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Mediterranean polyculture revisited: Olive, grape and subsistence strategies at Palaikastro, East Crete, between the Late Neolithic and Late Bronze Age

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A R T I C L E I N F O

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A B S T R A C T

This paper examines agriculture, farming and dietary resources in east Crete, and re-evaluates the role of grape and olive in its prehistoric economy, these being key in debates on the emergence of social complexity. To do so bioarchaeological, paleoenvironmental and landscape survey data from the Bronze Age town at Palaikastro and its territory are combined. The results indicate a highly compartmentalised landscape, including intensive crop cultivation and extensive animal herding with careful monitoring to maintain productivity. A heightened specialisation in ovicaprine management at Palaikastro and east Crete seems to be delineated. Marine resources were regularly exploited from easily accessible coastal areas. Other activities included viticulture since the Early Minoan period, with the possible involvement of several houses in wine-making. A final important activity in the area was large-scale olive tree management since the Final Neolithic period and through to the Late Bronze Age, that seems to be entangled with ovicaprine herding and grazing. Thus, the demand for olive oil production does not seem to have been the driving force behind the intensification of the tree management, at least initially, but a corollary of its use in other aspects of the local economy.

1. Introduction

A key debate in the investigation of the emergence of state organisation and social complexity in the Bronze Age (BA) southern Aegean is the nature of its economy. Colin Renfrew in his seminal *Emergence of Civilisation* (1972) argued that Minoan civilisation was based on the development of a polyculture of wheat, olive and vine by the Early Bronze Age. He saw the role of the olive and vine as particularly crucial in allowing diversification, specialisation and the commodification of resources, thus completely transforming the landscape and the basic 'cereal-pulse-livestock' Neolithic economy, and eventually leading to the emergence of complex, hierarchical societies in the BA. Since Renfrew's work, the timing of the beginning of the management of olive and grape and the reasons instigating their management (particularly olive oil and wine production) have been key in the debates on state formation, urbanisation and overall social organisation. Hansen (1988) and Hamilakis (e.g. 1996, 1999) criticised Renfrew's thesis, arguing that intensive exploitation of olive oil and wine were Late Minoan (LM, Late Bronze Age) phenomena, associated with elite competition and power negotiation. More recently Margaritis (2013) reviewed the available archaeobotanical (seeds, charcoal and pollen) evidence for the olive in the Aegean and concluded that olive cultivation started in the Early Bronze Age on a small-scale, possibly as a result of the use of its wood as fuel and in construction, and intensified in later periods. Valamoti et al.

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(2018) and Langgut et al. (2019) also provided new, robust reviews on the introduction of the olive and its management, based predominantly on charcoal/stones (in the Aegean) and palynological (in the Mediterranean) data respectively. The two research groups were led by their respective evidence to two different scenarios. The former group concluded that olive growing in the south Aegean started by the Early Bronze Age and significantly increased in the Late Bronze Age period, the introduction of its cultivation being most probably the result of the demand of oil for the elite and ritual ceremonies (Valamoti et al., 2018). The latter group suggested that olive first started to be exploited in the southern Levant around 6500 BP and later in the Aegean in the early/mid 6th millennium BP, as part of village economy and the completion of the 'secondary products revolution' (Langgut et al., 2019).

Other aspects of the BA economy in Crete in relation to agriculture and farming are less well understood, largely due to the still relatively limited availability of bioarchaeological material (see e.g. Livarda and Kotzamani, 2013; Livarda, 2014) and the lack of integration of archaeology, landscape and paleoenvironmental data towards a better understanding of the economic activities geared to production. In regards to the latter, part of the reason is that the vast majority of landscape studies focus on the identification of sites and only rarely they are integrated with excavation data (see e.g. Alcock and Cherry, 2004). Considering the state of research, this study aims to go back to a bottom up approach focusing at site level, employing a multidisciplinary methodology, to examine the role of agriculture, farming and subsistence resources in east Crete, and within this context re-evaluate the role of grape and olive in the BA economy. This study builds upon our previous palaeoenvironmental (Cañellas-Boltà et al., 2018) and landscape (Orengo and Knappett, 2018) work, and combines bioarchaeological, paleoenvironmental and landscape data from the BA town at Palaikastro and its territory in a novel approach that was specifically designed to investigate not only the available resources but also the scale of their participation in the local economy.

2. The site

The town in the archaeological site of Roussolakkos at Palaikastro is situated at the easternmost part of Crete (Fig. 1), in an area characterised by rocky coast and small littoral plains. The study area is one of the driest regions on the island, with low mean annual precipitation (300–500 mm; Voudouris et al., 2006) and strong winds especially in the summer. The excavations at Palaikastro, in the area known as Roussolakkos, were started by Bosanquet and Dawkins at the very beginning of the 20th century, in 1902. Another two campaigns in the 1960s and 1980s–1990s continued the excavations at the site, where a large Minoan settlement was gradually unearthed (e.g. MacGillivray and Sackett, 2010). The latest research programme at the site, PALAP (Palaikastro Phase 4. Urbanization in Bronze Age Crete: Between Palace and Landscape at Palaikastro), took place in 2012–16 and this paper reports on work conducted during this last project.

The excavations and previous surveys have yielded no evidence of occupation before the Final Neolithic II (FN II) period (c. 3600–3100 BCE) in the surrounding area of the site. For the FN II period, the only evidence available includes some surface finds, such as at Kastri between the bays of Chiona and Kouremenos (Fig. 1), while the situation is similar for the Early Minoan I (EM I) period (Nowicki, 2014, 85–87). The first indication of occupation at Roussolakkos was recorded for the EM II period during which the settlement was established near the coast, although no evidence of a harbour has been discovered to date (MacGillivray and Driessen, 1990, 398). Thereafter there was continuous occupation and the settlement expanded to become a large town sometime towards the end of the Middle Minoan (MM) period, around 1700 BCE (MacGillivray and Sackett, 2010). The town was one of the largest for the BA period across the island, organised in extensive town blocks, and lasted for a period of about 1500 years until the end of the LM IIIB period, roughly between 2700 and 1200 BCE.

The PALAP project aimed to explore issues concerning early urbanism in BA Crete, the relation of the town with its territory and resource management. Within this framework, archaeological excavation was

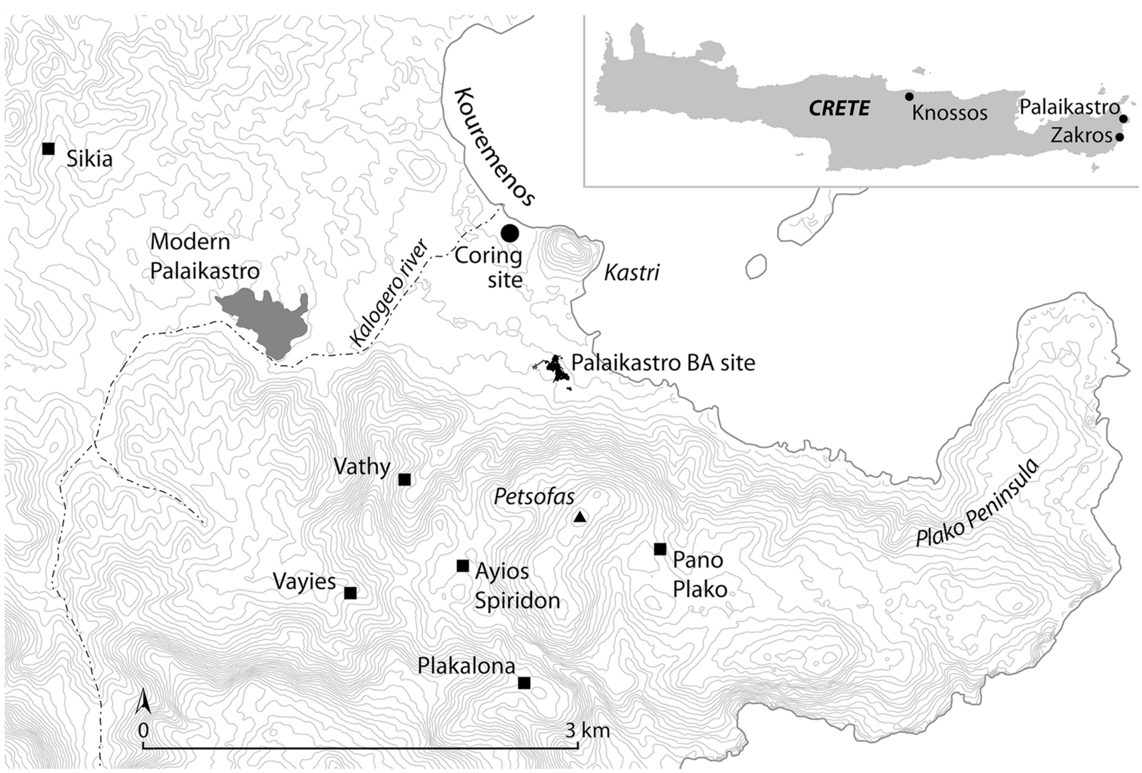

Fig. 1. Location of Palaikastro (square = Minoan farms identified by the landscape survey, see Orengo and Knappett, 2018; circle = area of palaeoenvironmental coring; triangle = peak sanctuary; BA = Bronze Age).

conducted to the east of the already excavated BA town and revealed a new cluster of three buildings dated to between the MM II and the LM IIIA2-B periods (Fig. 2). Table 1 provides a brief chronological guide of the key periods discussed in this study (for a detailed chronology see e.g. Tartaron, 2008; Manning, 2010; Nowicki, 2014).

3. Materials and methods

To address our research questions, we devised a purpose-built research strategy that fully integrated landscape survey, excavation, bioarchaeological and palaeoenvironmental analysis towards specific questions on the economic and social organisation of the town.

3.1. Bioarchaeology

Systematic bioarchaeological sampling was conducted during the PALAP project. Soil samples were taken from all excavated contexts with the exception of those visibly mixed and top-soil to allow recording of both the presence and absence of bioarchaeological remains. Soil samples of about 60 L were taken from the centre of each excavation unit, or from various places within a unit if that was particularly large. Flotation was carried out using chiffons with *c.* 0.25 mm aperture and meshes of 1 mm to capture the light floatable and the heavy fraction respectively. Small samples, collected from inside pottery and other features, were bucket floated using sieves with apertures 1 mm and 0.25 mm. Flotation was combined with rigorous hand collection of bigger, visible organic remains (bones, shells and large charcoal fragments). Standard laboratory methods were used to identify, quantify and assess each bioarchaeological assemblage (e.g. preservation, fragmentation, and where applicable sex, age, biometry, side, pathologies, butchery, weathering, wear and other modifications). Quantification was based for plants (other than charcoal) on the Minimum Number of Individuals (MNI), that is individual grains, seeds, and other plant parts, whereas for charcoal this was based on the number of fragments (NF). Shell remains were counted for the purposes of this study on the basis of the MNI and fish remains on the Number of Identified Specimens (NISP). Animal bones were counted using the Minimum Number of Anatomical Units (MinAU). This is a number that is calculated based on the Maximum Number of Anatomical Units (MaxAU). In practice MaxAU is a version of NISP, with the difference that only selected anatomical elements are recorded and that each long bone is divided into a proximal and distal half instead of being recorded as one single specimen as in the case of NISP. After the MaxAU has been calculated, in order to avoid artificial inflation of the number of body parts, taxa and age/sex groups due to fragmentation, MinAU is used by counting only one – the best preserved and thus most informative – of the specimens that belong to the same anatomical unit of the same animal in order to allow the examination of the relative abundance of taxa, body parts, *etc.* (for more details see Tzevelekidi, 2012, 24–25; Halstead, 2020, 1080, 1085). Finally, it must be noted that the vast majority of the bioarchaeological finds were dated to the Late Minoan (LM) period, and thus the MM data need to be treated as only tentative.

Table 1
Brief chronological guide for the study area (after Nowicki, 2014 for the Neolithic and after Manning, 2010 for the Bronze Age).

Period	Dates BC
Late Neolithic	c. 4500–3700/3600
Final Neolithic	c. 3700/3600–3100/3000
Early Minoan	c. 3100–2100/50
Middle Minoan	c. 2100/50–1700/1675
Late Minoan	c. 1700/1675–1075/50

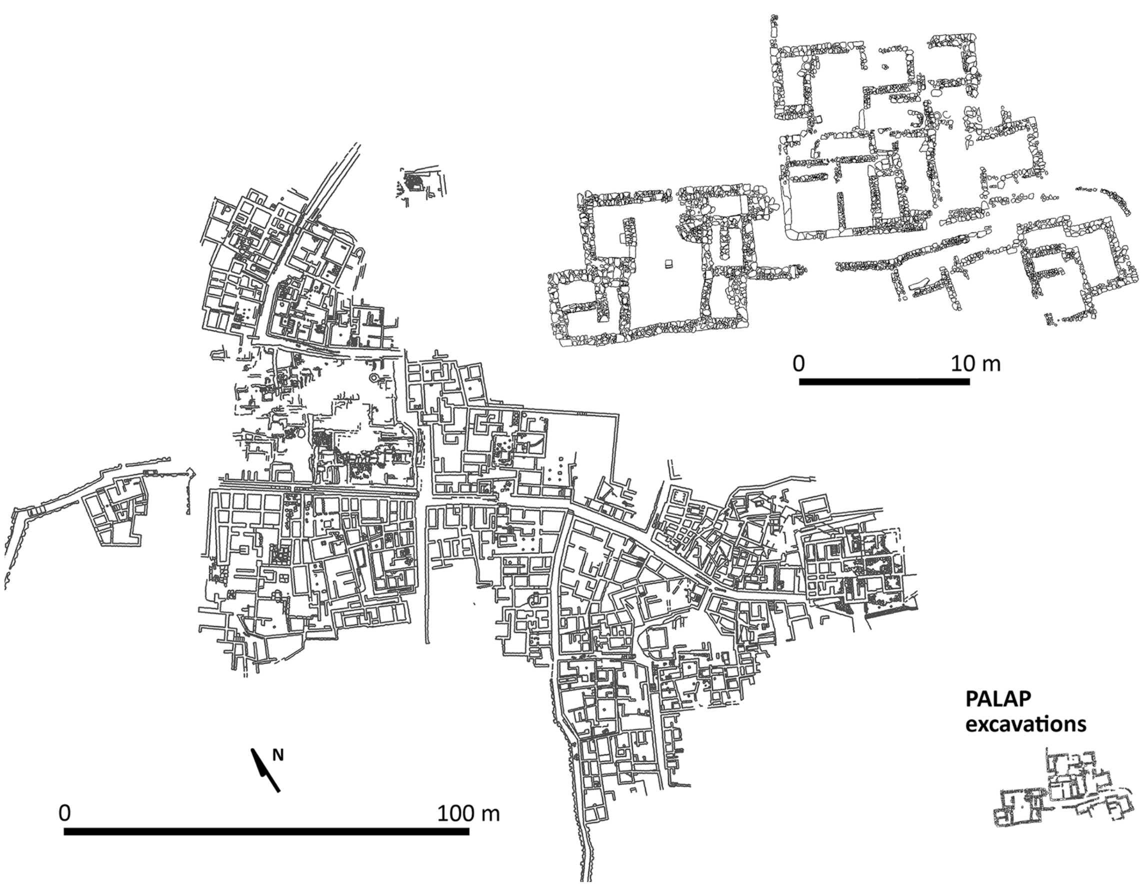

Fig. 2. Plan of the site excavated during the PALAP project and its relation to the previously excavated parts of the Bronze Age town.

3.2. Palaeoenvironmental analysis

Two paleoenvironmental cores (Core K5, 770 cm deep and Core K7, 640 cm deep) were obtained from the Kouremenos wetland (Fig. 1), 750 m to the north-west of the archaeological site, using a hand-operated 'Russian' auger. The two cores were 50 m apart and recorded similar sedimentological sequences. Multiproxy analysis was conducted, including pollen, fern spores, non-pollen palynomorphs (NPPs) and microcharcoal particles (for details see Cañellas-Boltà et al., 2018). Additionally, the two cores were sampled for sedimentological and faunal (molluscs, foraminifera, ostracods) analysis. The faunal proxies were included as indicators of past hydrological and geomorphological

Table 2
The archaeobotanical (other than charcoal) remains recovered during the PALAP project (EM = Early Minoan, MM = Middle Minoan, LM = Late Minoan, BA = Bronze Age, MNI = Minimum Number of Individuals, x = presence/uncountable specimens).

		EM	MM	MM/LM	LM	BA	TOTAL
CEREALS	**plant part**	MNI	MNI	MNI	MNI	MNI	MNI
Triticum dicoccum	grain	0	0	0	1	0	**1**
Triticum cf. *dicoccum*	grain	0	0	0	1	0	**1**
Triticum cf. *dicoccum*	glume base	0	0	0	2	0	**2**
Triticum aestivum/durum	grain	0	0	0	1	0	**1**
Triticum cf. *aestivum/durum*	grain	0	0	0	1	0	**1**
Triticum sp.	grain	0	0	0	8	0	**8**
Triticum sp.	terminal spikelet fork	0	0	0	1	0	**1**
Hordeum vulgare hulled	grain	0	0	0	1	0	**1**
Hordeum vulgare	grain	0	x	1	38	0	**39**
Hordeum vulgare	rachis segment	0	0	0	1	0	**1**
cf. *Hordeum vulgare*	grain	0	0	0	2	0	**2**
Cerealia	grain	1	x	0	25	0	**26**
Cerealia	culm node	0	0	1	1	0	**2**
cf. Cerealia	grain	0	0	0	3	0	**3**
LEGUMES							
Vicia ervilia	seed	0	0	0	1	0	**1**
Vicia faba	seed	0	0	1	1	0	**2**
Lens culinaris	seed	0	1	2	2	0	**5**
Lathyrus sativus/cicera	seed	0	0	0	0	1	**1**
cf. *Lathyrus sativus*	seed	0	0	0	4	0	**4**
Legume indeterminate	seed	0	0	0	33	1	**34**
FRUITS/NUTS							
Celtis sp.	endocarp mineralised	0	0	8	0	0	**8**
Ficus carica	drupelet carbonised	0	0	1	5	0	**6**
Ficus carica	drupelet mineralised	0	0	0	13	0	**13**
Prunus dulcis	shell (MNI)	0	0	0	15	1	**16**
cf. *Prunus dulcis*	shell fragment	0	0	0	0	1	**1**
Pistacia sp.	fruit endocarp	0	0	0	37	2	**39**
cf. *Pistacia* sp.	fruit endocarp	0	0	0	2	0	**2**
Vitis vinifera	pip	0	1	2	31	0	**34**
cf. *Vitis vinifera*	fruit fragment	0	0	2	5	0	**7**
Olea europea	stone (MNI)	0	3	3	87	3	**96**
cf. *Olea europea*	stone (MNI)	0	0	0	2	1	**3**
Olea europea	endocarp	0	0	0	4	0	**4**
Nut/Fruit indeterminate	shell/stone fragment	0	0	1	21	2	**24**
Fruit indeterminate	fruit pulp fragments	0	0	0	9	0	**9**
WILD							
Urtica sp.	seed	0	0	0	1	0	**1**
Polygonaceae	seed	0	0	0	1	0	**1**
Rumex sp.	seed	0	0	0	3	0	**3**
cf. *Portulaca oleracea*	seed	0	0	0	1	0	**1**
Caryophyllaceae	seed	0	0	0	2	0	**2**
Vaccaria hispanica	seed	0	0	0	1	0	**1**
Cruciferae	seed	0	0	0	4	1	**5**
Leguminosae	seed	0	0	0	3	0	**3**
Leguminosae small	seed	0	0	0	13	0	**13**
Astragalus sp.	seed	0	0	0	1	0	**1**
Medicago sp.	fruit	0	0	0	2	0	**2**
Malva sp. small	seed	0	0	0	4	0	**4**
Umbelliferae	seed	0	0	0	24	4	**28**
Lithospermum arvense	seed mineralised	0	0	0	2	0	**2**
Labiatae	seed	0	0	0	4	0	**4**
Labiatae small	seed	0	0	0	1	0	**1**
Compositae	seed	0	1	0	2	0	**3**
cf. *Anthemis cotula*	seed	0	0	0	1	0	**1**
Glebionis coronaria	seed	0	0	0	5	0	**5**
Glebionis sp.	seed	0	0	0	4	0	**4**
Gramineae	seed	0	0	0	12	0	**12**
Gramineae small	seed	0	0	0	10	0	**10**
Gramineae small, laterally flat, pointed apex	seed	0	0	0	5	0	**5**
Hordeum sp.	seed	0	0	0	1	0	**1**
wild indeterminate	seed	0	1	0	20	0	**21**
wild indeterminate	bud	0	0	0	2	0	**2**
TOTAL		**1**	**7**	**22**	**487**	**17**	**534**

conditions (Mazzini et al., 2015). The sedimentological analysis included: (a) determination of particle size and particle size distributions of the fine sediment fraction (b) estimation of the organic carbon content using the loss-on-ignition (LOI) method; and (c) measurement of the low and high frequency volume magnetic susceptibility (Veropoulidou et al., in prep). A robust depth-age model was built on the basis of eight radiocarbon dates (Cañellas-Boltà et al., 2018). Modern pollen samples were also taken as controls. The two paleoenvironmental records cover continuously the period between 4300 and 2500 cal BC, while paleoenvironmental data are also available for time 'windows' during the MM and the medieval periods.

3.3. Landscape survey

The landscape survey differed from traditional studies in the island (see e.g. Gkiasta, 2008) in that its objective was not to assess settlement patterns but to identify economic activities with the ultimate aim to allow contextualisation of the excavation finds and complement the bioarchaeological and paleoenvironmental research (for a full description of the methodology see Orengo and Knappett, 2018). The survey covered an area of about 32 km^2 around the BA town, from the coast to the surrounding mountainous areas, with only the latter providing substantial evidence for the BA period. First, extensive survey was conducted with handheld GPS to record locations, ceramic scatters and features. This was followed by visits to specific sites by ceramic specialists and their detailed mapping using DGPS, drone-based photogrammetric reconstructions and topographic analysis. Correlations between groups of structures and economic activities and practices were made through typological analyses and comparisons, structural relations between archaeological features and ethnoarcheological inference (for details see Orengo and Knappett, 2018).

4. Results and discussion

The on-site bioarchaeological and the paleoenvironmental work indicated the availability of a wide range of resources from both land and sea (Tables 2–6, Figs. 4 and 5), each of which played a different role in the town's economic organisation. As olive and grape have been the focus of extensive debate in the context of BA economy, these two resources are discussed separately.

4.1. Agriculture, farming and the subsistence base at Palaikastro

Archaeobotanical analysis of the town finds showed that staple food plants included three cereals and four legumes, pointing to staple crop diversification at least for the LM period (Table 2). Comparison between the buildings excavated during the PALAP project and with other areas of the town (Sarpaki, 1989, 2007, 2019) indicated a generally similar range of cereals and legumes across the (excavated) town, and thus, broadly standard food practices in relation to crops. All cereals and legumes were found in very low numbers, which restricts any quantitative analysis. On the basis of the available evidence, barley (*Hordeum vulgare*) was the most common cereal. Wheat could have also been cultivated in the area and indeed it was present in the town in the form of glume- (emmer, *Triticum dicoccum*) but also free-threshing wheat (*Triticum aestivum/durum*). The former is the most common wheat type in BA Crete (Livarda and Kotzamani, 2013). Free-threshing wheat is less well adapted to poorer environments compared to glume wheats and barley but its qualities allow for further variation in food, and seems to be part of the known Cretan diet at the time, as it has been found in various sites across the island and there is good evidence for its cultivation as a separate crop (ibid.). The identification of free-threshing wheat stored as a separate product at the cave of Ourania-to-Froudi near Zakros in eastern Crete, interpreted as a Neopalatial storage place (Sarpaki, 2009), adds further support for its presence in the broader area.

The variety of legumes across the town, with lentil (*Lens culinaris*), grass pea/chickling (*Lathyrus sativus/cicera*), bitter vetch (*Vicia ervilia*) and horse bean (*Vicia faba*) identified in the PALAP excavations in addition to pea (*Pisum sativum*) found elsewhere in the town (Sarpaki, 1989, 2019), further attest to the diversity of food ingredients available. This is in accordance with the general picture of the strong presence of legumes in the prehistoric diet of Crete (Sarpaki, 1992; Hansen, 2000; Livarda and Kotzamani, 2013; Livarda and Kotzamani, 2020). The cultivation of legumes has several advantages as they fix nitrogen and replenish the soil nutrients, and thus, when cultivated in rotation or together with cereals can help improve the cereal yield while adding another crop, a practice particularly well suited to intensive or 'horticulture' type of cultivation (Halstead, 1987). Ethnographic studies have also indicated that pulses for hay and/or human consumption are often sown under trees, such as olives (Halstead, 2014, 205–206), allowing variation in their management strategies.

The landscape survey has indicated that at least six Middle to Late Minoan farmsteads operated within the town's broader territory, linked with terraces for cultivation suited to dryland agricultural production (Orengo and Knappett, 2018; Fig. 1). The identified terraces were located in very close proximity to all these farmsteads (Orengo and Knappett, 2018), pointing to an intensive mode of farming during the Bronze Age – a strategy argued for and identified also elsewhere in the Aegean during this and the Neolithic period (e.g. Heaton et al., 2009; Halstead and Isaakidou, 2020). These terraces were all located on the

Table 3
The animal bone assemblage recovered during the PALAP project (MinAU = Minimum number of Anatomical Units, MM = Middle Minoan, LM = Late Minoan).

	MM		LM		TOTAL	
Species	**MinAU**	**%**	**MinAU**	**%**	**MinAU**	**%**
Cattle	5	**12.5**	113	**6.8**	118	**6.9**
Pig	1	**2.5**	80	**4.8**	81	**4.7**
Sheep	*8*	***20***	*295*	***17.8***	*303*	***17.7***
Goat	*5*	***12.5***	*87*	***5.2***	*92*	***5.4***
Sh/gt	*21*	***52.5***	*1086*	***65.1***	*1107*	***64.8***
Sheep, goat & sheep/goat	34	**85**	1468	**88**	1502	**87.9**
Dog	0	**0**	4	**0.2**	4	**0.2**
Hare	0	**0**	1	**0.06**	1	**0.1**
Fallow deer	0	**0**	2	**0.1**	2	**0.1**
Roe deer	0	**0**	1	**0.06**	1	**0.1**
ALL SPECIES PER PHASE	**40**		**1669**		**1709**	

Table 4
The charcoal remains recovered during the PALAP project.

	Middle Minoan		Late Minoan	
TAXA	**n**	**%**	**n**	**%**
Arbutus sp.	1	**0.35**	6	**0.13**
Cistaceae	1	**0.35**	63	**1.33**
Erica sp.	6	**2.08**	156	**3.29**
Fabaceae	3	**1.04**	79	**1.66**
Fagus sp.	0	**0**	3	**0.06**
Ficus carica	1	**0.35**	36	**0.76**
Fraxinus sp.	0	**0**	6	**0.13**
Juniperus sp.	0	**0**	9	**0.19**
Lamiaceae	0	**0**	38	**0.80**
Olea europaea	101	**34.95**	2576	**54.25**
Pinus spp.	168	**58.13**	656	**13.82**
Pistacia sp.	1	**0.35**	840	**17.69**
Prunus sp.	5	**1.73**	83	**1.75**
Quercus spp.	2	**0.69**	143	**3.01**
Rhamnus/Phillyrea	0	**0**	10	**0.21**
Rhus/Cotinus	0	**0**	18	**0.38**
Sambucus sp.	0	**0**	3	**0.06**
Vitis sp.	0	**0**	23	**0.48**
TOTAL fragments	**289**		**4748**	

Table 5
The marine shell assemblage recovered during the PALAP project (MM = Middle Minoan, LM = Late Minoan, MNI = Minimum Number of Individuals, x = presence/NISP but no MNI, NISP = Number of Identified Specimens).

Species	MM MNI	LM MNI	Ecology (Pope et al., 1991, 1993)
Acanthocardia tuberculata	x	2	On sand, mud or gravel bottoms from the intertidal zone to 100 m deep.
Arca noae		3	Lives attached with its solid byssus on rocks or shells. On all types of bottoms that contain hard substrates, from the low tide line down to 119 m.
Arca tetragona		x	From the extreme low tide line down to 120 m, attached to all kinds of hard substrate with its massive green byssus.
Astraea (Bolma) rugosa		2	Prefers rock bottoms between 8 and 50 m deep.
Barbatia barbata		1	On all types of bottoms with hard substrates, from the intertidal zone down to 280 m.
Bittium reticulatum		x	From the intertidal zone down to about 250 m deep. Lives on sea weeds (*Zostera, Posidonia, Cystoseira*) or on rocks.
Bolinus brandaris	1		On sand and sand/mud bottoms between 1 and 200 m deep.
Cancer pagurus		3	On bedrock, under boulders, mixed coarse grounds, and offshore in muddy sand; lower shore, shallow sublittoral and offshore to about 100 m.
Cardites antiquatus		x	Lives attached by its byssus, well hidden, in the roots of the larger species of algae or in rock crevices from the intertidal zone to a depth of 40 m.
Cerastoderma glaucum	x	x	Note this is marine/estuarine. In shallow, estuarine water, especially on sand or mud bottoms.
Cerithium lividulum	x	4	Intertidal to a few m deep. Prefers rock and rock/sand bottoms.
Cerithium protractum		1	In shallow water on sandy and muddy bottoms, as well as among *Posidonia*.
Cerithium rupestre	1	5	Intertidal to a few m deep. Prefers rock and rock/sand bottoms.
Cerithium sp.	x	1	
Cerithium vulgatum	x	2	In shallow water on sandy and muddy bottoms.
Chamelea gallina gallina		x	On mud and sand bottoms between 5 and 20 m deep.
Charonia tritonis	x	6	Lives in shallow water on rocky or rough gravel bottoms.
Columbella rustica	x	3	In shallow water under rocks and stones. Frequently found with *Zostera*.
Conus ventricosus (mediterraneus)		11	In shallow, quiet bays; its typical habitat consists of rocks covered with short, brown algae. During the day it hides in the sand pockets and crevices between the rocks.
Ctena decussata		x	On sand, mud and gravel bottoms below the low tide line. Also in algae.
Dosinia exoleta		x	It lives burrowed deeply in sand, mud and gravel bottoms from the intertidal zone to 73 m deep.
Euthria cornea	x	13	Common in shallow water in all kinds of rocky habitats.
Galeodea (Cassidaria) echinophora		1	On mud and sand/mud bottoms around 40 m deep.
Gibbula sp. (cf. *albida*)	x	x	Up to 20 m deep on all kinds of substrates, also on sand near *Posidonia*.
Glycymeris sp.	x	x	On muddy sand in the infralittoral zone.
Haliotis tuberculata		2	Between 1 and 30 m on rocky bottoms.
Hexaplex trunculus	509	6062	Between 1 and 100 m. It prefers mud bottoms and survives easily in polluted harbour-water.
Laevicardium oblongum		x	Buried in muddy sand from the subtidal zone down to 250 m.
Lima lima		x	Lives fixed with its byssus on or in rocks, stones and other hard substrates between 3 and 100 m deep.
Luria lurida		5	Lives under stones and rocks near sponges, often in a sandy biotope between 1 and 60 m.
Mactra stultorum	x	x	In clean sand from the low tide zone to far off-shore, down to 60 m.
Mangelia sp.		x	Fine sand and mud bottoms between 30 and 150 m.
Mitra (Episcomitra) sp. cf. zonata		1	Fine sand and mud bottoms between 30 and 150 m.
Monoplex parthenopeus		x	On all types of bottoms from around 10 m to 30 m, possibly deeper.
Mytilus sp.		x	lntertidal to 40 m deep on hard substrates.
Notocochlis (Natica) dillwynii		x	On coarse sand between 1 and 25 m deep.
Ostrea edulis		x	Lives in shallow water down to 90 m on all types of bottoms.
Paracentrotus lividus		x	Just below low water mark down to 20 m on rocks and boulders, and in seagrass meadows of *Zostera marina* and *Posidonia oceanica*.
Patella caerulea	3	77	Rocky shores, intertidally, to a few m in depth
Patella lusitanica (rustica)	1	196	Intertidal on rocks.
Patella sp.		1	
Patella ulyssiponensis		51	It prefers the lower parts of the intertidal zone on rocky shores. At low tide it can be found in pools or rivulets between the rocks.
Phorcus turbinatus	8	244	Intertidal to a few m deep on rocky shores.
Pinna nobilis		x	In sand, mud or gravel bottoms, half buried with its anterior part downwards. From the low tide line to 60 m deep. Often in *Posidonia oceanica* fields.
Pisania striata	1	4	Intertidal and just below the low tide line on rocky shores.
Rissoa ventricosa		x	Especially on weeds.
Semicassis undulata		1	On sand and sand/mud bottoms from 8 to 80 m deep.
Serpulidae		x	(annelid worm), lives attached on other shells
Spondylus gaederopus		x	Between 7 and 50 m deep, mainly on rock bottoms. They prefer exposed positions on vertical rocks with slow but steadily moving currents.
Stamonita haemostoma		x	On rocky shores intertidally to about 3 m deep. Some populations prefer deep water and others can be found on mud.
Tarantinaea (Fasciolaria) lignaria		x	Lives in shallow water on rocky shores. Hides under stones and in crevices during the day.
Tonna galea		x	In depths of between 20 and 80 m on all kinds of bottoms.
Tricolia pullus	x	x	Often in *Posidonia* fields in shallow water.
Tricolia sp. cf. *speciosa*		1	Shallow water, especially on *Posidonia*.
Tritia (Nassarius) mutabilis		1	Lives in shallow water, often in large colonies.
Tritia (Nassarius) reticulata		x	In mud and sand, intertidally, to more than 40 m deep; survives in salinities of less than 10‰.
Tritia sp. cf. *gibbosula*		1	In shallow water on sand bottoms.
Truncatella sp.		1	High on the shore under stones, wood and plants, often on places which are only occasionally wet by sea water.
Unidentified gastropod		x	
Venus verrucosa		x	

(continued on next page)

Table 5 (*continued*)

Species	MM MNI	LM MNI	Ecology (Pope et al., 1991, 1993)
			On all types of bottoms, but especially gravel bottoms, from the intertidal zone to about 100 m.
Vermetidae		18	In shallow water, attached on rocks or other shells.
TOTAL	**524**	**6724**	

Table 6
The fish remains recovered during the PALAP project (LM = Late Minoan, NISP = Number of Identified Specimens).

Species	LM - NISP	Body Part
Diplodus puntazzo	1	otolith
Sparidae	4	otolith, vertebrae
Sparidae-*Spicara*	5	otolith, vertebrae
Spicara smaris	3	otolith
Spicara sp.	4	vertebrae
Dicentrarchus sp.	2	otolith, vertebra
Epinephelus sp.	1	vertebra
Indeterminate	41	varia (mostly scales, followed by vertebrae and 1 otolith)
TOTAL	**61**	

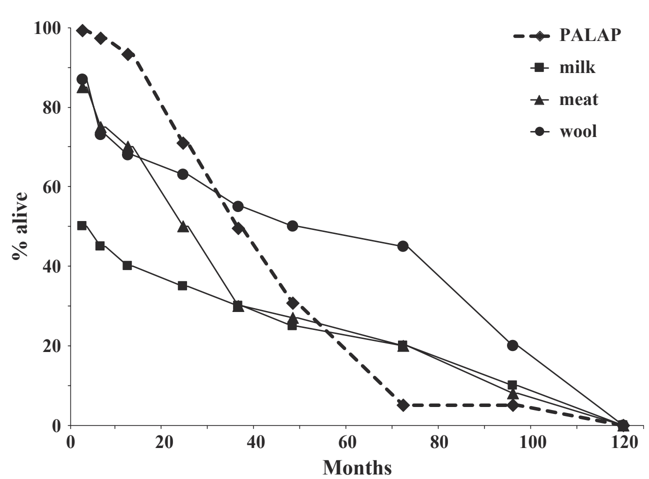

Fig. 3. Mandibular age curves for the LM III PALAP project sheep, goat and sheep/goat combined.

gentlest slopes of each site or where there was enough sediment present, which hints to pressures to use any suitable land available for cultivation (Orengo and Knappett, 2018). Preference for the cultivation of barley in these terraces is thus a real possibility, as this cereal is particularly hardy and well adapted to dry conditions and poor soils (Zohary and Hopf, 2000, 59). Equally, in this context, it is possible that cereal/pulse rotation/intercropping could have been employed as one of the risk buffering mechanisms to improve soil fertility. Soil fertility could have also been enhanced by the use of manure. Indeed, manuring in Bronze Age terraces (EM-LM I) has been geochemically detected in the island of Pseira (east Crete), providing good evidence for its application in agricultural practices of the period (Bull et al., 2001). On the basis of this evidence, agriculture in this marginal mountainous limestone zone (referred to here as ‘interior’ of the territory) appears to have been taking place at a more restricted scale, where land was available, to cover the immediate needs of the farmsteads and their territory.

The identified terraces were part of a highly compartmentalised landscape during the MM and LM periods. Whereas the land for cultivation seems comparatively restricted, the rest of the land in the interior of the territory included a complex system of enclosures suitable for ovicaprine management and a variety of devices to ensure water supply for the animals, while another regular feature was enclosure walls that protected the terraced fields from the wind and animal grazing (Orengo and Knappett, 2018). All these features together are suggestive of intensive cultivation coupled with extensive ovicaprine herding with careful monitoring to maintain productivity across the town’s interior territory (for details see Orengo and Knappett, 2018). At the same time, Palaikastro, being a large town by BA standards, required agricultural land, which the farmsteads in the interior would not have been able to supply. A more suitable area for agriculture would be potentially, for instance, the alluvial plain that existed during that period (the extent of which is currently unknown). Nevertheless, a fuller assessment of the optimal areas for prehistoric agriculture was beyond the scope of this project.

The PALAP animal bone study supports the identification of ovicaprine management in the area suggested by the landscape survey results. In particular, the animal bone assemblage was dominated by very high numbers of ovicaprines and mostly sheep that made up 87.9% of the whole assemblage (Table 3). In contrast, cattle and pig were present in low numbers, whereas dog and wild game (hare, fallow and red deer) were present in even lower quantities (Table 3). These results are consistent with those reported for other habitation areas of the town (Wall-Crowther, 2019). The ovicaprine percentages are particularly high and they are comparable only with those of LM III Mochlos (Reese et al., 2008; but note that ovicaprine percentages are very high throughout the LM phase at Palaikastro whereas at Mochlos they are not consistently as high) and LM I Pseira (where ovicaprines were the only taxa identified in the faunal assemblage, Reese, 1998a, 1998b), both located in east Crete. High ovicaprine percentages accompanied by <10% of other domesticates in earlier periods were encountered in only three EM sites, Myrtos Fournou-Koriphi (east Crete, Jarman, 1972), Priniatikos Pyrgos (east Crete, Molloy et al., 2014) and Debla (west Crete, Warren and Tzedhakis, 1974) (see also Moody, 2012 for a review of the zooarchaeological data in Crete). At Debla, however, there was only one deposit securely dated to the BA period and this, according to the available data, likely contained only a couple or in any case few individuals, and evidence for specialised ovicaprine herding is therefore not particularly strong (note that, as this was an early study, no details on anatomical parts were provided, hindering accurate calculation of the MNI). Thus, current data seem to indicate a heightened specialisation in ovicaprine management at Palaikastro and possibly across east Crete more broadly. A bowl found at Palaikastro with clay models of a shepherd and its flock dated to the MM I period (Bosanquet and Dawkins, 1923, pl. VII), may add some further indirect support to this argument.

The anatomical representation of the ovicaprine shows the presence of all body parts on the site, which suggests that at least some animals were present complete, either on the hoof or as undressed carcasses. The mortality profile of the ovicaprines (Fig. 3), based on the comparison of mandibular tooth eruption and wear rate, for the LM III period, for which enough evidence was available, is similar to that for management of sheep/goat opting for meat according to Payne’s (1974) models. Nevertheless, the Palaikastro curve does not fully align with Payne’s meat model and considering also that the meat mortality patterns are compatible with management for a mixture of products (Halstead, 2006, 44), potential management towards also other animal by-products (e.g. milk/cheese, wool/goat hair, skin) is likely, creating ‘noise’ in the age data.

The low frequencies of neonatal individuals in the bone assemblage (incompatible with the milk profile) may probably be related to pre-depositional human behaviour (e.g. slaughter at older age and/or discard of young animals elsewhere) rather than taphonomic biases. This is so as although bone hand collection may have adversely impacted their recovery, the percentage of neonatal specimens collected

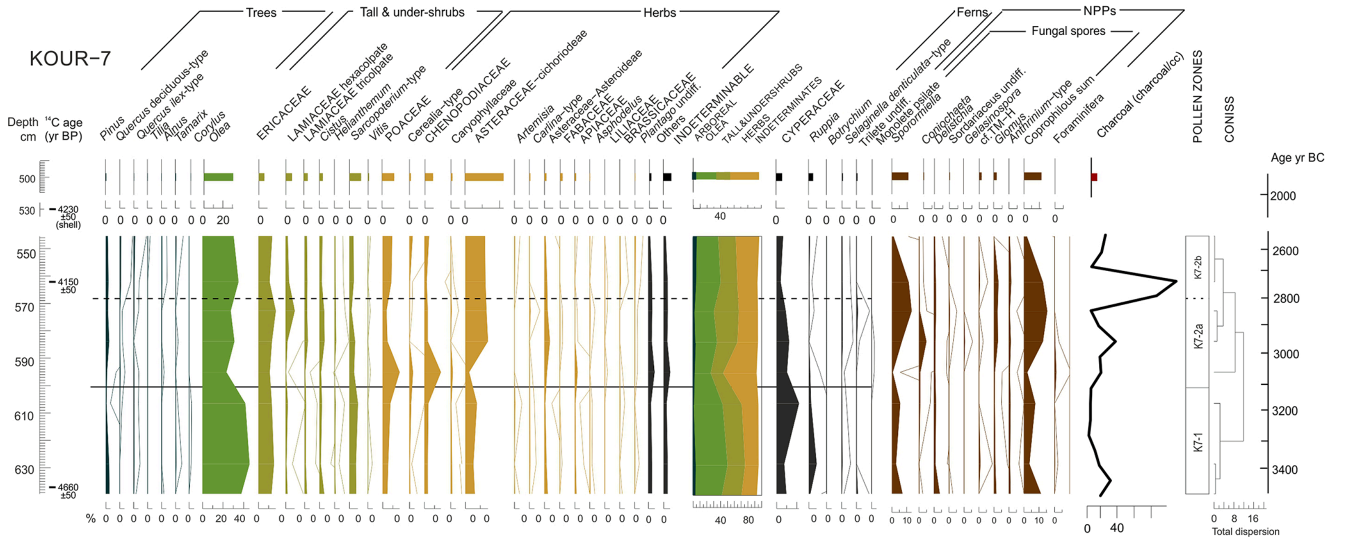

Fig. 4. Pollen, NPP and microcharcoal particles diagram of the Kouremenos-7 core. AMS^{14}C radiocarbon dates are indicated on the left of the diagram and calibrated dates on the right.

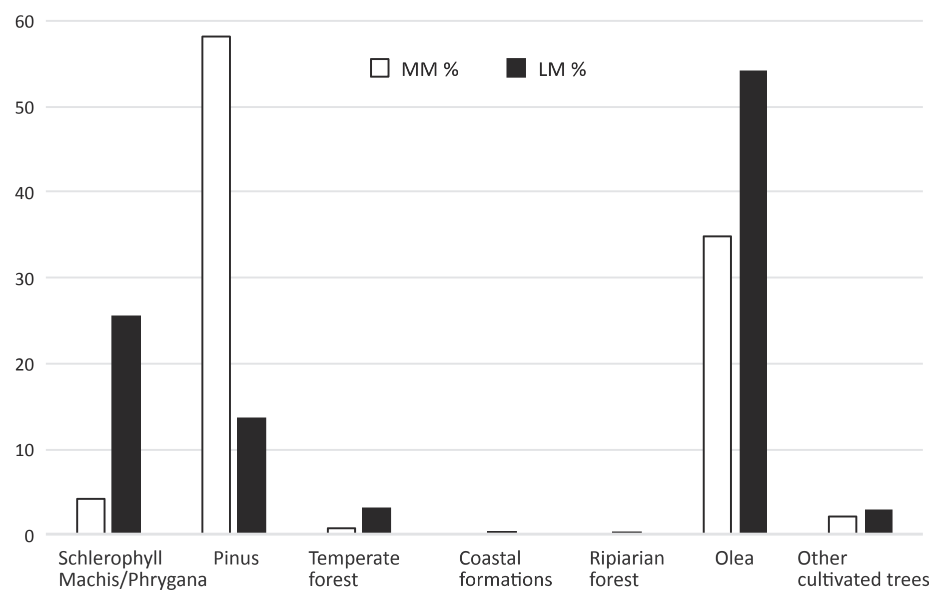

Fig. 5. The MM (Middle Minoan) and LM (Late Minoan) vegetation types according to the PALAP charcoal data (see Table 4).

during systematic flotation, which maximises recovery, accounts only for 6% of all bones from flotation samples, a percentage not much higher than that of the respective hand-collected material. Comparison of the Palaikastro mortality profile with that of BA Palatial Knossos (Isaakidou, 2006), which is the richest comparative source in Crete, indicates a very high degree of similarity between the two. This BA Knossos profile, most material for which derives from the 'public/elite core', although within the general 'meat model', shows a consistently much older kill-off (the age of the animal at the time of killing) pattern and a more balanced ratio of male/female adults compared to that of the previous, Neolithic Knossos 'meat model' profile (ibid.). This has been interpreted as compatible with Linear B evidence for an emphasis on wool production in the BA period (Isaakidou, 2006, 100–103). It should be also noted that if the animals/meat were brought to Palaikastro from the territory it is possible that they were specifically selected for meat consumption to cover the town's needs, and this does not necessarily reflect the management strategy and primary production aims of the town's territory.

Apart from staple crops and meat from domestic animals, the inhabitants of Palaikastro had access to a variety of other terrestrial resources. Possibly some land snails (Veropoulidou, in prep., Reese, 2019), and a variety of fruits and nuts was available, with olive, almond, fig, and grape brought to and consumed at the site (Table 2, see also Sarpaki, 1989, 2007, 2019, and below). Charcoal and pollen data also point to the availability of ecological niches and habitats that the townsfolk had access to and/or showed preference for the exploitation of their resources. The MM palaeoenvironmental data indicate a largely agropastoral, generally open and little forested landscape with grasslands, and mostly olive trees (Fig. 4, and see below). The MM and LM charcoal data (Table 4) support this picture of open, low vegetation habitats, according to the presence of a variety of sclerophyllous and heliophyllous shrubs (e.g. Cistaceae, *Erica* sp., Fabaceae, Lamiaceae, *Pistacia* sp.). Similar to the paleoenvironmental data, they also indicate the availability, in addition to olive, of pine and to a lesser extent of temperate trees (e.g. *Quercus* sp.) and potentially cultivated taxa (fig, grape and *Prunus*) (Table 4, Fig. 5), the latter being also supported by the seed evidence (Table 2). Given the available habitats, it is therefore likely that an additional variety of herbs, condiments and greens from the *maquis*/phrygana formations, grasslands, shrublands and possibly, to a lesser degree, from temperate forests (Fig. 5) would have been collected. Their archaeological absence is probably due to the preservation biases that these types of plants suffer (see e.g. Willerding, 1991; Wright, 2003; Moody, 2012, 21-22; Livarda and Kotzamani, 2013).

Evidence of wild animals that would potentially be available in these environments are very few at Palaikastro, including hare (one third phalanx), roe (one distal metacarpal) and fallow (two first phalanges) deer. The latter has been also recorded from a possible MM occupation surface at another part of the town, in Building 1 (two mandibles, one metacarpal and one metatarsal, Wall-Crowther, 2019). The few elements present are bones from extremities and not meaty parts, and therefore, it is possible that these were introduced to the town as skin, providing no secure evidence on wild animal consumption. Fallow deer bones (not only from extremities but also from meaty parts of the skeleton) have been identified at Neopalatial Knossos and it has been argued that this species of deer was present either in the wild or penned and managed on the island at least from this period onwards (Isaakidou, 2005, 297–8; Isaakidou, 2007, 16). This deer is well adapted to open habitats, such as open grasslands and open wood (Ferretti et al., 2011, 776), which were present across the broader territory of the ancient town at Palaikastro according to both the pollen (MM, Fig. 4) and the charcoal (LM, Table 4) data. Its local presence is thus a possibility although its very low representation by extremities may point rather to importation of these parts. The overall evidence, therefore, indicates a largely ‘domesticated’ and well organised, strongly (agro)pastoral landscape where access to and use of unmanaged, wild land resources seem to have played a secondary role, which is consistent with the evidence of earlier (Halstead, 2008, 237) but also contemporary (Moody, 2012, 243-4) periods in Crete suggesting a lesser contribution of wild resources to the diet (with the possible exception of parts of BA western Crete; Moody, 2012, 245).

This is not the case, however, for the sea and coastal resources. The marine shell (Table 5) and fish (Table 6) data suggest that, at least the former, had an important role in the lifeways of the town. Marine molluscs were ubiquitous across the site, with a very similar picture between the PALAP and the rest of the town assemblage (Reese, 2019 and references therein), indicating regular use of coastal resources. Sea molluscs and crabs were collected for food from easily accessible points, from the splash zone up to a few meters in depth, as indicated by the ecology of the taxa recovered (Table 5). Notably, there was some degree of selectivity in the choice of mollusk collection for food, as limpets (*Patella* spp.) and top-shells (*Phorcus turbinatus*) dominated the assemblage (Table 5, note that *Hexaplex trunculus* although edible, was used chiefly for purple dye production, Veropoulidou, in prep.), these being also among the most common species found in BA Crete (Moody, 2012, 256; Veropoulidou, 2012). Measurement of intact top-shells and limpets showed that people gathered mostly small specimens, with larger specimens that would have more flesh for consumption being very rare in the assemblage, thus suggesting collection of what was available at the rocks. The lack of measurement data for these species from other areas of Palaikastro does not allow a full appreciation of these results, but the generally small size of the PALAP assemblage indicates stress, either due to poor environmental conditions or overexploitation of these particular resources. Fish remains were relatively few and of a similar, although rather more restricted, range across the rest of the excavated (and sampled) town (Mylona, 2019). The fish accessed (Table 6) were mostly species living on rocky, sandy or algae bottoms, or in rock cavities; they were principally of small size and were caught near the shore. This assemblage is comparable to those from other BA sites on the island, such as Kommos (Rose, 1995), Mochlos (Mylona, 2004, 2016), Pseira (Rose, 1996), and Chryssi (Mylona 2020) where the dominant fish were small in size, mainly picarel and Sparidae (see also Moody, 2012, 24). The fish assemblages in all these sites, including Palaikastro, point to coastal fishing with the aid of nets or cast nets, hooks and lines for the bigger fish, as well as possibly harpoons for certain fish (Rose, 1994; Powell, 1996; Rose, 1995; Mylona, 2016). Overall, the marine bioarchaeological data at Palaikastro demonstrate regular exploitation of coastal resources from easily accessible areas. These seem to have been culturally determined, as similar types of species were found across many BA sites, while in the case of shells, despite the apparent stress, there seems to have been continuation of established food choices and gathering practices.

4.2. Grape

The pollen data from Kouremenos place the appearance of *Vitis* in the area towards the end of the Late Neolithic and suggest a possible higher engagement with this crop (viticulture) since the EM I late phase when more continuous pollen occurrence is registered (Cañellas-Boltà et al., 2018). In this context, vine seems to be one of the crops with some tradition in the area of Palaikastro. Macrobotanical evidence of *Vitis* found on site help identify the uses of the plant during later periods. Almost all finds were dated to the LM and only few to the MM period (Tables 2 and 4), although this must be also influenced by the much fewer MM deposits excavated. Grape pips and some possible fruit fragments were found across the area at Palaikastro excavated during the PALAP project, while grape pips were also recurrent finds in all other excavated and sampled parts of the town (Sarpaki, 2007, 2019). Grapes were certainly eaten across the town, as their remnants were found in association with those of other food plants. Charcoal fragments of *Vitis* were low both in quantity (Table 4) and ubiquity (occurrences in number of samples, Picornell-Gelabert, in prep), indicating a rather limited or occasional use of its wood as fuel in the town.

Primary archaeobotanical evidence for grape juice extraction was not found at Palaikastro, but there are some indirect indications that may point to its production. In particular, in Room 42 of Block M, an installation, including “*a plaster lined, low-walled tank, a large shallow ceramic basin with a large spout and a pithos*”, dated to the MM III period was identified as used for wine-making (Knappett and Cunningham, 2012, 65–67), and an LM structure described as wine press and an associated pithos were found in Room 29 of Block E (Bosanquet et al., 1902/1903, 295). More installations, whose use was originally related to oil production or was unclear but were later re-classified for wine-making (Platon and Kopaka, 1993), have been found elsewhere at Palaikastro, such as in Blocks B, Γ (Bosanquet et al., 1902/1903, 279), House N (Sackett et al., 1965, 264), and in Room 1 of Building 2 (MacGillivray et al., 1987, 151). On the basis of these finds/interpretations a number of houses were likely involved in wine-making and/or other activities involving grape juice processing across the town. For instance, the condensed must could have been used as a sweetener and in sweet making (Valamoti et al., 2007), while vinegar could have been used in food technologies, for example as preservation agent and condiment (Sarpaki, 2012b). Different uses, however, are not mutually exclusive of one another and indeed drinking practices, including possibly of wine, is apparent in the BA lifeways of the town. Decorated piriform jars and kraters, most probably linked with wine consumption, were found across the LM town (LM IB and LM III), as for example in Buildings 4, 5 and 7 (Langohr, 2019). In addition, copious amounts of conical and other cups and various other drinking and pouring vessels were unearthed during the PALAP excavations (Knappett et al., in prep.) as well as across the rest of the excavated town, often stored in stacks close to entrances and open areas, as in Building M (Knappett and Cunningham, 2012, 319–320). These ceramic vessels, however, should be treated with caution as their contents could include any sort of liquid, from water to other alcoholic drinks (Livarda and Kotzamani, 2013; see also Valamoti, 2018 for the coexistence of beer and wine in the prehistoric Aegean).

Primary archaeobotanical evidence for wine or rather grape juice making are rarely preserved in archaeological contexts, but some (e.g. remnants of the must) does exist elsewhere in Crete, at Prepalatial (EM

IIB) Myrtos Fournou Korifi (Renfrew, 1972b) and Protopalatial Monastiraki (Fiorentino and Solinas, 2006; Sarpaki and Kanta, 2011; Sarpaki, 2012b). About 30 EM to LM treading installations were also recorded across the island, rather small in size, and none in palaces (Sarpaki, 2012b; Platon and Kopaka, 1993). Organic residue analysis from pottery has also been conducted and identified possible wine (but see, Sarpaki 2012a) at sites such as Aphrodite's Kephali (Koh and Betancourt, 2010) and Pseira (Beck et al., 2008a, 72), both in east Crete. More plentiful is the written evidence for wine. According to Palmer (2005, 282) the Cretan Hieroglyphic form of the wine ideogram is present on sealstones and clay texts, while its later form also appears on both Linear A (across various sites in Crete) and Linear B (Knossos) written on tablets, ceramic vases (only Linear A) or sealings (only Linear B). The wine ideogram in Crete is particularly frequent in three centres, including Zakros, the broader region of which seems to be a 'major' exporter of wine following the combination of the presence of the particular version of the Zakros ideogram found elsewhere in the Cyclades by LM IB and the various townhouses and a villa in its territory containing installations interpreted as for wine making (Palmer, 2005, 283). Significantly, another variant of the wine ideogram present on both Linear A and B tablets has been interpreted as representing either must or more likely vinegar (ibid., 284), which highlights the importance of other by-products of grape juice. Written evidence is lacking from Palaikastro, but what our data seem to indicate at the very least is that viticulture was taking place in this area too already in the EM period and that grape fruits, and in all likelihood wine and other grape juice derivatives were used and consumed in the town by the LM period. These data, considering also the proximity and very similar landscape of Palaikastro and Zakros, thus suggest a possible broader involvement of the area of eastern Crete in vine management and related (by-)products production, although the scale of these activities within the Palaikastro territory cannot be fully assessed on current evidence. Additionally, the overall data, although not conclusive, seem to agree with Christakis' (2008, 31) argument against an elite restriction of wine (cf. Hamilakis 1996), hinting instead to its wider use in BA (at least east) Crete.

4.3. Olive

The two cores obtained from the Kouremenos bay, in close proximity to the BA town at Palaikastro (Fig. 1), indicate that since 4300 cal BC the area was characterised by shrubland vegetation in a generally open landscape where olive was already present (see Cañellas-Boltà et al., 2018). The appearance of the olive in east Crete can be thus now securely pushed back to at least the end of the 5th millennium BC. Some pastoral activities were already taking place in this phase whereas agricultural activities were first identified somewhat later at 3900 cal yr BC (ibid.). The Final Neolithic (FN), from 3600 cal BC onwards, saw significant changes with a considerable expansion of the olive, reaching values of >30% and 40% (ibid., Fig. 4) that are higher than the modern-day surface samples (in which olive reached 22–34%) recording modern agricultural practices whereby olive is the main crop in the area (ibid.). These results, considering also that there was no parallel expansion of other sclerophyllous trees that could point to environmental influences (see also Langgut et al., 2019), can be justified by human management as early as the Neolithic, placing eastern Crete among the earliest areas of specialised olive management in the island (Cañellas-Boltà et al., 2018). Olive was also present in the 5th millennium BC in paleoenvironmental registers from western and northwestern Crete. In the Delphinos core it appears around 6200 BP, at about the same time as at Palaikastro, but its expansion is coeval with that of oak (Bottema and Sarpaki, 2003), possibly suggesting the influence of climatic factors. The Tersana core positions the appearance of the tree earlier at *ca*. 4750 BCE, a period for which we have no palaeoenvironmental data from Palaikastro, peaking at 15% towards the LN/FN, which was interpreted as cultivation of the tree in the area (Moody et al., 1996; but note that fine resolution dating was not available for this register). However, the *Olea* percentages at Palaikastro are higher than those recorded in the western part of the island, and although this could be partly due to the drier conditions in the east favouring the expansion of the tree, it is possible that they point to an early area of specialisation in the eastern part of the island (Cañellas-Boltà et al., 2018).

These data alter what we knew until recently about the use and management of olive, at least for this part of the Aegean. Valamoti et al. (2018), for instance, reviewing olive charcoal and fruit stones across the Aegean, suggested the introduction of olive at the end of the Neolithic period in the south Aegean (mainly islands) where, they argue, it was used at a low level or more likely growing in small numbers. Our study at Palaikastro does not align with these results, providing the first palaeoenvironmental data with good dating resolution from this part of the Aegean showing an early intensive or specialised management of the tree. Given that a substantial amount of time is necessary for the establishment of extensive olive groves (Blitzer, 1993, 171), an earlier date of more dedicated and wider use of the tree in the Palaikastro area is also likely, highlighting the significance of east Crete in the dissemination of the use of the tree and its products across (and possibly beyond) the Aegean.

The trend of intensive presence of olive in the Palaikastro area continued into the BA. According to the palaeoenvironmental registers, during the Early Minoan (EM) period the landscape was open and degraded, dominated by olive trees and grasslands, with the former reaching values of 40–45% (Fig. 4; Cañellas-Boltà et al., 2018). The greater expansion of the olive may point to further intensification of its use in the socio-economic context of the area that seems to go hand in hand with animal keeping and grazing activities, as indicated by the increase of Cichorioideae pollen and NPP (Fig. 4, ibid.). For the MM period there is only one radiocarbon dated sample at 500 cm depth of the Kouremenos-7 core (Fig. 4) that corresponds to the late Prepalatial period (MM IA). Although there is no continuous record, this sample provides valuable insights into the period, confirming that by 2000 cal BC the landscape had undergone relatively minor changes. Olive crops continued to occupy extensive areas (recording pollen values of 30%), but there were changes in the configuration of shrub communities, mainly expansion of phryganic vegetation, indicated by high values of Sarcopoterium-type and Lamiaceae pollen (Fig. 4). This vegetal landscape degradation could have been related to an increase in grazing pressure, suggested by the rise of Cichorioideae pollen and coprophilous fungal spores that coincided with a reduction in cereal crops (Fig. 4). Such increased grazing pressures could have been the result of ovicaprine flock management specialisation, as observed in the landscape study for the MM (and the LM) period, with support from the zooarchaeological data for the LM period.

The importance of olive in the area in the MM and LM phases is also reflected by finds in the town, although the MM evidence is only tentative. The two dominant taxa of the charcoal assemblage were olive and pine. The values of the latter were relatively high during the MM period but much lower (14%) than those of the olive (60%) in the LM period (Table 4, Fig. 5). Pine could have potentially grown locally (interior, coastline) but the very low pollen values (Fig. 4, Cañellas-Boltà et al., 2018) of this high quantity-pollen producer tree possibly suggest the non-local origin of the wood or at least that the tree was not present at the littoral area near the town (up to at least the MM period). The next most important charcoal group was that of the schlerophyllous and heliophylous shrubs (Table 4, Fig. 5) that grow in *maquis*/phrygana formations, and are indicative of a generally open landscape, matching the results of an intensively managed landscape possibly for pastoral activities in the town's territory. Olive stone finds also dominate the archaeobotanical assemblage of both periods both in absolute numbers (Table 2) and ubiquity (Livarda in prep.), suggesting its widespread presence in the lifeways of the town. A comparison of the contexts containing olive stones and charcoal fragments shows that these do not always coincide and that the stones in more than half of the cases were associated with other food plants. Therefore, olive stones may have been introduced at the site along with but also separately from tree branches.

Combining the available evidence indicates a possible link between olive management and extensive pastoralism within Palaikastro's territory. Olive would have been well adapted to the LN to EM local open and largely deforested environment while its palatability to animals could have led to the mutually beneficial expansion of the two activities. Later, extensive pastoralism and its associated grazing activities may have been an important cause, or one of the causes, leading to the increased pressure on the landscape that is reflected on the MM and LM landscape survey data in the interior part of the town's territory (Orengo and Knappett, 2018) and the potential increased slope erosion rates recorded in the palaeoenvironmental cores according to preliminary geoarchaeological study (Veropoulidou, in prep.; Veropoulidou et al., in prep.). In this context and in the seemingly largely forest-free landscape of Palaikastro, the role of the olive would be particularly important in providing fuel and feed for the substantial animal flocks, while potentially also alleviating in part the impact of erosion (e.g. with its roots holding the soil in place and its foliage reducing the impact of wind and rain).

The potential specialisation of the area in olive management, as suggested by the particularly high percentages of olive pollen recorded for the FN, EM and MM periods and of olive charcoal and stones for the MM and LM periods, however, may further point to an increasingly significant role of the tree in the economy that eventually went beyond pastoral or environmental related needs. Certain olive products/by-products may have been commodified to enter different socio-economic networks. Whether olive oil, for instance, was produced is difficult to fathom for the Neolithic and EM period due to the lack of associated settlement data or enough deposits respectively, a situation that to some extent mirrors a large part of Crete. Direct evidence of olive oil in Crete in these periods is scarce. The earliest indication comes from the organic residue analysis from a bowl found at the Gerani cave in the west of the island, which is dated to *ca.* 4500–3800 BCE, but the evidence is tentative as the C9 fatty acid that was claimed to be indicative of olive oil is also present in other vegetable oils (Martlew, 1999, 80; Beck et al., 2008, 33). Organic residue analysis from two closed vessels from the EM I site of Aphrodite's Kephali on the east of the island also showed the presence of oleic acid that could potentially indicate olive oil (Koh and Betancourt, 2010). Neolithic olive stones and charcoal data for Crete are still too few to provide a fuller picture of the Neolithic use of olive products, as only three sites have been sampled/published to date, two of which include olive stones and one charcoal, while one of these has no available data on the presence/absence of the latter (Valamoti et al., 2018).

Ethnographic work has shown that olive management is done normally either a) by grafting wild trees in their original *maquis* environment with more limited yields, or b) by transplanting the trees on new clearings that results in higher yields (Blitzer, 1993; Halstead, 2014, 265). The latter, however, is a very lengthy process that requires substantial time and resource investment, is in competition with subsistence agriculture at least initially, and takes several generations to be established and lead to surplus of olives and olive oil (Blitzer, 1993). Olive is also a much riskier subsistence crop compared to annual crops (Halstead, 2004, 192–193). Therefore, management of the tree specifically towards olive oil surplus production would have required considerable incentives. The Neolithic and EM certainly lacked the social stratification observed in the later palatial structures of the BA southern Aegean that would give incentives for intensification of olive oil production as suggested by Hamilakis (1996, 1999). The expansion of trade contacts within and beyond the island in the later phases of the EM period (Wilson, 2008, 89–94) may have provided some alternative potential incentives but we lack ground evidence to test this hypothesis.

The LM data allow better insights into potential olive oil production. Olives at the PALAP excavation were found mostly in the form of stone fragments with only 23% of individual specimens occurring as complete stones. Examination of these fragments indicated that the vast majority exhibited rounded fractured faces, with an overall smooth and dull appearance, characteristics that have been taken to indicate their crushing for production of olive oil prior to charring (e.g. Neef, 1990; Margaritis and Jones, 2008), although post-depositional processes may have also played a role resulting in the same morphology (Braadbaart et al., 2016). If olives were used only as food in the town, however, they would not need to come into contact with fire prior to consumption and thus their charring could be an after-disposal result, in which case a higher proportion of complete stones would be expected. In addition, fragmentation of the olive stones cannot be solely attributed to the environment of deposition as, for instance, comparison with cereal grains indicates that only a small proportion of the latter were fragmented (63% of barley and 88% of wheat were complete grains, although the latter occurred in very low numbers, Livarda in prep.). Considering also the ubiquity of charred fragments of olive stones across the whole site an argument may be put forward for the potential use of olive oil processing residue as fuel. Further support for the hypothesis of olive oil production is provided by a number of structures unearthed across the town in previous excavations that have been interpreted as related to this activity, such as in Block X, and at houses D and A at Kouremenos (Bosanquet et al., 1902–1903, 331–334; Dawkins et al., 1904–1905, 276–277; Platon and Kopaka, 1993).

These data do not allow any estimation of the scale of the possible olive oil production but fit very well with the suggestion that intensive olive oil production was evidenced in the LM period in the southern Aegean (Valamoti et al., 2018). In Crete, installations related to olive oil production, such as spouted press-beds, become more visible in the MM and LM periods (Blitzer, 1993), olive oil production residues are first recorded archaeobotanically in the MM period (Sarpaki, 1999; Livarda and Kotzamani, 2013), and olive and olive oil are also mentioned in Linear A tablets (Blitzer, 1993; Pratt, under review). It is also in the Neopalatial period when a new bulk liquid transport container was created in Crete possibly for long-distance exchanges, the stirrup jar, which has been traditionally linked to olive oil, and found, among other places, at Palaikastro (Pratt, 2016, under review; see also e.g. Beck et al., 2008 for organic residue analyses in this type of container). In this context, considering all the evidence together and given that the management of the tree in the area had a long tradition (see also Langgut et al., 2019 on higher yield benefits and economic efficiency when reusing the same orchards), production of olive-oil in the area becomes a strong possibility. A corollary of its production would have been the availability of another fuel source, the residue left by its production, as tentatively suggested by the Palaikastro archaeobotanical remains. This fuel would be particularly valuable, adding extra incentives for this activity, due to both the scarcity of forest wood in the area that could have continued to the later periods (Figs. 4 and 5; Cañellas-Boltà et al., 2018), and the advantages that it has over wood, requiring smaller quantity to produce the same heat yield, being less bulky to transport, and producing a hotter and smoke free fire that is particularly suited for cooking indoors (Braadbaart et al., 2016).

5. Conclusions

Our interdisciplinary approach to the study of the land and sea resource management and related economic activities in the east of Crete indicates that we can no longer simplify and distinguish between a Neolithic and Bronze Age economy as 'cereals-pulses-stock *versus* olive-cereals-vine', first suggested by Renfrew back in the 1970s. Although each and every component was present in the economy of both periods, these seem to have played different roles according to the particularities of different societies. In east Crete, and specifically at Palaikastro and its territory, ovicaprine management and olive growing seem to have been of particular importance, being practiced to a scale that on current evidence seems larger compared to other areas further to the west in the island. Both activities seem to have had a long tradition that helped shape the fortunes of the town. A complex and organised landscape with complementary land uses and activities was already in place during the FN, which by the MM and until the LM period seems to have been managed by multiple farmsteads focusing on maximizing its potential. Resource exploitation at least from the MM period onwards appears to have been taking place in a largely 'domesticated' landscape with very little evidence for the exploitation of wild animal resources. Cereal and pulse cultivation, orchard production, fishing and shell gathering for food seem to have had a relatively more restricted role within the town's economy aiming to cover subsistence needs. Viticulture was identified as another possible early activity, rooted in the history of the area, in which a number of households across the town seem to have been involved either directly or indirectly (in the processing of its products/by-products).

This research has also shed new light on the much-debated management intensification of olive and its by-products. Intensive olive management, at least in this part of the Aegean, was neither an Early Bronze Age phenomenon (Renfrew, 1972a), nor a Late Bronze Age one (e.g. Hansen, 1988; Hamilakis, 1996, 1999). Our data, instead, strongly point to a much earlier, (at least) Final Neolithic beginning of its large-scale, intensive exploitation in the east of Crete that continued, if not intensified, in the EM period and possibly later. These results are consistent with those by Langgut et al. (2019) who see olive horticulture in the east Mediterranean as an earlier phenomenon that was only secondarily related to urbanisation and state formation. The olive expansion in the area of Palaikastro was very likely linked to animal (ovicaprine) management. The two activities seem to have been co-evolving since the first available evidence dated to the LN, with olive providing fodder, but also fuel and possibly some ecological support to the environment. Actual evidence for olive oil production in this earlier phase are not available. During the MM and LM periods olive cultivation and olive oil production in the area is a strong possibility, given also its long tradition of olive management, and may have been part of another wave of olive management intensification in the framework of new socio-economic settings and the emerging social complexity. In this context, the demand for olive oil production does not seem to have been the driving force behind the initial tree expansion and management (in contrast to Renfrew, 1972a; Hansen, 1988; Hamilakis, 1996, 1999; Valamoti et al., 2018) but a corollary of its use in other aspects of the local economy potentially already in the Neolithic.

To conclude, all activities for which enough evidence was available seem to have been rooted in the history of the town and its territory, suggesting that whatever the role of the town at Palaikastro within the island economy and beyond, this was based on an already existing specialisation of local resources that was long in place. In this sense, local specialisation alone, in this case of olive, does not seem to be *the reason* for the emergence of hierarchical societies, a conclusion also reached by Valamoti (2017, p.178) on wine production in the Aegean. What our study suggests is that a more fruitful way of understanding the Neolithic and BA economy and the emergence of hierarchical societies is to revaluate local economies, their individual histories and trajectories, and eventually how these functioned within the network of connections of each period within and beyond the island. In doing so, interdisciplinary research that fully integrates different lines of on-site and off-site evidence since the design stage of a project can become a powerful tool allowing a holistic picture of past lifeways.

CRediT authorship contribution statement

Alexandra Livarda: Conceptualization, Methodology, Formal analysis, Investigation, Supervision, Project administration. **Hector A. Orengo:** Conceptualization, Methodology, Formal analysis, Investigation, Visualization, Supervision. **Nuria Cañellas-Boltà:** Methodology, Formal analysis, Investigation, Visualization. **Santiago Riera-Mora:** Methodology, Formal analysis, Investigation, Supervision. **Llorenç Picornell-Gelabert:** Methodology, Formal analysis, Investigation, Visualization. **Vasiliki Tzevelekidi:** Methodology, Formal analysis, Investigation, Visualization. **Rena Veropoulidou:** Methodology, Formal analysis, Investigation. **Ricard Marlasca Martín:** Methodology, Formal analysis, Investigation. **Athanasia Krahtopoulou:** Methodology, Formal analysis, Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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