1999; Zeder and Hesse 2000; Redding 2005; Arbuckle and Özkaya 2006; Helmer 2008). The first reduced horn cores indicative of morphological change appear at Ali Kosh in the foothills of the central Zagros after an additional millennium (Hole et al. 1969; Zeder 2008, 2011b). Comparable to these slowly changing relations between humans and caprines, data on pig exploitation from Çayönü in southeastern Anatolia similarly indicate slowly changing culling patterns and the gradual establishment of morphological change over two millennia (Ervnyck et al. 2001). In combination, these patterns make clear why animal domestication must be seen as a slowly developing interdependency between humans and animal species, with morphological change being a poor marker for detecting the initial stages of domestication.

The same applies to plant domestication. Although experimental wild cereal cultivation suggests that central morphological domestication traits among cereals could have emerged within 20 to 200 years (Hillman and Davies 1990), the archaeobotanical record documents a much longer period of wild cereal and presumably also legume cultivation predating the establishment of morphological change. This phenomenon is conventionally labeled pre-domestication cultivation and has originally been described for PPNA sites along the upper Euphrates dating to between ca. 11,500 and 10,700 cal BP (van Zeist and Bakker-Heeres 1984; Colledge 2002; Willcox 2004, 2012; Willcox et al. 2008, 2009; Willcox and Stordeur 2012) and even for the Younger Dryas occupation at Abu Hureyra (Hillman 1975; Hillman et al. 2001). Suggestions of pre-domestication cultivation are mostly based on the increasing abundance of cereals and legumes parallel to a decrease in previously collected taxa, the concurrent establishment of potential arable weeds and an increase in cereal grain size over time. Taken together, scholars interpret these observations as indicative of cultivation practices allowing for the establishment of early weed floras (Willcox 2012) and selecting for larger grain sizes as one of the first automatic effects of sowing cereals in tilled soils (Fuller 2007). Authors studying botanical assemblages from the southern Levant rely on similar criteria and proposed pre-domestication cultivation of wild cereals and legumes for several PPNA sites as well (Kislev 1997; Colledge 2001; Meadows 2004; Weiss et al. 2006; Melamed et al. 2008; Kislev et al. 2010; White and Makarewicz 2012; Colledge and Conolly 2018). Clear evidence for morphological change based on genetic mutations appeared between 10,700 and 10,200 cal BP throughout the Levant and Anatolia, after approximately 1,000 years of pre-domestication cultivation (Tanno and Willcox 2012; Arranz-Otaegui et al. 2016a). These early evidences for morphological domestication traits consist of proportions of non-shattering spikelets that exceed those found in modern unmanaged populations (Kislev 1989). Whereas non-shattering spikelets comprise between 25-30 % of the cereal chaff from early PPNB Tell Aswad, Tell Qarassa, and Aşikli Höyük, it took an additional 2,000 years until fully non-shattering populations became established (Tanno and Willcox 2006a, 2012; Fuller 2007; Fuller et al. 2012a). Similar to the patterns for animals, plant domestication represents a continuum of increasing human-plant relationships with morphological change appearing slowly and quite late in the chronological sequence. We must, however, note that solid evidence for Near Eastern plant domestication is almost entirely based upon cereals, since the lack of preserved legume pod remains does not allow to investigate the establishment of non-shattering among pulse species (Zohary D. et al. 2012). Seed coat thickness represents a second important domestication marker, but charred legume seeds rarely exhibit the seed coat (Tanno and Willcox 2006b; Sonnante et al. 2009).

These protracted patterns represent the main arguments why most scholars nowadays reject the idea of animal and plant domestication being predominantly driven by conscious selection (Zohary D. et al. 1998; Tanno and Willcox 2006a, 2012; Purugganan and Fuller 2011; Vigne 2011; Fuller et al. 2012a; Allaby et al. 2017; but see Abbo and Gopher 2017 for a different perspective on plant domestication). Although Zeder (2006, 2012b) defines human intent as the basic characteristic that differentiates between domestication and any other mutual relationship, she emphasizes that this principle refers to the ability of humans to spontaneously change and transmit socially learned behavior and with this play a much more active role in a domesticatory relationship than plants or animals do. Contrastingly, she rejects the idea that human intent was responsible for inventing agriculture by deliberately and with foresight domesticating a species (Zeder 2015: 3192), a view which is widely shared today.

Since it became clear that domestication followed protracted pathways and took several millennia to unfold, scholars have built up different frameworks for explaining the slow pace of domestication, predominantly focusing on agro-technological and environmental issues. After we have clarified the essential terminology for discussing the origins of agriculture, we will survey these explanations for the slow pace of Near Eastern plant domestication in order to identify unsolved questions and the major research goals for the current study.

### *Terminology*

The terms domestication, cultivation and agriculture are essential for discussing the origins of agricultural societies and therefore need clarification before we continue to use them. Without going into the history of the terms, we will broadly follow the evolutionary model of Harris (1989, 1996a, b, 2007) and extend his concept where it seems necessary.

As we have seen, **domestication** primarily refers to genetic and phenotypic change induced by an increasing relationship between a human and a plant or animal partner. The set of traits that differentiate a domesticated species from its wild progenitor is conventionally called the "domestication syndrome" (Harlan et al. 1973; Hammer 1984; Wilkins et al. 2014). The time span in which this domestication syndrome became established has been used to separate the domestication process from subsequent evolution as characterized by the continuous selection on domesticates and landraces (Fuller 2007; Fuller et al. 2012a, 2014). Abbo and Gopher (2017) provide a different perspective and understand plant domestication as a pristine event of transferring seeds into prepared soil. They isolate this event from subsequent crop evolution, which in their model immediately starts with selection on the managed plants (Abbo et al. 2012, 2014a). However, this refined definition of plant domestication and crop evolution primarily builds up a different narrative for the Neolithic transition, but relies on the same archaeobotanical datasets (see below). For evaluating the differences between these two perspectives, we need to remember that domestication as a continuum does not necessarily need an end point to be applicable to prehistory. Most importantly, domestication unfolds with the gradual establishment of genetic and phenotypic traits that enhance the adaptability of an organism to the domesticatory relationship. We will therefore principally follow Zeder's notion of domestication as not having fixed thresholds that differentiate distinct phases of the domestication process (Zeder 2006: 107), although the establishment of single domestication traits of course indicates changes in management practices.

**Cultivation** refers to the process of propagating and harvesting fruits and seeds or any other desired organ of a plant. It commonly involves some sort of soil preparation, the sowing of seeds and possibly tending of the cultivars. Additional practices to promote plant growth may include weeding, manuring and irrigation. Harris (2007) notes that these practices can be applied to wild and domesticated plants and most scholars agree that domestication can only occur under cultivation (Harlan et al. 1973; Hammer 1984; Hillman and Davies 1990; but see Ladizinsky 1987). Turned around, this implies that cultivation should have started with wild plants (Helbaek 1960) and must have maintained a cultivated lineage in annually harvesting and sowing seeds for facilitating the genetic fixation of phenotypic changes.

For differentiating between cultivation and the promotion of resources in general, archaeologists adopted the term **resource management** or related expressions and acknowledge that also non-agricultural communities engage in activities to enhance the productivity of an ecosystem and the abundance of valuable resources (Zvelebil 1995; Smith 2001, 2007, 2011a; Chatters and Prentiss 2005; Zeder 2009; Zeder and Smith 2009; Matthews W. 2016). Key to this concept is the realization that subsistence strategies cannot satisfyingly be divided into a dichotomy of hunting-gathering and farming. This strict dualism has often been criticized and Smith (2001) proposed a third category for recognizing that societies of the so-called middle ground often engage in resource management, sometimes even in the cultivation of domestic plants, but do not correspond to the traditional concepts of hunter-gatherers or farmers. He criticizes terms such as "complex hunter-gatherers" or "incipient farmers" and emphasizes that "*societies of the middle ground are not pale reflections or logical extensions of either agriculturalists or hunter–gatherers, but a separate general class of extremely variable, successful long-term socioeconomic solutions*" (Smith 2001: 33-34).

The important question arises how **agriculture** can be differentiated from the economies of middle ground societies, which Smith labels "low-level food production". Different thresholds have been proposed, with agriculture relying to more than 50 % or "largely" upon domesticated resources (Harris 1996a, b; Zvelebil 1996). However, this definition contains an inherent problem, because we defined domestication as not corresponding to a fixed state either. If we understand domestication as a process, it would make sense to regard the associated subsistence economies as a continuum as well, along which the involvement of genetically altered organisms in resource management systems gradually increases. We will see that these rather flexible definitions correspond well with the actual socioeconomic development throughout the Near Eastern Neolithic transition, which in my opinion provides the strongest argument to reject fixed dichotomies of wild vs. domestic or hunter-gatherers vs. agriculturalists. Nevertheless, for distinguishing between different subsistence practices and associated impacts on a population, it is still helpful to apply the term **wild** to resources that do not exhibit any phenotypic domestication traits. The term **domestic** applies to individuals or populations that already exhibit phenotypic domestication traits, indicative of altered selection pressures in a domesticatory relationship.

## Explaining Patterns in Near Eastern Plant Domestication

The dominant model for Near Eastern plant domestication assumes a geographically dispersed development of early cultivation and a temporally protracted establishment of the domestication syndrome. Whereas most current scholars favor this model for explaining the archaeological and archaeobotanical record (e.g. Willcox 2002, 2005, 2013; Gebel 2004; Nesbitt 2002, 2004; Tanno and Willcox 2006a, b, 2012; Weiss et al. 2006; Feldman and Kislev 2007; Fuller 2007, 2010; Melamed et al. 2008; Willcox et al. 2008, 2009; Kuijt and Finlayson 2009; Fuller et al. 2010, 2011, 2012a, b, 2017; Zeder 2011b; Asouti and Fuller 2012, 2013; Asouti 2013, 2017; Riehl et al. 2013; Whitlam 2015; Snir et al. 2015a; Arranz-Otaegui et al. 2016a; Allaby et al. 2017), some authors have profoundly criticized this domestication model and tell a very different story of Near Eastern agricultural origins (e.g. Lev-Yadun et al. 2000; Gopher et al. 2001; Honne and Heun 2009; Abbo et al. 2010a, b, 2012, 2013a, 2014a, b; Haldorsen et al. 2011; Heun et al. 2012; Abbo and Gopher 2017). Major debates on Near Eastern pant domestication therefore involve its temporal development, whether domestication was centered or regionally dispersed and whether the single founder crop species (Weiss and Zohary D. 2011; Zohary D. et al. 2012) were domesticated more than once. In the following overview we will survey the two models and their argumentation in favor of distinct pathways into domestication and agricultural systems.

### *The Geography of Near Eastern Plant Domestication*

More than 30 years after Helbaek (1959, 1960, 1969) pioneered archaeobotanical research on the Near Eastern Neolithic, Miller concluded that the record for early cultivation is "frustratingly incomplete" (Miller 1992: 53) and she did not identify a confined region where crop cultivation and domestication started. Bar-Yosef and his colleagues expressed a contrasting view, expecting a core area for agricultural origins in the southern Levant where the most complete archaeological record had been compiled (Kislev 1984; Bar-Yosef and Belfer-Cohen 1989, 1991). Numerous excavations during the 1990s at sites along the upper Euphrates, including Jerf el Ahmar (Stordeur et al. 1996; Stordeur 2000), Dja'de (Coqueugniot 1998) and Göbekli Tepe (Schmidt 2000), changed this picture and urged scholars to include this region in their considerations about the geography of early plant domestication. Willcox (1996) significantly contributed to this development when he reported the recovery of wild cereals and pulses from Jerf el Ahmar and Dja'de, speculating whether the potential arable weeds included in the assemblages could reflect cultivation practices. The assumption of a confined southern Levantine core area was subsequently questioned and Belfer-Cohen and Bar-Yosef (2000) extended the center of origin to the whole Levantine corridor including the upper Euphrates region. Lev-Yadun et al. (2000) and Gopher et al. (2001) even argued for a new core area between the upper Euphrates and Tigris rivers (see also Kozlowski and Aurenche 2005). In an influential article, however, Nesbitt (2002) revised the evidence for the appearance of domesticated cereals throughout the Near East and concluded that the archaeobotanical record back then did not allow identifying a precise center of origin for the earliest domesticates within the Fertile Crescent. He reinforced this argument some years later (Nesbitt 2004) and his view was supported by several archaeologists, demanding to view the Neolithic transition as a mosaic-like process involving distinct socioeconomic trajectories among the sub-regions of the Fertile Crescent (e.g. Watkins 2003; Gebel 2004; Rollefson 2004).

These suggestions have widely been supported by archaeological and archaeobotanical research projects of the last two decades. Willcox (2002, 2005) recognized that the composition of exploited cereal species significantly differs between the sub-regions of the Fertile Crescent during the Early Holocene, but correspond well with modern species distributions. He concluded that PPNA groups increasingly exploited and eventually cultivated the locally available species, which represents the most important argument for rejecting a center of agricultural origins. Fuller et al. (2011, 2012b) and Arranz-Otaegui et al. (2016a) recently supported the multiregional model based on additional data and confirmed that a core area where crop cultivation and domestication emerged and subsequently spread out from cannot be identified.

Independently from archaeobotanical data, Abbo and Gopher (2017) rely on genetic studies that argue for monophyletic origins of several founder crops for supporting the idea of a core area between the upper Euphrates and Tigris rivers (Heun *et al*. 1997; Özkan *et al*. 2002; Allaby *et al*. 2005; van Oss *et al*. 2015). This represents a quite ambiguous line of evidence, as genetic data long indicate that barley domestication happened at least twice and outside of the proposed core area (Zohary D. 1999; Morrell and Clegg 2007; Poets *et al*. 2015; Allaby 2015; Pourkheirandish *et al*. 2015; Mascher et al. 2016), while other studies placed doubt on a monophyletic origin of modern einkorn and emmer wheat (Mori *et al*. 2003; Kilian *et al*. 2007; Luo *et al*. 2007; Civáň *et al*. 2013). Only in ignoring such "contradictory and unresolved" patterns (Özkan *et al*. 2011: 24), the core area model can still be maintained.

Additional significant arguments for understanding the Neolithic transition as a multiregional process provide the results of excavations at Early Neolithic sites in the Zagros Mountains and its foothills. Most importantly, Sheikh-e Abad (Matthews R. et al. 2013a) and Chogha Golan (Zeidi et al. 2012; Riehl et al. 2013) have been occupied since the late Younger Dryas and the earliest Holocene, respectively, suggesting that agricultural societies in the eastern arc of the Fertile Crescent evolved out of regional traditions and did not migrate into the region (Matthews R. et al. 2013b). Nashli and R. Matthews provide an interesting perspective on how to integrate this widespread record of Early Neolithic trajectories into a general model and refer to Whittle's (1996: 9) notion of the Neolithic as a "series of becomings" rather than the diffusion of an economy out of a core-area (Nashli and Matthews R. 2013: 2). This view primarily reflects the claim to move beyond an economic paradigm for investigating domestication and agricultural origins, which "*allows us to include within our purview those communities of Southwest Asia who were clearly still hunter-foragers, in purely subsistence terms, but who at the same time were already developing a sense of community and attachment to locale, and to available resources, that enabled the earliest stages of sedentism and all that followed on from it.*" (Nashli and Matthews R. 2013: 3). In addition, R. Matthews et al. (2013b) summarized the evidence for a continuous occupation of the Zagros Mountains since ca. 17,000 cal BP, emphasizing evidences for cultural continuity throughout the Pleistocene-Holocene transition (*cf.* Kozlowski 1999). A similar claim has been made by Baird et al. (2013) for the Neolithization process in central Anatolia. The Late Epipalaeolithic occupation at Pinarbaşi provided evidence for multiple socioeconomic aspects conventionally associated with the Natufian (e.g. Bar-Yosef 1998) including a more permanent site occupation, a broad-spectrum subsistence strategy and elaborated burial and ritual practices. Baird and his colleagues conclude that the Neolithic transition cannot longer be viewed within a "Natufian paradigm", i.e. to expect the origins of significant socio-cultural prerequisites for domestication exclusively in the southern Levantine Epipalaeolithic (Baird et al. 2013: 177).

This brief survey highlights two important aspects for investigating plant domestication. First, since the archaeobotanical record does not allow to identify a core area where plant cultivation initially developed, we must focus on integrating the various regional trajectories towards agricultural economies into a supra-regional framework. Second, we have to expect regionally distinctive and autochthonous trajectories of socioeconomic evolution throughout the Neolithic transition. As a consequence, plant domestication can only be understood by investigating the development of subsistence strategies against the backdrop of regional environmental and socio-cultural change. Such a perspective necessarily assesses the Neolithic transition on different geographic levels (*aka* Zeder 2009). Regionally, we might expect specific compositions of social, economic and environmental factors that shaped individual trajectories. On a supra-regional scale, we must search for overriding factors that shaped the general development towards the first agricultural societies in the Fertile Crescent.

*The Temporal Development of Near Eastern Plant Domestication*

In addition to the geographic origin of the first domestic plants, the temporal development of subsistence strategies and the appearance of domestication traits under cultivation are still highly debated. Whereas our knowledge on the geographic aspects of plant domestication relies on archaeobotanical materials and its identification and dating, the current models for explaining the temporal development of the domestication process much more depend upon experimental data and theoretical expectations.

Hillman and Davies (1990) cultivated wild einkorn in order to calculate domestication rates under distinct cultivation conditions. They applied different harvesting methods and concluded that sickle-reaping and uprooting of whole plants would select for non-shattering individuals, as the ripe ears of wild cereals shatter at maturity and would do so if they are shaken during the harvesting process. Accordingly, beating ripe ears into a container utilizes this trait and represents an effective harvesting method that would strongly discriminate against non-shattering mutants. They eventually conclude that the applied harvesting method represents a crucial factor for accelerating or inhibiting the establishment of non-brittle ears. Given sickle-reaping would have been applied by early cultivators, which they expected in light of the presence of sickle blades in Natufian and PPN lithic assemblages, non-shattering mutants would have increased in a cultivated population even in the absence of conscious selection. They eventually proposed a rapid domestication model for cereals involving 20-200 years until a population would comprise 100% non-shattering ears.

During the last two decades the analysis of numerous plant assemblages from the northern and southern Levant suggests that morphological domestication traits were only slowly and gradually established. As we briefly addressed above, the cultivation of shattering cereals has been proposed for numerous PPNA sites and is primarily based on the identification of potential weed floras, increased cereal grain sizes and the generally high proportions of cereal grains in charred assemblages (van Zeist and Bakker-Heeres 1984; Kislev 1997; Colledge 2001, 2002; Meadows 2004; Willcox 2004, 2012; Weiss et al. 2006; Willcox et al. 2008, 2009; Kislev et al. 2010; White and Makarewicz 2012; Colledge and Conolly 2018). First evidences for the establishment of morphological domestication traits is based on chaff remains containing more than 10 % of non-shattering spikelets and derive from early PPNB sites in the Levantine corridor and central Anatolia, dating to between ca. 10,700 and 10,200 cal BP after at least one millennium of pre-domestication cultivation activities (Nesbitt 2002; Tanno and Willcox 2012; Arranz-Otaegui et al. 2016a, b). The oldest evidence for increased percentages of non-shattering spikelets in the eastern arc of the Fertile Crescent derives from Chogha Golan in the foothills of the central Zagros and dates to about 9,800 cal BP (Riehl et al. 2013; Weide et al. 2015).

In plotting the percentages of non-shattering spikelets vs. shattering spikelets through time, Tanno and Willcox (2006a) were the first to propose a remarkably slow establishment of fully non-shattering cereal populations over more than 2,000 years, which has since then been supported by numerous additional studies involving quantitative data on non-shattering spikelets and grain sizes of cereals and legumes (Fuller 2007; Purugganan and Fuller 2009, 2011; Fuller et al. 2012a, 2017; Allaby et al. 2017). This protracted process of morphological domestication is in sharp contrast to the expected rapid fixation of phenotypic domestication traits and many authors have provided possible explanations for this disagreement between theoretical expectations and the archaeobotanical data. The absence of conscious selection represents a major paradigm in many contributions, emphasizing that selection should naturally be slow when domestication is viewed as a form of co-evolutionary development that was primarily driven by natural selection (Tanno and Willcox 2006a, 2012; Purugganan and Fuller 2009, 2011; Fuller et al. 2010, 2012a). Hillman and Davies' conclusion that several harvesting practices would inhibit the selection for non-shattering ears also figures prominently in the explanatory frameworks. Utilizing the brittleness of wild cereal ears by beating ripe spikelets into a basket or by collecting shed spikelets from the ground would continuously favor shattering spikelets (Hillman and Davies 1990; Kislev et al. 2004; Willcox et al. 2008). Additional possible factors include the harvesting of partially green ears to avoid yield loss through shattering or replenishing cultivated seed stocks after poor harvests by gathering in unmanaged stands (Tanno and Willcox 2006a, 2012; Willcox et al. 2008; Fuller et al. 2010; White and Makarewicz 2012). However, except for harvesting green cereals at sites along the upper Euphrates (Ibáñez et al. 2016) and possibly ground collecting at some sites in the southern Levant (Kislev et al. 2004), none of these practices could be linked to archaeobotanical datasets. Moreover, whether the use-wear patterns of sickles that suggest the cutting of green ears reflect continuous harvesting in unmanaged stands or reaping green culms of cultivated plants is unclear as well. The actual set of practices inhibiting selection for non-shattering ears under cultivation during the PPNA and protracting the establishment of fully non-shattering populations during the PPNB is therefore widely speculative.

This situation urged scholars to search for additional factors that possibly prolonged the pre-domestication cultivation phase. Based on a careful evaluation of radiocarbon dates, associated inconsistencies in the occupation of PPNA sites and the general criticism that permanent residential structures in PPNA settlements do not necessarily imply year-round occupation, Asouti and Fuller (2013) conclude that PPNA subsistence strategies should rather be seen as a diverse array of practices, of which wild plant cultivation was only one of various strategies. The “delayed” appearance of morphological domestication traits would therefore reflect that cultivation in the PPNA was simply not as widespread and continuous as most scholars assume. In addition, Asouti (2017) refers to episodes of climatic instability during the Early Holocene for suggesting that subsistence strategies prior to the emergence of fully agro-pastoral systems in the late PPNB were attuned to regularly changing and hardly predictable ecological conditions. With this, she transfers the expectation that climatic instability during the Late Pleistocene inhibited the long-term adoption of cultivation (e.g. Bettinger et al. 2009; Haldorsen et al. 2011; Asouti 2013) into the Early Holocene.

A certain school of thought completely dismisses the protracted domestication model, which represents an extreme alternative for “explaining” the time paradox. Abbo and Gopher (2017) recently summarized the arguments for rejecting evidence for a slow and gradual domestication process, which mostly relies on a different definition of domestication and crop evolution and the principal rejection of a pre-domestication cultivation phase. As we saw above, they perceive domestication as a pristine event of consciously selecting suitable genotypes for cultivation and regard any subsequent phenotypic change as crop evolution (Abbo et al. 2012, 2014a). This refined definition of domestication and crop evolution mostly relies on experimental evidence for the inefficiency of wild legume exploitation and cultivation. Wild legume species such as lentils (*Lens* spp.), peas (*Pisum* spp.) and chickpea (*Cicer judaicum*) produce few seeds per plant and the seeds have a very high dormancy (Abbo *et al*. 2008a, b, 2011, 2013b). These results suggest a different scenario for legume domestication, which has been argued since the 1980s, expecting the presence of free-germination wild stocks to productively cultivate wild legumes (Ladizinsky 1987, 1989, 1993; but see Zohary D. 1989). In addition, proponents of this alternative model assume a deep “naturalist knowledge” that allowed the first cultivators to reasonably assemble a nutritionally and agronomically balanced crop package that was crucial to render agriculture a reliable subsistence strategy (Abbo *et al*. 2010b, 2014b). Based on these theoretical expectations, they dismiss any claim for a prolonged period of pre-domestication cultivation, which in their perspective represents a paradox in itself. However, the reason why fully non-shattering cereal spikelets only appeared 2,000 years after the first selection for non-shattering ears at early PPNB sites cannot reliably be explained by proponents of the one-event model either. Heun et al. (2012) suspect that the analyzed cereal chaff from PPNB sites does not derive from cultivated plots only, possibly reflecting various activities including continuous gathering in unmanaged stands and the use of wild cereals for multiple purposes (see also Haldorsen et al. 2011). This argument has also been utilized for explaining the exact opposite scenario (e.g. Tanno and Willcox 2006a, 2012) and predominantly represents an unverified speculation. Heun and his colleagues further stress that the founder crops are self-fertilizing, which should support a rapid genetic isolation and a fast establishment of domestication traits (Honne and Heun 2009). In light of this important conclusion, it is even more intriguing why non-shattering individuals needed so long to dominate PPNB cereal assemblages.

An interesting case of potentially high relevance for reconsidering these explanatory frameworks can be found in the Early Epipalaeolithic site of Ohalo II. After several publications about the archaeobotanical assemblage from the site and its context (Kislev et al. 1992; Weiss et al. 2004a, b, 2008; Snir et al. 2015b), Snir et al. (2015a) recently reported emmer and barley chaff comprising between 25 and 36 % non-shattering spikelets, respectively. In combination with a potential weed flora, these astonishing findings suggest that cereal cultivation was already practiced 23,000 years ago, indicating that the agro-technological requirements to select for non-shattering ears were already present back then. Concentrating on hypothetical mixtures of non-selective cultivation practices for explaining why pre-domestication cultivation did not select for non-shattering individuals at any PPNA site for which this practice has been proposed therefore seems rather insufficient. Of course, climatic instability and a possibly still high mobility of PPNA groups, as suggested by Asouti (2017), would have inhibited the long-term establishment of domestic cereals, but both factors cannot sufficiently explain the striking absence of domestic-type chaff before the early PPNB[1].

In sum, we can conclude that the currently available archaeobotanical data suggest a slow and gradual establishment of non-shattering cereals throughout the Early Holocene. Sites dating to the PPNA in the Levant provide widespread evidence for the exploitation of morphologically wild cereals and pulses. Several strains of evidence suggest that cultivation started during the PPNA and an isolated dataset even dates to the Early Epipalaeolithic. The nature of evidence does not allow to precisely evaluate the importance of such early cultivation activities, leaving the question relatively open whether cultivation regimes during the PPNA did simply not select for non-shattering ears or whether PPNA communities engaged in cultivation at a much lower level than most researchers assume. The appearance of increased proportions of non-shattering spikelets since the early PPNB would then not only indicate changed cultivation regimes, but a significant intensification of cereal cultivation in general. Nevertheless, we can conclude that the main arguments for explaining this protracted process focus on agro-technological and environmental issues such as specific harvesting practices, continuous gathering in the wild for replenishing cultivated seed stocks, phases of climatic instability and argue within a paradigm of unconscious selection. An alternative perspective rejects evidence for this protracted scenario and assumes a conscious and rapid domestication event, based on a deep knowledge of the ecology of the wild progenitor species and their biological precondition to rapidly fix genetic mutations due to their tendency towards self-fertilization.

## Goals of Study

The main goals of my dissertation project focus on the reconstruction of subsistence developments on a site-specific, regional and supra-regional scale and an assessment of factors that potentially influenced socioeconomic evolution throughout the Near Eastern Neolithic transition in these three geographical perspectives.

[1] Note that Fuller et al. (2012a: Fig. 3, 2012b: Fig. 2) and Allaby et al. (2017: 8) report a mean value of 22 % of non-shattering einkorn spikelets from the late Younger Dryas occupation at Tell Qaramel in northern Syria. In contrast, Willcox et al. (2008: 315) and Willcox and Herveux (2012: 120) conclude in the full publication of the Qaramel assemblage that no evidence for domestic cereals could be found and that all einkorn spikelets belong to the wild type. Fuller, Allaby and their colleagues still assume 22 % of domestic-type einkorn spikelets, because they rely on the preliminary data from Tanno and Willcox (2006a), which include 0 domestic spikelet bases, 4 possible domestic bases, 14 wild bases and 88 non-diagnostic bases (see supplementary materials in Fuller et al. 2012a). Assuming a mean of 22 % domestic-type spikelets for the assemblage from Qaramel is therefore highly misleading and entirely based on the identification of four specimens as *possibly* domestic.

The first part of the study (chapter 2) includes the analysis of charred archaeobotanical material from the aceramic Neolithic site of Chogha Golan (Iran) in order to reconstruct local subsistence strategies and their development through time (site-specific scale). Major goals include:

- The analysis and interpretation of the taxonomic composition of the flotation samples with a focus on reconstructing their taphonomic history and the role of different taxa in the subsistence economy.
- Identifying phenotypic domestication traits with a focus on non-shattering cereal spikelets in order to assess whether the subsistence economy included the cultivation of domestic cereals.
- Assessing whether the common criteria for recognizing the cultivation of morphologically wild species can successfully be applied to the archaeobotanical record.
- Reconstructing the temporal development of subsistence strategies at the site.

The second part of the dissertation (chapter 3) focuses on identifying patterns and important factors in the socioeconomic evolution of Late Pleistocene and Early Holocene societies in the Zagros Mountains (regional scale) as compared to the Levantine corridor (supra-regional scale):

- Which patterns in the subsistence economies of aceramic Neolithic sites are typical for the Zagros Mountains?
- Can we identify a set of ecological and social factors that shaped this local trajectory towards agricultural societies?
- How do subsistence strategies throughout the Neolithic transition in the Zagros Mountains differ from other regions in the Fertile Crescent?
- In comparing the potential social and ecological factors that characterized economic developments in the Levantine corridor and the Zagros Mountains, which factors do considerably differ and might be responsible for different pathways towards the first agricultural societies?

# Chapter 2

# The Aceramic Neolithic Site of Chogha Golan

## Excavations, Stratigraphy and Artifact Assemblages

The site of Chogha Golan ('Mound of Flowers') is situated in the foothills of the central Zagros Mountains of Iran at an elevation of ca. 485 m asl and has been first described and investigated by Khalilian (1999: 36) and Nokandeh (2001). With a central mound rising 7-8 m above the surrounding landscape, the settlement covers about 3 hectares and is located 200 m from the right bank of the Konjan Cham River. The site is today situated in a desertic area with low agricultural potential, receiving 200-250 mm annual precipitation (Zeidi et al. 2012; Riehl et al. 2015).

A team of the Tübingen-Iranian Stone Age Research Project (TISARP) conducted the first systematic investigations at Chogha Golan during two field seasons in 2009 and 2010 (Zeidi et al. 2012), excavating a deep sounding and an excavation area A in the center of the mound. The deep sounding with an extent of 1.5 x 2 m reached sterile sediments at ca. 8 m below the current tell surface and the excavators divided the stratigraphy into eleven archaeological horizons (AH XI-I). A radiocarbon date from the geological horizon beneath the tell gave a *terminus post quem* of 11,740 ± 187 cal BP (KIA45647) for the accumulation of the oldest preserved anthropogenic deposits (Riehl et al. 2015: Tab. 1). AH XI with remarkably high concentrations of lithic artifacts and carbonized plant remains is about one meter thick and gave a radiocarbon date of 11,162 ± 220 cal BP (KIA44943) for its uppermost section, suggesting the beginning of repeated occupations at the site during the 12$^{th}$ millennium BP, postdating the Younger Dryas and contemporary to the early phase of the Levantine PPNA. Directly on top of the deposits of AH XI appear the first substantial architectural remains in form of a mudbrick wall and an associated plaster floor (Riehl et al. 2015: Fig. 2). The following AHs were separated from each other by further plaster floors or the accumulation of middens and the youngest deposits (AH I) date to 9,637 ± 54 cal BP (Beta336508). The full sequence spans about 2,000 years, whereas it is not fully clear when the lowermost anthropogenic deposits started to accumulate. If we take the first appearance of a mudbrick wall in AH X as an indicator for a more permanent occupation, then we may expect that the site represented a sedentary village since the late 12$^{th}$ millennium BP. Whether this translated into a seasonal or a year-round occupation will be evaluated below by discussing the bio-archaeological datasets. Due to the small horizontal extent of the deep sounding, the recovered materials and artifacts cannot be further contextualized.

Five meters from the deep sounding, a 2 x 4 m trench (area A) was excavated to a depth of about 1.5 m below the surface and contains the two uppermost horizons II and I (Zeidi et al. 2012). The stratigraphic correlation with the deep sounding is based on the Z-values, as no radiocarbon dates are available from this second excavation area. Architectural remains include an extensive plaster floor, an associated mudbrick wall and a hearth, suggesting an indoor area in AH II of this trench (Zeidi et al. 2012: Fig. 5; unpublished data).

The ground stone tools include a diverse array of mortars, pestles, grinding slabs, pounders and handstones (Conard and Zeidi 2013). Most of the material derives from the larger exposures in the two uppermost horizons, but two pestles were also recovered from AH X. In addition to expected food processing activities, the presence of pigments in a mortar and on handstones and traces of asphalt on a pestle indicate the multifunctional use of the tools. Bladelet production from conical and bullet-shaped bladelet cores characterizes the chipped lithic industry (Zeidi and Conard 2013). Bladelets exhibiting sickle gloss indicative of the reaping of plant stems, typically the culms of grasses or sedges, are surprisingly rare among the tools in the two uppermost horizons (Zeidi and Conard 2013: Tab. 3). Throughout the sequence there is little variance in tool types (Zeidi, pers. comm.). Miscellaneous artifacts include a plaster vessel, stone and bone pendants, clay cones and numerous anthropomorphic and animal clay figurines (Zeidi et al. 2012; Riehl et al. 2015).

## The Palaeoenvironmental Setting

A comparison between the modern climate and vegetation in the Zagros arc and the situation during the Pleistocene-Holocene transition provides first valuable insights for reconstructing the palaeoenvironmental setting of Chogha Golan. The principal reconstruction of modern potential vegetation zones in the region mainly depends on the studies of M. Zohary (1963, 1973). We speak of the potential vegetation, because much of the landscape has been significantly affected by anthropogenic impacts including agriculture, overgrazing, forest clearances and unsustainable woodland management, associated vegetation degradation and soil erosion (Zohary M. 1963; Ghazanfari et al. 2004; Pourhashemi et al. 2004; Pourreza et al. 2008).

Chogha Golan is today located in the treeless Mesopotamian steppe belonging to the Irano-Turanian phytogeographical zone, which is penetrated by elements of the Nubo-Sindian hot desert vegetation (Zohary M. 1963, 1973; Riehl et al. 2015: Fig. 3). Towards the central Zagros at elevations between ca. 700 and 2,000 m asl, the vegetation turns into an oak-dominated park-forest that is typical for many regions of the Fertile Crescent. *Pistacia-Amygdalus* woodlands characterize the semi-arid interior regions of the central Zagros highlands. The continental climate is today marked by cool winters and very hot and dry summers, while we have to expect variable climatic zones within short distances due to the multifaceted topography.

The most important sources for Early Holocene climate proxies represent Lake Mirabad (800 m asl) and Lake Zeribar (1,285 m asl), both located in the central Zagros at distances of 140 and 240 km from Chogha Golan, respectively. An Early Holocene low lake-level phase has been reconstructed from the ostracod fauna of Lake Mirabad (Griffiths et al. 2001) and the plant macrofossils from Lake Zeribar (Wasylikowa 1967). Based on multi-proxy studies at both lakes, Stevens et al. (2001, 2006) suggested increased summer evaporation as an important factor that resulted in these low lake-levels, which only began to rise by the mid-Holocene. Comparatively negative oxygen isotope values presumably indicate a distinct Early Holocene seasonality with mainly winter rainfalls as opposed to the modern patterns with more spring precipitation. However, several authors have doubted that these patterns indicate a drier Early Holocene climate as opposed to the Levant or present conditions in the central Zagros (Matthews W. et al. 2013c and references therein). For instance, Jones and Roberts (2008) hypothesize whether the strongly negative $\delta 18O$ values could also have been caused by the distance of the lakes from the source area of precipitations or a change in storm tracks during the Early Holocene. For explaining the local palynological record (see below), W. Matthews (2016) puts much emphasis on the possible influence of human resource management including vegetation burning, which would mean that climatic conditions were not the primary cause for differences in Early Holocene vegetation cover throughout the Fertile Crescent. This view was first expressed by Roberts (2002), but subsequently doubted by Wasylikowa (2005), because she could not identify an increase in charred plant macroremains during the Early Holocene at Lake Zeribar. The set of climatic and anthropogenic factors that shaped prehistoric landscapes in the Zagros is therefore somewhat unclear, although the regional vegetation development is today well reconstructed based on off- and on-site data.

Palynological analyses from both lakes generally indicate a replacement of the regional Late Pleistocene Chenopodiaceae-*Artemisia* steppe by grasslands and *Pistacia*-dominated woodlands after the Younger Dryas (van Zeist and Bottema 1977, 1991). This pattern differs from the Levantine palaeoenvironmental sequence, where oak woodlands spread with warmer and wetter conditions after cal 11,600 cal BP and multi-proxy studies even indicate higher precipitations than at present (Robinson et al. 2006). Oak forests today characterize the lower and mid-elevations of the Zagros Mountains (Zohary M. 1963), but only arrived from their main glacial refuges in the Levant by the mid-Holocene (van Zeist and Bottema 1977, 1991; Djamali et al. 2010: Fig. 2). As we have seen, this delayed spread of oak woodlands throughout the eastern arc of the Fertile Crescent was possibly influenced by an Early Holocene moisture deficit in the Taurus-Zagros arc (Griffiths et al. 2001; Stevens et al. 2001, 2006; Wasylikowa 2005; Djamali et al. 2010). Authors who doubt that predominantly climatic factors inhibited the establishment of oak woodlands in the Zagros suggested a significant anthropogenic influence on the vegetation development including anthropogenic fires to support grasslands and the development of agro-pastoral economies in general (Roberts 2002; Matthews W. 2016). Asouti and Kabukcu (2014) went a step further and suggested a key role of pastoralism and woodland management practices for eventually reducing the grass cover and supporting the growth of trees and the establishment of oak woodlands throughout Anatolia and the Taurus-Zagros arc, which they principally regard as anthropogenic vegetation.

The data from Mirabad and Zeribar do not directly inform us about the environmental conditions around Chogha Golan. One important question concerns the extend of the *Pistacia*-dominated woodlands, which seem to characterize Early Holocene landscapes between ca. 800 and 1,300 m asl, where we today find the typical Zagrosian oak forests. Based on the anthracological analyses from Chogha Golan, Asouti reconstructed two major vegetation zones in the vicinity of the site that have been exploited throughout its occupation (Riehl et al. 2015: Fig. 9). One of them was indeed the semi-arid *Pistacia-Amygdalus* woodland, which apparently characterized vast regions of the Zagros and its foothills during the Early Holocene. A second important vegetation unit represents the riparian vegetation along the ancient Konjan Cham River, indicated by Salicaceae and *Tamarix* sp. charcoal. As we will discuss in the next section, an integration of all bio-archaeological datasets contributes to a more detailed understanding of the surrounding landscapes and how they were exploited by the inhabitants of Chogha Golan and possibly affected by climatic developments through time.

## Patterns in Site Occupation and Subsistence Strategies

The reconstruction of the principal patterns in site occupation and subsistence strategies is based on the available datasets from anthracological, carpological, faunal, stable isotope and micromorphological analyses (Riehl et al. 2012, 2013, 2015; Karakaya 2013; Zanoni 2014; Baines 2015; Weide et al. 2015; Starkovich et al. 2016) in connection with the already described stratigraphic observations and artifact assemblages. The results of the archaeobotanical analyses of this dissertation project will be integrated into the general discussion and have been published separately (Weide et al. 2017 [Appendix A], 2018 [Appendix B]).

In light of the relatively long sequence at Chogha Golan, the question to which degree subsistence strategies changed through time dominated most analyses. To begin with the lower part of the sequence, we can already see high percentages of wild progenitor species and potential arable weeds in AH XI (Riehl et al. 2013: Fig. S1, 2015: Fig. 5). The wild progenitors include barley (*Hordeum spontaneum*) and lentil (*Lens* sp.), but are accompanied by various vetches (*Lathyrus* spp. and *Vicia* spp.) and abundant *Aegilops* sp. remains as a second large-seeded grass taxon. Interestingly, the proportions of wild progenitors, particularly barley, increase towards AH IX and the percentages of potential weeds parallel the wild progenitors throughout the whole sequence. Riehl et al. (2013, 2015) interpreted these patterns as indicative of developing cultivation activities during the early occupation of the site. Increasing barley grain dimensions supported this suggestion together with stable carbon isotope measurements that signal good growing conditions due to enhanced moisture availability towards AH IX (Riehl et al. 2015: Fig. 7, 10). Interestingly, the lowermost horizons XI and X are composed of soft, silty deposits, whereas AH IX accumulated above the oldest plaster floor and contains building debris (Zanoni 2014: 59-60). The intensification of barley exploitation therefore likely accompanied a general change in resident patterns towards more permanent occupations after ca. 11,000 cal BP that also included the construction of permanent buildings. Anthracological results indicate the regular exploitation of the *Pistacia*-*Amygdalus* woodlands during this early phase and the faunal data are dominated by caprines and fish remains (Starkovich et al. 2016).

Changing exploitation strategies of several resources characterize the develoment towards the mid-sequence. Percentages of *Pistacia* charcoal decrease to only ca. 6 % in AH VI and wood seem to have primarily been obtained from the riparian vegetation, dominated by Salicaceae and salt-tolerant *Tamarix* sp. Caprines still dominate the faunal assemblage, but increased percentages of gazelles first occur in AH VI and continue in AH V. Stable carbon isotope values from barley grains show a moderate drought stress signal for AH VI, corresponding to low proportions of barley in general. All these patterns point towards increasingly dry conditions in the surrounding of Chogha Golan towards the mid-sequence, which could explain the opening of the *Pistacia*-*Amygdalus* woodlands and increased values for gazelles that are characteristic for more open landscapes (Martin 2000). Interestingly, Borrell and his colleagues refer to an event of rapid climate change (RCC) that is visible in several palaeoclimatic records and associated with cooler conditions in the northern hemisphere at about 10,200 cal BP (Borrell et al. 2015 and references therein). A correlation of this RCC with the sequence at Chogha Golan is, however, problematic. AH VIII gave a radiocarbon date of ca. 10,600 cal BP and AHs VI-IV center around 10,000 to 9,900 cal BP (Riehl et al. 2015: Table 1), so the start of the development towards drier conditions that affected the overall landscape and resource availability cannot be dated precisely. Exploring the possibility that the observed developments at Chogha Golan could have been associated with this RCC is compelling, but the chronological resolution of the sequence does currently not allow such a correlation.

*Pistacia* percentages rapidly stabilize after AH VI between 20 and 40 % and increase towards ca. 90 % in the uppermost horizon. The riparian vegetation was continuously exploited for wood resources and only decreased in percentages towards the *Pistacia*-dominated AH II and I. The faunal data show decreased values for gazelles after AH VI, supporting the conclusion that *Pistacia-Amygdalus* woodlands again spread in the region. Particularly intriguing patterns derive from the carpological data and the isotope measurements. Towards AH V and IV, barley grain dimensions increase again and the isotope data indicate increased moisture availability comparable to the values from AH IX. These patterns are accompanied by generally increasing percentages for barley in the overall assemblage, which Riehl et al. (2015) take as the basis to suggest a second phase of intensified barley cultivation at Chogha Golan.

Contemporaneously, small-seeded grasses including *Phalaris*, *Eragrostis* and grains that resemble species of *Phleum* substantially increase and contribute between 45 and more than 60 % to the plant remains from AH V-III (Riehl et al. 2015: Fig. 5; Weide et al. 2018: Fig. 2). Reconstructing the origin of these high amounts of small caryopses is crucial and difficult at once. Generally, such high amounts of small seeds and fruits represent a potential indicator for the use of herbivore dung as fuel (e.g. Miller 1984; Miller and Smart 1984), which has been confirmed in various archaeological and experimental studies (e.g. Charles 1996; Valamoti and Charles 2005; Bogaard et al. 2013, 2014; Wallace and Charles 2013; Filipović 2014; Whitlam 2015). However, recovering high amounts of small fruits is not sufficient to reliably identify dung burning as an important taphonomic factor for the formation of a charred archaeobotanical assemblage. Additional criteria include the lack of sufficient wood resources in the landscape, the evidence for herbivore management at a site to collect large amounts of dung and the presence of actual burned dung pellets, ideally containing carbonized plant materials (Charles 1996; Miller 1996; Cappers and Neef 2012).

Quantifying the availability of wood resources in the landscape relative to the need of a community is almost impossible, but the anthracological data from Chogha Golan principally confirm that wood was exploited from two forested habitats throughout all levels of occupation. The horizons with indicators for heavily depleted *Pistacia* woodlands predate the increase in small caryopses, which could still indicate a delayed response to a shortage of wood resources. Generally, the absence of wood in the landscape, as e.g. evident from the site of Ali Kosh (Miller 1996), cannot be expected for Chogha Golan, but this leaves the question relatively open whether the available wood resources must have been supplemented by dung.

Equally inconclusive is the evidence for animal management at the site. The zooarchaeological data currently do not allow to draw conclusions on possible management practices or the domestication status of ungulates (Starkovich et al. 2016). A few dung fragments have been identified via micromorphology in thin sections from the midden deposits of AH VIII and in gypsum and mud plaster floors in AH III and II, respectively (Zanoni 2014). In addition, dung spherulites occur randomly throughout the whole sequence. These occasional finds suggest that dung was indeed collected and brought to the site, possibly as a building material, but burned dung pellets have not been retrieved. These patterns are quite ambiguous and cannot provide a final answer to the question whether the large amounts of small caryopses derive from the burning of herbivore dung or if they were brought to the site by other activities. Additional candidates for dung-derived plant remains are the numerous small legume seeds, but they are more abundant in the lower part of the sequence and do not increase with the amount of small grasses in AH V-III (Riehl et al. 2015; Weide et al. 2018).

To conclude, whether the small grasses and possibly also the small legumes derive from dung burning or other subsistence activities currently remains unclear. This is not surprising, because most studies that reliably argued for the burning of dung as an important taphonomic factor found burned dung pellets during the excavations (Miller 1996; Fairbairn et al. 2002) and could apply common criteria to recognize dung-derived plant remains in combination with multivariate statistics to disentangle various routes of entry of different botanical taxa (Bogaard et al. 2013, 2014; Filipović 2014; Whitlam 2015). Weide et al. (2018) generally concluded that such a multivariate approach is currently the only method for reliably identifying dung-derived plant remains, but also for disentangling arable weeds, crops and gathered resources. A fundamental prerequisite for applying this approach, however, is a sufficiently large horizontal exposure that provides the opportunity to extensively sample several contexts per settlement phase. The excavations at Chogha Golan concentrated at sampling the complete sequence in the deep sounding, which provided us with valuable insights into the temporal development of subsistence strategies at the expense of a horizontal analysis of the recovered materials.

These considerations lead us to the general question to which degree the inhabitants of Chogha Golan engaged in wild plant gathering in relation to possible cultivation practices. Until now we concentrated on possible evidences for cultivation of the wild progenitor species between AH XI and III and how the exploitation of the main wood and animal resources changed through time. In building up on the results from Riehl et al. (2012, 2013, 2015), Weide et al. (2018) analyzed an additional number of 23 flotation samples including ca. 23,500 plant remains from AH VII to III in order to increase the sample size for these horizons. This period is of particular importance for evaluating different trajectories towards early agricultural societies within the Fertile Crescent, because it dates to between 10,600 and 10,000 cal BP, where the first morphologically domesticated cereals appear in Anatolia and the Levant.

The general taxonomic composition and the proportions of the identified taxa from these samples are highly comparable to the already discussed samples. The patterns for the small-seeded grasses, the wild progenitor species and *Aegilops* as a second important large-seeded grass could be confirmed and we generally expect that the sample size throughout the sequence in the deep sounding was sufficient to reflect the actual archaeobotanical assemblages without a sampling bias. What has gained particular attention of Weide et al. (2018) are the numerous medium to large-seeded grasses other than *Hordeum spontaneum*, *Aegilops* sp. and the small-seeded taxa. The analyzed samples between AH VII and III yielded high numbers of grains from wild oat (*Avena* sp.), bromes (*Bromus* spp.), other wild barleys (*Hordeum* spp.), *Eremopyrum* sp., medusahead (*Taeniatherum caput-medusae*) and a member of the Triticeae with no known modern counterpart, called Triticoid type grains after van Zeist et al. (1984) (see Riehl et al. 2013: 66). Chaff from *T. caput-medusae* and an indeterminate spikelet type that does not correspond to any of the identified caryopses accompany the non-cereal taxa. All these remains add up to *H. spontaneum* and *Aegilops*, with their grains being even more abundant than caryopses of these two species (Weide et al. 2018: Fig. 2B). Such a high abundance of wild grasses generally characterizes the archaeobotanical assemblage from Chogha Golan and is also evident from the lower part of the sequence (Riehl et al. 2013: Tab. S1).

Experiments with ruminant dung proved that grains of cereals and comparable size-classes do not survive digestion (Valamoti and Charles 2005; Wallace and Charles 2013; see also Whitlam 2015: Tab. 7.9), so the abundant Poaceae remains should not derive from burned dung. Whether they were all collected for consumption is difficult to assess, but the scarcity of chaff from these taxa and culm nodes in general throughout the sequence seem to speak against a primary function as fuel or possible construction materials (*cf.* Willcox and Stordeur 2012; Fairbairn et al. 2014). Hence, the abundant medium and large caryopses most probably represent foods, which we also expect for grains from *H. spontaneum* and *Aegilops*. This conclusion is supported by the overall abundance of wild grasses from contemporary sites in the Zagros and adjacent areas (see Chapter 3), reflecting the reconstructed Early Holocene landscapes that exhibited a large grassland component.

The abundance of non-cereal grasses throughout the sequence raise the question whether we can focus on one species only for assessing possible cultivation practices of morphologically wild grasses. The evidence from proportions, grain sizes and stable carbon isotopes indeed speaks for the management of *H. spontaneum* populations, but the other taxa share the same habitat and grow together with wild barley in primary and secondary stands today (Zohary M. 1973; Zohary D. et al. 2012; Weide et al. 2018: Fig. 10). This indicates that all medium to large-seeded Poaceae taxa identified at Chogha Golan possibly grew together. My own harvesting experiments in the Upper Galilee and the Golan Heights in Israel in early May 2017 showed that all these species have a distinct growth habit, so they would not automatically end up in one harvest if only one of the species is targeted. The abundant occurrence of grains from smaller *Hordeum* species, oats, bromes, *Taeniatherum* and the Triticoid type grains therefore should reflect their deliberate harvesting alongside *Aegilops* and *H. spontaneum*. If we now assume that *H. spontaneum* stands have been intensively managed or cultivated, we might expand this expectation to the grass stands in general, which leads us to the ethnographically well documented concept of resource management (e.g. Smith 2001, 2007, 2011a and references therein). As defined in the introduction, resource management refers to the practice of facilitating the growth and productivity of resources in general and does not automatically involve domesticated resources, nor does it identify an economy as agriculture. It figures prominently in the application of Niche Construction Theory (NCT) to reconstruct prehistoric subsistence behaviors and also the behavioral context of plant and animal domestication (e.g. Zeder and Smith 2009; Smith 2011b; Wollstonecroft 2011; Zeder 2012a, 2016). Proponents of NCT assume that organisms, including humans, shape their own living habitat and with this influence the selection pressures acting on their own evolutionary pathway (Odling-Smee et al. 2003). Applied to prehistoric humans this would mean that also pre-agricultural societies could have engaged in activities that altered the landscapes they inhabited. Indeed, evidence for active resource management in the Fertile Crescent dates back to the Early and Middle Epipalaeolithic of the southern Levant (Ramsey et al. 2015; Snir et al. 2015a) and has been suggested for grasslands and wild caprines in the Zagros Mountains (Zeder and Hesse 2000; Roberts 2002; Zeder 2008, 2011b; Matthews W. 2016). Most important for us, however, is to recognize that active management practices for maintaining the availability of resources around a settlement go far beyond cultivation in its traditional sense (Anderson 2005), which we have to take into account for Chogha Golan as well. Ethnographically documented practices comprise broadcast sowing of seeds on alluvial sediments to ensure sufficient soil moisture (Smith 1992, 2011a: 839), the digging of simple irrigation canals to support the growth of "natural" communities of undomesticated plants (Bettinger 1977; Harris 1996b; Smith 2001; Anderson 2005) or the deliberate burning of vegetation for supporting grasslands over trees and attracting game species (Mellars 1976; Laris 2002; Sheuyange et al. 2005). However, the available data from Chogha Golan do not allow to identify specific resource management practices that could have been very diverse, but urge us to go beyond a simple differentiation between cultivating wild progenitors and gathering from unmanaged habitats. Several points raised by Weide et al. (2018: 22) further support this suggestion. At the upper Euphrates sites where pre-domestication cultivation of morphologically wild cereals and possibly pulses has been suggested, gathered river valley species clearly decline contemporaneous to an increase in wild progenitor species (Willcox et al. 2008, 2009). At Chogha Golan we do not see such a clear focus on a few intensively managed taxa or the decline in gathered resources, which provides additional arguments that possible management practices did rather target at whole vegetation units and not single species. This issue will be further discussed in the supra-regional perspective in chapter 3.

Generally, to which degree and how long the inhabitants of Chogha Golan possibly engaged in resource management practices or even cultivation before AH II is very difficult to assess and specific residence patterns as one important factor that could have influenced subsistence strategies is widely unknown. If we assume a sedentary community that harvests wild resources on an annual basis, we should expect a depletion of these resources with time. Turned around, evidence for a year-round occupation would provide an additional argument for expecting active resource management. The problem for Chogha Golan is that we currently cannot draw reliable conclusions on the permanence of occupation throughout the roughly 2,000 years. In assuming that the site was possibly not inhabited for several years or even decades and repeatedly re-settled, the inhabitants could possibly have relied on the available resources without engaging in management practices for considerable periods. Likewise, it is not fully clear whether the site was inhabited the whole year round. The carpological assemblage includes indicators for mainly spring (e.g. grasses) and late summer to early autumn occupation

(*Pistacia*), but evidence for a presence of humans during winter is not available. As no fruits ripen between autumn and early spring, only a few exploited resources such as migratory birds could inform about winter occupation (*cf.* Simmons and Nadel 1998; Snir et al. 2015a: S1 Fig). However, the faunal assemblage at Chogha Golan only contains a low proportion of bird bones (Starkovich et al. 2016), so the question whether the site was occupied the whole year-round remains open.

An additional problem concerns the interpretation of grain sizes for assessing whether cereals have been cultivated or gathered from unmanaged stands. Increased grain dimensions are commonly explained by a deeper burial depth indicative of cultivation (Fuller 2007), but are also correlated with overall growing conditions and climatic variables that considerably varied throughout the Early Holocene (Asouti 2017: 34). Whether the increased barley grain dimensions coupled with isotope values indicative of enhanced moisture availability indeed imply active management or simply changing precipitation regimes through time is somewhat open and the fluctuating values for both size and isotopes also show that possible management practices could have significantly varied through time (Riehl et al. 2015; Asouti 2017: 38). The most important conclusion is therefore that the sequence of Chogha Golan reflects successful long-term adaptations to the regional environments throughout roughly two millennia, presumably involving the active management of various resources or vegetation units before the cultivation of morphologically domesticated emmer wheat (*Triticum dicoccum*) started towards 9,800 cal BP (Riehl et al. 2013; Weide et al. 2015). Riehl et al. (2015) characterized the long-term patterns from the site as reflecting diverse and resilient subsistence strategies, a conclusion that is not significantly affected by the analyses of the additional samples. Particularly the stable values for the abundant medium and large-seeded wild grasses suggest a relatively secure and continuous exploitation of taxonomically diverse grasslands throughout virtually the complete occupation period of Chogha Golan (Riehl et al. 2013; Weide et al. 2017, 2018). More precise reconstructions can currently not be achieved and would also require methodological advancements to reconstruct ethnographically documented resource management practices from archaeological data (e.g. Smith 2011a: 839).

We will complete this discussion of long-term patterns in the subsistence economy of Chogha Golan with the data from the final settlement phase between ca. 9,800 and 9,600 cal BP (AH II and I, respectively). Since taphonomic analyses using a multivariate approach identified the assemblage from AH I as biased towards robust plant remains and heavily dominated by cereal chaff (Weide et al. 2017: Fig. 3, 4a), we will concentrate on the result from AH II. This horizon provided the first reliable evidence for the cultivation of morphologically domesticated emmer wheat, although the chaff remains still include considerable proportions of shattering spikelets (Riehl et al. 2013, Weide et al. 2017: Tab. 3). By implication, the archaeobotanical assemblage from this horizon should contain an arable weed flora, for which many identified taxa come into question (Riehl et al. 2013: Tab. S1; Weide et al. 2017: Tab. 4). However, a correlation of these potential arable weeds with chaff and grains from the cereal species of AH II did only yield very few positive and significant correlations (*cf.* Fairbairn et al. 2002; Tab. 2). Seeds of *Astragalus* and/or *Trigonella* positively correlate with barley chaff, while *Medicago* spp. seeds correlate with barley and emmer grains, possibly indicating that small-seeded legumes grew as weeds in fields or that *Astragalus* bushes were used as fuel alongside barley chaff. These are the only positive correlations possibly informing us about the state of some taxa as weeds and we are therefore left with a rather unclear origin of the diverse wild taxa in AH II. This situation could either reflect an insufficient number of sampled contexts for obtaining statistically significant results, or the fact that many fruits and seeds did simply not arrive at the site as arable weeds. For evaluating this second possibility, Weide et al (2017: Tab. 4) compiled ethnobotanical data from mainly the Near and Middle East for all taxa that have a ubiquity of >10 % in AH II and I. In combination with archaeological evidence for their deliberate use at other prehistoric sites, I argued that several wild taxa likely represent deliberately harvested and utilized resources. These include the numerous fruits or seeds from *Malva*, *Bolboschoenus glaucus*, *Capsella* or *Descurainia* and of course the *Pistacia* nuts. Seeds of the crucifers *Alyssum* sp. and *Lepidium* sp. together with *Atriplex* sp. fruits are particularly abundant in samples from the midden deposits of AH VI, likewise suggesting deliberate gathering activities (Weide et al. 2018: S2 Table). In addition, the abundant wild grasses including *H. spontaneum*, *Aegilops* and several other non-cereal taxa still make up considerable proportions of AH II and seem to have been continuously exploited alongside the early cultivation of domestic emmer. These patterns show that the cultivation of a morphologically domestic cereal was integrated into a traditional economy that to a large extent depended on wild resources and continued to do so.

**Table 2.** Pearson correlations of seeds/fruits of potential arable weeds with chaff (ch) and grains (gr) of the cereals including *Aegilops* sp. based on 30 samples with more than 100 identifiable items from AH II of both excavation areas. Statistically significant correlations ($p < 0.05$) are given in bold numbers. Analyses have been conducted with JMP (©2016 SAS Institute Inc.13).

| | *H. spontanum* ch | | *H. spontaneum* gr | | *Aegilops* ch | | *Aegilops* gr | | *Triticum* ch | | *Triticum* gr | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | rho | p | rho | p | rho | p | rho | p | rho | p | rho | p |
| *Astragalus/Trigonella* | **0.5117** | **0.0038** | 0.3274 | 0.0774 | -0.1577 | 0.4053 | -0.1866 | 0.3235 | 0.3078 | 0.098 | -0.2427 | 0.1963 |
| *Avena* | 0.2715 | 0.1466 | 0.0442 | 0.8167 | -0.0009 | 0.9964 | -0.2947 | 0.1139 | 0.2397 | 0.2019 | 0.0363 | 0.8489 |
| *Atriplex* | 0.0537 | 0.7781 | 0.3273 | 0.0775 | -0.0129 | 0.9459 | -0.1428 | 0.4515 | -0.0736 | 0.6991 | -0.0194 | 0.919 |
| *Bell./Muscari/Ornitho.* | 0.0549 | 0.7734 | 0.2975 | 0.1103 | -0.2218 | 0.2388 | -0.1436 | 0.4492 | -0.3119 | 0.0933 | -0.1307 | 0.4912 |
| *Bolboschoenus* | 0.2748 | 0.1416 | -0.1541 | 0.4163 | -0.2278 | 0.226 | -0.1622 | 0.3918 | -0.1336 | 0.4816 | -0.1703 | 0.3681 |
| *Bromus* | **-0.379** | **0.0389** | **-0.4593** | **0.0107** | 0.039 | 0.838 | **0.399** | **0.0289** | **-0.4792** | **0.0074** | 0.0587 | 0.7579 |
| *Buglossoides arvensis* | -0.0346 | 0.8558 | 0.0475 | 0.8033 | **-0.3754** | **0.0409** | -0.2294 | 0.2226 | 0.0901 | 0.6357 | 0.1974 | 0.2958 |
| *Buglossoides tenuiflora* | 0.1762 | 0.3517 | 0.1292 | 0.4964 | -0.1522 | 0.422 | -0.1247 | 0.5114 | 0.0034 | 0.9856 | 0.015 | 0.9371 |
| *Capsella/Descurainia* | 0.3097 | 0.0958 | 0.0365 | 0.8483 | 0.2098 | 0.2658 | -0.1395 | 0.4622 | 0.2073 | 0.2717 | -0.2133 | 0.2578 |
| *Centaurea* type | 0.1779 | 0.3469 | 0.3045 | 0.1018 | -0.0658 | 0.7298 | -0.1471 | 0.4378 | -0.0303 | 0.8736 | 0.0996 | 0.6004 |
| *Galium* | 0.1674 | 0.3766 | 0.3249 | 0.0798 | 0.3582 | 0.052 | -0.1402 | 0.4599 | 0.0522 | 0.7842 | -0.132 | 0.4869 |
| *Gypsophila/Silene* | -0.0773 | 0.6848 | 0.0349 | 0.8548 | -0.0023 | 0.9904 | -0.079 | 0.6781 | **-0.4339** | **0.0166** | -0.1313 | 0.489 |
| *Heliotropium* | 0.1237 | 0.5148 | 0.086 | 0.6515 | -0.3147 | 0.0903 | 0.1016 | 0.5932 | 0.2168 | 0.2498 | 0.0014 | 0.9943 |
| *Hordeum* | 0.0624 | 0.7432 | **-0.3768** | **0.0401** | 0.0784 | 0.6804 | 0.0837 | 0.6603 | -0.0232 | 0.9033 | -0.353 | 0.0557 |
| *Malva* | -0.276 | 0.1398 | 0.0716 | 0.707 | -0.1715 | 0.3648 | 0.1665 | 0.3791 | -0.177 | 0.3493 | 0.0043 | 0.9822 |
| *Medicago* | -0.0024 | 0.99 | **0.3772** | **0.0399** | -0.0639 | 0.7372 | -0.2065 | 0.2736 | 0.1565 | 0.4089 | 0.0265 | 0.8895 |
| *Medicago radiata* | 0.2679 | 0.1523 | 0.1355 | 0.4753 | **-0.6631** | **<.0001** | -0.2471 | 0.188 | **0.483** | **0.0069** | 0.0566 | 0.7664 |
| *Phalaris* | -0.229 | 0.2236 | 0.0052 | 0.978 | -0.3183 | 0.0865 | 0.1399 | 0.4609 | -0.199 | 0.2918 | 0.0339 | 0.8588 |
| *Phleum* type | -0.1686 | 0.3732 | -0.3481 | 0.0594 | 0.0843 | 0.658 | 0.1161 | 0.5413 | -0.2397 | 0.202 | 0.2045 | 0.2784 |
| *Taeniatherum* (gr+ch) | -0.0864 | 0.65 | 0.08 | 0.6742 | 0.2533 | 0.1769 | -0.0633 | 0.7397 | | | 0.0519 | 0.7853 |
| Triticoid type | 0.101 | 0.5954 | -0.206 | 0.2748 | -0.1679 | 0.375 | -0.0302 | 0.8742 | 0.1901 | 0.3144 | 0.0388 | 0.8385 |

# Chapter 3

# The Zagros Mountains during the Neolithic Transition

## The Epipalaeolithic-Neolithic Sequence in the Zagros Mountains

Figure 1 gives an overview of the chronology of the most important sites in the central and northern Zagros Mountains and the adjacent Mesopotamian plain. After abandonment of vast areas of the Zagros during the LGM (Hole 1996), Epipalaeolithic occupations are attested for several sites including Zarzi rock shelter (Garrod 1930; Wahida 1981) and Shanidar Cave (Solecki 1963; Solecki and Solecki 1983) in the northern Zagros and Palegawra (Braidwood R. and Howe 1960; Turnbull and Reed 1974), Warwasi (Braidwood R. et al. 1961; Turnbull 1975; Olszewski 1993) and Pa Sangar (Hole and Flannery 1967) in the central Zagros (Olszewski 2012; Matthews R. et al. 2013b).

A possible settlement gap in the Zagros highlands during the Younger Dryas represents a highly debated issue. Whereas scholars traditionally assume that the highlands of the Zagros were not inhabited during the time between ca. 13,000 to 11,500 cal BP (Hole 1996; Darabi 2012: Fig. 1), R. Matthews et al. (2013b) refer to several sites farther north to argue that at least the mid-altitudes of the Zagros were not fully abandoned. Excavations at Shanidar Cave (layer B1) yielded an early cemetery that dates to roughly 12,400 cal BP (Solecki et al. 2004: 5). The nearby site of Zawi Chemi Shanidar yielded a comparable radiocarbon date (~12,800 cal BP) and supports the evidence for a Younger Dryas occupation of the northern Zagros between ca. 425 and 750 m asl (Solecki et al. 2004: 5). Whether Karim Shahir at ca. 850 m asl, ca. 200 km to the south-east, was also inhabited during the Younger Dryas is somewhat unclear since no radiocarbon date is available, but the similarity of the artifact assemblage to Shanidar and Zawi Chemi might indicate a contemporary occupation (Howe 1983; Matthews R. et al. 2013b). Zeder (2008: Tab. 3, 2012: Fig. 2) also dates the late occupation at Palegawra into the Younger Dryas. Although Darabi (2012) still emphasized that no continuous sequence from the Late Pleistocene to Early Holocene can currently be reconstructed for the central Zagros, indirect evidence for continuous traditions from the Epipalaeolithic to the Neolithic comes from chipped lithic assemblages (Olszewski 1994; Kozlowski 1999) and from the focus on wild caprines that were presumably managed since the later Epipalaeolithic and herded since at least 10,000 cal BP (Zeder and Hesse 2000; Zeder 2008). These evidences point towards autochthonous developments of early agricultural societies in the Zagros and the perceived settlement gap might be more realistically explained by a research gap and the possibility that many prehistoric sites in the Zagros region were buried under thick Holocene deposits (Kozlowski 1999; Nashli and Matthews R. 2013). Moreover, numerous sites with lithic components attributed to the Epipalaeolithic are known from surveys in the Zagros, also from further south (Conard et al. 2006), and have the potential to provide valuable information on the settlement history and continuity of the Zagros during the Late Pleistocene.

For the Early Holocene, we will follow the chronological scheme adopted by Nashli and R. Matthews and avoid terms such as "Transitional Neolithic" (Darabi 2012) or "Proto-Neolithic" (Solecki et al. 2004) that put much emphasis on defining the Neolithic as a cultural

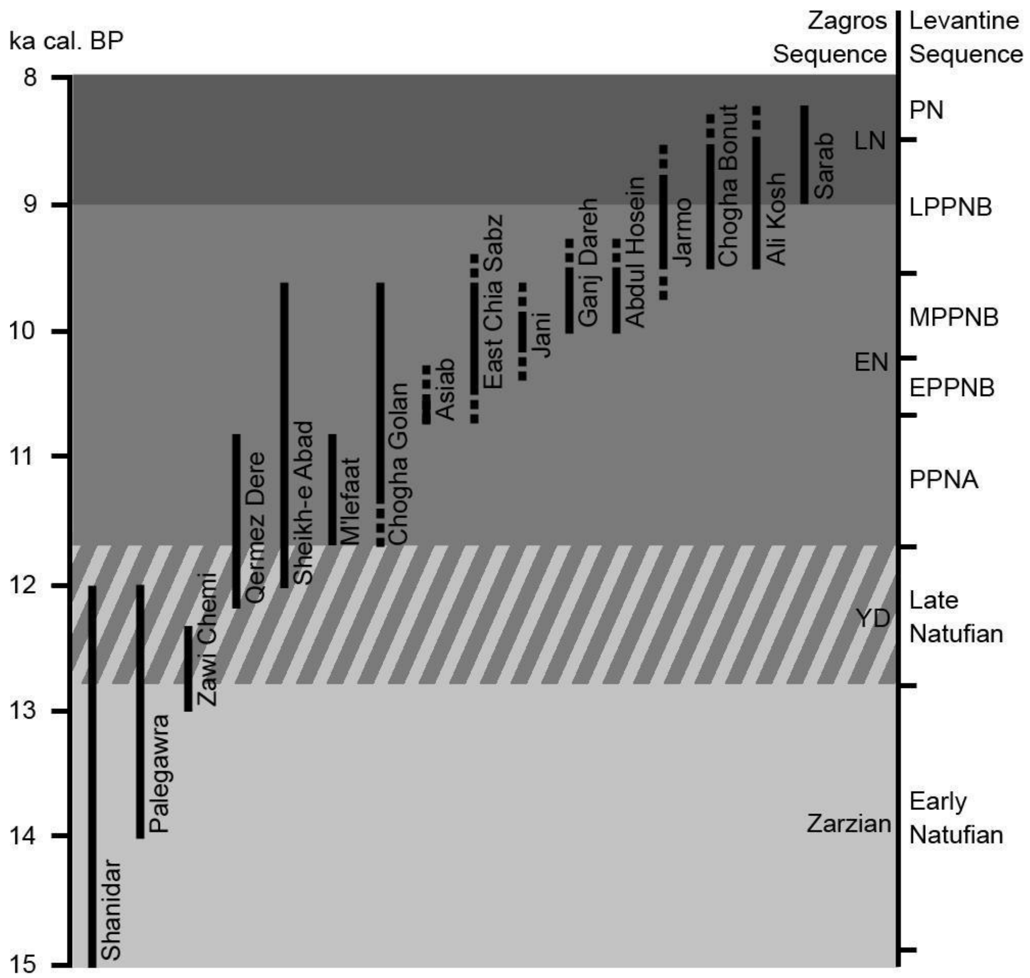


**Fig. 1.** Chronology of selected sites from the central and northern Zagros Mountains and the adjacent Mesopotamian plain. Absolute dates are based on Zeder (2008, 2011b), Exoriente (2018) and references given in text.

stage including a reliance on domesticates. Nashli and R. Matthews (2013: 7) only distinguish an Early Neolithic (EN) between ca. 11,700 - 9,000 cal BP and a Later Neolithic (LN) between ca. 9,000 and 7,500 cal BP. The Early Neolithic includes all Early Holocene settlements and occupation phases without ceramics (= aceramic Neolithic), while towards ca. 9,000 cal BP ceramic vessels become widely used in the region (Aurenche et al. 2001).
Evidence for occupation of the central Zagros highlands at ca. 1,400 m asl during the earliest Holocene comes from Sheikh-e Abad. Several radiocarbon dates place the sequence between ca. 12,000 cal BP and 9,600 cal BP (Matthews et al. R. 2013a). Chogha Golan in the foothills of the central Zagros provided comparable dates, although the age of the earliest occupations is not fully clear and might date to the second half of the 12$^{th}$ millennium (see Chapter 2). Both sites represent the only known Early Holocene settlements of the central Zagros until Asiab and East Chia Sabz were settled between ca. 10,700 and 10,500 cal BP (Braidwood R. 1960; Zeder 2008; Darabi et al. 2011). Occupation at Ganj Dareh started around 10,100 cal BP and possibly lasted for only two to three centuries (Zeder and Hesse 2000; Meiklejohn et al. 2017). Abdul Hosein should be roughly contemporaneous (Hole 1987; Pullar 1990), while the only date from Jani so far available places its mid-sequence to ca. 10,100 cal BP (Matthews R. et al. 2013a). Adjacent to the central Zagros and bordering the Mesopotamian plain, Chogha Bonut (Alizadeh 2003) and Ali Kosh (Hole et al. 1969; Zeder and Hesse 2000) represent the first sites that include deposits from the Later Neolithic, to which also the campsite of Sarab (Braidwood R. 1960) in the highlands is dating (Zeder 2008: Tab. 3). Qermez Dere and M'lefaat near the Tigris in northern Iraq complement the regional archaeological record (Watkins et al. 1989; Kozlowski 1998). Both sites were occupied during the earliest Holocene until ca. 10,800 cal BP, while the earliest dates from Qermez Dere even date to the late Younger Dryas (see overview in Exoriente 2018).

## Exploiting Early Holocene Ecosystems

Based on this chronological sequence we can assume a continuous occupation of the Zagros Mountains throughout the Pleistocene-Holocene transition, although settlement activities presumably shifted to lower altitudes during the Younger Dryas. Evidence for a regional tradition without a fundamental influence of the Levantine Pre-Pottery Neolithic predominantly comes from lithic and faunal data. Olszewski (1994: 85-87) first addressed evidence for continuities in chipped stone assemblages from the Zarzian to the Early Neolithic and put emphasis on the presence of microliths in both techno-complexes. Kozlowski (1999: 59-62) built up on

Olszewski's suggestion and supported her argument, particularly emphasizing similarities between the assemblage of Zawi Chemi Shanidar and the M'lefatian industries present at many Early Neolithic sites of the region. In addition to the chipped stone artifacts, Zarzian and Early Neolithic assemblages include ground stone tools that were presumably used for processing plant foods (Olszewski 2012) and raw materials including asphalt (Conard and Zeidi 2013). Zarzian sites did not yield plant remains, but they provide evidence for the increasing exploitation of small mammals, fishes and molluscs alongside a wide range of wild ungulates including goat, sheep, gazelle, onager, boar, red deer and aurochs (Garrod 1930; Turnbull and Reed 1974; Turnbull 1975; Wahida 1981; Solecki and Solecki 1983; Olszewski 2012). Solecki et al (2004: 180) reported particularly intriguing patterns from the stable carbon isotope data of human skeletal remains from the cemetery at Shanidar B1, which document significant contributions of C3 plants to the overall diet during the Younger Dryas. These few Late Pleistocene case studies suggest that Epipalaeolithic groups of the Zagros arc exploited a high diversity of resources and may represent an important precursor for local Early Neolithic economic adaptations.

Research on animal domestication in the Zagros has long indicated an autochthonous sequence of specialized exploitation strategies for caprines since the Late Pleistocene. In his investigation of the Zawi Chemi Shanidar faunal assemblage, Perkins (1964) detected an emphasis on young males among the sheep and suggested, in combination with other arguments, Late Epipalaeolithic sheep domestication. Zeder (2008) re-analyzed this assemblage and confirmed Perkins' results, but also argued that the age profile of the Zawi Chemi sheep does not fully correspond to typical herding signatures characterized by a focus on young males and a delayed slaughtering of females (Redding 1981). Zeder compared her data to the assemblages from Ganj Dareh (Hesse 1978; Zeder 1999, 2005; Hesse and Zeder 2000) and Ali Kosh (Hole et al. 1969; Zeder and Hesse 2000), which both provide early reliable evidence for goat herding in the central Zagros region after ca. 9,900 and 9,500 cal BP, respectively. In addition, the goats from Ali Kosh show a gradual change in horn core shape and size over a period of ca. 1,000 years, indicative of the early appearance of morphological domestication traits (Hole et al. 1969). Evidence for early caprine herding has also recently been proposed for Sheikh-e Abad and Jani. Multi-proxy studies involving archaeozoological, micromorphological and micro-archaeological analyses suggest goat herding at both sites, based on the heavy accumulation of unburned and burned dung in all sampled layers that date to or after ca. 10,000 cal BP (Matthews R. et al. 2013a, d). The pattern detected at Zawi Chemi Shanidar might therefore better be explained as a selective hunting strategy in the Epipalaeolithic focusing on young males to assure a vital free-living population (Zeder 2008, 2011b). It compares well with the assemblages of the PPNA sites of Hallan Çemi and Körtik Tepe in the upper Tigris area, which both seem to reflect similar hunting strategies that predate active herd management (Arbuckle and Özkaya 2005; Redding 2005). The available data do not fully clarify where and when goat domestication initially took place within the Zagros, but they strongly suggest that an autochthonous development towards goat herding and selection for morphological domestication traits started at least around ca. 10,000 cal BP and is predated by selective hunting strategies that date back to the late Epipalaeolithic.

Whereas faunal data have long served for highlighting the importance of the Zagros arc for the Neolithization process in the Near East (e.g. Reed 1959; Hole et al. 1969; Hole 1984, 1996), archaeobotanical data that could shed light on plant cultivation and domestication during the first millennia of the Holocene were absent until recently. We surely can regard Charles' (2007) review on the spread of farming into the Zagros arc as a valuable summary of the state of research one decade ago that also demonstrates how profoundly our picture of socioeconomic developments can change with the excavation of only a few sites. When Charles wrote his article, Ganj Dareh yielded the oldest known and fully published archaeobotanical assemblage from the central Zagros highlands and the older lowland settlements of Qermez Dere, M'lefaat and Nemrik did not yield high proportions of wild progenitors and no domestic crops (Kozlowski 1989; Nesbitt 1995, 1998). The reasonable conclusion was therefore to assume that plant cultivation and domestication emerged farther west in the Levantine corridor and subsequently spread into the Zagros, comparable to the spread of farming into Anatolia and southeast Europe (Colledge et al. 2004; Charles 2007).

This picture changed with the excavation of several Early Neolithic sites during the last decade. Based on the full publication of the plant remains from Qermez Dere and M'lefaat (Savard 2004; Savard et al. 2006) and the recently investigated assemblages from Sheikh-e Abad (Whitlam 2015; Whitlam et al. 2018) and Chogha Golan (Riehl et al. 2013, 2015; Weide et al. 2015, 2017), Weide et al. (2018) suggested that local subsistence strategies since the late Younger Dryas focused on the exploitation of the regional grasslands, since all assemblages included considerable proportions of medium- to large seeded wild grasses alongside *Hordeum spontaneum* and several large-seeded legume species. Wild progenitors do not dominate any of these assemblages, which include grains of other wild *Hordeum* species, *Avena*, *Bromus*, *Lolium*, *Piptatherum*, *Stipa*, *Taeniatherum*, and the Triticoid type. Savard et al. (2006) and Whitlam (2015) both interpreted the abundant wild grasses from Qermez Dere, M'lefaat and Sheikh-e Abad as deliberately gathered foods, which Weide et al. (2017, 2018) likewise concluded for the medium and large- seeded Poaceae taxa from Chogha Golan (see above). Remains of one or possibly several *Aegilops* species outnumber those of *H. spontaneum* at M'lefaat, in some horizons at Chogha Golan and at East Chia Sabz (Riehl et al. 2012), which indicates that this large-seeded taxon played an important role in local subsistence economies during the 12$^{th}$ and 11$^{th}$ millennium BP. These patterns are in good accordance with the palaeoenvironmental reconstructions of the central Zagros, characterized by open landscapes with a large grassland component (van Zeist and Bottema 1977).

As we discussed in chapter 2, the patterns from Chogha Golan with the continuous exploitation of local grasslands coupled with fluctuating barley grain dimensions and isotope data point towards active resource management that involved *H. spontaneum* and possibly targeted on whole stands or vegetation units rather than the cultivation of only one species. Whitlam et al. (2018) also suggested a possible management or "auditioning" of the exploited wild grasses from Sheikh-e Abad, comparable to our interpretation of the Chogha Golan material. Based on the identification of a crop-weed-group including domestic-type barley grains and a potential weed flora in the scatter plot of a correspondence analysis, Whitlam (2015; et al. 2018) assumes the cultivation of domestic barley at Sheikh-e Abad since ca. 10,000 cal BP. She does not expect a local pre-domestication cultivation phase, because *H. spontaneum* remains were not retrieved from the older deposits. These patterns match the data from Chogha Golan, where emmer wheat chaff abundantly appears around the same time and includes increased proportions of non-shattering rachises in samples dating to about 9,800 cal BP (Riehl et al. 2013; Weide et al. 2015, 2018: Fig. 3). The emergence of barley and emmer cultivation coincides with the decrease of gathered wild grasses in assemblages that roughly date to or are younger than 9,800 cal BP. Ganj Dareh already shows a dominance of domestic-type barley grains (van Zeist et al. 1984), whereas the few wild grasses at Ali Kosh (Helbaek 1969) and Chogha Bonut (Miller 2003) most likely represent arable weeds. The domestication status of the legumes is less clear for these sites, but lentil is ubiquitous since the 10$^{th}$ millennium and represents the most important cultivated legume species. We can therefore principally follow Charles (2007), who concluded that barley, emmer and lentil characterized early crop cultivation of the Zagrosian Neolithic. The fact that barley and lentils have already been exploited in the 12$^{th}$ millennium supports the hypothesis of a local and autochthonous emergence of crop cultivation (Riehl et al. 2013, 2015). Less clear, however, is the origin of morphologically domesticated emmer at Chogha Golan, as there are no older finds for this taxon in the region. Whether emmer was domesticated locally or introduced from somewhere in the Levant will be discussed in the next section.

We close this discussion of Early Holocene subsistence strategies in the Zagros arc with more general considerations on the development of sedentism and possibly associated resource management practices. In several articles, the team of the Central Zagros Archaeological Project (CZAP) incorporated their results from Sheikh-e Abad and Jani in a wider perspective of regional socioeconomic developments (Matthews R. et al. 2013a, b; Matthews W. et al. 2013c; Matthews W. 2016). They draw particular attention to the basal deposits of many regional sites, which commonly lack substantial architectural remains such as plaster floors or mudbrick and pisé walls, but exhibit thick ash layers rich in burned materials. Such deposits occur at the base of e.g. Sheikh-e Abad (Matthews W. 2016: Fig. 3), Ganj Dareh (Smith 1975, 1978), Jani (Matthews W. 2016: Fig. 5) and Chogha Golan (Riehl et al. 2013: Fig. 2; Zanoni 2014), where they all predate deposits with evidence for more permanent occupations. In the highlands, rectangular buildings start to appear at several sites around 10,000 cal BP without comparable round or oval predecessors that are so typical for the Levantine PPNA (Kuijt and Goring-Morris 2002; Darabi 2012). The appearance of permanent rectangular buildings corresponds well with the earliest evidences for the cultivation of morphologically domesticated cereals and caprine herding, marking a significant stage in the regional socioeconomic development.

Apparently, many Early Neolithic tells of the central Zagros highlands developed out of more ephemeral occupations, resembling developments at sites in the adjacent regions including Çayönü (Özdoğan 1999), Qermez Dere (Watkins et al. 1991) and Nemrik (Kozlowski 1989). These patterns provide an additional important argument for an autochthonous Neolithization process, involving mobile communities that over time developed a strong commitment to fixed places (Matthews R. et al. 2013b, d; Darabi 2012, 2016). Interestingly, the early date of the oldest mudbrick wall and associated plaster floors of AH X at Chogha Golan might point to a different development in Zagros foothills. Directly built on top of AH XI, these architectural remains are possibly not much younger than 11,000 cal BP and definitely predate 10,600 cal BP, the age of AH VIII. Given the date of 10,000 cal BP is representative for the general appearance of comparable architectural features in the central Zagros highlands, early developments towards increased sedentism and permanent buildings in the lowlands could be up to one millennium older. Differing mobility patterns continue in the highlands after 10,000 cal BP, as the Later Neolithic campsites of Sarab and Tepe Tula'i indicate (Braidwood R. 1960; Hole 1974, 2004). Based on these data we must assume distinct mobility patterns throughout the local Neolithic, with some groups maintaining a mobile lifestyle while the first tells appear that provide evidence for crop cultivation and animal husbandry (Matthews R. et al.

2013b, d). Whether these patterns suggest an early development of mobile pastoralism is difficult to evaluate, but they are significant for understanding local socioeconomic developments.

In linking these general patterns to the palaeoenvironmental record of the central Zagros Mountains, W. Matthews (2016) argues for a strong interrelatedness between the regional environmental and cultural developments. Many authors highlighted the increased influx of microcharcoal particles in Near Eastern lake sediments during the Early Holocene, including Lake Zeribar (Yasuda et al. 2000; Wick et al. 2003; Wasylikowa et al. 2006; Turner et al. 2008, 2010), indicating a growing influence of wildfires on the vegetation development. Although it is hardly possible to differentiate between natural and human-induced wildfires, W. Matthews follows Roberts (2002) in hypothesizing that the higher fire frequencies in the Early Holocene possibly involved deliberate vegetation burning in order to maintain grass-dominated vegetation units. She refers to the thick ashy deposits at the base of many regional tells, which provide additional evidence for a possibly significant influence of anthropogenic fire activities on the Early Holocene landscapes. The goal for engaging in large-scale vegetation burning could have been the creation of pastures for livestock or open areas for dryland cultivation (Roberts 2002: 1008), but could also have been applied by foragers for maintaining suitable hunting grounds in connection with wild game management and for maintaining vegetation units rich in edible grasses (Matthews W. 2016: 116). These interpretations must of course receive further support by future research and clearly stand in a tradition of Niche Construction Theory, which generally assumes an active resource and landscape management of prehistoric humans. They generally build up a scenario in which Early Holocene groups in the Zagros engaged in resource management activities before the cultivation of selected species started around ca. 10,000 cal BP. Of course, the question arises whether we can take these regional patterns to further interpret the site-specific patterns from Chogha Golan. On the one hand, the data from the site may point towards the management of grassland communities over considerable parts of its occupation history, a hypothesis that would be supported by the regional perspective. On the other hand, we currently cannot draw reliable conclusions on the specific character of possible management strategies at Chogha Golan using the data from the site only and we must be cautious in applying patterns from the Zagros highlands onto a site in the lowlands, where at least mobility patterns seem to have been different. A reasonable conclusion would therefore be to regard the active management of grasslands around Chogha Golan and in the whole central Zagros region as a working hypothesis, which needs to be verified by future research. This must involve the application of a multivariate approach to more sites and archaeobotanical assemblages (Weide et al. 2018: 31) and methodological advancements in general for more reliably reconstructing ethnographically documented resource management practices from archaeological datasets (Smith 2011a: 839).

## The Zagros Mountains in the Near Eastern Perspective

The new data from several Early Holocene sites in the central Zagros Mountains considerably expand our knowledge on local subsistence developments during the Neolithic transition. In order to more comprehensively understand and characterize these patterns, we will now integrate the Zagros Mountains into a supra-regional perspective and concentrate on a comparison with the record from the Levantine corridor. This discussion includes the results of a review on wild grass use throughout the Epipalaeolitic and Pre-Pottery Neolithic in the whole Fertile Crescent (Weide et al. 2018 [Appendix B]) and a theoretical approach for correlating economic, architectural and social developments in the Levant in order to better understand patterns in the emergence of cereal cultivation and domestication (Appendix C).

### *Regional Ecosystems and Subsistence Economies*

A striking feature of Early Neolithic subsistence strategies in the Zagros arc represents the exploitation of various large-seeded grasses and legumes since the $12^{th}$ millennium BP. Chogha Golan yielded abundant remains from *Hordeum spontaneum*, lentils and various vetch species from the earliest horizon onwards, highlighting that wild progenitor species and comparable resources thrived in the local ecosystems at least since the Early Holocene. A lack of wild cereal and legume species can therefore not account for potentially different socioeconomic developments in this region of the Fertile Crescent (*cf.* Wright 1983: 508; Hole 1984: 50) and on-site data generally place doubt on the assumption that the Early Holocene in the Zagros was much drier than in Anatolia or the Levant (Matthews W. et al. 2013c; Riehl et al. 2015). Moreover, the relatively high proportions of *Aegilops* sp. remains at Chogha Golan, M'lefaat and Chia Sabz point to an important role of this large-seeded grass in local subsistence economies. Weide et al. (2017, 2018) included *Aegilops* in the cereal category for the analyses at Chogha Golan and suggested an equal importance of *Aegilops* and *H. spontaneum* throughout the sequence. Particularly intriguing is the absence of wild wheats in the region, which have been abundantly exploited in the southern Levant since at least the LGM (Kislev et al. 1992; Feldman and Kislev 2007; Snir et al. 2015a). Except for some grains identified as *Triticum* sp. at Qermez Dere, no site further east yielded significant proportions of *Triticum* remains prior to approx. 10,000 cal BP. Weide et al. (2018: 27) therefore suggested that regional stands of *Aegilops* possibly compensated for the lack of indigenous wheat populations, which also raises the question where the early domestic emmer remains at Chogha Golan came from?

Modern wild emmer (*Triticum dicoccoides*) has its main area of distribution in the southern Levant, while isolated stands occur throughout the whole Fertile Crescent and also in the central Zagros Mountains (Zohary D. et al. 2012). Early archaeobotanical finds of securely identified emmer grains or chaff equally concentrate on the southern Levant and only appear in the upper Euphrates region and central Anatolia during the early PPNB (Nesbitt 2002; Feldman and Kislev 2007; Willcox et al. 2008; Tanno and Willcox 2012; Weide 2015). This pattern may principally suggest that emmer was first exploited in and around the Jordan Rift Valley and only later outside the southern Levant. However, genetic analyses on the geographic origin of modern domesticated emmer provided ambiguous result and most scholars located the origin of domestic emmer somewhere in southeast Anatolia (Özkan et al. 2002, 2005; Mori et al. 2003; Luo et al. 2007). Özkan et al. (2011) tried to explain these patterns with the "dispersed-specific" domestication model, which assumes that a plant was taken into cultivation in a particular location and then brought to other regions before domestication traits became genetically fixed. Genetic analyses would then point towards a monophyletic origin, although the archaeobotanical record does not indicate such a core area. This interesting attempt to integrate the archaeobotanical and genetic data received surprisingly strong support in a recent genetic study. Civáň et al. (2013) analyzed wild and domestic emmer from all over the Fertile Crescent and found that domestic accessions share polygenetic signals with virtually all wild populations. They interpret this as a reticulated origin of domesticated emmer wheat and propose a model in which early cultivated emmer from several regions became intermixed during the pre-domestication cultivation phase. Quite similar to the dispersed-specific model, Civáň and colleagues do not assume a linear development from the initial cultivation to the subsequent genetic fixation of morphological domestication traits within one genetic line. They rather expect the transport of early cultivars over significant distances (*cf.* Willcox 2005) and even speculate whether the wild populations east of the Euphrates could in general descend from such dispersals of early cultivated but genetically wild grains. Since wild *Triticum* stands seem to have been absent from the Zagros in the Early Holocene, but emmer chaff appears towards 10,000 cal BP and includes increased proportions of non-shattering spikelets since 9,800 cal BP, this model might indeed explain current pattern in emmer domestication, although we need more data to confirm such a hypothesis.

A related issue concerns the postulation of a pre-domestication cultivation phase in the central Zagros, analogous to PPNA subsistence strategies in the upper Euphrates region and the southern Levant. In concentrating on the presence of *H. spontaneum* remains accompanied by a potential arable weed flora, Riehl et al. (2013, 2015) suggested the cultivation of morphologically wild barley already in the lower horizons at Chogha Golan. Willcox (2013) incorporated these data into a supra-regional perspective, proposing that pre-domestication cultivation of wild progenitors in the Zagros started around the same time as in other regions of the Fertile Crescent. In the previous discussions I suggested that resource management in the Zagros did possibly not target on single cereal species, also because the taxa in question do not dominate the archaeobotanical assemblages and are accompanied by many other grass taxa that today thrive in the same habitats. In contrast, PPNA communities in the Levantine corridor heavily focused on the exploitation of wild cereals (Weide et al. 2018: Fig. 5), which represents one of the main arguments to propose a pre-domestication cultivation phase (Willcox et al. 2008; Willcox and Stordeur 2012). Willcox et al. (2009: Fig. 2) provided an analysis of wild progenitor proportions over time for several sites in the upper Euphrates region, which they plotted against previously gathered taxa. In comparing the data from Willcox and his colleagues to a similar graph that displays the patterns for sites from the Zagros arc, we see that a decline of gathered species in favor of wild progenitors did not take place prior to the appearance of morphologically domesticated emmer chaff (Fig. 2). Even if we cannot fully rule out that management practices in the Zagros arc prior to 10,000 cal BP targeted at single species, possibly *H. spontaneum* at Chogha Golan, we must account for these significant differences in modeled subsistence developments and I suggest not to apply the concept of pre-domestication cultivation to the Early Neolithic of the Zagros Mountains. Whitlam et al. (2018) recently suggested the same for the 12$^{th}$ and 11$^{th}$ millennium occupation at Sheikh-e Abad, highlighting the distinctive regional patterns. The trajectory towards the cultivation of morphologically domestic cereals in the Zagros was apparently different from that in the Levant and if we assume an introduction of emmer from outside the region, the question arises whether autochthonous plant domestication took place at all in the Zagros arc?

Comparable to emmer, genetic data from modern domestic barley suggest a diffused geographic origin with genetic similarities to many different wild populations (Poets et al. 2015), while Morrell and Clegg (2007) even proposed a second domestication east of the Fertile Crescent. Barley had been exploited since the 12$^{th}$ millennium in the central Zagros and became a principal crop of the region, which may support the suggestion of a local domestication process (*cf.* Riehl et al. 2013, 2015; Willcox 2013). Interestingly, Helbaek (1959: 370,

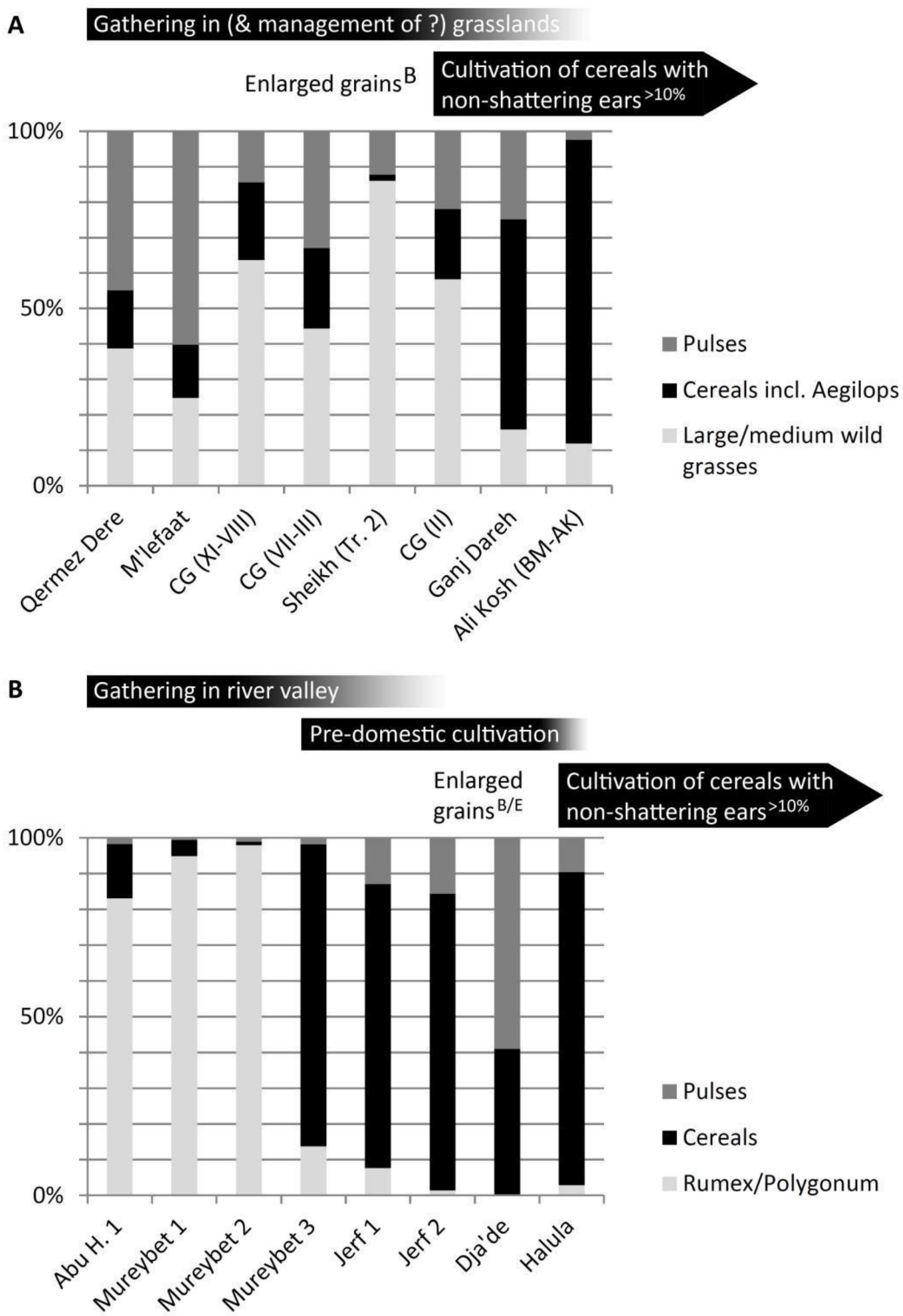


**Fig. 2.** A comparison of models for subsistence developments in the eastern arc of the Fertile Crescent (A) and the upper Euphrates region (B) including proportions of wild progenitor species and gathered resources during the Pleistocene-Holocene transition. Proportions of the displayed taxa are based on their total abundance on the respective sites and exclude chaff. Note the significant increase in cereal grains at the Euphrates sites prior to the appearance of morphological domestication traits. This increase corresponds to the postulated pre-domestication cultivation phase, which is not indicated by increasing proportions for wild progenitors in the Zagros region. Data from Helbaek (1969); van Zeist et al. (1984); Savard (2004); Willcox et al. (2009); Riehl et al. (2013); Whitlam (2015); Weide et al. (2017, 2018). B = barley; E = einkorn; CG = Chogha Golan.

1969: 401) emphasizes the wild-type character of the two-row barley remains from Jarmo and Ali Kosh, possibly indicating that morphological domestication traits of *H. spontaneum* still needed several centuries to become established. In combination with the evidence from domestic emmer, these patterns suggest that domestic cereals in the central Zagros possibly have different origins, which highlights that there was no linear and uniform development towards plant domestication in the Fertile Crescent (Fuller et al. 2011, 2012b; Civáň et al. 2013; Allaby 2015; Poets et al. 2015; Allaby et al. 2017) and that we have to expect diverse interregional contacts that shaped local socioeconomic trajectories (Gebel 2004; Nashli and Matthews R. 2013). Equally, an autochthonous development towards cultivation and domestication of lentils in the Zagros is supported by the long sequence of wild lentil exploitation from Chogha Golan. More important, however, is the fact that lentils and various other large-seeded pulses have been locally exploited since the 12$^{th}$ millennium, definitely speaking against a centered domestication event during the early PPNB in the upper Euphrates area that transformed pulses into an effective food resource (e.g. Lev-Yadun et al. 2000; Abbo and Gopher 2017).

We have now established that communities in the Levant heavily focused on wild cereals since the late Younger Dryas, while groups in the Zagros exploited the indigenous grasslands without such a strong focus on single species. This also raises the question to which degree non-cereal grasses were exploited in the Levantine Neolithic, since they made up large proportions of the plant remains from the Early Epipalaeolithic site of Ohalo II (Weiss et al. 2004a). In general, only a few Epipalaeolithic sites yielded macrobotanical remains and although wild grasses are abundant at most of these sites, e.g. at Abu Hureyra 1 and Wadi al-Hammeh 27, phytolith analyses suggest a focus on wetland resources including sedges and reed grasses in other locations (Ramsey and Rosen 2016; Ramsey et al. 2016, 2017). Based on these patterns we can expect the routine exploitation of grasses, also non-cereal taxa, during the Levantine Epipalaeolithic, but this conclusion is based on a limited number of sites and grasses were apparently not the only important plant resource (Weide et al. 2018).

For the subsequent development during the PPNA, Weiss et al. (2004b) concluded that non-cereal Poaceae taxa substantially lost in importance and have negligible proportions. However, after Weiss and his colleagues reviewed wild grass use in the Levant, several PPN assemblages with important evidences for the possible use of wild grasses have been published. These include Qaramel, Jerf el Ahmar and Dja’de (Willcox et al. 2008; Willcox and Herveux 2012) in the upper Euphrates region and el-Hemmeh (White and Makarewicz 2012) in the southern Levant. Taxa such as *Aegilops*, *Avena*, *Hordeum*, *Stipa* or *Taeniatherum* could theoretically represent arable weeds at these sites, also at Netiv Hagdud (Kislev 1997), but there is actually no further evidence for this conclusion and all authors regarded these taxa as potentially edible resources that were possibly exploited alongside the wild cereals (Weide et al. 2018: Tab. 2). In light of the widespread evidence for wild grass use from the Levantine Epipalaeolithic and also the Zagros Mountains, these patterns suggest the exploitation of wild grasses alongside wild cereals during the PPNA. However, a more precise conclusion is currently not possible and would require a re-analysis of these assemblages using multivariate statistics.

An additional point regards the subsequent development into the PPNB, where domestic plants are present and provide inevitable evidence for crop cultivation. Interestingly, all grass taxa that were ubiquitous during the Epipalaeolithic and PPNA are continuously present at farming sites, which is indicative for their development from gathered resources to common arable weeds. Some typical weed taxa, such as *Lolium* spp. and *Bromus* spp., even show a remarkable increase in ubiquity values since the early PPNB (Weide et al. 2018: Fig. 9), which presumably indicates that cultivation and crop processing techniques were further developed with the cultivation of domestic crops. Single sites such as Çatalhöyük, where high concentrations of *Taeniatherum* remains point to the deliberate storage and use of a wild grass towards the end of the aceramic Neolithic (Fairbairn et al. 2007), highlight that long after domestic crops were established wild resources may still have played a role in food consumption practices. The fact that many segetal grasses had been gathered previously supports the suggestion that edible weeds like *Taeniatherum* may have been intentionally utilized or even promoted during the Early Neolithic (Hillman 1978: 168; White 2013: 483-484). All these results together provide an interesting perspective on wild grass use throughout the Neolithic transition in the Levant, which seems to continue for longer and includes additional aspects than Weiss et al. (2004b) suggested.

To conclude on the differences among ecosystems and subsistence strategies between landscapes throughout the Fertile Crescent, locally distinct trajectories do not seem to have been significantly predicted by the availability of resources. Wild cereals were present in the vast and diverse grasslands of the Zagros since the earliest Holocene and have been exploited alongside other wild grasses and pulses. A pre-domestication cultivation phase equivalent to the Levantine corridor can currently not be reconstructed, which means that economic developments towards early farming societies took different pathways. In the Levant we see a strong focus on wild cereals since the late Younger Dryas, which certainly explains why non-cereal Poaceae taxa were not as intensively used. However, we must emphasize that evidence for the exploitation of wild grasses exists, even at late PPNB sites. Concerning plant domestication in the central Zagros, the currently available evidence points towards a possibly autochthonous domestication process of two-row barley and lentil, while emmer wheat was most probably introduced. These patterns point towards contacts to neighboring regions, presumably involving the area between the upper Tigris and Euphrates, and draw attention to socio-cultural developments that co-evolved with subsistence strategies and allowed the transition to societies with an agro-pastoral economy during the 10$^{th}$ millennium BP in all regions of the Fertile Crescent (Zeder 2008; Asouti and Fuller 2013; Weide et al. 2018).

*Trends in Socio-Cultural Developments*

While we are able to reconstruct the basic features of changing subsistence strategies in the Zagros Mountains, we can only draw preliminary conclusions on the concurrent social developments and how they interrelated with resource management practices and the emergence of morphologically domestic crops. This is mostly due to the relatively small number of excavated sites, some of which have not been fully published. However, some features of changing social relations can be reconstructed from the current archaeological record of the central Zagros and give interesting insights into possible differences and similarities to the Levantine sequence. Roger and Wendy Matthews' team emphasize several intriguing features of the Zagrosian Neolithic (Matthews R. et al. 2013b), of which the egalitarian character of Early Holocene societies and the absence of evidences for central leaders represents a clear analogy to the Levantine Neolithic (*cf.* Kuijt and Goring-Morris 2002: 420-423). Darabi (2016) follows this assumption, which is primarily based upon the fact that mortuary practices show no marked differences between individuals, although grave goods are sometimes present. In addition, obsidian is very rare during the Early Neolithic and first appeared after 10,000 cal BP in the upper levels at Chia Sabz and Chogha Golan (Darabi et al. 2011; Darabi and Glascock 2013; Zeidi and Conard 2013), whereas it is absent at Sheikh-e Abad (Nasab et al. 2013). R. Matthews and his colleagues interpret this as possibly reflecting social sanctioning mechanisms, which served for limiting social inequalities and inhibited the accumulation of valuable raw materials such as obsidian or exotic sea shells (Matthews R. et al. 2013d: 232). They also speculate whether the fire-related activities that formed the thick ash layers at the base of many mounds included feasts, which would have represented a possible context for negotiating social tensions (Benz 2006, 2010; Twiss 2008).

As we will see further below, widespread evidence for ritual behavior and the construction of communal and ceremonial buildings characterize PPN sites in the southern Levant and the upper Euphrates region. In contrast, Bernbeck (2004) concluded that the Iranian Neolithic does not provide any evidence for an own symbolical or ideological tradition. This recently changed with two important discoveries at Sheikh-e Abad and Bestansur, both providing striking evidence for long-term ritual traditions and the construction of public or ritual buildings in the central Zagros. At Sheikh-e Abad, the remains of a T-shaped building were uncovered just below the modern tell surface and included the deliberate deposit of skulls from four wild goats and a wild sheep at one end of the room (Matthews R. et al. 2013b: Fig. 2.4, 2.5). This building dates to about 9,500 cal BP and also includes a large wing bone associated with a pestle. The deposition of five wild caprine skulls in this building might hint to a ritual context that interestingly involved animals that were being kept at the site by this time. Moreover, the large wing bone in the same room resembles an interesting find at Zawi Chemi Shanidar, where more than two dozens of caprine skulls and large wing bones of predatory birds were placed in a pit (Solecki and McGovern 1980). The association of wing bones and caprine skulls in the special building at Sheikh-e Abad might therefore hint at continuities in ritual practices from the Younger Dryas into the mid-10$^{th}$ millennium BP and indeed provide the local Neolithic with an own ritual tradition that seems to have its roots in the Epipalaeolithic.

At Bestansur, a site in the Iraqi Zagros Mountains, excavations revealed a relatively large building with 55 secondary burials placed under the floor of the largest room (Matthews R. et al. 2016: Fig. 3). The building is roughly contemporary to the special building at Sheikh-e Abad and the excavators clearly attribute a "social significance well beyond that of a single resident family" to this house (Matthews R. et al. 2016: 223). Based on ethnographic comparisons, secondary mortuary practices and associated ceremonies have been interpreted as important means to integrate single social units, e.g. nuclear households, into the wider community (Kuijt 2000a, 2001). Such findings therefore generally pose the question how Early Neolithic societies in the central Zagros were socially constructed, which cannot be convincingly answered at the moment.

Research on the social organization of societies focuses on themes like the formation of corporate groups and households, associated notions of ownership, storage systems, leadership and the gaining and possible transmission of authority (Woodburn 1982; Testart 1982; Ingold 1983; Kuijt 2000b; Bar-Yosef 2001; Flannery 2002; Banning 2003; Benz et al. 2017). We already saw that R. Matthews et al. (2013b) and Darabi (2016) principally reconstruct Early Neolithic societies in the Zagros as widely egalitarian. Changing social relations with the possible emergence of households is expected for around 10,000 cal. BP, when the first permanent buildings appear in the highlands (Darabi 2012, 2016). Additional evidence for an emphasis on the house as a confined social space comes from architectural and micro-stratigraphic observations at several sites. For instance, floor surfaces from the upper sequence at Jani have repeatedly been cleaned and renewed, indicative of the long-term maintenance of building space by the associated social units (Matthews W. 2012: 204-207). At Jarmo, outdoor fireplaces have been relocated into houses during the occupation of the site, reflecting an increasing privatization of domestic activities and possibly the hiding of stored foods (Matthews W. 2016: 120-123 with reference to Braidwood L. et al. 1983). A related issue concerns private or individual ownership, which is associated with the emergence of households and private space (Flannery 2002; Kuijt 2008, 2015). Darabi (2016) refers to the appearance of the first permanent buildings around 10,000 cal BP in the Zagros highlands and suggests that early forms of ownership systems developed during the 11$^{th}$ millennium and subsequently allowed for the emergence of private ownership systems alongside the emergence of crop cultivation and animal herding. This suggestion generally follows ethno-archaeological theories on the development of food storage, ownership systems and farming (Testart 1982; Benz 2000; Kuijt 2008; Bowles and Choi 2013), but is also based on a very small number of sites and contexts in the Zagros, particularly for the period before 10,000 cal BP. We may therefore conclude that the available data seem to support certain aspects of anthropological theories on the evolution of agricultural societies, e.g. the gradual appearance of households and private ownership alongside the adoption of crop cultivation, but we are still far from having an archaeological sequence that allows us to support or adjust these general hypotheses with solid data and detailed observations.

The Levantine Pre-Pottery Neolithic offers profoundly different opportunities for investigating the interrelatedness of social and economic change, because much more excavated sites are available and many explanatory frameworks that rely on archaeological data have been developed, tested and adjusted since ca. 50 years (e.g. Binford 1968; Flannery 1969; Wilson 1988; Bar-Yosef and Belfer-Cohen 1989; Hayden 1990; Hodder 1990; McCorriston and Hole 1991; Cauvin 2000; Byrd 2005; Zeder 2009; Atakuman 2014; Sterelny and Watkins 2015; Watkins 2016). It is generally accepted that the origins of sedentism date back to the Early Natufian during the Late Epipalaeolithic, where central base-camps such as at Ain Mallaha include substantial residential structures indicative of more permanent occupations (Bar-Yosef and Belfer-Cohen 1989; Bar-Yosef 1998; Byrd 2005). Important aspects of the social development since the Natufian and during the PPN include population growth (Rosenberg 1998; Kuijt 2000c, 2008), the emergence of households (Flannery 1972, 2002; Byrd 1994; Kuijt 2000c), associated social inequalities, the negotiation of social tensions (Hayden 1990, 2009; Kuijt 1996, 2002; Bar-Yosef 2001; Benz 2010) and the development of symbolism and ritual life in general (Cauvin 2000; Goring-Morris 2000; Kuijt 2000a, 2001; Schmidt 2000, 2010; Rollefson 2000; Kuijt and Goring-Morris 2002; Watkins 2004, 2016; Atakuman 2014). We see a continuous increase in the number and size of sites throughout the PPN, which indicates a continuous population growth during the Early Holocene (Kuijt 2000c). Sites in the upper Euphrates area and the southern Levant that date to the PPNA period (ca. 11,700 - 10,700 cal BP) yielded evidence for a communal engagement in the construction and maintenance of monumental buildings including the enclosures at Göbekli Tepe (Schmidt 2000, 2010) and the tower at Jericho (Kenyon 1981). Smaller public buildings are present at e.g. Wadi Faynan 16 (Mithen et al. 2011), Hallan Çemi (Rosenberg and Redding 2000), Jerf el Ahmar and Mureybet (Stordeur et al. 2001). Associated with these abundant communal and ritual structures are rich symbolic expressions, manifested in engravings on portable objects (Benz and Bauer 2013), figurines and high reliefs on stone pillars (Schmidt 2010; Hauptmann 2011). Watkins interpreted this "explosion of symbolic imagery and architecture" (Watkins 2004: 6) in the PPNA as a necessary response to the new social challenges in larger communities, in which every individual is confronted with a multitude of relations that need to be organized and structured. In a feedback mechanism, this new world of symbolic expressions significantly shaped the perception and cognition of humans, triggering the evolutionary development towards larger societies that will eventually organize themselves as no society ever did before (Watkins 2008, 2016). This reading of the PPN puts much emphasis on carrying human cognitive evolution across the Pleistocene-Holocene border and regards the Neolithic as a major period for the emergence of modern humans from a psychological and social perspective (Sterelny and Watkins 2015; Watkins 2017). An additional feature of the PPNA is the widespread evidence for a communal organization of subsistence practices in contrast to the emergence of nuclear households and presumably private ownership systems since the early PPNB (Flannery 2002; Banning 2003; Kuijt 2008; Asouti and Fuller 2013). Several structures at sites in the southern Levant have been interpreted as communal granaries (Bar-Yosef and Gopher 1997; Kuijt and Finlayson 2009; Finlayson et al. 2011), while cells in a public building at Jerf el Ahmar even yielded charred grains and chaff of wild cereals (Willcox and Stordeur 2012). Other contexts provide evidence for an association of possible ritual buildings with stored plant foods and ground stone tools, e.g. at Tell 'Abr or Jerf el Ahmar (Stordeur et al. 2001; Yartah 2005; Willcox et al. 2008; Willcox and Stordeur 2012). This communal and sometimes ritual character of many contexts in which cereal storages and plant processing tools have been found represents the main argument for reconstructing subsistence practices and particularly wild cereal cultivation during the PPNA as communal activities, possibly related to feasts (Asouti and Fuller 2013; Asouti 2017; see also Dietrich et al. 2012).

Kuijt (2008, 2015) emphasized that the difficulty of recognizing prehistoric storage structures represents a major limitation for reconstructing changing storage practices throughout the PPN, but he also demonstrates that there is a significant change from predominantly extramural storage facilities to indoor storage from the PPNA to the PPNB. In relying on anthropological theories on the association of storage and ownership systems (e.g. Woodburn 1982; Testart 1982; Ingold 1983), Kuijt interprets the shift towards indoor storage and eventually dedicated storage rooms as a clear indicator for the emergence of households and private property (*cf.* Flannery 1972, 2002). This development was accompanied by the appearance of new aspects of mortuary rites, an increased engagement in feasts, and interconnected household and community ceremonies in general (Byrd 1994; 2005; Rollefson 2000; Kuijt 2001; Kuijt and Goring-Morris 2002). Secondary mortuary rites including skull removal were practiced since the Natufian, but during and after the middle PPNB selected skulls have been elaborately prepared for ritual use by covering them with plaster and the modeling of facial traits. Although being an indication of social inequality among household members, Kuijt (2000a, 2001) regards secondary mortuary rituals as important contexts for integrating single households into the community. Many authors offered similar perspectives in interpreting the evidence for public and ritual buildings at middle and late PPNB sites, emphasizing that communal ceremonies represent important contexts for building up group identity and cohesion and negotiating tensions in light of increasing social inequalities (Byrd 1994; 2005; Rollefson 2000; Simmons and Najjar 2006; Benz et al. 2017). The increasing number of feasting contexts since the middle PPNB support these interpretations (Twiss 2008), particularly as meat sharing presumably represented an important means for legitimating private food storage (Bogaard et al. 2009).

The last contribution to this dissertation (see Appendix C) builds up on the socioeconomic developments outlined above and argues for a causal connection between the development towards households and private ownership systems and the concurrent appearance of morphologically domesticated cereals. Many authors reconstruct PPNA subsistence practices as involving pre-domestication cultivation activities to differing degrees (e.g. Colledge 2002; Fuller 2007; Willcox et al. 2008; Fuller et al. 2012b; Asouti and Fuller 2013; Asouti 2017), while it is still debated why morphologically domestic cereals only appear after ca. 1,000 years towards the early PPNB. As discussed in the introduction to this thesis, explanations for this delayed establishment of domestic traits focus on agro-technological and environmental issues, while some authors emphasized the importance of social developments for explaining the emergence of plant domestication (Willcox 2005; Fuller 2007; Bettinger et al. 2009; Asouti 2017; Weide et al. 2018). The change from a communal organization of cultivation and storage towards a privatized household-level organization also involved a reduction in the size of a social unit that together engages in cereal cultivation. This translates into more homogeneous cultivation and harvesting practices within a group, which in turn support the selection for morphological domestication traits (*cf.* Hodder 2017: 167). Turned around, all grains harvested from cultivated populations that were under selection for domestic traits during the PPNA ended up in communal granaries together with all grains that were not under selection for domestic traits or even harvested from unmanaged stands. Hence, selection for domestic traits would be strongly inhibited as long as different harvesting practices contributed to one seed stock (*aka* Hillman and Davies 1990). Only the development of individual ownership systems that allowed a household to store the harvested grains separately established the conditions for the selection of domestic traits. In this perspective, differentiating between conscious and unconscious selection for explaining the slow pace of plant domestication only becomes reasonable after the social mechanisms that allowed individuals to maintain a selection chain had been developed. Moreover, the case from Ohalo II, where Snir et al. (2015a) documented the selection for non-shattering ears 23,000 years ago, clearly shows that the agro-technological prerequisites for morphological domestication traits to become fixed were long present. A focus on non-selective cultivation or harvesting techniques connected to climatic instabilities can therefore not be sufficient for explaining the total absence of domestic-type cereal chaff throughout the complete PPNA.

This attempt to integrate social factors in the explanatory framework for the evolution of plant cultivation and domestication in the Levantine corridor shows that the emergence of agricultural societies involved complex and interrelated societal and economic developments. For investigating the Neolithic in the Zagros Mountains this means that we are currently not in a situation where we can comprehensively integrate all these factors into an explanatory framework. Nevertheless, Darabi (2012) and Roger and Wendy Matthews' team (Matthews R. et al. 2013b, d) recently developed models for approaching the famous *why* question of agricultural origins in the central Zagros. Surprisingly, both models heavily rely on human-induced resource pressure for explaining why Early Holocene groups in the Zagros developed plant cultivation and animal husbandry. Darabi puts much emphasis on increased population growth induced by a warmer and wetter climate during the Early Holocene, which then caused the depletion of important resources (Darabi 2012: Fig. 5). With the management of these important but depleting resources, humans had to decrease their mobility, became sedentary and eventually secured a sedentary life in cultivating plants and herding animals. The model of R. Matthews et al. (2013b, d) argues in a quite similar way and emphasizes the evidence for the heavy use of herbivore dung and an animal pen at Sheikh-e Abad and Jani since ca. 10,000 cal BP. In their model, Early Holocene groups were increasingly engaging in resource management practices including vegetation burning (*cf.* Matthews W. 2016), which resulted in the depletion of wood resources that had to be replaced by an alternative fuel source. As only the penning of animals would supply sufficient and predictable amounts of dung, the lack of wood resources subsequently triggered the development of animal herding. For feeding the herds the whole year-round, R. Matthews et al. suggest that humans had to intensify cereal cultivation in order to feed their livestock, which eventually forced them to become sedentary farmers. They indeed speak of the "first human-induced environmental disaster" (Matthews R. et al. 2013b: 29), capturing humans in a self-made chain of entanglements that could only be dealt with in intensifying cultivation for feeding herded animals the whole year-round.

We need to remember that both these models rely on a very small number of excavated and fully published sites and make use of predominantly palaeoenvironmental and bioarchaeological data, logically emphasizing the ecological aspects of the Neolithization process in the Zagros. Darabi (2016) recently made an attempt to reconstruct the concurrent social development, but with the excavation of e.g. Sheikh-e Abad, Bestansur and Chogha Golan, we are only beginning to understand the enormous dimension of the local Neolithic in both its richness in ritual activities and the autochthonous development of resource management strategies. Our knowledge on the development of households and associated ownership systems in the central Zagros in relation to subsistence strategies and plant domestication is very fragmentary. The lack of a comprehensive data basis for reconstructing the social development of course results in models that lack a strong social component, but should also make us cautious in explaining local agricultural origins in a manner that scholars focusing on the Levant long abandoned. After the social relations of the Levantine Neolithic with its rich symbolic record have been studied in more detail since the 1990s and particularly during the 2000s (e.g. Hodder 1990; Benz 2000, 2004; Cauvin 2000; Kuijt 2000a, b, 2001, 2008; Schmidt 2000, 2010; Flannery 2002; Kuijt and Goring-Morris 2002; Watkins 2004, 2016, 2017; Twiss 2008; Bogaard et al. 2009), most authors rejected a focus on resource pressure and population growth for understanding the Neolithic transition (e.g. Verhoeven 2004; Byrd 2005; Zeder

2009, 2011a; Zeder and Smith 2009; Sterelny and Watkins 2015; Hodder 2017). As a result, I regard the models of Darabi and from R. and W. Matthews' team as important approaches to understand the ecological and economic dimension of the Neolithic in the Zagros, but we must remember that these factors do not explain the Neolithic transition as a whole, i.e. including the transformation of society in all its social, cognitive and mythological aspects.

# Conclusion

# Pathways Towards Domestication

## The Site-Specific Perspective

The site of Chogha Golan represents a good example for illustrating what it means to become Neolithic. Long before morphologically domesticated plants appear in the sequence, a tell started to develop and soon exhibited substantial architectural remains indicative of more permanent occupations. We only have a very limited understanding of the specific mobility patterns and social relations that characterized the local socioeconomic development throughout the 12$^{th}$ and 11$^{th}$ millennium BP, but this example demonstrates that the Neolithic does not start with the appearance of morphologically domestic crops. Grain size fluctuations linked to isotope values that indicate enhanced growing conditions suggest the temporal management of *Hordeum spontaneum*. Such practices presumably targeted at whole vegetation units, since so many medium and large-seeded grasses that today grow together with wild barley abundantly occur in the analyzed samples. A reasonable working hypothesis for the local economic development would therefore include resource management practices, assuring the long-term availability of resource-rich open grasslands in the surroundings of the settlement. We may also expect that many synanthropic species including the wild grasses were favored by anthropogenic disturbances, which would have facilitated their resilient exploitation. A further remarkable feature is the presence of several large-seeded pulses at the site since its first occupation. These species, including wild lentil, provide poor yields in harvesting and cultivation experiments due to their high dormancy and low productivity nowadays. For the patterns from Chogha Golan this means that the regularly exploited wild legumes either had a different ecology in the Early Holocene or belonged to the managed species as well. Furthermore, it shows that the Near Eastern founder crops were not domesticated in a single event in a confined core area between the upper Euphrates and Tigris rivers and that similar economic developments co-occurred throughout vast regions of the Fertile Crescent. Unfortunately, we cannot draw reliable conclusion on management or the domestication status of the exploited ungulates, but the faunal data equally indicate the exploitation of a broad spectrum with a focus on caprines and fish. Seeds and fruits of several edible wild plants that are commonly interpreted as arable weeds show high ubiquities in the samples from the upper sequence and occur in abundance in other horizons, possibly indicating their deliberate collection. The appearance of morphologically domesticated emmer around 9,800 cal BP marks the beginnings of crop cultivation at the site. The inhabitants integrated this economic practice in a traditional economic system that made use of a high diversity of wild resources and continued to do so alongside the cultivation of a domestic crop. Emmer was presumably introduced to the site and does not derive from local wild populations, which hints at inter-regional contacts that influenced the local developments. Contrastingly, *H. spontaneum* was exploited for more than 1,500 years without selecting for morphological domestication traits, but later became a typical crop in the region. These patterns stand for different pathways towards domestication that did not follow a linear development from gathering to cultivation and domestication, but emphasize the complexity of the domestication process that can only be understood by moving beyond the site-specific perspective.

## The Regional Perspective

The Neolithization process in the Zagros Mountains was rooted in the local Epipalaeolithic. Several lines of evidence point to a long tradition of subsistence and ritual practices, including specialized caprine hunting, a broad spectrum diet, features of local lithic industries and the association of caprine skulls and large wing bones in ritual contexts. Ecosystems profoundly changed with the onset of the Holocene and the spread of *Pistacia*-dominated woodlands and vast grasslands provided local groups with an abundance of resources that represented the basis for the following socioeconomic developments. Early Neolithic sites throughout the entire Zagros Mountains provide evidence for the regular exploitation of wild pulses and medium to large-seeded wild grasses. Subsistence strategies did not focus on wild progenitor species, although these were present in the local ecosystems and have been exploited since the earliest Holocene. This makes clear that the socioeconomic development of the Zagros arc was not shaped by the lack of resources, but by an individual pathway into early agricultural societies. Differing mobility patterns characterize the economic adaptations of local communities and possibly indicate an early development towards mobile pastoralism and transhumance. Long after the first tells appeared, ephemeral campsites were inhabited by groups that continued to live a more mobile lifestyle in the same environmental zones. Although the exact relation between these tells and campsites is poorly understood, it shows that local socioeconomic developments were influenced by differing residence patterns. Thick ash layers represent a remarkable feature of the basal deposits of many tell sites, indicative of a local development towards sedentism out of less permanent occupations that involved fire-related activities. To which degree these ash layers reflect region-wide vegetation burning must be debated, but evidence for resource management practices of local groups accumulates and may point towards traditions that even date back to the Epipalaeolithic. These patterns are based on a limited data basis and definitely require further research, but they demonstrate that the Levantine sequence with its long Epipalaeolithic tradition may not be unique among the landscapes of the Fertile Crescent. This conclusion is supported by patterns of domestication processes in the Zagros arc. Whereas we may expect an introduction of emmer wheat due to the absence of wild wheat populations in the Early Holocene ecosystems, barley and lentil were exploited since the 12$^{th}$ millennium and presumably domesticated within the Zagros arc. All three species became principal crops of the local Neolithic, while an autochthonous domestication of goats is well documented either and adds up to the evidence for local domestication pathways. Unfortunately, the currently known archaeological record does not allow to comprehensively evaluate the interrelatedness of social and economic developments in the Zagros. However, the data we have indicate that themes such as emerging households as basic social units of agricultural societies associated with household and community-wide rituals and private ownership systems were also important for the Zagrosian Neolithic.

## The Supra-Regional Perspective

Although there is no general agreement on the specific causal factors that pushed and pulled humans through the Neolithic transition in the Levantine corridor, the available archaeological data allow a much more detailed reconstruction of socioeconomic developments compared to the Zagros arc. Rooted in ethno-archaeological and psycho-cognitive theories, the socioeconomic developments during the PPN have often been interpreted from a social and cognitive perspective, emphasizing the fundamental role of symbols, architecture and associated rituals for carrying societies through times of profound socioeconomic changes, until agricultural systems with their private organization of social and economic life were legitimated.

The PPNA is characterized by a communal organization of subsistence practices, indicated by the prevalence of storage facilities in extramural locations and communal buildings. Faced with social challenges and tensions in growing societies, public rituals gained in importance and communities even constructed monumental buildings at central ritual places to create the contexts for building up identity and group cohesion. This early florescence of ritual activities became consolidated during the early and middle PPNB, where cult buildings appeared at many sites and were accompanied by the appearance of rectangular domestic dwellings. Most scholars interpret this architectural development as the emergence of nuclear households, which organized their subsistence individually, including private food storage. It is no coincidence that ritual life and also extended mortuary practices flourish during the middle PPNB, where morphologically domestic crops have appeared at many sites throughout the Levantine corridor. Apparently, social and economic developments we co-dependent on each other and cannot be understood as separate spheres of human societies. A nuanced approach to link these two dimensions puts emphasis on the emergence of private ownership systems that allowed single households to store their own harvests, establishing the conditions under which domestication traits could be selected and fixed. In this perspective, differentiating between conscious and unconscious selection for domestication traits only becomes reasonable when we speak about societies in which individuals have the incentive and the possibility to consciously select favorable traits. Understanding the protracted development of plant and animal domestication therefore requires a much more holistic view, which regards the social organization of a society as deeply entangled with the management of resources and the appearance of domesticatory relationships. This fundamental principle must likewise be applied to the Neolithic transition in the Zagros arc. The currently available models that aim at understanding this individual trajectory put much emphasis on the environmental and economic components of Early Holocene socioeconomic developments. I consider this situation as a logical consequence of our biased understanding of the local archaeological record and we must keep in mind that overarching explanatory frameworks for the Levantine Neolithic long abandoned population growth and resource pressure as primary causal factors. In moving beyond the paradigm of agriculture as being a solution to resource stress situations, we will be able to put more emphasis on the socio-cultural developments that represent the actual substrate on which subsistence choices are negotiated. As we already concluded, however, the current archaeological record of the Zagros does not allow to reconstruct this development in sufficient detail. We must therefore admit that our understanding of the Neolithic transition in the Zagros Mountains is enormously incomplete, particularly regarding the social developments, but archaeological research in the region definitely has the potential to equate the importance of the Zagrosian Neolithic with the better known sequence in the Levantine corridor.

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# Appendix A

## Reconstructing subsistence practices: taphonomic constraints and the interpretation of wild plant remains at aceramic Neolithic Chogha Golan, Iran

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ORIGINAL ARTICLE

# Reconstructing subsistence practices: taphonomic constraints and the interpretation of wild plant remains at aceramic Neolithic Chogha Golan, Iran

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**Abstract** In this paper we discuss the plant-based subsistence economy during the formation of archaeological horizons (AH) II and I at the aceramic Neolithic site of Chogha Golan, Iran. The deposits date to between 9,800 and 9,600 cal BP. In order to reconstruct subsistence practices and their development reliably, we conducted a taphonomic analysis to identify factors that influenced the composition of the archaeobotanical assemblage. The flotation samples derive from two excavation areas in the centre of the tell, the deep sounding and area A. Using correspondence analysis, we link the biased composition of the plant remains from AH I to their relatively poor preservation. Two different sampling strategies applied in excavation area A also affected the composition of the samples. In contrast, we did not find compositional differences among the samples from AH II of both excavation areas. Our results emphasize the need for taphonomic analyses prior to interpreting the taxonomic composition of charred archaeobotanical assemblages. Considering these results, we discuss the subsistence economy of Chogha Golan. Domestic emmer wheat was cultivated from AH II onwards. Wild barley, *Aegilops* sp., lentils, peas and various vetches may have been cultivated as well. This spectrum of typical Neolithic food plants was supplemented by a high diversity of other potential wild food resources, including medium and small-seeded grasses, *Pistacia, Bolboschoenus glaucus, Malva* and Brassicaceae. A compilation of ethnobotanical data, mainly from the Near and Middle East, represents the basis for assessing the potential uses of the wild plants.

**Keywords** Aceramic Neolithic · Central Zagros Mountains · Taphonomy · Cultivation · Gathering · Ethnobotany

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## Introduction

Since the first Neolithic sites were excavated in the Zagros Mountains and the Levant, archaeobotanists have aimed to reconstruct the origin and evolution of early agricultural systems (Helbæk 1959, 1966, 1969; van; Zeist and Bakker-Heeres 1982, 1984; Hopf 1983; van; Zeist et al. 1984). During decades of research, detecting the first attempts at cultivation and identifying the earliest domesticated crops became the main aims of aceramic Neolithic archaeobotany. Whereas identification methods for domestic cereals are still subject to debate and investigation (Tanno and Willcox 2012; Snir and Weiss 2014; Weide et al. 2015), criteria applied to argue for pre-domestication cultivation are well established. A relatively common argument for pre-domestication cultivation is the presence of a weed flora, which consists of taxa nowadays thriving in agricultural fields (Colledge 2002; Willcox et al. 2008; White and Makarewicz 2012), or whose fruits and seeds have no ethnographically documented use (Willcox 2012). Other arguments include the presence of wild cereals outside their natural distribution range (Willcox 2000), their large-scale storage in permanently occupied habitations (Weiss et al. 2006), or the high frequency of wild plants that are equally abundant as presumably cultivated crops (Melamed et al. 2008).

Focusing on pre-domestication cultivation and domestication led to the tendency that archaeobotanists often regard wild plant remains as mostly representing crop processing by-products. Only specific contexts, such as the wild seed storage features at Çatalhöyük East, clearly reveal the exploitation of wild plants in farming communities (Fairbairn et al. 2007). However, at late Epipalaeolithic and early Neolithic sites without evidence for pre-domestication cultivation of wild cereals or pulses, namely at Hallan Çemi, Demirköy, Qermez Dere, M'lefaat and Körtik Tepe in the northern Fertile Crescent, wild plant taxa regularly interpreted as arable weeds are alternatively interpreted as intentionally gathered resources (Savard et al. 2006; Benz et al. 2015). For instance, Hillman et al. (2001), White and Makarewicz (2012) and Arranz-Otaegui et al. (2016a) regard small-seeded grass taxa such as *Hordeum, Eremopyrum* and *Phalaris*, small-seeded legumes belonging to the Trifolieae as well as the gromwells *Arnebia* and *Buglossoides* as arable weeds. In contrast, all these taxa are abundant at one or several of the sites mentioned above, where the authors interpret them as deliberately gathered resources. Although it is understandable to interpret these taxa as arable weeds, the examples from the northern Fertile Crescent indicate that alternative interpretations are fully justified, and particularly as most fruits or seeds are only identified to the genus level and most genera include arable weeds and economically or medicinally valuable species. The importance of wild plants among farming communities is further demonstrated by ethnobotanical research conducted in the Near and Middle East, which clearly shows how intensively wild plants are gathered in traditional farming societies up to the present time (Ertuğ 2000; Ibrar et al. 2007; Mosaddegh et al. 2012; Akan et al. 2013; Ahmad et al. 2014; Nawash et al. 2014).

In this paper we present a reconstruction of the subsistence economy of archaeological horizons (AH) I and II at the aceramic Neolithic site of Chogha Golan in Ilam province, Iran. The economy during this occupation phase was already characterized as an early agricultural system, based on the identification of domestic emmer wheat (Riehl et al. 2013; Weide et al. 2015). Here, we focus on understanding the taphonomy of the plant remains and on assessing the role of the diverse wild plant resources in the subsistence economy.

### The site of Chogha Golan and its environment

The aceramic Neolithic site of Chogha Golan is located in the foothills of the central Zagros Mountains in Iran (Fig. 1). Members of the Tübingen Iranian Stone Age Research Project (TISARP) and the Iranian Center for Archaeological Research excavated the site in 2009 and 2010 (Zeidi et al. 2012). The tell covers an area of about 3 ha and is situated at an elevation of 485 m a.s.l. near the right bank of the river Konjan Cham. Radiocarbon dates suggest occupation from about 11,700 to 9,600 cal BP (Riehl et al. 2015). Two trenches were opened in the centre of the mound (ESM Fig. 1a, b). The deep sounding was 2 × 1.5 m in area and was excavated down as far as sterile sediments that represented the palaeosurface below the tell. The excavators divided the stratigraphy of the deep sounding into eleven archaeological horizons (ESM Fig. 1c). At a distance of about 5 m from the deep sounding, excavation area A, with an area of 2 × 4 m, was excavated to a depth of about 1.5 m below the modern ground surface. The ground stone implement assemblage consisted of mortars, pestles, grinding slabs, handstones and pounders, while the chipped stone industry was dominated by bladelet production and there was little variance in tool types (Conard and Zeidi 2013; Zeidi and Conard 2013).

Riehl et al. (2015) presented the first results on the environments surrounding Chogha Golan. According to the charcoal analysis, the village was located in the semi-arid *Pistacia-Amygdalus* woodland steppe. The riparian vegetation along the nearby river, indicated by Salicaceae and *Tamarix* wood charcoal, represented a second major vegetation unit. The proximity to both these ecotopes set the basis for a resilient long-term occupation of the site, providing the inhabitants with sufficient fuel and food resources for over 2,000 years. This is also indicated by the faunal data, which are characterized by a predominance of ungulates and a high abundance of fish remains (Starkovich et al. 2016).

## Materials and methods

In both trenches, AH I and II consisted of homogenous sediments that represented collapsed building materials intermixed with occupation deposits (Fig. 2a–c; Zeidi et al. 2012; Zanoni unpublished). Judgment samples were collected for flotation from ashy deposits and all sediments containing visible plant remains. In area A, no such sediments occurred in AH I, but several ash lenses were sampled in the building debris that formed AH II (Fig. 2b). None of the judgment samples were associated with specific structures or artefacts, and most probably contained accumulations of charred plant remains deriving from a

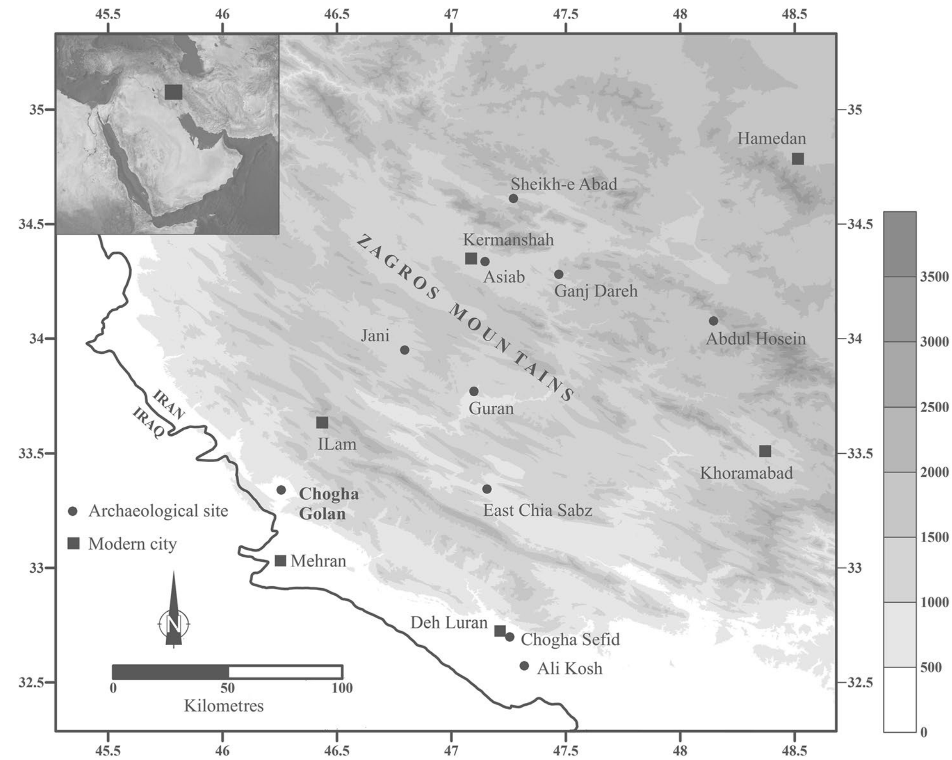


**Fig. 1** The location of Chogha Golan and other aceramic Neolithic sites of the central Zagros Mountains region

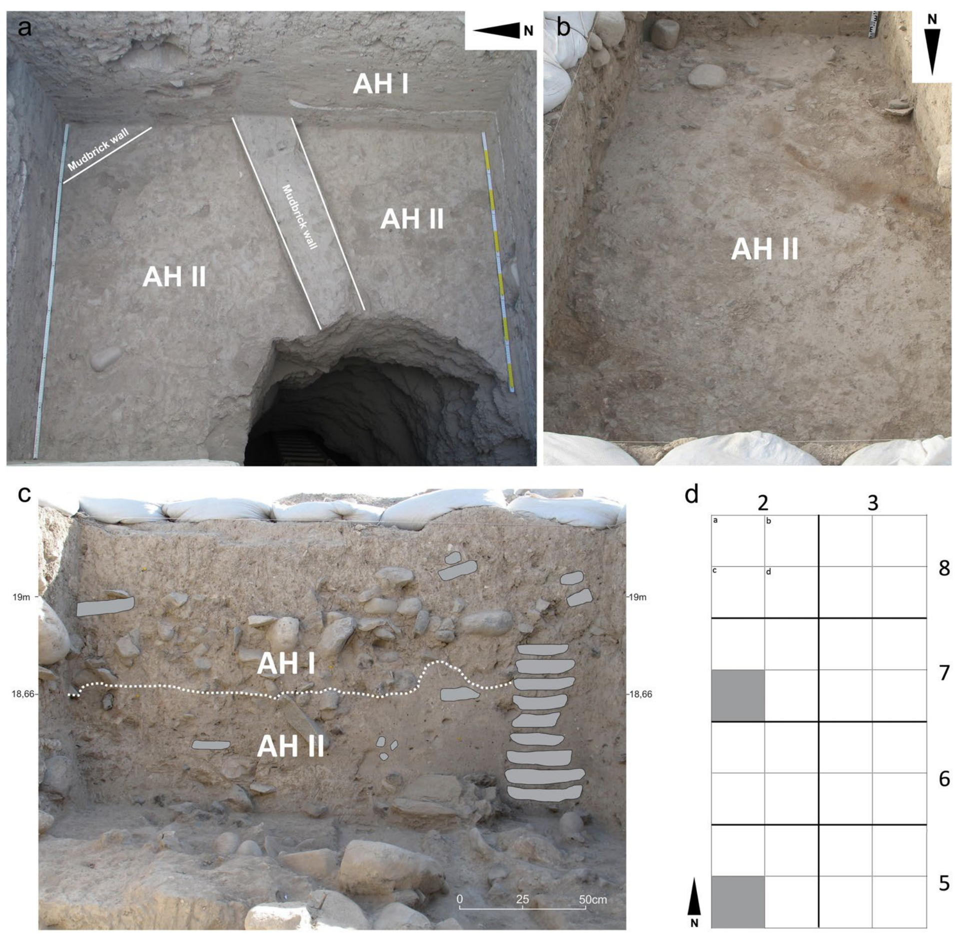


**Fig. 2** **a** AH I and II in the deep sounding during excavation; a plaster floor visible in the profile was used to distinguish both horizons; **b** AH II in area A during excavation; judgment samples were collected from these sediments for flotation; **c** south profile of area A with the transition from AH I to AH II; a mudbrick wall and several isolated mudbrick remains are visible (in *grey*); **d** excavation grid of area A; the *shaded sub-squares* were systematically sampled; all photos by M. Zeidi 2010

variety of activities. In addition to the judgment samples, all excavated buckets from two subsquares in area A were systematically floated (Fig. 2d). This strategy resulted in two entirely floated columns throughout AH I and II of area A.

Virtually all plant remains extracted from the soil by water flotation were charred, and the few uncharred specimens may represent modern intrusions. A number of samples from the two systematically sampled columns contained only a few charred plant remains. We therefore excluded all samples with less than one item per litre soil from the analysis. Consequently, the number of samples from AH I considered in this paper was reduced from 37 to 25. Table 1 gives the number of analysed flotation samples and basic data on the identified plant remains. The analysis of wheat chaff includes 20 additional samples that were screened for chaff remains only and this material has already been published by Weide et al. (2015). This makes a total of 108 samples of AH II, from which we analysed wheat chaff. Another 22 samples from AH I and II in the deep sounding have already been analysed and published by S. Riehl and D. Karakaya (Riehl et al. 2013, 2015). They are not included in the statistical analysis of this paper, but will be considered in the final discussion. Laboratory and quantification methods and information on taxonomic identifications of *Triticum, Aegilops* and *Bolboschoenus* remains are given in ESM Figs. 2 and 3.

**Table 1** Floated sediments, analysed flotation samples and macrobotanical remains from AH I and II of Chogha Golan

| Archaeological Horizon (AH) | AH I | | AH II |
|---|---|---|---|
| Radiocarbon date (cal BP) | 9,600 | | 9,800 |
| Excavation Area | Area A | Area A | DS[a] |
| Floated sediments (l) | 211 | 732 | 178 |
| Judgment samples | 2 | 28 | 15 |
| Systematic samples | 23 | 32 | |
| Total | 25 | 60 | 15 |
| Highest z-value (m) | 19.51 | 18.68 | 18.33 |
| Lowest z-value (m) | 18.67 | 17.96 | 17.73 |
| Mean sample volume (l) | 8 | 12 | 12 |
| Items per liter soil | 2.8 | 7.7 | 18.1 |
| Identified taxa | 41 | 56 | 56 |
| Total number of counts | 581 | 5,645 | 3,222 |

Z values refer to the minimum and maximum depth from which samples were analysed

The number of identified taxa represents the number of identified genera and species in the assemblage; categories such as grains and chaff were not counted separately. This table does not include the 20 samples from the deep sounding that were screened for wheat chaff only

[a]Deep sounding

Using CANOCO 5, we applied correspondence analysis to examine how the analysed flotation samples differed in their taxonomic composition. Correspondence analysis is an established multivariate statistical method, developed to evaluate the complex relationships between variables of a contingency table (Greenacre 1984). In the first analysis, we tested whether the samples from AH I and II analysed for this study formed separate groups. The second correspondence analysis tested for differences between the judgment and systematic samples from AH II within area A. With a third analysis we tested, whether the samples from AH II of area A and the deep sounding had distinct compositions. Data preparation followed the protocol outlined by van der Veen (1992) and was modified for this study. We omitted all samples containing less than 50 items from the analysis. Only for the first correspondence analysis, 30 items per sample were used as a threshold, because only 3 samples from AH I contained more than 50 plant remains. To condense the data matrix and to reduce the impact of rare taxa, we defined a ubiquity of 5% as the threshold to include taxa and plant groups. By reasonably combining taxa with less than 5% ubiquity, a reduction in the number of cases (or columns in the contingency table) has been achieved without substantially altering the dataset. This form of data preparation reduced the number of taxa and groups for analyses 2 and 3 from 56 to 38, but maintained the total number of counts. For the first analysis we condensed the dataset to only seven variables, which represent the major plant categories of the assemblage (ESM Table 1).

## Results

### General composition of the archaeobotanical material and differences between horizons, sample types and trenches

Table 2 gives the taxa identified in samples from AH I and II of both excavation areas. *Aegilops* sp., *Triticum* spp. and *Hordeum spontaneum* contribute a major portion to the plant remains of both horizons (Fig. 3). Their remains mainly consist of rachis and glume fragments, whereas caryopses are less abundant. Small-seeded grasses and medium to small-seeded legumes represent the two other categories that characterize the plant remains from AH II. Both considerably decrease towards AH I. In contrast, medium-seeded grasses remain relatively stable and large-seeded legumes (*Lathyrus, Lens, Pisum* and *Vicia*) occur frequently, but have low proportions in both horizons. Apart from the cereals, only wild fruits and seeds of families other than grasses or legumes substantially increase towards AH I. This is partly due to a significantly greater

**Table 2** Identified macrobotanical remains from AH I and II of Chogha Golan

| | AH I | | | AH II | | |
|---|---|---|---|---|---|---|
| | Total (*n*) | Percentage | Ubiquity | Total (*n*) | Percentage | Ubiquity |
| Amaranthaceae | | | | | | |
| *Atriplex* sp. bract | – | – | – | 2 | 0.02 | 3 |
| *Atriplex* sp. seed | – | – | – | 5 | 0.06 | 7 |
| cf. *Salsola* sp. | – | – | – | 1 | 0.01 | 1 |
| *Suaeda* sp. | 1 | 0.17 | 4 | 16 | 0.18 | 8 |
| Amaranthaceae | 2 | 0.34 | 8 | 15 | 0.17 | 16 |
| Anacardiaceae | | | | | | |
| *Pistacia* sp. | 20 | 3.44 | 40 | 236 | 2.66 | 89 |
| Apiaceae | | | | | | |
| Apiaceae | 1 | 0.17 | 4 | – | – | – |
| Asparagaceae | | | | | | |
| *Bellevalia*/*Muscari*/*Ornithogalum* | 3 | 0.52 | 12 | 31 | 0.35 | 31 |
| *Muscari*/*Ornithogalum* | – | – | – | 1 | 0.01 | 1 |
| Asteraceae | | | | | | |
| *Centaurea* sp. | 3 | 0.52 | 12 | 7 | 0.08 | 8 |
| Asteraceae | 3 | 0.52 | 8 | 4 | 0.05 | 4 |
| Boraginaceae | | | | | | |
| *Buglossoides arvensis* uncarbonized | 34 | 5.85 | 48 | 76 | 0.86 | 44 |
| *Buglossoides tenuiflora* uncarbonized | 3 | 0.52 | 12 | 12 | 0.14 | 12 |
| *Heliotropium* sp. | – | – | – | 14 | 0.17 | 13 |
| Brassicaceae | | | | | | |
| *Camelina* type | – | – | – | 3 | 0.03 | 3 |
| *Capsella*/*Descurainia* | 3 | 0.52 | 12 | 19 | 0.21 | 16 |
| *Erysimum*/*Sisymbrium* type | – | – | – | 2 | 0.02 | 1 |
| Brassicaceae | – | – | – | 5 | 0.06 | 5 |
| Caryophyllaceae | | | | | | |
| *Dianthus* sp. | 1 | 0.17 | 4 | – | – | – |
| *Gypsophila* sp. | 1 | 0.17 | 4 | 5 | 0.06 | 7 |
| *Silene* sp. | 2 | 0.34 | 8 | 13 | 0.15 | 13 |
| *Silene*/*Gypsophila* | – | – | – | 13 | 0.15 | 15 |
| cf. *Vaccaria* sp. | – | – | – | 1 | 0.01 | 1 |
| Caryophyllaceae | – | – | – | 14 | 0.16 | 13 |
| Cyperaceae | | | | | | |
| *Bolboschoenus glaucus* | 4 | 0.69 | 16 | 63 | 0.71 | 43 |
| Cyperaceae | 1 | 0.17 | 4 | 14 | 0.16 | 13 |
| Euphorbiaceae | | | | | | |
| *Euphorbia* sp. | – | – | – | 1 | 0.01 | 1 |
| Fabaceae | | | | | | |
| *Astragalus* sp. | 5 | 0.86 | 16 | 308 | 3.47 | 75 |
| *Lathyrus* type | – | – | – | 12 | 0.14 | 13 |
| *Lathyrus*/*Vicia* | 1 | 0.17 | 4 | 18 | 0.20 | 16 |
| *Lathyrus*/*Vicia*/*Pisum* | 15 | 2.58 | 44 | 186 | 2.10 | 81 |
| *Lens* sp. | 14 | 2.41 | 36 | 154 | 1.74 | 71 |
| *Medicago* sp. | – | – | – | 9 | 0.10 | 9 |
| *Medicago radiata* | 2 | 0.34 | 8 | 35 | 0.39 | 25 |
| *Onobrychis* sp. | – | – | – | 1 | 0.01 | 1 |
| *Pisum* sp. | – | – | – | 3 | 0.03 | 4 |
| *Trigonella astroites* type | 8 | 1.38 | 24 | 266 | 3.00 | 75 |

**Table 2** (continued)

| | AH I | | | AH II | | |
|---|---|---|---|---|---|---|
| | Total (*n*) | Percentage | Ubiquity | Total (*n*) | Percentage | Ubiquity |
| *Trigonella* type 2 | 2 | 0.34 | 4 | 239 | 2.70 | 65 |
| *Trigonella/Astragalus* | 35 | 6.02 | 44 | 591 | 6.66 | 92 |
| Fabaceae medium-small | 10 | 1.72 | 24 | 377 | 4.25 | 84 |
| Malvaceae | | | | | | |
| *Malva* sp. | 23 | 3.96 | 12 | 175 | 1.97 | 72 |
| Malvaceae | – | – | – | 7 | 0.08 | 8 |
| Poaceae | | | | | | |
| *Aegilops* sp. grain | 2 | 0.34 | 8 | 86 | 0.97 | 52 |
| *Aegilops* sp. spikelet | 77 | 13.25 | 76 | 1,007 | 11.36 | 99 |
| *Agropyron/Eremopyrum* | 1 | 0.17 | 4 | 1 | 0.01 | 1 |
| *Avena* sp. | 3 | 0.52 | 8 | 28 | 0.32 | 24 |
| *Bromus* type 1 | – | – | – | 20 | 0.23 | 20 |
| *Bromus* type 2 | – | – | – | 4 | 0.05 | 4 |
| *Hordeum* sp. | 2 | 0.34 | 8 | 66 | 0.74 | 48 |
| *Hordeum spontaneum* grain | 6 | 1.03 | 12 | 111 | 1.25 | 61 |
| *Hordeum spontaneum* spikelet | 12 | 2.07 | 32 | 238 | 2.68 | 73 |
| *Pennisetum* type | – | – | – | 3 | 0.03 | 1 |
| *Phalaris* sp. | 20 | 3.44 | 52 | 573 | 6.46 | 89 |
| *Phleum* type | 1 | 0.17 | 4 | 671 | 7.57 | 73 |
| *Phragmites* sp. | – | – | – | 1 | 0.01 | 1 |
| *Taeniatherum caput-medusae* grain | – | – | – | 16 | 0.18 | 17 |
| *Taeniatherum caput-medusae* spikelet | 5 | 0.86 | 20 | 8 | 0.09 | 11 |
| Triticoid type grain | – | – | – | 31 | 0.35 | 28 |
| cf. *Triticum* spp. grain | 1 | 0.17 | 4 | 30 | 0.34 | 17 |
| *Triticum* spp. spikelet | 55 | 9.46 | 88 | 499 | 5.63 | 91 |
| Indet. spikelet type | 9 | 1.55 | 24 | 105 | 1.18 | 49 |
| Indet. cereal rachis | – | – | – | 3 | 0.03 | 3 |
| Indet. spikelets | 49 | 8.43 | 88 | 251 | 2.83 | 89 |
| Poaceae large | 16 | 2.75 | 44 | 261 | 2.94 | 89 |
| Poaceae medium | 47 | 8.09 | 72 | 496 | 5.59 | 99 |
| Poaceae small | 18 | 3.10 | 48 | 1,070 | 12.07 | 96 |
| Polygonaceae | | | | | | |
| *Rumex/Polygonum* | – | – | – | 3 | 0.03 | 4 |
| Rubiaceae | | | | | | |
| *Galium* sp. | 2 | 0.34 | 4 | 12 | 0.14 | 12 |
| Rubiaceae | – | – | – | 1 | 0.01 | 1 |
| Indet. fruits and seeds | 58 | 9.98 | 64 | 318 | 3.64 | 64 |
| Total | 581 | 100 | | 8,867 | 100 | |

The data for AH II comprise the material of both trenches. If no other information is given, identifications represent charred fruits or seeds

amount of *Buglossoides arvensis* nutlets, but mainly a result of the proportional decrease in small-seeded grasses and medium to small-seeded legumes. For the same reason, the percentage of unidentified fruits and seeds increases as well.

The plant remains from AH I have a worse preservation than those from AH II. This is reflected in the greater fragmentation and surface erosion of the material. The reduced number of plant remains per litre sediment supports this view (Table 1). As a result, many identified taxa exclusively occur in AH II, such as *Atriplex, Camelina*-type, *Erysimum/Sisymbrium*-type, *Pisum* and *Phragmites*. We identified most of these taxa by using few but well preserved specimens (Table 2). This implies that the reduced diversity of identified plant taxa in AH I

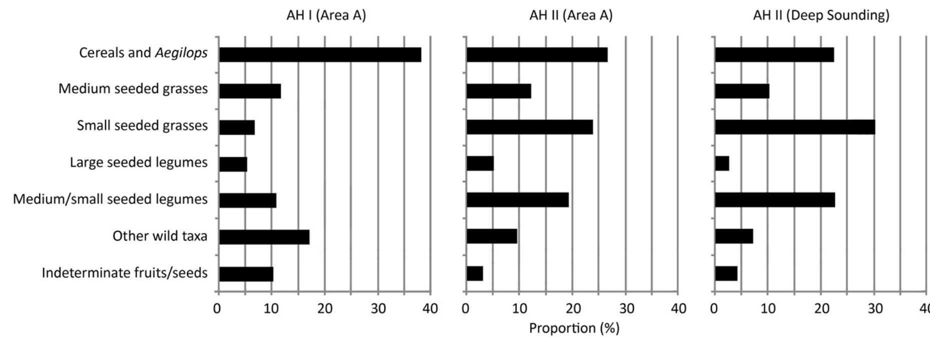


**Fig. 3** Overall composition of the archaeobotanical remains from AH I and II of Chogha Golan in the samples analysed for this study. Proportions for the grass categories include grains and chaff

primarily reflects the worse preservation conditions and not cultural preferences.

Figure 4 gives the results of the correspondence analyses. In the first analysis, six of the seven AH I samples are divided from the bulk of AH II samples along axis 1, which separates samples dominated by cereal chaff from those dominated by medium to small-seeded legumes and small-seeded grasses (Fig. 4a). This confirms the patterns already visible in Fig. 3 by only using the richest samples. The second correspondence analysis separates the systematic samples of AH II in area A from the judgment samples along axis 2 (Fig. 4b). The proportion of *Triticum* chaff, which is substantially higher in the systematically collected samples, is the main variable that leads to this pattern. Apart from this, these samples yielded fewer small-seeded grasses and a smaller number of wild taxa (absent are *Suaeda*, Asteraceae, Boraginaceae, *Camelina*-type, Brassicaceae, *Medicago, Onobrychis*, Malvaceae, *Phragmites*, Rubiaceae). The third correspondence analysis did not lead to a clear separation of the AH II samples from area A and the deep sounding (Fig. 4c). Although the samples from area A contained fewer plant remains per litre soil, this does not bias their taxonomic composition (Fig. 3). We therefore combined all samples from AH II to reconstruct the subsistence economy during the formation of this horizon. However, it is surprising that the total number of identified taxa from area A, from where four times the amount of sediment has been analysed, is equal to the number of taxa from the deep sounding. This either reflects a loss of taxa due to taphonomic reasons in area A, or it indicates that the smaller amount of analysed sediments from the deep sounding was sufficient to record the full taxonomic diversity in AH II.

## The grasses (Poaceae)

The Poaceae remains are dominated by cereals and small-seeded grasses. Among the cereals, *Aegilops* (Fig. 5a, b) is most abundant followed by *Triticum* and *Hordeum spontaneum* (Fig. 5c, d, l, m). Based on its high abundance and ubiquity, we regard *Aegilops* as equally important as the classic cereals for the subsistence economy of Chogha Golan and place it in the same functional category. All cereals are mainly represented by chaff, which presumably contributed to the domination of *Aegilops*, particularly as its glume bases are very thick and robust, preserving better compared to the *Triticum* glume bases and the thin rachis segments of *H. spontaneum*. A few poorly preserved and mostly fragmented grains resemble *Triticum*, but they cannot be reliably identified. *Aegilops* grains are clearly underrepresented in relation to the amount of chaff remains, while those of *H. spontaneum* are relatively abundant (Table 2).

Table 3 shows the categorization of *H. spontaneum* and *Triticum* chaff remains from AH II. The domestic-type barley rachises make up only 2.1% of all recovered rachises and 9.6% of the diagnostic specimens, which is still in the range for wild populations (Kislev 1989; Snir and Weiss 2014). Among the *Triticum* chaff remains, specimens that show features typical of *T. monococcum* are relatively scarce, whereas *T. dicoccum*-type specimens make up the majority of the diagnostic glume and rachis fragments. The identification of domesticated emmer in AH II at Chogha Golan has already been suggested (Weide et al. 2015). In the present study we confirm this identification based on a larger amount of analysed wheat chaff. Only 13% of all wheat rachis fragments exhibited an abscission scar diagnostic of the domestication status, which is thought to be a result of dehusking practices (Tanno and Willcox 2012) and carbonization (Weide et al. 2015). But a considerable proportion of the diagnostic emmer rachises belong to the domestic morphotype, indicating the establishment of non-shattering ears in a cultivated population (Table 3).

The medium-seeded grasses *Avena, Bromus, Hordeum, Taeniatherum caput-medusae* and the triticoid type grains (Fig. 5e–i) each have a ubiquity of 20% or more in AH II. Taken together, they are as numerous as the grains of large-seeded taxa. Even more abundant are the small-seeded taxa such as *Phalaris* and a type resembling *Phleum* (Fig. 5j, k), which make up a considerable proportion of the grains recovered from this horizon. Both these groups are diverse and contain a high variety of undetermined morphotypes. The fragmentation of grains within the medium-seeded

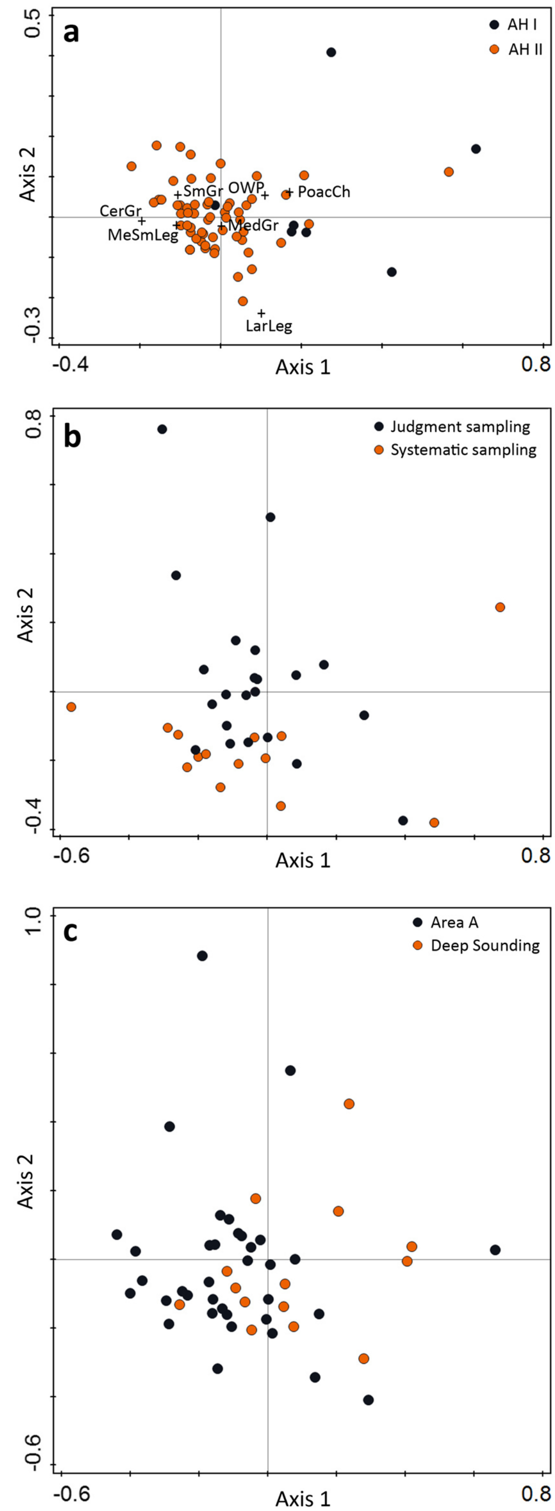


**Fig. 4** Results of the three correspondence analyses: **a** scatter plot ▸ of flotation samples from AH I and AH II of both excavation areas, axis 1 accounts for 41.85% of the total variation, axis 2 for 18.57%. CerGr, cereal grains; LarLeg, large legume seeds; MedGr, medium-sized grass fruits; MeSmLeg, medium-small legume seeds; OWP, other wild plants; PoacCh, Poaceae chaff; SmGr, small grass fruits. **b** scatter plot of different sample types from AH II in area A, axis 1 accounts for 13.69% of the total variation, axis 2 for 11.37%; **c** scatter plot of flotation samples from AH II in the deep sounding and excavation area A, axis 1 accounts for 12.6% of the total variation, axis 2 for 11.03%

grasses hampered further reliable identifications, whereas the subtle differences between the well preserved small grass seeds generally make their identification a formidable challenge (Nesbitt 2006). We do not provide an estimate of the total number of different grass species present in the analysed samples, but the results indicate that there was a high diversity of Poaceae species in the surrounding vegetation units.

## The legumes (Fabaceae)

Four pulse genera which include wild progenitor species were present in the analysed samples. Seeds of *Lens* could easily be distinguished, but we were confronted with a high morphological diversity within the *Lathyrus*/*Pisum*/*Vicia* group (Fig. 6a–c). Because seeds exhibiting the hilum and testa were very rare, we hardly achieved more precise identifications. Only for AH II, some seeds with the hilum preserved confirmed the presence of *Pisum*, and a *Lathyrus* seed type has been identified by its angular outline. In term of absolute counts, medium to small-sized seeds dominate the legumes by far. They mostly consist of *Astragalus* and *Trigonella* species, as well as *Medicago* spp. and various undetermined morphotypes (Fig. 6d–h). This spectrum is very similar to the taxa which van Zeist et al. (1984) reported for Ganj Dareh and presumably also to the spectrum that Helbæk (1969) found in the Ali Kosh material, although he did not provide a detailed description of the small-seeded legumes.

## Additional wild plant resources

Plant remains other than grasses and legumes yielded 30 different wild plant taxa, of which only 17 occurred in AH I, while 28 were present in AH II (see Fig. 6i–o for examples of more frequent taxa). The importance of these taxa is mostly reflected in their ubiquity values. *Buglossoides arvensis* (ubiquity of 48%) and *Pistacia* (40%) represent the most frequent wild plants in AH I, followed by *Bolboschoenus glaucus* (16%), *Bellevalia*/*Muscari*/*Ornithogalum*, *Buglossoides tenuiflora*, *Capsella*/*Descurainia*, *Centaurea* and *Malva* (all 12%). Among the wild taxa of AH II, *Pistacia* is most frequent (89%), followed by *Malva* (72%), *Buglossoides arvensis* (44%), *Bolboschoenus glaucus* (43%), *Bellevalia*/*Muscari*/*Ornithogalum* (32%), *Capsella*/*Descurainia* (16%), *Heliotropium* (15%), *Silene* (13%) and *Galium* (12%). The high to very high ubiquity values for *Pistacia* and *B. arvensis* fruits reflect, at least


**Fig. 5** **a** *Aegilops* sp.; **b** *Aegilops* sp. spikelet base from above (*left*) and below (*right*) with a detailed picture of the heart-shaped abscission scar (*outlined by the dashed line*); **c, d** *Hordeum spontaneum;* **e** *Hordeum* sp.; **f** Triticoid type; **g** *Taeniatherum caput-medusae*; **h** *Bromus* type 1; **i** *Avena* sp.; **j** *Phalaris* sp.; **k** *Phleum* type; **l** *H. spontaneum* rachis fragment (wild type); **m** *H. spontaneum* rachis fragment (domestic type). *Bars* represent 1 mm

**Table 3** Classification of *Hordeum* and *Triticum* chaff remains from AH II

| | *Hordeum spontaneum* | *Triticum boeoticum* | *T. dicoccoides/dicoccum* | *Triticum* sp. |
|---|---|---|---|---|
| Glume bases | | 56 | 427 | 936 |
| Upper abscission scars | | | | |
| Domestic-type | 5 | | 21 | |
| Wild-type | 47 | 1 | 13 | 3 |
| Not diagnostic | 186 | 15 | 87 | 154 |
| Terminal spikelets | | | 23 | |
| Total | 238 | 72 | 571 | 1,093 |

This table includes *Triticum* chaff from the additional 20 samples of the deep sounding and the material published in Weide et al. (2015), which makes a total of 108 samples sorted for *Triticum* chaff remains

partly, their robustness. Particularly the high amount of *Buglossoides* fruits should be treated with caution. The fact that their silica skeletons survive over millennia without being carbonized easily leads to accumulations in archaeobotanical assemblages with a high risk of modern intrusions (van Zeist and Bakker-Heeres 1982). In contrast, less resistant fruits and seeds were also frequently found. This requires alternative explanations, such as deliberate gathering or their occurrence as common weeds in cultivated fields. Table 4 gives the potential uses for wild taxa from AH I or II with ubiquity values of 10% or higher. If more than one taxon may be represented in a morphotype, we listed the respective taxa separately.

## Discussion

### Implications of the taphonomic analyses

The composition of the plant remains in the samples from AH I and AH II analysed for this study is different. A logical explanation for the observed patterns would be a change in the subsistence strategy of the inhabitants towards the final occupation phase. A decrease in small-seeded grasses and medium to small-seeded legumes, coinciding with a pronounced dominance of wild and domestic cereals, could indicate an increased focus on farming and a reduced investment in wild plant gathering. However, a closer look at the identified plant remains from both horizons suggests taphonomic reasons for this pattern. The small numbers of recovered items per litre of soil from AH I in area A, together with a stronger fragmentation and erosion of the archaeobotanical remains, reflects the poor preservation conditions there. High values for cereal chaff and the marked decrease in medium and small fruits and seeds rather indicate a bias towards resistant plant remains. The increased proportions of *Buglossoides arvensis* fruits and the smaller number of identified taxa in AH I add to this picture. We therefore regard the plant remains from AH I in area A as unsuited to reliably reconstruct the subsistence economy of the final settlement phase, as their composition seems to be significantly affected by the poor preservation conditions. This suggestion finds support in the data published by Riehl et al. (2013), in which only samples from the deep sounding were analysed. The decrease in small-seeded grasses and medium to small-seeded legumes towards AH I is much less pronounced here. This confirms that the preservation conditions of AH I in area A are worse compared to AH II in the same trench, but also to AH I in the deep sounding. The on-site sampling strategy in excavation area A combined judgment and systematic sampling. Whereas most taxa are equally present in the two sample types from AH II, systematically collected samples contained a much higher proportion of *Triticum* chaff. Surprisingly, chaff of *Hordeum spontaneum* or *Aegilops* does not show such a clear trend, which we cannot explain at this stage of our research. The systematic samples contained fewer small-seeded grasses and a smaller number of wild taxa. This again indicates a bias towards more resistant plant remains, although the relatively similar proportions of *Hordeum* and *Aegilops* chaff are not supportive of such an interpretation. These compositional differences between the judgment and systematic samples offer an additional explanation for the observed patterns in AH I. Here, all but two samples derive from the systematically sampled columns (Table 1). This lack of judgment samples possibly amplified the bias towards resistant plant parts.

The similar composition of flotation samples from AH II in both excavation areas indicates that neither the sampling locations nor the different sampling strategies significantly affected the data obtained from this horizon. The enhanced preservation of charred plant remains in AH II and the availability of both systematic and judgment samples reduced the effect of the different sampling strategies.

Taphonomic analyses of archaeobotanical assemblages are not confined to questions regarding the preservation and representivity of the studied material. Central questions concern the origin and deposition of the recovered

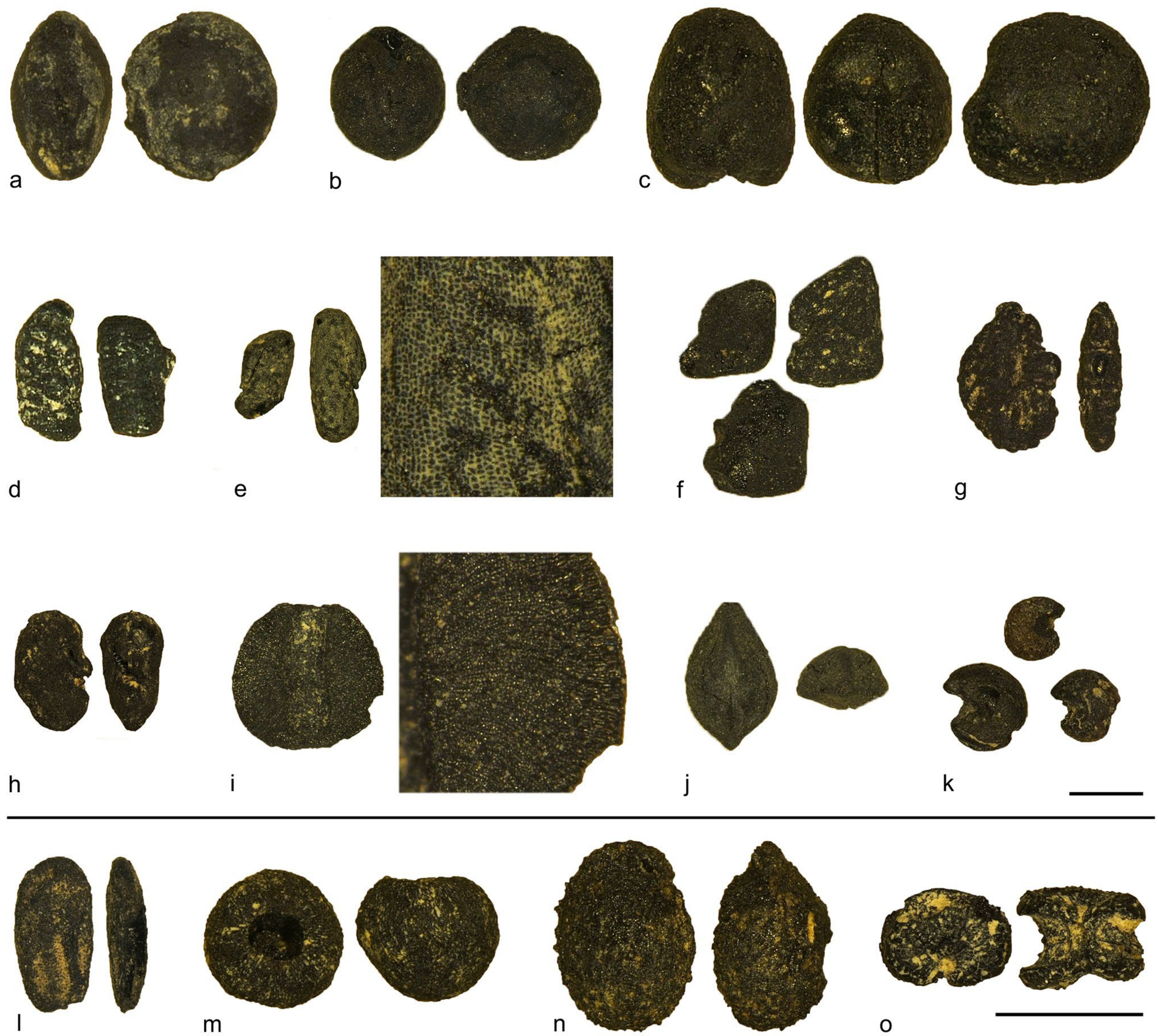


**Fig. 6** **a** *Lens* sp.; **b** *Pisum* sp.; **c** *Lathyrus*/*Vicia*; **d** *Trigonella astroites* type; **e** *Trigonella* type 2 with a detailed picture of the testa surface; **f** *Astragalus* spp.; **g** *Medicago radiata*; **h** *Medicago* sp.; **i** *Bellevalia*/*Muscari*/*Ornithogalum* with a detailed picture of the endosperm cell structure (*right*); **j** *Bolboschoenus glaucus*; **k** *Malva* sp.; **l** *Capsella*/*Descurainia*; **m** *Galium* sp.; **n** *Heliotropium* sp.; **o** *Silene* sp. *Bars* represent 1 mm

plant remains, particularly the identification of dung used as fuel (Miller and Smart 1984; Miller 1996). Riehl et al. (2015) already discussed why we do not regard the archaeobotanical material from Chogha Golan as mainly dung-derived. Wood resources were available throughout the occupation period, but overall no herd management of wild ruminants could be proven at the site. The large number of additional samples analysed for this study supports this view. They yielded abundant grains of *H. spontaneum, Aegilops* as well as various other grass taxa. Valamoti and Charles (2005) demonstrated that glume wheat grains fed to goats, as whole spikelets or after dehusking, do not survive digestion in an identifiable form. There is no reason why this should only apply to glume wheat grains and we therefore regard the presence of identifiable large and medium-sized caryopses in virtually all of the studied samples as further evidence that dung-derived plant remains do not represent the major portion of the studied material.

**Table 4** Possible interpretations of plant taxa present in AH I and II of Chogha Golan excluding the cereals and pulses, taxa with a ubiquity smaller than 10% and taxa for which no records could be found in the literature

| Taxon | Pot. arable weed | Potential uses | | | Species concerned in the ethnobotanical literature | References for potential uses |
|---|---|---|---|---|---|---|
| | | Food | Medicine | Others | | |
| *Astragalus* | X | Fl/Fr | L/Ro/St | Fuel, gum tragacanth | *A. angustifolius, barba-jovis, cicer, elatus, fragrans, kirshehiricus, microcephalus, psilocentros, russelii, subrobustus* | Ertuğ (2000), Özgen et al. (2004), Ajaib et al. (2010), Güneş and Özhatay (2011), Akan et al. (2013), Mükemre et al. (2016) |
| *Avena* | X | | Ae/Se | | *A. barbata, wiestii* | Ghasemi et al. (2013), Sargın et al. (2013) |
| *Bellevalia* | X | B/Fl/L | | | *B. gracilis, olivieri, sarmatica* | Güneş and Özhatay (2011), Doğan and Tuzlacı (2015), Mükemre et al. (2016) |
| *Bolboschoenus glaucus* | X | B/Fr | | | also *B. maritimus* | Wollstonecroft et al. (2011) |
| *Bromus* | X | | | | | |
| *Buglossoides arvensis* | X | L/St | W | Dye | *Buglossoides* species in general and *B. arvensis* in particular | Pustovoytov et al. (2004), Cansaran and Kaya (2010) |
| *B. tenuiflora* | X | | W | Dye | *Buglossoides* species in general | Pustovoytov et al. (2004) |
| *Capsella* | X | W | Ae/Se | Oil | *C. bursa-pastoris* | Simsek et al. (2004), Fairbairn et al. (2007), Hussain et al. (2008), Cakilcioglu and Turkoglu (2010), Güneş and Özhatay (2011), Mosaddegh et al. (2012) |
| *Centaurea*[a] | X | W | Ae | | *C. cyanus, depressa, iberica, nemecii, solstitialis* | Ertuğ (2000), Simsek et al. (2004), Kargıoğlu et al. (2008), Kültür (2008), Uysal et al. (2010), Güneş and Özhatay (2011), Akan et al. (2013), Nawash et al. (2014), Doğan and Tuzlacı (2015), Mükemre et al. (2016) |
| *Descurainia* | X | | Se | Oil | *D. sophia* | Ghorbani (2005), Fairbairn et al. (2007), Mosaddegh et al. (2012) |
| *Galium*[b] | X | | Ae | | *G. aparine, cruciata, verum* | Özgökçe and Özçelik (2004), Cakilcioglu and Turkoglu (2010), Shafaghat et al. (2010) |
| *Gypsophila* | X | Ro | Fl/Ro/St | | *G. arabica, eriocalyx, perfoliata* | Sathiyamoorthy et al. (1997), Simsek et al. (2004) |
| *Heliotropium*[b] | X | | W | | *H. crispum, curassavicum, europaeum, strigosum* | Qureshi and Bhatti (2008), Ahmad et al. (2014) |
| *Hordeum*[b] | X | B | Se | | *H. bulbosum, glaucum* | Simsek et al. (2004), Bahmani et al. (2012), Mükemre et al. (2016) |
| *Malva* | X | W | W | | *M. neglecta, nicaeensis, parviflora, sylvestris* | Ertuğ (2000), Özgen et al. (2004), Simsek et al. (2004), Kargıoğlu et al. (2008), Kültür (2008), Uysal et al. (2010), Güneş and Özhatay (2011), Kızılarslan and Özhatay (2012), Nawash et al. (2014), Doğan and Tuzlacı (2015) |
| *Medicago*[b] | X | L | Ae | | *M. arabica, minima, orbicularis, polymorpha* | Ibrar et al. (2007), Kızılarslan and Özhatay (2012), Abbasi et al. (2013), Sargın et al. (2013) |
| *Muscari* | | W | Ae | | *M. armeniacum, caucasicum, comosum, neglectum* | Ertuğ (2000), Lotfipour et al. (2008), Akan et al. (2013), Lim (2014), Mükemre et al. (2016) |
| *Ornithogalum* | X | W | Ae | | *O. cuspidatum, procerum, sigmoideum* | Delazar et al. (2009), Nazifi et al. (2010), Kızılarslan and Özhatay (2012), Dastan and Aliahmadi (2015) |

**Table 4** (continued)

| Taxon | Pot. arable weed | Potential uses | | | Species concerned in the ethnobotanical literature | References for potential uses |
|---|---|---|---|---|---|---|
| | | Food | Medicine | Others | | |
| *Phalaris* | X | Se[c] | | *P. minor* stored with wheat grains to keep away mice | *P. caroliniana, minor* | Rea (1997), Chaudhari et al. (2013) |
| *Pistacia* | | Fr/L/Se | Ae/Re | Resin as glue, oil | *P. atlantica, eurycarpa, khinjuk, lentiscus, palaestina, terebinthus, vera* | Ertuğ (2000), Uysal et al. (2010), Bozorgi et al. (2013), Nawash et al. (2014), Doğan and Tuzlacı (2015) |
| *Silene* | X | W | W[c] | | *S. ampulata, compacta, coniflora, conoidea, peduncularis, vulgaris* | Ertuğ (2000), Simsek et al. (2004), Akan et al. (2013), Chandra and Rawat (2015), Doğan and Tuzlacı (2015) |
| *Trigonella* | X | Fl | W | | *T. aurantiaca, coelesyriaca, corniculata, mesopotamica* | Ertuğ (2000), Singh (2006), Akan et al. (2013) |

*Ae* all aerial parts, *B* bulbs, *Fl* flowers, *Fr* fruits, *L* leaves, *Re* resin, *Ro* roots, *Se* seeds, *St* stems, *W* whole plant

The used literature on arable weeds includes Zohary (1950), Feinbrun-Dothan (1978), Wollstonecroft et al. (2011) and Willcox (2012). Potential uses of wild plant taxa were compiled using mainly the ethnobotanical literature from the Near and Middle East

[a]Only present/frequent in AH I

[b]Only present/frequent in AH II

[c]Includes ethnobotanical records from beyond the Near and Middle East

## Which plants were cultivated at Chogha Golan?

Here we only briefly address plant cultivation and domestication, as Riehl et al. (2015) and Weide et al. (2015) have already discussed these topics. The analysis of wheat chaff from AH II indicates the presence of cultivated emmer, which produced an increased proportion of non-shattering ears compared to wild populations. A minor component of the wheat chaff belongs to wild einkorn, which possibly grew in the fields as a weed (Helbæk 1969; Miller 2003). *H. spontaneum* represents a further staple, but still produced shattering ears. Riehl et al. (2015) suggest that wild barley was cultivated at Chogha Golan, based on the development of grain sizes and staple carbon isotope ratios. The appearance of emmer in AH II corresponds to decreasing grain sizes of *H. spontaneum*, which may reflect reduced efforts in barley cultivation. Apart from the cereals, the large seeded pulses *Lens, Pisum* and *Lathyrus*/*Vicia* are the most likely candidates for having been cultivated plants at Chogha Golan.

Scholars commonly focus on the wild progenitors of the Near Eastern founder crops to identify early plant cultivation in the aceramic Neolithic (for example, Kislev 1997; Colledge 2002; Willcox et al. 2008; White and Makarewicz 2012). However, several wild grasses and legumes have been interpreted as cultivars that did not become established as domesticated crops during the emergence of agriculture or they became extinct at an early stage, such as rye, wild oat or *Vicia peregrina* (Hillman 1978; Hillman et al. 2001; Weiss et al. 2006; Melamed et al. 2008; Abbo et al. 2013). Following this, we interpret *Aegilops* at Chogha Golan as an important food resource, which may even have been cultivated. We do not argue that the pure abundance of a wild plant in an archaeobotanical assemblage can be used to assess its state as a gathered resource or cultivated crop, because it has been demonstrated that wild grasses can be harvested with a high efficiency (Harlan 1989). But as chaff and grains of *Aegilops* are as abundant and frequent as those of domestic emmer and presumably-cultivated barley, we regard it as the logical consequence to likewise interpret *Aegilops* as a pre-domestic cultivar.

## Gathering of wild plant resources

The under-representation of gathered wild plants in prehistoric archaeobotanical assemblages is widely recognized and attributed to several taphonomic rather than cultural factors (Colledge and Conolly 2014). Taphonomic agents resulting in this pattern include differing survival ranges of plant organs and taxa exposed to heat (Wilson 1984; Boardman and Jones 1990; Wright 2003; Märkle and Rösch 2008), the fact that most wild plants are gathered for their vegetative parts and not for their fruiting structures (for example, Jacomet et al. 1989; but see also Table 4), and also differences in site formation, which allow plants from a wider range of origins to accumulate in waterlogged sediments (Jacomet 2013). Demonstrating the edibility of arch$$$aeologically recorded wild plants is a further challenge (Jacomet 2009; Tolar et al. 2011; van Amerongen 2016).

In order to identify wild plant resources which possibly played a role in the subsistence economy at Chogha Golan, we use the ubiquity of wild fruits and seeds rather than their absolute counts. As Table 4 indicates, 20 out of 22 taxa with a ubiquity of at least 10% can principally be interpreted as arable weeds, based on their present day ecology. In light of the evidence for emmer cultivation in AH II, such an interpretation would be fully justified, and we consider crop processing activities and subsequent disposal of by-products in domestic fires as a likely scenario, which resulted in the accumulation of charred weed fruits and seeds in the sampled deposits. However, ethnobotanical research demonstrates how intensively wild plants are gathered in non-industrial farming communities all over the world (Johnston and Cleland 1943; Harlan 1989; Rea 1997; Ertuğ 2000; Ibrar et al. 2007; Mosaddegh et al. 2012). We predominantly use the results of ethnobotanical research in Near and Middle Eastern countries to assess the potential uses of wild taxa regularly interpreted as arable weeds. This ethnobotanical database clearly indicates that most of these taxa are used for various purposes and therefore they may represent the remains of intentionally gathered resources and not necessarily crop processing by-products. In the following paragraphs, we will discuss this possibility for the most frequent wild fruits and seeds. Only the *Pistacia* nuts do not require a more detailed discussion, as they represent the most obvious example of collected wild fruits at Chogha Golan.

The green parts of several *Malva* species are regularly gathered for food and medicinal purposes in rural Anatolia and Jordan today (Özgen et al. 2004; Simsek et al. 2004; Kargıoğlu et al. 2008; Kültür 2008; Uysal et al. 2010; Kızılarslan and Özhatay 2012; Nawash et al. 2014; Doğan and Tuzlacı 2015). Ertuğ (2000) and Güneş and Özhatay (2011) document the gathering of *M. neglecta* seeds in particular for their medical properties. Archaeobotanical evidence for the gathering and processing of *M. parviflora* has been reported from a working space in a brush hut at Ohalo II (Weiss et al. 2008). Based on this ethnographic and archaeobotanical evidence for the use of several mallow species, the high frequency of *Malva* seeds at Chogha Golan may be interpreted as indicating their deliberate collection.

The tiny seeds of either *Capsella* or *Descurainia* occur with a ubiquity of 16% in AH II and 12% among the samples from AH I in Area A. This is surprising, as oily seeds have a reduced probability of being preserved by carbonization (Wilson 1984; Wright 2003) and we see a clear bias towards resistant plant remains in the uppermost sediments. The presence of *Capsella*/*Descurainia* seeds in AH I therefore suggests that they were much more abundant at the site prior to charring and this may indicate their deliberate collection. Seeds of these and related taxa are well suited to being used to produce a vegetable oil (Fairbairn et al. 2007) and are gathered in Pakistan and Iran for medicinal purposes today (Hussain et al. 2008; Mosaddegh et al. 2012). They have been found as storage finds in the Neolithic lakeshore settlement of Hornstaad-Hörnle (Schlichtherle 1990; Maier 2001) and at Çatalhöyük East (Fairbairn et al. 2007). Despite the small size of the seeds, *Capsella* and *Descurainia* plants produce high yields and can be effectively exploited (Maier 2001; Maier and Harwath 2011).

A striking feature of many charred plant assemblages from the Near Eastern Neolithic is the great abundance of Trifolieae seeds, which at Chogha Golan are mainly represented by *Astragalus* and *Trigonella* spp. In discussing this feature for Abu Hureyra, de Moulins (1997) concludes that various hypotheses could explain their high abundance. Possible explanations include their having been gathered for food or animal fodder, their cultivation together with crops to naturally fertilize the fields, or they became abundantly charred through the burning of dung. In addition, ethnographic reports have documented the regular collection of *Astragalus* shrubs as fuel (Ertuğ 2000; Özgen et al. 2004; Ajaib et al. 2010; Güneş and Özhatay 2011; Akan et al. 2013). As is the case with other sites like Abu Hureyra, the record from Chogha Golan does not give us a solution to this issue.

Hillman (2000) and Wollstonecroft et al. (2008) investigated possible ways of preparing *Bolboschoenus* plant parts and concluded that particularly nutlets and tubers can be processed into delicate foods. We did not find tubers in the flotation samples from Chogha Golan, but charred nutlets occur frequently. According to G. C. Hillman, they need to be roasted and can then be consumed pure or pounded into flour. Whether the *B. glaucus* nutlets from Chogha Golan were roasted to prepare them for consumption is unclear. However, based on the experimental results we consider these fruits as a potential food resource that was possibly gathered. Wollstonecroft already discussed the frequent occurrence of *Bolboschoenus* nutlets in archaeobotanical assemblages from the Fertile Crescent and regarded it as "entirely feasible that this plant was used as a food by late Pleistocene and Holocene Near Eastern people" (Wollstonecroft et al. 2011, p 460).

The two last groups to be considered here are the frequent medium and small-seeded grasses and the wild taxa for which the ethnobotanical literature does not report known uses of their fruits or seeds. We interpret the high frequency and diversity of medium and small caryopses as representing the harvesting of wild grasses in the environments around Chogha Golan. Exploiting natural stands of grasses demonstrably has a long tradition in the Epipalaeolithic and even the Palaeolithic of the Near East (Weiss et al. 2004; Lev et al. 2005; Savard et al. 2006; Benz et al. 2015; Arranz et al. 2016b), which seems to have been replaced only gradually by domestic cereals. The rich ethnographic record for the exploitation of wild grasses by hunter-gatherers as well as traditional farmers around the world supports this interpretation (Johnston and Cleland 1943; Bohrer 1975; Harlan 1989, 1999; Rea 1997; Batello et al. 2004).

Among the wild plants with a ubiquity of more than 10% and without reported uses for their fruiting structures, we mostly find genera containing classic arable weeds (Table 4). However, all these taxa include species whose vegetative parts can be consumed or used as a remedy. Although the deliberate gathering of such plant parts cannot be demonstrated using charred plant assemblages, we want to emphasize the huge use potential of the recorded genera. Regardless of whether the fruits and seeds recovered from the deposits represent crop processing by-products or not, these taxa grew in the environments around Chogha Golan. As Hillman (2000) pointed out, they alternatively may represent exploited resources, for which we will hardly find direct evidence in charred archaeobotanical assemblages from the Near East.

## Conclusions

We applied correspondence analysis to the flotation samples from AH I and II of Chogha Golan to investigate which taphonomic factors and sampling strategies affected the archaeobotanical material. At first, we demonstrated that the composition of charred plant remains from both horizons is different. We attribute this to the poor preservation conditions in the uppermost horizon, which are primarily reflected in a stronger fragmentation and surface erosion of the archaeobotanical material. Additionally, resistant plant remains such as cereal chaff and *Buglossoides* nutlets are abundant, while medium and small-sized fruits and seeds decrease considerably compared to AH II. We observed a similar but less pronounced trend towards resistant plant parts among samples collected by two different sampling strategies. Samples systematically collected from two columns in excavation area A contained a significantly higher proportion of *Triticum* chaff, but fewer small-seeded grasses and a lower number of identified wild taxa than the judgment samples. Nearly all samples from AH I in area A derive from these two columns, which further compounded the trend towards resistant plant parts and a reduced taxonomic diversity. In contrast, the taxonomic composition of the samples from AH II was similar between the two different excavation areas. These statistical analyses demonstrate the need for taphonomic analyses prior to the reconstruction of the subsistence economy and its development through time, as the preservation of charred botanical assemblages can significantly be affected by post-depositional processes as well as the applied sampling strategy.

The subsistence economy during the formation of the two uppermost horizons is characterized by the emerging cultivation of domestic emmer wheat. Wild barley, *Aegilops* sp., lentils, peas and various vetches were possibly cultivated as well. Archaeobotanical analyses of prehistoric lakeshore settlements and ethnobotanical investigations in the Near and Middle East indicate that wild plant resources are routinely gathered by non-industrial farming communities. The high frequency and diversity of medium to small fruits and seeds such as grasses, nutlets of *Bolboschoenus glaucus*, seeds of *Malva* and *Capsella*/*Descurainia* may therefore indicate their deliberate gathering. Although archaeobotanists regularly interpret many of the medium and small-seeded taxa identified at Chogha Golan as arable weeds, we make use of alternative explanations for their frequent occurrence. The ethno- and the archaeobotanical record from the Near and Middle East justifies such an approach, although we do not rule out that crop processing activities contributed to the formation of the archaeobotanical assemblage.

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**ESM Vegetation History and Archaeobotany**

**Reconstructing subsistence practices: taphonomic constraints and the interpretation of wild plant remains at aceramic Neolithic Chogha Golan, Iran**

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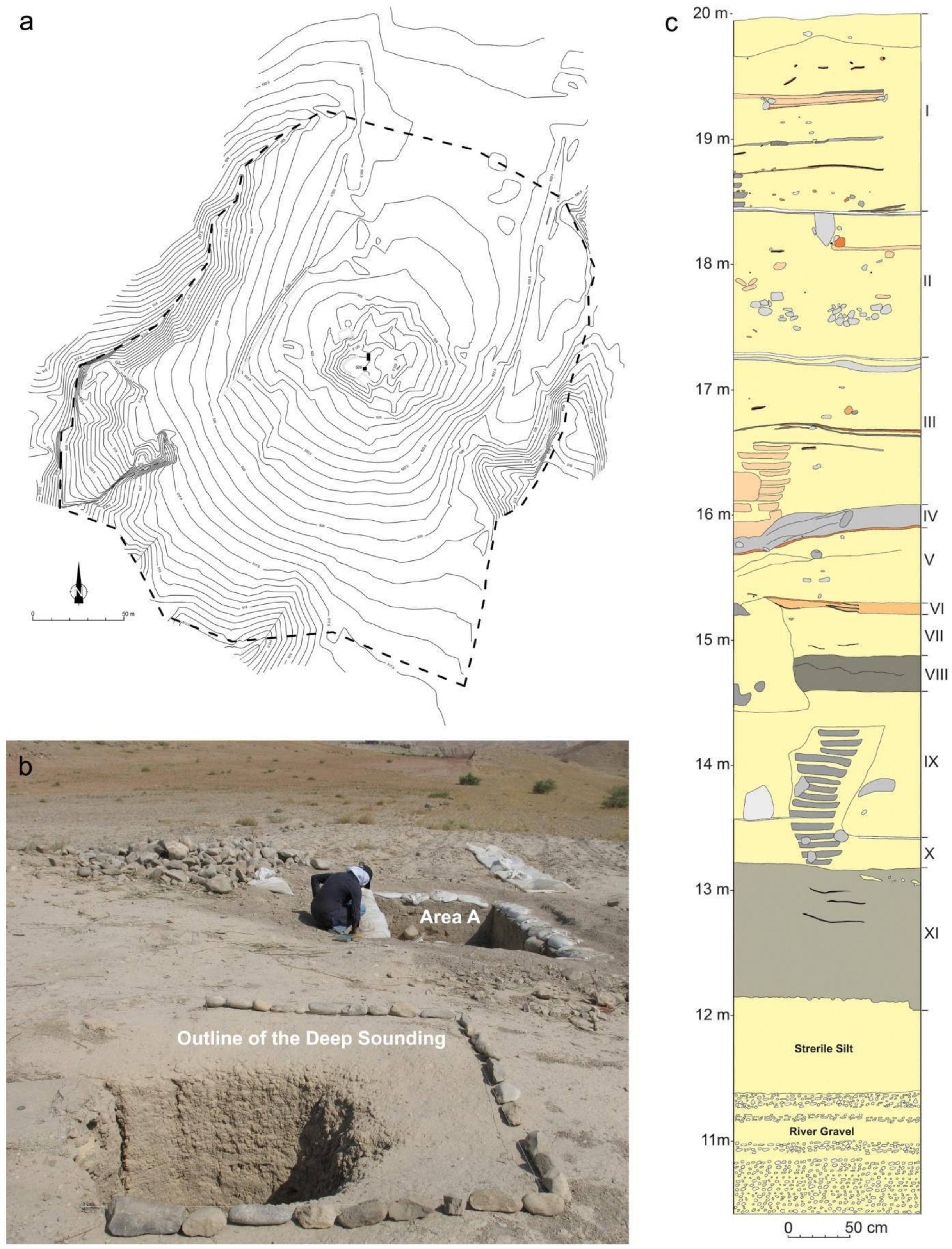



**ESM Fig. 1 a** Outline of Chogha Golan with the location of the deep sounding and excavation Area A in the center of the mound; **b** The deep sounding and excavation Area A in 2010, note the looter's pit within the outline of the deep sounding; **c** The south profile of the deep sounding showing the position and depth (z-values in m) of AH I and II. All figures and photos by M. Zeidi

**Laboratory and quantification methods**

Sediments were floated on-site using sieves with mesh sizes of 200 $\mu$m. We conducted all laboratory work in the Institute for Archaeological Sciences at the University of Tuebingen. The botanical remains were identified using a Euromex binocular with 10x to 60x magnifications and the botanical comparative collection. Measurements and photos were taken with a Keyence VHX-500FD Digital Microscope with 20x to 200x magnifications. For convenience, designation of species within the Triticeae follows the traditional classification.

Complete seeds and fruits including fragments of which >50% is preserved were counted as one. Specimens with <50% preservation were also counted as one, except if two of those fragments of the same sample complemented each other. Specific quantification methods were applied to pistachio shell fragments, Poaceae grain fragments and cereal chaff remains.

The material from Chogha Golan hardly contains complete pistachios, which could provide a reference value for the mean weight of one complete pistachio shell. We therefore applied the value used by van Zeist and Bakker-Heeres (1982), who weighed 37 complete nutshells from Ramad and obtained a mean weight of 0.021 g.

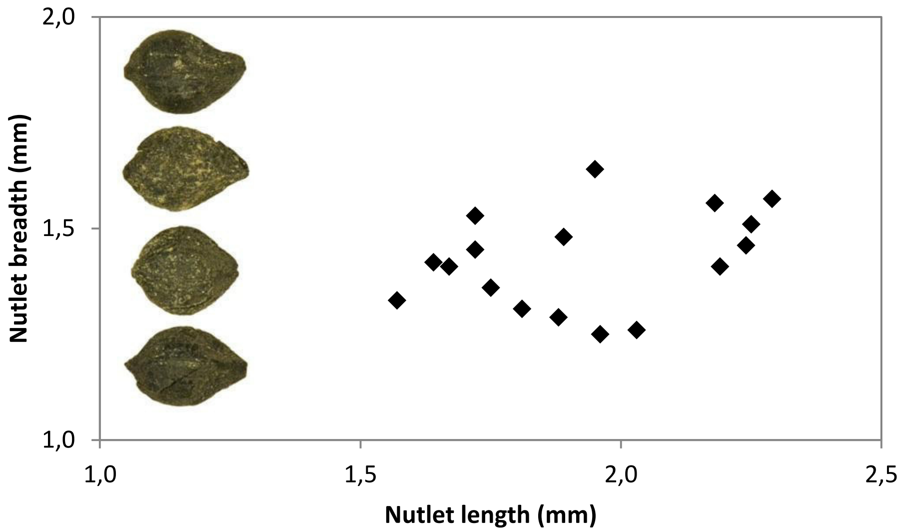
Most samples contain a high amount of large to medium-sized Poaceae grain fragments. To estimate the minimum number of whole grains present in one sample, only fragments representing the embryo-end of a grain were counted and added to the number of whole grains (cf. Jones 1990). Sometimes a few caryopsis fragments of a certain species occur in a sample and none of them shows the embryo-end. In this case we calculated a MNI by counting all caryopses with >50% preserved. *Triticum* chaff was quantified according to the method proposed by Hillman et al. (1996), where two glume bases were counted to equal one spikelet fork. *Aegilops* chaff was quantified in the same way with a spikelet base (cf. Fig. 4b) being equivalent to a wheat spikelet fork.

**Information on morphological identification criteria**

Among the taxa which we attempted to identify to the species level, *Triticum dicoccoides*/*dicoccum* and *boeoticum*, *Aegilops* sp. and *Bolboschoenus glaucus* require additional information. Among the *Triticum* chaff remains we differentiated between einkorn- and emmer-type chaff. Einkorn chaff is characterized by glumes with large primary keels, well developed secondary keels and a smooth glume surface. The keels are less prominent among the emmer specimens, which show a prominent tertiary venation on the glume surface (cf. Hillman et al. 1996). However, only glumes and spikelet forks in which these features are very distinctive can be assigned to either einkorn or emmer. The majority of chaff remains did now allow distinguishing between both taxa, because the typical features were hardly characteristic or badly preserved. The high number of terminal spikelets further indicates a predominance of emmer in the wheat remains from Chogha Golan.

*Aegilops* spikes produce two different types of diaspores, according to their mode of rachis disarticulation: the wedge type and the barrel type spikelets (Morrison 1994). Among the chaff remains from Chogha Golan, no wedge type spikelets were found and all complete spikelet bases have a heart-shaped abscission scar, which is small in relation to the whole spikelet base (Fig. 4b). This combination of morphological features is characteristic for the section *Vertebrata*, in which Hammer (1980) places the species *A. tauschii*, *crassa*, *ventricosa*, *juvenalis* and *turcomanica*. However, the morphological differences between these species are yet to be studied in detail and we do not provide a more precise identification.

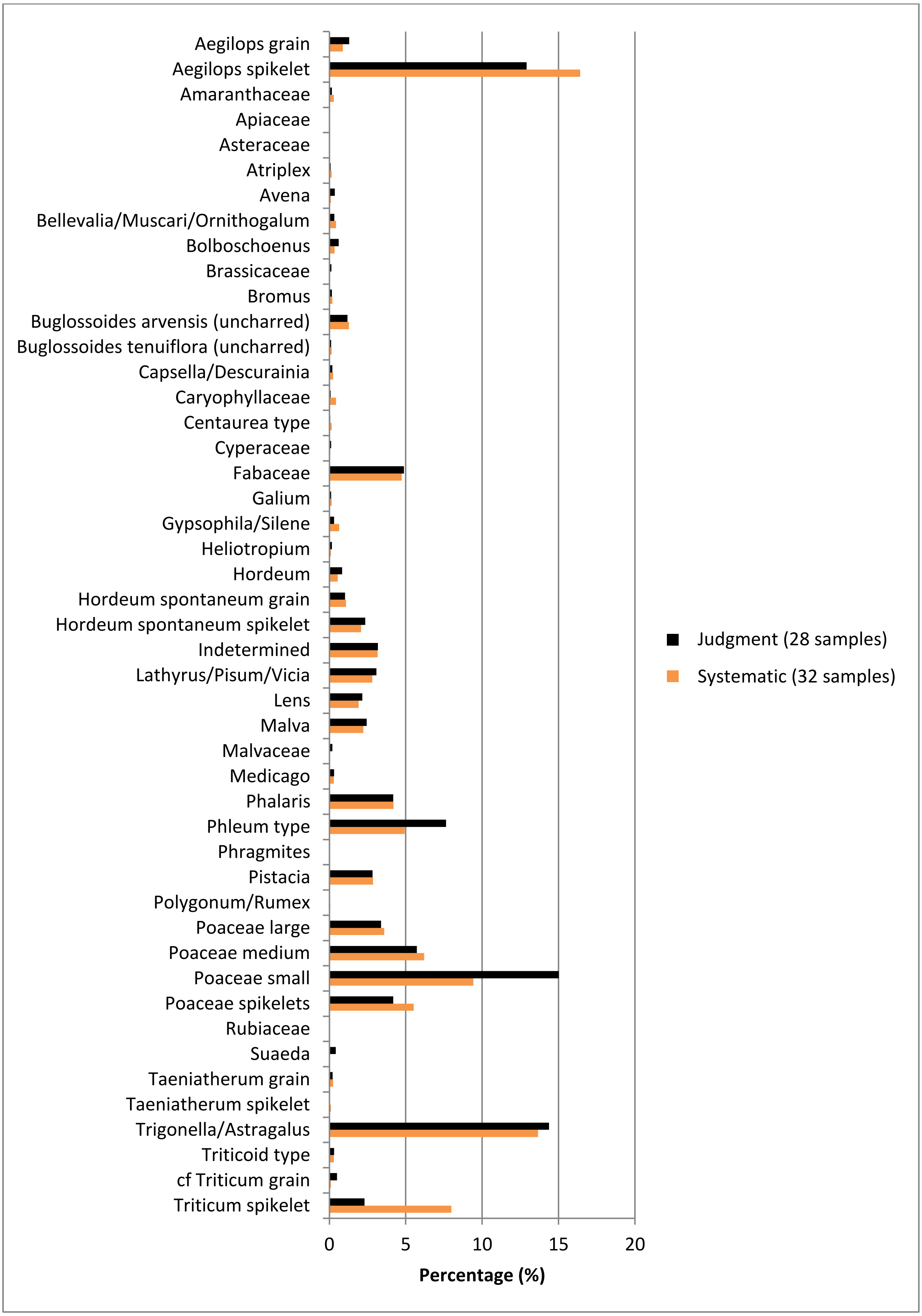
The size range as well as the shape of the charred *Bolboschoenus* nutlets from Chogha Golan corresponds to that of archaeobotanical *B. glaucus* finds from Near Eastern Neolithic sites (Wollstonecroft et al. 2011; ESM Fig. 1). The nutlets from Chogha Golan have a thin exocarp and a thick mesocarp and are therefore distinguishable from *B. maritimus*, which has a thick exocarp consisting of radially elongated, cylindrical cells (cf. Wollstonecroft et al. 2011, Fig. 1). Based on these morphological and anatomical features, we identified the nutlets from Chogha Golan as *B. glaucus*.




**ESM Fig. 2** Shape and size variability of *Bolboschoenus* nutlets from AH II of Chogha Golan. Mean dimensions and size ranges of 17 nutlets are 1.93(1.57-2.29) x 1.43(1.25-1.64) mm

**ESM Table 1** Taxa and groups represented by the major plant categories that were used in the first correspondence analysis and for characterizing the overall botanical composition of samples analyzed for this study. The category "other wild plants" contains all taxa and groups not listed here (gr=grain, sp=spikelet)

| **Cereal grains** | **Poaceae chaff** | **Medium-seeded grasses** | **Small-seeded grasses** | **Large-seeded legumes** | **Medium/small-seeded legumes** |
|---|---|---|---|---|---|
| *Aegilops* gr | *Aegilops* sp | *Agropyron/ Eremopyrum* | *Pennisetum* type | *Lathyrus* type | *Astragalus* |
| *H. spont.* gr | *H. spont.* sp | *Avena* | *Phalaris* | *Lathyrus/Vicia* | *Medicago* |
| cf. *Triticum* gr | *Triticum* sp | *Bromus* type 1 | *Phleum* type | *Lathyrus/Vicia/Pisum* | *M. radiata* |
| Poaceae large | *Taeniatherum* sp | *Bromus* type 2 | *Phragmites* | *Lens* | *Onobrychis* |
| | indet. sp type | *Hordeum* | Poaceae small | *Pisum* | *T. astroites* type |
| | indet. cereal rachis | *Taeniatherum* gr | | | *T.* type 2 |
| | indet. sp | Triticoid type gr | | | *Trigonella/Astragalus* |
| | | Poaceae medium | | | Fabaceae med-small |




**ESM Fig. 3** The influence of the two different sampling strategies on the composition and proportion of plant remains in AH II of excavation area A. Note that particularly small seeded grasses including *Phleum* type have higher proportions in the judgment samples, whereas *Triticum* chaff has significantly higher proportions in the systematically floated columns. *Aegilops* chaff only shows a weak trend towards such a pattern. All other taxa are equally present in both sample types

**Works only cited in the ESM**

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# Appendix B

## A systematic review of wild grass exploitation in relation to emerging cereal cultivation throughout the Epipalaeolithic and aceramic Neolithic of the Fertile Crescent

Alexander Weide, Simone Riehl, Mohsen Zeidi & Nicholas J. Conard

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RESEARCH ARTICLE

# A systematic review of wild grass exploitation in relation to emerging cereal cultivation throughout the Epipalaeolithic and aceramic Neolithic of the Fertile Crescent

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## Abstract

The present study investigates the occurrence of wild grasses at Epipalaeolithic and aceramic Neolithic sites in the Near East in order to assess their role in subsistence economies alongside the emergence of cereal cultivation. We use Chogha Golan in the foothills of the central Zagros Mountains (ca. 11.7–9.6 ka cal. BP) as a case study, where the archaeobotanical data suggest the frequent exploitation of a complex of wild grasses for almost 2,000 years. Domesticated emmer replaced these wild grasses as the major food resources towards the end of occupation at the site (ca. 9.8 ka cal. BP). We discuss possible implications of this development and conclude that the traditional concept of pre-domestication cultivation seems unsuited for explaining the patterns from Chogha Golan. These data are in good accordance with the overall picture in the Zagros Mountains, where wild grasses were routinely gathered throughout the early Holocene. In contrast, wild grasses were gradually replaced by wild cereals in the Levantine corridor since the end of the Pleistocene. However, several sites located in this region provide evidence for a continuous exploitation of wild grasses alongside emerging cereal cultivation and most of these taxa were part of the earliest segetal floras that evolved with the appearance of domestic cereals throughout the 11$^{th}$ millennium cal. BP. Some sites contemporary to the Pre-Pottery Neolithic B still provide evidence for the usage of wild grasses, which possibly reflects the utilization of edible arable weeds and continuous gathering of wild grasses by more mobile groups.

## Introduction

The aceramic Neolithic in the Near East is characterized by the emergence of sedentary farming communities and marks a major change in human subsistence economies. Although still disputed [1–4], many scholars regard the "Neolithic Revolution" as a mosaic-like and protracted process, which is characterized by distinct trajectories towards farming in different

**Competing interests:** The authors have declared that no competing interests exist.

sub-regions of the Fertile Crescent [5–19]. Archaeobotanical research on the emergence of agriculture has long focused on the origins and identification of domesticated cereals [20–24], which represents a major research area until today [25–27]. The last 20 years saw major advances in methodological and theoretical approaches, which eventually resulted in the proposition of the pre-domestication cultivation hypothesis [28–32]. This scenario assumes that the focus on wild cereals at sites in the southern and northern Levant during the early Pre-Pottery Neolithic (PPN) reflects the beginnings of cultivation, although morphological signs of domestication are still rare or absent. Besides evidence for increasing grain sizes over time [33–35] and the gradual replacement of gathered wild species by wild progenitors [32,36], this hypothesis is based on the interpretation of potential arable weeds as indicators for cultivation activities [37,38].

Today we owe this intensive archaeobotanical research a much clearer picture of emerging cultivation than during the 1990s and substantial methodological advances for the analysis of Neolithic plant assemblages. However, such a heavy focus on emerging cereal cultivation and domestication automatically tends to neglect the exploitation of wild plant resources by early farming communities. Many authors acknowledged the presence of a high diversity of potentially usable wild plants in aceramic Neolithic assemblages, but predominantly interpreted fruits and nuts from *Pistacia*, *Ficus*, *Vitis*, *Capparis* or *Amygdalus* as gathered foods [23,28,32,35,39–41]. This is mainly due to the fact that these fruit-bearing trees, shrubs and climbers produce large, calorie-rich fruits and do not contribute to crop-processing products or by-products. In contrast, many potentially usable wild plants are part of arable weed floras and their fruiting structures often accumulate in archaeobotanical assemblages consisting of threshing and sieving remains. Disentangling gathered species and arable weeds therefore represents a major challenge in interpreting prehistoric archaeobotanical assemblages [42–44].

Based on finds from Ohalo II, Hayonim cave and Kebara cave we know that wild plant foods, including grasses and legumes, have been exploited by Middle Palaeolithic and Epipalaeolithic hunter-gatherers [45–47]. Particularly Ohalo II yielded a rich archaeobotanical assemblage with a high proportion of wild grasses. Weiss et al. interpreted these finds as representative of staple foods that have been gathered alongside wild cereals and formed part of the "broad spectrum revolution" originally postulated by Flannery in 1969 [48–50]. Additional evidence for the frequent exploitation of wild Poaceae species that have never been domesticated came from sites in the eastern wing of the Fertile Crescent. Savard et al. found high proportions of wild grains in the early Holocene assemblages from Qermez Dere and M'lefaat [51], supporting the view of Weiss and his colleagues that non-cereal taxa played an important role in subsistence economies prior to the beginnings of cultivation. Similarly surprising were the storage finds of wild grains from PPNA Gilgal and the aceramic levels at Çatalhöyük, suggesting that wild grasses have been continuously consumed alongside cultivated wild and possibly even domestic cereals [52,53]. However, Weiss et al. demonstrated a decrease in abundance for non-cereal taxa towards the PPNA in the Levant, having negligible proportions during the PPN and being insignificant for the diet of the earliest farmers [48]. This assumption was in accordance with the overall development of early Holocene subsistence strategies in the Levantine corridor, but at the same time raises the question of whether this view is applicable to the aceramic Neolithic as a whole? Particularly as scholars seem to agree upon a substantial diversity in subsistence strategies that characterize the late Pleistocene and early Holocene human groups in the Near East [12,18,51,54–60]. Moreover, several rich archaeobotanical assemblages from the Levantine corridor have been investigated and published since 2004, making it sensible to re-evaluate the relation between wild grass use and emerging cereal cultivation in this region.

## Focus and goals of the study

In this paper we present additional evidence for the routine exploitation of wild grasses alongside wild cereals from the aceramic Neolithic site of Chogha Golan in the foothills of the central Zagros Mountains. Based on this case study we discuss how the emergence of agriculture on the site relates to the gathering of wild grains that directly "competed" with domesticated cereals in the subsistence economy. In this regard, our main goals are to investigate how the roles of wild grasses and wild and domestic cereals change throughout the site's occupation and whether the traditional pre-domestication cultivation hypothesis is suited to explain this development.

By using Chogha Golan as a starting point, we systematically reviewed the occurrence of wild grasses at Epipalaeolithic and aceramic Neolithic sites in the entire Fertile Crescent. Our main goal is to trace the development of wild grass exploitation in relation to emerging cereal cultivation and domestication. For investigating this, we conducted a spatial and temporal analysis on the occurrence of wild grasses and cereals. In addition to proportions and ubiquity values, we considered the interpretation of the wild grasses by the individual authors and their occurrence in specific contexts. The major aims of these analyses are to evaluate how the role of wild grasses changed through time and whether we see differences in plant exploitation strategies among the sub-regions of the Fertile Crescent. This is of major significance for understanding the Neolithic transition, because the harvests of wild grasses directly compete with cultivated grains and may shed light on the reasons why initial cereal cultivation appeared with a high temporal variability throughout the Near East.

A further goal of this paper is to identify constraints in the currently available information on Near Eastern wild grass use and to evaluate how future research should address this issue to proceed in reconstructing the origin of charred grains in anthropogenic deposits.

# Material and methods

## The site of Chogha Golan and its palaeoecology

The aceramic Neolithic site of Chogha Golan is located in the foothills of the Central Zagros Mountains in Iran (Fig 1). Members of the Tübingen Iranian Stone Age Research Project (TISARP) and the Iranian Center for Archaeological Research excavated the site in 2009 and 2010 [61]. The tell covers an area of about 3 hectares and is situated near the right bank of the Konjan Cham River (S1A Fig). Two trenches, a deep sounding and excavation area A, were opened in the center of the mound (S1B Fig). The deep sounding has an extent of 2 x 1.5 m and was excavated into sterile sediments 8 m below the tell surface. The excavators divided the stratigraphy of the deep sounding into eleven archaeological horizons (hereafter AH; S1C Fig). A series of radiocarbon dates places the occupation between ca. 11,700 and 9,600 cal. B.P. [16]. First evidences for substantial architecture, represented by remains of a mud-brick wall and a plaster floor, date to between ca. 11,000 and 10,600 cal. B.P., suggesting that permanent occupation at Chogha Golan lasted for at least 1,000 years or longer. The ground stone assemblage consists of mortars, pestles, grinding slabs, handstones, and pounders, while the chipped stone industry is characterized by bladelet production and little variance in tool types [62,63].

Riehl et al. presented first results on the palaeoecology of Chogha Golan [64]. According to the anthracological analysis, the nearby semiarid *Pistacia-Amygdalus* woodland steppe and the riparian vegetation were exploited for wood resources. The faunal material is dominated by ungulates and contains a high abundance of fish remains, but the preliminary results and the small sample size do not allow drawing final conclusions on possible management practices or morphological domestication [65]. The available archaeobotanical data indicate the

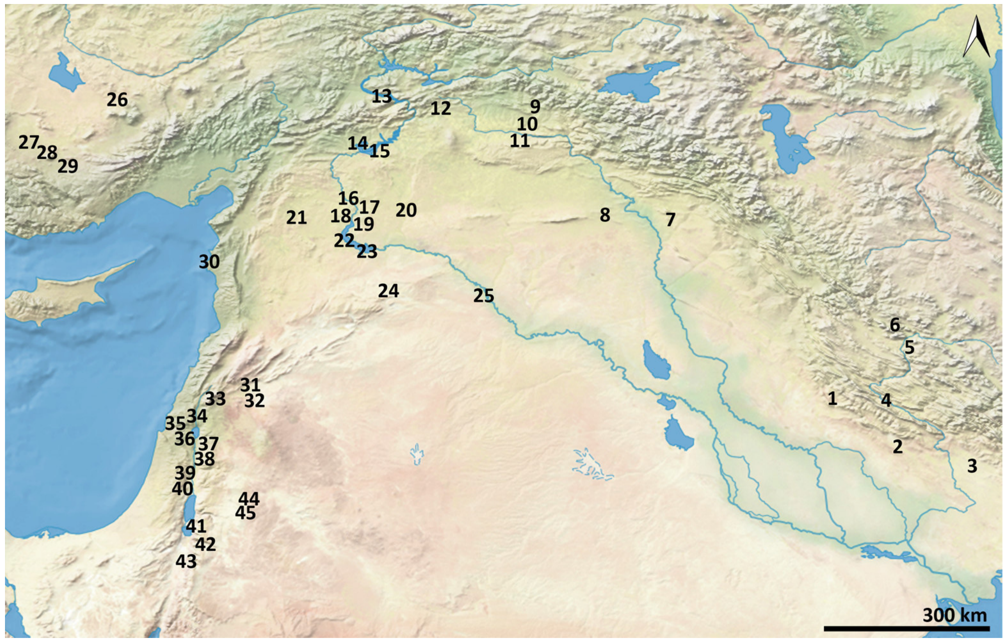


**Fig 1. Epipalaeolithic and aceramic Neolithic sites mentioned in the text.** (1) Chogha Golan; (2) Ali Kosh; (3) Chogha Bonut; (4) Chia Sabz; (5) Ganj Dareh; (6) Sheikh-e Abad; (7) M'lefaat; (8) Qermez Dere; (9) Hallan Çemi; (10) Demirköy; (11) Körtik Tepe; (12) Çayönü; (13) Cafer Höyük; (14) Gritille; (15) Nevali Çori; (16) Tell 'Abr; (17) Dja'de; (18) Halula; (19) Jerf el Ahmar; (20) Sabi Abyad II; (21) Tell Qaramel; (22) Mureybet; (23) Abu Hureyra; (24) El Kowm II; (25) Tell Bouqras; (26) Aşikli Höyük; (27) Çatalhöyük; (28) Pinarbaşi; (29) Can Hasan III; (30) Ras Shamra; (31) Tell Ghoraifé; (32) Tell Aswad; (33) Tell Ramad; (34) Eynan; (35) Hilazon Tahtit; (36) Ohalo II; (37) Wadi al-Hammeh 27; (38) Iraq ed-Dubb; (39) Gilgal; (40) Netiv Hagdud; (41) ZAD 2; (42) el-Hemmeh; (43) Wadi Faynan 16; (44) Kharaneh IV; (45) Wadi el-Jilat 6 & 7.

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exploitation of a high diversity of wild plant resources including a large component of wild progenitor species [16,44]. A considerable increase in small-seeded grasses between AH V and III may indicate a shift in resource availability with a possible contribution of climatic fluctuations. The abundant wild barley grain and chaff remains, combined with temporal grain size increases paralleled by high δ13C values indicative of enhanced growing conditions, may reflect management practices during this phase [64] and we do not rule out this possibility for the equally abundant *Aegilops* sp. remains [44]. Domestic-type emmer wheat chaff dominates the cereal remains of AH II and I and represents the first unequivocal evidence for the cultivation of a domestic crop at the site by ca. 9,800 cal. BP [16,27,44].

## Sampling and laboratory methods

For the present study the first author analyzed 23 additional flotation samples from AH VII to III of the deep sounding in order to increase the sample size for the occupation period that precedes the beginnings of agriculture at Chogha Golan and is contemporary to the early and middle PPNB of the Levantine sequence. A radiocarbon date from AH VIII dates to about 10,600 cal. BP and predates the sediments studied in this paper, for which radiocarbon dates accumulate between ca. 10,000 (AH VI-IV) and 9,800 (AH III-II) cal. BP [64]. Whether the age of AH VII is more close to 10,600 or 10,000 cal. BP is currently not clear. For illustrating the development of gathering and cultivation practices after the accumulation of these sediments, we use the data from 15 samples from AH II of the deep sounding. These have been analyzed by Weide et al., who showed that they are representative of the general subsistence economy during this final settlement phase [44].

The analyzed flotation samples derive from two main sediment types. Collapsed and decayed building debris intermixed with occupation deposits formed AHs II, III, V and VII, whereas AHs IV and VI represent midden deposits mostly consisting of ash, charcoal, bone fragments and stone artifacts [61]. Sediments macroscopically containing a high ash component and carbonized plant remains were sampled for bucket flotation using a 0.2 mm mesh. All laboratory work was conducted at the Institute for Archaeological Sciences at the University of Tuebingen, where the archaeobotanical material is currently archived. The botanical remains were identified using a Euromex binocular with 10 to 60x magnifications and the botanical comparative collection. For convenience, designation of species within the Triticeae follows the traditional classification [66]. Quantification methods followed the procedure described elsewhere [44]. We did not calculate ubiquity values for the taxa in the samples from the deep sounding, because most of them would have a very high frequency of up to 100% as an artifact of the small sampling area.

## Classification of the Poaceae taxa

Archaeobotanists traditionally divide Poaceae taxa into groups according to the dimensions of their caryopses. As an alternative approach we decided to use grain weight, based on the average 1000 seed weight given in the Seed Information Database of the Royal Botanic Gardens Kew [67]. Due to the variability and overlap in grain dimensions and weight, a strict division of taxa into size classes can hardly be achieved without additional criteria (S1 Table, S2 Fig). We therefore used the common functional interpretation of grasses alongside grain weight to form groups for our analyses (Table 1).

The "small-seeded wild grasses" comprise genera with an average grain weight of less than 3g. Many species in this group are commonly interpreted as representative of dung-burning or fuel collection activities. From this group we separate all genera with an average grain weight of 3g or more. These taxa are commonly regarded as potential food plants or arable weeds and most of them have a reduced probability of being preserved in herbivore dung due to their

**Table 1. Classification of Poaceae taxa frequently identified among Epipalaeolithic and aceramic Neolithic archaeobotanical assemblages from the Near East.**

| Wild and/or domestic cereals[1] | Large to medium-seeded wild grasses[2] | Small-seeded wild grasses[3] |
|---|---|---|
| *Hordeum spontaneum*/*distichum* | *Aegilops* spp. | *Aeluropus* spp.[4] |
| *Triticum boeoticum*/*monococcum*/*urartu* | *Avena* spp. | *Alopecurus* spp. |
| *Triticum dicoccoides*/*dicoccum* | *Bromus* spp. | *Agrostis* spp.[4] |
| | *Echinaria capitata* | *Crypsis* spp.[4] |
| | *Eremopyrum* spp. | *Echinochloa* spp. |
| | *Hordeum* spp. (without *spontaneum*) | *Eragrostis* spp.[4] |
| | *Lolium* spp. | *Phalaris* spp. |
| | *Piptatherum* spp. (only the larger | *Phleum* spp. |
| | *holciforme*-type has been identified) | *Poa* spp.[4] |
| | *Secale* spp. | *Puccinellia* spp.[4] |
| | *Stipa* spp. | *Setaria* spp. |
| | *Taeniatherum caput-medusae* | *Sporobolus* spp.[4] |

[1] Wild progenitor species and their domesticated relatives; commonly interpreted as food plants

[2] Wild grasses with an average 1000 seed weight of 3g or more that do not belong to the founder crops; commonly interpreted as food plants and/or weeds

[3] Wild grasses with an average 1000 seed weight less than 3g; high proportions are often interpreted as representing dung-burning or fuel collection

[4] These taxa have been interpreted as fuel or dung-derived [18,39,57,85,87,90].

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larger grain size [18,68,69]. We further differentiate among these taxa between grasses that were domesticated during the aceramic Neolithic and were thus often interpreted as pre-domestic cultivars, and those that are no progenitors of the classical founder crops [70]. We refer to this second group as "large to medium-seeded wild grasses", whereas the first group contains the "wild and domestic cereals". A possible classification of some large-seeded wild grasses such as *Avena sterilis* or *Aegilops* spp. as cereals will be discussed below. In this regard it is important to note that the functional interpretations assigned to taxa within a group are not mandatory and single taxa can still be interpreted differently. Combining different criteria based on physiological characteristics of grains and possible usage currently provides the most plausible, knowledge-based classification for our analyses.

## Correspondence analysis

Correspondence analysis is a multivariate statistical method routinely used by archaeologists to examine the complex relationships between variables in a contingency table [71]. In our analysis the variables represent the botanical taxa identified from the charred plant remains, whereas the cases represent the flotation samples. We applied correspondence analysis to investigate how the samples from AH VII-II of the deep sounding differ in their taxonomic composition and whether these differences can be attributed to the chronological order of the horizons or the sediment types.

The original dataset included 93 taxa in 38 samples. To avoid the bias of rare species and a poor preservation, we omitted all taxa with a ubiquity lower than 10% and all samples containing less than 100 identified specimens from the analysis. Because this procedure would have substantially influenced the original dataset, we combined rare taxa with a similar taxonomic rank or ecological implication in order to reach a ubiquity of 10%. Following this procedure we could maintain the majority of the original data and generated a table comprising 47 taxa in 36 samples.

Multivariate statistics can be used to disentangle cultivated species, arable weeds, gathered resources and dung-derived plant remains, given a large dataset deriving from a multitude of contexts is available (see e.g. [18]). As the majority of samples from Chogha Golan derives from the relatively narrow deep sounding, only representing one context per settlement phase, we could unfortunately not apply a multivariate approach to disentangle the botanical taxa in this regard.

## A temporal and spatial analysis of Near Eastern wild grass use

We systematically reviewed the published archaeobotanical literature for examining wild grass use throughout the Epipalaeolithic and aceramic Neolithic. After screening all published reports, we defined standard criteria for subsequent analyses, which resulted in differing sets of sites for the conducted analyses and allowed to consider a maximum number of datasets for reviewing wild grass use (S3 Fig). A total of 14 individual archaeobotanical assemblages were excluded, because the plant remains were too poorly preserved or not fully published. Assemblages deriving from only one single context, e.g. the grain storage from Gilgal I, were also omitted from the quantitative analyses.

For our analyses we used the proportions of the different Poaceae taxa and categories together with their ubiquity values. Taphonomic processes and diverging quantification methods can result in a heavy overrepresentation of single botanical taxa in charred assemblages. For instance, several PPNA sites in the southern Levant yielded extremely high counts for fig nutlets and *Pistacia* shell fragments, which resulted in a strong proportional decrease of all other plant groups [28,35,72]. To avoid such biases in our interpretations, we did not plot the proportions of the grass categories together with all other plant remains. Instead, we only analyzed the proportions of the different grass categories for all sites that yielded more than 100 caryopses, regardless of the analyzed sample number. Furthermore, we excluded Poaceae chaff remains and indeterminate cereal grain fragments from this analysis. Chaff of non-cereal taxa is rarely preserved in charred archaeobotanical assemblages, which often contain high proportions of identifiable cereal chaff. This disproportion in the occurrence of spikelet remains from different groups would substantially bias our results towards decreased percentages for non-cereal taxa. Similarly, indeterminate cereal grain fragments are often very abundant and included in the published data. Their numbers are rather indicative of fragmentation rates and regularly result in extremely high proportions of the cereal grain category. Therefore, we only compared the identifiable cereal grains with the number of caryopses from non-cereal taxa, which rarely contain high counts of indeterminate fragments. This procedure gave consistent results and effectively reduced the influence of different survival ranges or quantification methods.

Ubiquity values were used to plot the occurrence and frequency of selected genera over time. We defined a threshold of ten flotation samples to include sites into this analysis. Different occupation phases have occasionally been combined in order to reach this minimum number of samples. For Chogha Golan we combined the samples from the deep sounding with those from excavation area A [44] to obtain unbiased frequencies. Ten samples is a quite low number to calculate ubiquity values, but as we can show below, it proved sufficient to investigate wild grass abundance over time. In addition, we included all sites with more than ten analyzed flotation samples into this analysis, from which ubiquity values could not be calculated based on the way the data were published. For these sites we only indicated the presence or absence of taxa. Interestingly, such publications accumulate in the Epipalaeolithic and PPNA. Excluding them would have resulted in a biased occurrence of wild grasses for these periods. Finally we have to clarify that, for practical reasons, we only use the term Pre-Pottery Neolithic and its subdivisions into PPNA, early, middle and late PPNB in a strict chronological and not in a cultural sense.

## Results

### The composition of the archaeobotanical material from Chogha Golan

S2 Table gives the plant remains from the samples analyzed for this study. The assemblage comprises 81 taxa from 20 families, summing up to about 23,500 items. The midden deposits of AH IV and VI provided the richest samples with an average find density of 195 items/liter soil and a maximum of 360 items/liter soil in a sample from AH IV. Samples from the decayed building debris had lower find densities with an average of 55 items/liter soil and a maximum of 147 items/liter soil in AH III.

**The Poaceae remains.** Poaceae grains and chaff represent the most abundant plant remains in the analyzed samples with overall proportions between 34% in AH VI and 75% in AH IV (Fig 2A). The small-seeded taxa *Phalaris* sp. and *Phleum* type, together with small indeterminate grains, contribute the major portion to the grass remains. Large to medium-seeded taxa such as *Avena* sp., *Bromus* sp., *Hordeum* sp., *Eremopyrum* sp., *Taeniatherum caput-medusae* and Triticoid type form a second abundant group. They are mostly represented by grains and yielded only few identifiable chaff remains. Along with fragmented spikelet bases of *T. caput-medusae*, spikelets of an indeterminate type have been frequently found. Among the cereal species, *Hordeum spontaneum* is well represented by both grains and rachis segments. The domestic-type rachises reach their highest proportion in AH VII with 3.6%, still indicative of a population with shattering ears. Species of *Triticum* only yielded glume bases and spikelet

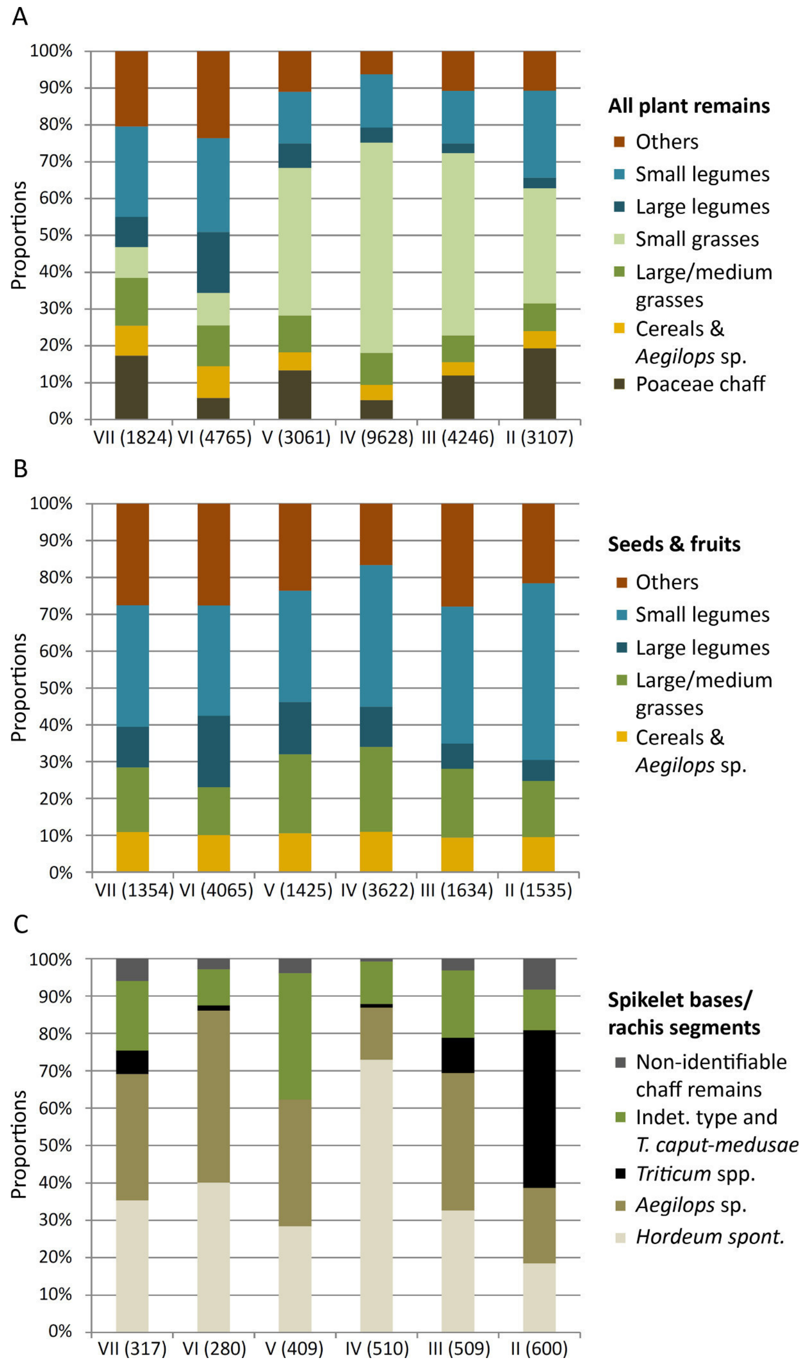


**Fig 2. Proportional development of the major taxonomic groups from AH VII to II in the deep sounding of Chogha Golan.** (A) Proportions of all analyzed plant remains; (B) proportions of all seeds and fruits without the small-seeded grasses; (C) proportions of Poaceae chaff only. Numbers in brackets give absolute counts.

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forks, but virtually no identifiable grains. The major portion of the identifiable rachis and glume base fragments could be attributed to emmer wheat, whereas einkorn constitutes a minor component of the wheat chaff. The emmer chaff from AH II was identified as phenotypically domesticated [16,27,44], whereas the chaff remains from the older horizons mostly contain non-diagnostic specimens. *Aegilops* sp. grains and chaff yielded proportions comparable to these typical cereal species. We therefore regard *Aegilops* sp. as economically equally important as *H*. *spontaneum* and the *Triticum* species and include it into the cereal category at Chogha Golan (but see the discussion below).

Since the cereals yielded such abundant identifiable chaff remains, but the other wild grass taxa did not, we excluded the Poaceae chaff to evaluate the relative proportions between cereals and the large to medium-seeded wild grasses. Here, the small-seeded grasses have also been omitted, because their high percentages have a large impact on the relative proportions of all other taxonomic categories. Excluding these two groups allowed interpreting the proportional development of the cereals and large to medium-seeded wild grasses more directly (Fig 2B). Now, grains of *H*. *spontaneum* and *Aegilops* sp. continuously make up about 10% of the assemblage, whereas the other large to medium-seeded wild grasses show a gradual development throughout the analyzed sequence. They increase from AH VII (18%) to AH IV (23%) and again decrease towards AH II (15%). In their entirety, these large to medium-sized grains constitute higher proportions to the analyzed material than cereal grains. However, the lower grain volumes of the medium-seeded grasses have to be taken into account while assessing the relative importance of these taxa compared the cereals (see S2 Fig).

Fig 2C gives the relative proportions of the analyzed chaff remains. Rachises and spikelet bases of *H*. *spontaneum* and *Aegilops* sp. dominate AH VII to III, where they contribute between 62% and 87% to all chaff remains. In these horizons they are equally abundant except for AH IV, where *H*. *spontaneum* rachises outnumber *Aegilops* spikelets by far. This trend is also visible for the grains and might represent a bias due to unknown factors that contributed to the formation of these midden deposits. *Triticum* chaff has relatively low values between AH VII and III, but substantially increases towards AH II where it dominates the chaff remains (42%). The spikelets of the indeterminate type and *Taeniatherum caput-medusae* fluctuate throughout the sequence (10–34%) and only reach proportions comparable to the cereal species in AH V.

Although most grass taxa are solely represented by grains and *Triticum* spp. only yielded chaff, the temporal development of the different grasses becomes apparent by plotting all these data together (Fig 3). Despite the paucity of identifiable chaff remains among the large to medium-seeded wild grasses, they reach counts as high or higher as the cereals between AH VII and IV, indicating an important role in the subsistence of Chogha Golan. With the appearance of *Triticum* spp. chaff in AH III and its dominating status in AH II, all wild grasses together with *H*. *spontaneum* and *Aegilops* sp. decrease in absolute and relative numbers.

**Fruits and seeds of other plant groups.** Legume seeds represent the second largest group of plant remains in the analyzed samples. Large legumes such as *Lens* sp., *Pisum* sp. and species of *Lathyrus* and *Vicia* contribute about 17% to AH VI, but range between 3% to 8% in all other horizons. These values are only slightly smaller than the proportions for the cereal grains, which remain constant while the large legume seeds steadily decline towards AH II (Fig 2A and 2B). In contrast, small legume seeds belonging to the genera *Astragalus*, *Trigonella* and *Medicago* reach percentages between 14% and 25% (Fig 2A). The development of their relative abundance is significantly affected when plotted together with the small-seeded grasses and the Poaceae chaff. Then they seem to decline from the older horizons towards AH III, but show rather constant percentages after the small grasses and chaff remains are excluded (Fig 2B).

In addition to the grasses and legumes, between 6% and 24% of the assemblages per horizon consist of fruits and seeds of other wild taxa (Fig 2A; S2 Table). After excluding the small grasses and chaff remains, they have fluctuating percentages between 17% and 28%. Among them, edible fruits and seeds of *Atriplex* sp., *Bolboschoenus glaucus*, *Malva* sp. and several crucifers (*Alyssum* sp., *Capsella*/*Descurainia*, *Lepidium* sp.) abundantly occur in the analyzed

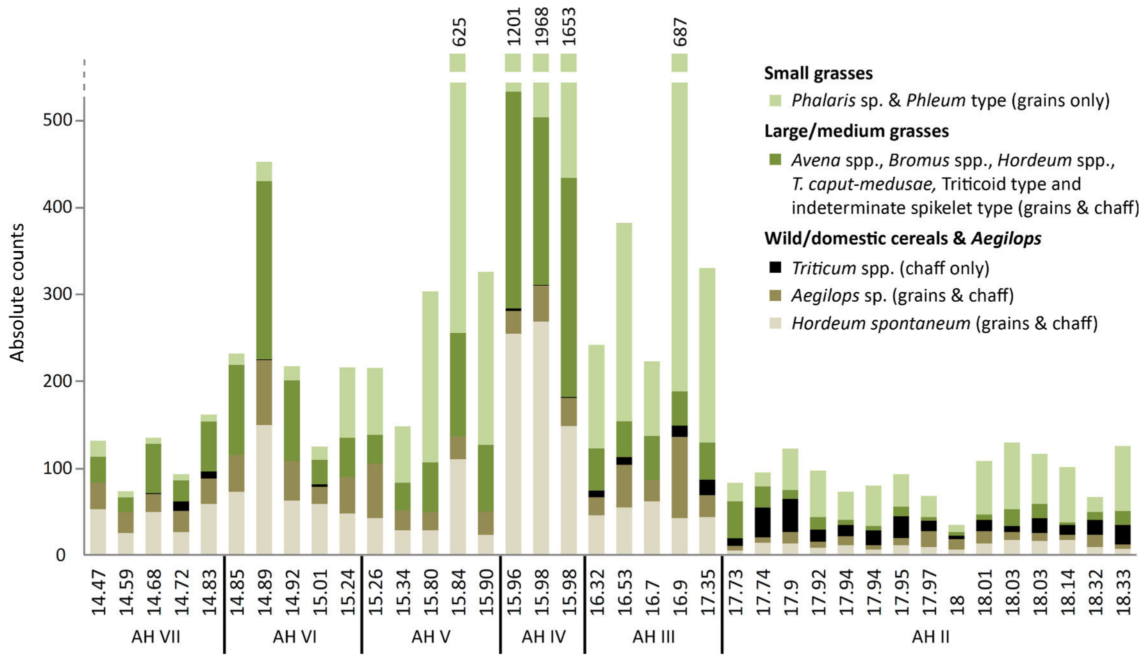


**Fig 3. Composition of identifiable Poaceae remains in samples from AH VII to II in the deep sounding of Chogha Golan.** Note that the categories are represented by different plant organs. The x-axis gives z-values of the deep sounding starting with 20m at the tell surface; the y-axis gives absolute counts up to 500, higher counts are given above the respective bars.

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samples. Particularly *Atriplex* sp. and *Alyssum* sp. seeds reach high counts in the samples from the midden deposits of AH VI. Nutshell fragments of *Pistacia* represent the only remains of a gathered tree-fruit. They constantly occur in all samples, but are significantly less abundant in the middens of AH VI and IV (S2 Table).

## Major factors influencing sample composition at Chogha Golan

The correspondence analysis plot in Fig 4 shows a sample distribution that follows a parabola, which is also known as "horseshoe-effect" [71]. Samples from AH II are placed at the left end

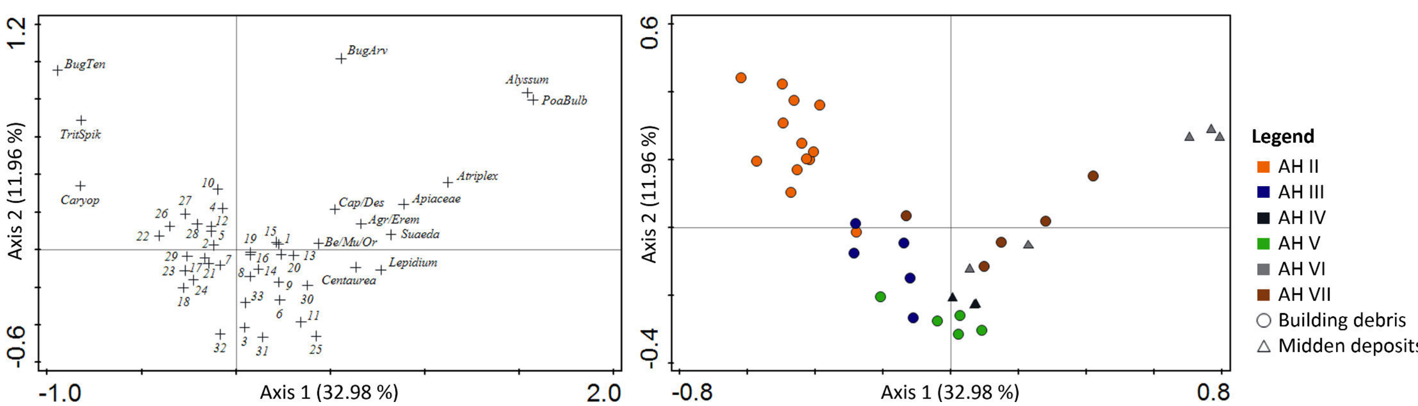


**Fig 4. Scatter plots of a correspondence analysis testing for inter-sample variation in the deep sounding.** The plots show the distribution of (A) 47 taxa/categories from (B) 36 flotation samples. See S3 Table for coding of the variables and S4 Fig for the composition of Poaceae remains in the samples used in the correspondence analysis.

https://doi.org/10.1371/journal.pone.0189811.g004

of the first axis and are clearly separated from samples of the underlying horizons III to VII along axis one. Chaff of *Triticum* spp. together with seeds from the Caryophyllaceae family and uncarbonized *Buglossoides tenuiflora* nutlets are the most important variables that induce this separation. Among the other horizons, AH III is separated from AH IV and V along the first axis. These two horizons completely overlap and are again separated from the oldest horizons VI and VII. Three samples from AH VI form a distinct group at the right end of axis one. This is particularly due to a high proportion of *Alyssum* sp. and *Atriplex* sp. seeds and bulbils of *Poa bulbosa* in these midden-derived samples. Only here the taxonomic composition of the samples is significantly influenced by the type of deposit, whereas all other samples follow a strong chronological trend throughout the stratigraphy. The overall composition of Poaceae remains also follows this temporal trend (S4 Fig).

## Wild grasses in the Epipalaeolithic and aceramic Neolithic of the Near East

**Grain proportions, single contexts and author's interpretations.** Fig 5 shows the proportions of four groups within the Poaceae grains identified at Epipalaeolithic to late PPNB sites of the Near East. References for all investigated sites including their general chronological order and basic information about the author's interpretations of the wild grass remains are

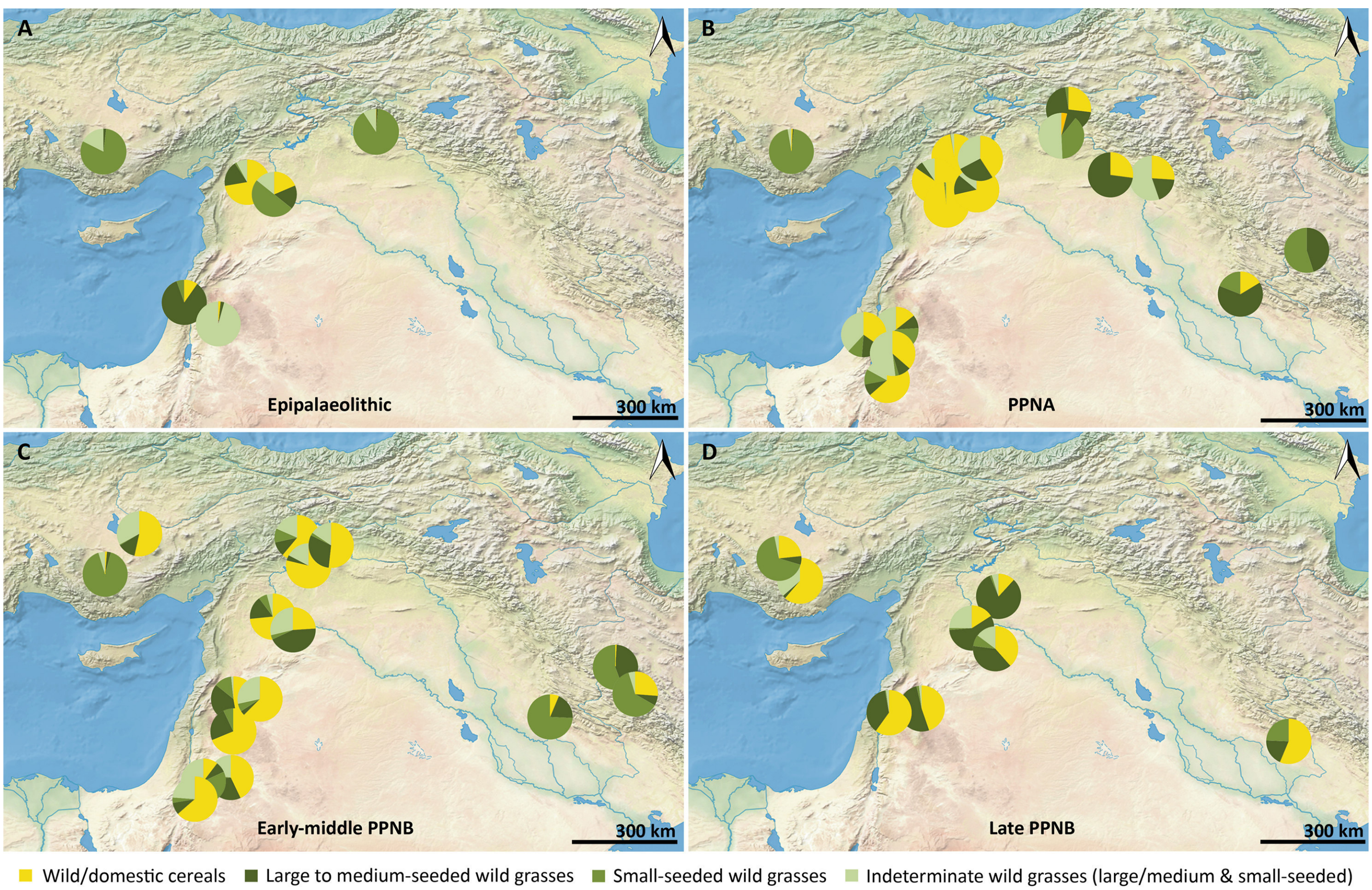


**Fig 5. The composition of Poaceae grains in archaeobotanical assemblages dating to the Epipalaeolithic and Pre-Pottery Neolithic of the Near East.** See S5 Fig for a detailed key to the sites represented by the pie charts.

https://doi.org/10.1371/journal.pone.0189811.g005

given in Table 2. From 72 published archaeobotanical datasets including distinct sub-phases of several sites, we used 46 datasets that yielded more than 100 Poaceae grains.

The data from the Epipalaeolithic comprise six sites that span a relatively large time period from ca. 23,000 to the 12th millennium cal. BP (Fig 5A). Ohalo II is the oldest of these sites and contains, like Wadi al-Hammeh 27 and Körtik Tepe, a minor proportion of wild cereal grains. These sites are dominated by large to medium-seeded wild grasses, indeterminate specimens and small-seeded taxa, respectively. Despite these differences in the dominant groups, wild grasses have been regarded as important food resources at all three sites, possibly representing staples at Ohalo II and Körtik Tepe [40,49,60,73,74]. Wild progenitors are completely absent at Pinarbaşi, where small-seeded taxa were possibly gathered for fuel or construction materials [75]. In contrast, horizon 2 at Qaramel and the early phases at Mureybet date to the Pleistocene-Holocene transition and already show increased values for the cereal group. Non-cereal taxa including *Eremopyrum* sp., *Echinochloa* sp. and a type resembling *Setaria* still make up the major portion of grains at Mureybet and were regarded as possible food resources [24]. At Qaramel cereal grains clearly dominate the assemblage and seem to represent the earliest evidence for such a strong focus on wild progenitor species, in this case einkorn and barley. Willcox and Herveux regarded the large to medium-sized grains, of which the far majority comes from one single sample and was identified as *Stipa* sp., as a possible contaminant of the wild cereal harvests [76].

During the PPNA wild cereals became the dominating taxa at sites in the Levantine corridor (Fig 5B). This development was associated with the emergence of potential arable weed floras, a gradual decrease of formerly gathered species and an increase in cereal grain size at sites in the upper Euphrates region. Willcox et al. interpreted this pattern as the beginnings of wild cereal cultivation at Jerf el Ahmar, Qaramel, Dja'de and 'Abr [32]. Colledge explored the data from Mureybet with multivariate statistics and came to the same conclusion [30], as already hypothesized by van Zeist and Bakker-Heeres [24]. Large to medium-seeded wild taxa are not numerous at these sites except for Jerf el Ahmar and Dja'de. Willcox et al. regarded them as potential arable weeds, but also noted that they represent potentially edible resources [32]. At Jerf el Ahmar, *Hordeum murinum*/*bulbosum* grains have very high counts and a single concentration of *Aegilops* spikelet bases possibly represents the remains of threshing. For Dja'de, grains of *Taeniatherum caput-medusae* reach counts comparable to the wild cereals. These patterns possibly indicate deliberate gathering of several wild grasses alongside early cereal cultivation in the upper Euphrates region. However, as the authors pointed out, their lower overall grain volume speaks against an economic role comparable to the cereals.

Although the assemblages from the southern Levant show a less marked dominance of wild cereal grains, pre-domestic cultivation has been proposed for all sites included in this analysis [28,35,40,72]. Identifiable large to small-seeded wild grasses represent a minor component of the grains from these sites. However, the major portion of the non-cereal grains from most sites remained unidentified, but would significantly add up to the percentages of identified specimens. Except for ZAD 2, where Meadows did not explicitly discuss these non-cereal taxa [72], all authors regarded them as possible food sources. Particularly for Netiv Hagdud and Iraq ed-Dubb, species of *Avena* or *Phalaris* were possibly exploited alongside wild cereals [28,40]. However, with the proposition of pre-domestication cultivation for many PPNA sites, scholars increasingly view crop-processing activities as possible explanations for the occurrence of these wild grasses in archaeobotanical assemblages. For instance, White and Makarewicz listed *Bromus* sp., *Hordeum glaucum* and *Phalaris* sp. as potential arable weeds, although they admitted that "there are many distinct plant exploitation strategies that could each produce an archaeobotanical assemblage exhibiting a weedy botanical spectrum (. . .)" [77]. Following this, they regarded the potential weed taxa as resources that were possibly harvested

**Table 2. The sites included in the quantitative analyses of this study with information on the number of samples, mesh size used during water flotation and the interpretation of the wild grass finds by the respective authors.** Periods follow the Levantine sequence and have no strict cultural implications.

| Site (phase or area) | C-14 dates (ka cal. BP; | Samples or | Mesh size | Author(s) interpretation(s) | Contextual evidence | References for botanical |
|---|---|---|---|---|---|---|
| | based on individual site | loci (n) | (mm) | of wild grasses* | for wild grass* use/ origin | data and interpretations |
| | reports and [133,134]) | | | | | |
| **Epipalaeolithic** | | | | | | |
| Ohalo II | 23 | unknown | unknown** | Staple food/arable weeds | *in situ* working area | [38,49,73,74] |
| Pinarbaşi (Epipalaeolithic) | 16.2–12.9 | 25 | 0.1 | Fuel, construction materials | | [75] |
| Wadi al-Hammeh 27 | 14–13.7 | 14^Ub | 0.3 | Potential food | | [40] |
| Wadi el-Jilat 6 | 13.7 | 10^Ub | 0.3 | Potential food | | [40] |
| Abu Hureyra (1) | 13.2–12.8 | unknown | 1 | Potential food/arable weeds | | [121] |
| Körtik Tepe (Younger | 12.4–11.7 | 116^Ub | 0.2 | Staple food | | [60] |
| Dryas) | | | | | | |
| **Epipalaeolithic/PPNA** | | | | | | |
| Tell Qaramel (H2) | 12.3–11.3 | 108 (H1-3) | 0.5 | Harvested accidentally with | *Stipa* sp. grains concentrated | [76] |
| | | | | wild cereals | in one sample | |
| Mureybet (I-II) | 12.2–11.3 | 33^Ub | unknown | Potential food | | [24] |
| Qermez Dere | 12.1–10.8 | 47^Ub | 0.35 | Staple food | | [51,130] |
| **PPNA** | | | | | | |
| Sheikh-e Abad (Trench 1) | 11.8–11.2 | 5 | 0.25 | Potential food and dung | Separated in CA from crop/ | [18] |
| | | | | burning (esp. *Poa* type 1) | weed group | |
| Hallan Çemi | 11.7–11.3 | 175^Ub | 0.35 | Potential food | | [51,130] |
| M'lefaat | 11.7–10.8 | 4 | 0.35 | Staple food | | [51,130] |
| Körtik Tepe (Early | 11.6–11.3 | 231^Ub | 0.2 | Staple food | | [60] |
| Holocene) | | | | | | |
| Chogha Golan (XI-VIII) | 11.7–10.6 | 13 | 0.2 | Undetermined | | [16] |
| Iraq ed-Dubb (structures) | 11.5–11.3 | 7 | 0.3 | Potential food/arable weeds | | [40] |
| Jerf el Ahmar | 11.5–10.6 | 266^Ub | 0.5 | Potential food/arable weeds | Context with concentration of | [32] |
| | | | | | *Aegilops* sp. spikelet bases | |
| Demirköy | 11.4–11.3 | 12^Ub | 0.35 | Potential food | | [51,130] |
| Mureybet (III) | 11.4–10.5 | 28^Ub | unknown | Potential food | | [24] |
| Netiv Hagdud | 11.3–10.9 | 58 | 0.5 | Potential food | | [28] |
| Tell Qaramel (H3) | 11.3–10.9 | 108 (H1-3) | 0.5 | Harvested accidentally with | | [76] |
| | | | | wild cereals | | |
| Tell 'Abr | 11.3–10.9 | 30^Ub | 0.5 | Arable weeds | | [32] |
| el-Hemmeh | 11.2–10.6 | 15 loci^Ub | 0.25 | Potential food/arable weeds | | [35,80] |
| ZAD 2 (Structure 1) | 11.1–10.8 | 18 loci^Ub | 0.5 | Subsistence *sensu lato* | | [33,72] |

(*Continued*)

**Table 2.** (*Continued*)

| Site (phase or area) | C-14 dates (ka cal. BP; | Samples or | Mesh size | Author(s) interpretation(s) | Contextual evidence | References for botanical |
|---|---|---|---|---|---|---|
| | based on individual site | loci (n) | (mm) | of wild grasses* | for wild grass* use/ origin | data and interpretations |
| | reports and [133,134]) | | | | | |
| Pinarbaşi (early) | 11–10.6 | 13Ub | 0.1 | Potential food or fuel | | [57] |
| **PPNA/early PPNB** | | | | | | |
| Wadi Faynan 16 | 11.4–10.3 | 44 | 0.25 | Potential food | | [131] |
| Tell Aswad (I) | 11.3–10.4 | 9 | unknown | Arable weeds | | [23] |
| Dja'de | 11.1–10.3 | 227Ub | 0.5 | Potential food/arable weeds | | [32] |
| **early PPNB** | | | | | | |
| ZAD 2 (Structure 2) | 10.7–10.5 | 8 loci | 0.5 | Subsistence *sensu lato* | | [72] |
| Tell Qarassa (Area XYZ) | 10.7–10.2 | 58Ub | 0.25 | Arable weeds/ undetermined | | [81] |
| Çayönü (grill-channel) | 10.6–10.2 | 96Ub | unknown | Arable weeds/ undetermined | | [79] |
| **early/middle PPNB** | | | | | | |
| Tell Aswad (II) | 10.6–9.5 | 21Ub | unknown | Arable weeds | | [23] |
| Pinarbaşi (late) | 10.6–9.7 | 27Ub | 0.1 | Potential food or fuel | | [57] |
| Nevali Çori | 10.5–9.6 | 267 | 0.35 | Arable weeds/ undetermined | | [94] |
| Cafer Höyük | 10.3–9.5 | 62Ub | 0.3 | Undetermined | | [42] |
| Aşikli Höyük | 10.3–9.4 | 144Ub | unknown | Undetermined | | [82] |
| **middle PPNB** | | | | | | |
| Chogha Golan (VII-II) | 10.2–9.8 | 98Ub | 0.2 | Staple food | | This paper and [44] |
| Ganj Dareh | 10–9.5 | 122Ub | unknown** | Potential food/ undetermined | | [39] |
| Sheikh-e Abad (Trench 2) | 10 | 9 | 0.25 | Potential food and dung | Separated in CA from crop/ | [18] |
| | | | | burning (esp. *Poa* type 1) | weed group | |
| el-Hemmeh | 9.8–9.6 | 31 lociUb | 0.25 | Arable weeds/animal fodder | | [80] |
| Sheikh-e Abad (Trench 3) | 9.6 | 27Ub | 0.25 | Potential food and dung | *Poa* type 1 constitutes over | [18] |
| | | | | burning (esp. *Poa* type 1) | 90% to the samples | |
| **middle/late PPNB** | | | | | | |
| Çayönü (cobble-cell) | 10.3–9.4 | 105Ub | unknown | Arable weeds/ unspecified | | [79] |
| Abu Hurerya (2A) | 9.8–9.4 | 41Ub | 1 | Potential food/arable weeds | | [42] |
| Tell Halula | 9.8–9 | 96 | 0.2 | Potential food (*Aegilops*)/ | | [108] |
| | | | | arable weeds | | |
| Wadi el-Jilat 7 (Middle) | 9.7–9.4 | 21Ub | 0.3 | Potential food/arable weeds | | [40] |
| Tell Ghoraifé (I) | 9.9–9.4 | 18Ub | unknown | Arable weeds | | [23] |
| **late PPNB** | | | | | | |

(*Continued*)

**Table 2.** (*Continued*)

| Site (phase or area) | C-14 dates (ka cal. BP; based on individual site reports and [133,134]) | Samples or loci (n) | Mesh size (mm) | Author(s) interpretation(s) of wild grasses* | Contextual evidence for wild grass* use/ origin | References for botanical data and interpretations |
|---|---|---|---|---|---|---|
| Ali Kosh (BM-AK) | 9.5–9 | unknown | unknown | Arable weeds/wild resources | | [21] |
| Sabi Abyad II | 9.5–8.8 | 10 | unknown | Arable weeds | | [89] |
| Ras Shamra (Vc) | 9.5–9.1 | 25[Ub] | unknown | Arable weeds | | [95] |
| Gritille | 9.5–8.7 | 52[Ub] | 1 | Undetermined | | [132] |
| Can Hasan III | 9.5–8.5 | 4 | 1 | Arable weeds/ undetermined | | [83,129] |
| Abu Hurerya (2B) | 9.4–9.1 | 43[Ub] | 1 | Potential food/arable weeds | | [42] |
| Tell Bouqras (Sq. 16/ 13) | 9.4–8.2 | 97[Ub] | unknown | Undetermined | | [96] |
| Tell Ramad (I) | 9.3–9 | 13[Ub] | unknown | Arable weeds | | [23] |
| Tell Ghoraifé (II) | 9.1 | 17[Ub] | unknown | Arable weeds | | [23] |
| Çatalhöyük East (VI-PXII) | 9.1–8.5 | 61[Ub] | 0.3 | Potential food/arable weeds/ dung burning, basketry | Storage finds of *Taeniatherum caput-medusae* grains | [41,53,87,88] |
| El Kowm (II) | 9–8.5 | 31[Ub] | 0.3 | Arable weeds/dung burning | | [42] |

[Ub] ubiquity was given in/calculated based on publication

* regardless of the wild cereals, which might be interpreted differently

** no information available, but small-seeded grasses were recovered in considerable abundance

CA = correspondence analysis

https://doi.org/10.1371/journal.pone.0189811.t002

from the fields as a minor food source alongside the cultivated wild cereals. Based on similar considerations, Colledge did also not strictly distinguish between the non-cereal taxa as possible weeds or collected foods during the PPNA phase of Iraq ed-Dubb [40]. In contrast, grains and chaff remains of *Avena sterilis* associated with *Hordeum spontaneum* in a storage context at Gilgal clearly indicate that some large to medium-seeded wild grasses did represent important foods in the Levantine PPNA [78]. Weiss et al. even raised the possibility that this finding represents a harvest from cultivated fields [52], which would attribute wild oats a status as early cultivars.

Outside the Levantine corridor, evidence for an increased focus on the wild progenitor species during the PPNA does not exist. For central Anatolia we are currently left with only one site, Pinarbaşi, where wild cereals are virtually absent. The only abundant grass remains are charred culm nodes and the small grains of a *Puccinellia* species, which Fairbairn et al. interpreted as a possible fuel source [57]. In contrast, many sites in the Zagros and Taurus Mountains and the adjacent lowlands provide good evidence for diverse wild grasses gathered as food sources during the PPNA, with large to medium-seeded taxa being more abundant than the wild cereals. Whereas at Hallan Çemi and Demirköy the gathered grasses did not contribute a large portion to the whole charred assemblage and might represent a minor food resource, they are regarded as major foods and even staples at all other sites of this region included in the present analysis [18,51,60,64]. Pre-domestication cultivation was recently proposed for Körtik Tepe and Chogha Golan [16,60,64]. However, on both sites the wild progenitor grains are less abundant than the entirety of non-cereal taxa.

The overall pattern that was characteristic for the PPNA continues into the early and middle PPNB, where domestic cereals provide unequivocal evidence for the beginnings of farming [6,25]. Sites in the Levantine corridor display a clear focus on cereals, now including domestic species (Fig 5C). Large to medium-seeded wild grasses make up considerable proportions of many assemblages and were much more confidently interpreted as arable weeds [23,79–81]. Sites where the abundant non-cereal taxa were still regarded as possible foods are Abu Hureyra and Wadi el-Jilat 7, but also here domestic cereals are present and the wild grasses could represent weeds [40,42].

Such a clear focus on a cereal-based subsistence strategy continues to be rare outside the Levantine corridor in the early and middle PPNB. Aşikli Höyük represents the only site in central Anatolia where domestic cereals were cultivated [25,82]. Recent analyses indicate that wild grasses are still frequent at the site (M. Ergun, pers. communication) and we should wait for the final publication of the new results. In contrast, Pinarbaşi represents a presumably sedentary hunter-gatherer community, indicating the co-occurrence of distinct subsistence economies during the local establishment of agriculture [57]. In the central Zagros Mountains, plant domestication was proposed based on domestic-type emmer chaff for Chogha Golan and on domestic-type barley grains for Sheikh-e Abad and Ganj Dareh [16,18,27,39,44]. As shown above, large to medium-seeded wild grasses represent major foods at Chogha Golan and decrease with the emergence of domestic emmer. At Sheikh-e Abad wild grasses are also abundant in the levels dating to the middle PPNB, whereas they are outnumbered by barley grains at Ganj Dareh. Whitlam interpreted the non-cereal taxa at Sheikh-e Abad as gathered wild foods based on the outcome of correspondence analyses [18]. In her plots, the large to medium-seeded wild grasses are separated from a crop-weed-group comprising the domestic-type barley grains and potential arable weeds.

Full agricultural societies are established in all regions of the Fertile Crescent with the late PPNB (Fig 5D). The archaeobotanical record for central Anatolia and the central Zagros is again very poor and the few investigated sites represent typical farming villages with a clear focus on crop cultivation [21,41,83]. Dung burning seems to have played a critical role in the formation of the charred plant assemblages from Çatalhöyük and Ali Kosh and dung pellets were found during both excavations [41,84,85]. Fairbairn and his colleagues used Pearson correlations for associating the potential weeds with cereal grains and chaff at Çatalhöyük. Among the analyzed taxa, *Eremopyrum*-type and *Stipa* sp. grains positively and significantly correlated with cereal grains, supporting their interpretation as common field weeds. Interestingly, grains of *Taeniatherum caput-medusae* did not show a significant correlation, but were found in storage contexts together with *Eremopyrum*-type grains [53]. The authors regarded these edible grains as potential resources, which were possibly utilized after crop procession rather than being disposed. In applying standard criteria for the recognition of dung-derived plant material in archaeobotanical assemblages [86] and correspondence analysis, Filipović confirmed the state of *Taeniatherum* and *Eremopyrum* as arable weeds at the site [87]. Grasses have also been gathered for other purposes, incl. basketry, which was demonstrated via phytolith analyses [88].

A remarkable development in the Levantine corridor, particularly the upper Euphrates area, is the increase in non-cereal taxa towards the late PPNB. Whereas de Moulins did not strictly rule out continuing gathering activities at Abu Hureyra [42], this pattern clearly reflects the establishment of some grass species as successful arable weeds at sites such as Ghoraifé, Ramad, El Kowm and Sabi Abyad II [23,42,89]. *Lolium* sp. represents the most common weed

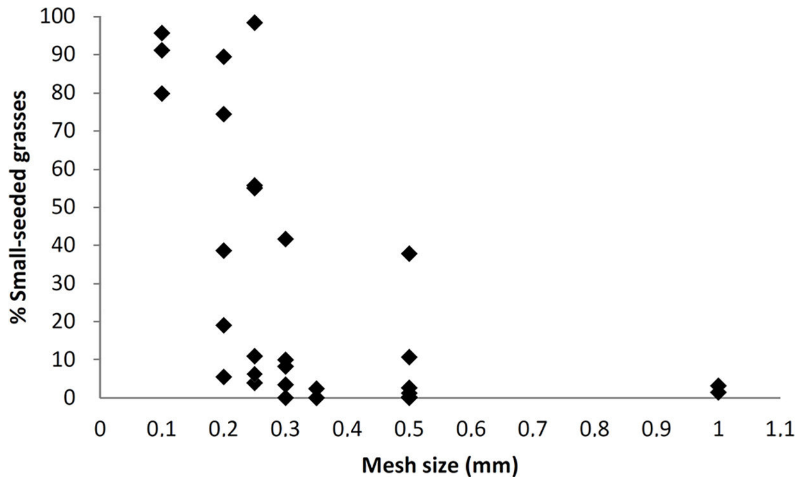


**Fig 6. The proportions of small-seeded grasses among all Poaceae grains in relation to the mesh size used during water flotation.**

https://doi.org/10.1371/journal.pone.0189811.g006

at these sites, which is accompanied by *Aegilops* sp. at Sabi Abyad II and by *Bromus* sp. at El Kowm.

**Patterns in the record of the small-seeded grasses.** Fig 6 shows the proportions of small-seeded grasses among Poaceae grains in relation to the mesh size applied during water flotation. This analysis includes 32 assemblages that yielded more than 100 grains. We found a decrease in the abundance of small-sized caryopses at sites where sieves had mesh sizes of $>$ 0.25mm. The absence or scarcity of small-seeded taxa at these sites might therefore be biased by the applied field methods. However, the proportions of small caryopses can also be very low despite the application of fine sieves. At sites where sieves had mesh sizes of 0.25mm or less, the percentage of small-seeded grasses among all Poaceae grains varies between 0 and almost 100%. This suggests taphonomic rather than methodological factors for explaining the observed variability.

Plotting the proportions of small caryopses through time did not reveal a temporal trend towards increasing or decreasing percentages (Fig 7). Instead, sites where small grasses clearly dominate the Poaceae grains are missing in the southern Levant. Here, the highest proportions of small caryopses occur at Epipalaeolithic Iraq ed-Dubb (exclusively *Phalaris*, 42%) and ZAD 2 (cf. *Poa bulbosa* bulbils and *Setaria* type, 38%). Colledge regarded the *Phalaris* grains as possible food sources or arable weeds [40], whereas Meadows did not explicitly discuss these small grains [33,72].

The highest proportions of small-seeded grasses with more than 60% of all grains occur, with increasing percentages, at Ganj Dareh, Çatalhöyük East (VI-PXII), Chogha Golan (AH VII-II), Körtik Tepe (Younger Dryas occupation), Pinarbaşi and Sheikh-e Abad (Trench 3). Most authors explained this phenomenon with the collection of herbivore dung or the grasses itself for fuel [18,39,57,90]. For Çatalhöyük, the combination of multivariate statistics, contextualized sampling and the application of common criteria to recognize dung-derived plant materials reliably demonstrated that dung was used as a fuel source throughout the whole occupation period [85,87,91]. As a result, small grains from taxa such as *Sporobolus*, *Aeluropus* or *Eragrostis* were abundantly brought into the site. Besides Çatalhöyük, such an approach to disentangle arable weeds, crops and dung-derived seeds was only applied to Sheikh-e Abad, where Whitlam also argued for dung burning as the most likely source for the high abundance of the Poa-type caryopses [18]. Riehl and her colleagues reject the dung-burning hypothesis

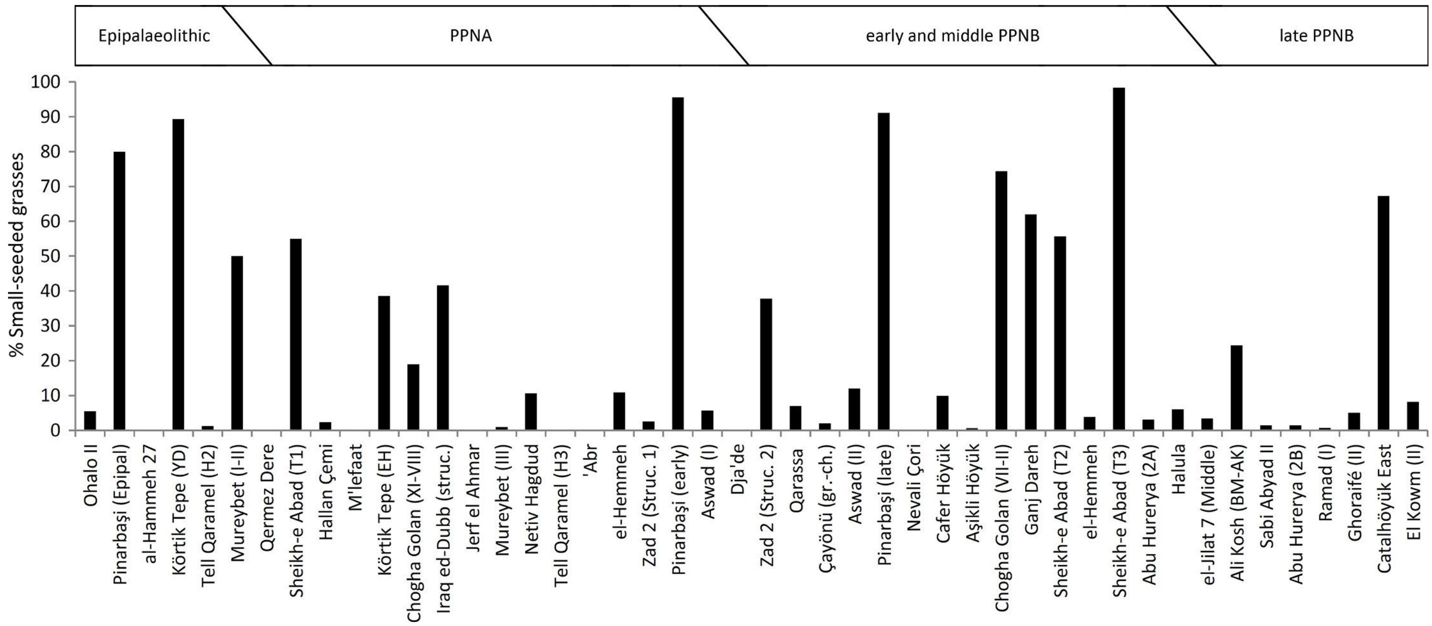


**Fig 7. The proportions of small-seeded grasses among all Poaceae grains recovered from sites dating to the Epipalaeolithic and Pre-Pottery Neolithic.** At sites that yielded > 60% of small-seeded grasses, types resembling *Agrostis*, *Alopecurus*, *Eragrostis*, *Phalaris*, *Phleum*, *Poa* or *Puccinellia* contributed the major portions.

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for Chogha Golan and Körtik Tepe, because they view animal management as an important requirement for the routine use of dung as fuel and such evidence is absent at both sites [60,64].

**The long-term development of selected wild grasses based on ubiquity values.** A total of 47 sites/phases could be included in the analysis of wild grass ubiquity over time. Most identified Poaceae taxa in Epipalaeolithic and aceramic Neolithic assemblages occur infrequently among these sites and their identification rarely has major implications for reconstructing gathering or cultivation activities. In contrast, some genera are very frequent among the analyzed datasets, which possibly indicates a role in the prehistoric subsistence economies. Among these frequently identified non-cereal taxa, two different developments through time can be observed.

The first set of taxa abundantly occurs at Epipalaeolithic to PPNA sites as well as during the PPNB (Fig 8). They do not follow an overall trend towards increasing or decreasing ubiquity values and show a relatively equal occurrence among the sites of the different periods. This set of taxa comprises species of *Aegilops*, *Avena*, *Eremopyrum*, *Hordeum*, *Stipa* and the monotypic genus *Taeniatherum*. Many authors consider them as gathered resources at Epipalaeolithic and PPNA sites, with food as the most frequently mentioned usage. Particularly remains of *Aegilops* spp., *Avena* spp., *Hordeum* spp., *Stipa* spp. and *Taeniatherum caput-medusae* seem to be uniformly interpreted in this way, given they occur with a certain abundance in the analyzed assemblages [28,51,60,73,74,88]. Other authors interpreted their occurrence more cautiously, mostly because they discussed pre-domestication cultivation for sites where wild cereals are clearly dominant [24,32,35,76]. Here we start to see a pattern where the relative abundance between wild cereals and other wild grass species seems to influence the interpretation of the wild grains as food sources or arable weeds indicative for cultivation. We should therefore be cautious to follow these original interpretations, if they are not supported by more detailed taphonomic analyses.

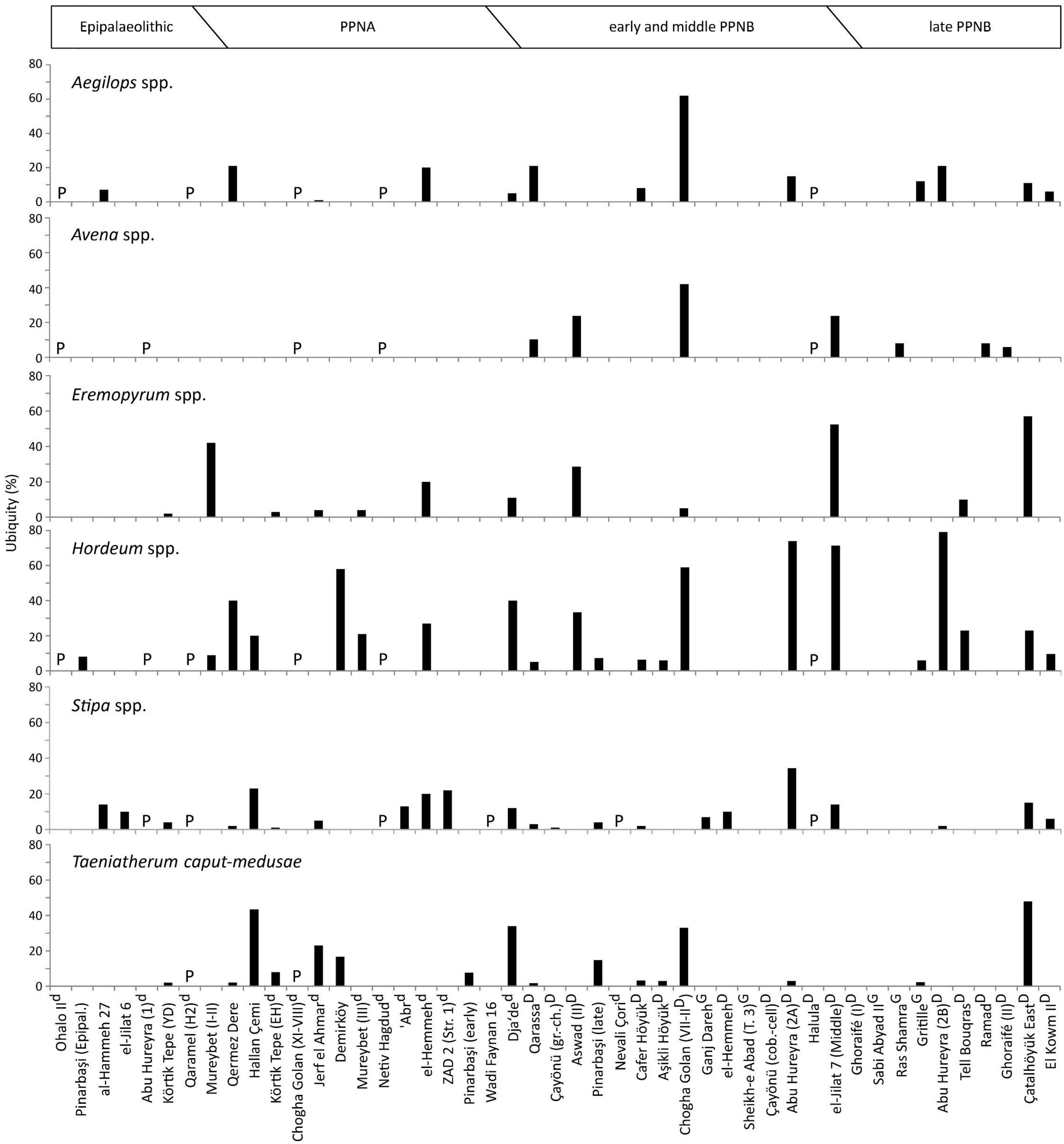


**Fig 8. The ubiquity of grains from selected Poaceae taxa representing gathered resources at many Epipalaeolithic and PPNA sites and became common arable weeds during the PPNB.** (P) present; (d) proposed pre-domestication cultivation; (D) presence of domestic cereal chaff; (G) domestic status of cereals based on grains.

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*Eremopyrum* species are relatively rare on most PPNA sites except for the early phases of Mureybet, where grains occur in many samples but always with low numbers. Van Zeist and Bakker-Heeres discussed a possible interpretation of *Eremopyrum* as an arable weed [24]. However, they note that the frequency of *Eremopyrum* grains and other potential weeds decreases alongside the increase of einkorn towards phase III. This seems to speak against an interpretation as crop-processing by-products and they leave the interpretation of these taxa undetermined.

With the appearance of domestic cereals during the early and middle PPNB, the abundance of these taxa does not substantially change. All above mentioned genera comprise species which occur as arable weeds in the Near East today [92,93]. Based to this, many archaeobotanists interpreted them as arable weeds at early and middle PPNB sites [23,40,77,79,81,94]. Others still considered these grasses as possible food resources at sites outside the Levantine corridor [18,39,44,57]. At Abu Hureyra and Wadi el-Jilat 7, where especially *Eremopyrum*, *Hordeum* and *Stipa* grains have very high ubiquities, de Moulins and Colledge did not rule out deliberate gathering activities [40,42]. These relatively diverse interpretations apparently reflect the difficulty to assess the route of entry of wild taxa into agricultural assemblages. Following this, for Cafer Höyük and Aşikli Höyük, these wild grasses were not interpreted [42,82].

The role of the considered grass taxa as arable weeds at late PPNB sites is mostly unquestioned [21,23,89,95,96]. For Çatalhöyük, the state of the wild grasses as arable weeds is supported by the results of the statistical analyses and the authors also discussed whether the *Taeniatherum caput-medusae* grain storages represent stored weeds outsorted from the crop harvests [41,53]. De Moulins had problems to solely interpret the abundant wild grasses at Abu Hureyra as weeds, where grass gathering seems to have had a long tradition [42].

Fig 9 gives the development of ubiquity values for taxa that follow a different temporal pattern. *Echinaria capitata* and *Lolium* spp. grains substantially increase in abundance towards the PPNB, where they are present at much more sites than during the Epipalaeolitic and PPNA. *Bromus* spp. grains occur on most sites of all periods, but similarly show higher ubiquity values in the PPNB. The increase in abundance of *Phalaris* species can be seen in their frequency among the sites. *Phalaris* spp. grains are present at around 23% of the Epipalaeolitic to PPNA sites and at 52% of the PPNB sites.

Evidence for the exploitation of these taxa prior to the PPNB is limited. Weiss and his colleagues interpreted *Bromus pseudobrachystachys*/*tigridis* as gathered foods at Ohalo II, where the grains occur with high numbers in a plant-food preparation area in a brush hut [49,73,74]. *Lolium* sp. was presumably gathered at Sheikh-e Abad [18], but nowhere else and *Phalaris* may have been exploited at Pinarbaşi, Netiv Hagdud, el-Hemmeh and Chogha Golan (28,64,75,77). During the PPNB, all these taxa apparently became common arable weeds. *Lolium* species developed into the most successful segetals, whose grains are present in 94% to 100% of all samples from late PPNB Ghoraifé and Ramad [23]. A regional exception is Chogha Golan, where *Phalaris* and *Bromus* are abundant prior to the emergence of domestic emmer and may represent gathered resources.

## Discussion

### Subsistence strategies at Chogha Golan and in the Zagros Mountains

**Explaining variability among the charred assemblages from Chogha Golan.** We conducted a correspondence analysis to test, whether the analyzed flotation samples from occupation and midden deposits differ in their taxonomic composition. Interestingly, the samples followed a parabolic distribution in the scatter plot. Such a pattern is the result of a factor within the data table, which orders the samples along a specific gradient. This means that the

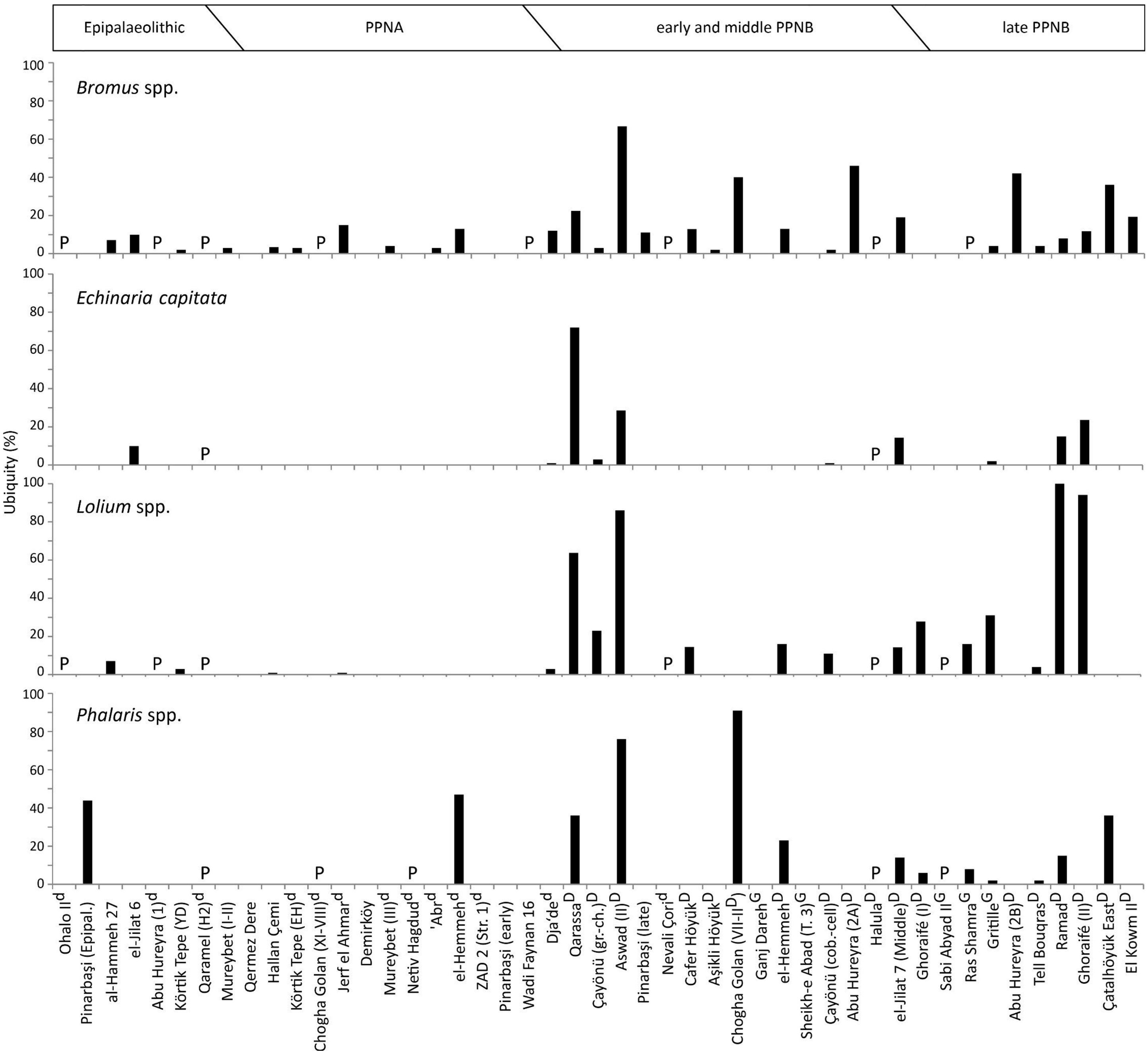


**Fig 9. The ubiquity of grains from selected Poaceae taxa, which increase in abundance during the PPNB due to their establishment as typical arable weeds.** (P) present; (d) proposed pre-domestication cultivation; (D) presence of domestic cereal chaff; (G) domestic status of cereals based on grains.

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samples at both ends of the ordered data table show the largest difference and all other samples are gradually more similar to one another. Such a pattern can be problematic, e.g. for ecologists, because the distances between the data points in a parabolic plot do not reflect the "real" distances between the observed cases. However, this issue is of limited importance in an archaeological application [97]. The cases that archaeologists use, for example artifact types that occur at sites in a given region, often follow a chronological order. Here, the absolute distances between the data points are of no interest, because the aim is to order the sites according to their relative chronology [98].

At Chogha Golan the cases represent flotation samples characterized by their taxonomic composition, which derive from the deep sounding of a tell excavation. The parabolic distribution of the samples therefore means that their composition follows a strong temporal trend throughout the sequence, which allows us to interpret the compositional differences between the samples as a temporal development. The type of deposit is only a secondary factor influencing the formation of the charred assemblages. As an exception to this overall pattern, only three samples from the midden deposits of AH VI are clearly separated from the other samples along axis one, because possibly gathered seeds of *Atriplex* sp. and *Alyssum* sp. and bulbils of *Poa bulbosa* accumulated here.

**Wild grasses in the subsistence of Chogha Golan.** In the first archaeobotanical reports about Chogha Golan the presence of cereals, their status as pre-domestic or domestic cultivars and the high proportions of small-seeded grasses between AH V and III were discussed in detail [16,27,44,56,64]. Therefore, the significance of the new results lies in the high amount and diversity of the large to medium-seeded wild grasses. Their grains are considerably more abundant among the analyzed samples from horizons VII to III than grains of *Hordeum spontaneum*, *Triticum* spp. and *Aegilops* sp., which also applies to the older horizons XI to VIII [16,64]. These high proportions of large to medium-sized grains from wild *Avena*, *Bromus*, *Eremopyrum* and *Hordeum* species, the indeterminate Triticoid type and *Taeniatherum caput-medusae* raise the question of whether they were exploited as food resources and how their state in the subsistence economy relates to the wild cereals.

We previously argued that *H. spontaneum* and possibly even *Aegilops* sp. were cultivated at Chogha Golan [16,44,64]. Such pre-domestication cultivation systems are traditionally seen as scenarios in which grains of wild species are sown on tilled soils where they experience enhanced growing conditions and are accompanied by arable weeds [6,15,16,28,31,32,35,37, 99]. Applied to Chogha Golan this scenario could explain the high abundance of wild cereal remains, the temporal grain size increases of *H. spontaneum* and the presence of many wild grasses representing potential segetals. However, in light of accumulating archaeobotanical data for Chogha Golan and other aceramic Neolithic sites in the Zagros Mountains, we became increasingly cautious in interpreting the observed patterns using this explanatory framework. Although the patterns from Chogha Golan basically fulfill the criteria commonly used to apply the pre-domestication cultivation hypothesis, we see considerable differences between this dataset and those from the Levantine corridor.

Central for the proposition of pre-domestication cultivation, particularly for sites in the upper Euphrates area, was the interpretation of several potential weeds as representative of an early segetal flora, but also the gradual and clear decrease of gathered resources contemporaneous to a marked increase in wild cereals [32,36]. This development resulted in a strong dominance of wild cereal remains and only minor portions for other wild grasses at all PPNA sites of this region (see discussion below). Contrastingly, the sequence at Chogha Golan does not display a major shift towards an increasing focus on wild cereals and a gradual decrease of gathered wild plants. These data seem to indicate constant exploitation strategies throughout the sequence and are in good accordance with datasets from other sites in the Zagros Mountains (see discussion below and [18,51,56]). In fact, the patterns seem to be reversed here, with diverse large to medium-seeded grasses dominating the assemblages and wild cereals only representing a few among many important food resources.

Applying the traditional concept of pre-domestication cultivation to Chogha Golan would ignore all these patterns, which we identified during our ongoing analyses. In light of this conclusion we have to ask how we will now characterize this subsistence economy? We are left with the finding that *H. spontaneum* and *Aegilops* sp. presumably represent staple foods and that they were routinely exploited throughout the entire occupation period. Large to medium-seeded grasses exhibit the same patterns and, following the general picture for wild grass exploitation in the Zagros Mountains, they presumably represent routinely gathered foods as well. However, we are still confronted with the exploitation of diverse wild grasses throughout an occupation period of about 2,000 years. During the major part of this period, but at least 1,000 years, the inhabitants constructed permanent architecture indicative of a sedentary community. This leads us to the question if humans could continuously rely on these resources without any form of resource management? A look at the taxonomic composition of the identified wild grasses with regard to their present day ecology might give an additional clue for reconstructing subsistence practices.

In extant Near Eastern ecosystems, where we find the species under discussion, wild cereals, including *Aegilops* spp., often dominate the herbaceous vegetation and grow together with e.g. *Avena sterilis*, *Bromus* spp., *Hordeum bulbosum* or *Taeniatherum caput-medusae* (Fig 10) [66,93]. It is important to note that many of these taxa include well known synanthropic species, today adapted to ruderal and segetal habitats, which substantially affects their present day distribution [92,100,101]. Using the modern ecology of wild cereals and other wild grasses for interpreting prehistoric botanical assemblages therefore includes the danger of drawing false assumptions based on differing ecological adaptations in present and ancient ecosystems. However, the botanical remains from Chogha Golan are surprisingly similar in their taxonomic composition to these extant stands, suggesting that the exploited early Holocene grasslands were not very different from populations we can observe today. This finding possibly indicates that the wild cereals and grasses at Chogha Golan were gathered from "natural" stands rather than harvested from a cultivated field. Moreover, the fact that most wild cereals and many of these wild grasses developed into successful synanthropic species and dominate many primary as well as secondary habitats today raises the question of how early these traits developed and if they played a role in the ability of the inhabitants of Chogha Golan to exploit them as major food resources for almost two millennia? We will not be able to draw final conclusions on this issue in the present paper, also because more research in this field is needed, but we want to emphasize the importance of the potential synanthropic ecology of many of the wild grasses under discussion. As we will demonstrate below, several typical segetals abundantly occur among charred botanical assemblages as soon as domesticated cereals appeared in the early PPNB. These taxa were able to quickly adapt to human disturbances, in this case soil tillage and crop cultivation. We can therefore principally expect that some extant synanthropic species could immediately adapt to anthropogenic disturbances by prehistoric humans [38] and, as a result, were possibly "pulled" into the sedentary human environment.

In the surroundings of Chogha Golan, the exploited wild grasses were presumably favored by anthropogenic disturbances, which inevitably and increasingly must have occurred after humans became sedentary. The creation of disturbed and open habitats did not play a primary role in the choice of the inhabitants to exploit wild grasses as major foods, because local palaeoenvironmental data indicate generally open landscapes with a large grass component during the early Holocene [102,103]. However, they could have facilitated the long-term exploitation of wild grasses. Size increases of *H. spontaneum* grains indicative of enhanced growing conditions towards AH IX and IV possibly point towards deliberate management practices [64], but their exact nature is yet to be established.

Independent from these issues we can conclude that the inhabitants of Chogha Golan developed an effective and sustainable subsistence strategy, which allowed a sedentary lifestyle for at least one millenium, if not substantially longer, without relying on domesticated plant resources. This subsistence strategy must be characterized as a resilient long-term solution and


**Fig 10. Associations of wild cereals and other wild grasses in northern Israel.** (A) Rich stands of *Aegilops peregrina* in open woodlands of *Quercus calliprinos* and *Pistacia palaestina* at Mount Carmel, accompanied by *Hordeum bulbosum*, *Bromus lanceolatus* and *Avena sterilis*, whereas *Hordeum spontaneum* represents a minor component; (B) ruderal habitat along the road between Rosh Pina and Safed in the Upper Galilee Mountains, dominated by *Avena sterilis* and *Aegilops peregrina* and accompanied by *Hordeum spontaneum* and *Triticum dicoccoides*. Wild emmer wheat even grew within the village of Safed on waste places, which it apparently invaded from nearby primary stands; (C) same location near Safed, only about 50m away; dominated by *Hordeum spontaneum* (ears below) and *Hordeum bulbosum* (ears above) with *Triticum dicoccoides*, *Avena sterilis* and *Aegilops peregrina* as minor components. These wild stands display a considerable diversity in taxonomic composition on a small spatial scale. Small to medium-seeded taxa such as *Bromus* spp., *Lolium rigidum*, *Poa bulbosa* and *Phalaris* spp. were regularly associated with these wild cereal stands. Photos by A. Weide, 2017.

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not as "on the way" to domestication, which the term pre-domestication cultivation would imply. The only obvious and presumably permanent shift in this subsistence economy was the adoption of domesticated emmer wheat towards the end of occupation at the site. This coincided with decreasing percentages of the formerly exploited wild grasses, representing an additional argument for why we consider the wild cereals and the large to medium-seeded grasses as representative of one uniform exploitation strategy. Otherwise they would not have equally competed with domesticated emmer wheat.

## Patterns in subsistence economies of the Zagros Mountains

The archaeobotanical remains from Chogha Golan with the high proportions of non-cereal taxa are in good accordance with results from many other broadly contemporaneous sites of the eastern wing of the Fertile Crescent. These include East Chia Sabz and Sheikh-e Abad in the central Zagros [18,56] as well as M'lefaat and Qermez Dere, located in the Mesopotamian plain in northern Iraq (51). At all these sites wild grasses, including species of *Hordeum*, *Lolium*, *Piptatherum*, *Stipa*, *Taeniatherum*, and the Triticoid type, are abundant and accompany the cereals. Savard et al. and Whitlam clearly regard these wild taxa as gathered food resources [18,51]. At East Chia Sabz and M'lefaat, *Aegilops* grains or chaff outnumber those of *Hordeum spontaneum*, supporting our view that one or several *Aegilops* species were among the local staples, whose role in the subsistence economies was equally important than that of *H. spontaneum* [44]. Towards the Taurus Mountains, patterns in subsistence strategies seem to have been different. The wild grasses at Körtik Tepe, predominantly small-seeded taxa, are regarded as staple foods that decrease in importance with the onset of the early Holocene [60]. This development matches the data from Hallan Çemi and Demirköy, where Savard et al. found valley-bottom species of *Rumex*, *Polygonum* and *Bolboschoenus* to be the major food plants [51]. The high importance of large to medium-seeded wild grasses in the diet of early Holocene sedentary communities therefore seems to be a regional pattern in the Zagros Mountains and the adjacent Mesopotamian plain, where domestic plants appear later than in the Levantine corridor [19].

Wild grasses start to decrease in abundance in the central Zagros with the onset of the 10$^{th}$ millennium cal. BP. At Chogha Golan, this correlates with the emergence of domestic emmer in AH II at around 9,800 cal. BP. These finds of domestic emmer chaff currently represent the oldest evidence for a non-shattering cultivar in the eastern wing of the Fertile Crescent and seem to mark a major change in regional subsistence strategies. The assemblage from trench 2 of Sheikh-e Abad still contains a considerable portion of gathered large to medium-seeded grasses and is roughly of the same age as the middle and upper horizons of Chogha Golan [18]. Domestic-type barley grains have been identified, but the subsequent development is hardly detectable, because the samples from the youngest layers in trench 3 are heavily dominated by small-seeded grasses. Whether the proposed onset of barley cultivation at Sheikh-e Abad resulted in a decreased importance of other wild grass resources can unfortunately not be evaluated due to this huge taphonomic bias.

All sites and settlement phases in the central Zagros, which roughly date to or are younger than 9,800 cal. BP, show a different pattern. At Ganj Dareh, van Zeist et al. found a minor component of large to medium-seeded grasses accompanying domestic-type barley grains [39]. Whether these grains derive from non-shattering barley ears is impossible to assess, but the overall patterns continue a trend where wild grasses show decreasing proportions. At the subsequent sites of Ali Kosh and Chogha Bonut [21,104], the few wild grasses most likely represent weeds and emmer, barley and lentils are well established as domestic crops throughout the central Zagros by the middle of the 10$^{th}$ millennium cal. BP [90].

## The role of wild grasses at hunter-gatherer and farming sites of the Fertile Crescent

**Epipalaeolithic and PPNA: Gathered resources compete with early cultivars.** Almost all Epipalaeolithic sites with a rich record of macro-botanical plant remains provide evidence for wild grass gathering and their state as important food resources. Weiss et al. suggested that wild grasses were part of the food diversification during the late Pleistocene [48], which Flannery originally named the "broad spectrum revolution" [50]. Among the routinely exploited grasses of the Epipalaeolithic, small and medium-seeded taxa such as *Alopecurus*, *Bromus* or *Hordeum* similarly contributed to the grain harvests as opposed to the wild cereals. However, this pattern is based on a limited number of sites and only phytolith analyses from the two

Late Natufian sites of Eynan and Hilazon Tahtit in the Hula valley and Galilee provide additional evidence for the frequent exploitation of wild grasses and cereals [105]. We therefore have to speculate whether wild grasses were continuously gathered throughout the Epipalaeolithic and the phytolith evidence rather points to shifting subsistence strategies, depending on the changing availability of plant resources through space and time. Phytolith evidence from Kharaneh IV in the Azraq basin in Jordan, combined with Ohalo II, indeed suggests that localized year-round habitations during the Early-Middle Epipaleolithic in the southern Levant were mainly based on wetland resources and not primarily on the exploitation of wild grasses and cereals [58,106,107].

Even though Snir et al. saw the earliest evidence for wild cereal cultivation at Ohalo II [38], it is not until the end of the Epipalaeolithic and the onset of the early Holocene in the Levantine corridor that the wild progenitors were primarily used as staple foods. During the early phases at Qaramel, Mureybet and Abu Hureyra, wild cereals were increasingly exploited, indicating the beginnings of a major change in human subsistence strategies. All sites in the Levantine corridor dating to the PPNA now show a very pronounced focus on wild cereals, which most scholars explained with the emergence of wild cereal cultivation (28,32,35,40,48,52).

Although non-cereal taxa occur on many of these sites, sometimes in considerable quantities, and many authors regard these grains as potential food sources, wild grass gathering has been regarded as negligible in importance after the onset of the early Holocene. Weiss and his colleagues came to this conclusion by examining a selection of Levantine sites and calculating the ratio of the cereals compared to the other wild grasses with respect to the steep gradient of declining grain volumes. It is absolutely right that the non-cereal taxa did not contribute substantial proportions to the whole grain harvests after humans began to focus on cereals. However, studies accomplished during the last ten years provided evidence for the possible exploitation of wild grasses during the PPNA in the Levantine corridor, even though most of them focused on the interpretation of the wild cereals [32,35,52,76,78,108]. We must therefore adjust our presumptions about the demise of wild grass exploitation with the onset of the early Holocene.

A consistent line of evidence we found for the PPNA in the Levantine corridor indicates a continuous tradition of wild grass use at many sites, although wild cereals start to heavily dominate the assemblages. The accumulated finds and high counts for wild grasses such as *Aegilops*, *Avena*, *Hordeum*, *Stipa* or *Taeniatherum* at sites such as Netiv Hagdud, el-Hemmeh, Qaramel, Jerf el Ahmar or Dja'de could theoretically be explained by their state as arable weeds in predomestic cereal fields, but there is no contextual evidence at either of these sites that would support this conclusion. Typical segetals only increased in abundance with the appearance of domestic cereals in the early and middle PPNB, but all above mentioned taxa were already ubiquitous throughout the Epipalaeolithic and PPNA. This is at best explained by their continuous exploitation as food resources, most apparent at Gilgal, where *Avena sterilis* and *Hordeum spontaneum* grains were found together in one storage context [52,78]. Weiss et al. were right when they stated that the cereals replaced the wild grasses as major foods, but new data indicate a continuous exploitation of wild grasses by PPNA communities in the Levant, which were only later fully replaced by domestic cereals in established agricultural systems. However, we must keep in mind that these interpretations are mostly based on the relative frequency of wild grass and cereal remains. As we will more clearly point out below, comprehensive taphonomic analyses using a multivariate approach should be applied to datasets suited for such an analysis in order to more reliably disentangle arable weeds and deliberately gathered resources.

Another issue is the study region. The origins of agriculture are traditionally seen in the Levantine corridor [109–111]. Hence, many studies on the subsistence development in the early Holocene focused on this region, although recent evidence suggests multiple trajectories towards farming in different regions within the Fertile Crescent [15,16]. In this paper we present additional evidence for a significant regional variability in subsistence strategies, supporting previous evidence for a reliance on wild grasses in the Zagros Mountains during the 12th and 11th millennia BP [18,51]. Here, in contrast to the Levantine corridor, wild grasses were not replaced by the wild cereals as major food sources after the end of the Younger Dryas. Although different climatic and environmental conditions contributed to an uneven availability of wild cereal species throughout the Fertile Crescent [9,59,112], they were present and have been exploited in the Taurus-Zagros Mountains from the very beginnings of the Holocene onwards [18,51,60,64]. *Triticum* species are almost absent from this record, but *Aegilops* is present in high quantities at M'lefaat, Chia Sabz and Chogha Golan and occurs frequently among the samples from Qermez Dere. This again highlights why we include *Aegilops* in the group of wild cereals in the Zagros Mountains, which possibly compensated for the lack of wild *Triticum* stands.

Taking the Fertile Crescent as a whole, *H*. *spontaneum* was routinely exploited in all regions and has been accompanied by *T*. *dicoccoides* and *Avena* spp. in the southern Levant, one and two-seeded einkorn and rye in the northern Levant and *Aegilops* spp. in the Zagros Mountains. As Fuller et al. already pointed out, this extended list of intensively exploited and increasingly managed wild cereals characterized subsistence economies during the PPNA, although not all of these species became established as a domestic crop during the following periods [15]. Based on this evidence, the absence of a heavy focus on wild cereals in the Zagros cannot be explained by a lack of wild cereal stands. Alternatively, the ecosystems in the eastern wing of the Fertile Crescent seem to have been exploited in a different way that was equally successful. Discussing possible reasons for such different trajectories is beyond the focus of this paper, but we want to refer to important contributions that discuss early cultivation in the light of evolving sedentism, monumental architecture, food storage, feasting, symbolism and emerging property, which are highly entangled with one another in the archaeological record, suggesting the socio-cultural background as a determining factor influencing the development of subsistence strategies [113–120].

**PPNB: Invading the fields.** With the appearance of domestic cereals in the early and middle PPNB, many grasses became common arable weeds. We could identify two different patterns that are indicative of this development. A first one in which formerly exploited grasses seem to have invaded fields and are equally abundant at sites occupied by hunter-gatherers and farmers. These taxa include species of *Aegilops*, *Avena*, *Eremopyrum*, *Hordeum*, *Stipa* and *Taeniatherum*, all of which include known segetals today and have been interpreted as such by the respective authors at PPNB sites. The second pattern is representative for species which considerably increase in abundance with the appearance of domestic cereals, suggesting that they are more indicative of arable weeds in the overall archaeobotanical record than as gathered resources. Among them, *Lolium* spp., *Phalaris* spp. and *Echinaria capitata* show the most profound increase in abundance and occur on more sites and in greater abundance during the PPNB. However, these taxa are not fully absent from the list of potentially gathered resources in the earlier periods. Particularly *Bromus* is present on most Epipalaeolithic and PPNA sites, but then occurs more frequently in the charred assemblages of farming villages. Likewise, *Phalaris* species seem to have been exploited at some PPNA sites, possibly also at Chogha Golan, but then clearly developed into successful arable weeds. An interesting pattern is the increasing abundance of *Echinaria capitata* in the southern Levant and at Halula at the upper Euphrates [108]. The species is not known as a typical arable weed today [92,93], but was apparently part of PPNB segetal communities.

The overall proportions of large to medium-seeded wild grasses do not substantially decrease after the PPNA. Particularly at late PPNB sites such as Sabi Abyad II, El Kowm and Ghoraifé, they outnumber the cereal grains. Apparently, *Lolium* species have developed into successful segetals, making up the majority of arable weed remains at these sites. Here it is important to note that the weeds are not solely representative of cereal agriculture. Van Zeist examined the proportions of *Lolium* grains for sites in the Balikh basin in northern Syria, which show a fair correlation with *Linum* sp. seeds, indicating that *Lolium* species were major weeds in flax fields [89]. The continuously high percentages of wild grasses also highlight the different taphonomic agents that now contributed to the formation of charred archaeobotanical assemblages. As de Moulins discussed [42], wild plant use is hardly detectable as soon as farming developed, because crop-processing by-products will end up in the charred plant materials. Without applying multivariate methods it is then often impossible to identify the deliberately gathered species. This is a well-known problem and has been addressed by many studies, who sought to disentangle the archaeobotanical assemblages in this regard [18,24,37,40,43,44,81,87,91]. Concerning the wild grasses that have been exploited during the Epipalaeolithic and PPNA, but still frequently occur in PPNB assemblages, we are mostly left with the overall assumption that these taxa now represent weeds and not gathered resources. A central argument for this interpretation is that the cultivation of domestic cereals makes wild grass gathering redundant, because they would not significantly contribute to the grain diet [48,53]. Moreover, the substantial increase of major segetal taxa like *Bromus* or *Lolium* since the early PPNB is indicative of developing crop-processing techniques, which increasingly contribute to the formation of charred botanical assemblages at PPNB sites including high proportions of weed seeds.

Despite this general agreement, several authors were confronted with patterns or features that led them to discuss a potential utilization of wild grasses at middle and late PPNB sites such as Abu Hureyra, Wadi el-Jilat 7 or Çatalhöyük [40,42,53]. For Abu Hureyra, de Moulins emphasized the taxonomic composition of the PPNB plant remains, which is strikingly similar to the Epipalaeolithic remains of the site. At most middle or late PPNB sites where wild grasses make up large proportions of the plant remains they are commonly dominated by a few weeds such as *Bromus* sp. or *Lolium* sp. In contrast, the abundant wild grasses at Abu Hureyra include many more taxa, of which *Stipa*, *Secale* or wild *Hordeum* species were interpreted as exploited resources during the Epipalaeolithic occupation [121,122]. This pattern may indicate that most taxa gathered during the Epipalaeolithic entered cultivated fields as arable weeds during the PPNB at the site, or it is indicative of a continuous exploitation of these grasses. The information we currently have do unfortunately not allow to distinguish between these two hypotheses, emphasizing the need for more detailed taphonomic analyses.

At Wadi el-Jilat 7, it is the location in the "marginal zone" of the environments in the southern Levant that provides an argument to have a closer look at the wild grasses. The development of distinct subsistence strategies has long been recognized for the drier and steppic regions of the southern Levant, where archaeological sites have a more ephemeral character in contrast to the Mediterranean zone with its rich record of sedentary farming villages [123,124]. Although Garrard and colleagues solely discussed the finds of domestic crops for sites in the Azraq basin in eastern Jordan [54], Colledge included the abundant non-cereal taxa dominated by *Eremopyrum* and *Hordeum* into her list of plants that "would have provided sources of food" at Jilat 7 [125]. As indicated by this dataset, wild grasses were possibly exploited alongside domestic cereals in environments bordering the deserts of the Sinai, Negev and Jordan, from which informative archaeobotanical datasets are almost absent. Although this must remain hypothetical, we should be cautious in regarding wild grasses as generally outcompeted and unattractive resources among PPNB societies, which apparently display a considerable diversity in settlement patterns and subsistence strategies and of which some continued to live a more mobile lifestyle in these "marginal environments" [55,126]. Furthermore, it is conspicuous that wild *Hordeum* and *Eremopyrum* grains, but also *Avena* and *Stipa*, reach their most frequent occurrence during the PPNB at Abu Hureyra, Jilat 7, Chogha Golan and Çatalhöyük (see Fig 8), which are all sites where wild grass exploitation has been addressed.

At Çatalhöyük this was inferred by the two possible storage finds of *Taeniatherum caput-medusae*, accompanied by *Eremopyrum*-type grains. Both taxa seem to represent common weeds at the site [41,53] and this particular case highlights the importance of singular contexts for our understanding of wild plant exploitation in farming societies. Although Fairbairn and his colleagues are cautious in interpreting *Taeniatherum caput-medusae* as a stored food, its accumulated appearance in two subsequent settlement phases clearly speaks for a planned utilization of the grains. Apparently, the status of a taxon as a common arable weed, like *Taeniatherum caput-medusae* in Anatolia, cannot be taken as a strict indicator of its role in subsistence economies. Modern societies have very different conceptions of weeds [127,128] and Hillman reported an interesting case of Anatolian families preferring a bread from wheat harvests that were "severely infested" by weedy forms of *Secale cereale* and *Vicia sativa* [129]. In contrast to the concept of a weed as an undesired plant without any value, early Holocene people could have accepted, utilized and probably even supported edible weed species, particularly as many segetals represented exploited resources prior to the emergence of crop cultivation. The patterns from Abu Hureyra and Çatalhöyük may be indicative of such practices, which White also discussed for el-Hemmeh [80]. By specifically addressing this issue in future archaeobotanical analyses, implementing multivariate methods more intensively, we can hopefully shed more light on the treatment and status of arable weeds in prehistoric subsistence economies.

**The small-seeded grasses.** Accumulations of small caryopses heavily dominate some charred archaeobotanical assemblages we considered in the present study. This phenomenon occurs from the Epipalaeolithic through to the late PPNB, mainly in the Zagros Mountains and Anatolia. Types resembling *Agrostis*, *Alopecurus*, *Eragrostis*, *Phleum*, *Poa* and *Puccinellia* have been reported as the dominating taxa contributing to these assemblages. The classification of nearly all taxa as "cf." or "types" illustrates the difficulty of identifying these charred grains, which are extremely small and are often measure less than 1mm in length. Recovering large amounts of such small-seeded grasses require particular recovery techniques. We are therefore confronted with the question to which degree methodological aspects, such as the mesh sizes applied during water flotation, bias the observed patterns.

By plotting the proportions of small grasses among all Poaceae grains against the applied mesh sizes, we found that sieving seems to have an impact on the abundance of small caryopses, given the mesh sizes were 0.3mm or larger. However, we do not know whether the lower percentages of small grains at sites where larger meshes have been used are really due to a methodological bias. Willcox et al. tested mesh sizes smaller than 0.5mm at Jerf el Ahmar, Dja'de, Qaramel and 'Abr without retrieving significant amounts of identifiable plant remains (they did not indicate which mesh sizes were tested) [32]. In addition, at many sites where mesh sizes smaller than 0.3mm have been used, small caryopses are likewise rare or absent. Field methods, as far as this can be evaluated using the published literature, therefore seem not to be a major cause of variation for the proportions of small-seeded grasses, which Weiss and colleagues similarly concluded [48].

When we assume taphonomic processes as the main factors causing this variability, we are confronted with a geographical rather than a temporal pattern. As concluded above, the Taurus-Zagros Mountains and central Anatolia display considerably different developments in subsistence practices as opposed to sites in the Levantine corridor. All sites with small-seeded grasses making up more than 60% of the Poaceae grains are located here, which suggests local subsistence practices being a major factor that induces this pattern. In the Zagros Mountains, subsistence strategies are characterized by the exploitation of wild grasses for food and the small-seeded taxa possibly represent deliberately collected resources as well. Riehl and her colleagues favor this explanation for Chogha Golan and Körtik Tepe, whereas the collection of grasses or herbivore dung as fuel has been suggested by most other authors [18,39,57,90].

Fairbairn et al. reported dung-pellets for the early phases at Çatalhöyük and considered particularly *Bolboschoenus* nutlets as being dung-derived, because their ecology made sedges the most plausible taxa being grazed by livestock and not harvested with the grown crops [41]. Further studies could later confirm that the *Bolboschoenus* nutlets as well as the small grains from *Aeluropus* sp., *Crypsis* sp., *Eragrostis* sp. and *Sporobolus* sp. are indeed dung-derived [85,87,91], whereas the origin of the abundant cf. *Alopecurus* grains from the early levels remains unclear. Çatalhöyük is therefore the only early Neolithic site where most small-seeded grasses could reliably be linked to dung-burning. The comprehensive application of multivariate statistics, in combination with a good situation for contextualized sampling and the application of established criteria to recognize dung-derived plant materials, represents the basis for these very informative archaeobotanical studies. Such a comprehensive approach was/could not be applied the other Anatolian or Zagrosian sites and we are therefore left with a quite unsatisfactory picture, which does not allow us to draw robust conclusions on the high proportions of small-seeded grasses at the sites under discussion. We should not take abundant small-seeded grasses *per se* as indicators for dung-burning, because different taphonomic factors also resulted in the incorporation of large to medium-sized grains in charred assemblages and include gathering and crop-processing. Whitlam eventually noted that herbivore dung as a major source for large amounts of small-seeded grasses in charred assemblages must remain hypothetical unless dung pellets including identifiable grains are found [18] and we fully agree with this assumption. However, it needs to be emphasized that a multivariate approach is currently the most promising way to reconstruct the taphonomic history of burned plant remains and must be applied more regularly in the future to proceed with solving such interpretative problems.

## Synthesis, main conclusions, and a future perspective

Chogha Golan provides an exceptional case for analyzing the development of early Neolithic subsistence strategies and for evaluating the importance of gathered resources in relation to emerging crop cultivation. The inhabitants of the Neolithic village routinely exploited a complex of wild grasses comprising wild cereals, large to medium-seeded and possibly also small-seeded taxa. *Hordeum spontaneum* formed a major component of the consumed grasses and was harvested for almost 2,000 years without inducing the establishment of non-shattering ears. Then, as soon as domesticated emmer wheat dominates the cereal remains by ca. 9,800 cal. BP, all wild grasses decrease in relative abundance. This complex of wild grasses was presumably harvested as staple foods and was subsequently outcompeted by a domestic crop. Whether the wild cereals were ever cultivated at Chogha Golan is therefore not clear and we consider the ability of the exploited wild grasses to invade anthropogenically disturbed habitats around the sedentary village as an important factor that possibly facilitated their sustainable long-term exploitation. To which degree management practices were applied to maintain the wild grass stands is unclear, but this scenario significantly deviates from the traditional concept of pre-domestication cultivation and must be seen as a successful and resilient long-term subsistence strategy that did not heavily focus on wild progenitor species.

The archaeobotanical results from Chogha Golan are in good accordance with the overall patterns of the aceramic Neolithic in the Zagros Mountains. Wild grasses were exploited as major food sources at many sites in the uplands and in the foothills bordering the Mesopotamian plain throughout the 12$^{th}$ and 11$^{th}$ millennium cal. BP. This is in sharp contrast to the development in the Levantine corridor, where wild grasses formed important components of Epipalaeolithic subsistence strategies and were gradually replaced by wild cereals as major food sources since the end of the Younger Dryas.

For evaluating wild grass gathering in relation to the emergence of cereal cultivation, we analyzed the occurrence of wild grasses throughout almost 15,000 years considering the entire Fertile Crescent. We were able to visualize spatial patterns and long-term developments, which we regard as crucial for interpreting the role of wild grasses throughout the aceramic Neolithic. We provide additional evidence for a considerable diversity among early Neolithic subsistence strategies on the inter-regional level and conclude that many wild grasses were gathered for food, fuel or other purposes from the Epipalaeolithic onwards and demonstrably into the PPNA period. Many of these gathered grasses were part of the earliest segetal communities that emerged with the beginnings of farming, emphasizing the potential dietary value of these weed species. This pattern is of major importance for evaluating the status of weeds in early farming communities. The archaeobotanical datasets from e.g. Çatalhöyük, Abu Hureyra or el-Hemmeh suggest the utilization of arable weed species, which is plausible in light of this result. A high diversity of wild grasses also co-occurs with domestic cereals at some sites in the "marginal zones" of the Levant, such as Jilat 7, which presumably indicates the utilization of these species by groups that maintained a more mobile lifestyle.

Finally we want to emphasize the great potential multivariate approaches have to reconstruct prehistoric subsistence practices. Our review unmistakably shows that we will not proceed in disentangling arable weeds, deliberately collected food resources and dung burning activities if we do not implement the full spectrum of analytical techniques available to date. Among these, multivariate statistical methods such as correspondence analysis, coupled with contextualized sampling from relatively extensive excavations, represent the most promising approach that has been successfully applied to a small number of sites. It is clear that some assemblages are not suited for such analyses due to a poor preservation of the plant remains or small excavation areas, but many published assemblages fulfill these criteria and can be investigated in future analyses to more reliably interpret the role of wild resources in relation to emerging cultivation and domestication.

## Supporting information

**S1 Table. Average 1000 seed weight of Poaceae species.** Based on the Seed Information Database of the Royal Botanic Gardens Kew [67].
(DOCX)

**S2 Table. Analyzed flotation samples and identified plant remains from AH II to VII from the deep sounding of Chogha Golan.**
(DOCX)

**S3 Table. Coding of the variables in the correspondence analysis.**
(DOCX)

**S1 Fig. The site of Chogha Golan.** (A) The landscape around Chogha Golan; (B) outline of the site with the location of the deep sounding and excavation Area A in the center of the tell; (C) the south profile of the deep sounding showing Archaeological Horizons I to XI and the related z-values. Figures and photos by M. Zeidi.
(TIF)

**S2 Fig. Average grain weight of Poaceae taxa frequently identified among charred archaeobotanical assemblages from the Near East.** Calculations are based on the average 1000 seed weight given in the Seed Information Database (SID) of the Royal Botanic Gardens Kew [67]. Numbers in brackets give the number of extant Near Eastern species or subspecies for which measurements were available. The average seed weight for the single species is also based on multiple measurements from different accessions; for information on these data please see SID.
(TIF)

**S3 Fig. PRISMA flow diagram showing the impact of the selection criteria on the screened datasets.**
(TIF)

**S4 Fig. The composition of Poaceae remains in the samples used in the correspondence analysis.** Note that the strong temporal trend throughout the sequence is also visible in the Poaceae remains. Whereas the older samples from AH VII and VI have low percentages of small grains (right end of axis 1), samples from the middle part of the analyzed sequence are dominated by these taxa. Emmer wheat chaff remains characterize samples from AH III and II, where small grains are still very abundant (left end of axis 1). Large to medium seeded wild grasses are in all samples more abundant than grains of *H. spontaneum* and *Aegilops* sp. together.
(TIF)

**S5 Fig. Detailed key for the sites included in the temporal and spatial analysis of grain proportions.**
(TIF)

**S6 Fig. PRISMA checklist for the systematic review.**
(TIF)

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**S1 Table. Average 1000 seed weight of Poaceae species.** Based on the Seed Information Database of the Royal Botanic Gardens Kew [67].

| Taxon | Average 1000 seed weight (g) |
|---|---|
| ***Aegilops* spp. mean** | **36.55** |
| *Aegilops bicornis* | 9.20 |
| *Aegilops crassa* | 17.31 |
| *Aegilops cylindrica* | 26.60 |
| *Aegilops geniculata* | 71.50 |
| *Aegilops juvenalis* | 18.76 |
| *Aegilops kotschyi* | 47.60 |
| *Aegilops peregrina* | 87.80 |
| *Aegilops speltoides* | 22.85 |
| *Aegilops tauschii* | 27.30 |
| ***Aeluropus* spp. mean** | **0.23** |
| *Aeluropus lagopoides* | 0.26 |
| *Aeluropus littoralis* | 0.20 |
| ***Agrostis* spp. mean** | **0.09** |
| *Agrostis canina* | 0.06 |
| *Agrostis capillaris* | 0.08 |
| *Agrostis castellana* | 0.17 |
| *Agrostis gigantea* | 0.08 |
| *Agrostis stolonifera* | 0.07 |
| ***Alopecurus* spp. mean** | **1.02** |
| *Alopecurus aequalis* | 0.17 |
| *Alopecurus apiatus* | 1.50 |
| *Alopecurus arundinaceus* | 0.50 |
| *Alopecurus bulbosus* | 0.46 |
| *Alopecurus geniculatus* | 0.28 |
| *Alopecurus gerardii* | 1.17 |
| *Alopecurus glacialis* | 0.66 |
| *Alopecurus myosuroides* | 1.99 |
| *Alopecurus pratensis* | 0.90 |
| *Alopecurus rendlei* | 2.66 |
| *Alopecurus textilis* | 1.73 |
| *Alopecurus utriculatus* | 0.87 |
| *Alopecurus vaginatus* | 0.33 |
| ***Avena* spp. mean** | **26.12** |
| *Avena barbata* | 11.00 |
| *Avena fatua* | 28.00 |
| *Avena sterilis* | 50.00 |
| *Avena ventricosa* | 15.48 |
| ***Bromus* spp. mean** | **4.43** |
| *Bromus alopecurus* | 2.20 |
| *Bromus arvensis* | 2.20 |
| *Bromus danthoniae* | 5.67 |
| *Bromus fasciculatus* | 1.76 |
| *Bromus japonicus* | 2.61 |
| *Bromus lanceolatus* | 3.93 |
| *Bromus madritensis* | 3.33 |

**S1 Table.** Continued.

| Taxon | Average 1000 seed weight (g) |
|---|---|
| *Bromus pectinatus* | 4.10 |
| *Bromus rigidus* | 10.19 |
| *Bromus sterilis* | 9.50 |
| *Bromus tectorum* | 3.20 |
| ***Crypsis* spp. mean** | **0.27** |
| *Crypsis aculeata* | 0.29 |
| *Crypsis acuminata* | 0.19 |
| *Crypsis alupecuroides* | 0.20 |
| *Crypsis factorovskyi* | 0.33 |
| *Crypsis minuartioides* | 0.37 |
| *Crypsis schoenoides* | 0.24 |
| ***Echinaria capitata*** | **5.50** |
| ***Echinochloa* spp. mean** | **1.15** |
| *Echinochloa colonum* | 0.80 |
| *Echinochloa crus-galli* | 1.50 |
| ***Eragrostis* spp. mean** | **0.07** |
| *Eragrostis barrelieri* | 0.09 |
| *Eragrostis cilianensis* | 0.08 |
| *Eragrostis japonica* | 0.03 |
| *Eragrostis minor* | 0.09 |
| *Eragrostis pilosa* | 0.07 |
| ***Eremopyrum* spp. mean** | **3.09** |
| *Eremopyrum bonaepartis* | 3.95 |
| *Eremopyrum distans* | 4.98 |
| *Eremopyrum orientale* | 0.34 |
| ***Hordeum* spp. mean** | **13.33** |
| *Hordeum brevisubulatum* | 3.52 |
| *Hordeum bulbosum* | 11.00 |
| *Hordeum glaucum* | 3.24 |
| *Hordeum leporinum* | 6.84 |
| *Hordeum marinum* | 11.80 |
| *Hordeum murinum* | 23.40 |
| *Hordeum secalinum* | 6.43 |
| *Hordeum spontaneum* | 41.70 |
| *Hordeum violaceum* | 12.00 |
| ***Lolium* spp. mean** | **5.74** |
| *Lolium multiflorum* | 2.90 |
| *Lolium perenne* | 2.20 |
| *Lolium persicum* | 9.64 |
| *Lolium rigidum* | 3.45 |
| *Lolium temulentum* | 10.50 |
| ***Panicum* spp. mean** | **1.19** |
| *Panicum antidotale* | 1.00 |
| *Panicum maximum* | 1.10 |
| *Panicum repens* | 0.65 |
| *Panicum turgidum* | 2.00 |

**S1 Table.** Continued.

| Taxon | Average 1000 seed weight (g) |
|---|---|
| ***Phalaris* spp. mean** | **2.05** |
| *Phalaris aquatica* | 1.69 |
| *Phalaris arundinacea* | 0.70 |
| *Phalaris brachystachis* | 1.90 |
| *Phalaris canariensis* | 5.20 |
| *Phalaris minor* | 1.50 |
| *Phalaris paradoxa* | 1.30 |
| ***Phleum* spp. mean** | **0.28** |
| *Phleum alpinum* | 0.41 |
| *Phleum arenarium* | 0.20 |
| *Phleum bertolonii* | 0.41 |
| *Phleum exaratum* | 0.25 |
| *Phleum montanum* | 0.12 |
| *Phleum phleoides* | 0.15 |
| *Phleum pratense* | 0.40 |
| ***Poa* spp. mean** | **0.31** |
| *Poa alpina* | 0.36 |
| *Poa angustifolia* | 0.22 |
| *Poa annua* | 0.30 |
| *Poa bulbosa* | 0.90 |
| *Poa caucasica* | 0.25 |
| *Poa compressa* | 0.20 |
| *Poa nemoralis* | 0.20 |
| *Poa pratensis* | 0.25 |
| *Poa trivialis* | 0.10 |
| ***Puccinellia* spp. mean** | **0.17** |
| *Puccinellia bulbosa* | 0.10 |
| *Puccinellia ciliata* | 0.20 |
| *Puccinellia distans* | 0.20 |

**S1 Table.** Continued.

| Taxon | Average 1000 seed weight (g) |
|---|---|
| ***Secale* spp. mean** | **8.17** |
| *Secale anatolicum* | 3.70 |
| *Secale montanum* | 12.10 |
| *Secale sylvestre* | 8.70 |
| ***Setaria* spp. mean** | **1.82** |
| *Setaria glauca* | 3.75 |
| *Setaria verticillata* | 0.70 |
| *Setaria viridis* | 1.00 |
| ***Sporobolus* spp. mean** | **0.14** |
| *Sporobolus spicatus* | 0.14 |
| *Sporobolus virginicus* | 0.15 |
| ***Stipa* spp. mean** | **8.97** |
| *Stipa arabica* | 2.79 |
| *Stipa bromoides* | 5.15 |
| *Stipa capensis* | 1.68 |
| *Stipa capillata* | 8.20 |
| *Stipa caucasica* | 5.61 |
| *Stipa holoserica* | 8.65 |
| *Stipa lagascae* | 9.10 |
| *Stipa parviflora* | 1.19 |
| *Stipa pennata* | 20.46 |
| *Stipa pulcherrima* | 25.95 |
| *Stipa tirsa* | 14.65 |
| *Stipa turkestanica* | 4.15 |
| ***Taeniatherum* spp. mean** | **6.19** |
| *Taeniatherum caput-medusae* | 7.03 |
| *Taeniatherum crinitum* | 5.35 |
| ***Triticum* spp. mean** | **27.21** |
| *Triticum boeoticum* | 13.00 |
| *Triticum diccoccoides* | 41.41 |

**S2 Table.** Analyzed flotation samples and identified plant remains from AH II-VII from the deep sounding of Chogha Golan.

| Archaeological Horizon (AH) | II | | III | | IV | | V | | VI | | VII | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Floated sediments (l) | 178 | | 58 | | 32 | | 56 | | 40 | | 54 | |
| Samples | 15 | | 5 | | 3 | | 5 | | 5 | | 5 | |
| Mean sample volume (l) | 12 | | 12 | | 11 | | 11 | | 8 | | 11 | |
| Items per liter soil | 17.5 | | 73.2 | | 300.9 | | 54.7 | | 119.1 | | 33.8 | |
| Number of identified taxa | 58 | | 68 | | 66 | | 53 | | 64 | | 67 | |
| Total number of analyzed plant remains | 3107 | | 4246 | | 9628 | | 3061 | | 4765 | | 1824 | |
| | *n* | % | *n* | % | *n* | % | *n* | % | *n* | % | *n* | % |
| **Amaranthaceae** | | | | | | | | | | | | |
| *Atriplex* sp. | 1 | 0.03 | - | - | 3 | 0.03 | 3 | 0.10 | 255 | 5.35 | 32 | 1.75 |
| cf. *Atriplex* sp. | - | - | - | - | - | - | 3 | 0.10 | - | - | 3 | 0.16 |
| *Atriplex* sp. bracts | - | - | - | - | - | - | - | - | 35 | 0.73 | 4 | 0.22 |
| *Chenopodium* sp. | - | - | - | - | 1 | 0.01 | - | - | - | - | - | - |
| cf. *Salsola* sp. | - | - | - | - | - | - | - | - | - | - | 2 | 0.11 |
| *Suaeda* sp. | 1 | 0.03 | - | - | 8 | 0.08 | - | - | 16 | 0.34 | 10 | 0.55 |
| Amaranthaceae indet. | 4 | 0.13 | 4 | 0.09 | 9 | 0.09 | 12 | 0.39 | 1 | 0.02 | 8 | 0.44 |
| **Anacardiaceae** | | | | | | | | | | | | |
| *Pistacia* sp. | 38 | 1.22 | 70 | 1.65 | 38 | 0.39 | 79 | 2.58 | 10 | 0.21 | 37 | 2.03 |
| **Apiaceae** | | | | | | | | | | | | |
| Apiaceae type 1 | - | - | 1 | 0.02 | - | - | 1 | 0.03 | 14 | 0.29 | 6 | 0.33 |
| *Coriandrum* sp. | - | - | 1 | 0.02 | - | - | - | - | - | - | - | - |
| Apiaceae indet. | - | - | 1 | 0.02 | - | - | - | - | - | - | - | - |
| **Asparagaceae** | | | | | | | | | | | | |
| *Bellevalia*/*Muscari*/*Ornithogalum* | 11 | 0.35 | 6 | 0.14 | 17 | 0.18 | 26 | 0.85 | 117 | 2.46 | 25 | 1.37 |
| *Muscari*/*Ornithogalum* | - | - | 1 | 0.02 | - | - | - | - | - | - | 1 | 0.05 |
| **Asteraceae** | - | - | - | - | - | - | - | - | - | - | - | - |
| *Centaurea* sp. | 2 | 0.06 | 7 | 0.16 | 20 | 0.21 | 9 | 0.29 | 60 | 1.26 | 6 | 0.33 |
| cf. *Centaurea* sp. | - | - | 1 | 0.02 | 2 | 0.02 | - | - | - | - | 2 | 0.11 |
| *Cirsium* type | - | - | - | - | 2 | 0.02 | - | - | - | - | 1 | 0.05 |
| Asteraceae indet. | 3 | 0.10 | 2 | 0.05 | 1 | 0.01 | - | - | - | - | 4 | 0.22 |
| **Boraginaceae** | | | | | | | | | | | | |
| *Buglossoides arvensis* (uncharred) | 7 | 0.23 | 1 | 0.02 | 1 | 0.01 | - | - | 8 | 0.17 | - | - |
| *Buglossoides tenuiflora* (uncharred) | 5 | 0.16 | 1 | 0.02 | - | - | - | - | - | - | 1 | 0.05 |
| *Heliotropium* sp. | 6 | 0.19 | 1 | 0.02 | 8 | 0.08 | 2 | 0.07 | 3 | 0.06 | 6 | 0.33 |
| **Brassicaceae** | | | | | | | | | | | | |
| *Alyssum* sp. | - | - | 1 | 0.02 | - | - | - | - | 126 | 2.64 | 14 | 0.77 |
| *Capsella*/*Descurainia* | 7 | 0.23 | - | - | 19 | 0.20 | 4 | 0.13 | 40 | 0.84 | 24 | 1.32 |
| *Erysimum*/*Sisymbrium* type | 2 | 0.06 | - | - | - | - | - | - | - | - | - | - |
| *Lepidium* sp. | - | - | 4 | 0.09 | 20 | 0.21 | 8 | 0.26 | 43 | 0.90 | 7 | 0.38 |
| cf. *Lepidium* sp. | - | - | 1 | 0.02 | - | - | 1 | 0.03 | - | - | - | - |
| Brassicaceae indet. | 3 | 0.10 | 20 | 0.47 | 1 | 0.01 | 2 | 0.07 | 4 | 0.08 | 6 | 0.33 |
| cf. Brassicaceae indet. | - | - | - | - | - | - | - | - | - | - | 4 | 0.22 |
| Brassicaceae silique fragments | - | - | 5 | 0.12 | 1 | 0.01 | - | - | 1 | 0.02 | 1 | 0.05 |
| **Caryophyllaceae** | | | | | | | | | | | | |
| *Dianthus sp.* | 1 | 0.03 | - | - | - | - | - | - | - | - | - | - |
| *Gypsophila* sp. | 2 | 0.06 | 2 | 0.05 | 26 | 0.27 | 7 | 0.23 | 39 | 0.82 | 6 | 0.33 |
| *Gypsophila*/*Silene* | 4 | 0.13 | 6 | 0.14 | 31 | 0.32 | 9 | 0.29 | 44 | 0.92 | 8 | 0.44 |
| *Silene* sp. | 1 | 0.03 | 1 | 0.02 | 21 | 0.22 | 7 | 0.23 | 8 | 0.17 | 5 | 0.27 |
| Caryophyllaceae indet. | 2 | 0.06 | 2 | 0.05 | 1 | 0.01 | - | - | - | - | - | - |
| **Cyperaceae** | | | | | | | | | | | | |
| *Bolboschoenus glaucus* | 34 | 1.09 | 20 | 0.47 | 35 | 0.36 | 17 | 0.56 | 18 | 0.38 | 12 | 0.66 |
| Cyperaceae indet. | 9 | 0.29 | 3 | 0.07 | 3 | 0.03 | 1 | 0.03 | 8 | 0.17 | 6 | 0.33 |
| **Euphorbiaceae** | | | | | | | | | | | | |
| *Euphorbia* type | 1 | 0.03 | 1 | 0.02 | - | - | - | - | - | - | - | - |
| **Fabaceae** | | | | | | | | | | | | |
| *Astragalus* sp. | 122 | 3.93 | 112 | 2.64 | 357 | 3.71 | 118 | 3.85 | 402 | 8.44 | 114 | 6.25 |
| *Lathyrus* type | 6 | 0.19 | 8 | 0.19 | 9 | 0.09 | 7 | 0.23 | 5 | 0.10 | 3 | 0.16 |

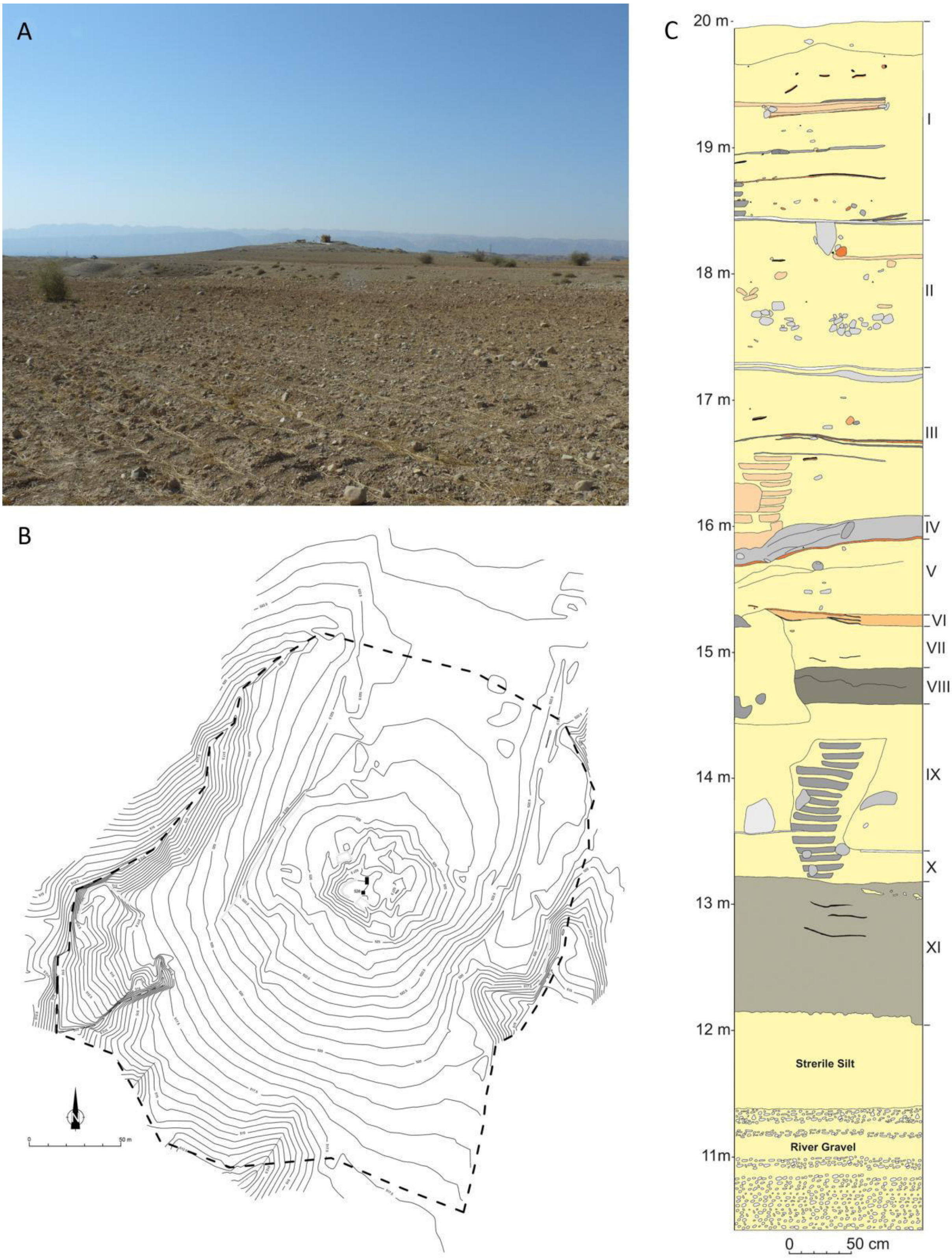
| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Lathyrus*/*Vicia* | 3 | 0.10 | 11 | 0.26 | 19 | 0.20 | 8 | 0.26 | 8 | 0.17 | 3 | 0.16 |
| *Lathyrus*/*Pisum*/*Vicia* | 40 | 1.29 | 43 | 1.01 | 150 | 1.56 | 76 | 2.48 | 233 | 4.89 | 45 | 2.47 |
| *Lens* sp. | 37 | 1.19 | 34 | 0.80 | 170 | 1.77 | 81 | 2.65 | 517 | 10.85 | 87 | 4.77 |
| *Medicago* sp. | 4 | 0.13 | 8 | 0.19 | 23 | 0.24 | 8 | 0.26 | 66 | 1.39 | 13 | 0.71 |
| cf. *Medicago* sp. | - | - | 1 | 0.02 | - | - | 1 | 0.03 | - | - | 3 | 0.16 |
| *Medicago radiata* | 23 | 0.74 | 17 | 0.40 | 43 | 0.45 | 21 | 0.69 | 18 | 0.38 | 9 | 0.49 |
| *Onobrychis* sp. | 1 | 0.03 | - | - | - | - | - | - | - | - | - | - |
| *Pisum* sp. | 1 | 0.03 | 3 | 0.07 | 23 | 0.24 | 7 | 0.23 | 7 | 0.15 | 1 | 0.05 |
| cf. *Pisum* sp. | - | - | 1 | 0.02 | - | - | - | - | 1 | 0.02 | 2 | 0.11 |
| *Trigonella astroites* type | 113 | 3.64 | 75 | 1.77 | 167 | 1.73 | 51 | 1.67 | 145 | 3.04 | 33 | 1.81 |
| *Trigonella* type 2 | 83 | 2.67 | 115 | 2.71 | 66 | 0.69 | 30 | 0.98 | 46 | 0.97 | 64 | 3.51 |
| *Trigonella foenum-graecum* type | - | - | 1 | 0.02 | 1 | 0.01 | - | - | 1 | 0.02 | - | - |
| *Trigonella*/*Astragalus* | 284 | 9.14 | 191 | 4.50 | 637 | 6.62 | 174 | 5.68 | 467 | 9.80 | 177 | 9.70 |
| *Vicia ervilia* | - | - | - | - | 1 | 0.01 | - | - | - | - | - | - |
| Fabaceae indet. large | 1 | 0.03 | 11 | 0.26 | 23 | 0.24 | 23 | 0.75 | 16 | 0.34 | 8 | 0.44 |
| Fabaceae indet. medium-small | 105 | 3.38 | 87 | 2.05 | 97 | 1.01 | 27 | 0.88 | 70 | 1.47 | 34 | 1.86 |
| **Lamiaceae** | | | | | | | | | | | | |
| cf. *Salvia* | - | - | - | - | 1 | 0.01 | - | - | - | - | - | - |
| *Ziziphora* sp. | - | - | 1 | 0.02 | 1 | 0.01 | - | - | - | - | - | - |
| Lamiaceae indet. | - | - | - | - | - | - | - | - | 4 | 0.08 | - | - |
| **Linaceae** | | | | | | | | | | | | |
| *Linum* sp. | - | - | - | - | 1 | 0.01 | - | - | - | - | - | - |
| **Malvaceae** | | | | | | | | | | | | |
| *Malva* sp. | 42 | 1.35 | 47 | 1.11 | 52 | 0.54 | 43 | 1.40 | 31 | 0.65 | 35 | 1.92 |
| **Papaveraceae** | | | | | | | | | | | | |
| *Fumaria* sp. | - | - | - | - | - | - | - | - | 1 | 0.02 | - | - |
| **Plantaginaceae** | | | | | | | | | | | | |
| *Plantago* sp. | - | - | - | - | - | - | - | - | - | - | 1 | 0.05 |
| **Poaceae** | | | | | | | | | | | | |
| *Aegilops* sp. | 20 | 0.64 | 24 | 0.57 | 28 | 0.29 | 19 | 0.62 | 93 | 1.95 | 20 | 1.10 |
| *Aegilops* sp. spikelets | 121 | 3.89 | 187 | 4.40 | 71 | 0.74 | 139 | 4.52 | 129 | 2.70 | 107 | 5.87 |
| *Avena* sp. | 13 | 0.42 | 54 | 1.27 | 259 | 2.69 | 80 | 2.61 | 117 | 2.46 | 60 | 3.29 |
| cf. *Avena* sp. | - | - | 12 | 0.28 | 42 | 0.44 | 9 | 0.29 | 15 | 0.31 | 16 | 0.88 |
| *Avena* sp. awn fragments | p | | p | | p | | p | | p | | p | |
| *Bromus* sp. | 14 | 0.45 | 29 | 0.68 | 123 | 1.28 | 34 | 1.11 | 79 | 1.66 | 34 | 1.86 |
| *Eremopyrum* sp. | - | - | - | - | - | - | - | - | 8 | 0.17 | 3 | 0.16 |
| *Eremopyrum*/*Agropyron* | 1 | 0.03 | 2 | 0.05 | 11 | 0.11 | 2 | 0.07 | - | - | 1 | 0.05 |
| *Hordeum* sp. | 23 | 0.74 | 24 | 0.57 | 46 | 0.48 | 59 | 1.93 | 181 | 3.80 | 49 | 2.69 |
| *Hordeum spontaneum* | 51 | 1.64 | 79 | 1.86 | 293 | 3.04 | 114 | 3.72 | 275 | 5.77 | 98 | 5.37 |
| *Hordeum* cf. *spontaneum* | 3 | 0.10 | 18 | 0.42 | 18 | 0.19 | 6 | 0.20 | 22 | 0.46 | 20 | 1.10 |
| *Hordeum spontaneum* spikelets | 111 | 3.57 | 166 | 3.91 | 372 | 3.86 | 116 | 3.79 | 112 | 2.35 | 112 | 6.14 |
| *Pennisetum* type | 3 | 0.10 | - | - | - | - | - | - | - | - | - | - |
| *Phalaris* sp. | 337 | 10.85 | 151 | 3.56 | 498 | 5.17 | 128 | 4.18 | 37 | 0.78 | 17 | 0.93 |
| *Phleum* type | 295 | 9.49 | 977 | 23.01 | 2943 | 30.57 | 776 | 25.35 | 109 | 2.29 | 30 | 1.64 |
| *Poa bulbosa* bulbils | - | - | 1 | 0.02 | 1 | 0.01 | 1 | 0.03 | 76 | 1.59 | 6 | 0.33 |
| *Taeniatherum caput-medusae* | 3 | 0.10 | 14 | 0.33 | 26 | 0.27 | 14 | 0.46 | 10 | 0.21 | 3 | 0.16 |
| *Taeniatherum caput-medusae* spikelets | 5 | 0.16 | 12 | 0.28 | 10 | 0.10 | 9 | 0.29 | 1 | 0.02 | 2 | 0.11 |
| Triticoid type | 17 | 0.55 | 41 | 0.97 | 113 | 1.17 | 56 | 1.83 | 49 | 1.03 | 11 | 0.60 |
| cf. *Triticum* sp. | 6 | 0.19 | - | - | - | - | - | - | - | - | - | - |
| *Triticum boeoticum* spikelets | 11 | 0.35 | 7 | 0.16 | - | - | - | - | - | - | 1 | 0.05 |
| *Triticum dicoccoides*/*dicoccum* spikelets | 77 | 2.45 | 16 | 0.38 | 2 | 0.02 | - | - | 1 | 0.02 | 5 | 0.27 |
| *Triticum* sp. spikelets | 165 | 5.34 | 25 | 0.59 | 3 | 0.03 | - | - | 3 | 0.06 | 14 | 0.77 |
| Indeterminate spikelet type | 60 | 1.93 | 80 | 1.88 | 48 | 0.50 | 129 | 4.21 | 26 | 0.55 | 57 | 3.13 |
| Poaceae indet. glumes | 47 | 1.51 | 8 | 0.19 | - | - | 3 | 0.10 | - | - | - | - |
| Poaceae indet. spikelets | 3 | 0.10 | 8 | 0.19 | 4 | 0.04 | 13 | 0.42 | 8 | 0.17 | 19 | 1.04 |
| Poaceae indet. large | 66 | 2.12 | 33 | 0.78 | 59 | 0.61 | 12 | 0.39 | 21 | 0.44 | 10 | 0.55 |
| Poaceae indet. medium | 163 | 5.25 | 129 | 3.04 | 214 | 2.22 | 51 | 1.67 | 69 | 1.45 | 60 | 3.29 |
| Poaceae indet. small | 337 | 10.85 | 974 | 22.94 | 2054 | 21.33 | 322 | 10.52 | 198 | 4.16 | 100 | 5.48 |
| **Polygonaceae** | | | | | | | | | | | | |
| *Rumex*/*Polygonum* | 2 | 0.06 | - | - | - | - | - | - | - | - | - | - |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ranunculaceae** | | | | | | | | | | | | |
| *Adonis* sp. | - | - | 2 | 0.05 | 2 | 0.02 | - | - | 4 | 0.08 | - | - |
| **Rubiaceae** | - | - | - | - | - | - | - | - | - | - | - | - |
| *Galium* sp. | 5 | 0.16 | 3 | 0.07 | 3 | 0.03 | 9 | 0.29 | 8 | 0.17 | 1 | 0.05 |
| **Indeterminate types** | | | | | | | | | | | | |
| Indeterminate type 1 | - | - | 2 | 0.05 | - | - | - | - | - | - | - | - |
| Indeterminate type 2 | - | - | 3 | 0.07 | - | - | - | - | 1 | 0.02 | - | - |
| Indeterminate type 3 | - | - | - | - | 4 | 0.04 | - | - | 4 | 0.08 | - | - |
| Indeterminate type 4 | - | - | - | - | 4 | 0.04 | - | - | - | - | - | - |
| Indeterminate type 5 | - | - | - | - | - | - | - | - | 3 | 0.06 | - | - |
| Indeterminate type 6 | - | - | - | - | 8 | 0.08 | - | - | 25 | 0.52 | 8 | 0.44 |
| Indeterminate | 139 | 4.47 | 236 | 5.56 | 260 | 2.70 | 94 | 3.07 | 193 | 4.05 | 87 | 4.77 |

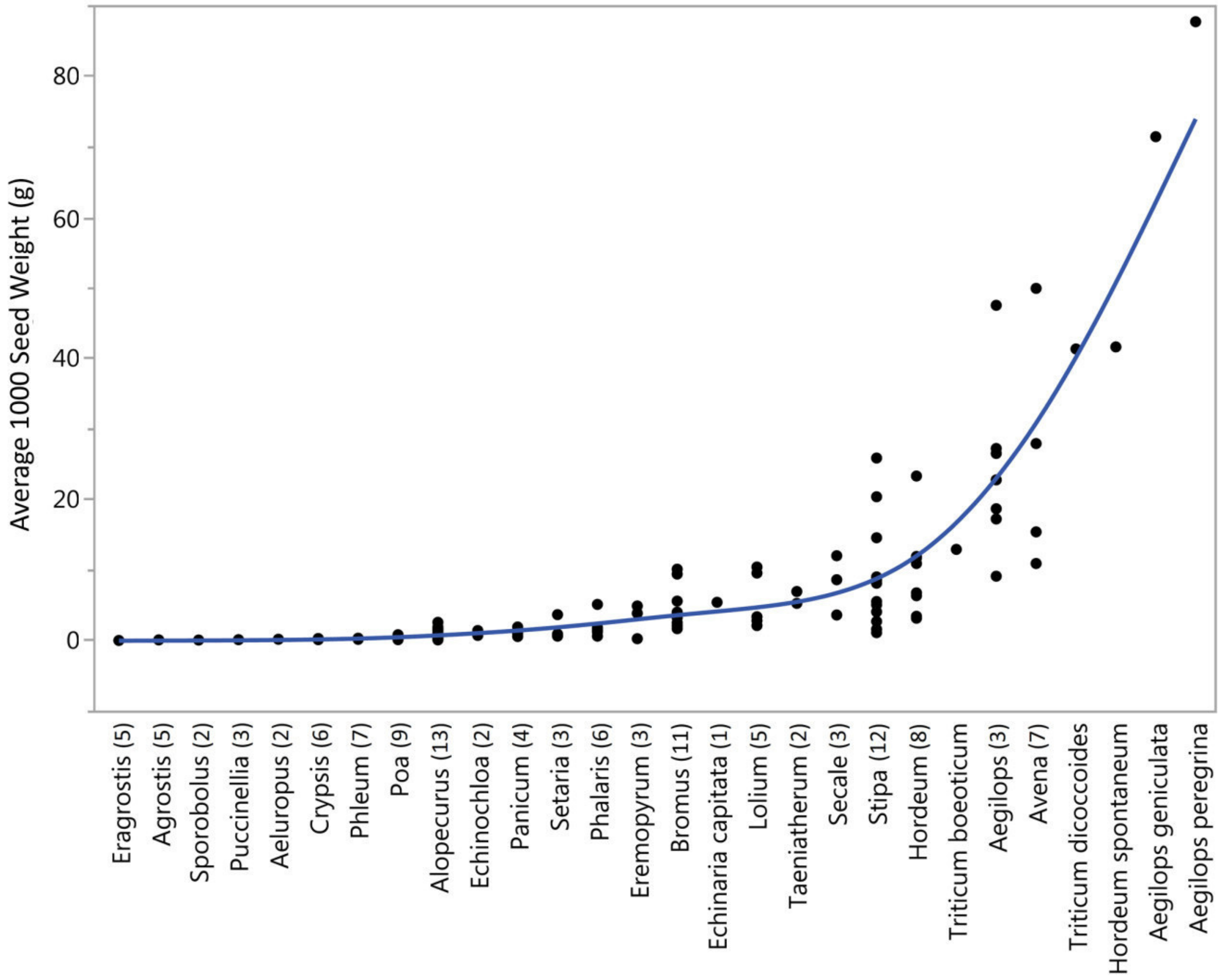
If no other information is given, identifications represent charred fruits or seeds. Note that the data from AH II were already published elsewhere [44]; p = present.

**S3 Table.** Coding of the variables in the correspondence analysis.

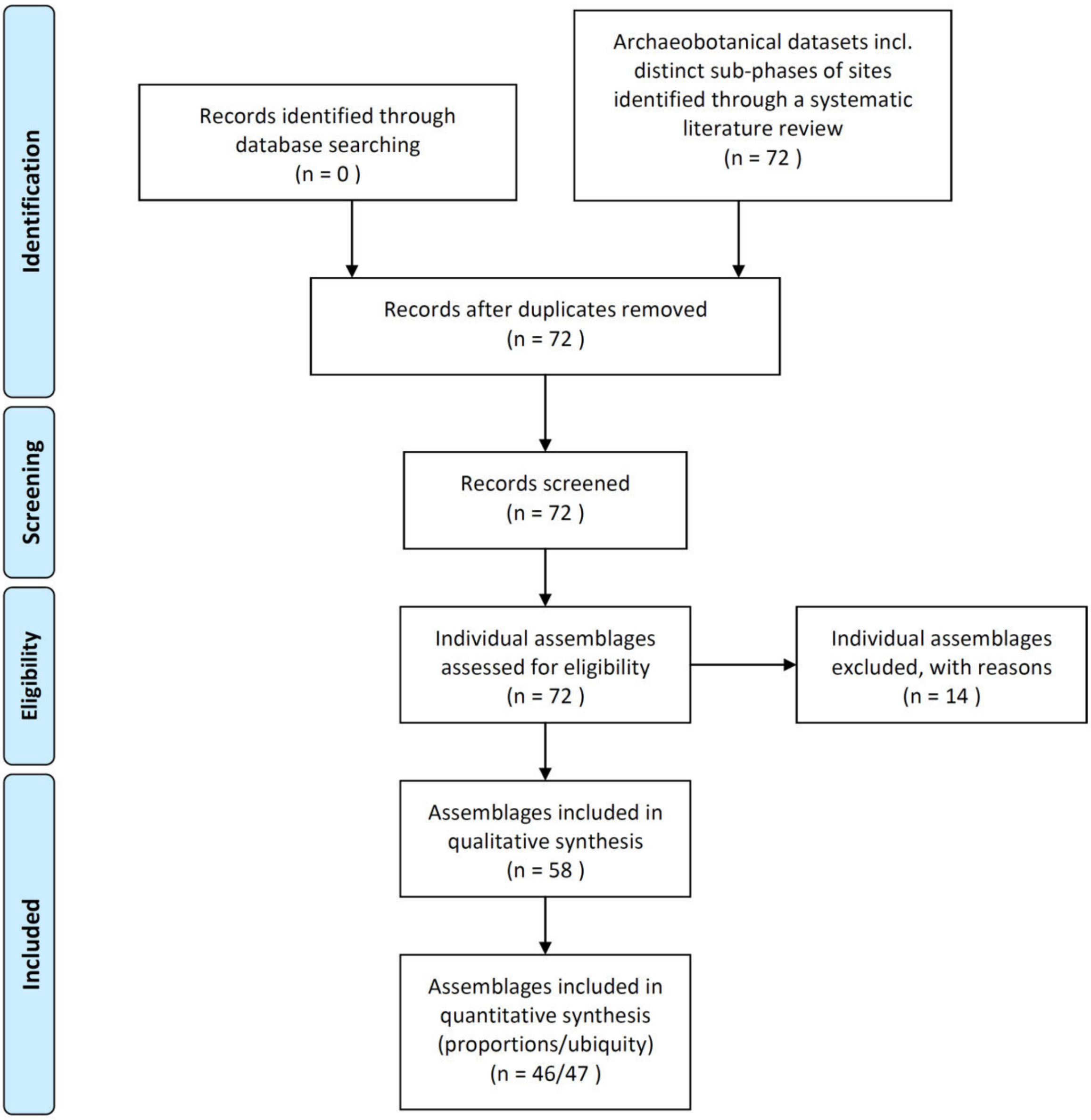
| Number/Code | Taxon/category |
|---|---|
| 1 | *Aegilops* grain |
| 2 | *Aegilops* spikelets |
| 3 | Amaranthaceae |
| 4 | Asteraceae |
| 5 | *Astragalus*/*Medicago*/*Trigonella* |
| 6 | *Avena* |
| 7 | *Bolboschoenus glaucus* |
| 8 | Brassicaceae |
| 9 | *Bromus* |
| 10 | Cyperaceae |
| 11 | Fabaceae inet. large |
| 12 | Fabaceae indet. medium-small |
| 13 | *Galium* |
| 14 | *Heliotropium* |
| 15 | *Hordeum* |
| 16 | *Hordeum spontaneum* grain |
| 17 | *Hordeum spontaneum* spikelets |
| 18 | Indet. spikelet type |
| 19 | *Lathyrus*/*Pisum*/*Vicia* |
| 20 | *Lens* |
| 21 | *Malva* |
| 22 | *Phalaris* |
| 23 | *Phleum* type |
| 24 | *Pistacia* |
| 25 | *Pisum* |
| 26 | Poaceae chaff indet. |
| 27 | Poaceae indet. large |
| 28 | Poaceae indet. medium |
| 29 | Poaceae indet. small |
| 30 | *Silene*/*Gypsophila* |
| 31 | *Taeniatherum caput-medusae* grain |
| 32 | *Taeniatherum caput-medusae* spikelets |
| 33 | Triticoid type |
| Agr/Erem | *Agropyron*/*Eremopyrum* |
| Bell/Mus/Orni | *Bellevalia*/*Muscari*/*Ornithogalum* |
| BugArv | *Buglossoides arvensis* |
| BugTen | *Buglossoides tenuiflora* |
| Cap/Des | *Capsella*/*Descurainia* |
| Caryop | Caryophyllaceae |
| PoaBulb | *Poa bulbosa* bulbils |
| TritSpik | *Triticum* spikelets |




**S1 Fig. The site of Chogha Golan.** (A) The landscape around Chogha Golan; (B) outline of the site with the location of the deep sounding and excavation Area A in the center of the tell; (C) the south profile of the deep sounding showing Archaeological Horizons I to XI and the related z-values. Figures and photos by M. Zeidi.



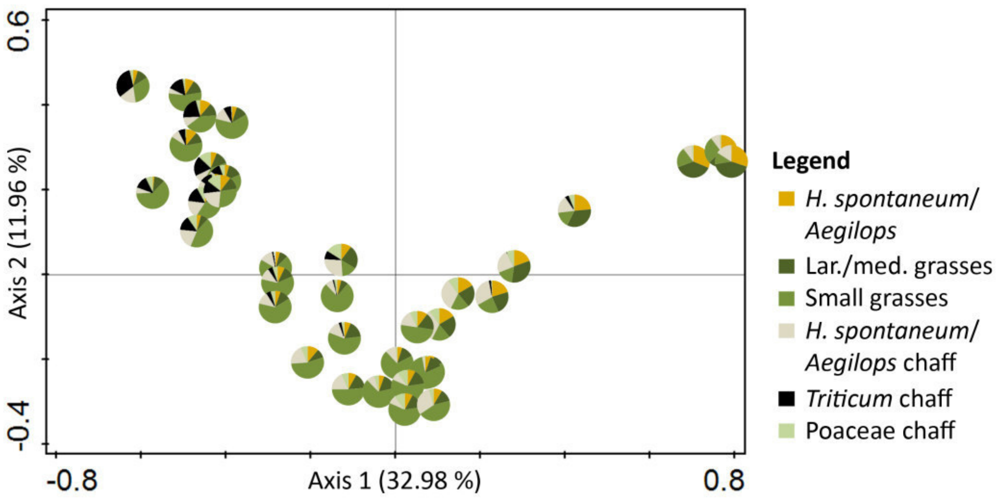

**S2 Fig. Average grain weight of Poaceae taxa frequently identified among charred archaeobotanical assemblages from the Near East.** Calculations are based on the average 1000 seed weight given in the Seed Information Database (SID) of the Royal Botanic Gardens Kew [67]. Numbers in brackets give the number of extant Near Eastern species or subspecies for which measurements were available. The average seed weight for the single species is also based on multiple measurements from different accessions; for information on these data please see SID.



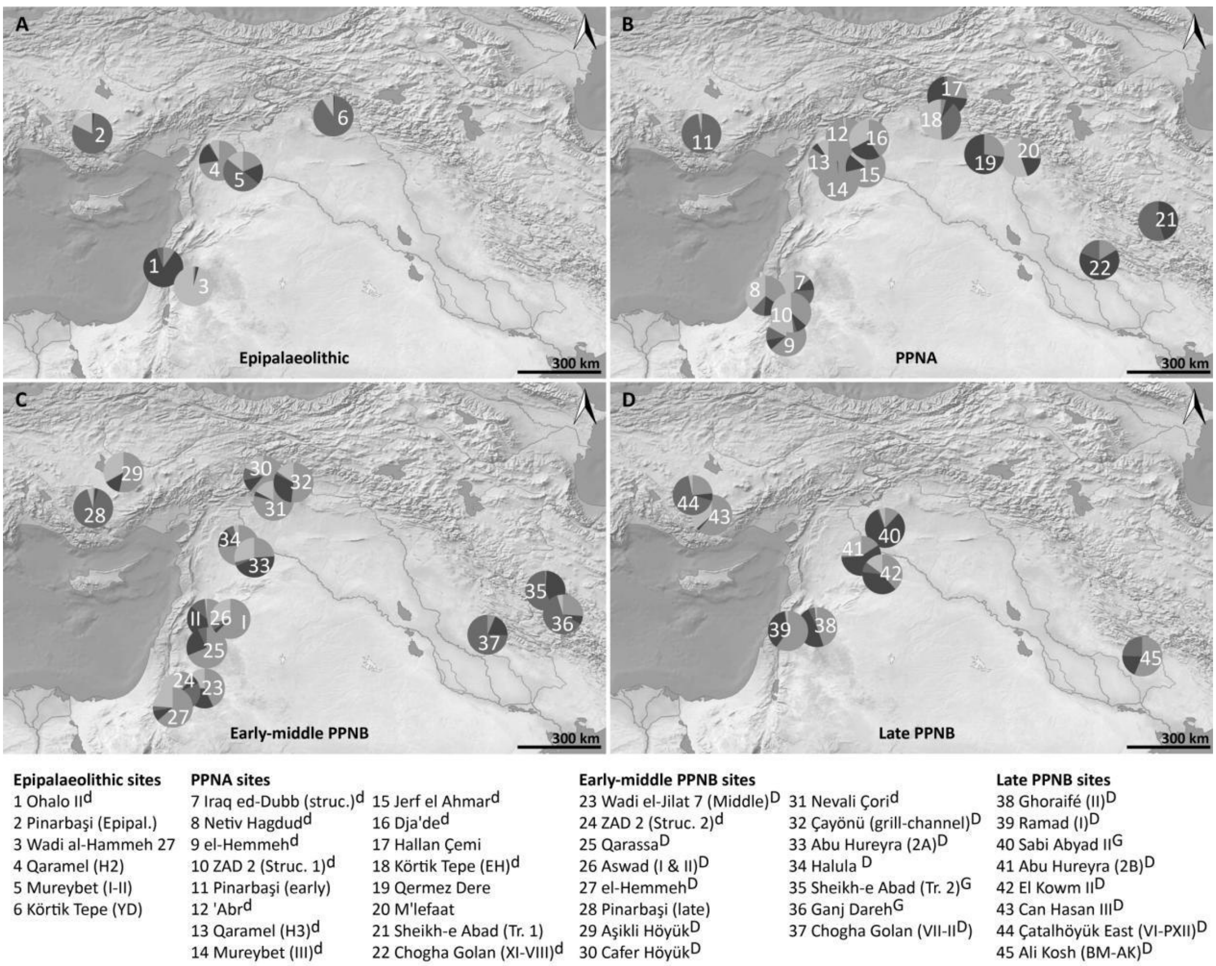

*From:* Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

**For more information, visit www.prisma-statement.org.**

**S3 Fig. PRISMA flow diagram showing the impact of the selection criteria on the screened datasets.**




**S4 Fig. The composition of Poaceae remains in the samples used in the correspondence analysis.** Note that the strong temporal trend throughout the sequence is also visible in the Poaceae remains. Whereas the older samples from AH VII and VI have low percentages of small grains (right end of axis 1), samples from the middle part of the analyzed sequence are dominated by these taxa. Emmer wheat chaff remains characterize samples from AH III and II, where small grains are still very abundant (left end of axis 1). Large to medium seeded wild grasses are in all samples more abundant than grains of H. spontaneum and Aegilops sp. together.




**S5 Fig. Detailed key for the sites included in the temporal and spatial analysis of grain proportions.**

# Appendix C

## The Significance of Social Change

## for Understanding Patterns in Near Eastern Cereal Domestication

**Alexander Weide**

**Submitted to Paléorient (28th February 2018)**

# The Significance of Social Change for Understanding Patterns in Near Eastern Cereal Domestication

Alexander Weide

**Abstract**

This paper aims at integrating social factors in the explanatory frameworks for the emergence and development of cereal cultivation and domestication in the Levant. The current model is characterized by a pre-domestication cultivation phase during the Pre-Pottery Neolithic (PPN) A and a protracted appearance of phenotypic domestication traits since the early PPNB. Most researchers focus on agro-technological and environmental factors for explaining these patterns, while arguing within a paradigm of unconscious selection. In assessing which social factors are highly entangled with subsistence developments in anthropological theory and the archaeological record, I suggest changes in storage practices and their relation to different notions of ownership on the way to independent households as the major features, which need to be considered in current explanatory frameworks. Viewed from this socioeconomic perspective, we will be able to better integrate the evidence for cultivated cereals from Ohalo II, dating back to 23,000 cal BP, into the current model. I finally propose that the slow pace of Near Eastern cereal domestication was based on a socioeconomic environment that only slowly established the conditions for selection, both automatic and conscious, highlighting that we need a more nuanced argumentative basis for rejecting conscious selection in the initial domestication phase.

Cet article a pour but d'intégrer les aspects sociaux dans les structures explicatives de l'émergence et du développement de la cultivation des céréales et de la domestication dans le Levant. Le modèle actuel se caractérise par une phase de cultivation pré-domestication pendant le Néolithique précéramique A et une apparence une prolongation de l'apparence des traits de domestication à partir du Néolithique précéramique B. Une majorité de chercheurs se concentrent sur les facteurs agro-technologiques et de l'environnement pour expliquer ce modèle, argumentant dans le cadre d'un paradigme de sélection inconsciente. Dans l'évaluation des facteurs sociaux hautement mêlés au développement de subsistance selon la théorie anthropologique et l'empreinte archéologique, je propose des changements dans l'usage des stockages et leurs relations avec différentes notions de possession et propriété sur le chemin vers des ménages indépendants en tant que caractéristiques majeures, qui nécessitent d'être considéré dans les cadres explicatifs actuels. De ce point de vue socio-économique, nous serons capables de mieux intégrer les preuves archéologiques de céréales cultivées de Ohalo II, daté à 23000 cal BP, dans le modèle actuel. Enfin, je propose que le lent cours de la domestication de céréales dans le Proche Orient était basé sur un environnement socio-économique qui établit de manières ralenti les conditions pour la sélection, à la fois automatique et consciente, mettant ainsi l'accent sur notre besoin d'une d'argumentation pour le rejet de sélection consciente dans la première phase de domestication plus nuancée.

**Keywords**

Pre-Pottery Neolithic; Domestication; Ownership; Households; Unconscious Selection

Néolithique Précéramique; Domestication; Possession; Ménages; Sélection Inconsciente

**INTRODUCTION**

The domestication of plants and animals represents an essential component of the Neolithic transition in the Near East, deeply entangled with social developments during times of profound climatic changes. Based on a detailed archaeological record and a long research history, current scholars who investigate the origins of agricultural societies in the Levant place domestication at the very end of a long evolutionary development from the Last Glacial Maximum (LGM) into the Early Holocene (Bar-Yosef and Belfer-Cohen 1989; Bar-Yosef and Meadow 1995; Byrd 2005; Zeder 2009, 2011a; Sterelny and Watkins 2015; Watkins 2016; Hodder 2017). Within these frameworks, domestication is commonly defined from a biological perspective: The accumulation of morphological and physiological traits selected for under increasing human influence on the reproduction cycle of an animal or plant species (Darwin 1868; Harlan *et al*. 1973; Bökönyi 1989; Ducos 1989; Hillman and Davies 1990; Gepts 2004). This traditional definition received important feedbacks and adjustments from archaeological fieldwork. Particularly research on animal domestication in the Zagros Mountains revealed that morphological domestication markers cannot serve for detecting the initial steps towards domestication, as a considerably long time of selective hunting and herding strategies predates morphological change in sheep and goats (Zeder and Hesse 2000; Zeder 2008). This is also true for plant domestication in the Fertile Crescent, as cereal and legume cultivation presumably predated the appearance of phenotypic domestication traits by at least one millennium (Tanno and Willcox 2006; Fuller 2007; Willcox *et al.* 2008). Zeder (2006, 2015) therefore defines domestication as a continuum of increasing interdependence between humans and an animal or plant species. In contrast to an understanding of domestication as an intended process of humans achieving control over an animal or plant species (Bökönyi 1989; Ducos 1989; Meadow 1989), she instead adopts the view of domestication being a mutual relationship between two partners (Rindos 1984). In this perspective, the ability of humans to spontaneously adopt and transmit socially learned behaviors represents the major difference between domestication and any other mutual relationship or symbiosis (Zeder 2006).

A definitive line between a wild and a domestic animal or plant can, based on this approach, hardly be defined for most bio-archaeological materials dating to the Pleistocene-Holocene transition (Zeder 2006; Fuller *et al.* 2012a). Although this definition brings along serious limitations in detecting initial steps towards domestication, it is today widely accepted and supported by empirical observations (Zeder and Hesse 2000; Willcox *et al.* 2008; Purugganan and Fuller 2011; Vigne 2011; Zeder 2009, 2011b). Besides a protracted period of time considered in these domestication models, the interconnectedness between biological, technological and socio-cultural factors characterizes modern domestication research (Zeder 2015).

The earliest well dated and fully published evidences for plant remains exhibiting morphological domestication features derive from sites in the southern Levant and central to southeast Anatolia and date to between 10,700 – 10,200 cal BP in the early Pre-Pottery Neolithic (PPN) B period (Tanno and Willcox 2012; Arranz-Otaegui *et al*. 2016a). They are represented by chaff fragments from non-shattering cereals, which emerged after a period of wild cereal cultivation, also called pre-domestication cultivation, of at least 1,000 years throughout the PPNA. However, experimental research has indicated that cereals could have been domesticated within 20 to 200 years (Hillman and Davies 1990). The long period of wild cereal cultivation during the PPNA therefore needs some explanation and, as I will point out in more detail below, most scholars argue from a strong agro-technological perspective, interwoven with ecological factors, for explaining this pattern. In addition, the absence of conscious selection represents a major paradigm under which many scholars view the slow pace of Near Eastern plant domestication (Harlan *et al*. 1973; Purugganan and Fuller 2011; Fuller *et al*. 2012a; Tanno and Willcox 2012; but see Abbo and Gopher 2017).

Snir *et al*. (2015) recently published additional data from the Early Epipalaeolithic site of Ohalo II at the shore of the Sea of Galilee and suggested small-scale cereal cultivation at around 23,000 cal BP. The evidence is based on an arable weed flora and relatively high percentages of domestic-type barley (36 %) and emmer wheat (25 %) rachises. As the authors note, this evidence for cultivation practices, apparently selecting for domestic-type individuals, predates the conventional date for the emergence of cultivation by almost 12,000 years and challenges the view that plant cultivation and domestication is a predominantly Holocene phenomenon (Bettinger *et al*. 2009; Willcox *et al.* 2009; Asouti and Fuller 2012; Asouti 2013, 2017). This finding adds an interesting perspective on Near Eastern cereal domestication, as it highlights that the pure technological requirements for the selection of domestication traits were already met 23,000 years ago. In light of this assumption, a focus on agro-technological factors for explaining the slow pace of cereal domestication might be insufficient and social developments during the PPN were indeed rarely considered to understand this distinctive pattern. This is in accordance with several recent studies on cereal domestication, which emphasized the importance of social factors for understanding economic change throughout the Neolithic transition (e.g. Willcox 2005; Fuller *et al.* 2010; Asouti and Fuller 2013; Arranz-Otaegui *et al.* 2016a; Asouti 2017; Weide *et al.* 2018).

In this paper I attempt to integrate several social factors in the existing explanatory framework for the initial appearance and subsequent development of cereal cultivation and domestication. I will first outline the current model for Near Eastern plant domestication and argue that explanations emphasizing agro-technological factors and a lack of conscious selection fall too short for understanding this pattern. In the next section I discuss which social factors are highly entangled with subsistence developments in anthropological theory and the archaeological record and suggest changes in storage practices and their relation to different notions of ownership on the way to independent households as the major features, which need to be incorporated into current domestication models. Based on this discussion, I will finally evaluate the importance of conscious selection and the place of Ohalo II in the general framework of Near Eastern agricultural origins.

## PATTERNS IN NEAR EASTERN CEREAL DOMESTICATION

I will confine this overview to the subject of plant domestication in the Levantine corridor (Bar-Yosef and Belfer-Cohen 1989: 484) and focus on the evidence for cereals (barley, emmer and einkorn), because this taxonomic group provides the best record for investigating domestication and the concurrent social developments. Besides cereals, legumes are an important group of which several species have been domesticated during the Early Neolithic, but pod remains as the most important morphological markers for early domestication traits are hardly preserved on Near Eastern sites (Zohary *et al*. 2012). The record for legume domestication is therefore frustratingly incomplete and cannot be compared to the socioeconomic development with the same detail.

### THE PROTRACTED, MULTIPLE-CENTER DOMESTICATION MODEL

The majority of researchers who investigated Near Eastern plant domestication during the last two decades regard cereal domestication as a regionally diffused and temporarily protracted process (Colledge 2001; Nesbitt 2004; Willcox 2002, 2005; Tanno and Willcox 2006, 2012; Fuller 2007; Allaby *et al*. 2008, 2017; Willcox *et al.*

2008; Asouti and Fuller 2012, 2013; Fuller *et al.* 2012a, b; Riehl *et al.* 2013; Arranz-Otaegui *et al.* 2016a; Weide *et al.* 2018). This protracted, multiple-center domestication model is predominantly based upon the cereal record and assumes a considerable time gap of at least 1,000 years between the onset of cereal cultivation with the end of the Younger Dryas and the appearance of phenotypic domestication traits shortly after ~10,700 cal BP. Such a pre-domestication cultivation period is indicated by a heavy focus on wild cereals at many sites since the late Younger Dryas, which was accompanied by increasing cereal grain sizes, declining percentages of formerly gathered taxa and an increase in the number of potential arable weeds (Colledge 2002; Willcox 2004, 2012; Willcox *et al*. 2008, 2009). This combined evidence was originally compiled for sites along the upper Euphrates, but a protracted period of pre-domestication cultivation has also been suggested for several sites in the southern Levant (Kislev 1997; Colledge 2001; Meadows 2004; Weiss *et al*. 2006; White and Makarewicz 2012; Colledge and Conolly 2018), and therefore characterizes subsistence strategies throughout most of the PPNA in the Levantine corridor (ca. 11,700 – 10,700 cal BP). The potential cultivars under discussion comprise all wild progenitor species of the Near Eastern founder crops (Zohary *et al*. 2012). In addition, wild oat (*Avena sterilis*), rambling vetch (*Vicia peregrina*) and parthenocarpic figs (*Ficus carica*) have possibly been cultivated in the southern Levant (Kislev *et al*. 2006; Weiss *et al.* 2006; Melamed *et al.* 2008), wild ryes (*Secale* spp.) in the northern Levant and seeds of *Vicia faba*, although rare, appear on PPNA sites in the entire Levant (Fuller *et al.* 2012b).

Early evidence for morphologically domesticated cereals dates to the early PPNB (ca. 10,700 – 10,200 cal BP) and comes from the sites of Çayönü and Cafer Höyük in southeast Anatolia, Aşikli Höyük in central Anatolia, and Tell Aswad and Tell Qarassa in southern Syria (Tanno and Willcox 2012; Arranz-Otaegui *et al*. 2016b). Due to this geographically widespread appearance of the first domesticates, a single origin of all founder crops is widely rejected by proponents of this model (Willcox 2002, 2005; Fuller *et al*. 2011, 2012b; Arranz-Otaegui *et al*. 2016a). Early evidences for domestic cereals consist of proportions of non-shattering spikelets among the chaff remains that exceed those found in modern wild populations (Kislev 1989). Although the domestication syndrome for plants comprises a much longer list of adaptive traits (Harlan *et al*. 1973; Hammer 1984), many authors refer to the loss of natural seed dispersal as a central domestication feature (Zohary 1969; Hillman and Davies 1990; Gepts 2004). The relatively robust chaff remains are regularly preserved and non-shattering can be directly identified among archaeobotanical specimens, as opposed to other domestication traits such as reduced dormancy or synchronous ripening (Fuller 2007). For cereals with spikes, non-shattering can be identified by investigating the abscission scars on the rachis segments of the single spikelets, which appear regular and smooth in wild (=shattering) cereals and rough in domestic (=non-shattering) cereals (Tanno and Willcox 2012). The identification of >10% of non-shattering rachises among the chaff remains of an archaeobotanical assemblage is therefore commonly interpreted as the emergence of one domestication trait, but not as a completed domestication event (Snir *et al*. 2015). The appearance of entirely non-shattering populations co-occurred with the establishment of modern grain sizes and stretched over an additional 2,000 years (Fuller *et al*. 2012a). This slow and gradual appearance of single domestication traits characterizes the protracted domestication model, which as a result assumes low selection rates under domestication and no or only a limited influence of conscious selection (Purugganan and Fuller 2011; Fuller *et al*. 2012a; Allaby *et al*. 2017).

Taken as a whole, the pre-domestication cultivation period during most of the PPNA, the first appearance of domestic-type cereal chaff during the early PPNB, and the establishment of entirely non-shattering populations towards the late PPNB, took about 3,000 years. In this scenario, one particular feature must be emphasized and further discussed. Hillman and Davies (1990) experimentally cultivated wild einkorn and concluded that it could have been domesticated (100% non-shattering ears) by as little as 20 to 200 years. This calculation excluded conscious selection during the initial phase of cultivation and assumed that sickle harvesting or uprooting of entire plants favors non-shattering individuals, as the ripe, brittle ears would shatter during the harvesting process. This suggestion, that cereal domestication could have been rather fast, even without conscious selection in its initial stages, is in major conflict with the archaeobotanical record and requires explanation.

Most authors suggest different harvesting methods and variable cultivation regimes to explain this "time paradox". For their rapid model, Hillman and Davies assumed a certain mix of factors and practices, including a harvesting technique that favors non-shattering individuals and a change of location of the cultivated plot from time to time. If seeds are sown on the same field every year, the grains that shattered in the preceding harvesting season would contribute to the next stock, reducing the selection for non-brittle ears. Kislev *et al*. (2004) specifically discussed ground collection, which would also continuously favor shattering ears under cultivation. While these practices would only reduce the selection for non-shattering individuals, harvesting methods that make use of the brittleness of wild cereal ears would subsequently not select for non-shattering types at all. Beating ripe spikelets into a basket represents such a method, which is well documented ethnographically (Bohrer 1972; Harlan 1989; Batello *et al*. 2004) and was found an effective harvesting method by Hillman and Davies. Additional factors discriminating against non-shattering individuals might have been harvesting partially green ears to avoid yield loss through shattering or replenishing seed stocks after poor harvests by gathering in wild stands (Tanno and Willcox 2006, 2012; Willcox *et al*. 2008; Fuller *et al.* 2010; White and Makarewicz 2012). However, except for harvesting partially green ears (Ibáñez *et al.* 2016) and possibly ground collecting (Kislev *et al*. 2004), none of these factors could be linked to PPNA subsistence practices based on archaeological data, so they remain hypothetical (Asouti 2013). Other contributions emphasized the generally slow rate of selection under domestication, also specifically discussing possible agro-technological factors or genetic constraints as responsible for this pattern, which is then viewed within a paradigm of a naturally slow co-evolution between humans and domesticates (Fuller *et al*. 2010, 2012a, 2015; Purugganan and Fuller 2011; Allaby *et al.* 2015a, 2017).

Asouti (2013, 2017) expressed a somewhat different view and generally challenges the opinion that pre-domestication cultivation during the PPNA was an intensive and widespread subsistence strategy (see also Asouti and Fuller 2013). In accordance with many other authors (see below), she doubts that PPNA villages can be equalized with fully sedentary communities and expects a still high residential mobility among early Holocene groups. This would be an important factor inhibiting the long-term adoption of cultivation during the Early Holocene, which could have lead to the appearance of domestic cereals. As a second reason for why cultivation during the PPNA was not as widespread as many authors assume, she refers to palaeoclimatic data and suggests that still unstable environmental conditions did not render Early Holocene cultivation a reliable long-term subsistence strategy (Asouti 2017).

In conclusion, the protracted domestication model mostly relies on archaeobotanical evidence for non-shattering in cereals. The slow pace of Near Eastern cereal domestication is commonly explained with a hypothetical mix of agro-technological practices and possibly a still high degree of mobility that resulted in a slow and by implication unconscious selection for phenotypic traits, stretching over about 3,000 years during the Early Holocene.

## NON-SHATTERING CEREALS AT OHALO II

What I have not taken into consideration until now is the recently published evidence for the appearance of relatively high percentages of non-shattering cereal spikelets at Ohalo II (Snir *et al*. 2015). The loss of natural seed dispersal significantly reduced the ability of a plant to reproduce and to survive in its habitat (Harlan *et al*. 1973; Hammer 1984; Hillman and Davies 1990). It is therefore generally assumed that non-shattering cereals can only emerge under cultivation. Based on this assumption, the Ohalo II data raise two important points: (1) If the inhabitants of Ohalo II could cultivate cereals in a way that favored non-shattering individuals, the necessary agro-technological requirements were obviously met 23,000 years ago and should not be a major constraint for the selection of domestication traits during the PPNA. (2) If we assume a still high mobility of PPNA groups, coupled with unstable environmental conditions, for explaining the absence of morphological evidence for domestic cereals during ca. 1,000 years of pre-domestication cultivation, we must also ask why a small band of foragers during the LGM was able to select for non-shattering cereals under cultivation? More precisely, residential mobility and climatic instability might explain why cultivation was not adopted for the long-term during the PPNA (Asouti 2013, 2017), but the case study from Ohalo II suggests that non-shattering cereals still could have emerged over and over again at various PPNA settlements. This was, however, not the case and I feel this striking absence of any domestic cereal remains during the PPNA requires a more nuanced explanation than simply assuming a hypothetical “non-selective” cultivation regime, based on the absence of conscious selection and a still high seasonal mobility. Linked to these issues is the curial question why non-shattering cereals did eventually emerge during the early PPNB and became established in many communities during the middle PPNB? In my opinion, this rather distinctive pattern of Near Eastern cereal domestication is not simply a matter of unconscious selection. If we assume a change in agro-technological practices to be responsible for the emergence of non-shattering cereals since the early PPNB, then we might pose the question what exactly induced this change of cultivation practices?

While some authors view the data from Ohalo II as indicative of a dead-end development with no further significance for agricultural origins (Gibbs and Jordan 2016; Ibáñez *et al.* 2016), or discount the interpretation as an outgrowth of the pre-domestication cultivation paradigm (Abbo and Gopher 2017), Allaby and his colleagues tried to integrate it into the protracted domestication model (Allaby *et al.* 2017). In revising their calculations of selection coefficients for non-shattering cereals throughout the Neolithic transition, they identified the period between ca. 10,500 and 9,500 cal BP (~ early and middle PPNB) where selection coefficients were highest for hulled barley, einkorn and emmer wheat. Selection coeffients dropped after this episode, because high percentages of non-shattering spikelets were already achieved. The authors also used these calculations to trace back the origins of selection in time. For barley and emmer wheat they determined a start of selection somewhere between ca. 17,800 and 25,600 cal BP. This matches the data from Ohalo II, dating to about 23,000 cal BP, and they indeed cite this dataset in support of their calculations (Allaby *et al.* 2017: 5). In a short attempt to explain such an early start of selection, they speculate whether cultivation was possibly not involved at all, and if the impacts of intensive gathering activities could have caused selection for non-shattering ears. They do not maintain this argument as such effects, given they would exist, should have been more regularly detected among archaeobotanical datasets of Late Pleistocene foragers. This conclusion is similar to my argument above, raising the question why such patterns exist at Ohalo II but nowhere else until the early PPNB? For most Epipalaeolithic sites this is easily explained, because carbonized plant remains have not been retrieved from most excavations due to taphonomic reasons and poor preservation conditions (Bar-Yosef 1998; Asouti and Fuller 2012). In contrast, PPNA sites yielded plenty of charred plant remains, but cereal chaff well into the PPNB is dominated by shattering spikelets.

In order to build up on recent discussions on the slow pace of Near Eastern cereal domestication, the next section surveys anthropological and ethno-archaeological models for the interrelatedness of social and economic change. Many scholars applied these models to the PPN record, which provides interesting insights into possible links between the social organization and the subsistence strategy of Early Holocene communities.

## ECONOMIC AND SOCIAL CHANGE IN ANTHROPOLOGICAL THEORY

At the core of the discussion about the emergence of social complexity and its strong link to economic change lies a quite simple observation. In an influential article, Woodburn (1982) proposed a division of hunter-gatherer societies into those having an immediate-return and a delayed-return subsistence strategy. The former are characterized by the direct consumption of hunted and collected foodstuffs and the absence of sophisticated processing or storage techniques. The latter are characterized by the regular use of valuable harvesting and processing implements such as boats, nets, pit-traps, etc., the construction of storage facilities and resource management strategies. These practices altogether result in a temporal gap between the initial labor input into food acquisition/processing and consumption and are commonly associated with ownership systems and a variable degree of social inequality. In fact, the correlation between a delayed-return strategy and social inequality is his most significant observation, as Woodburn eventually proposed that the strong social leveling mechanisms in egalitarian (immediate-return) societies should inhibit the development of cultivation. More precisely, as food in immediate-return systems is not owned by individual persons or social groups and must obligatorily be shared, nobody would have the incentive to invest in labor-intensive cultivation or other time-consuming exploitation strategies.

At about the same time, Testart (1982) proposed a similar categorization of hunter-gatherers and concentrated on the presence of large-scale food storage to differentiate between egalitarian and socially complex societies. Like Woodburn, he recognized substantial differences in social complexity between storing and non-storing societies and put food storage and associated socioeconomic consequences in the center of his division. According to his model, large-scale food storage is based on seasonal variation in resource availability and a high efficiency of seasonal exploitation strategies. Furthermore, storage requires elaborate planning of these seasonal harvesting and food conservation practices and causes sedentism, because large amounts of stored foods cannot be transported over significant distances. He therefore rejected the presence of agriculture as the most fundamental economic division of non-industrial societies and proposed that the presence of large-scale food storage is more fundamental for differentiating egalitarian and socially complex communities. With this he provided an interesting perspective, but has also been criticized for this rather dogmatic view.

In his comment to Testart's thesis and a further article, Ingold (1982, 1983) argued that food storage *per se* is by no means indicative of social inequality, as stored foods can be communally owned and widely shared within and beyond social groups. He therefore differentiates between practical storage and social storage. The former simply represents the setting aside of food, the latter being the transmission of rights over foods (or materials in general) to individuals or groups, which constrain access to these resources and link their distribution to specific interests. Exactly this differentiation, the presence of large-scale storage facilities versus the development of property rights, will be important for the discussion. However, the debate in the ethnological and anthropological literature on the foundations of social complexity is still ongoing and far from being solved. Morgan (2012) provides an informative summary of the current models that discuss the relations between food storage and social complexity and concludes that there is only one point on which most researchers seem to agree: Social complexity, wherever it occurs, is always linked to storage and a high population density, but the simple presence of storage facilities cannot be used to infer social complexity and inequality. A relatively egalitarian society can thus store large amounts of food, as long as these foods are communally shared (Ingold 1983: 568).

Many archaeological theories modeling the Neolithic transition from a socioeconomic perspective rely on these principles (Bender 1978; Hayden 1990, 2009; Benz 2000; Bar-Yosef 2001; Kuijt and Goring-Morris 2002; Byrd 2005). Egalitarian societies with an immediate-return system know no individual property and obligatorily share food, which is part of a system of generalized reciprocity (Benz 2010). This practice, coupled with other leveling mechanisms, prevents the accumulation of material wealth to individuals and with this the gaining of authority. Turned around, this means that on the road to more complex societies with social inequalities, which always have some sort of delayed-return economic system, generalized reciprocity must be lowered and particularly cultivation and food storage require some form of property rights (Bowles and Choi 2013).

Benz (2000) arrived at similar conclusions by examining 43 hunter-gatherer groups and by investigating whether she could identify regularities during the transition to sedentism, storage and cultivation. She could not identify any fixed sequence of changes in these developments, which according to her results can occur in very different situations. Based upon these observations she concluded that the most important prerequisite for the successful, long-term adoption of cultivation is the lowering of reciprocity itself, which, as a minimal consequence, must allow for food storage. This involves the emergence of some sort of property rights and the reduction of the size of the social group with whom to share food. The actual reasons for the initial lowering of generalized reciprocity can be diverse, but include the increasing difficulties to share foods within a group or a failure of social sanctioning mechanisms, both related to stress situations in which mobility is no alternative solution. Hence, they should occur in increasingly sedentary communities.

Linked to a lowered reciprocity in growing sedentary communities is the need for new mechanisms to cope with social tensions. Mobile hunter-gatherers can react to social stress by leaving the group, but in light of an increased dependence on local or cultivated resources, this mechanism works no longer (Woodburn 1982). Increasing sedentism as a possible trigger for population growth is therefore an additional factor in the development of social inequalities. This perspective highlights the complex interrelatedness of social, economic and ecological factors during the transition to agricultural societies, with the development of different notions of ownership at the heart of socioeconomic change.

## TRENDS IN SOCIAL ORGANIZATION THROUHGOUT THE PRE-POTTERY NEOLITHIC

Studies on Early Neolithic social organization focus on the emergence of sedentism, associated population growth, increasingly independent and autonomous households, their integration into the wider community and the negotiation of social tensions that are linked to social differentiation and potential economic inequality. Comparable to the development of plant cultivation and domestication, most authors agree that social change only gradually unfolded throughout the PPN and acts in a complex web of interrelated factors (Byrd 1994, 2000, 2005; Bar-Yosef and Meadow 1995; Kuijt and Goring-Morris 2002; Zeder 2009; Kuijt *et al.* 2011; Atakuman 2014).

In the broadest sense, PPNA settlements in and around the Jordan Rift Valley, along the upper Euphrates and in southeast Anatolia represent sedentary hamlets and villages that reached sizes of up to 5 hectares (Bar-Yosef and Meadow 1995; Kuijt and Goring-Morris 2002; Byrd 2005; Özdoğan *et al.* 2011). Residential structures are commonly circular or oval in outline, often semi-subterranean and sometimes built on stone foundations. The significant investment in the construction and maintenance of these structures is traditionally taken as an argument for sedentism, although this cannot be equalized with a year-round occupation in general (Bar-Yosef and Meadow 1995; Bar-Yosef 2001; Asouti and Fuller 2013; Atakuman 2014; Asouti 2017). Residential buildings are often identified by associated "domestic" artifacts such as ground stone tools, whereas hearths were often located in open spaces (Kuijt and Goring-Morris 2002). Alongside such simple dwellings, some PPNA settlements contain structures that appear to have been used differently.

At Hallan Çemi and Körtik Tepe in the catchment area of the upper Tigris, the presence of several "public" or "special" buildings has been proposed by the excavators. The "public" buildings at Hallan Çemi are larger than residential structures, contain stone benches, lack domestic artifacts and instead yielded imported materials such as copper ore and obsidian (Rosenberg and Redding 2000; Rosenberg 2011). Özkaya and Coşkun (2011) interpret three structures at Körtik Tepe as possible "public" or "special" buildings, comparable to Hallan Çemi, and refer to their unique dimensions, floor preparation techniques and the presence of wild goat horns in one of the associated burials. In addition, round structures with pebble paved floors that are smaller than the residential buildings were excavated at both sites and possibly represent extramural storage facilities (Rosenberg and Redding 2000: fig. 3; Özkaya and Coşkun 2011: fig. 7). Comparable to the patterns at Hallan Çemi and Körtik Tepe, one semi-rectangular building at the nearby site of Gusir Höyük is significantly larger than the other round buildings and contains a central stone pillar. Karul (2011) emphasizes the similarities to Hallan Çemi and cautiously interprets this structure as a "special" or "cult" building. He notes, however, that several buildings at the site contained pillars, so the associated activities were possibly not restricted to this largest building.

More clear and quite elaborate communal buildings are known from PPNA sites along the upper Euphrates. At Jerf el Ahmar, several subterranean circular structures have been excavated, each containing peripheral benches and two being partitioned into several cells (Stordeur 2000; Stordeur *et al*. 2001). Within two of the cells in communal building 30, high densities of charred wild barley grains and chaff have been found, which Willcox and Stordeur (2012) take as the basis for interpreting the cells as communal storage facilities. Additionally, in the earlier building 47, a concentration of charred wild rye or einkorn grains could represent grain storage as well, possibly once stored in a basket. This building also contained three aurochs skulls and a hearth encircled by several pounders, which could link this possible grain storage to a ritual context (Stordeur 2000; Willcox and Stordeur 2012; Asouti and Fuller 2013). The general suggestion of cereal storage in the communal buildings at Jerf el Ahmar is supported by the fact that no other buildings at the site seem to contain storage structures (Stordeur and Willcox 2009). A communal building similar to building 30 at Jerf el Ahmar is also known from Mureybet and comparable structures have been excavated at Tell 'Abr (Stordeur *et al*. 2001; Yartah 2005). The sediments of the "public" building M1 at Tell 'Abr contained high densities of wild rye or einkorn grains, comparable to the finding in building 47 at Jerf el Ahmar. This large subterranean building also yielded aurochs bucrania, limestone basins and several querns (Yartah 2005). Willcox *et al*. (2008) likewise interpret this finding as indicative of a burned storage structure, which contributes to the general pattern of cereal storage in public or ritual contexts at the upper Euphrates during the later part of the PPNA. Noticeable, however, is the lack of storage structures in the youngest communal building at Jerf el Ahmar, which only contains a peripheral bench and dates to the PPNA/PPNB transition (Stordeur *et al*. 2001).

Altogether, the non-residential structures at several PPNA sites in the upper Tigris and Euphrates regions, often referred to as "special", "communal" or "cult" buildings, seem to represent a significant pattern. Due to the difficulties in reconstructing the exact activities performed in these buildings, their function is widely hypothetic and might encompass communal meetings, ritual ceremonies and are associated with storage of valuable raw materials and cereals (Stordeur 2000; Rosenberg 2011; Willcox and Stordeur 2012; Asouti and Fuller 2013). Food storage cannot be linked to the non-residential buildings at the Tigris sites, but the small circular paved structures at Hallan Çemi and Körtik Tepe possibly represent extramural storage silos.

Comparable non-residential buildings were long absent from excavated PPNA settlements in the southern Levant. The only larger structures that clearly represent communal building activities are the tower and the associated wall at Jericho (Kenyon 1981). Bar-Yosef (1986) and Kuijt (1996) interpret the tower as possibly linked to special rituals and referred to a collective burial situated in the tower entrance. Smaller structures around the tower have been considered to be communal storage facilities, although this is not fully clear (Bar-Yosef 1986; Kuijt and Goring-Morris 2002). Additional evidence for large communal structures has recently been reported from Wadi Faynan (WF) 16 in southern Jordan (Mithen *et al.* 2011). Adjacent to smaller circular buildings, the excavators unearthed a 22 x 19 m wide oval structure that comprises a multi-layered mud plaster floor and a decorated two-level bench over at least half of its circumference. Although the exact activities carried out in the structure remain unclear, Mithen *et al.* (2011) refer to the tower of Jericho and the monumental enclosures at Göbekli Tepe (Schmidt 2000, 2010) for highlighting its communal character in both, its construction and the performed activities.

Alongside such large structures that most likely were associated with rituals or communal gatherings, several free-standing storage silos have been excavated at WF 16, Dhra' and presumably also at Netiv Hagdud. Finlayson *et al*. (2011) interpret structure 045 at WF 16 as a storage silo, because it provides evidence for a suspended floor and contains a smaller structure made of pisé walls. While it is clear that structure 045 is no good candidate for a simple residential dwelling, Finlayson *et al.* (2011) compare this silo from WF 16 to a similar structure at Dhra', which has equally been interpreted as a free-standing storage silo. Four such structures were excavated at Dhra' and the general reconstruction depends on one well preserved example (Kuijt and Finlayson 2009). The authors draw particular attention to the *in situ* excavated upright notched stones, which presumably carried a suspended floor analogous to the structure at WF 16. Bar-Yosef and Gopher (1997) reported comparable structures from Netiv Hagdud, although here the notched stones are missing. The authors originally interpreted this structure as a possible storage silo, which the better preserved structures from Dhra' and WF 16 seem to support. Due to their size, extramural character and placement near the center of the settlements, these storage silos are thought to have been communally owned. By associating the large communal structure at WF 16 and the tower of Jericho with the communal granaries from WF 16, Dhra', Netiv Hagdud and possibly Jericho, patterns emerge that are comparable to the possible storage facilities in communal buildings at several upper Euphrates sites (Kuijt and Finlayson 2009; Finlayson *et al*. 2011). The PPNA throughout the entire Levantine corridor therefore seems to be characterized by communal engagements in the construction of large buildings and possibly also a communal organization of cereal cultivation (Watkins 2010; Willcox and Stordeur 2012; Asouti 2013; Asouti and Fuller 2013), indicated by architectural and archaeobotanical evidence for communal food storage at WF 16, Dhra', Netiv Hagdud, Jerf el Ahmar, Tell 'Abr and possibly also at Jericho and Mureybet. As cereals are not particularly abundant at Hallan Çemi and Körtik Tepe (Savard *et al*. 2006; Rössner *et al*. 2017), the possible storage structures at these sites indicate that cereals were presumably not the only communally stored plant resources.

Important developments in architecture and ritual activities characterize the transition to the PPNB and are thought to reflect changes in the social organization of the studied communities (Bar-Yosef and Meadow 1995; Kuijt and Goring-Morris 2002; Byrd 2005; Zeder 2009). A gradual shift from circular to rectangular buildings occurred throughout the whole Levantine corridor, although with some temporal variability. Rectangular buildings already appear during the later PPNA at e.g. Jerf el Ahmar and Çayönü, dating to the early 11th millennium cal BP, whereas this shift occurred between ca. 10,700 and 10,200 cal BP in the southern Levant (Kuijt and Goring-Morris 2002; Kozlowski and Aurenche 2005). Generally associated with this architectural development were growing populations and an increase in internal space and the number of compartments per house, while hearths were now more often located inside buildings (Kuijt and Goring-Morris 2002; Kuijt 2000a, 2008a). This more formalized use of space presumably indicates an increasing consolidation of the co-residential groups that inhabit these buildings (Byrd 2000; Kuijt 2000a, 2008a; Erim-Özdoğan 2011; Atakuman 2014). Much has been written about the social implications of this architectural development and, although there is no general consensus, scholars agree that this trend reflects an increasing emphasis on households as social and economic units within the wider community (Byrd 1994, 2000, 2005; Kuijt 2000a, 2008a; Rollefson 2000; Flannery 2002; Kuijt and Goring-Morris 2002; Banning 2003; Goring-Morris and Belfer-Cohen 2008; Bogaard *et al*. 2009; Kuijt *et al.* 2011). These interpretations are not solely based upon the appearance of differently organized residential structures. Changing mortuary, ritual and storage practices that accompany architectural developments equally reflect the appearance of increasingly independent households throughout the PPNB as the principal socioeconomic units of early agricultural societies (Kuijt *et al.* 2011).

Atakuman (2014) uses several strains of evidence to argue for the increasing importance and independence of households among PPNB communities in the upper Euphrates and Tigris areas. One important argument is the appearance of "public" and "cult" buildings during the PPNA, a development that became consolidated with the early and middle PPNB. At Çayönü, the earliest phase of the "Skull Building", a communal tomb for secondary burials, dates to the emergence of the "Channel Building" phase during the early PPNB (Erim-Özdoğan 2011). The "Flagstone Building" was in use during the same time, representing a second "special" building in the settlement. Its significance became clear after the excavation of a similar and better preserved structure at the nearby site of Nevali Çori. At this settlement, inhabited during the early and middle PPNB, a rectangular building with benches and monumental stone pillars around the periphery and in the center was uncovered, reminiscent of the "Flagstone Building" from Çayönü (Hauptmann 2011). The excavators termed this structure the "Cult Building" and of particular importance is the one preserved T-shaped pillar from the center of the building that closely resembles the pillars found at Göbekli Tepe (Watkins 2006; Schmidt 2010). While the communities at Çayönü and Nevali Çori considerably invested in the construction of local "cult buildings" and monuments, this former ritual center was already in decline and subsequently fell out of use during the middle PPNB (Schmidt 2005). Atakuman (2014) interprets this as a consequence of upcoming tensions between the communities that regularly gathered at Göbekli Tepe, possibly also due to unequal access to resources. The construction of elaborate cult buildings at the local places could reflect an increasing emphasis on the individual community and, on the other hand, the need to integrate socially differentiated communities. As Benz (2000) emphasizes, growing communities almost automatically organize themselves in smaller social units, which increasingly results in social tensions and conflicts. In light of growing socioeconomic differentiation, community-wide rituals and feasts are effective mechanisms to build up group cohesion and mask inequalities (Twiss 2008; Benz 2010). The growing emphasis on community and ritual buildings at individual sites since the later part of the PPNA is therefore thought to reflect the need to integrate increasingly independent households into growing communities.

A further line of evidence for this process comes from mortuary data. The end of the "Skull Building" at Çayönü correlates with the gradual relocation of burials into houses towards the late PPNB, indicating the "reclaiming of burials by the individual dwellings" (Atakuman 2014: 28). A building for community-wide ceremonies is, however, still represented by the "Terrazzo Building". Where the "Skull Building" had been located, the inhabitants of Çayönü constructed an open space, the "Plaza", with several stelae marking the way to the new cult building (Erim-Özdoğan 2011). This development indicates that communal ceremonies were still of a high importance for creating a symbolic society with an "egalitarian ethos" (Benz 2010; Atakuman 2014).

For Halula at the Euphrates, Kuijt *et al.* (2011) identified increasingly differentiated intra-household burial practices towards the late PPNB, based on the location of burials and the abundance of grave goods among individuals. Contrastingly, residential structures and storage facilities suggest relative inter-household equality and continuity from the middle to the late PPNB. This pattern is reminiscent of an important principle that seems to characterize the socioeconomic development of PPNB communities throughout the entire Levantine corridor and beyond. Whereas particularly the mortuary data suggest increasing social complexity, data on the size and organization of houses, storage facilities and access to resources indicates limited household inequality (Rollefson 1997; Kuijt and Goring-Morris 2002; Özdoğan *et al*. 2011).

Mortuary data and evidence for household and community-wide rituals at sites from the southern Levant equally document the endeavor to integrate single households into growing societies and to create a symbolic community that legitimates emerging social differentiation. Particularly since the middle PPNB, traditional mortuary practices whose origins date back to the Late Natufian have been standardized and expanded (Bar-Yosef and Meadow 1995; Kuijt and Goring-Morris 2002). Throughout the entire PPNA, adults and children have been buried in variable contexts, often associated with architecture, and always without any grave goods. Whereas the absence of grave goods indicates equality among the dead, the skulls of selected individuals were removed from primary burials and presumably have been used in rituals before they were buried in secondary skull caches. Although the exact utilization of the skulls remains unknown, Kuijt (2000b, 2001, 2008b) relies on ethnographic models in suggesting that mortuary practices in general and secondary burial ceremonies in particular integrate household and community-wide rituals, which involve the construction of social memory and identity across kinship lines. With the middle PPNB, most removed skulls were buried in groups in extramural caches, giving these secondary burials an evidently public character. Additionally, certain skulls have been elaborately prepared for ritual use. Some exhibit modeled facial traits out of plaster and occasionally shells were used to represent the eyes, whereas other skulls have been painted. The removal of some skulls for secondary use throughout the whole Levant and the elaborate preparation of an even smaller selection of skulls at southern Levantine sites indicate an exclusive treatment of some individuals and provides the main argument for social differentiation during the PPN (Benz 2012). In its broadest sense this phenomenon has been interpreted as part of an ancestor cult (Kenyon 1957; Amiran 1962; Kuijt 1996; Goring-Morris 2000).

Many authors agree that these mortuary practices are part of a more complex set of rituals and ceremonies that link single households to community interests (Byrd 1994; Bar-Yosef and Meadow 1995; Rollefson 1997, 2000; Goring-Morris 2000; Kuijt 2000b, 2001, 2008b; Benz 2010, 2012). Non-residential structures presumably representing the context for public and ritual ceremonies have been excavated at several middle and late PPNB sites, including Beidha, ‘Ain Ghazal, Ghwair I and Kfar HaHoresh. Similarly to the “cult” buildings in the northern Levant, they are interpreted as non-residential buildings based on the absence of domestic artifacts or the presence of elaborately constructed hearths, wall niches or orthostats (Byrd 1994; Goring-Morris 2000; Rollefson 2000; Kuijt and Goring-Morris 2002; Simmons and Najjar 2006). Interestingly, wall niches, sometimes with displayed objects, have been documented from within and outside of residential buildings, which provides a further argument for the interrelatedness of household and community rituals (Kuijt and Goring-Morris 2002; Kuijt 2008a).

An important component of PPN rituals were feasts beyond co-residential groups, which can be regarded as formalized communal food sharing events in light of a substantially lowered reciprocity (Rosenberg and Redding 2000; Bogaard *et al*. 2009; Benz 2010). In investigating the scale and development of feasts throughout the southern Levantine PPN, Twiss (2008) concludes that evidence for communal feasts is relatively rare during the PPNA, but becomes much more abundant towards the middle and late PPNB. She links its increasing importance in PPNB communities to the transition to larger societies with growing socioeconomic inequality. Possible indicators for feasts are complex and include large amounts of food waste in ritual contexts, e.g. skeletal remains of eight wild aurochs in association with a grave at Kfar HaHoresh (Horwitz and Goring-Morris 2007), or large cooking facilities in outdoor locations or non-residential buildings at e.g. Beidha (Byrd 1994), ‘Ain Ghazal (Rollefson 2000) and Yiftahel (Garfinkel 1987). Evidences for communal feasts are, however, not restricted to the middle and late PPNB in the southern Levant. Rosenberg and Redding (2000) identify the central open area at Hallan Çemi, associated with dense concentrations of animal bones, fire-cracked stones and an arrangement of sheep crania, as the context for regular public feasts. Dietrich *et al.* (2012) associate Göbekli Tepe with large communal feasts, since the backfills of the monumental enclosures contained large amounts of smashed animal bones. Özdoğan (1999) interprets the display of an aurochs skull in a possible late PPNB “public” building at Çayönü as suggestive of former feasts, mirroring the regional patterns from Hallan Çemi and Göbekli Tepe.

An interesting aspect of meat sharing in feasting contexts is its relation to food storage. Bogaard *et al*. (2009, 2010) reported an interesting case from Çatalhöyük, where aurochs bucrania were displayed in the entrance areas of houses. Separate rooms in the back of the houses, invisible from the entrance areas, contained the private storage facilities. Bogaard and her colleagues interpret this scheme as indicative of the importance of meat sharing, symbolically represented by the displayed aurochs bucrania, for legitimating private food storage. Comparable patterns have been reported from Yiftahel in the lower Galilee (Garfinkel 1987) and the display of aurochs bucrania generally represents a prominent feature of many sites in the upper Euphrates area (Cauvin 2000; Helmer *et al.* 2004). In taking these evidences together, a pan-regional pattern emerges that may hint to the important symbolic role of feasts and meat sharing to legitimate the gradual privatization of food storage throughout the PPNB (as further outlined below; see also Simmons and Najjar 2006 for the association of one *Bos* and several goat skulls with cached lithic tools at Ghwair I).

To conclude, an important feature of socioeconomic change throughout the entire PPN in the upper Tigris and Euphrates regions and the southern Levant represents the emergence of increasingly independent households as basic socioeconomic units of early agricultural societies. This development correlates with growing community sizes and a gradually lowered reciprocity. As evident from anthropological studies, these developments should have resulted in growing social tensions within PPN communities, which require mechanisms to build up trust and group cohesion (Benz 2000; Kuijt and Goring-Morris 2002; Watkins 2004, 2016). Particularly towards the middle and late PPN, mortuary practices, interrelated household and community rituals and feasts as contexts for communal food sharing events have been standardized and expanded to cope with the emerging social challenges and to mask inequalities. This is exactly the context in which we have to see the "florescence" of cultic activities in early agricultural villages since the middle PPNB in the southern Levant (Kuijt 2001: fig. 4; Kuijt and Goring-Morris 2002: 418).

How do all these social developments relate to our previously outlined record of pre-domestication cultivation for about 1,000 years during the PPNA and the "delayed" emergence of the first non-shattering cereals during the early and middle PPNB? Before turning to the final discussion, I close this overview with recent insights on the pace of PPN food storage and its possible association with changing notions of ownership.

## FOOD STORAGE AND CHANGING NOTIONS OF OWNERSHIP

In a series of recent articles, Kuijt (2008a, 2009, 2011, 2015) raises attention to the fundamental importance of the mode of food storage for understanding socioeconomic organization throughout the PPN. As food storage links the social structure of a community, particularly ownership systems, to the subsistence strategy, it is suited to inform us about the interrelatedness between social and economic change. Whereas our principal understanding on the relation of storage, ownership and social complexity derives from anthropological models (e.g. Woodburn 1982; Testart 1982; Ingold 1983; Morgan 2012), the limited archaeological visibility of storage facilities confines our understanding of food storage throughout prehistory. Plant foods, or any other goods, can be stored in containers out of perishable materials or outside of settlements, which both hamper its archaeological recognition. Moreover, most containers are found empty, making their identification as food storage facilities a matter of argumentation. We are therefore confronted with a very incomplete record of storage facilities throughout the PPN and Kuijt even postulates that archaeologists have yet to develop a comprehensive understanding of prehistoric food storage systems in general. Additional problems relate to the scale of storage, whether significant surplus was stored and how storage facilities relate to social units that use them. On the other hand, as I outlined above, recent excavations have documented a wide range of possible storage facilities that considerably expand our understanding of PPN food storage, given the interpretations of such structures are not fundamentally wrong or their uneven archaeological visibility does not significantly bias the overall picture. Food storage can therefore be modeled throughout the PPN, but only on a very general level and based on a small number of well documented case studies (table 1).

From a socioeconomic perspective, Kuijt characterizes the principle development of PPN food storage as subjected to increasing privatization and necessarily coupled to the emergence of individual property rights. As outlined above, PPNA settlements from the whole Levantine corridor provide evidence for communal storage facilities. The clearest examples are the communal buildings containing *in situ* concentrations of charred cereals from Jerf el Ahmar and Tell 'Abr at the upper Euphrates and the extramural storage silos from WF 16, Dhra' and Netiv Hagdud in the southern Levant. At Hallan Çemi and Körtik Tepe, circular paved structures could equally represent the remains of extramural storage silos, but their exact function is more ambiguous. Kuijt (2008a, 2015) emphasizes that extramural and communal storage structures do not represent the only possible PPNA storage facilities, as small bins at e.g. Jericho and Netiv Hagdud could possibly represent indoor food storage (Kenyon 1981; Bar-Yosef and Gopher 1997). At Gilgal, a large hoard of charred wild barley and oat grains, together with *Pistacia atlantica* nutlets and acorns, is representative of indoor storage, emphasizing the variability of storage practices during the PPNA (Weiss *et al.* 2006; Kislev *et al.* 2010).

**Table 1** – List of possible PPN storage structures and contexts. For references see Kuijt (2008a), Bogaard *et al.* (2009, 2010) and text.

| Site | Period | Storage mode | Evidence |
|---|---|---|---|
| Hallan Çemi | PPNA | extramural | caches of almonds and small paved structures |
| Körtik Tepe | PPNA | extramural | small paved structures |
| Çayönü | PPNA | extramural | storage pits, sometimes plastered |
| Jerf el Ahmar | PPNA | intramural, communal/ritual context | cereal grains/chaff in cells of communal building and cereal grain concentration in building with aurochs bucrania |
| Tell ʻAbr | PPNA | intramural, communal/ritual context | cereal grains in communal building with aurochs bucrania |
| Jericho | PPNA | intramural + extramural | bins + possible silos around tower |
| Netiv Hagdud | PPNA | intramural + extramural | bins, charred seed accumulation with barley chaff + extramural storage silo |
| Gilgal | PPNA | intramural | cereal grains, *Pistacia* nutlets, acorns, pulses and figs in baskets |
| Dhra' | PPNA | extramural | storage silos |
| WF 16 | PPNA | extramural | storage silos |
| Çayönü | early-late PPNB | intramural | charred seed concentrations; no extramural storage pits; storage rooms |
| Beidha | early-middle PPNB | intramural | charred *Pistacia* nutlets in baskets |
| Cafer Höyük | middle PPNB | intramural | storage silos/bins |
| Jericho | middle PPNB | intramural | clay bins |
| ʻAin Ghazal | middle PPNB | intramural | charred cereal/pulse deposit near door |
| Yiftahel | middle PPNB | intramural | charred pulses in clay silo and perishable container |
| Halula | middle-late PPNB | intramural | storage rooms |
| ʻAin Ghazal | late PPNB | intramural | accumulation of charred pulse seeds |
| Es-Sifyia | late PPNB | intramural | storage rooms |
| Basta | late PPNB | intramural | storage rooms |
| Çatalhöyük | late PPNB | intramural | storage bins in separate rooms |

More significant, however, is the disappearance of communal storage facilities towards the PPNB. As has been noticed by other authors (e.g. Byrd 1994; Rollefson 1997; Wright 2000; Flannery 2002; Banning 2003; Bogaard *et al.* 2009, 2010; Kuijt *et al.* 2011), the formalization of space and architecture since the early PPNB coincides with the construction of predominantly internal storage facilities, which presumably were owned by the respective household units. This privatization of food storage represents a slow and gradual trend and peaks in the middle and late PPNB, where for the first time separate rooms dedicated to storage appear in the archaeological record, e.g. at Halula at the upper Euphrates, Çayönü in southeast Anatolia (cell buildings) or Es-Sifyia and Basta in the southern Levant (Kuijt 2008a; Erim-Özdoğan 2011; Kuijt *et al.* 2011). The movement of storage facilities inside buildings restricts the access to the stored goods, both visually and practically, which necessitates some form of private ownership system (Testart 1982; Woodburn 1982; Ingold 1983; Kuijt 2008a). In addition to the lack of communal storage contexts after the PPNA, Kuijt (2015) provides data on the scale of extra- and intramural storage facilities from selected sites in the southern Levant through time. Although evidence for internal food storage exists throughout the entire PPN, he concludes that the volume of extramural storage structures was highest during the PPNA, whereas the ratio was inverted by the middle PPNB, where intramural storage becomes the principal storage mode (Kuijt 2015: fig. 5, table 4). Additional long-term evidence for changing storage practices comes from Çayönü in southeast Anatolia. Erim-Özdoğan (2011) mentions extramural storage pits in the earliest "Round Building Subphase". Similar pits in open areas were dug and plastered during the "Grill Building Subphase", still dating to the late PPNA. She notes a movement of most daily activities in front and inside of houses towards the late "Grill Building Subphase" in the early PPNB, which was possibly accompanied by a shift in storage practices. The fact that the inhabitants of Çayönü carefully cleaned houses before they destroyed and "buried" them for to the construction of new buildings explains why indoor storage facilities like small bins or remains of stored plant remains are very rare. Exceptions represent the accumulation of charred *Lycium*-type seeds in an early PPNB channeled building and high concentrations of *Vicia ervilia* seeds in a late PPNB cell building, both indicative of PPNB intramural seed storage (van Zeist and de Roller 1991/92). Additional evidence for middle PPNB intramural storage silos in southeast Anatolia comes from several buildings at Cafer Höyük (Cauvin *et al.* 2011: fig. 11-13).

Taken together, the outlined trends in the location and scale of possible PPN food storage facilities point towards an increasing privatization of stored foods, which must have been associated with the appearance of individual property rights. On the one hand, this process only very gradually unfolded over a course of several millennia. On the other hand, the disappearance of extramural storage silos and storage facilities inside communal buildings with the end of the PPNA coincides well with the overall architectural development towards rectangular, multi-roomed residential structures. If we can identify any significant change in the mode of storage in addition to the appearance to dedicated storage rooms, then I suggest the disappearance of extramural storage silos and communal buildings comprising storage structures represents such a major change in the mode of PPN food storage and ownership systems.

**DISCUSSION**

Asouti (2017) recently re-revaluated the evidence for pre-domestication cultivation during the PPNA and concluded, based on a thoughtful consideration of palaeoclimatic, archaeobotanical and archaeological data, that this subsistence strategy was possibly much less widespread than is normally assumed (see also Asouti and Fuller 2013). She particularly refers to "short- to medium-term climatic instability" during the early Holocene that should have had profound consequences for local ecosystems, resource availability and yield predictability (Asouti 2017: 24). Coupled with discontinuities in the radiocarbon record of PPNA settlements, she argues for a still high mobility of Early Holocene groups that did/could not engage in long-term wild cereal cultivation. Recognizing that wild cereal cultivation presumably represented just one of many resource management and exploitation strategies is crucial for interpreting the overall Early Holocene record of socioeconomic change (Weide *et al.* 2018: 27). However, the evidence for non-shattering cereals from Ohalo II should render us cautious in overemphasizing residential mobility and climatic instability as principally inhibiting the emergence of domesticates. These factors partly explain why cultivation did not become a long-term strategy of PPNA groups and why cereal domestication took so long to unfold. On the other hand, they cannot explain why domestic cereals did not emerge at one single site throughout at least 1,000 years of possibly discontinuous pre-domestication cultivation, although a small band of people at Ohalo II selected for such phenotypes. In building up on Asouti's considerations, I see additional crucial factors in the development of ownership systems influencing subsistence practices during the PPN.

Reminiscent of anthropological models for the co-evolution of social complexity, food storage and ownership systems, the appearance of communal food storage facilities during the PPNA suggests that Early Holocene groups developed a complex system of behavioral codes and property rights to organize food storage in growing and increasingly sedentary societies. The pure fact that food is stored for future use results in several problems: It must be protected from free-riders and raids, individual community members do not have the possibility to immediately access these resources and the control over stored resources can result in the accumulation of power and authority to individuals (Testart 1982). For understanding PPNA socioeconomic organization, it is therefore helpful to apply Ingold's division of practical and social storage (Ingold 1983). In a practical sense, PPNA communities stored large amounts of foods in public storage facilities that are relatively freely accessible. In term of social storage this pattern suggests that the stored resources were communally shared and that no individual appropriation of important resources was tolerated. We may therefore assume a communal ownership over cereal harvests, which was part of important leveling mechanisms in PPNA societies that helped to maintain a relatively egalitarian social structure in light of growing community sizes.

In following the organization of storage and associated ownership systems into the PPNB, we see a continuous development towards indoor storage, whose access is increasingly restricted and controlled by the respective households. As proposed by ethno-archaeological theory, these developments have a huge potential for conflict and increasingly require social mechanisms to establish group identity and trust in one another (Byrd 1994; Benz 2000, 2004; Kuijt 2000a, 2008a; Bar-Yosef 2001; Atakuman 2014). The most important contexts to organize village life during this process seem to have been meat sharing during feasts, secondary mortuary practices and communal ceremonies in general, indicated by public and cult buildings in both the northern and southern Levant. It is therefore crucial to follow the evidence for PPNB ritual life in order to understand the wider context for emerging households as the principal socioeconomic units of these societies.

The main point I want to put forward here is the obvious correlation between the emergence of the first high proportions of non-shattering cereal spikelets and the emergence of independently organized households towards the early PPNB. This is exactly the period in which communal storage contexts had disappeared, indicating that these households now began to manage their own cultivated resources. As repeatedly emphasized, sometimes indirectly, the genetic isolation of a particular "breeding line" would be crucial for the rapid fixation of domestication traits (Hillman and Davis 1990; Gepts 2004; Fuller *et al.* 2010; Allaby *et al*. 2015b; Abbo and Gopher 2017). Turned around, replenishing seed stocks after poor harvests by gathering in unmanaged stands, collecting shed spikelets from the ground to enhance yields or cultivating wild cereals in the same plot over and over again would result in the incorporation of shattering individuals in the managed populations and with this inhibit the selection for non-shattering ears (Hillman and Davies 1990; Kislev *et al*. 2004; Willcox *et al.* 2008; Tanno and Willcox 2012). Consequently, we must ask why genetic lines of potential domesticates became increasingly isolated towards the early PPNB?

For the socioeconomic development from PPNA to PPNB communities, we may expect a reduction in the size of a socioeconomic group that together engages in subsistence activities. Whereas PPNA communities possibly stored all harvested cereals in communal granaries, the development of new property rights allowed PPNB households to store their own grain. An important aspect of this development is the decreasing number of persons that contribute to an individual harvest, which hypothetically can be correlated with a decreasing variability of applied cultivation and harvesting techniques within a socioeconomic unit. Simply put, all grains harvested from unmanaged stands or by beating brittle spikelets into a basket would have ended up in one granary together with grains from populations that are already under selection for non-shattering during the PPNA. Instead, with the disappearance of communal storage towards the early PPNB, those groups that selected for non-shattering ears under cultivation would have stored their harvests separately. In this scenario, the probability of selection for non-shattering ears increases with the reduction in the size of a socioeconomic unit. As a result, the first increased proportions of non-shattering cereal spikelets appear between 10,700 and 10,200 cal BP, because some of the emerging households were now able to isolate genetic lines under individual cultivation regimes (Tanno and Willcox 2012; Arranz-Otaegui *et al*. 2016a, b). Most communities cultivated domestic cereals by the middle PPNB, which went hand in hand with a "florescence" of cultic and ritual activities to mask upcoming inequalities (Kuijt 2001; Kuijt and Goring-Morris 2002). These considerations are not new (Fuller 2007: 921; Hodder 2017: 167), but need to be incorporated more vigorously into the existing models for Near Eastern cereal domestication.

Identifying the size of a socioeconomic unit as an important factor for the selection of non-shattering cereals is also of interest for evaluating the evidence from Ohalo II. We cannot precisely estimate how many people occupied this camp, possibly even the whole year-round (Snir *et al*. 2015: S1 fig.), but rough estimates for Early Epipalaeolithic group sizes range between 10-20 (Byrd 2005: 254) or even up to 40 individuals (Bar-Yosef and Belfer-Cohen 1989: 456). The first estimate fits quite well to the six small huts present at Ohalo II. In analogy to hunter-gatherer camps in which such huts harbor only a few individuals each (Flannery 2002), the six huts likely reflect a maximum group size of 18-24 persons, given all huts were simultaneously occupied. The actual group of people who would engage in small-scale cultivation is presumably smaller, at least excluding elderly people and small children, and rather resembles the size of a few households of early or middle PPNB societies instead of a full PPNA community. This small group then engaged in wild barley and emmer wheat cultivation, eventually selecting for non-shattering individuals. Necessarily involved would have been some sort of storage to sow parts of the harvest in the next season and relatively uniform cultivation and harvesting practices throughout several years. This latter feature would have been supported by the small group size. In such a situation, even Early Epipalaeolithic people engaging in resource management practices were able to select for domestication traits, highlighting that the pure agro-technological requirements for domestication were already met 23,000 years ago. On the other hand, we have no reason to expect that this early lineage would have been maintained, as the long-term adoption of domesticates requires much more than establishing the principal conditions for selection. The complex development towards PPNB farming communities emphasizes on how many levels socioeconomic change must take place, obviously supported by a warmer and wetter climate, to allow for the long-term integration of domesticates into a society.

This perspective recalls the discussion on conscious versus unconscious selection for explaining the slow pace of Near Eastern plant domestication. Most scholars reject the idea that early domestication traits could have been consciously selected, because the establishment of the domestication syndrome only gradually unfolded over several millennia. In arguing from a predominantly agro-technological or genetic perspective, this reasoning may explain the available datasets. However, the genetic isolation of a potentially domesticate under cultivation can be strongly affected by the mode of food storage, which itself is linked to different notions of ownership and the general socioeconomic organization. Viewed from this perspective, the paradigm of unconscious selection for explaining the slow pace of plant domestication becomes a vague framework and does not encompass a complete chain of causal factors. If we have to expect strong social leveling mechanisms throughout the Neolithic transition that also affected food storage, distribution and consumption, the protracted appearance of phenotypic domestication traits is much more a result of a socioeconomic environment that did not establish the conditions for selection, both automatic and conscious. Woodburn (1982) expected social leveling mechanisms including food sharing as acting against the development of cultivation in immediate-return systems. Similarly, communal grain storage during the PPNA could have strongly selected against genetic change among the managed plants and possibly also against any incentive to intensify subsistence practices. This also means that no consciously selected non-shattering mutant would have been maintained, as the cultivating individual or group would not have been allowed to store the harvests of this selection chain separately. In this framework, genetic change becomes a matter of social organization, along with a multitude of additional factors, highlighting why agro-technological or environmental issues alone cannot sufficiently explain the slow pace of plant domestication.

## CONCLUSION

In both dimensions, economic and social, we must think of a continuum of slowly changing relations between individuals, households, communities and their environments. Economic and social change during the Near Eastern Neolithic did not appear as sudden, short-term, revolutionary events. Rather, they represent long-term evolutionary developments, highly entangled and co-dependent on each other. In correlating the emergence of non-shattering cereals and independent socioeconomic units, I tried to link both dimensions of Early Neolithic communities. Based on the current state of research, we should characterize PPNA groups as still relatively mobile and as engaging in various resource management practices. One of them, the cultivation of wild cereals, foreshadowed the subsequent emergence of agricultural societies. Along with significant alterations in community and ritual life since the early PPNB, new property rights allowed single households to store their own harvests and resulted in a decrease of individuals that together engaged in subsistence practices. Simultaneously, the first morphological evidences of cereal domestication appeared, which I link to the increased genetic isolation of cultivated lineages within households. This correlation allows us to identify small group sizes as an important factor helping to reduce the variability of cultivation and harvesting methods and to select for morphological domestication traits. Explaining the slow pace of Near Eastern cereal domestication therefore becomes a matter of social change that eventually established the conditions for selection and for adopting domesticates as principal components of new agricultural societies. Ohalo II echoes these principles and highlights that agro-technological preconditions can explain the simple emergence of morphological domestication traits, but their long-term maintenance requires profound socioeconomic change to have taken place.

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