Unwinding the thread

Interdisciplinary research on early wool craft in Greek prehistory

Sophia Vakirtzi

National and Kapodistrian University of Athens
sophievak@gmail.com

Katerina Papayianni

National and Kapodistrian University of Athens
katerinapapayiannis@gmail.com

Eleni Mantzourani

National and Kapodistrian University of Athens
emantzou@arch.uoa.gr

ABSTRACT

This paper presents the results of an interdisciplinary research on early wool craft in mainland and insular Greece between the 7th millennium (Early Neolithic) and the 3rd millennium B.C. (Early Bronze Age), a period devoid of textile remains in the archaeological record. An interdisciplinary methodology is implemented, combining zooarchaeology and technological analysis of textile tools. In the zooarchaeological approach, a synthetic reassessment of published caprine mortality profiles and sex ratios from Neolithic and Early Bronze Age sites is presented in order to detect patterns of flock construction. Furthermore, the Coefficient of Variation of published sheep bone measurements from the same contexts is estimated in order to trace skeleton size fluctuations attributable to sheep improvement efforts. Also, geometric morphometrics analysis is applied to sheep astragali from two case studies, Sitagroi, Drama, north Greece and Alepotrypa, Laconia, Peloponnese, south Greece, to identify changes in the sheep skeleton shape. In the technological approach, objects identified as spindle whorls in the archaeological literature are surveyed to detect significant shifts in the technological apparatus of yarn production in the periods under study. The patterns deriving from the bibliographical survey as well as from a first-hand examination of tool assemblages from Sitagroi and Alepotrypa are discussed in the frame of the anthropology of technology. The technological approach also takes into consideration ethnographic data and the results of experimental archaeology published in the literature. The study concludes to a research hypothesis arguing for the possibility of wool craft being practiced already in the Greek Middle Neolithic (mid-6th millennium B.C.), and stresses the need for further interdisciplinary work to test this hypothesis.

INTRODUCTION

Scholarly interest on the archaeology of wool as textile fiber in Europe and the Near East has developed after the publication of two influential theoretical models which attributed a "revolutionary" significance to

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the innovation of wool following sheep domestication. The first was the "Secondary Products Revolution" model proposed by A. Sherratt (henceforth SPR; Sherratt 1981, 1983). Based primarily on a survey of artifactual and pictorial evidence (pottery, figurines, representations of ploughs and wheels) and written sources (Mesopotamian cuneiform archives), as well as on few woolen textile fragments from 3rd millennium B.C. sites in Central and North Europe, the SPR model suggested that wool production must have begun towards the end of the 4th/middle of the 3rd millennium B.C., along with other "inventions", like the exploitation of animals for traction (cattle, equids) and the dispersal of the double plough. The second model was formulated in a paper titled "The Fiber Revolution" by J. McCorriston (1992), who critically examined the development of political economy in the Near East and proposed a link between wool economy and urbanization. She suggested that a fundamental shift in social (labor and gender) relationships in prehistoric Mesopotamian societies should be causally associated with the dominance of wool over flax as primary raw material in the textile industry. According to this hypothesis, such a shift must have already taken place by the end of the 4th millennium B.C., as indicated by iconography, archaic Sumerian texts, and zooarchaeological analyses.

These theories evoked specialized research agendas that focused on the social, the aesthetic, the technological and the economic significance of wool. Most notably, the 2012 conference on "Wool Economy in the Ancient Near East and the Aegean"(Breniquet and Michel 2014) held in Nanterre, France, brought together international scholars who discussed rich corpora of data in a comparative perspective. The research project "The Textile Revolution" (Becker et al. 2016) hosted by the Freie Universität in Berlin within the Excellence Cluster Topoi Research Network (henceforth "the Topoi project") has set out to investigate the beginning of wool production on an interdisciplinary basis and to test the "wool strand" of the SPR theory against palaeoenvironmental, zooarchaeological (caprine bones) and technological (spindle whorls) evidence from several sites in southeastern Europe and the Near East. The Topoi project ultimately concluded that the above classes of evidence indicate a "pastoral turn" from the mid-5th millennium B.C. in the regions under investigation and that it is possible to suggest an intensification of wool husbandry in the 4th millennium B.C. (Schier 2020). Nonetheless, it was also clearly acknowledged that the large spatio-temporal scales of analyses employed in the Topoi project tend to mask nuances that would potentially emerge, should more refined scales of analysis be used (Schier 2020, 68).

In the case of Greek prehistory, the beginning of wool craft is still poorly understood. Despite the results of the Topoi project, which integrated sheep bone data from Greek prehistoric sites into its zooarchaeological component (Becker et al. 2020), there exist several individual zooarchaeological studies of caprine remains in the archaeological literature which leave the possibility of wool exploitation before the 4th, or even the mid-5th millennium B.C. open (see below, part a). Furthermore, a synthetic zooarchaeological study targeting early wool craft in Greek prehistory has yet to take into consideration the technological evidence of yarn production, namely spindle whorls from Greek prehistoric sites which were not integrated in the Topoi project research (cf. Grabundžija and Schoch 2020). Finally, one should not discount the suggestion that textile polychromy was achieved in the Greek Neolithic, a hypothesis put forward on the grounds of cross-craft transfer: Sarri (2018, 170) has pointed out that Neolithic ceramic vessels often bear decorative patterns that resemble woven patterns, and such patterns are often rendered in bright colors, like black and red. If these patterns imitate textiles, the argument goes, the textile prototypes would have been woolen, because wool absorbs organic dyes very well, unlike linen (or other bast-made) yarn which is especially resistant to dyes. Ultimately, the possibility of wool use by Neolithic weavers, at least from the MN onwards, should not be ruled out (Sarri and Mokdad 2019, 89). In all, when wool as textile fiber became available in prehistoric Greece, appears to be an open question.

The present paper is the outcome of a research project titled "he beginnings of wool craft in prehistoric Greece" hosted at the Department of History and Archaeology of the National and Kapodistrian University of Athens between April 2020 and October 2021. Its aim was to specify the question of the beginning of wool craft to the case of prehistoric Greece, and to contribute to its disentanglement by attempting an interdisciplinary synthesis of zooarchaeological and technological evidence related to sheep husbandry and to yarn production respectively, from sites dated from the mid-7th through the 3rd millennia B.C., i.e., spanning the Greek Neolithic and Early Bronze Ages. During this long period of about five millennia, wool craft in prehistoric Greece is vague although husbandry of domesticated sheep and textile craft are both attested archaeologically. It is only after the Early Bronze Age, i.e., after the 3rd millennium B.C., that fully-fledged, specialized wool industries on the southern Greek mainland and on Crete are testified on the basis of the Aegean epigraphic sources of the 2nd millennium (or the Middle and Late Bronze Ages: Killen 2007; Nosch 2014; Rougemont 2014). Moreover, the earliest organic remains of woolen textiles found so far in Greece are dated also to the 2nd millennium B.C. (Moulherat and Spantidaki 2008). What was happening in the region of Greece before the 2nd millennium, in terms of wool craft, has been the core question driving the research communicated in this article.

MATERIALS AND METHODOLOGICAL PRINCIPLE

A major challenge in this research is the lack of direct evidence, i.e., material remains of woolen artifacts and textual sources hinting at wool industries. To address this challenge, an interdisciplinary methodology was implemented aiming at identifying indications of wool production and wool processing in the archaeological record of the periods in question. Wool production is investigated through zooarchaeology, based on specialized analyses of archaeological sheep bones which aim at reconstructing aspects of sheep husbandry practices. Wool processing undergoes a long operational chain before weaving that may leave traces in the archaeological record, especially in terms of the technological equipment of yarn manufacture, such as spindle whorls, the remains of spindles, the oldest type of tool for twisting thread. The analysis of archaeological textile tools addresses several aspects of prehistoric textile technology, including the question of fiber provenance. Thus, this project employed a research methodology combining a *zooarchaeological approach* and a *technological approach*.

The archaeological literature of the Greek Neolithic and the Early Bronze Ages (7th – 3rd millennia B.C.) was surveyed for zooarchaeological and textile tool data in order to identify patterns of sheep husbandry and yarn technology potentially indicative of wool, on the basis of specific analytical methodologies for sheep bones and spindle whorls (for details see below, the *zooarchaeological approach* and the *technological approach* respectively). Because the publications of individual sites do not necessarily include *both* zooarchaeological studies *and* textile tool studies, the data feeding each approach do not overlap, but rather depend on the relevant availability of each dataset in the literature (for the surveyed sites see the map of Fig. 1; for chronological abbreviations see Table 1).

In addition to the secondary, bibliographical research, two sites were selected as case studies for primary analysis by the authors, and for a synthesis at the intra-site level, of sheep bones and spindle whorls. These sites are Sitagroi in east Macedonia (north Greece) and Alepotrypa in Laconia (Peloponnese). They were selected because they provided an opportunity to test hypotheses regarding the possible use of wool, as they were expressed by the zooarchaeologists who undertook the faunal analyses at each site. In the case of Sitagroi, Bökönyi (1986, 80) suggested that "it is likely that both meat- and wool-producing individuals were kept in the early phases of Sitagroi". In the case of Alepotrypa, Hadjikoumis (2018, 293) considers that "it is possible that wooly sheep, long-haired goats or both were present at Alepotrypa, at least in its FN phase". Moreover, these two sites also yielded textile tools for yarn manufacture, so that a critical examination of the zooarchaeological hypotheses can take into consideration the evidence of fiber technology as well (Elster 2003; Katsipanou-Margeli 2011).

The main part of the paper is structured in the following sections: a) the zooarchaeological approach, b) the technological approach, c) discussion of the results, followed by the conclusions.

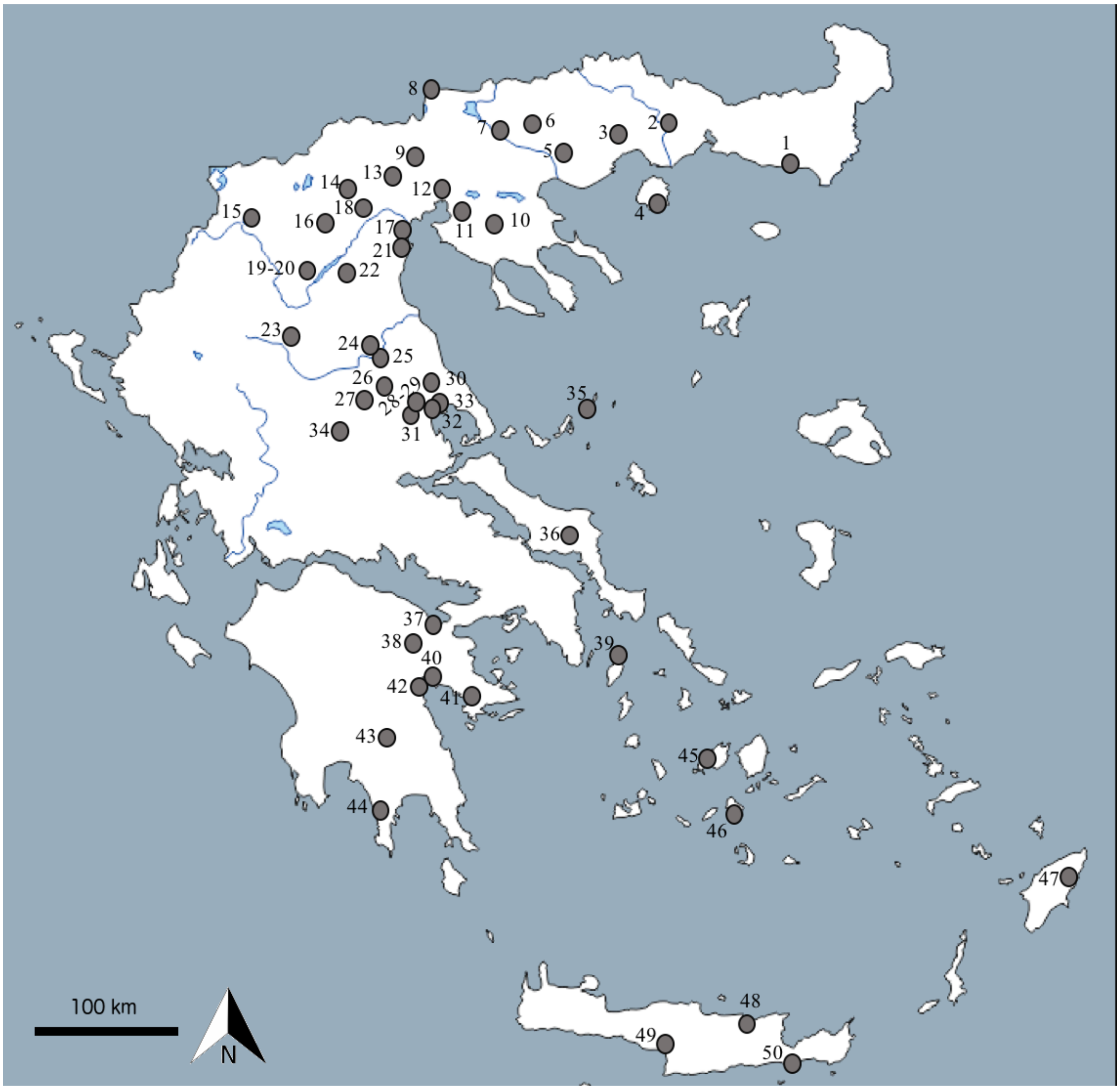

Fig. 1. Map with sites mentioned in the text and the tables. 1. Makri, 2. Paradeisos, 3. Dikili-Tash, 4. Skala Sotiros, 5. Dhimitra, 6. Sitagroi, 7. Pentapolis, 8. Promachon, 9. Kastanas, 10. Vassilika C, 11. Thermi B, 12. Stavroupoli, 13. Giannitsa, 14. Megalo Nissi Galanis, 15. Dispilio, 16. Toumba Kremastis Koiladas, 17. Makriyalos I, 18. Nea Nikomedeia, 19. Mavropigi-Fyllotsairi, 20. Xirolimni-Portes, 21. Revennia, 22. Servia, 23. Theopetra Cave, 24. Otzaki Magoula, 25. Argissa Magoula, 26. Agia Sofia Magoula, 27. Platia Magoula Zarkou, 28. Mikrothives, 29. Rachmani, 30. Dimini, 31. Achilleion, 32. Sesklo, 33. Pevkakia Magoula, 34. Prodromos, 35. Agios Petros, 36. Skoteini Cave, 37. Corinth, 38. Tsoungiza, 39. Kephala, 40. Tiryns, 41. Franchthi, 42. Lerna, 43. Kouphovouno, 44. Alepotrypa, 45. Saliagos, 46. Ftelia, 47. Kalythies Cave, 48. Knossos, 49. Phaistos, 50. Myrtos. Original map from www. d-maps.com, modified for this article.

Table 1. Chronological abbreviations and date ranges mentioned in the text.

Period	Abbreviation	Date	Reference
Aceramic Neolithic	AN	7000–6500 BC	Papadimitriou 2010, 14–15
Early Neolithic	EN	6500–5800 BC	Papadimitriou 2010, 14–15
Middle Neolithic	MN	5800–5400 BC	Papadimitriou 2010, 14–15
Late Neolithic	LN	5400–4600 BC	Tsirtsoni 2016, table 1
Final Neolithic/ Chalcolithic	FN/CH	4600–3300 BC	Tsirtsoni 2016, table 1
Early Bronze Age	EBA	3100–2000 BC	Knappett 2020, xv

A. THE ZOOARCHAEOLOGICAL APPROACH

I. BACKGROUND TO THE RESEARCH

a) Models for prehistoric caprine husbandry

Zooarchaeological analyses have dealt with the question of caprine secondary products (milk, wool) before and after the publication of the SPR model, trying to establish husbandry practices through caprine mortality profiles. Payne (1973, 281–82) associated the killing of surplus male lambs at 6–9 months with the production of milk and meat, based on ethnographic observations from Anatolian sheep and goat flocks; sheep flocks reared for their meat are usually slaughtered in adulthood, around 2–3 years of age, when they have reached full body growth. Wool production from the same Anatolian flocks was based on the maintenance of adult animals up to more or less 6 years, the castration of rams not used for breeding and the running of wether flocks (Payne 1973, 281, 302). Payne (1973, 281) also noted that wool quality degrades with the aging of the animal and this is the reason why Anatolian herders did not preserve animals beyond 6 years. Payne's observations were visualized in survivorship curves, showing the ideal age distribution of a flock for the three production targets, meat, milk and wool, destined to be sold in modern urban markets. His ethnographic study resulted also in a system of recording ages-at-death of sheep and goats based on the eruption and wear stages of mandibular teeth, which is the basis of most zooarchaeological studies of caprines mortality profiles. Survivorship curves depict the potential flock composition and idealized rather than actual husbandry strategies across sites. Also, factors of uniformitarianism, optimization and equifinality can obscure the interpretation of ages-at-death (Halstead 1998). Even though Payne's curves were created after observation of flocks reared to be sold to modern urban markets, they are immediately comparable with survivorship curves and are thus helpful in understanding the (potential) husbandry strategies of one or more sites.

Payne's pioneering work has been improved or refined ever since, because the tooth eruption and wear system is the commonest method to document ages-at-death in fine resolution (Deniz and Payne 1982; Helmer 2000; Halstead et al. 2002; Zeder and Pilaar 2010; Gillis et al. 2011). In particular Helmer et al. (2007) proposed an enriched set of "production targets" with five stages (milk type A and B, meat and tender meat, fleece), maintaining Payne's age categories. The five stages proposed by Helmer et al. (2007) allow the detection of harvesting multiple products from the same flock by interpreting the varied ages-at-death, which are usually the norm in a deadstock assemblage.

b) Evidence (?) for the arrival of wooly sheep in continental Europe

A fundamental question regarding prehistoric sheep husbandry is when sheep's fleece changed to a wooly coat, suitable for textile manufacture. On the basis of preserved prehistoric textiles and hides, it is indicated that it must have happened gradually during the millennia after initial domestication (Ryder 1992; Greenfield 2010, 35; Halstead and Isaakidou 2011, 67). Before the publication of Sherratt's SPR theory (Sherratt 1981), Bökönyi (1971) had identified large-sized sheep from sites in southeast and central Europe dated to the late Chalcolithic or the beginning of the Bronze Age and thus suggested that new sheep breeds with good quality wool arrived in Europe during the Early Bronze Age, locating their origin in the Levant. One of these sites was Sitagroi in north Greece, where the sheep size increase in Sitagroi phase V (EBA) sheep was considered a result of wooly sheep arrival from SW Asia (Bökönyi 1986, 79–80). The timing for the arrival of the wooly sheep suggested by Bökönyi was incorporated in the SPR theory and has been generally accepted by zooarchaeologists. Greenfield (2010, 46) stated that the SPR model was correct in timing the emergence of the wooly sheep around 4000 B.C. in the Middle East and around 3500–3100 B.C. in Europe. Halstead (1996, 31) suggested that the size change identified in sheep remains from 3rd millennium Thessalian sites was "either a result of better feeding or a result of the influx of new breeds including wooly sheep".

The evolution of sheep's kempy fleece into a softer, woolen one can be disassociated from weaving or exchanging woven artifacts, but can be associated with the improvement of the quality of early textiles (Halstead and Isaakidou 2011, 64). If there were any attempts of wool production prior to 3500–3100 B.C., they would have been intermediate evolutionary stages of a local, small-scale (Greenfield 2010). Zooarchaeologists try to locate such local, small-scale, wool production through sporadic "wool mortalities" of adult sheep/goats, like the ones documented at 7th millennium B.C. El Kowm 2 in Syria (Helmer et al. 2007) or those deriving from the zooarchaeological material of several 4th millennium B.C. sites in Mesopotamia (Davis 1993; Grigson 2000) – the latter can be regarded as compatible to the SPR model. Specialized "wool mortalities" occur in later periods, like those documented at 2nd millennium Acemhöyük in Anatolia (Arbuckle et al. 2009), where the caprine assemblage contained mainly adult sheep with a high proportion of males consumed in both palatial and non-palatial contexts.

Variations in sheep size or bone morphology has also been associated with the issue of the wooly sheep evolution. Sheep remains from 4th millennium (Uruk period) Syrian sites had horns of horizontal spiral type and were larger in size than earlier sheep (Vila and Helmer 2014; Vila et al. 2021, fig. 1). Sheep from 3rd millennium Syrian sites had coiled horns and were smaller in size than those dated to the 4th millennium (Vila and Helmer 2014). Given that near eastern iconographic evidence of the 3rd millennium depict sheep with coiled horns and "wooly" coats and that contemporaneous written testimonies provide detailed information about improved sheep types with fat tales, varied wool qualities and colours (Breniquet and Michel 2014), the zooarchaeologists who studied the respective sheep assemblages hypothesize a connection between urbanization, increased textile demand and the evolution of wooly breeds in Mesopotamia (Vila et al. 2021).

The archaeological identification of wooly sheep types is so far elusive, because there is no biomolecular evidence to prove that wooly sheep existed in the 4th/3rd millennium timeframe. Analysis of aDNA from sheep bones or from rare textile fragments would give a direct answer for the evolution of wooly sheep in prehistory, however such analyses have not yet been fruitful. A recent archaeogenetic study rejected the scenario of a wooly sheep import to Europe from the Levant, whereas the possibility for wooly sheep to have evolved within Europe still remains open pending to more analyses (Nikulina and Schmölcke 2020).

c) Caprine husbandry practices in Neolithic and EBA Greece

The taxonomic composition of zooarchaeological assemblages across Neolithic and Bronze Age sites in Greece is largely in favor of caprines (sheep and goats) over the rest domestic species (cattle, pigs) (Kazantzis 2018, 139–41, fig. 6.3, table 141; Becker et al. 2020, 86–7). The ratio between sheep and goat bones from most sites is largely in favor of sheep, with very few exceptions of sites where goat remains outnumber those of sheep (Suppl. Table 1; most of the data retrieved from the TOPOI research database: http://repository.edition-topoi.org/collection/WOLL/single/00003/0). In the EN, this ratio varies between 1.4 and 5.4 sheep for 1 goat with an average of 2.3 sheep for 1 goat; in the MN this average is 2.1 sheep per 1 goat with the exception of the MN–LN transition in Platia Magoula Zarkou, where 14.5 sheep equal to one goat. During the LN this ratio diverges between 18.7 sheep for 1 goat at Sitagroi I and 1 sheep for 1 goat at Makri with an average 4.3 sheep for 1 goat. During the transition between the LN and FN the average ratio is 3.1 sheep for 1 goat and during the FN the average ratio drops to 2.4 sheep for 1 goat. Average ratios of sheep against goats are 2 for the transition between the FN and the EBA and 2.1 for the EBA (see also relevant discussions at Becker et al. 2020, 88 and Halstead 2006).

Caprine husbandry practices from Neolithic or Bronze Age sites in Greece have been extensively studied at the intra-site level, whereas inter-site level studies are limited (e.g., Halstead 1996, 2006; Halstead and Isaakidou 2013; Tzevelekidi et al. 2014; Kazantzis and Albarella 2016). In most intra-site publications postdating the 1990s, the management of caprines is inferred based on the mortality profiles of sheep and goats, which in turn are estimated by mandibular tooth eruption and wear. Some publications suggest varied production targets of caprine husbandry (meat, milk, wool) along the Neolithic period. Knossos, a multi-period site, is a characteristic example: Aceramic through LN sheep and goat husbandry focused in the production of meat, without precluding, though, non-systematic milk or wool/hair exploitation (Isaakidou 2006, 103, 108). Sheep were consistently slaughtered in younger ages than goats throughout the Neolithic at Knossos, a pattern interpreted by Isaakidou (2006, 103) as "a desire to balance meat with some other product". Halstead and Isaakidou (2013) do not exclude sporadic non-intensive use of dairy products and wool during the EN and MN of Greece in general, neither do they support a "secondary products revolution" during the transition from the 4th to 3rd millennium B.C., as there is no relevant evidence. Greenfield (2010, 34, 37) also accepts small-scale milking for the European Neolithic in the light of lipid analyses, but not as a component of a mixed economy. Moreover, he argues that there could have only been occasional collection of fluffs of wool from Neolithic sheep and non-intensive wool industry prior to the Chalcolithic.

The Neolithic pattern of meat strategy and potential small-scale milking of caprines detected at Knossos is also attested in LN Makriyalos I and Toumba Kremastis Koiladas. At both sites female adult sheep predominate among the deadstock, whereas the late slaughtering of some male goats is interpreted as a social preference for large carcasses and impressive horns (Tzevelekidi 2012, 87, 92–3, 96, 104–5; Tzevelekidi et al. 2014, 431). Sheep and goat mortality profiles at LN Promachon indicate slaughtering for meat between six months and three years of age, i.e., when individuals have reached maximum body weight and a potential for small-scale sheep milking (Kazantzis 2018, 85).

Inter-site comparison of LN caprine management in Greek Macedonia was discussed by Kazantzis (2018, 144–51) on the basis of published ages-at-death from Dimitra, Thermi, Makriyalos I, Toumba Kremastis Koiladas (all estimated by mandibular age) and Sitagroi (epiphyseal bone fusion). At all these sites a meat exploitation regime was the norm, permitting milk harvest at Dimitra, Makriyalos and Toumba Kremastis Koiladas. Finally, Munro and Stiner (2020) suggest the possibility of non-systematic milk and wool harvesting at FN Franchthi based on the survivorship of older male and female sheep, which they propose is the case for most Neolithic sites in Greece.

Specialized wool-exploiting caprine husbandry is detected in the Knossos Bronze Age mortality patterns (Isaakidou 2004; 2006). Similar specialized caprine husbandry patterns are also reflected in the sex ratios of Knossian sheep: more adult females (milk-producing animals) than males were identified in the Neolithic bone sample, whereas male individuals (better quality wool-bearers) were commoner in Prepalatial and Palatial samples (Isaakidou 2006, 101). The Prepalatial sample depicts higher male than female survivorship, whereas in the Palatial sample the male-female percentages are equal; in both periods the kill-off patterns of caprines betray older individuals (Isaakidou 2006, 102–3, table 8.2). The overall Bronze Age kill-off patterns at Knossos indicate a specialized production, different than the Neolithic one, and tentatively associated with Linear B records found at the site and mentioning wool ratios and flocks of castrated rams (Killen 1993; Isaakidou 2006, 102). Similarly, caprine mortality profiles and sex ratios from Bronze Age Tiryns and Pevkakia indicate potential wool harvest (Jordan 1975; Amberger 1979; Halstead 1987; von den Driesch and Boessneck 1990) again clearly different from Neolithic culling strategies and indicative of a probably specialized production (Halstead and Isaakidou 2011).

Biometric data reflecting changes in sheep skeleton have indicated an intensification of husbandry practices towards secondary products, such as wool, at Sitagroi LN–EBA horizon (Bökönyi 1986). Bökönyi (1986, 79–80) mentions an increase in sheep skeleton size at EBA Sitagroi phase V, which he associates with the import of a new sheep "breed" potentially from SW Asia. Moreover, Hadjikoumis (2018, 293) suggests the improvement of sheep for wool/milk harvesting in association with a higher survivorship of older rams in the FN horizon of Alepotrypa. To investigate the evolution of wool production and intensive management strategies, there is a need for large-scale mortality and biometric analysis of caprine remains from multiple sites.

II. RESEARCH QUESTIONS , METHODOLOGIES AND MATERIALS

Research questions

The research of this part of the paper revolves around the issues of flock construction and sheep improvement for potential fleece amelioration. Prehistoric husbandry strategies indicative of primary (meat) or secondary product (milk, wool) harvest and consumption will be sought for from the available demographic evidence (caprine ages-at-death, male/female sheep ratios). Also, changes in the sheep skeletons will be investigated to check potential sheep improvement efforts. In order to answer all these questions and clarify details of prehistoric husbandry practices, we applied a combination of zooarchaeological methodologies.

Methodologies

Sheep and goat bones are abundant finds in excavations of prehistoric sites and conventionally used for demographic analysis and biometric evaluation of the prehistoric flocks. In order to infer prehistoric flock construction, we utilized published caprine demographic data (ages-at-death and sex ratios); in order to test prehistoric sheep improvement efforts, we applied skeletal biometric and morphometric comparisons of modern and fossil sheep bones (see Table 2 for the sites included in the analyses).

a) Demographic analysis

Even though taphonomic factors obscure the accurate estimation of the flock composition in individual sites, especially because the bones of neonatal and very young individuals do not easily survive (Halstead 1996, 24; 1998, 13), a comparison of caprine mortality profiles from several sites allows for an overall perspective of changes in husbandry practices over time and space. The age composition of the caprine deadstock, namely *ages-at-death* (Reitz and Wing 2008, 178–81, 194–99) are used to document husbandry strategies and are abundant in the literature. Ages-at-death are usually estimated either via long bone epiphyseal fusion or mandibular tooth eruption and wear; the last method offers higher resolution of ages-at-death because it reflects the actual timing of death rather than the paucity of long bone growth (Payne 1973, 283). Caprine *ages-at-death* based on mandibular tooth eruption and wear stages were gathered from publications of sites in continental and insular Greece dated between the EN and the EBA. Counting methods, on which ages-at-death are calculated, differ across publications: *Number of Identified Specimens* (NISP), *Minimum Numbers of Individuals* (MNI), *Minimum Number of Elements* (MNE) and *Minimum Anatomical Units* (MinAU) are the most common ones in the sourced literature. Table 2 presents the counting method employed for each site discussed below (Reitz and Wing 2008, 167, 202–10, 226–30; Halstead 2011). Ages-at-death from the literature are presented in the Suppl. Table 2 as both actual and percent values; graphs of Figs. 3–4 and 6–9 present the survivorship curves extracted from the % values of published ages-at-death of sheep and goats combined against Payne's (1973) curves for meat, milk and wool production based on values from Marom and Bar-Oz (2009).

For the demographic analysis, we incorporated ages-at-death of sheep and goat mandibles from Sitagroi trenches KL and ZA (Papayianni et al. under review), because the caprine mortality profiles published by Bökönyi (1986) were based on epiphyseal fusion data. Bökönyi (1986) mentions mandibles from other trenches as well, which were not located in the storage area of the Drama Museum. Ages-at-death for the Sitagroi caprines was estimated according to eruption and wear stages following Payne (1973, 1987) and Helmer (2000). Sheep and goat distinction follows Halstead et al. (2002). Sitagroi mandibles were recorded per chronological phase of the site. Sitagroi I–II fall into the LN horizon, Sitagroi III falls into the FN horizon and Sitagroi IV–V fall into the EBA horizon (see Table 1 for dates; Tsirtsoni 2016).

To estimate prehistoric flock construction, we investigated the ratios of male and female individuals. Sex ratios were gathered from the literature and are presented as the % values of the sexed individuals; castrates are not included in the sex ratio graphs, because they were not mentioned in all zooarchaeological reports. Sex identification protocols can be found in the original zooarchaeological report of each site and were based on different bones: **a. pelvis** (Prodromos, Agia Sofia Magoula, Alepotrypa, Knossos, Toumba Kremastis Koiladas, Dimini, Pevkakia Magoula, Platia Magoula Zarkou, Skoteini cave, Tsoungiza; Jordan 1975; von den Driesch and Enderle 1976; Halstead and Jones 1980; Halstead 1987, 1992, 2020; Becker 1991; Kotjabopoulou and Trantalidou 1993; Isaakidou 2004, 2006; Tzevelekidi 2012; Hadjikoumis 2018), **b. horns** (Agia Sofia Magoula, Pevkakia Magoula, Platia Magoula Zarkou, Sitagroi; Jordan 1975; von den Driesch and Enderle 1976; Bökönyi 1986). No sexing protocol is mentioned for the assemblage of Megalo Nissi Galanis (Greenfield et al. 2005). In order to obtain valid percentages, we compared sites with 10 or more sexed bones. The survivorship curves and sex ratio diagrams were produced in Excel.

Table 2. Sites sourced for caprine mortality profiles, sex ratios and sheep bone measurements used in the demographic and biometric analyses. Ages-at-death, sex ratios, average sheep bone measurements and page numbers of references including these data are in the Suppl. Tables 2–4.

Site name	Period	Counting method	Age estimation method	Dental Age estimation method	Reference
Achilleion	EN	NISP	Horns, epiphyseal fusion		Bökönyi 1989
Agia Sofia Magoula	LN	NISP, MNI	Dental age	Habermahl 1961, Silver 1969, own method	von den Driesch and Enderle 1976; von den Driesch 1987
Alepotrypa	EN, LN, FN	MinAU	Dental age, epiphyseal fusion	Payne 1973 and 1987	Hadjikoumis 2018
Argissa-Magoula	AN, EBA	MNI	Not mentioned		Boessneck 1960; von den Driesch 1987
Dhimitra	LN	MNI	Dental age	Payne 1973	Yannouli 1994
Dikili Tash	FN	NISP, MNI	Dental age	Payne 1985	Helmer 2000
Dimini	LN	NISP	Dental age	Payne 1973, Deniz and Payne 1982	Halstead 1992, 35, table 2a
Dispilio	MN, LN	MNI	Dental age	Deniz and Payne 1982, Greenfield and Arnold 2008, Moran and O'Connor 1994, Payne 1973, Reitz and Wing 1999	Ioannidou 2005; Phoka-Cosmetatou 2008
Franchthi	EN, MN, LN, FN	MNE	Dental age	Payne 1973, Grant 1982	Munro and Stiner 2020
Ftelia	LN	NISP, MNI	Dental age	Payne 1973	Panagiotidou 2018
Kalythies Cave	EN	NISP	Dental age	Payne 1973	Halstead and Jones 1987
Kastanas	EBA	NISP, MNI	Epiphyseal fusion		Becker 1986
Kephala	FN	NISP	Dental age	Silver 1969	Coy 1977
Knossos	MN, LN	NISP	Dental age	Payne 1973, Deniz and Payne 1982	Perez-Ripoll 2013
Kouphovouno	MN, LN	MNI	Dental age	Gardeisen 1997	Rivals et al. 2011
Lerna	MN	NISP	Dental age	Own method, Silver 1969	Gejvall 1969
Makriyalos I	LN	MinAU	Dental age	Not mentioned	Isaakidou and Halstead 2018, table 5.1; Tzevelekidi et al. 2014

Site name	Period	Counting method	Age estimation method	Dental Age estimation method	Reference
Mavropigi-Fyllotsairi	EN	MNI and MNE	Dental age, epiphyseal fusion	Payne 1973 and 1987, Deniz and Payne 1982	Michalopoulou 2017
Megalo Nissi Galanis	LN, FN	NISP	Dental age, epiphyseal fusion	Grant 1982	Greenfield et.al 2005; Arnold and Greenfield 2006
Paradeisos	FN	NISP	Epiphyseal fusion		Larje 1987
Pentapolis	EBA	MNI	Dental age	Payne 1973	Yannouli 1994
Pevkakia Magoula	FN, EBA	Not mentioned	Not mentioned	Not mentioned	Jordan 1975; Amberger 1979; von den Driesch 1987
Phaistos	LN	NISP, MNI	Not mentioned	Not mentioned	Wilkens 1996
Platia Magoula Zarkou	MN, FN, EBA	NISP, MNI	Epiphyseal fusion and dental age	Not mentioned	Becker 1991 and 1999
Prodromos 1–2–3	EN	NISP	Dental age	Payne 1973	Halstead and Jones 1980
Promachon	FN	NISP	Dental age, epiphyseal fusion	Payne 1973 and 1987	Kazantzis 2018
Sitagroi	LN, FN, EBA	NISP	Dental age, epiphyseal fusion	Payne 1973 and 1987	Bökönyi 1986; Papayianni et al. under review
Skala Sotiros	EBA	MNI	Dental age	Payne 1973	Yannouli 1994
Skoteini cave	LN	NISP, MNI	Dental age	Payne 1973	Kotjabopoulou and Trantalidou 1993
Thermi B	LN	MNI	Dental age	Payne 1973	Yannouli 1994
Tiryns	EBA	NISP	Not mentioned	Not mentioned	von den Driesch and Boess-neck 1990
Toumba Kremastis-Koiladas	LN	Min AU	Dental age	Payne 1973, Deniz and Payne 1982	Tzevelekidi 2012
Tsoungiza	EN, FN	MinAU	Dental age	Payne 1973 and 1987	Halstead 2011 and 2020
Vassilika C	LN	MNI	Dental age	Payne 1973	Yannouli 1994
Xirolimni-Portes	EN	MNI and MNE	Dental age, epiphyseal fusion	Payne 1973 and 1987, Deniz and Payne 1982	Michalopoulou 2017

b) Skeletal biometric and morphometric comparisons

The analysis for any skeletal changes was performed on prehistoric against modern sheep, the latter used as the standard of domestic unimproved or improved individuals, depending on the question (see below). The scale of analysis is twofold: inter-site scale for complete skeleton fluctuations and intra-site scale for specific bone changes. The CV of each bone measurement is calculated according to the equation: *StDev/Average * 100*, where StDev is the standard deviation of all available values of a specific measurement against the average value of all available values of a specific measurement. The Sheep Project compared the CVs of the Shetland sheep to those deriving from zooarchaeological material found at late medieval and post-medieval sites in Britain. The aim was to test the hypothesis that during those periods sheep breeds may have undergone improvement, a suggestion initially based on both zooarchaeological and textual data (Albarella and Davis 1996; Albarella et al. 2009; Popkin et al. 2012, 1789). The average CV was calculated for all bones excluding the pelvis, because this bone depicts high variance in male, female and castrated individuals, continues growth throughout lifetime and is difficult to measure (Popkin et al. 2012). The results showed that, whereas the average CV for the Shetland population was 5.8, sheep bones from sites dating between the 14th and the 19th century had an average CV (excluding the pelvis) exceeding 6. This CV value was interpreted as an indication either for the presence of two or more sheep breeds at a site, or for a significant size change of a single breed during the studied timeframe (Popkin et al. 2012, table 15).

For this research we applied the method developed by Popkin et al. (2012) to test the average CVs of sheep bone assemblages from Neolithic and EBA sites in Greece. The average CV value for each site/phase is based on each bone measurement available for the respective assemblage. The choice of the measurements for the estimation of the CV (Table 3) was made according to the commonest ones across publications, unlike the Sheep Project that utilizes all possible measurements of all limb bones and scapula (Popkin et al. 2012, table 14).

Small sample sizes can impact the average CV values and it is therefore advisable to test the CV on large assemblages. The British sites dated to the late medieval and post-medieval periods yielded substantial bone assemblages with some hundreds or thousands available sheep bone measurements, from which average CV values were calculated (Albarella and Davis 1996, 85, table 25; Albarella et al. 2009, 59, table 29). Sheep bone assemblages from Neolithic and EBA Greece do not exceed 400 bone measurements for reasons ranging from taphonomic conditions and bone preservation to excavation and sampling methods or uncovered site size. Given this limitation, we applied this method on assemblages containing at least 50 measurable sheep bones; in this way we stress the potential of the method for investigating the existence of sheep breeds in future studies with larger datasets (see Suppl. Table 4).

Table 3. Linear measurements of the main postcranial adult (fused) bones included in the CV estimation (after von den Driesch 1976; check Suppl. Table 4 for abbreviations).

Bone/ Measurement	GL	GB	GLP	GLl	GLm	Bd	Bp	Bt	BFp	BFd	DC	Dd	SLC
Humerus	✓		✓			✓		✓					
Radius	✓					✓	✓		✓	✓			
Metacarpus	✓					✓	✓						
Metatarsus	✓					✓	✓						
Femur	✓					✓	✓				✓		
Tibia						✓	✓					✓	
Scapula			✓										✓
Astragalus				✓	✓	✓							
Calcaneus	✓	✓											

For the intra-site approach, we applied Geometric Morphometrics analysis (henceforth GMM) on sheep astragali from Sitagroi settlement (Drama, north Greece) and Alepotrypa cave (Peloponnese, south Greece) in order to detect fluctuations in their size and shape, which could indicate changes in the sheep skeleton. GMM is a non-destructive technique that allows the comparison of shape and size at the same time in many specimens of the same species. It is applied digitally on 2D images or 3D digital reconstructions of biological objects targeting phenotypic differences (Zelditch et al. 2004). GMM was chosen for this project because it is common in domestication and evolutionary studies regarding pig domestication (Evin et al. 2013), the evolution and domestication of equids (Cucchi et al. 2017), the commensalism and dispersal of the house mouse by humans (Cucchi et al. 2020). Furthermore, it was successfully applied to compare modern domestic and wild sheep populations from Anatolia against archaeological populations with the aim to differentiate the species and detect diachronic changes in the skeleton of Neolithic sheep (Pöllath et al. 2018, 2019; Haruda et al. 2019).

For the GMM, we utilized sheep astragali. This choice was based on the following criteria: a) astragalus is solid and compact and it is frequently preserved intact in archaeological deposits unlike other bones, especially long ones (Davis 2017, 50–1; Haruda et al. 2019), b) it grows quickly and reaches adult size and shape quite early in a sheep's lifetime (Davis 2017, 50–1; Pöllath et al. 2018, 210; Haruda et al. 2019, 51), therefore we ensure the inclusion of different age classes in the same analysis, c) its overall morphology is not sex-dependent (Popkin et al. 2012, 1786), apart from the trochlea proximal view, which was not used in our study, d) astragalus is affected the least by nutrition, age and sexual dimorphism compared to other bones (Davis 2017, 60): nutrition can affect only distal breadth growth (Popkin et al. 2012, 1784), whereas age can slightly affect the ratio of breadth (Bd) versus length (Dl) of the astragalus, with higher values from older animals (Davis 2017, 60). GMM has the potential to reveal small but significant shape changes between groups of specimens that are otherwise lost when using traditional linear measurements; GMM can maintain any shape information related to size, so any shape fluctuations can be described as differences between populations (Pöllath et al. 2018, 208; Haruda et al. 2019, 51). Pöllath et al. (2019, 815) applied a Procrustes ANOVA statistical test in their GMM data of both modern and archaeological sheep astragali to test for shape versus size differences due to age and sex. They concluded that these two factors have no significant effect, so specimens of all age and sex groups can be used in the same analysis. Given that astragalus is not sex or age-dependent and it is the least affected by nutrition, it has a greater potential for GMM than other bones.

The acquisition of GMM data for the astragalus morphology analysis was performed on 2D images of the dorsal view of the bone, according to the protocol of Pöllath et al. (2019). Following this protocol, 11 landmarks and 14 sliding semi-landmarks were digitized on the dorsal view of the astragalus; the landmarks were positioned on the muscular scars and the sliding semi-landmarks between landmarks 1 and 3 along the outline of the trochlea between the medial and lateral ridge (Fig. 2). The images were acquired by a Canon EOS 100D digital camera with a Canon EF 40mm f/2.8 STM fixed focal length lens. The Cartesian co-ordinates of landmarks and semi-landmarks were recorded on the images using tpsDig v. 2.31 (Rohlf 2015). The position, orientation, and scaling information from the raw coordinates were standardized by a Generalized Procrustes Analysis (GPA) in MorphoJ software (v.1.07a, Klingenberg 2011) producing a mean astragalus shape. In this way the semi-landmarks slided along the curve of the trochlea, minimizing the distances between the mean shape of the astragalus and each specimen, thus permitting the detection of shape differences (Zelditch et al. 2004). Phenotypic relations between modern and fossil sheep astragali were obtained with a Principal Components Analysis (PCA) of the Procrustes coordinates. We then performed a Canonical Variate Analysis (CVA) to test the within-group variation of mean shape in the astragalus of modern and archaeological populations separated by geographical provenance as grouping variable (Zelditch et al. 2004) (see Tables 4–5 for the provenance of the specimens). Average CVA calculation (Fig. 10) was performed in Excel.

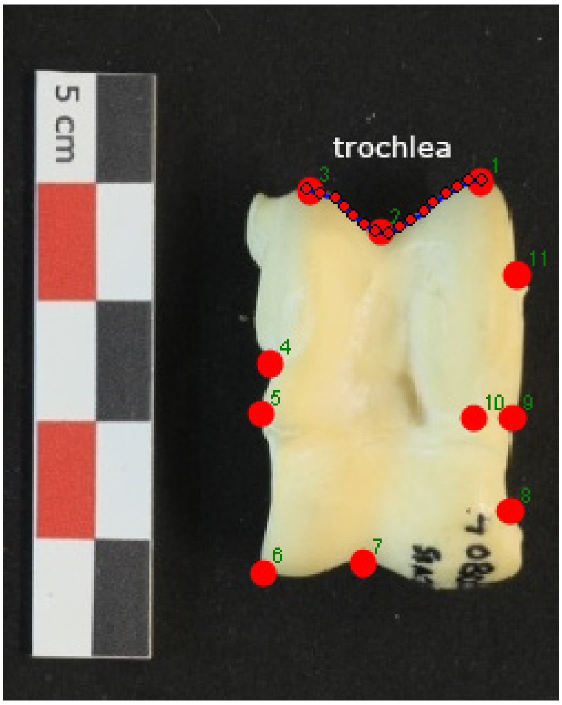

Fig. 2. Astragalus GMM Protocol (combination of landmarks and semilandmarks on the dorsal view) after Pöllath et al. 2019.

Materials

Due to several limitations resulting from COVID restrictions, the modern dataset used for the GMM analysis is limited: we were able to include only 30 modern specimens from the reference collections of the Fitch Laboratory (British School at Athens), the Wiener Laboratory (American School of Classical Studies at Athens) and the Institute for the Aegean Prehistory Study Center for East Crete (INSTAP-SCEC) (Table 4). Twenty-four of these specimens have not been genotyped to breed level and were either collected as road kills or purchased as carcasses around Greece (except for one specimen from Outer Hebrides located in the Fitch Lab). Three sheep of the Chios breed were donated to the Wiener Lab from the Veterinary Department of the Aristotelian University of Thessaloniki. The Chios breed is a native Greek breed of even-wool fat-tailed sheep used mainly for milk production (Rogdakis 2002, 71). Ideally the modern dataset should have included more specimens from native Greek breeds, both mixed-wool and even-wool ones. The modern dataset did not include any wild specimens, since the fossil sample included only domesticated individuals, given the fact that sheep arrived in Greece in a domestic state. The archaeological dataset for the GMM analysis included sheep astragali from Sitagroi and Alepotrypa (Table 5) dating from LN and FN layers. Astragali bones from Sitagroi phase V (EBA) that are published by Bökönyi (1986) were not available for study.

Table 4. Modern sheep astragali included in the GMM analysis.

Specimen	Collection	Provenance	Breed	Age/Sex	Side
Am_1031	Wiener Lab	Neapoli (east Crete)	Unknown	Adult, female	L, R
Am_1032	Wiener Lab	Tzermiado (east Crete)	Unknown	Adult, male	L, R
Am_1076	Wiener Lab	Piskokefalo (east Crete)	Unknown	Adult, female	L, R
Am_A	Wiener Lab	Kolchiko (Thessaloniki)	Chios	1 year, female	L, R
Am_B	Wiener Lab	Kolchiko (Thessaloniki)	Chios	1 year, female	L, R
Am_C	Wiener Lab	Kolchiko (Thessaloniki)	Chios	1 year, female	L, R
KAV_12	INSTAP SCEC	Kavoussi (east Crete)	Unknown		R
KAV_91-53_30	INSTAP SCEC	Kavoussi (east Crete)	Unknown	Young, male	L, R
ARV_733	INSTAP SCEC	east Crete	Unknown		L, R
CVI	INSTAP SCEC	Pachia Ammos (east Crete)	Unknown	Young	L, R
ARV_723	INSTAP SCEC	east Crete	Unknown		L
0003	Fitch Lab	Athens meat market	Unknown	Juvenile	L, R
0005	Fitch Lab	SW Outer Hebrides	Unknown	Female	R
00021	Fitch Lab	Athens meat market	Unknown	Juvenile	L, R
00040	Fitch Lab	Knossos field (Herakleion)	Unknown	Female	R
00080	Fitch Lab	Xiloupoli (Macedonia)	Unknown	Female	L, R
00088	Fitch Lab	Xiloupoli (Macedonia)	Unknown	3–4 years old, male	L, R

Table 5. Fossil sheep astragali from Sitagroi and Alepotrypa included in the GMM analysis.

Site	Context	Date
Alepotrypa	Θ.15–19	FN
Alepotrypa	Z/22B/669, T.226, 26/8/98	EN to FN
Alepotrypa	Neolithic staircase	FN
Alepotrypa	B/2/100, 23/1/71	FN
Alepotrypa	B/5/101, 23/1/71	FN
Alepotrypa	B/6/124, 11/2/71	FN
Alepotrypa	B/2/102, 26/1/71	FN
Alepotrypa	B/2, 3/2/71	FN
Alepotrypa	B/1/27, 19/8/70	FN
Alepotrypa	B/5/103, 26/1/71	FN
Alepotrypa	B/6/136, 18/2/71	FN
Alepotrypa	B/1/51, 24/8/70	FN
Alepotrypa	B/5/103b, 26/1/71	FN
Alepotrypa	B/2/109, 28/171	FN
Alepotrypa	B/3/106, 1/2/71	FN
Alepotrypa	B/2/100b, 23/1/71	FN
Alepotrypa	B/K1/56, 4/12/70	FN
Alepotrypa	B/1/52, 25/8/70	FN
Alepotrypa	B/2/102b, 1/71	FN
Alepotrypa	B/2/100c, 22/1/71	FN
Alepotrypa	B/1/200, 17–20/7/78	LN
Alepotrypa	B/1/219, 22/1/71	FN
Alepotrypa	B/3/125, 11/2/71	FN
Alepotrypa	Petrocheilou refuse, 16–31/8/71	mixed
Sitagroi	KL111a	LN
Sitagroi	KL111b	LN
Sitagroi	KL 111, Bb 20	LN
Sitagroi	KLb 126	LN
Sitagroi	KL 114	LN
Sitagroi	KL 2a, fill deposit beneath floor 15	LN mixed
Sitagroi	KL 2b, fill deposit beneath floor 15	LN mixed
Sitagroi	KL 2c, fill deposit beneath floor 15	LN mixed
Sitagroi	MMd 66	FN
Sitagroi	ZA 46s	FN
Sitagroi	ZA 46s	FN
Sitagroi	ZA 47δ	FN

III. RESULTS OF THE ZOOARCHAEOLOGICAL APPROACH

a) Demographic reassessment of Neolithic and EBA caprine assemblages

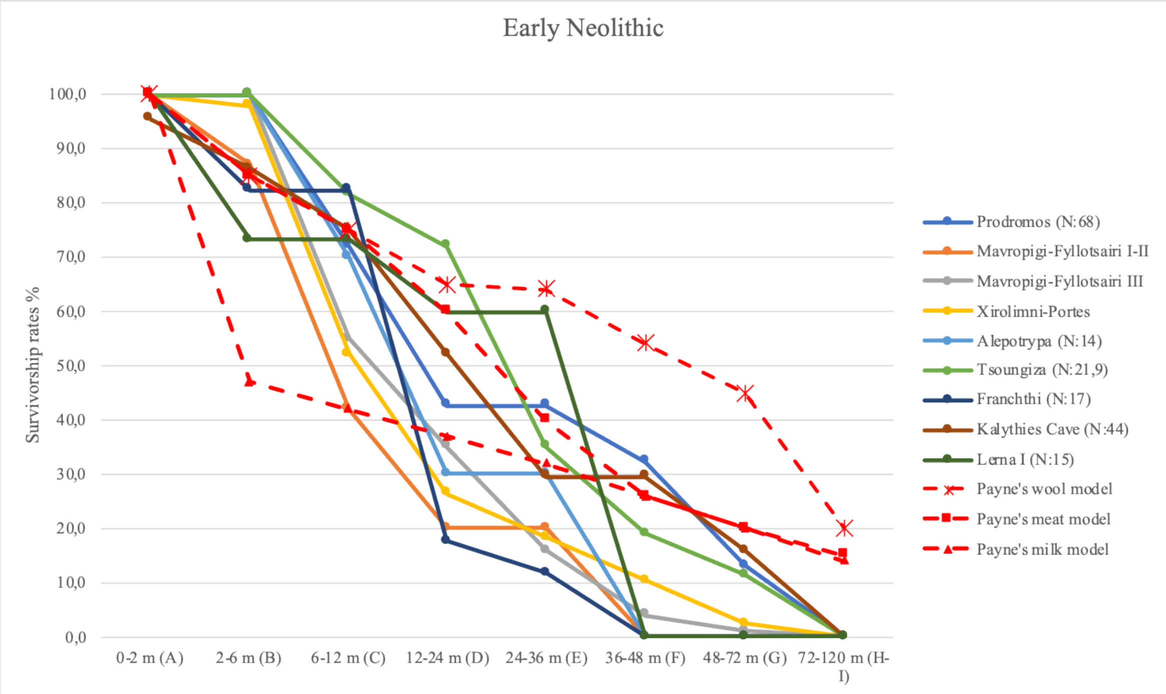

Fig. 3. Sheep/goat survivorship curves based on mandibular age from Early Neolithic sites. N: total sample size (not available for Mavropigi Fyllotsairi and Xirolimni Portes). Details of samples sizes and percentages per site can be found in the Suppl. Table 2. Age classes after Payne 1973: A: 0–2 months, B: 2–6 months, C: 6–12 months, D: 1–2 years, E: 2–3 years, F: 3–4 years, G: 4–6 years, H–I: 6–10 years.

Figures 3–4 depict the survivorship curves of caprines exploited at EN and MN sites (see Suppl. Table 2 for actual values and percentages from the sites discussed in this part and relevant references).

Beginning with the Initial Neolithic, the only site from which there is evidence is Franchthi cave, where 76% of the caprine assemblage is of 1–2 years of age. Regarding the EN the following observations can be made: the recovery of very young caprines (2–6 months) at EN Lerna I, the mandibles of which were studied by Gejvall (1969) before the publication of Payne's aging system, is remarkable. In Mavropigi-Fyllotsairi, Xirolimni-Portes, Alepotrypa and Franchthi the majority of the recovered caprine mandibles belonged to individuals ranging from 6 months to 2 years of age, with an emphasis in the age group 6–12 months and 1–2 years. At Tsoungiza, Lerna I and Kalythies the majority of the recovered caprines are between 2–4 years of age, which is the peak of body size growth and meat yield. Survivorship of low numbers of individuals older than 4 years is attested at Prodromos, Mavropigi-Fyllotsairi III, Xirolimni-Portes, Tsoungiza and Kalythies cave.

Regarding the MN (Fig. 4), we notice the survivorship of individuals between 2–4 years at Kouphovouno, Dispilio and Lerna II. At Franchthi we notice a high percentage of caprines aged between 1–2 years. We still notice a preference at full body growth carcasses in all sites as in the previous period. During the MN all of the above four sites yielded substantial numbers of juvenile caprines (6–12 months) with an exceptionally high percentage at Lerna II. Older individuals were also recovered from MN Kouphovouno, Dispilio and Franchthi. These mortality patterns correspond to husbandry strategies indicative of meat consumption from maximum-sized individuals, as depicted clearly in the survivorship curve of MN Dispilio of Figure 4, which is parallel to Payne's meat model. However, the possibility of dairy or even wool harvest cannot be excluded, given the recovery of both very young and mature or even senile individuals during the MN. Sex ratios from both EN and MN sites are in favor of female versus male sheep. The exception is Aceramic Knossos, where their percentages are equal (Fig. 5). A random exploitation of secondary products during the MN period cannot be excluded, given the existence of mature or senile individuals.

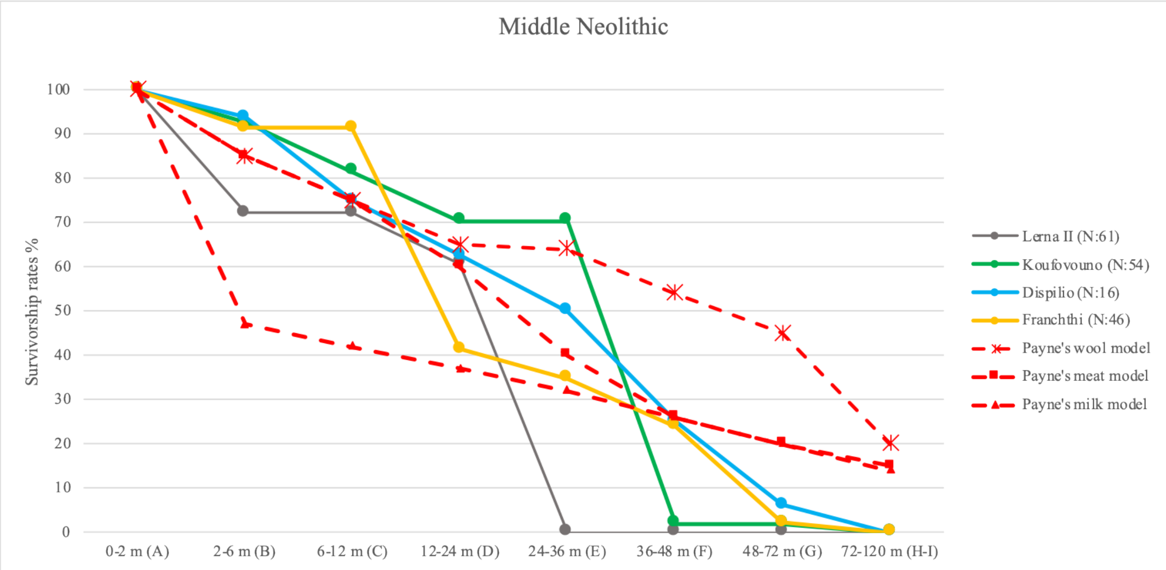

Fig. 4. Sheep/goat survivorship curves based on mandibular age from Middle Neolithic sites. N: total sample size. Details of samples sizes and percentages per site can be found in the Suppl. Table 2. Age classes after Payne 1973: A: 0–2 months, B: 2–6 months, C: 6–12 months, D: 1–2 years, E: 2–3 years, F: 3–4 years, G: 4–6 years, H–I: 6–10 years.

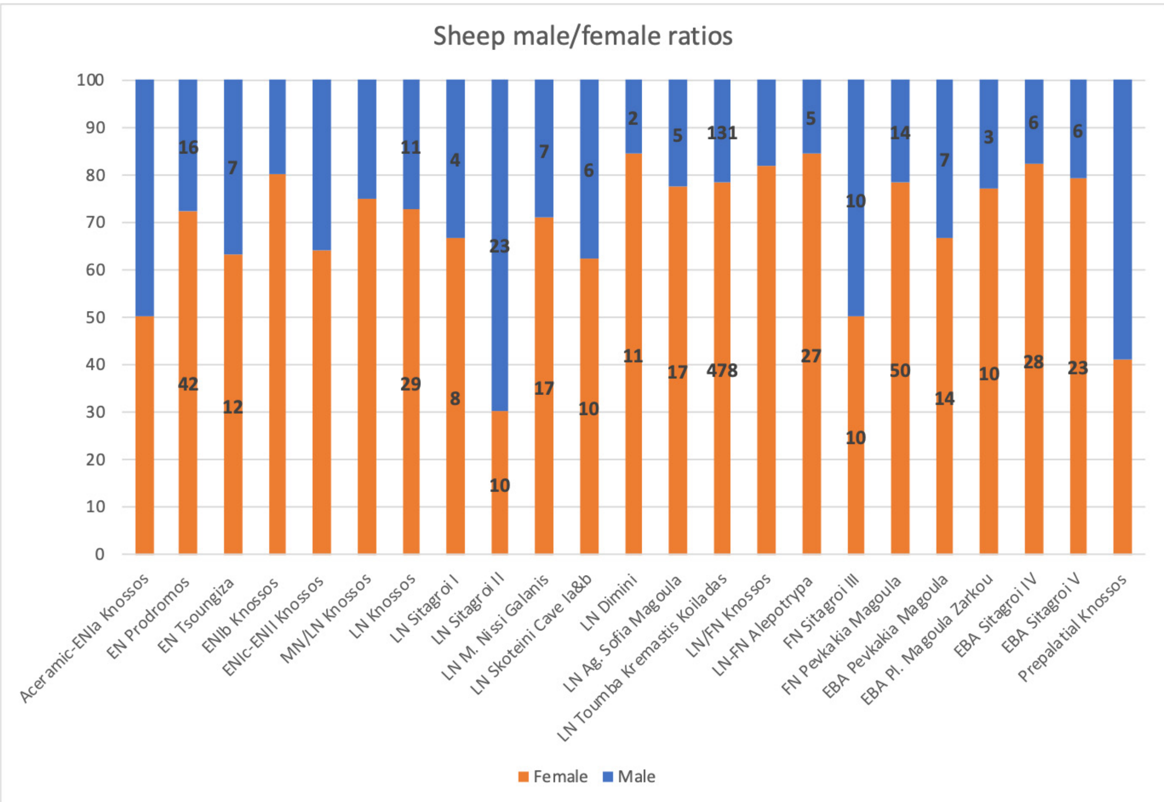

Fig. 5. Diachronic male/female sheep representation from different sites. Total actual sample size indicated in the bars. Details of male/female ratios and percentages per site can be found in the Suppl. Table 3.

More sites dating to the LN and FN period yielded ages-at-death than from EN and MN. The Sitagroi settlement provided material dated to these two periods and the EBA, the survivorship curves of which are depicted in Figure 6 (Suppl. Table 2; Papayianni et al. under review). Mandibles belonging to neonatal (0–2 months) and very young caprines (2–6 months) were recovered from all phases, with peaks of neonatal individuals at LN Sitagroi II (17.4%) and EBA Sitagroi V (46.4%). Caprines aged between 1 and 4 years were found in substantial numbers in all Sitagroi phases, with a peak (41.9%) in LN Sitagroi II and a lowest value in EBA Sitagroi V (21.4%). When it comes to individuals beyond 4 years (adult/mature and senile), the peak comes from FN Sitagroi III (40.9%), followed by LN Sitagroi I (37.1) and the lowest value from EBA Sitagroi V (10.7%). The Sitagroi IV assemblage dates also to the EBA but was limited to only two mandibles of adult individuals and is not discussed further. Turning to the survivorship curves, the Sitagroi I and III curves lie between Payne's wool and meat model, with a curvature more similar to meat for LN Sitagroi I and to wool for FN Sitagroi III. The LN Sitagroi II curve is compatible with the meat model, whereas the one of EBA Sitagroi V is more compatible to the milk model. However, the high percentage of newborn/milk sheep of phase V can also be a result of natural infant mortality next to the culling regime (Halstead 1998). The curves betray a mixture of culling regimes for secondary products (milk and wool) along with meat during Sitagroi I–II and V. Regarding male/female ratios estimated by Bökönyi (1986), in Sitagroi I, IV and V females outnumber males; in Sitagroi II male are twice as many as the female individuals, whereas in Sitagroi III their percentages are equal (Fig. 5).

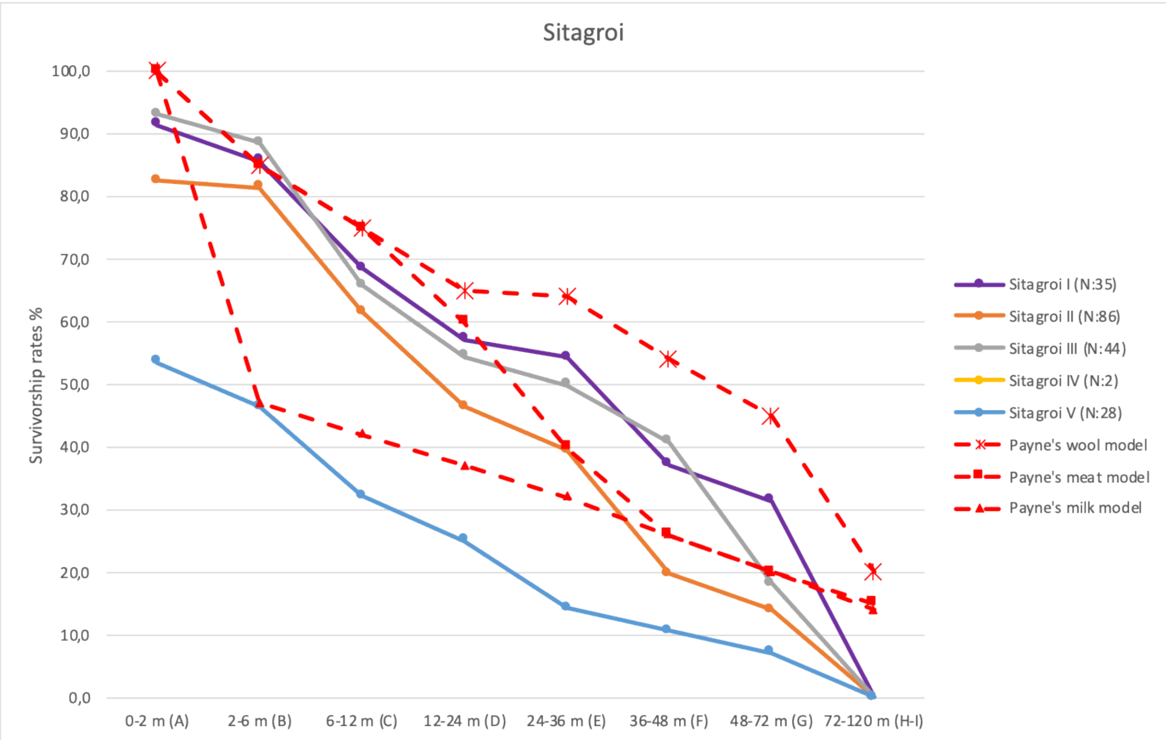

Fig. 6. Sitagroi survivorship curves from phase I to phase V. N: total sample size. Details of samples sizes and percentages per site can be found in the Suppl. Table 2.

Regarding the rest of the LN sites, young caprines were culled between 1 and 4 years of age; these are the predominant ages in all sites (Fig. 7). Newborn caprines (0–2 months) were found in Agia Sofia Magoula and Megalo Nissi Galanis. Juvenile caprines between 6–12 months were recovered from all sites but Vassilika C III–IV, Thermi B, Dispilio and Megalo Nissi Galanis; this age class peaks at Kouphovouno, Franchthi and Knossos. The augmentation in the survivorship of older ages (4–6 years and 6–10 years) is noticeable at all sites, apart from Agia Sofia Magoula, Megalo Nissi Galanis and Kouphovouno, with peaks at Dhimitra, Vassilika C I–II and Dispilio. The curves of Dhimitra I–II, Vassilika C I–II and Dispilio (Fig. 7) are close to Payne's wool curve and the rest approximate the one of meat. The exception is the curve of Megalo Nissi Galanis that approximates Payne's milk curve.

The FN sites are fewer than the LN ones (Fig. 8). Newborn sheep were found at Dikili Tash, Pevkakia Magoula and Alepotrypa, whereas young juveniles (2–6 months) were found in all sites with a peak at Franchthi (22.6 %). At Megalo Nissi Galanis all caprines were slaughtered young, between 6 months and 2 years of age. In the rest of the sites caprines were also slaughtered both in the age of full body growth (2–4 years) as well as beyond 4 years and up to 8–10 years. The FN Promachon and Tsoungiza curves indicate preservation of adult/mature and senile individuals and are close to Payne's wool curve. The curves of Dikili Tash and Franchthi are close to Payne's milk curve. During both the LN and the FN, the analogies between male and female sheep are again in favor of females, apart from LN Sitagroi II and FN Tsoungiza (Fig. 5).

Regarding EBA, newborn sheep (0–2 months) were found only in Pevkakia Magoula and Tiryns EB II; very young juveniles (2–6 months) were found in all sites but Pentapolis with a peak at Tiryns (22.6%) (Suppl. Table 2; Fig. 9). In all sites the caprines were slaughtered mostly between 1 and 4 years of age. Individuals slaughtered beyond 4–6 years of age were found in all sites except Lerna II. The survivorship curves of EBA sites indicate meat strategies apart from Sitagroi V, which is closer to Payne's milk curve (Fig. 9). The survivorship curve of Prepalatial Knossos sheep is closer to Payne's meat model (Isaakidou 2006, 101, fig. 8.2). During the Early Bronze Age female sheep predominate against male sheep (Fig. 5). Male sheep have a slight predominance in Prepalatial Knossos (Suppl. Table 2; Isaakidou 2006, 102, table 8.2), though it is not clear for which phase of the Prepalatial period.

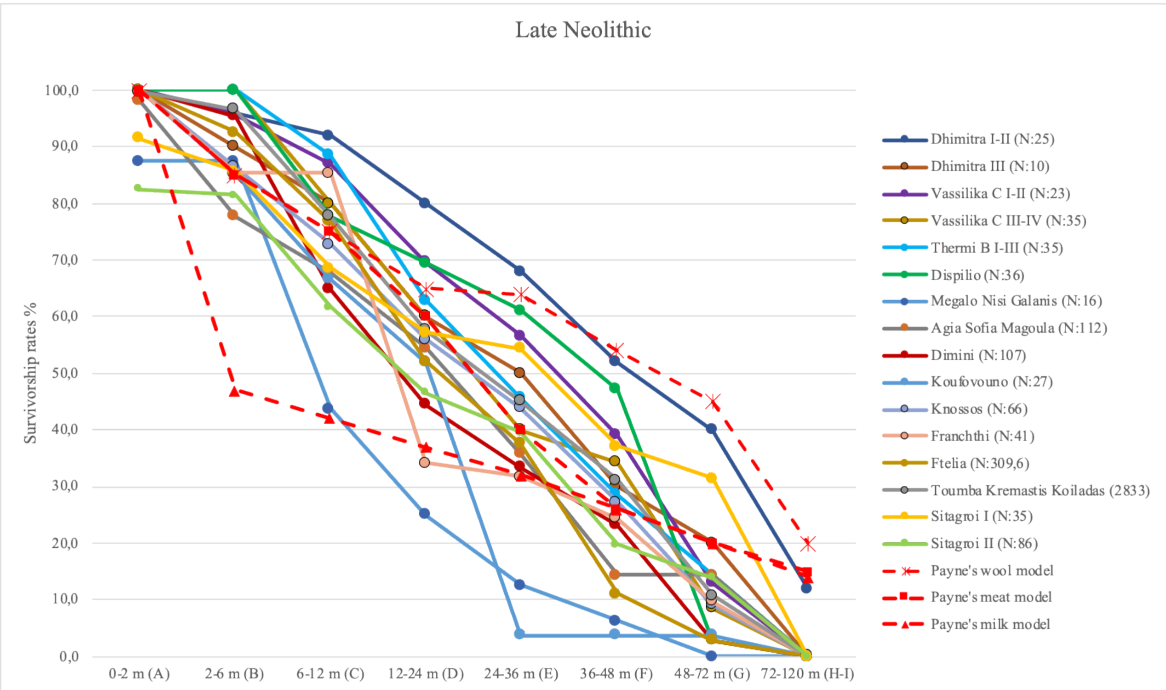

Fig. 7. Sheep/goat survivorship curves based on mandibular age from Late Neolithic sites. N: total sample size. Details of samples sizes and percentages per site can be found in the Suppl. Table 2. Age classes after Payne 1973: A: 0–2 months, B: 2–6 months, C: 6–12 months, D: 1–2 years, E: 2–3 years, F: 3–4 years, G: 4–6 years, H–I: 6–10 years.

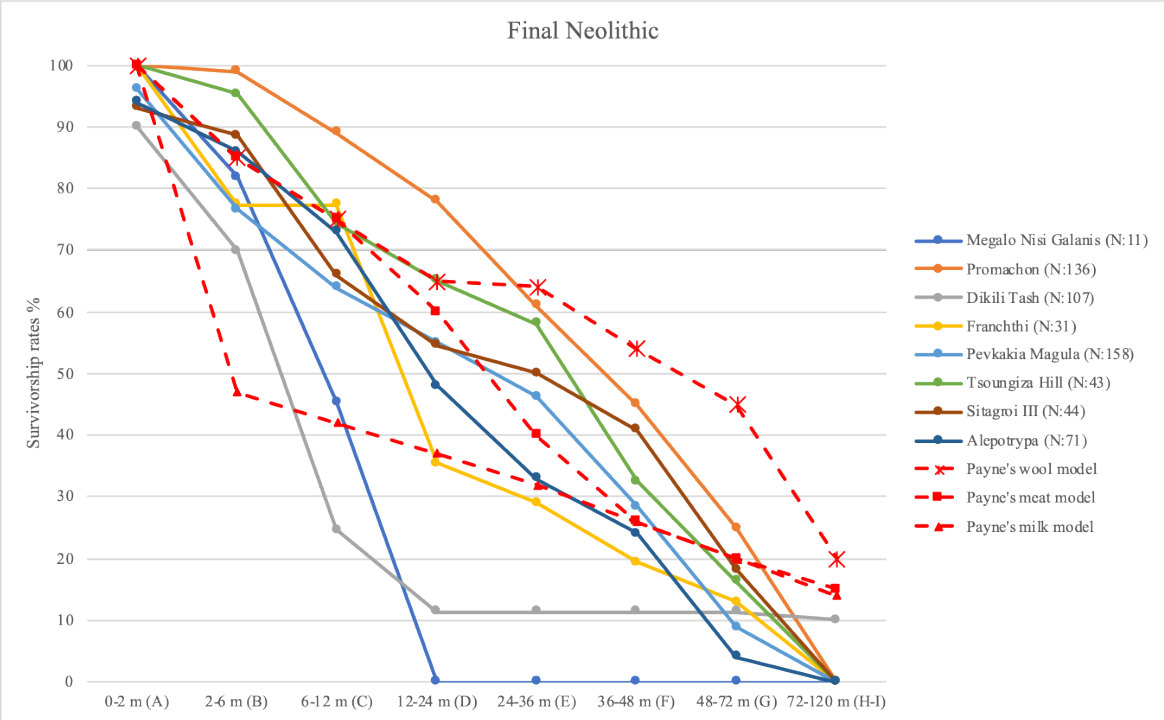

Fig. 8. Sheep/goat survivorship curves based on mandibular age from Final Neolithic sites. N: total sample size. Details of samples sizes and percentages per site can be found in the Suppl. Table 2. Age classes after Payne 1973: A: 0–2 months, B: 2–6 months, C: 6–12 months, D: 1–2 years, E: 2–3 years, F: 3–4 years, G: 4–6 years, H–I: 6–10 years.

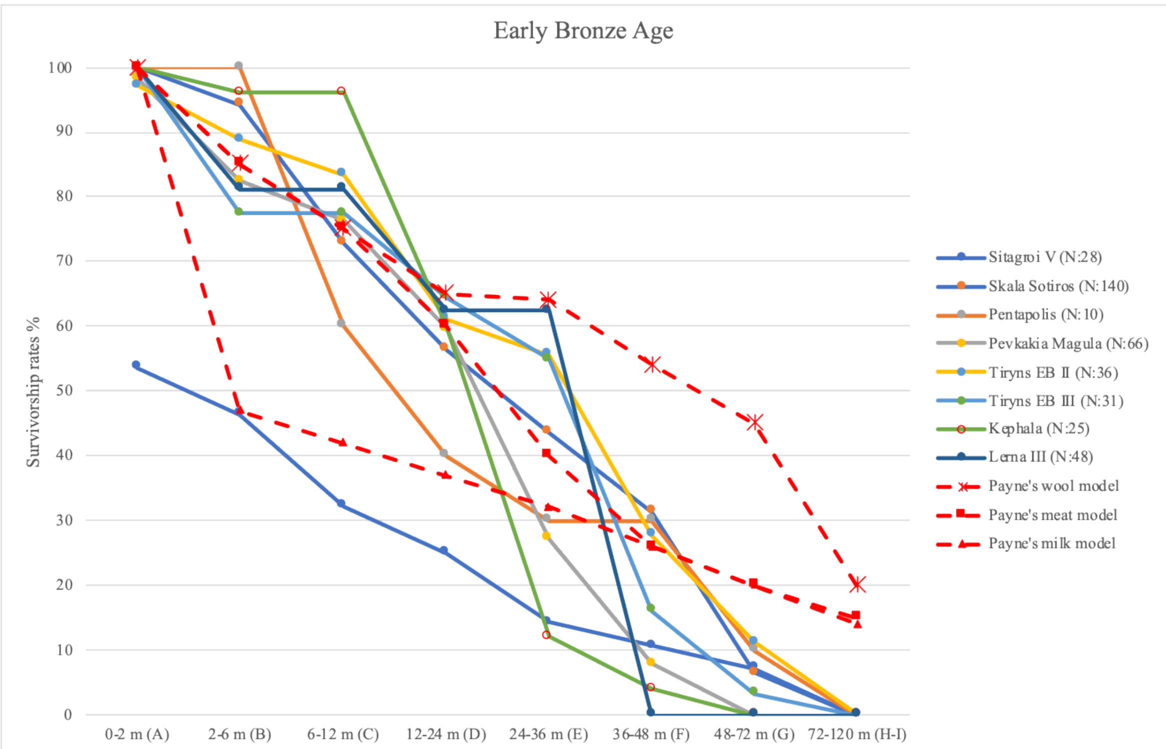

Fig. 9. Sheep/goat survivorship curves based on mandibular age from Early Bronze Age sites. N: total sample size. Details of samples sizes and percentages per site can be found in the Suppl. Table 2. Age classes after Payne 1973: A: 0–2 months, B: 2–6 months, C: 6–12 months, D: 1–2 years, E: 2–3 years, F: 3–4 years, G: 4–6 years, H–I: 6–10 years.

To sum up the aforementioned evidence, we notice the steady pattern of slaughtering caprines of adult age and full body growth in all periods and sites in the frame of "meat" strategies. The slaughter of newborn and very young juveniles is attested from the MN onwards, with peaks in the FN and the EBA. The culling of individuals older than 4 years is attested in all periods, although it becomes more evident from the MN onwards and more frequent during the LN–FN. The overall predominance of female versus male sheep during all periods apart from LN Sitagroi II reflects the reproductive stock of the Neolithic flocks. The available sex evidence does not report the existence of castrates among the deadstock, which would potentially have better quality of wool. Biometric approaches to long bones used to distinguish male, female and castrated individuals, like the *Logarithmic Size Index*, can shed new light in the percentages of the three sexes from prehistoric sites, where sexable bones are not found, and thus give more detailed data about Neolithic flock synthesis in future studies.

Meat husbandry strategies were the rule during all periods; however, the harvest of milk and wool/hair cannot be excluded for some sites, as depicted in the survivorship curves and in the occasional patterns of recovery of frequent newborn or mature individuals. Retaining older female sheep after the end of their use as dairy animals provides large carcasses for consumption and perhaps also wool. One would argue that high infant mortality or preference in large-sized carcasses achieved with maintaining mature male and female animals are the reasons affecting the preservation of bones from the respective age classes. Natural infant mortality cannot be proven via bone examination and large carcass preference cannot be proven if there is no feasting evidence in the excavated contexts. Subsequently, the possibility for random dairy or wool (or both) harvest should not be ruled out.

Insights from Greek ethnography indicate the predominance of female over male caprines in traditional flocks, which of course served different needs than those of the Neolithic societies. Traditional herders (Sarakatsani, herders of the Argolid and the Tzoumerka) kept one or two rams or bucks for every 25–30 ewes or does in order to secure reproduction and avoid overpopulation (Koster 1977, 263; Karatzenis 1991; Kavvadias 1991) (Table 6). Castrated rams or bucks were kept by all folk groups as flock leaders, with an example of 4–5 castrated rams for a flock of 300 ewes and 25 non-castrated rams (Karatzenis 1991; Kavvadias 1991; Botos 1982). For the Sarakatsani herders, the age of males defined the ratio with the females probably because younger males were considered less experienced than mature ones and seniles weaker: younger rams of 1–2 years of age were kept for every 20 ewes, more mature rams or bucks were kept for 35–40 ewes or does, whereas senile rams or bucks for fewer ewes or does (Botos 1982). The male offspring were sold a month to 40 days after birth by all traditional herders (Koster 1977, 224–25; Karatzenis 1991; Kavvadias 1991), a fact that liberated the milk of ewes for dairy production as well as maintained a steady flock size. Wool and lambs (soft meat) were the secondary income sources for the Sarakatsani, whereas milk and cheese were the primary sources (Halstead 1996, 22). On the contrary, lambs, milk, wool (unspun and textile) as well as transport with pack animals were the major income sources of the Vlachs (Halstead 1996, 22). Older female animals were culled when not any more useful for reproduction or dairying, whereas older male animals were castrated and fattened for a year before being sold to the butcher (Koster 1977, 239; Botos 1982, 140; Karatzenis 1991, 245).

Table 6. Traditional flock construction and male/female ratios.

Traditional Herders	Adult Male/ Females	Year-old male/ Females	Total Males	Total Flock	Castrated males (wethers)	Reference
Sarakatsani	1/35–40	1/20				Botos 1982; Kavvadias 1991
Tzourmerka herders	2/25	2/25	25	300	4–5	Karatzenis 1991
Argolid 'Arvanites'	1/25			250–500		Koster 1977

Direct comparisons between the ethnographic sources and the Neolithic or EBA zooarchaeological evidence for flock demography should not be made, due to both the vast chronological gap and the different sociocultural conditions behind them. However, traditional flocks of societies that profited from woolen textiles and dairy products were constructed of many more female versus male sheep and goats and not by many castrated rams like the system mentioned in Mycenaean texts. It seems that the wool that was harvested to be sold by Vlachs or Sarakatsani came mainly from female sheep, given the low numbers of rams and wethers. The culling regimes of newborn caprines followed by traditional herders correspond to Payne's milk model and are different by those read through the caprine bones of most Neolithic and EBA sites. Furthermore, 'wool mortalities' among traditional flocks do exist but served mainly flock maintenance purposes.

b) Skeletal changes of prehistoric sheep: results of the CV approach

Table 7 details the CVs based on published sheep bone measurements (see also Suppl. Table 4). In nine cases the CV exceeds number 6 (highlighted in bold): MN–LN–EBA Platia Magoula Zarkou, FN Megalo Nissi Galanis, and EBA Pevkakia Magoula. The two case studies, Alepotrypa and Sitagroi, gave CVs above 6 for the FN (Alepotrypa, Sitagroi III) and Early Bronze Age (Sitagroi phases IV–V).

The CV approach can be applied on sheep bone assemblages from excavations, though with caution: the long-time span between prehistoric sheep bones from Greece and the modern Shetland sheep is far larger than the time span between the 21st century AD (Sheep Project) and the evidence for British medieval breeds (14th–16th centuries AD). It should be kept in mind, also, that Shetland sheep have lived in a different climate and terrain than Greek sheep. Ideally, a future thorough study of the skeletal changes due to nutrition, sex, castration and breeding age could be applied on Greek or Balkan sheep to serve as comparative evidence for the CV approach attempted here. Also, the method should be tested in later period bone assemblages, especially in Mycenaean and historical period ones, for which we already know that there was specialized wool production.

Table 7. CV values for sheep bone measurements from sites spanning from the EN to the EBA. CV: Coefficient of Variation; N: Number of measurements used. Bold: evidence for sheep skeleton improvement. Average bone measurements from each site can be found in the Suppl. Table 4.

Site	Period	CV	N	Site	Period	CV	N
Prodromos	EN	5.64	93	**Sitagroi III**	FN	**6.12**	241
Achilleion III–IV	MN	5.94	70	Pevkakia Magoula	FN	5.27	187
Pl. Magoula Zarkou	MN	**6.69**	50	**Megalo Nissi Galanis**	FN	**6.84**	306
Pl. Magoula Zarkou	LN	6.22	63	**Alepotrypa**	FN	**9.79**	286
Alepotrypa	LN	3.96	63	Megalo Nissi Galanis	FN/EBA	5.26	58
Phaistos	LN	4.62	65	**Pevkakia Magoula**	EBA	**7.02**	247
Sitagroi II	LN	5.33	146	**Sitagroi IV**	EBA	**7.94**	53
Alepotrypa	LN/FN	4.84	63	**Sitagroi V**	EBA	**8.1**	168
Franchthi	FN	3.62	80	**Pl. Magoula Zarkou**	EBA	**6.25**	228
Agia Sofia Magoula	FN	4.70	186				

c) GMM analysis of sheep astragali: results

The combination of CV1 and CV3 depicted in the scatter plot of Figure 10 illustrates the differences between fossil and modern astragali. The average shapes of the astragali from Sitagroi and Alepotrypa are well-discriminated from the modern ones along the Y axis (CV3), but at the same time no breed indication is produced for the fossil specimens, probably due to the very limited modern reference material. We should also consider if it was perhaps too early for any improvement to have happened. Given the long timespan between the Neolithic period and our time, which would have enabled one or more sheep population turnovers, the GMM analysis should ideally be run in a much broader diachronic dataset comprising fossil specimens from different periods and regions around Greece as well as modern Greek, Balkan and Anatolian sheep specimens from different breeds.

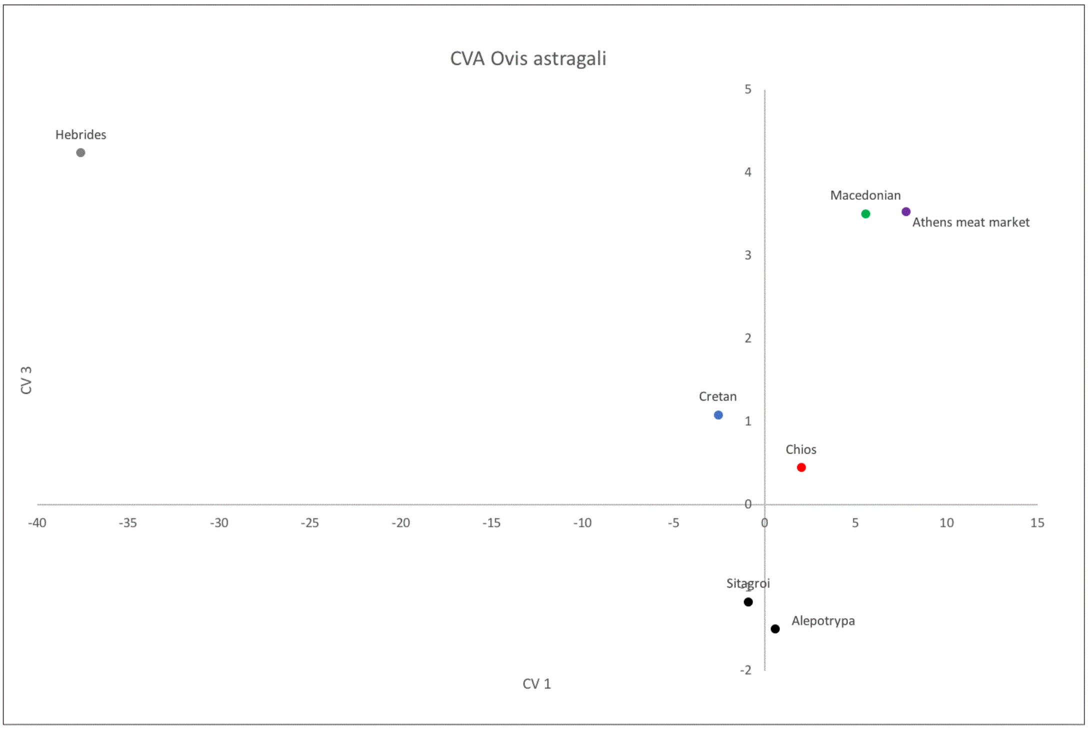

Fig. 10. Canonical Variate Analysis (CV1 vs CV3) of the mean shape of fossil and modern sheep astragali.

IV. PREHISTORIC SHEEP AGE, SEX AND SIZE: DISCUSSION OF THE EVIDENCE AND THEIR IMPLICATION FOR WOOL RESEARCH

First, the examined diachronic flock construction reflects the human nutritional needs mainly for meat and secondarily for dairy products, at least in some of the sites, during the Neolithic period. The preservation of females in combination with the culling of juvenile males is the standard pattern for the maintenance of a more or less steady flock size that permits also milk harvest. Any random or incidental wool harvest was not a priority but only a possibility, since the livestock was available, during the Neolithic and the EBA.

Secondly, the sheep sex ratios recorded from the different sites show a clear diachronic dominance of female versus male sheep. LN Sitagroi II is an exception to this pattern. The ethnographic evidence from 19th and 20th century AD traditional pastoralism in Greece with few males and castrates cannot be directly compared to Neolithic flocks consisting of mostly female sheep. These flock constructions might be similar, but different needs were served by the traditional flocks. Evidently, the ability of female sheep to produce good quality wool was not underestimated by traditional herders. Specialized wool production has so far been associated with the Mycenaean example of wether flocks reared for their wool, according to the Linear B tablets that record *livestock* (Killen 1993). This predominance of wethers is not supported by zooarchaeological finds from Mycenaean sites, because the latter examine *deadstock* (Halstead 1998–1999, 182). Such deadstock was comprised of a mixture of domestic species corresponding to various ages and not only of adult male sheep (Halstead 2007, 40). At LBA Tiryns the sheep bone metrical data suggest existence mainly of female sheep, fewer male and even fewer castrates; for this reason, emphasis on wool production at Tiryns must have relied in young male and adult female sheep rather than wethers – the latter not kept alive for very long (von den Driesch and Boessneck 1990, 98; Halstead 1998–1999, 177). If wool from female sheep served palatial production standards at Tiryns, perhaps it also served the non-specialized but random wool production attempts of Neolithic communities. Mature or senile female sheep of the Neolithic deadstock had decreasing reproduction abilities, thus the exploitation of their fleece appears as a theoretical possibility in contemplating their maintenance. The persistent question remains whether their fleece would have been wooly enough for textile craft.

In terms of sheep improvement targeted for better fleece quality, the presented data is insufficient. The CV approach provides evidence for changes in the sheep's skeleton during the Neolithic period. This method, though, does not indicate if the changes were a result of breeding sheep targeting better wool, more milk, larger meat yield or if it was a random phenomenon and should be tested to traditional Greek sheep breeds too. The alternative to the CV method is the GMM analysis, the results of which do not depict any breed indication due to reasons already explained. However, we consider the method promising, if the fossil dataset is enlarged with more specimens spanning a long period and the modern reference dataset enriched with more specimens of known breeds.

B) THE TECHNOLOGICAL APPROACH

This section of the paper addresses the question of early wool craft in prehistoric Greece from the viewpoint of yarn technology. Ethnographic and archaeological evidence demonstrate that pre-industrial thread manufacture relied on a basic technological principle, i.e., joining together individual fibers into a long, continuous, strong and coherent filament, either with bare hands, or with the use of a spindle, or by a combination of both (Barber 1991, 39–54). The analysis of extant ancient textiles further indicates that two basic techniques, each pertinent to fibers of plant and animal origin respectively, were developed in antiquity: splicing is the technique developed for fibers of plant origin, including tree basts, and draft-spinning is the technique developed for fibers of animal origin, in particular sheep wool (Barber 1991, 49–50; Gleba and Harris 2018). Splicing involves joining by hand individual plant fibers from end-to-end, or along their length continuously, slightly twisting the joints, and thus forming a long filament. The spliced threads can then be strengthened by plying them with the use of a spindle which adds extra twist to the filament (Barber 1991, 47–8; Gleba and Harris 2018). Draft-spinning involves drawing fibers from a rove of raw material and twisting them continuously into thread with the use of a spindle, usually equipped with a spindle whorl which acts as a flywheel that enhances the rotation of the spindle (Barber 1991, 41–3). The two techniques may be distinguished in the end-products, the yarns woven into textiles, by the presence of splices or continuous twists respectively.

According to a reconstruction of the evolution of fiber crafts, splicing predated draft-spinning by several millennia since wild plant/tree bast fibers were available to humans throughout the Palaeolithic and the Mesolithic Ages, whereas the procurement of animal fibers for textile use required domestication, i.e., the advent of the Neolithic, which brought caprines under direct human control and triggered the gradual mutation of their kempy coats into wooly hides through selective breeding, eventually making wool available for textile weaving (Barber 1991, 50). It has also been suggested that after its invention, draft-spinning, the technique most suitable to the soft, elastic and relatively shorter wool fibers, was ultimately adopted for the transformation of plant fibers (such as flax) into thread as well, despite the fact that splicing continued to be used well into the Bronze Age and even later in some regions (Barber 1991, 50; Gleba and Harris 2018, 2340). The two techniques have been characterized as "fundamentally different" (Gleba and Harris 2018, 2329).

In theory, then, evidence for draft-spinning wool may allow the archaeological diagnosis of early wool craft; or, conversely, evidence for the exclusive use of splicing would point to the exclusive use of plant fibers. Distinguishing archaeological indicators of the yarn manufacturing technique(s) employed by a community of crafters should allow insights as to which of the two broad categories of the perishable raw materials of yarn, plant or animal fibers, were preferred by, or available to, the prehistoric community in question. In Greece the perishable, organic elements of the technological apparatus of fiber crafts do not survive in the archaeological record. Only spindle whorls are usually preserved from the equipment used in prehistoric crafts, and less often, the spindle shaft.

The challenge is that both technological systems make use of spindles and spindle whorls: these tools are essential for draft-spinning and they may also be sometimes used in a secondary stage of the splicing technique, to strengthen the splices which are initially formed with bare hands (Gleba and Harris 2018). This degree of technological overlap between splicing and draft-spinning prohibits a clear-cut association between technique and fiber category on the basis of the surviving equipment alone. The *crucial methodological issue* is whether archaeological spindle whorls can be shown to have been used exclusively for draft-spinning of wool versus for plying spliced yarns or for draft-spinning of plant fibers.

Research aiming at clarifying ancient craft techniques and the function of textile tools found in archaeological excavations has amplified since the publication of E. Barber's seminal work *Prehistoric Textiles* (Barber 1991) and several analytical methodologies have been initiated. Combining ethnographic data and experimental archaeology, scholars have been working towards disentangling the complex relation between the skills of the craftsperson, the tools and the raw material, with the aim of interpreting archaeological finds and shedding light to ancient textile craft.

In the remaining of this section, these recent developments and their potential for prehistoric fiber crafts research, and wool archaeology in particular, will be reviewed. Then the focus will shift to datasets from prehistoric Greece in order to examine if spindle whorl assemblages dated between the EN and the end of the EBA provide indications of wool spinning, based on the criteria of interpretation deriving from textile tools study, i.e., typological and metrological analysis, ethnographic analogies and experimental spinning. The *main question* to be answered is: do patterns derived from Neolithic and EBA spindle whorl assemblages found in Greece allow for the identification of a major technological change that could indicate the innovation of wool?

I. TOWARDS THE TECHNOLOGICAL INTERPRETATION OF ARCHAEOLOGICAL SPINDLE WHORLS VIS-À-VIS THE QUESTION OF EARLY WOOL CRAFT

a) Spinning as a socially embedded, technological system

All technologies are systems comprised of five basic elements, i.e., specialist knowledge (skills), energy, gestures, matter (raw material) and objects (tools). Change in one of the five elements of the system will most likely affect the remaining four elements (Lemonnier 1992, 8). Moreover, technical traditions are socially embedded because they are learned within a community of practice, and technologies reflect more than material constraints; they also incorporate "social representations" about "how things work, are to be made, and to be used" (Lemonnier 1993), that is, the "mental traditions" that direct the materialization of a technical tendency (Lemonnier 1992, 79–89). Change in a given technological system is a demonstration of a significant disruption or adaptation in the social process of learning and it reveals a shift in the respective mental schemes generating these "social representations". Such a shift will likely have a physical manifestation in the adaptation of gestures, tools or other aspects of the technical tradition (Lemonnier 1993, 21–2).

The systemic and social nature of pre-industrial fiber technologies is indicated in several archaeological and ethnographic examples, demonstrating associations between variations in gestures, tool types and raw materials in various communities of practice of fiber craft. In this paper, archaeological examples are derived from pharaonic Egypt, the Neolithic Swiss dwellings, classical Athens and the pre-Columbian Mesoamerican Mayas culture. Ethnographic examples are drawn from early 20th century AD Greece.

Pharaonic Egyptian art includes representations of spinners who use spindles to ply yarn from separate, pre-formed threads (probably made with splicing, the dominant yarn manufacturing technique in that period and culture). The pharaonic spindles belonged to the high-whorl variation of the tool and were equipped with whorls of discoid or conical shape. The stereotypical whorl type depicted in art is discoid (Barber 1991, 53, fig. 2.7, 2.10). Spinners are depicted standing or kneeling while performing this task (Klebs 1922, 126, fig. 91–2). Pharaonic Egypt is known as the land of flax, so that these gestures and tools are associated with plant fibers in this cultural context.

Archaeological textiles found at the Neolithic lake-dwellings in Switzerland demonstrate the consistent use of the splicing technique followed by plying, for manufacturing yarns with fibers of plant origin (often tree basts, cf. Rast-Eicher 2016). The dominant spindle whorl type found in those settlements is the low/wide type usually described as "discoid" (Rast-Eicher 2005).

In classical Athens, a different way of using the spindle known as draft-spinning (Barber 1991, 41) was very common. Women are depicted on vase paintings spinning with the drop-spindle (suspended) technique using low-whorl spindles, while sitting on chairs or standing (Keuls 1983, 214–15). In classical Attica, wool was not the only type of fiber used, as flax was also very common (Spantidaki 2016). However, it is probable that the artistic representations of spinning on Attic vases capture wool spinning, as this would be in accordance with a thematic focus of Attic vase painters on the representation of domestic wool working (Bundrick 2008). Common tool types in classical Athens are tall conical whorls, like those found in the Sanctuary of the Nymphe on the south slope of the Athenian Acropolis (Eleftheratou 2020, 59, fig. 56).

Moving to a different continent and era, in the Mesoamerican culture of the Mayas artistic representations of textile work show spinners spinning cotton fibers with supported, low-whorl spindles bearing cylindrical or biconical spindle whorls, while they are kneeling down (Smith and Hirth 1988, 351, fig. 2B).

Ethnographic work of the early 20th century AD demonstrates that wool spinning in Greece was performed with draft-spinning, especially by the Vlachs and the Sarakatsani who were nomadic and semi-nomadic pastoralists (Kavvadias 1991). Thanks to early photographers, both international visitors to Greece and Greeks who were often attracted by the sight of spinners working outdoors, it is possible to observe tools and, to some degree, technical gestures related to spinning. Well-known early photographers and cinematographers include Frederic Boissonas (cf. Baud-Bovy and Boissonas 1910; 1919) and Milto and Yanaki Manaki, who filmed women working with wool in 1905 in the village of Avdella near Grevena, a region that was largely populated by the semi-nomadic and wool-producing Vlachs (Zacharia 2008, 323). In this project, a database of ethnographic images related to traditional spinning in early 20th century AD Greece was initiated to collect data for a comparative, "iconographic" study of traditional spinning technical gestures and tools.

The photographic images we present here (Figs. 11–16) date from 1903 to 1955 and document spinners in Ladas, Peloponnese (1903), Paramythia, Thesprotia, northwest Greece (1913), Florina, north Greece (1917), Crete (ca. 1934), Preveza, west Greece (1938) and mount Olympos, north Thessaly (1955). The photographers captured women draft-spinning wool, either with suspended spindles or with hand-held, rotating spindles. The spinners in Figures 11 and 13 are holding a full spindle in their palm, twisting it with one extended arm, while drawing fibers from a distaff held under the armpit of the other arm; the woman in Figure 11 is spinning while walking outdoors; the eyes of the sitting spinner in Figure 13 seem to focus on the drawing gesture, not on the hand rotating the spindle; the woman in Figure 12, also in a seated position, appears to be pausing her spinning to observe, or to pose for the photographer. She rests the hand holding the spindle on her leg, and it is not possible to discern if she was using the suspending or the hand-held rotating technique. However, as in the previous examples, the woman is also holding a distaff full of wool, an essential tool for draft-spinning. The spinners in Figures 14 and 15 are practicing draft-spinning with suspended spindles while standing. This is also the technique used by both the seated woman and the standing young girls in Figure 16.

Spindle whorls can be discerned clearly on the spindles in Figures 12, 15 and 16. In shape these are low conical (Fig. 12), tall conical (Fig. 15) and either discoid or low conical (Fig. 16). It is not clear if the lower part of the spindles in Figures 11 and 13 bear whorls. The spinner in Figure 14 is probably using a spindle without a whorl. Where whorls are clearly discerned, they are fixed on the bottom part of the spindle (low-whorl spindles). Size estimation of the whorls is not possible.

Fig. 11. Girl spinning while walking, Ladas village, Messenia, south Greece 1903.
Photo by Frédéric Boissonas, Voyage en Grèce II: Péloponnèse, Bibliothèque de Genève, Numéro d'Inventaire bge y630 02 086.

Fig. 12. Woman spinning while sitting outdoors in the company of other women, Paramythia, northwest Greece, 1913.
Photo by Frédéric Boissonas, L' Épire, berceau de Grecs, Genève, Editions d'Art Boissonnas 1920.

Fig. 13. Woman spinning while sitting outdoors in the company of other women, Florina north Greece, 1917.
Photo by René Bénézech, https://www.photo.rmn.fr , 17-524010, Femmes devant une maison, Bénézech René, Bénézech Jacqueiline, Paris, Musée du quai Branly-Jacques Chirac. Last accessed August 25th 2022.

Fig. 14. Girl spinning while standing outdoors, Crete, 1934.
Photo by René Zuber, https://renezuber.fr/la-crete/. Last accessed August 25th 2022.

Fig. 15. Sarakatsana woman spinning while standing outside her stray hut, Preveza, west Greece, 1938.
Photo by Spyros Meletzis, published in Rizospastis, issue of June 14th 2009, https://www.rizospastis.gr/story.do?id=5129523 . Last accessed August 25th 2022.

Fig. 16. Young woman and girls spinning on Olympos mountain, central Greece, 1955.
Photo by T. Tloupas, http://takis.tloupas.gr , «Παραδοσιακές ασχολίες» (traditional tasks), No. 24. Last accessed August 25th 2022.

What these images convey is a fairly consistent technological system: wool-spinners employ the draft-spinning technique. The gesture varies, as some use the suspended spindle and others use the hand-held-rotating spindle technique. Spindle whorls also appear to slightly vary in terms of type, but what remains undifferentiated in the examples discussed above is the place of the whorl on the bottom of the spindle shaft. Although this small collection of images is far from exhaustive in documenting draft-spinning wool in modern Greece, their geographical and temporal span suggest that this spinning technique was widespread in the first half of the 20th century AD. Textile scholars have often commented on this system which is typical of spinning wool in rural 20th century Greece (Barber 1991, fig. 2.3; Tzachili 1997, 116). Of course, the technique was not exclusive to the inhabitants of the Greek mainland or of the Aegean islands, as it is also widely attested in the Balkans, and more generally in the southeast and east Europe, where the nomadic communities of herders were practicing long-distance transhumance from the medieval period through the early 20th century AD (Greenfield 1999; Hadjigeorgiou 2011, 4–6; Juler 2014, 4–7). Most of the images also demonstrate that spinning was often a socializing activity that brought together spinners and other women carrying out other textile-related tasks. It is also obvious from many early photographs that spinning was often combined with taking care of young children, and this also points to the intergenerational transfer of technological knowledge.

The above archaeological and ethnographic examples indicate that communities of practice of textile craft have developed standardized technical gestures, but there is always a degree of variety, small adaptations or deviations within a given tradition. Draft-spinning and spindles are common elements in all the examples presented above, but the technical gesture of how the spindle is handled and the type –or presence– of spindle whorl vary, possibly due to the "mental traditions" or "social representations" of how these tools should look like and how they should be used.

More importantly, the archaeological and ethnographic examples combined, demonstrate that, although wool draft-spinning does not depend functionally on spindle whorls strictly defined in terms of type, nevertheless a specific community of practice will most likely develop a standard type –and the respective manufacturing practice– within a given technological tradition. Thus, even though whorls may not be direct evidence of wool (or other fiber) craft, the study of typological patterns within and/or among archaeological assemblages can reveal adherence to, or deviation from, traditions within the wider technological system of yarn manufacture, including spindle whorl manufacture. "Mapping" significant shifts in spindle whorl morphology within the Greek Neolithic and EBA can be an important first step in recognizing potential change in manufacturing traditions of textile tools: the physical manifestation of the mental schemes, of "how things work, are to be made, and to be used" (Lemonnier 1993, 3) in early prehistoric communities of practice of fiber crafts. Ultimately, this can be the first step in recognizing technological change in yarn raw material.

b) Functional analysis of spindle whorls and the contribution of experimental spinning

Functional analysis of textile tools is a recently developed methodology for the study of ancient textile craft. It has been advanced primarily by the Centre for Textile Research (CTR) at the University of Copenhagen (Mårtensson et al. 2009; Andersson Strand and Nosch 2015). This approach propagated the idea that a shift of focus from the typological (morphological) study of ancient textile tools to the study of how they functioned within a technological system, allows important insights in ancient textile craft and an appreciation of the usually perished end-products, the yarns and textiles. The key to disentangling the function of ancient textile tools (primarily spindle whorls and loomweights which are often archaeologically preserved) is to recognize their *functional attributes*, that is elements in their shape and/or size that would have been crucial for the successful outcome of spinning or weaving on the warp-weighted loom.

It has been suggested that the functional attributes of spindle whorls, which are of primary interest in this paper, are the weight and diameter as well as their shape – in terms of height/diameter ratio, and the central hole where the spindle shaft is fixed. These attributes should have a considerable effect in how well or how long the spindle rotates, given the quality of the specific fibers to be spun: long or short, fine or coarse. This general axiom is evoked in the archaeological literature of prehistoric textile craft to interpret spindle whorls functionally, but the specifics in these interpretations vary from one scholar to the other.

For example, Barber (1991, 52–3), in clarifying the functional attributes, suggested a range of hole diameters representative for spindle whorls, based on ethnographic work by Liu (1978) and she underlined an association between tightly-spun threads and whorls with small-diameter, or, conversely, loosely-spun threads and large-diameter whorls, following the rational of Hochberg (Barber 1991, 53). With regard to weight, she stated that "spindle whorls…must fall within a certain range of weights in order to do a particular job". She then proposed specific associations between weight ranges and general types of raw materials in terms of fiber length, regardless of fiber origin (animal or plant), based on Liu, Hochberg and Ryder (Barber 1991, 52, with references). The general idea stemming from this argument was that heavier spindle whorls are used with long fibers, while lighter ones are necessary to spin shorter –and finer– fibers. However, long fibers are not necessarily equated with heavy, thick thread, since, for example, "a 33-gram whorl used with long wool…suggests a fine thread" (Barber 1991, 52).

Crewe prioritized weight as the main functional attribute of the tool over diameter and height in her study of Bronze Age whorls found in Cyprus (Crewe 1998, 13, 21, 29, 32). She also suggested an association between whorl weight ranges and spinning techniques, attributing tools weighing below 35 gr to the spinning of short-staple wool with a supported spindle, whorls between 40–50 gr to spinning a "thicker grade of woolen thread" with a suspended spindle, and whorls weighing between 60–95 gr to spinning flax with a suspended spindle (Crewe 1998, 29).

Verchecken (2010, 258) asserted that "the main function of a spindle whorl…is its rotational characteristics", and suggested that calculating the moment of inertia of whorls, incorporating the parameters of form, dimensions and mass of these objects, facilitates "a direct comparison of spindle-whorl assemblages from different geographical and/or historical backgrounds". However, he clarifies that employing the moment of inertia as a criterion for direct comparison of whorls does not simplify their association with specific raw materials or yarn qualities, unless there are additional indications stemming from the archaeological record. More processes and parameters play a role in the outcome of spinning, such as the preparation of the fibers or "the influence of the person spinning" (Verchecken 2010, 268). In attempting to explain the morphological variability that spindle whorls demonstrate over time and across cultures, artistic predisposition and a sort of cultural inertia ("…perpetuated by tradition…") are evoked by the author (Verchecken 2010, 263).

Grabunžija et al. (2021) compared prehistoric spindle whorls from two regions, central-north Europe ("pre-Alpine") on the one hand, and east-central Europe ("Pannonian") on the other hand, to trace fiber craft innovation in relation to population mobility. Starting from the suggestion (based on Rast-Eicher 2005 and on Gleba and Harris 2019) that "flat" spindle whorls were used in prehistoric Europe for plying spliced threads made of plant fibers, whereas whorls of greater height (i.e., conical) were used to spin wool, the research team studied the typological distribution of conical and "flat" types, and applied multivariate discriminant analysis on a large sample comprising of several distinct assemblages of spindle whorls (Grabunžija et al. 2021, 633–38). They concluded that metrological variability in the examined whorls generally correlates with assemblages of distinct "cultural groups" (Grabunžija et al. 2021, 633); also, that the appearance of the conical whorl type in the pre-Alpine sites indicates an important technological change in fiber crafts, possibly the shift from plant to wool (if relevant zooarchaeological data are taken into account), under the influence of "newcomers" from central-east Europe, from the 4th millennium B.C. onwards (Grabunžija et al. 2021, 640–43). In this approach, the height-diameter ratio, materialized in the whorl shape, is considered as a functional attribute and a diagnostic criterion for technological change.

A different research strand developed through experimental archaeology in order to investigate ancient textile craft in general, and to assess the functional potential of spindle whorls in particular. Several projects of experimental spinning have been conducted in recent years. Within its research program "Tools and Textiles – Texts and Contexts" (TTTC), the Centre for Textile Research (CTR) organized experimental activities aiming to investigate the function of prehistoric textile tools from the Eastern Mediterranean, and ancient textile production in general (Olofsson 2015, 31). The experimental tests were based on the premise that archaeological textile tools carry information that can be useful in recreating certain aspects of ancient textile crafts (Andersson Strand 2015) and, following this rational, a suite of experiments by specialist spinners with replicas of prehistoric spindle whorls found in Greece were carried out. The aim was to clarify the interplay of spinners, tools and the materials spun, with regard to the outcome of spinning and the quality of the spun yarn (Olofsson et al. 2015). Another aim of the experiments was to test the functionality of spindle whorls weighing less than 10 gr, a weight value set as an arbitrary limit for spindle whorl functionality in earlier studies (Carington Smith 1975; Liu 1978). In the CTR experiments, low-whorl spindles and the drop-spindle (suspended) technique of spinning were employed (Olofsson et al. 2015). The results showed that, all things being equal (i.e., spinner, method of spinning and raw material) the lighter the whorl, the finest the thread spun; that spindle whorls of different size and weight or different fibers contributed to the different types of yarn *more* than individual spinners did. Moreover, these tests showed that both plant and animal fibers can be spun with very light whorls (i.e., weighing as little as 8 gr). Earlier spinning tests were also discussed, during which it was defined that whorls of 30 gr and 50 gr were suitable for producing a wider range of thread qualities than very light whorls, which should therefore be considered as specialized tools (Olofsson et al. 2015).

Another spinning experiment designed by Kania (2015) to investigate, likewise, the contribution of spinner, tool and raw material in the spinning result, involved hand-spinning with the drop-spindle (suspended) technique, using clay and wood whorl replicas modeled after a medieval (ca. 12th century AD) cylindrical whorl found in London, with a weight value of 16 gr. The replicas were modeled into slightly differentiated sizes so that differences in whorl mass could be tested as a factor in the spinning process. The raw materials used in the experiment were two types of industrially-produced wool, the fine Merino variety and the coarser variety of Tyrolean Bergschaf wool. After spinning similar types of wool with whorls weighing 5 gr, 15 gr and 52 gr, the resulting yarns were compared and the author asserted that the whorl size had a minimal impact on the process, because of an observed overlap in yarn qualities produced with all three types of whorls (Kania 2015).

The preliminary results of the experimental project TEXPA, conducted at the University of Padova, which investigated the association between fibers and spindle whorls in the cultural context of north-east Roman Italy also showed that the spinners' skills and the type of fiber affect the result of spinning more than the tools (Bursana et al., 2020).

In sum, spinning experiments conducted so far have produced contradictory results regarding the contribution of spindle whorl morphometry to the outcome of the spinning process, the quality of the spun thread, or the exact association between specific whorl and specific type of fiber. The complication of this observation with regard to the *crucial methodological issue* of whether archaeological spindle whorls can be shown to have been used exclusively for draft-spinning of wool, is that such a demonstration cannot be grounded on functional criteria alone. This is also implied by the fluidity of the exact criteria of whorl functionality observed in the various studies of prehistoric textile craft and/or archaeological assemblages, described above (Barber 1991; Crewe 1998; Verchecken 2010; Grabunžija et al. 2021). Context, whether archaeological, cultural, or historical in nature, is important in any attempt towards the technological interpretation of spindle whorls, as it allows a perspective taking into consideration technological choices and practices influenced by social representations operating within a given community (Lemonnier 1992, 88–9).

It can hardly be doubted that prehistoric whorl manufacturers were making choices as to the raw material, the form and the size of the tools used in fiber crafts, inherent in the mental schemes that dictated what a tool for a specific task should be like (Lemonnier 1992, 79–103). Thus, examining fluctuations in tool type and size, not as mere indicators of functionality, but as indicators of spindle whorl manufacturing traditions, in the timespan of the Neolithic and the EBA and across different sites, has the potential to indicate shifts in the technological practice of whorl manufacture, which is systemically related to yarn technology.

Based on this premise, the next section presents a brief survey of archaeological assemblages of spindle whorls from Greek Neolithic sites, drawing mainly from publications, and, in the cases of Sitagroi and Alepotrypa also from a first-hand examination of the material by S. Vakirtzi. There follows a comment on the much better documented and studied Early Bronze Age whorl assemblages. It should be kept in mind that any bibliographical survey of textile tools from prehistoric Greece faces important shortcomings: the limited inclusion of detailed catalogues of textile (or possible) textile tools in publications, the heterogeneous terminologies employed in different studies, the lack of contextual details, and the fact that metric data and images of the tools' sections (profiles) are often missing from the respective chapters.

II. SURVEY OF SPINDLE WHORLS FROM NEOLITHIC GREECE

The EN horizon (mid-7th – early 6th millennium B.C.)

With few exceptions, objects from the Greek EN that are usually published in spindle whorl inventories are limited to rounded or roundish, centrally perforated pottery sherds (henceforth potsherds). In north Greece, the EN site of Nea Nikomedeia yielded spindle "whorls made of potsherds" (Rodden and Rodden 1964).

At the site of Servia, 22 perforated potsherds found in EN deposits were published as potential spindle whorls (Carington Smith 2000, 207–9). Metric ranges for these were published as well: diameters range from 3.1 cm to 6.3 cm with the average at 4.4 cm, and weights range from 12 gr to 40 gr with the average weight at 19 gr (Carington Smith 2000, 208, table 4.5).

At the site of EN Mavropigi-Fyllotsairi, rounded perforated potsherds are preliminarily characterized as "spindle whorls" (Karamitrou-Mentessidi et al. 2016, 62, fig. 37). Moreover, the preliminary report depicted a few ceramic globular objects with central perforations, related to textile tools (Karamitrou-Mentessidi et al. 2016, fig. 38), but after first-hand examination by S. Vakirtzi it was realized that most of those are miniature artifacts usually classified as beads (out of 17 items the largest has a diameter of 2 cm and weighs 5 gr, while the smallest has a diameter of less than 1 cm and weighs less than 1 gr). The thorough study and publication of this assemblage will elucidate the issue of textile technologies and the tool repertoire at EN Mavropigi-Fyllotsairi (Vakirtzi, in preparation).

Finds such as "loomweights" and "spindle whorls" are reported from rescue excavations at EN Giannitsa, but they are neither described nor depicted (Chrysostomou 1992, 127; Chrysostomou and Chrysostomou 1993, 175; Chrysostomou 1997, 137). North Greece is promising in the exploration of EN textile tools because many more EN sites have been traced compared to the southern mainland, as long as systematic studies of textile technologies are advanced (Andreou et al. 1996, 568; Besios et al. 2003; Kotsakis and Halstead 2004). So far, however, only preliminary reports are available and these rarely dedicate more than a brief reference to possible textile tools.

Further south, in Thessaly, only perforated potsherds were reported as spindle whorls from the EN levels at the settlement of Achilleion (Gimbutas 1989, 254–56). Metric data for these potsherds were not published. The scale on their drawings (Gimbutas 1989, 256, fig. 8.12) suggests diameters of 3 cm to 4 cm, at least for the pieces illustrated, although these are indiscriminately attributed to "phases IIa through IVa" (EN through MN).

In the south Greek mainland, EN spindle whorls were reported from the excavations of Corinth and Tsoungiza, both conducted in the first half of the 20th century AD. The material of Corinth included both perforated potsherds and modeled clay spindle whorls (Walker-Cosmopoulos 1948, 41–2, fig. 15). The term "modeled" is used to refer to spindle whorls formulated into a chosen shape from raw clay and then fired, as opposed to rounded or roundish, centrally perforated potsherds. Carington Smith (1975, 119) employs the terms "made whorls" and "sherd whorls" respectively to distinguish between these two distinct categories of manufacturing. It should be noted that the occurrence of modeled whorls in EN Corinth is extremely dubious, especially given the lack of detailed stratigraphic control in pre-WW II excavations. Moreover, according to Walker-Cosmopoulos (1948, 72), modeled whorls were infrequent finds at Corinth until "Period IV". As expected from such an early publication, no metric data are provided for the textile tools.

At Tsoungiza, near the classical site of Nemea, Corinthia, an EN site with characteristic EN pottery was explored in the 1920s. Spheroid and biconical spindle whorls were included in the preliminary report (Caskey and Blegen 1975, 272, plate 69), but a recent study of the finds and contexts of the old excavation showed that this was not a closed EN assemblage. In fact, it was a mixed deposit with material dating as late as the FN (Dabney et al. 2020, 3).

It should be mentioned that either perforated sherds or modeled spindle whorls have yet to be published from closed EN contexts of Franchthi in the Argolid (Jacobsen 1981) and of Alepotrypa in Laconia (Papathanasopoulos 2011; Papathanasiou 2018), two sites with cultural sequences spanning the Greek Neolithic.

The MN horizon (mid-6th millennium B.C.)

Although the MN is today much better documented and understood owing both to re-evaluations of old excavations and to new ones (Sarris et al. 2017), textile tools (or possible textile tools) from a series of recently explored MN sites have yet to be published.

In north Greece, at the site of Servia, modeled spindle whorls of the biconical type were found in MN levels. These are two fragmentary, but apparently large biconical whorls, judging from their diameters which measured ca. 4.5 cm. The original weight for one of those was estimated at 40 gr (Carington Smith 2000, 215–16). Perforated potsherds were also found in MN levels. In fact, these were more numerous than the modeled spindle whorls (Carington Smith 2000, 212–14).

A similar picture is drawn from the Neolithic settlement excavated at Stavroupoli, near Thessaloniki, which has MN and LN phases: both modeled spindle whorls and perforated potsherds are published from both phases, but perforated potsherds are far more numerous in the publication (Grammenos and Kotsos 2004).

In Thessaly, the MN coincided with the main occupational phase of the Thessalian Neolithic type-site, Sesklo. However, the spindle whorls of this settlement are ill-defined. Tsountas (1908, 343), who excavated the site in the beginning of the 20th century AD, indiscriminately refers to spindle whorls found at all the sites he explored, including LN Dimini, as well as finds from the Bronze Age levels of the respective settlements. In the publication, Table 44 illustrates several types of whorls including the discoid, the conical, the biconical and the spheroid (Tsountas 1908). K. Sarri (2020, 98), who reexamined the textile tools found at Sesklo, attempted a finer chronological distinction by comparing their ceramic fabrics with those of the respective pottery categories. She also documented the metrological data for these finds: diameters range between 3 cm and 5.5 cm and weight values between 7 gr and 35 gr (Sarri 2020, 98). However, an exact attribution of these whorls to specific loci and phases is impossible. At Achilleion spindle whorls modeled from clay in the "globular" (spheroid) type (cf. Gimbutas 1989, 254) were found in MN levels. Only a very broad range of diameter measurements between 2 cm and 4 cm was provided in the publication.

Again, as is the case with EN, textile tools from secure MN levels have not yet been published from Franchthi in the Argolid and Alepotrypa in Laconia. Likewise, no textile tool assemblages are so far published from secure MN levels at the important open-air settlement of Kouphovouno in Laconia (Renard 1989; Renard and Cavanagh 2017). Only one low, conical spindle whorl from the 1941 trenches dug at Kouphonvouno has been published, which is not clearly contextualized and it is possible that it originates from the Early Bronze Age levels of the site (Renard 1989, 95, table XXXII).

The LN and FN horizons (late 6th – late 4th millennium B.C.)

Spindle whorls uncovered at the sites of Sitagroi (phases I–III) and of Dikili Tash (phases I–II) document yarn production in north Greece during the LN and the FN phases, spanning two millennia. It should be mentioned that Sitagroi phases I and II were attributed to the MN by Gimbutas and Renfrew at the time of publication of the first volume (Renfrew et al. 1986), but were subsequently recognized as LN phases (Tsirtsoni 2016). For the current article the latter periodization is used. The material from Sitagroi was published in detail including an extensive catalogue of finds (Elster 2003), while that of Dikili Tash was presented in a more summarized format (Treuil 1992). Nonetheless, both assemblages are among the most important spindle whorl corpora known from the LN and FN phases in Greece, each including more than a hundred tools.

The whorls found at Sitagroi were modeled in a variety of shapes, some with incised decoration. The published spindle whorl assemblage of Sitagroi phase I (LN I) includes nine ceramic items found in four different trenches (Elster 2003, 258), but after close examination and review of the contexts, only seven items can be securely included in the phase I whorl assemblage. Cat. no. 77 and object 2522 were excluded because the former came from a "mixed context" (trench OL, stratum 7, Elster and Renfrew 2003, xxix, table 3) while the latter does not appear to be a whorl: the break at one distal end reveals a manufacture technique that is not typical of spindle whorls i.e., two concentric "rings" of clay (Fig. 17).

Fig. 17. Sitagroi, Phase I. Object with cat. nr. 2522 (cat. nr. in Elster 2003, photos by the author, courtesy of the Ephorate of Antiquities of Drama).

Two of the seven whorls are intact and three are fragmentary, one of which is preserved in half. The typology of the seven whorls includes the shallow conical, the flat and the biconical types. Table 8 summarizes the metric data recorded in the publication and those resulting from our survey. It is worth keeping in mind the co-occurrence, in phase I deposits, of significantly different tools, both metrologically and typologically, such as the conical whorl 2502 weighing 24 gr and the flat whorl 2541 weighing 125 gr.

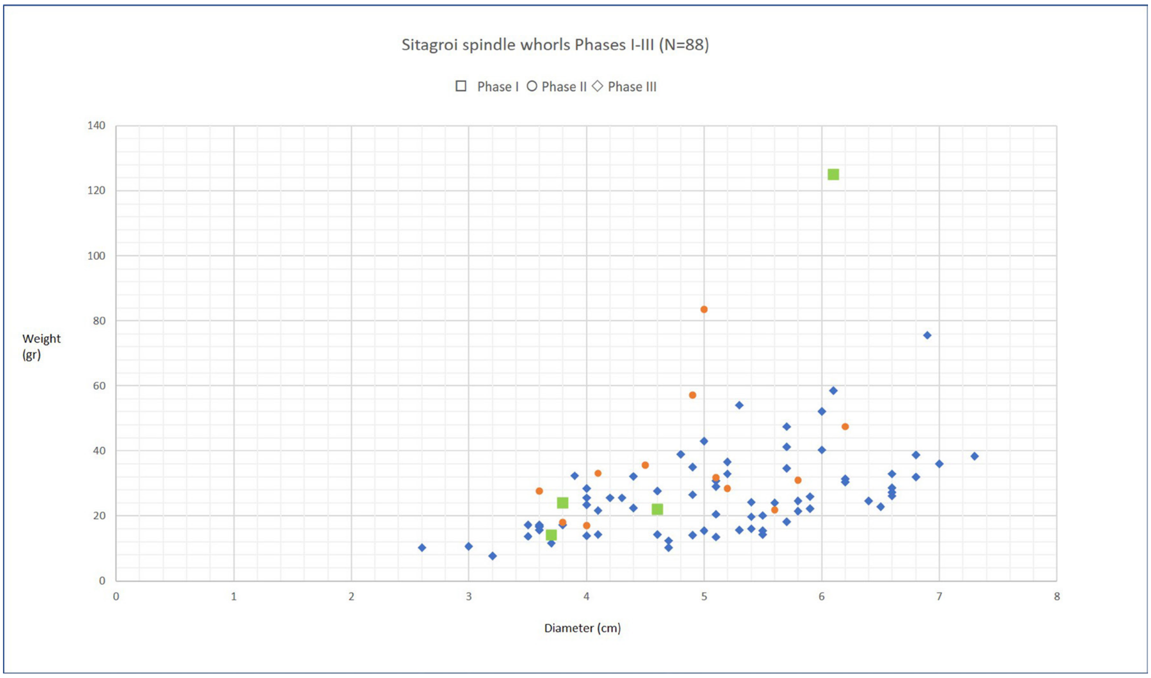

Table 8. Diameter/weight scatterplot of Sitagroi phases I–III spindle whorls.

The published spindle whorl assemblage of Sitagroi phase II (also LN I) includes 17 items from seven trenches (Elster 2003, 259). Of those, 13 were available for examination. Eight were fragmentary, four are almost intact and one is intact. The preservation status is not always explicit in the publication, nor are metric data systematically published, a fact that leaves ambiguity with regard to the items not examined (whorls 509a, 809, 1546 and 5025). The group of phase II includes five types (biconical, flat, shallow conical, deep conical and spheroid). There is also one rounded, pierced sherd. The most popular type is the shallow conical. Two spindle whorls reported in the publication as biconical are rather low cylindrical or squat spherical (whorls 5200 and 5351, Fig. 18), rendering the biconical type an exception.

Fig. 18. Sitagroi, Phase II. Spindle whorls cat. nrs. 5200 and 5351 (cat. nrs. in Elster 2003, photos by the author, courtesy of the Ephorate of Antiquities of Drama).

In this phase, grooved decoration, a hallmark of phase III whorls, makes its appearance with three examples (whorls 3618, 413, 424, Elster 2003, 235). All three belong to the shallow conical type. In terms of metrology, the whorls of phase II include both large and heavy tools and lighter ones (Table 8). The intact and almost intact items we were able to examine (five in total) have diameters between 3.8 cm and 5 cm and weight values between 14 gr and 84 gr. It is important to point out that the distinction between the very large spindle whorls and the lighter ones correspond to typological groupings. The heavy whorls are mainly formulated into the flat, the deep conical and the spherical types. The lighter ones are modeled into the shallow conical, often incised type (but see phase III, below, for a further subdivision of the "shallow conical" category). The published spindle whorl assemblage of Sitagroi phase III (FN or LN II) includes 103 spindle whorls found in eight trenches (Elster 2003, 261–66), attributed to this phase. Of those, 84 were accessible for examination, and 51 were found fragmentary, while 11 are almost intact and 22 are intact. The fragmentary objects amount to 66 if we include the ones not examined but published as incomplete items. The typology includes four types, the shallow conical, the biconical, the deep conical and the flat. There is also a category of rounded pierced sherds. Upon examination of the material, subtypes of the flat category were discerned based on the section shape (i.e., lentoid versus plano-convex). Most importantly, the shallow conical category merges two distinct subtypes: a) the low conical type with convex or slightly concave sides, and b) the extremely low conical (almost discoid) whorl with protruding hole rim (cf. Elster 2003, Figs. 6.6, 6.11–6.12). The majority of whorls in this group measure over 4 cm in diameter, while weight values for intact/almost intact items range between 7.6 gr and 75.5 gr, with most clustering between 20–50 gr (Table 8). Those preserved in half, weigh between 11 gr and 54 gr, reflecting original weight values between 40 gr and 80 gr, and in one case reaching ca. 108 gr (cat. nr. 466). Light whorls weighing less than 20 gr are scarce. The two subtypes of the shallow conical category distinguished above appear to correspond to distinct size classes: in terms of diameter, items of the shallow conical (a) cluster in diameter values between 3 cm – 5 cm and in weight values below 30 gr. Items of the shallow conical (b) cluster in diameter values between 4 cm – 7 cm and in weight values above 30 gr (Table 9). It should also be mentioned that the biconical category includes whorls lighter than 30 gr and those with the smallest diameters reported from phase III, i.e., between 2.6 cm and 4 cm.

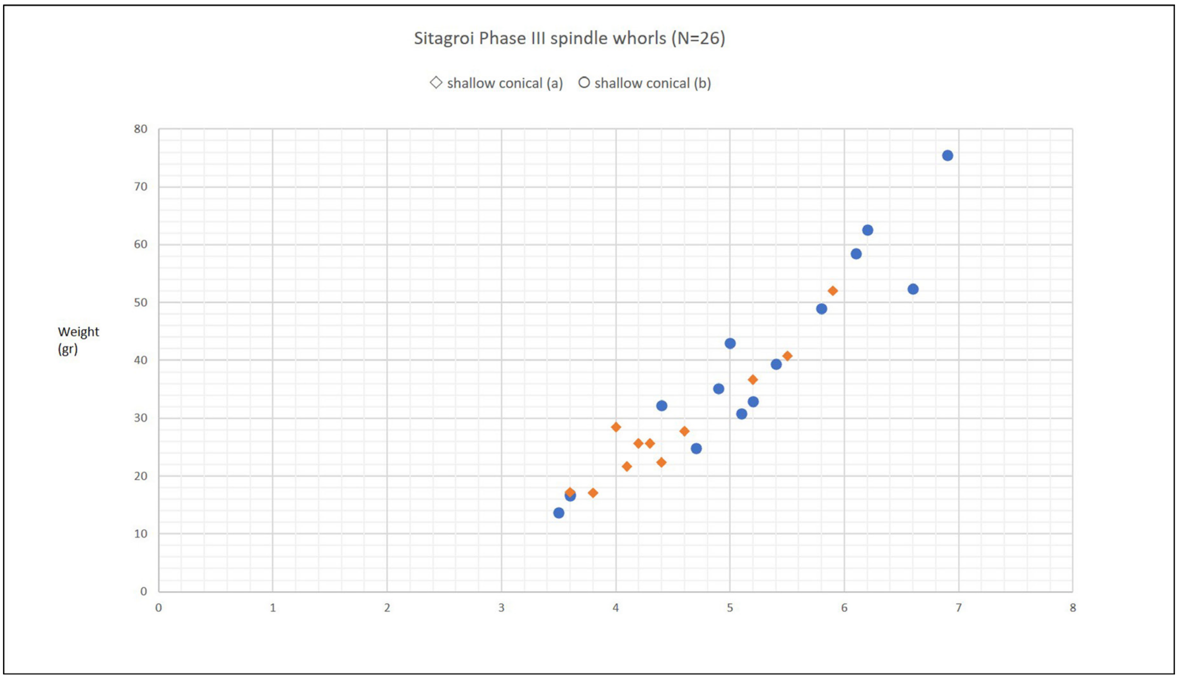

Table 9. Diameter/weight scatterplot of Sitagroi phase III shallow conical subtypes.

The spindle whorls of LN Dikili Tash manifest typological and metrological variation (Treuil 1992). Although the descriptive terminology of the typology differs, it is clear that the tools have parallels in the Sitagroi assemblage. The LN whorl assemblage at Dikili Tash includes types such as the biconical, the conical, and the discoid with subtypes distinguished based on the diameter-height ratio, as well as to the configuration of the profile (convex versus concave). The conical types, and especially the low conical, dominate the LN whorl assemblage of Dikili Tash, just like at contemporary Sitagroi. The Dikili Tash publication does not include metrological data for individual whorls, but provides ranges of diameter and height values per type. Overall, whorl diameters range from 2 cm to 7 cm and height values range from 1.4 cm to 4.5 cm (Treuil 1992, 125–26).

At Servia, west Macedonia, only two biconical whorls are published from LN levels, with diameters of 3.4 cm and 3.9 cm and weight values of 19 gr and 33 gr respectively (Carington Smith 2000, 216).

Further south, in Thessaly, the LN horizon is documented at the type-site of Dimini while the FN at the site of Rachmani. As mentioned before, the whorl assemblage from Dimini was indiscriminately published along with that of Sesklo by Tsountas. However, Tsountas pointed out that the discoid type was characteristic of "the later period of the lithic age" i.e., of the LN (Perlès 2001, 98). Wace and Thompson affirmed that low conical types predominated in the Thessalian FN along with "flat" whorls, apparently the same category as the discoid type (Wace and Thompson 1912, 134). Low conical and "flat" whorls from their excavations are exemplified in an illustration where 22 spindle whorls are threaded with a string (Wace and Thompson 1912, fig. 28).

From the Cave of Theopetra in central Greece, perforated potsherds and modeled spindle whorls of the conical, the biconical and the cylindrical types are preliminarily reported from the LN levels of the site. Whorl diameters range between 2.6 cm and 3.6 cm and height values range between 0.7 cm and 2.5 cm (Kyparissi-Apostolika 2000, 203–4, 230, fig. 14.16).

Discoid, conical and biconical spindle whorls are illustrated in a preliminary report of the excavation at FN Mikrothives, Thessaly, but metric data for these tools are not reported (Adrymi-Sismani 2007, 77, plate XIIs; Adrymi-Sismani 2016).

Further south, in northeast Peloponnese, a few spindle whorls from the Neolithic levels of Lerna in the Argolid were recently published but among these only two are securely attributed to the FN. These are a conical and a biconical whorl weighing 10 gr and 13 gr respectively (Banks 2015, 244).

At the Cave of Franchthi in the Argolid, both perforated potsherds and modeled spindle whorls were found. Although the cave preserved a deep stratigraphy, including the complete Neolithic sequence, modeled ceramic spindle whorls are published so far only from the LN/FN horizon, mostly of the conical and biconical types (Vitelli 1999, 105–10). Their publication also records metric data, at least diameter and height values. Diameter values range between 1.9 cm and 4.6 cm and height values between 0.9 cm and 2.7 cm.

The Cave of Alepotrypa in Laconia, south Peloponnese, yielded a comparable assemblage. Spindle whorls published so far from the anthropogenic deposits of the cave include six ceramic items (Katsipanou-Margeli 2011). Four of them were found in the North Sector of Chamber B, in particular in trenches B3, B6 and B7, while one was found in the Central Sector, in trench B1 (for the nomenclature of the cave/excavation areas, cf. Papathanasiou 2018, 14–7). One whorl was found in a disturbed deposit (cat. nr. 703, Katsipanou-Margeli 2011, 124). All five whorls originating from the trenches dug in Chamber B were found in deposits dated to the FN phase of the occupation of the cave (Papathanasiou pers. comm.; Katsipanou-Margeli pers. comm.). Their preservation status is very good, since all are intact except one which is almost intact, with only small chips missing. Typologically these six items are diverse (Fig. 19): two belong to the discoid type (including cat. nr. 703 which is published as squat biconical), two belong to the conical and two belong to the biconical type.

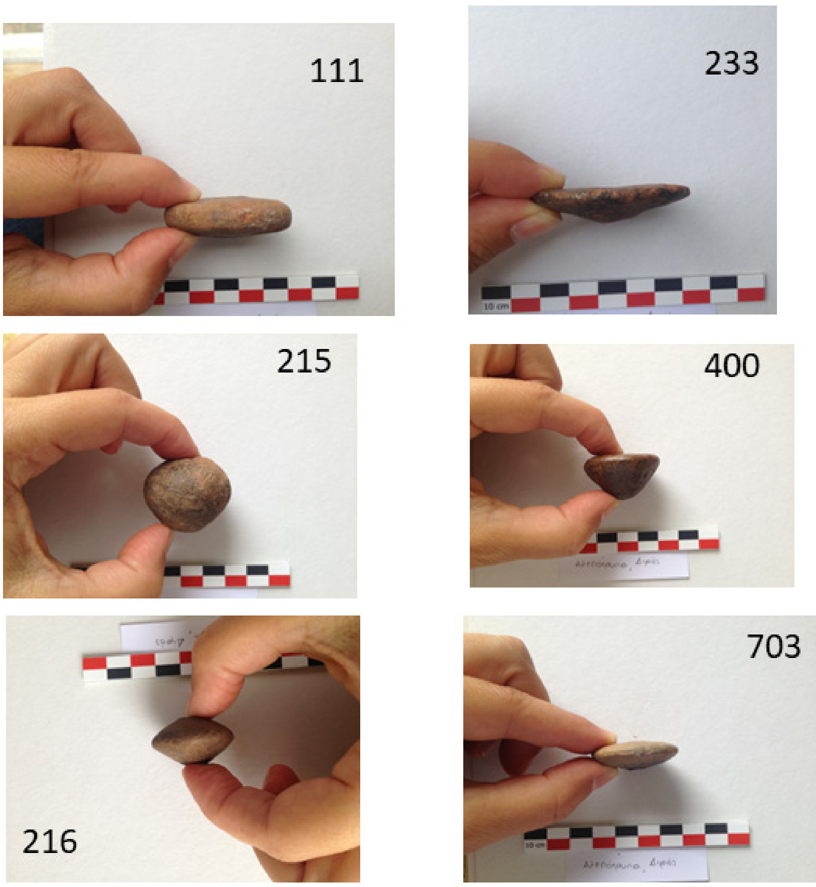

Fig. 19. Alepotrypa, spindle whorls from FN levels (cat. nrs. in Margeli-Katsipanou 2011, photos by the author courtesy of the Ephorate of Palaeoanthropology and Speleology).

According to the metric data collected by the author, these spindle whorls have diameters ranging from 3 cm to 4.8 cm and weight values ranging from 12 gr to 33 gr (Table 10). A general observation that should also be mentioned is that five out of the six whorls had a very smoothed –even burnished– surface.

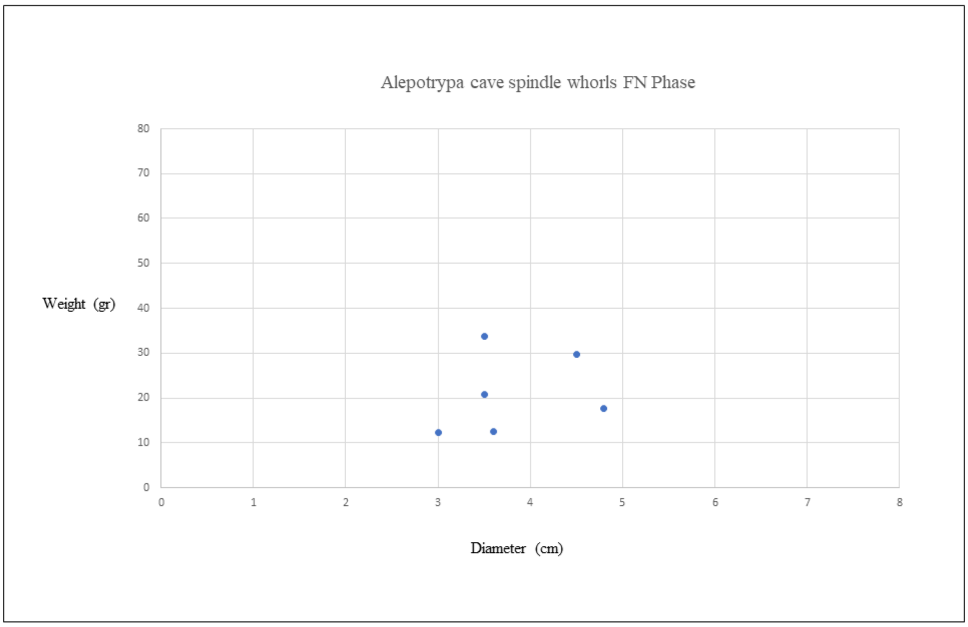

Table 10. Diameter/weight scatterplot of Alepotrypa FN spindle whorls.

Finally, LN and FN spindle whorls are also published from the Cyclades. At LN Saliagos, only perforated potsherds are published as spindle whorls, as well as two perforated disks made of marble. Their diameters range between 4 cm and 5.5 cm (Evans and Renfrew 1968, 70, fig. 84, Plate L1). At Ftelia, on the island of Mykonos, the spindle whorl assemblage includes whorls modeled in clay in the conical, the biconical and the discoid types, and two whorls made of bone in the conical and the discoid type respectively. The whorl diameters range between 2.6 cm and 4.6 cm and the weight values between 9 gr and 48 gr, although clusters are observed between 2.6 cm and 4 cm and between 15 gr and 20 gr respectively (Sampson 2002, 221–26; Vakirtzi 2018a).

Comment on the survey of spindle whorls from Neolithic Greece and comparison with the EBA assemblages

The basic scheme of spindle whorl assemblages from the Greek Neolithic was first shaped in the 1970s with the work of Carington Smith (1975). The present review demonstrates that it has remained largely unchanged, despite the proliferation of Neolithic research in Greece since the 1970s. This fact demonstrates the slow pace and/or low priority of textile tools publication by excavators, which may be conditioned by funding and research agendas. Recent publications are more consistent with current publication standards of textile tools, but older ones suffer from brevity and an overwhelming lack of metric data, as mentioned above. Due to these shortcomings, inherent in the archaeological literature, the survey presented here could be neither systematic in the presentation of typologies, contexts and metric data from one assemblage to the other, nor exhaustive. Nevertheless, we observed the following patterns:

The EN spinning toolkit probably consisted only of centrally perforated potsherds which abound in this horizon. It must be stressed that there is no way to be certain that all, whether most or some of these perforated potsherds were indeed used as spindle whorls. We can only hypothesize that they could have been used as such. Modeled spindle whorls from this period are so far reported only from Corinth (Walker-Cosmopoulos 1948), but their attribution to secure EN levels is dubious. It should be kept in mind that both the excavation and the publication were conducted in the first half of the 20th century AD with excavation methodologies that leave much space for ambiguity, especially with regard to stratigraphy control and chronology. With the exception of the publication of the Servia material, there is a complete absence of metric data of EN spindle whorls. Nevertheless, it should be noted that the average weight of 19 gr reported for the Servia potsherds falls in the metrological area of spindle whorls found in later periods, indeed in the 2nd millennium B.C. when wool was certainly used as textile fiber (Andersson Strand and Nosch 2015; Vakirtzi 2018b).

The MN whorl data are limited, despite the fact that this horizon is better documented. Textile tools have not been systematically published so that the spinning equipment of the period is poorly known. What is clear, however, is that in addition to perforated potsherds that continued from the earlier period, the MN assemblages include modeled, ceramic spindle whorls in the biconical and the spheroid types. The limited metric data that have been published so far do not allow the possibility to assess the metrological range of MN spinning tools. Nevertheless, the practice of manufacturing the accessories of the spindle from raw clay in a shape other than the discoid (which corresponds typologically to the shape of perforated potsherds) and the control of both the whorl's shape and desired dimensions, should be pointed out as a novelty and as a significant change in the whorl manufacturing practices that prevailed on the Greek mainland until then.

The spinning toolkits of the LN and FN phases are better documented. Spindle whorls become frequent finds from the LN onwards. Some assemblages include as many as 100 whorls (cf. above Sitagroi, Dikili Tash, Franchthi). Typological categories appear more or less standardized, despite the fact that whorl assemblages usually include a variety of types and size classes. A preference for low types can be observed: low conical or discoid whorls are the dominant types in most LN and FN assemblages throughout the region. The metrological data published at the site-level, indicate a range of whorl sizes, from small and light to large and heavy.

The EBA is much better studied in terms of textile cultures (cf. EBA assemblages in Andersson Strand and Nosch 2015; Siennicka et al. 2018; Vakirtzi 2015, 2018b, 2020): metrological scatterplots of EBA whorl assemblages routinely demonstrate a wide range of sizes. It is noteworthy that regional morphometric variations are observed. The biconical and the tall conical types were preferred in the north (Treuil 1992; Elster 2003; Vakirtzi et al. 2014). At Sitagroi, in particular, the EBA phases IV and especially V are marked by a sharp contrast in spindle whorl typologies: the shallow conical type that was dominant in phase III now becomes very rare, and the biconical spindle whorl dominates the whorl assemblage (Elster 2003; Elster et al. 2015). In the Argolid, the conical type and the domed whorl type were dominant in the beginning, but by the end of the millennium the biconical type enriched the Helladic repertoire as well (Rahmstorf et al. 2015; Banks 1967). In the insular region, the EBA Cycladic communities have a preference for the low conical type. Gradually, however, they adopt the biconical type, while in the East Aegean islands the biconical whorls predominate throughout the 3rd millennium B.C. (Vakirtzi 2018b). Finally, Early Minoan spindle whorl assemblages have yet to receive the updated attention, given that the focus on Crete is on 2nd millennium textile cultures (Cutler 2021). Nonetheless, wool use for textile production has been suggested by Warren on the base of "collateral" finds at Myrtos, south Crete. Mostly cylindrical and a few conical and biconical whorls were found there, some with the very rare –by prehistoric Aegean standards– painted decoration. Height and diameter ranges were published for this assemblage, and, again, a range of sizes can be surmised from the published metric data (Warren 1972, 215–16, 228–30).

III. DISCUSSION OF THE TECHNOLOGICAL APPROACH

In this study, the technological approach underlined the contribution that the anthropology of technology can make to the research of early wool craft in prehistoric Greece. Technological change is socially and historically embedded and technological choices are influenced not only by material factors *sensu stricto*, but also by social logics and mental representations. Technological traditions, technical inventions and innovations manifest a dynamic and complex interplay in both archaeological and ethnographic examples.

This section reviewed recent research that has focused on the function of prehistoric textile tools, including experimental projects testing the functional criteria of spindle whorls, the most common archaeological testimony of fiber crafts. It was stressed that, although fruitful in demonstrating the potential of textile tools study in general, the direct identification of wool craft has not been achieved on the basis of spindle whorl functionality. In fact, it was concluded that seeking to approach this issue on the basis of functional criteria alone, may not be effective because functionality, too, is a concept that may be culturally embedded.

The technological approach integrated a survey of spindle whorls of the Greek Neolithic and EBA in order to identify potential technological change in fiber crafts in a diachronic perspective. This endeavor was compromised by the serious shortcomings of the documentation and publication status of prehistoric spindle whorl assemblages. However, it was possible to identify a significant turning point in the technological system of spindle whorl manufacture, which implicates significant change in fiber crafts, too, given the systematic and social aspect of technology. In particular, present evidence indicates that, whereas recycled, rounded, perforated pottery sherds were used as spindle whorls in the EN, at some MN communities, spinners modeled their whorls from raw clay. The new manufacturing practice became widespread and established by the end of the FN.

These two manufacturing practices correspond to different operational sequences. Rounded perforated potsherds allow little divergence in the shape of spindle whorls. The resulting tool will be a discoid object. In the operational sequence of this manufacturing practice there is no need to select and prepare the clay, to make decisions about what shape to give to the whorl, or whether and how to treat and decorate its surface. There is also no need to (know how to) fire the tool. Ceramic technology has little relevance for spinners who manufacture whorls from rounded, perforated potsherds. Modeled clay spindle whorls, on the contrary, are ceramic artifacts in their own right and their manufacture requires a series of technological decisions: what clay to select, what shape and size to give to the whorl, how to treat the clay surface, and especially, how to fire it for the best possible result. This operational sequence allows much more flexibility in deciding the combination of tool shape, size and surface configuration. Ceramic technology and fiber technology are entangled in a direct way in the "new" system. Once the practice of manufacturing modeled spindle whorls is established, a variety of morphometric categories emerges. Modeled spindle whorls represent a tendency for the use of specialized technological equipment for fiber processing and a more accentuated possibility for technological choice. In Greek prehistory, this new manufacturing practice can be securely dated to the MN on present evidence.

With regard to the *main question* put forward in the beginning of this section, the present study puts forward the working hypothesis that the shift from using rounded, perforated potsherds to using modeled spindle whorls is the single most important, archaeologically traceable, technological change in diachronic perspective, in the chronological frame in question, given the current state of affairs in prehistoric fiber research. It signifies that the millennia-old tradition of using rounded perforated potsherds as spindle whorls meets with a profoundly new concept about what spindle whorls should be like: specialized ceramic artifacts in their own right.

C) DISCUSSION OF THE RESULTS

This paper discusses the beginning of wool craft in prehistoric Greece based on an interdisciplinary research approach. Zooarchaeological and technological evidence related to sheep husbandry and to yarn production respectively, spanning the Greek Neolithic and Early Bronze Age, were critically examined. The authors revisited caprine bones and spindle whorls from Sitagroi, north Greece, and Alepotrypa, south Greece. Moreover, the relevant literature was surveyed for the identification of significant patterns.

The re-examination of the Sitagroi material permitted the following observations. Caprine mandibles from Sitagroi were assigned to all age classes for each phase except for phase IV. Mature and senile individuals were identified among the material from all phases with the highest percentages in phases I and III. Mature and senile individuals are the ones traditionally kept for wool harvest, especially male or castrated ones (Payne 1973). Male sheep predominate only in the phase II assemblage but they cannot be attributed to specific age groups with certainty, therefore wool potential during Sitagroi phase II remains an open question from the zooarchaeological perspective. From a technological point of view, the re-examination of the spinning equipment of Sitagroi with a focus on morphometric classification, allowed the reconsideration of LN/FN fiber crafts. The sample of phase I is too limited to draw any secure conclusions. Nonetheless, from phase II onwards, the occurrence of significantly different types of tools in terms of size and shape was documented. It is suggested that this pattern implies the "negotiation" of different technical traditions. Phase III spindle whorls follow the typology of the earlier periods, but now manifest a pattern of accentuated standardization within different typological categories. The spindle whorls of Sitagroi phases I–III are almost exclusively modeled types.

For Sitagroi phase V, the zooarchaeological analysis pointed out the high percentage of newborn individuals, a attern that was not documented in Bökönyi's study. However, it needs to be reaffirmed through the examination of caprine mandibles from trenches not included in this study. Wool potential in phase V is for the moment supported by low percentages of mature and senile individuals. In terms of textile technology, tools from phases IV and V testify the establishment of new practices. This is indicated both from the distinct whorl typologies characterized by the dominance of the biconical whorl and from the almost complete disappearance of the shallow conical type. Moreover, phases IV and V are characterized by the occurrence of loomweights that were negligible in earlier phases' deposits, attesting to the use of the vertical, warp-weighted loom at EBA Sitagroi (Elster 2003; Elster et al. 2015).

At Sitagroi, the zooarchaeological evidence allow to consider the possibility of wool craft, at least on a modest scale, from phase I. The survivorship curves of caprine husbandry betray a mixture of culling regimes for meat and secondary products (milk and wool) during phases I–III and V; on the other hand, the whorl assemblages of phases II–III, in which modeled types predominate, may represent a stage in the local history of prehistoric fiber crafts characterized by the technological meeting of old traditions (splicing and plying of plant/bast fibers?) and the emergence of new ones (draft-spinning of wool?).

The caprine ages-at-death from Alepotrypa published by Hadjikoumis (2018) reflect the management of mainly young, juvenile and subadult caprines during the EN, a period when adult individuals were also culled. All age classes are represented in the material from the LN–FN period with a preponderance of subadult and mature adult individuals, including more sheep than goats as well as rams (Hadjikoumis 2018, 283). In all phases of the Alepotrypa sequence, female sheep are more than male ones (Hadjikoumis 2018, 286, table 14.9). Caprine husbandry for secondary products (milk, wool/hair) next to meat production is suggested by Hadjikoumis on the basis of mortality percentages of both newborn sheep as well as older sheep and rams during the FN (Hadjikoumis 2018, 293–94). From a technological point of view, the few spindle whorls that have been published so far and were re-examined for this study, indicate a sophisticated level of whorl manufacture, with well-formed and burnished tools. Comparison to the contemporary FN Franchthi assemblage implies shared traditions and an emergent pattern or region-wide standardization. Confirmation of these observations should await the publication of the remaining spindle whorls found at Alepotrypa (Papathanasiou, pers. comm.; Katsipanou-Margeli, pers. comm.).

The survey of the archaeological literature permitted the following observations. A reconstruction of husbandry practices was possible to some degree based on caprine ages-at-death and sheep sex ratios. Whereas in the majority of the sites the slaughter of young adult and adult individuals is the norm, a gradual augmentation of percentages of mature and senile individuals in the deadstock assemblages is attested in the MN and especially in the LN–FN–EBA. Furthermore, the available sex ratios favor by far female sheep versus male sheep diachronically. The maintenance of mature and senile females in flocks dominated by younger reproductive females is a pattern that should be further explored with regard to the potential of wool exploitation.

The implementation of the CV approach showed that the Alepotrypa FN sheep assemblage, along with the Sitagroi III–IV–V and a few other sheep assemblages, could represent some type of prehistoric "breed". Bökönyi's initial observation for larger sheep in Sitagroi phase V, one of the initial triggers for this research, probably signifies some different "breed" that remains to be identified. The GMM approach did not indicate similarities between prehistoric and modern sheep for reasons already discussed. However, the results of the CV approach should be used as a guide for the design of a future GMM approach between prehistoric and modern sheep.

From a technological point of view, fiber processing was discussed on the basis of objects interpreted as spindle whorls in the relevant literature. The emerging pattern of complete absence of modeled spindle whorls from the Greek EN suggests a clear distinction between this period and the subsequent ones, in terms of spindle whorl manufacturing traditions. MN tool assemblages at some sites include both rounded perforated potsherds, and for the first time, modeled spindle whorls in biconical and spheroid types. Compared to the MN, the whorl assemblages of the LN and the FN are characterized by subtle differences. Although rounded, perforated potsherds continue to be used, modeled whorls are now abundant; typologies at distinct sites usually include more than one type; and often each whorl type manifests a considerable degree of standardization at the site level. EBA spindle whorl assemblages further stress the crystallization of local traditions of spindle whorl manufacture, that gradually gives way to a homogeneity manifested in the dominance of the biconical type.

Taking into consideration the diachronic fluctuations of spindle whorl morphometry in the Neolithic and the Early Bronze Age, a significant turning was traced after the EN. The beginning of the MN marks the end of a millennia-old tradition of manufacturing spindle whorls from pottery sherds only, and the beginning of a new practice that is well established throughout mainland and insular Greece by the end of the Neolithic: manufacturing ceramic spindle whorls as artifacts from raw clay into various shapes and sizes. It is suggested that such a significant shift may be related to the emergence of wool as textile fiber in the MN, a possibility not excluded by the present zooarchaeological study, but certainly a research hypothesis to be tested in the future.

CONCLUSIONS

Interdisciplinary inquiry into the beginnings of wool craft in prehistoric Greece was based on the analysis of archaeological assemblages of caprine bones and spindle whorls used for yarn manufacture. Given the present state of research (analytical methodologies, publication status), this study has argued for the possibility of wool craft being practiced already in the Greek Middle Neolithic. To test this hypothesis and to advance this research, zooarchaeological approaches should focus on a combination of morphometric and archaeogenetic analyses. The CV and the GMM analyses have the potential for the distinction of ancient sheep breeds should they be applied to larger datasets. Analysis of aDNA from sheep bones could, ideally, isolate genes associated with fleece amelioration and/or fine wool and trace prehistoric breeds. Technological studies of textile tools, continuing to build on ethnography and experimental archaeology, but also informed by the anthropology of technology, are an essential component of research on prehistoric wool craft. Thorough documentation of tool assemblages, both those deriving from recent excavations and those found in important, old publications after reexamination, are fundamental prerequisites for the successful contribution of textile tool analysis to the research of early wool craft in Greek prehistory.

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Suppl. Table 1. Taxonomic composition of sheep (*Ovis*) and goat (*Capra*) remains from sites dating between the Prepottery Neolithic and the Early Bronze Age. The red color indicates ratios in favor of goats.

Site	Phase	Period	*Ovis*	*Capra*	Ratio *Ovis*: *Capra*	Method	Reference
Argissa Magoula	Prepottery	EN	33	0	0.0	NISP	Boessneck 1960, 338–39; 1962, 28–30, 58–60, Abb. 1–2, table 1–3, T. 12.2; 1962, 40–1; von den Driesch 1987, 4, table 1b
Achilleion	I	EN	16	9	1.8	NISP	Bökönyi 1989, 316, 319, tables 13.2, 13.4
Achilleion	II	EN	37	9	4.1	NISP	
Achilleion	III	EN/MN	124	72	1.7	NISP	
Achilleion	IV	EN/MN	106	45	2.4	NISP	
Agios Petros	Period I–III	EN/MN	0	12	0.0	NISP	Schwartz 1985, 155, table 2
Kalythies Cave	total	EN–MN–LN	157	168	0.9	NISP	Halstead and Jones 1987, 141
Lerna	Lerna I	EN	3	0	0	NISP	Gejvall 1969, p. 6, 10, 13, 24–6, 44–7, tab. 3, 6, 9, 14–6, 30–1
Prodromos	P1+2+3	EN	147	29	5.1	NISP	Halstead and Jones 1980, 112, table 5
Tsoungiza		EN	66	32	2.1	MinAU	Halstead 2020, 195, table 2
Franchthi		IN	73	18	4.1	NISP	Munro and Stiner 2020, suppl. table 1
Franchthi		EN	48	17	2.8	NISP	
Mavropigi-Fyllotsairi		EN	1826	901	2.0	NISP	Michalopoulou 2017, Appendix tables 4.3, 4.4, 4.5, 5.3
Xirolimni-Portes		EN	2567	1501	1.7	NISP	
Alepotrypa		EN	49	36	1.4	MinAU	Hadjikoumis 2018, Appendix tables, 300–5
Revennia		EN	1571	470	3.3	MinAU	Isaakidou et al. 2018, table 1
Knossos (Evans campaign)		AN	189	59	3.2	MinAU	Isaakidou 2004, 205, table 6.16
Knossos (Evans campaign)		ENIa	106	21	5.0	MinAU	
Knossos (Evans campaign)		ENIb	409	76	5.4	MinAU	
Knossos (Evans campaign)		ENIc–II	516	148	3.5	MinAU	
Knossos (Karetsou campaign)		ENI	6	0	0	NISP	Pérez-Ripoll 2013, 135, table 8.1
Knossos (Karetsou campaign)		ENII	2	0	0	NISP	
Lerna	Lerna II	MN–LN	11	35	0.3	NISP	Gejvall 1969, p. 6, 10, 13, 24–6, 44–7, tab. 3, 6, 9, 14–6, 30–1
Otzaki Magula	Sesklo	MN-LN	19	33	0.6	NISP	Boessneck 1956, 4, 6–7, 18, table 1, 3; von den Driesch 1987, 4, table 1a

Site	Phase	Period	*Ovis*	*Capra*	Ratio *Ovis*: *Capra*	Method	Reference
Franchthi		MN	74	25	3.0	NISP	Munro and Stiner 2020, suppl. table 1
Knossos (Evans campaign)		MN	787	377	2.1	MinAU	Isaakidou 2004, 205, table 6.16
Dispilio		MN	12	4	3	MNI	Phoka-Cosmetatou 2008, Appendix 3
Knossos (Karetsou campaign)		EN–MN	6	2	3	NISP	Pérez-Ripoll 2013, 135, table 8.1
Knossos (Karetsou campaign)		MN	6	2	3	NISP	
Zarkou Platia Magoula		MN–LN	58	4	14.5	NISP	Becker 1999, 9, table 3; 1991, 18, table 2
Dhimitra	phase I+II	LN	132	39	3.4	NISP	Yannouli 1994, 169–70, 173, tables 6.3, 6.8
Makri	Makri II	LN	5	5	1.0	NISP	Efstratiou et al. 1998, 46, table 1; Curci and Tagliacozzo 2003, 125–29, tab. 13.2, 13.4
Phaistos	total	LN	78	55	1.4	NISP	Wilkens 1996, 241–42, table 20.1
Sitagroi	phase I	LN	206	11	18.7	NISP	Bökönyi 1986, 68, tables 5.2.a
Skoteini Cave	LN Ia + LN Ib	LN	321	346	0.9	NISP	Kotjabopoulou and Trantalidou 1993, 402, tables 6–7
Thermi B	phase I–III	LN	114	28	4.1	NISP	Yannouli 1994, 169–70, 173, tables 6.2, 6.7
Vassilika C	phase I + II	LN	125	51	2.5	NISP	Yannouli 1994, 169, 173, tables 6.1, 6.6
Dispilio		LN	2320	171	13.5	NISP	Samartzidou 2012, 2, figure 14.2
Franchthi		ELN1	63	25	2.5	NISP	Munro and Stiner 2020, suppl. table 1
Franchthi		ELN2	153	51	3.0	NISP	
Promachon	LN I	LN	411	100	4.1	NISP	Kazantzis 2018, table 5.18, 38–9
Knossos (Evans campaign)		LN	1655	765	2.2	MinAU	Isaakidou 2004, 205, table 6.16
Knossos (Karetsou campaign)		LN	98	14	7	NISP	Pérez-Ripoll 2013, 135, table 8.1
Makriyalos I		LN	3324	1410	2.4	MinAU	Isaakidou and Halstead 2018, 71, table 5.1
Toumba Kremastis Koiladas		LN	14.456	2.586	56	MinAU	Tzevelekidi 2012, 25, table 2.5
Zarkou Platia Magoula		LN	47	7	6.7	NISP	Becker 1991, 18, 20, table 2
Agia Sofia Magoula	Dimini	LN–FN	249	64	3.9	NISP	von den Driesch and Enderle 1976, 33, table 1; von den Driesch 1987, 5, table 1c
Otzaki Magoula	Dimini	LN–FN	7	6	1.2	NISP	Boessneck 1956, 4, 6–7, 18, table 1, 3
Pevkakia Magoula	Dimini	LN–FN	25	9	2.8	NISP	Jordan 1975, 7, 17, 61, 113, Tab. 1, 4; von den Driesch 1987, 5, Tab. 1d

Site	Phase	Period	*Ovis*	*Capra*	Ratio *Ovis*: *Capra*	Method	Reference
Dimini		LN–FN	188	46	4.1	Nr id. Units	Halstead 1992, 34, 39, tables 1a, 4
Sitagroi	phase II	LN–FN	341	75	4.5	NISP	Bökönyi 1986, 68, tables 5.2.a
Megalo Nisi Galanis		LN–FN	39	11	3.5	NISP	Greenfield et al. 2005, 33–4, table 10
Alepotrypa		LN–FN	239	127	1.9	MinAU	Hadjikoumis 2018, Appendix tables, 300–5
Alepotrypa		EN–FN	75	30	2.5	MinAU	Hadjikoumis 2018, Appendix tables, 300–5
Dhimitra	phase III	FN	91	57	1.6	NISP	Yannouli 1994, 170, 173, tables 6.3, 6.8
Megalo Nisi Galanis		FN	469	121	3.9	NISP	Greenfield et al. 2005, 33–4, table 10; Arnold and Green-field 2006, 52, tables 7.24–25
Otzaki Magula	Larissa-Eutrisis	FN	3	3	1	NISP	Boessneck 1956, 4, 6–7, 18, table 1, 3; von den Driesch 1987, 4, table 1a
Skoteini Cave	LN IIa	FN	126	103	1.2	NISP	Kotjabopoulou and Trantalidou 1993, 402, tables 6–7
Franchthi		FN	114	34	3.4	NISP	Munro and Stiner 2020, suppl. table 1
Promachon	LN II	FN	143	29	4.9	NISP	Kazantzis 2018, table 5.18, 38–9
Alepotrypa		FN	496	342	1.5	MinAU	Hadjikoumis 2018, Appendix tables, 300–5
Vassilika C	phase III + IV	FN	136	92	1.5	NISP	Yannouli 1994, 169, 173, tables 6.1, 6.6
Kephala	total	FN	55	63	0.9	Nr Frag	Coy 1977, 129, table 1
Paradeisos (Klise Tepe)	Stratum 1–7	FN–EBA	36	29	1.2	NISP	Larje 1987, 94, 97–8, 107, fig. 8–13, table 2
Pevkakia Magoula	Rachmani	FN–EBA	378	196	1.9	NISP	Jordan 1975, 7–8, 18, 51–5, 61, 116, table 1, 5, 15-16; Amberger 1979, 16, 53–4, 60–1, 106, table 1, 12, 16, 24; von den Driesch 1987, 5, table 1d
Sitagroi	phase III	FN–EBA	631	156	4.0	NISP	Bökönyi 1986, 68, tables 5.2.a
Tsoungiza Hill	FN–EH	FN–EBA	83	106	0.8	MinAU	Halstead 2011, 751, 797, tables 13.9, 13.54
Argissa Magoula		EBA	19	17	1.1	NISP	Boessneck 1962, 43, 63, 65–7, tables 1, 6, 8–10; von den Driesch 1987, 4, table 1b
Lerna	Lerna III	EBA	4	52	0.1	NISP	Gejvall 1969, 6, 10, 13, 24–6, 44–7, tab. 3, 6, 9, 14–6, 30–1
Megalo Nisi Galanis		EBA	96	18	5.3	NISP	Greenfield et al. 2005, 33–4, table 10; Arnold and Greenfield 2006, 52, tables 7.24-25

Site	Phase	Period	*Ovis*	*Capra*	Ratio *Ovis*: *Capra*	Method	Reference
Pentapolis	phase I–II	EBA	29	27	1.1	NISP	Yannouli 1994, 171,174, tables 6.4, 6.9
Pevkakia Magoula		EBA	466	314	1.5	NISP	Amberger 1979, 16, 53–4, 58, 60–1, 64, 66, 77, 80–1, 106, 133, tables 1, 12, 15–7, 19, 24
Sitagroi	phase IV	EBA	153	28	5.5	NISP	Bökönyi 1986, 68, tables 5.2.a
Sitagroi	phase V	EBA	319	106	3.0	NISP	
Skala Sotiros	phase I + II	EBA	568	597	1	NISP	Yannouli 1994, 171, 174, tables 6.5, 6.10
Tiryns	EH II	EBA II	8	4	2.0	NISP	von den Driesch and Boessneck 1990, 93, 134–37, tables 5, 34
Tiryns	EH III	EBA III	2	0	0	NISP	von den Driesch and Boessneck 1990, 93, 134–37, tables 5, 34
Zarkou Platia Magoula		EBA	118	33	3.6	NISP	Becker 1991, 18, 20, table 2
Knossos (Evans campaign)	EMI–III	EBA	504	186	2.7	MinAU	Isaakidou 2004, 205, table 6.16
Kastanas	Schicht 20–28	EBA–MBA	32	10	3.2	NISP	Becker 1986, 49–50, 106, 338, tables 15–6, 18, 40, VIII

Suppl. Table 2. Sheep and goat ages-at-death (actual values, percentages) from sites discussed in the text.

Payne's age system	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H–I**	**Reference**
Age in months/years	**0–2 M**	**2–6 M**	**6–12 M**	**1–2 Y**	**2–3 Y**	**3–4 Y**	**4–6 Y**	**6–10 Y**	
Initial Neolithic Franchthi		5		22	2				Munro and Stiner 2020, suppl. table 6
%		17.2		75.9	6.9				
				EARLY NEOLITHIC					
Prodromos			19.0	20.0		7.0	13.0	9.0	Halstead and Jones 1980, 110, table 3c
%			27.9	29.4		10.3	19.1	13.2	
Mavropigi-Fyllot-sairi I–II				not available					Michalopoulou 2017, 140, 226–31, 355–58
%		13.0	45.0	22.0		20.0			
Mavropigi-Fyllot-sairi III				not available					
%			45.0	20.0	19.0	12.0	3.0	1.0	
Xirolimni-Portes				not available					
%		2.0	45.8	25.8	8.0	8.0	8.0	2.4	
Alepotrypa				not available					Hadjikoumis 2018, 281–82, fig. 14.9
%			30.0	40.0		30.0			
Tsoungiza			4.0	2.1	8.1	3.5	1.7	2.5	Halstead 2020, 207. table 14
%			18.3	9.6	37.0	16.0	7.7	11.4	
Franchthi		3.0		11.0	1.0	2.0			Munro and Stiner 2020, suppl. table 6
%		17.6		64.7	5.9	11.8			
Kalythies Cave	2.0	4.0	5.0	10.0	10.0		6.0	7.0	Halstead and Jones 1987, 150, table III
%	4.5	9.1	11.4	22.8	22.7		13.6	15.9	
Lerna I		4.0		2.0		9.0			Gejvall 1969, 13, table 9
%		26.7		13.3		60.0			
				MIDDLE NEOLITHIC					
Lerna II		17		7		37			Gejvall 1969, table 9, 13
%		27.8		11.5		60.7			
Kouphovouno		4	6	6		37		1	Rivals et al. 2011, 530, table 2
%		7.4	11.1	11.1		68.5		1.9	
Dispilio		1	3	2	2	4	3	1	Phoka-Cosmetatou 2008, Appendix 4
%		6.25	18.75	12.5	12.5	25	18.75	6.25	
Franchthi		4		23	3	5	10	1	Munro and Stiner 2020, suppl. table 6
%		8.70		50.00	6.52	10.87	21.74	2.17	
				LATE NEOLITHIC					
Dhimitra I–II		1	4	3	3	4	3	7	Yannouli 1994, 180, 183, tables 6.12–14
%		4.0	16.0	12.0	12.0	16.0	12.0	28.0	
Dhimitra III		1	1	2	1	2	1	2	
%		10.0	10.0	20.0	10.0	20.0	10.0	20.0	

Payne's age system	A	B	C	D	E	F	G	H–I	Reference
Age in months/years	0–2 M	2–6 M	6–12 M	1–2 Y	2–3 Y	3–4 Y	4–6 Y	6–10 Y	
Vassilika C I–II		1	2	4	3	4	6	3	Yannouli 1994, 180, 183, tables 6.12, 6.14
%		4.3	8.7	17.4	13.0	17.4	26.1	13.0	
Vassilika C III–IV			7	7	7	2	9	3	
%			20.0	20.0	20.0	5.7	25.7	8.6	
Thermi B I–III			4	9	6	6	5	5	
%			11.4	25.7	17.1	17.1	14.3	14.3	
Dispilio			8	3	3	5	16	1	Ioannidou 2005, 83, tables 6–7
%			22.2	8.3	8.3	13.9	44.4	2.8	
Megalo Nissi Galanis	2		7	3	2	1	1		Greenfield et al. 2005, 103–8, tables 41–7
%	12.5		43.8	18.8	12.5	6.3	6.3		
Agia Sofia Magoula	2	23	11	15	21	24		16	von den Driesch and Enderle 1976, 39, table 8
%	1.8	20.5	9.8	13.4	18.8	21.4		14.3	
Dimini		5	33	22	12	11	22	3	Halstead 1992, 35, table 2a
%		4.6	30.6	20.4	11.1	10.2	20.4	2.8	
Kouphovouno		4	5	4	13			1	Rivals et al. 2011, 530, table 2
%		14.8	18.5	14.8	48.2			3.7	
Knossos		9	9	11	8	11	12	6	Pérez-Ripoll 2013, 157, table 8.12
%		13.6	13.6	16.7	12.1	16.7	18.2	9.1	
Franchthi		6		21	1	3	6	4	Munro and Stiner 2020, suppl. table 6
%		14.6		51.2	2.4	7.3	14.6	9.8	
Ftelia		18.06	52.4	98.57	44.15	69.81	21.03	5.62	Panagiotidou 2018, table 3a
%		7.5	15.7	24.8	14.6	26.5	8.2	2.8	
Toumba Kremastis Koiladas	9	89	536	567	358	395	578	301	Tzevelekidi 2012, 89, table 5.8
%	0.3	3.1	18.9	20	12.6	13.9	20.4	10.7	
					FINAL NEOLITHIC				
Alepotrypa				Not available					Hadjikoumis 2018, 283, fig. 14.10
%	6.0	8.0	13.0	25.0	15.0	9.0	20.0	4.0	
Megalo Nissi Galanis		2	4	5					Greenfield et al. 2005, 103–8, tables 41–7
%		18.2	36.4	45.5					
Promachon		1	14	15	24	21.5	27	33.5	Kazantzis 2018, 89, table 5.88
%		1.0	10.0	11.0	17.0	16.0	20.0	25.0	

Payne's age system	A	B	C	D	E	F	G	H–I	Reference
Age in months/years	0–2 M	2–6 M	6–12 M	1–2 Y	2–3 Y	3–4 Y	4–6 Y	6–10 Y	
Dikili Tash	2	9	30	20	13.5	13.5	12	7	Helmer 2000, table 2, 37
%	8.6	19.3	42.8	14.3	4.8	4.8	4.3	1.2	
Franchthi		7		13	2	3	2	4	Munro and Stiner 2020, suppl. table 6
%		22.6		41.9	6.5	9.7	6.5	12.9	
Pevkakia Magoula	6	31	20	14	14	28	31	14	Jordan 1975, 7, 17, 61, 113, Tables 1, 4; von den Driesch 1987, 5, Tab. 1d
%	3.8	19.6	12.7	8.9	8.9	17.7	19.6	8.9	
Tsoungiza Hill		2	9	4	3	11	7	7	Halstead 2011, 757, table 13.18
%		4.7	20.9	9.3	7.0	25.6	16.3	16.3	
Kephala		1		9	12	2	1		Coy 1977, 131–32
%		4.0		36.0	48.0	8.0	4.0		
EARLY BRONZE AGE									
Skala Sotiros		8	30	23	18	17	35	9	Yannouli 1994, 187, table 6.16
%		5.7	21.4	16.4	12.9	12.1	25.0	6.4	
Pentapolis			4	2	1		2	1	
%			40.0	20.0	10.0		20.0	10.0	
Pevkakia Magoula	1	3	9	5	25	15	8		Jordan 1975, 7–8, 18, 51–5, 61, 116, tab. 1, 5, 15–6; Amberger 1979, 16, 53–4. 60–1, 106, tab. 1, 12, 16, 24
%	1.8	15.8	6.1	16.7	32.5	19.3	7.9		
Tiryns EB II	1	3	2	8	2	10	6	4	von den Driesch and Boessneck 1990, 97–table 8, 131–table 30
%	2.8	8.3	5.6	22.2	5.6	27.8	16.7	11.1	
Tiryns EB III		7		4	3	12	4	1	
%		22.6		12.9	9.7	38.7	12.9	3.2	
Lerna III		9		9		30			Gejvall 1969, Table 9, 13
%		18.8		18.8		62.4			

Payne's age system	A	B	C	D	E	F	G	H–I	Reference
Age in months/years	0–2 M	2–6 M	6–12 M	1–2 Y	2–3 Y	3–4 Y	4–6 Y	6–10 Y	
SITAGROI AGES AT DEATH									
Phase I	3	2	6	4	1	6	2	11	Papayianni et al. under review
%	8.6	5.7	17.1	11.5	2.9	17.1	5.7	31.4	
Phase II	15	1	17	13	6	17	5	12	
%	16.3	2.3	19.8	15.1	7.0	19.8	5.8	14.0	
Phase III	3	2	10	5	2	4	10	8	
%	2.4	4.8	23.8	11.9	4.9	9.5	23.8	19.0	
Phase IV				1		1			
%				50		50			
Phase V	13	2	4	2	3	1	1	2	
%	46.4	7.1	14.3	7.1	10.7	3.6	3.6	7.1	
SITAGROI SURVIVORSHIP CURVES									
Phase I	94.3	77.2	65.7	62.8	60.0	42.8	37.1	5.7	Papayianni et al. under review
Phase II	83.7	81.4	61.6	46.5	39.6	19.8	14.0	0.0	
Phase III	97.6	92.9	69.0	57.1	52.2	42.7	18.9	-0.1	
Phase IV	100.0	100.0	100.0	50.0	50.0	0.0	0.0	0.0	
Phase V	53.6	46.4	32.1	25.0	14.3	10.7	7.1	0.0	
Payne's wool model	100.0	85.0	75.0	65.0	64.0	54.0	45.0	20.0	After Marom and Bar-Oz 2009, 1186, table 1
Payne's meat model	100.0	85.0	75.0	60.0	40.0	26.0	20.0	15.0	
Payne's milk model	100.0	47.0	42.0	37.0	32.0	26.0	20.0	14.0	

Suppl. Table 3. Sheep sex ratios discussed in the text.

Date/Site	Female (N)	Female %	Male (N)	Male	Σ	Reference
Aceramic–ENIa Knossos		50		50	26	Isaakidou 2006, 102, table 8.2
EN Prodromos	42	72.4	16	27.6	58	Halstead and Jones 1980, 112, table 5
EN Tsoungiza	12	63.2	7	36.8	19	Halstead 2020, 207, table 15
ENIb Knossos		80.0		20.0	35	Isaakidou 2006, 102, table 8.2
ENIc–ENII Knossos		64.0		36.0	39	Isaakidou 2006, 102, table 8.2
MN/LN Knossos		75		25	64	Isaakidou 2006, 102, table 8.2
LN Knossos	29	72.5	11	27.5	40	Perez-Ripoll 2013, 160, table 8.16
LN Sitagroi I	8	66.7	4	33.3	12	Bökönyi 1986, 79, table 5.6
LN Sitagroi II	10	30.3	23	69.7	33	
LN M. Nissi Galanis	17	70.8	7	29.2	24	Greenfield et al. 2005, 100–1, table 39–0 Arnold and Greenfield 2006, 52, tables 7.24–5
LN Skoteini Cave Ia&b	10	62.5	6	37.5	16	Kotjabopoulou and Tranta-lidou 1993, 425, table 14
LN Dimini	11	84.6	2	15.4	13	Halstead 1992, 39, table 5
LN Ag. Sofia Magoula	17	77.3	5	22.7	22	von den Driesch and Enderle 1976, 34, table 3
LN Toumba Kremastis Koiladas	478	78.5	131	21.5	609	Tzevelekidi 2012, 93, table 5.10
LN/FN Knossos		82		18	192	Isaakidou 2006, 102, table 8.2
LN–FN Alepotrypa	27	84.4	5	15.6	32	Hadjikoumis 2018, 285–86, table 14.9
FN Sitagroi III	10	50	10	50	20	Bökönyi 1986, 79, table 5.6
FN Pevkakia Magoula	50	78.1	14	21.9	64	Jordan 1975, 7–8, 18, 51–5, 61, 116, table 1, 5, 15–6
EBA Pevkakia Magoula	14	66.7	7	3.3	21	Jordan 1975, 7–8, 18, 51–5, 61, 116, table 1, 5, 15–6
EBA Pl. Magoula Zarkou	10	76.9	3	23.1	13	Becker 1991, 22, 56, 58, 60, tab. II–IV
EBA Sitagroi IV	28	82.4	6	17.6	34	Bökönyi 1986, 79, table 5.6
EBA Sitagroi V	23	79.3	6	20.7	29	
Prepalatial Knossos		41		59	27	Isaakidou 2006, 102, table 8.2

Suppl. Table 4. Coefficient of variation (CV) of sheep postcranial bone measurements from sites with more than 50 available measurements. Red color: CV values exceeding 6, evidence for sheep skeleton improvement.

Abbreviation	**GL**	**GB**	**GLp**	**BT**	**BFp**	**BFd**	**Bp**	**Bd**	**DC**	**Dd**	SLC	GLl	GLm
Measurement	Greatest length	Greatest breadth	Greatest length of processus articularis	Breadth of trochlea	Breadth of facies articularis proximalis	Breadth of facies articularis distalis	Breadth of proximal end	Breadth of distal end	Depth of caput femoris	Depth of distal end	Smallest length of collum scapulae	Greatest length of lateral half	Greatest length of medial half

	Achilleion III–IV	**CV**	**Agia Sofia Magoula**	**CV**	**Alepotrypa LN**	**CV**	**Alepotrypa LN/FN**	**CV**	**Alepotrypa FN**	**CV**	**Franchthi ELN2**	**CV**	**M. Nissi Galanis FN**	**CV**
Humerus GL			1		1				2	8.35				
Humerus Bd	13	5.76	23	6.03	4	2.44	5	5.39	11	32.54	12	4.19	4	6.15
Humerus GLP														
Humerus BT			22	4.61	5	4.92	9	6.48	14	28.55	12	5.02	4	6.39
Radius GL			3	2.19	1		2	4.15	7	5.55				
Radius BP			11	6.56	11	5.97	9	6.80	35	9.74	3	4.09	6	8.16
Radius Bd			12	2.99	3	2.25	2	1.03	15	6.85			1	
Radius BFp			11	5.70	11	6.17	9	6.17	35	8.01	3	1.19	6	9.81
Radius BFd													1	
Metacarpus GL	3	4.91	5	6.68	1				5	6.65				
Metacarpus Bp	11	7.83	16	6.18	1				5	8.34	1		3	2.57
Metacarpus Bd	21	5.88	7	7.57	2				9	6.23	2	3.53		
Metatarsus GL	2	4.58	2	2.09	1		2	0.62	3	7.35				
Metatarsus Bp	8	6.07	10	4.21	2	1.13	2	6.99	3	7.81				
Metatarsus Bd	12	6.56	13	5.31	3	3.01	2	8.40	6	5.84				

	Achilleion III–IV	CV	Agia Sofia Magoula	CV	Alepotrypa LN	CV	Alepotrypa LN/FN	CV	Alepotrypa FN	CV	Franchthi ELN2	CV	M. Nissi Gala-nis FN	CV
Femur GL									1					
Femur Bp			1		1		2	2.04	3	11.40			1	
Femur Bd			3	3.03					1				1	
Femur DC					1		2	5.80	5	3.13				
Tibia Bp									3	6.37				
Tibia Bd					5	3.29	6	6.94	16	7.32	8	2.34	2	3.97
Tibia Dd					3	5.74	5	6.66	14	7.06	8	2.84	2	1.59
Scapula GLP			11	4.70	2	6.87	3	1.61	18	6.18	4	4.41	1	
Scapula SLC			17	5.86	3	6.63	3	3.54	21	12.40	5	3.11	1	
Calcaneus GL			2	5.81					4	6.53	4	2.64	3	3.48
Calcaneus GB			3	5.26					4	12.82			3	0.98
Astragalus Bd			5	1.69	3	1.71			16	10.87			7	7.04
Astragalus GLl			5	4.45	4	2.62			16	9.69	10	4.85	6	7.74
Astragalus GLm			5	3.11	4	2.68			16	9.17	9	5.26	6	8.19
Average	70	**5.94**	**188**	**4.70**	72	**3.96**	63	**4.84**	288	**9.79**	80	**3.62**	58	**5.26**
Reference	Bökönyi 1989, 328–30. t.E7. E9		von den Driesch and Enderle, 1976. 40–4. t.10		Hagdik-oumis. unpu-bished data						Munro and Stiner 2020, 14–6. Appendix B		Greenfield et al. 2005. 165–78. Appendix 4C	

	Pevkakia Magoula FN	CV	Pevkakia Magoula-EBA	CV	Phaistos total	CV	Pl. Magoula Zarkou MN	CV	Pl. Magoula Zarkou LN	CV	Pl. Magoula Zarkou EBA	CV	Prodromos P1+2+3	CV
Humerus Bd	16	7.16	16	8.61	11	7.67	3	5.75	6	5.56	10	6.11		
Humerus GLP									7	6.98				
Humerus BT	20	1.93	22	7.75	11	8.12	4	3.72			11	4.84	49	7.10
Radius GL									1		2	0.63		
Radius BP	12	5.63	11	4.29	4	6.29	2	1.77	8	5.20	5	3.53	24	6.44
Radius Bd	8	7.39	7	5.25	3	2.84	2	7.60	3	0.58	4	7.84		
Radius BFp	14	6.25	11	4.78			2	2.93	8	4.45	5	4.22		
Radius BFd							2	10.66	3	1.41	4	8.52		
Metacarpus GL											11	5.69		
Metacarpus Bp	18	5.03	13	7.82			3	5.51	1		13	7.72		
Metacarpus Bd	9	5.44	6	6.95			2	6.85	1		14	8.62		
Metatarsus GL	1										4	11.41		
Metatarsus Bp	10	3.48	7	3.77	4	2.67	2	7.28	1		11	6.38		
Metatarsus Bd	4	4.82	5	6.27	2	0.67	3	3.24	1		8	6.99		
Femur GL											1			
Femur Bp	4	4.19			2	5.71					4	6.13		
Femur Bd	1		1		1						3	3.87		
Femur DC	4	1.63			2	14.81					4	6.26		
Tibia Bp			1						1					
Tibia Bd			26	8.23			4	12.03	5	7.07	30	6.04	20	3.38
Tibia Dd							4	6.58	4	7.57	29	6.67		
Scapula GLP	9	4.96	12	6.64	8	3.17	8	9.38	1		4	9.44		
Scapula SLC	11	5.04	15	9.86	8	2.12	9	10.34	2	9.65	3	13.19		
Calcaneus GL	6	9.38	15	8.88	1				3	3.54	2	2.60		
Calcaneus GB	7	11.44	14	7.53	1				3	8.86	2	5.19		
Astragalus Bd	16	3.75	22	7.25	2	0.96			2	13.76	15	6.09		

	Pevkakia Magoula FN	CV	Pevkakia Magoula-EBA	CV	Phaistos total	CV	Pl. Magoula Zarkou MN	CV	Pl. Magoula Zarkou LN	CV	Pl. Magoula Zarkou EBA	CV	Prodromos P1+2+3	CV
Astragalus GLl	17	3.34	22	5.58	2	2.45			1		15	3.79		
Astragalus GLm	17	3.98	21	9.95	3	2.60			1		15	4.55		
Average	187	**5.27**	247	**7.02**	65	**4.62**	50	**6.69**	63	**6.22**	229	**6.25**	93	**5.64**
Reference	Amberger 1979. 16. 53–4. 60–1. 106. t. 1. 12. 16. 24; von den Driesch 1987. 5. t. 1d				Wilkens 1996, 254–55, Appendix 20.1		Becker 1999. 20. t. 8		Becker 1991. 21. 62–6. t. 6				Halstead and Jones 1980, 113. t. 6	

	Sitagroi II	CV	Sitagroi III	CV	Sitagroi IV	CV	Sitagroi V	CV
Humerus GL	1		2	0.60			1	
Humerus Bd	26	7.01	36	6.77	9	10.03	24	7.61
Humerus GLP								
Humerus BT								
Radius GL	4	6.44	4	2.92			3	11.29
Radius BP	4	4.98	5	10.95	1		3	10.35
Radius Bd	4	5.66	3	3.03			3	9.83
Radius BFp								
Radius BFd								
Metacarpus GL	3	1.09	13	6.03	1		5	4.23
Metacarpus Bp	26	5.90	51	5.69	19	7.52	50	6.07
Metacarpus Bd	14	4.09	31	6.52	2	3.67	14	4.67
Metatarsus GL	1		4	3.46			1	

	Sitagroi II	CV	Sitagroi III	CV	Sitagroi IV	CV	Sitagroi V	CV
Metatarsus Bp	6	6.22	26	4.79	2	16.49	14	6.23
Metatarsus Bd	18	5.73	35	6.03	3	8.44	11	8.83
Femur GL								
Femur Bp	3	1.27						
Femur Bd								
Femur DC								
Tibia Bp			3	0.00			1	
Tibia Bd								
Tibia Dd								
Scapula GLP	6	8.94	5	7.43	1		6	5.59
Scapula SLC	6	12.06	5	9.93	2	1.75	6	13.04
Calcaneus GL	4	3.36	3	12.70	2	11.77	7	7.19
Calcaneus GB	4	6.55	3	7.90	2	12.98	5	12.75
Astragalus Bd	6	4.10	4	8.91	6	4.51	7	6.19
Astragalus GLl	6	3.68	4	5.59	6	2.28	7	6.88
Astragalus GLm	6	3.48	4	6.96				
Average	148 **5.33**		241	**6.12**	56 **7.94**		168	**8.05**
Reference	Bökönyi 1986. 106-112. table 5.26							

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