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One sea but many routes to Sail. The early maritime dispersal of Neolithic crops from the Aegean to the western Mediterranean

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ABSTRACT

This paper explores the first maritime westward expansion of crops across the Adriatic and the northern coast of the western Mediterranean. Starting in Greece at *c*.6500 cal BC and following the coastline to the Andalusian region of Spain to *c*.4500 cal BC, the presence of the main cereal, pulse, oil and fibre crops are recorded from 122 sites. Patterns in the distribution of crops are explored through ubiquity scores, correspondence analysis and Simpson's diversity index. Our findings reveal changes in the frequencies of crops as farming regimes developed in Europe, and show how different crops followed unique trajectories. Fluctuations in the diversity of the crop spectrum between defined areas are also evident, and may serve to illustrate how founder effects can explain some of the patterns evident in large-scale spatio-temporal evaluations. Within the broader westward expansion of farming, regionalism and multi-directional maritime networks described through archaeological materials are also visible in the botanical records.

1. Introduction

The first dispersal of Neolithic farmers into Europe took place along two main routes: inland through Bulgaria, Macedonia and the western Balkans, and seaward following the coastlines of the Adriatic and Mediterranean (e.g. Bocquet-Appel et al., 2009). The migration of the Neolithic was not a uniform or linear progression but consisted of an advance interrupted by variable pauses of settling and adaptations (Guilaine, 2001, 2013). After reaching the Aegean the spread of farming stopped for *c*.500 years, apparently during a period of Rapid Climate Change (RCC: 6550–6050 cal. BC, Krauss et al., 2017). It has been highlighted that the resumed expansion coincided with the end of the 8.2Ka cooling event, after which a climate more favourable to the cultivation of Neolithic crops is thought to have prevailed (Berger & Guilaine, 2009; Krauss et al., 2017: 2; Pilaar Birch & Vander Linden, 2018: 186). Without falling into a dogmatic climatic determinism, it seems clear that climate was one of the many variables influencing the spread of farming. Both Adriatic coastlines were colonized simultaneously (Biagi et al., 2005; Bocquet-Appel et al., 2009, 2012; Forenbaher and Perhoč, 2015; Mazzucco et al., 2017; McClure et al., 2014), initially by pioneer seafarers who led the way for larger, more permanently settled communities (Forenbaher and Miracle, 2005; Forenbaher et al., 2013). The advance into the Mediterranean also happened as a 'leap-frog colonization' (Guilaine, 2017; Zilhão, 2001), though it is calculated to have occurred at a faster rate (Henderson et al., 2014: 1297). Westerly sites dated to the early sixth millennium BC, such as Arene Candide in Liguria (Italy), Pont-de-Roque Haute and Peiro Seignado in the South of France and Mas D'Is near Valencia (Spain), are testimony to the rapid advance of the Neolithic (Manen et al., 2018a; Garciá-Puchol et al., 2017). Radiocarbon dates and material culture speak of varied temporalities, regionalism and numerous multi-directional maritime excursions through which connections with established settlements were maintained as new coastal areas were settled (Guilaine, 2017, 2018; Manen et al., 2018a, 2018b; Rigaud et al., 2018).

The Neolithic is recognised through its 'package', consisting of plants and animals domesticated in the Near East, along with particular architectural, tool and ceramic styles and technologies. However, research has shown that whilst the Neolithic 'package' contained all the necessary ingredients for a farming lifestyle, the neolithisation of

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Europe is better understood through its related yet diverse packages (Guilaine, 2003, 2013, 2018; Manen et al., 2018b; Rigaud et al., 2018; Thomas, 2003; Vander Linden, 2011). Spatio-temporal variations in the plant and animal diets are evident during the neolithisation of Europe, as packages are seen to change, not only with the spread of farming, but also *in situ* through time as pioneer communities became firmly established (e.g. Antolín et al., 2015; Colledge et al., 2005; Conolly et al., 2011; Fiorentino et al., 2013; Gaastra et al., 2019; Manning et al., 2013; Orton et al., 2016; Rottoli and Castiglioni, 2009; Zapata et al., 2004). The pioneer Neolithic colonisation of new areas saw a reduction in the range of crops utilized, before additional crops were, in some areas, re-introduced to the original Near Eastern 'package' (Coward et al., 2008; Colledge and Conolly, 2007a,b; Colledge et al., 2004; de Vareilles, unpublished; McClatchie et al., 2014). Explanations for changes in the suite of cultivated crops, as well as in the importance of particular crop species have been sought through social or cultural forces, and natural adaptations to changing ecological and climatic environments (e.g. Bogaard and Halstead, 2015; Colledge et al., 2005; Gaastra et al., 2019; Krauss et al., 2017; Kreuz et al., 2014; Peña-Chocarro et al., 2018; Whitford, 2018). Other explanations include the effects of different modes of inheritance, such as neutral drift (change resulting from the random copying of certain traits over others, and innovations – Hahn and Bentley, 2003) and homophily (whereby successful interactions between similar people are more likely than between dissimilar people – McPherson et al., 2001: 416), both of which may have resulted in reducing crop diversity during the first neolithisation (Drost and Vander Linden 2018; Pérez-Losada and Fort, 2011; though see Conolly et al., 2008 for negligible effects of drift).

In this article we explore changes in the crop spectrum during the first westward maritime spread across the Adriatic and Mediterranean. Starting at *c*.6500 BCE in Greece, we looked for the archaeobotanical traces of the first farmers to colonize the Adriatic and the north-western Mediterranean. Previous studies have focused on specific areas of the Neolithic Adriatic (e.g. Fiorentino et al., 2013; Reed, 2015; Rottoli and Castiglioni, 2009) and European Mediterranean (e.g. Antolín and Buxó, 2012; Antolín and Jacomet, 2015; Antolín et al., 2015; Bouby et al., 2016; Peña-Chocarro et al., 2018; Zapata et al., 2004), or included coastal zones with inland trajectories for continental-scale analyses (Colledge et al., 2005; Coward et al., 2008). However, it has been demonstrated that the crops cultivated along the maritime and inland routes of the European neolithisation developed independently (Gaastra et al., 2019), and whilst inland developments between SE Europe and the Linearbandkeramik are relatively well understood (Colledge and Conolly, 2007a; Colledge et al., 2005; de Vareilles, unpublished; Krauss et al., 2017; Kreuz et al., 2005), little has been done to investigate the European maritime route (though see Bogaard and Halstead, 2015; Pérez-Jordá et al., 2017). The present study hopes to redress this imbalance by pooling archaeobotanical data from Early Neolithic settlements pertaining to the European maritime route, offering the first statistical approach to describe and interpret developments in the crop spectrum.

2. Methodology

One hundred and twenty-two sites from the Aegean to the coast of Málaga, Spain (up to Cueva del Toro at −4.5423 longitude) are included in this research (Table 3). Every effort was made to locate original archaeobotanical reports, although many, particularly from Italy, are not widely published. However, the regional reviews used (referenced in Table 1) are internationally accepted and care was taken to source any re-evaluations of site dates and details. Sites were chosen according to a strict chronological framework to represent the very first European westward maritime dispersal of cultivated crops (Fig. 1). The four phases are divided into 500 year brackets, starting at *c*.6500 cal BC, and Phases 1 to 3 roughly correspond to renewed colonizations of coastal areas and the developments of new ceramic expressions (Table 1). Phases 3 and 4 along the western northern Mediterranean are less distinct, representing both pioneer settlements of coastal zones and the second phase of habitation in others (sites 96, 99, 102, 104 and 117). Although sites in Italy that clearly post-date the sixth millennium BC are not included, 13 have broad chronological brackets that span both Phases 3 and 4 (sites 53 to 55 and 57 to 66). The same is true of three French sites (sites 74, 75 and 76). Finds from the site of Balma Margineda (Andorra) are not included because AMS dates obtained from plant remains, all found within a single context, span across the sixth and fifth millennium BC (Manen et al., 2018a) and our Phases 2 to 4. However, a naked barley grain was dated to 5665–5555 cal BC (95.4%) and is included in barley finds of Phase 2 (Fig. 5). Sites were assigned to a phase following relevant radiocarbon dates where available or cultural attribution as defined in Table 1.

The dataset comprises of 122 site/phases with records of domesticated crops. The crops included in this study are the main cereals and pulses cultivated during the Early Neolithic (Table 2). Opium poppy and flax are also included to document possible early findings. Records of spelt (*Triticum spelta*) and broomcorn millet (*Panicum milliaceum*) are excluded from this study. Low concentrations of spelt suggestive of its presence as a crop contaminant are noted for the Early Neolithic (e.g. Huntley, 1996; Kreuz, 1990; Marinval, 2003b; Sargent, 1987), while the first clear evidence of domestic spelt dates to the Bell Beaker period (Akeret, 2005). Dated millet seeds from Neolithic contexts tend to belong to much later periods, even if the occasional seed (perhaps a weed) is found to be of Neolithic date (Hunt et al., 2008; Motuzaite-Matuzeviciute et al., 2013). Indeed, millet cultivation in Europe is unlikely to pre-date the Bronze Age (e.g. Filipović and Obradović, 2013: 42-3; Reed, 2015: 612; Stevens et al., 2016: 1545; Tafuri et al., 2018; Valamoti, 2013).

The recording and publication of archaeobotanical remains from the research area varies greatly, from publications with contextualised and/or quantified data (e.g. Antolín, 2016; Buxó, 1997; Pérez-Jordá and Peña-Chocarro, 2013; Reed and Colledge, 2016; Valamoti, 2011), to mere lists of taxa by site (e.g. Fiorentino et al., 2013; Marijanović, 2009; Renfrew, 1979; Rottoli and Castiglioni, 2009). Preservation also varies; whilst most sites reported carbonised remains, 13 only had data from impressions in ceramics and/or plaster/daub, and waterlogged plant remains were retrieved from La Draga and La Marmotta (Table 3). In order to overcome such disparities, findings were reduced to presence/absence of taxa by site/phase as the common means of quantification. Plant parts (e.g grain or chaff), archaeological contexts and quantities (absolute or relative) were not considered, such that a rise in a ubiquity score does not necessarily translate to an increase in the absolute number of a taxon. There are a growing number of successful uses of such parsimonious data (ubiquity by site/phase) to explore spatio-temporal patterns in the distribution of taxa across large geographical areas (e.g. Colledge et al., 2004, 2005; Coward et al., 2008; Gaastra et al., 2019).

Patterns in the binary dataset were illustrated through ubiquity scores of taxa by phase (Fig. 4), Simpson's diversity index (Fig. 7) and correspondence analysis (Fig. 8). The latter two were undertaken in R software (R Development Core Team, 2008). Simpson's index (S) is a measure of diversity more commonly used in ecology, that can be performed on presence/absence data (Gardener, 2014: 151–159). As such, the higher the value of S, the less diverse the assemblage. As this behaviour is somewhat counter-intuitive, it is frequent to use a value of 1-S, often referred to as Simpson's index of diversity (D), so that the greater the value, the higher the sample diversity. This specific index was calculated using the diversity function in the R package vegan (Oksanen et al., 2019), and then all values plotted as boxplots based upon their phase attribution (using the R package ggplot2: Wickham, 2016). Correspondence analysis is used to search for patterns in complex data, by ordering units of analyses according to their similarities. This multivariate statistical method of ordination is increasingly used to analyse archaeobotanical assemblages and is suitable for presence/

Table 1
The chronologies, geographical coverage and cultural entities of Phases 1 to 4.

Phase	Chronology (cal. BC)	Extent of the coastal spread	Main archaeological groups
1	c.6500–6100/6000	Greece and Crete	Monochrome, proto-Sesklo
2	c.6100/6000–5500	Dalmatia, South Italy, Sardinia and the Portiragnes area of France	Impressed-Ware, Impresso-Cardial, Guadone
3	c.5500–5000	North Italy and across the northern half of the western Mediterranean	Impressed-Ware, Stentinello, Fiorano, Friuli, Vhó, à Fagninola, Isolino, VBQ (square-mouthed pottery), Gaban, Cardial/Epicardial, Néolithique Ancien Valaisan
4	c.5000–4500	Developments within the western Mediterranean zone	Cardial/Epicardial, Néolithique Ancien Valaisan

absence data (Smith, 2014). Here it is used to compare variations in the presence of taxa by phase and site type (R package 'ca'; Nenadić and Greenacre, 2007).

Whilst some crops may not have been used at particular sites, their absence from archaeobotanical records may in fact result from the effects of preservation, excavation, sampling strategies and sample treatment procedures. For example, some reports note that bulk samples were sieved or floated using large mesh sizes (1 mm or even 2 mm). Whilst this approach undoubtedly leads to the loss of small seeds, such as those of poppy and possibly flax, we feel that cereal grains and most of the cultivated pulses would have been retained. The considerable range in the number of samples taken from sites may also explain the variation in the number of represented crops per site. To assess the effects of some potential biases on the patterns of crop distributions, three additional analyses were performed. Our use of the correlation function tests whether crop diversity is correlated to sample quantities by plotting the 57 sites with known quantities of samples against their species richness (Fig. 2). Logarithmic values were used to account for the large range of sample numbers (from 1 to 1281 from site 44; following Lyman, 2015). Similarly, the recovery of plant impressions without bulk soil sampling (representing 23% (n = 9) of Phase 2 sites) can create biases against particular crops. Cereals added to the temper of pottery or daub may represent a very specific and selective range of species, and casts of pulses, not to mention other seeds, fruit stones and nuts, are rarely identified (*cf.* Fuller et al., 2014: 199-205; McClatchie and Fuller, 2014). Site function is the third condition we assess. Cave sites (including rockshelters) are sometimes described as temporary or seasonal settlements (e.g. Bonsall et al., 2015; Reed, 2015: 615; Martín et al., 2010) where crop processing and consumption may have been less prominent/diverse. As 34% (n = 41) of the samples originate from cave sites, we tested for the effect of site function on crop diversity (Figs. 3 and 8).

3. Results

3.1. Evaluating the patterns

The analyses performed on sample numbers, preservation type and site type suggest that patterns of crop distributions are not significantly biased by these external conditions. Fig. 2 shows a weak positive correlation between the number of samples and the number of taxa per site (Spearman's rho: 0.458, $p < 0.05$), and that this association only accounts for a very small fraction of the total variance (R^2: 0.1467, $p < 0.05$). Therefore the number of samples cannot be described as a significant bias against the variable presence of crop taxa by site. Neither was the diversity by phase influenced by sites with records of crops solely from impressions. For instance, the majority of sites with impressions comes from phase 2 (9 out of 13 sites), though this sample size remains limited when compared to the number of sites with remains obtained through flotation for the same period (n = 31). Simpson's index by phase was also calculated without records of impression (not shown here) but the results were almost identical to Fig. 7, demonstrating that the diversity of crop packages is not strongly biased by the inclusion of impressions.

The function of sites and possible variations in the use of crops may have influenced distribution patterns. A third of all sites were caves or rockshelters, the majority of which were from Phases 3 and 4 (50%, n = 34). However, Fig. 3 demonstrates that caves/rockshelters did not, on average, contain fewer taxa or indeed a specific range of taxa compared to other site types. None of the site types form a distinct

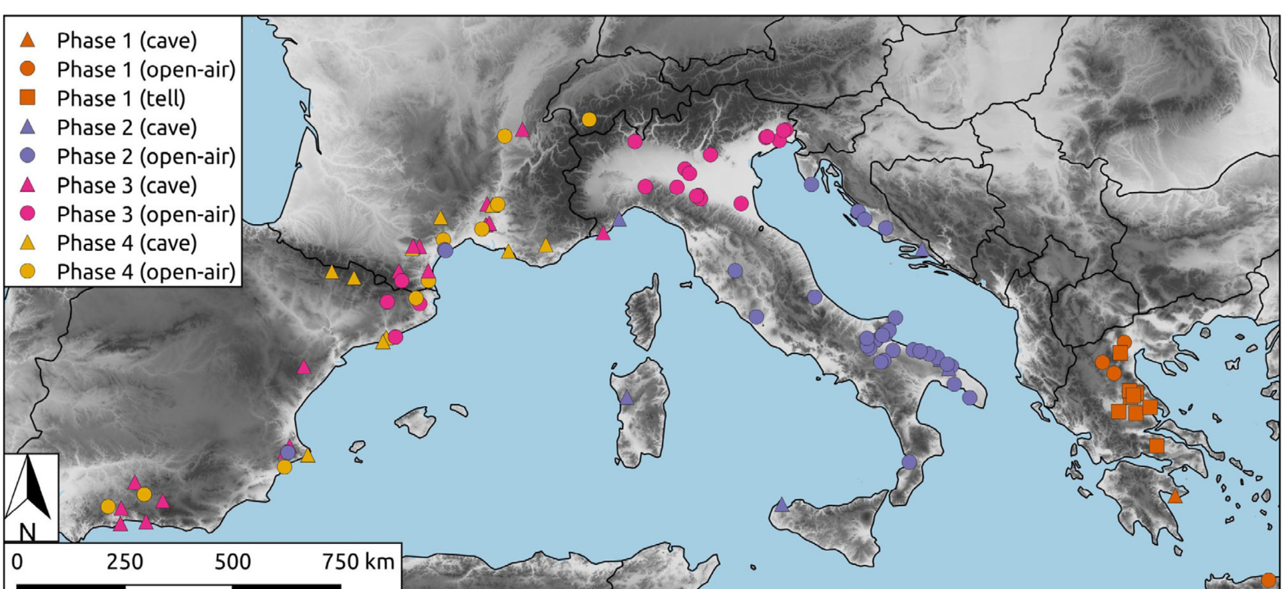

Fig. 1. Location of sites used in the study. See Table 1 for the description of phases.

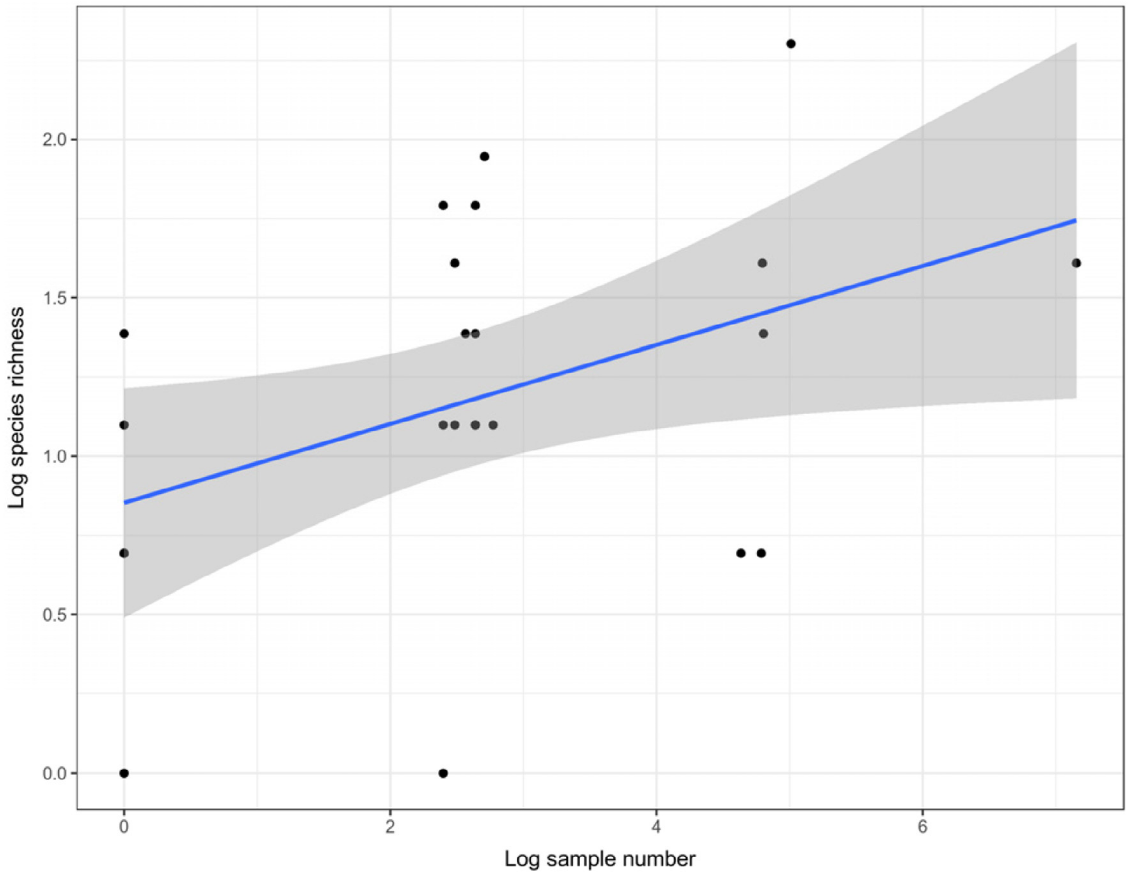

Fig. 2. Graphical representation of the relationship between sample numbers and the species richness per site (the number of species included in this study, not their absolute quantities), for the 57 sites with known sample numbers.

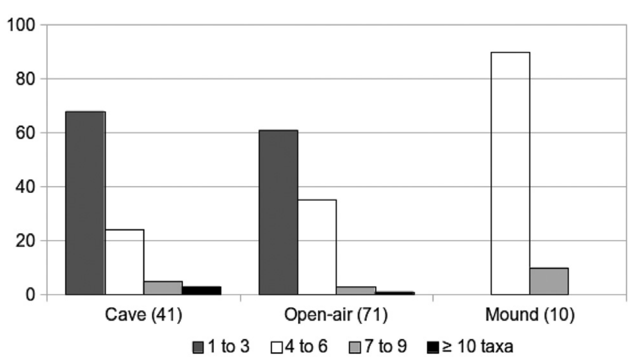

Fig. 3. Ubiquity values for the number of crop taxa found at the three types of sites.

cluster in the correspondence analyses, which indicates that the distribution of crop taxa is not simply influenced by site type.

4. Frequency charts and crop distribution

The 122 sites/phases are not evenly distributed between the three phases. Phases 2 and 3 have a similar amount of sites (n = 40 and 43 respectively), but Phase 1 only has 14 and the last Phase 25. Discrepancies are also visible in their geographic distributions, with an absence of sites form coastal areas of Albania, Montenegro, western Italy and parts of southern Spain.

Barley, emmer, einkorn, free-threshing wheat, lentil, pea, grass/red pea, bitter vetch and flax are present throughout the investigated area. Broad bean and poppy are not recorded from Greek sites, and common

Table 2
Crop taxa included in the study.

Crop category	Species included
Barley	Grains and chaff of *Hordeum vulgare sensu lato, H. vulgare vulgare, H. vulgare nudum*
Glume wheats	Grains and chaff of *Triticum monococcum* (einkorn) and *T. dicoccum* (emmer)
Free-threshing wheats	Grains and chaff of *T. aestivum/durum/turgidum*
'New' glume wheat	Grains and chaff of *T.* cf. *timophevii*, 'new type'
Lentil	Seeds of *Lens culinaris, Lens* sp.
Pea	Seeds of *Pisum sativum, Pisum* sp.
Grass/red pea	Seeds of *Lathyrus sativus, Lathyrus cicera*
Bitter vetch	Seeds of *Vicia ervilia*
Broad bean	Seeds of *Vicia faba*
Common vetch	Seeds of *Vicia sativa*
Chickpea	Seeds of *Cicer arietinum*
Flax	Seeds of *Linum usitatissimum*
Poppy	Seeds and capsules of *Papaver segiterum/somniferum*

vetch is only present in North Italy (sites 59, 60 and 64) and Spain (sites 96 and 108). Chickpea has an unusual distribution, being only present at one of the earliest (site 10) and one of the latest (site 96) sites. The 'new' glume wheat is currently recorded from five sites. It is present in Greece (sites 5 and 7), northern Italy (sites 62 and 111) and Spain (site 96).

The glume wheats emmer and einkorn are ubiquitous in Greece but their frequencies are seen to drop with the westward expansion of farming. They are only recorded from a third of sites in France and Spain during the final Phase 4. The almost exact opposite pattern is evident for free-threshing wheat, which is present in 36% (n = 5) of Greek sites (Phase 1) but 84% (n = 21) of French and Spanish Phase 4

Table 3
Summary information on the sites included in the study.

No.	Site	Type	Phase	Preservation status	Source (including C14 dates)
Greece and Crete					
1	Achilleion	Tell	1	Charred	Ivanova et al. 2018; Renfrew 1979; Valamoti & Kotsakis 2007
2	Argissa Magoula	Tell	1	Charred	Renfrew 1979; Valamoti & Kotsakis 2007
3	Franchti	Cave	1	Charred	Renfrew 1979; Valamoti & Kotsakis 2007
4	Gediki	Tell	1	Charred	Ivanova et al. 2018; Renfrew 1979; Valamoti & Kotsakis 2007
5	Giannitsa B	Open-air	1	Charred	Ivanova et al. 2018; Valamoti & Kotsakis 2007
6	Knossos	Tell	1	Charred	Colledge 2016; Renfrew 1979; Valamoti & Kotsakis 2007
7	Mavropigi-Fyllotsairi	Open-air	1	Charred	Valamoti 2011
8	Nea Nikomedeia	Tell	1	Charred	Ivanova et al. 2018; Renfrew 1979; Valamoti & Kotsakis 2007
9	Otzaki Magoula	Tell	1	Charred	Ivanova et al. 2018; Valamoti & Kotsakis 2007
10	Podromos	Tell	1	Charred	Ivanova et al. 2018; Valamoti & Kotsakis 2007
11	Servia-Varytimides	Open-air	1	Charred	Ivanova et al. 2018
12	Sesklo	Tell	1	Charred	Colledge 2016; Ivanova et al. 2018; Renfrew 1979; Valamoti & Kotsakis 2007
13	Soufli	Tell	1	Charred	Colledge 2016; Ivanova et al. 2018; Renfrew 1979; Valamoti & Kotsakis 2007
14	Toumba Balomenou	Tell	1	Charred	Sarpaki 1995; Valamoti & Kotsakis 2007
Croatia (Dalmatia)					
15	Crno Vrilo	Open-air	2	Charred	Marijanović 2009
16	Kargadur-Ližnjan	Open-air	2	Charred	Komšo 2005
17	Krćina pećina	Cave	2	Impressions	Müller 1994
18	Pokrovnic	Open-air	2	Charred	Reed & Colledge 2016
19	Tinj-Podlivade	Open-air	2	Charred	Huntley 1996
Sardinia, South and Central Italy					
20	Acconia, area C	Open-air	2	Charred	Costantini and Stancanelli 1994
21	Canosa	Open-air	2	Charred	Fiorentino et al. 2013
22	Coppa Nevigata	Open-air	2	Charred	Fiorentino et al. 2013; Sargent 1987
23	Defensola A	Open-air	2	Charred	Fiorentino et al. 2013
24	Filiestru	Cave	2	Charred	Ucchesu et al. 2017
25	Foggia, Ex-ippodromo	Open-air	2	Charred	D'Oronzo and Fiorentino 2006; Fiorentino et al. 2013
26	à Foggia, Villa Communale	Open-air	2	Charred	Nisbet 1982; Fiorentino et al. 2013
27	Fontanelle	Open-air	2	Impressions	Coppola and Costantini 1987; Fiorentino et al. 2013
28	Grotta delle Mura	Cave	2	Charred	Fiorentino et al. 2013
29	à Grotta dell'Uzzo	Cave	2	Charred	Costantini and Stancanelli 1994; Shennan and Steele, 2000
30	Grotta Sant'Angelo	Cave	2	Impressions	Costantini and Stancanelli 1994
31	Lagnano da Piede	Open-air	2	Charred	Jones 1987; Fiorentino et al. 2013
32	Lago di Rendina, Sito n.3	Open-air	2	Charred	Costantini and Stancanelli 1994
33	La Marmotta	Open-air	2	Charred and waterlogged	Rottoli 1993
34	Le Macchie	Open-air	2	Impressions	Costantini and Stancanelli 1994
35	Masseria Candelaro	Open-air	2	Charred	Costantini and Stancanelli 1994; Fiorentino et al. 2013
36	Masseria Valente	Open-air	2	Charred	Costantini and Stancanelli 1994; Fiorentino et al. 2013
37	Monte Aquilone	Open-air	2	Impressions	Evett and Renfrew 1971
38	Monte Calvello	Open-air	2	Charred	D'Oronzo et al. 2008
39	Monte San Vincenzo	Open-air	2	Charred	D'Oronzo et al. 2008
40	Palese	Open-air	2	Impressions	Evett and Renfrew 1971
41	Pulo di Molfetta	Open-air	2	Charred	Fiorentino et al., 2013; Primavera and Fiorentino, 2011
42	Rendina	Open-air	2	Charred	Costantini and Stancanelli 1994; Shennan and Steele (2000)
43	Ripa Tetta	Open-air	2	Charred	Costantini and Stancanelli 1994; Fiorentino et al. 2013
44	Scamuso	Open-air	2	Charred	Costantini and Stancanelli 1994; Fiorentino et al. 2013
45	Terragne	Open-air	2	Charred	Fiorentino et al. 2013; Mercuri et al. 2015
46	Títolo	Open-air	2	Charred	Fiorentino et al. 2013
47	Torre Canne	Open-air	2	Impressions	Coppola and Costantini 1987; Evett and Renfrew 1971; Fiorentino et al. 2013
48	Torre Sabea	Open-air	2	Charred	Costantini and Lentini 2003; Fiorentino et al. 2013; Marinval 2003a, 2003b
49	à Villagio Leopardi	Open-air	2	Impressions	Evett and Renfrew 1971; Costantini and Stancanelli 1994
North Italy					
50	Arene Candide	Cave	2	Impressions	Arobba et al., 2017; Pearce 2013; Rottoli and Castiglioni 2009
51	Bazzarola	Open-air	3	Charred	Carra 2012; Carra and Ricciardi 2007
52	Cava Barbieri	Open-air	2	Charred	Costantini and Stancanelli 1994
53	Cecima	Open-air	3	Charred	Pearce 2013; Rottoli and Castiglioni 2009
54	Chiozza	Open-air	3	Impressions	Evett and Renfrew 1971; Pearce 2013
55	à Fagninola	Open-air	3	Charred	Pearce 2013; Rottoli and Castiglioni 2009
56	Lugo di Grezzana	Open-air	3	Charred	Pearce 2013; Rottoli et al. 2015
57	Lugo di Romagna	Open-air	3	Charred	Pearce 2013; Rottoli, in press; Rottoli and Pessina, 2007
58	Ostiano-Dugali Alti	Open-air	3	Impression	Nisbet 1995; Pearce 2013
59	Pavia di Udine	Open-air	3	Charred	Pearce 2013; Rottoli and Castiglioni 2009
60	Piancada	Open-air	3	Charred	Pearce 2013; Rottoli and Castiglioni 2009
61	Pizzo di Bodio	Open-air	3	Charred	Pearce 2013; Rottoli and Castiglioni 2009
62	Ponte Ghiara	Open-air	3	Charred	Carra 2012
63	à Rivaltella Cà Romensini	Open-air	3	Charred	Carra 2012; Marziani and Tacchini 1996
64	Sammardenchia	Open-air	3	Charred	Pearce 2013; Rottoli and Castiglioni 2009
65	Valler	Open-air	3	Charred	Pearce 2013; Rottoli and Castiglioni 2009
66	Vhò di Piadena-Campo Ceresole	Open-air	3	Charred	Castelletti and Maspero 1992; Pearce 2013
France					
67	Abri Roc Troué	Cave	4	Charred	Erroux 1992
68	Aspre del Paradís	Open-air	4	Charred	Bouby et al. 2016; Manen et al. 2001
69	Balma de l'Abeurador	Cave	3	Charred	Vaquer and Ruas 2009

(*continued on next page*)

Table 3 (*continued*)

No.	Site	Type	Phase	Preservation status	Source (including C14 dates)
70	Baume Bourbon	Cave	4	Charred	Erroux 1976
71	Baume d'Oulen	Cave	3	Charred	Bouby et al. 2016
72	Cova de l'Esperit	Cave	3	Charred	Marinval 1988
73	Font Juvénal	Cave	4	Charred	Marinval 1988
74	Font aux-Pigeons	Cave	4	Impressions	Marinval 1988
75	Fontbrégoua	Cave	4	Charred	Savard 2000
76	Grotte de l'Aigle	Cave	3	Charred	Erroux 1979
77	Grotte du Gardon	Cave	3	Charred	Bouby 2009
78	Grotte du Taï	Cave	3	Charred	Bouby et al. 2018; Manen et al. 2018a
79	Grotte Gazel	Cave	3	Charred	Bouby et al. 2016; Manen et al. 2018a
80	Grotte Saint Marcel	Cave	4	Charred	Erroux 1988
81	La Resclauza	Open-air	4	Impressions	Bouby et al. 2016
82	Le Valladas	Open-air	4	Charred	Beeching et al. 2000
83	Mas de Vignoles X	Open-air	4	Charred	Bouby and Figueiral 2014
84	Mas Neuf	Open-air	4	Charred	Bouby and Figueiral 2014
85	Peiro Signado	Open-air	2	Charred	Bouby et al. 2016; Manen et al. 2018a
86	Pendimoun	Cave	3	Charred	Binder et al. 1993
87	Périphérique Nord-Lyon	Open-air	4	Charred	Vital et al. 2007
88	Pont de Roque Haute	Open-air	2	Charred	Marinval, 2007
89	Roc de Dourgne	Cave	4	Charred	Marinval 1993
Switzerland					
90	Tourbillon	Open-air	4	Charred	Martin 2015
91	La Gillière	Open-air	4	Charred	Martin 2015
92	La Planta	Open-air	4	Charred	Martin 2015
Spain					
93	Abric de la Falguera	Cave	3	Charred	Pérez-Jordà 2013
94	C/Reina Amàlia 31–33	Open-air	4	Charred	Antolín 2016
95	Can Sadurní	Cave	3	Charred	Antolín and Buxó, 2011, Antolín and Schafer, submitted; Edo et al. 2011
96	Can Sadurní	Cave	4	Charred	
97	Caserna de Sant Pau	Open-air	3	Charred	Buxó and Canal 2008
98	Coro Trasito	Cave	3	Charred	Antolín et al. 2018; Clemente et al. 2016
99	Coro Trasito	Cave	4	Charred	
100	Cova de l'Or	Cave	3	Charred	Pérez-Jordà 2013
101	Cova de les Cendres	Cave	3	Charred	Buxó 1997
102	Cova de les Cendres	Cave	4	Charred	
103	Cova de Sant Llorenç	Cave	3	Charred	Antolín 2016
104	Cova de Sant Llorenç	Cave	4	Charred	
105	Cova del Sardo	Cave	4	Charred	Antolín 2016
106	Cueva Bajondillo (Torremolino)	Cave	3	Charred	Peña-Chocarro and Zapata 2010; Pérez-Jordá et al., 2017
107	Cueva de los Mármoles	Cave	3	Charred	Peña-Chocarro et al. 2018
108	Cueva de los Murciélagos de Zuheros	Cave	3	Charred	Peña-Chocarro 1999
109	Cueva del Toro (IV)	Cave	3	Charred	Buxó 2004
110	Cueva de Nerja	Cave	3	Charred	Aura Tortosa, et al., 2005; Pérez-Jordá et al., 2017
111	Font del Ros	Open-air	3	Charred	Pallarès et al. 1997
112	Hostal Guadalupe	Cave	3	Charred	Peña-Chocarro et al. 2018
113	La Draga	Open-air	3	Charred	Antolín 2016; Antolín and Buxó 2011a; Buxó et al. 2000; Berrocal et al., in press
114	La Higuera	Open-air	3	Charred	Espejo Herrerías et al. (2013)
115	Los Arcos	Open-air	3	Charred	Peña-Chocarro et al. 2005
116	Los Castillejos	Open-air	3	Charred	Rovira 2007
117	Los Castillejos	Open-air	4	Charred	
118	Mas d'Is	Open-air	2	Charred	Pérez-Jordà 2005, 2013
119	Mas Cremat (Cingle del)	Cave	3	Charred	Pérez-Jordà 2010
120	Plansallosa	Open-air	4	Charred	Bosch et al., 1998
121	Roca Chica	Cave	3	Charred	Peña-Chocarro et al. 2018
122	Tossal de les Basses	Open-air	4	Charred	Pérez-Jordà 2013

sites. It is during *c*.5500–5000 cal. BC in northern Italy, France and Spain when both hulled and naked wheats appear to have been as frequent.

Although barley is present at almost every site, its high frequency may be misleading compared to those of the wheat types. Unlike the latter it is not split into its hulled and naked forms, which may also show bigger spatio-temporal variations. Indeed, where possible, records of naked and hulled barley were accounted for (Fig. 6), though results must be seen as preliminary until further identifications can be made on the finds of indeterminate barley that dominate the records. Nevertheless, the gradual decline in hulled barley and incline in naked barley between Phases 1 to 4 is comparable to the same trajectory evidenced in the wheats. Together the records suggest that hulled cereals were the main crops during the first two phases, after which an increasing preference for naked cereals is apparent.

Lentil is present in all the Greek sites, and pea and bitter vetch in at least half of them. A sharp decline in frequencies is seen over Dalmatia and southern Italy, particularly for lentil (Phase 2). Bitter vetch then remains rare throughout the Mediterranean whilst the frequency of lentil continues to drop, whilst that of pea shows a slight increase. Although lentil is ubiquitous at the earliest sites in Greece, by the time the westward expansion of farming has reached northern Italy, France and Spain pea is more frequent.

The ubiquity scores for grass/red pea are not as high as those for pea but follow a similar pattern. The main difference is that grass/red pea is rarest from the latest sites. Broad bean and common vetch have relatively high frequencies during Phase 3. Indeed, broad bean is the third most frequent pulse in northern Italy, France and Spain during the first half of the sixth millennium BC. Although frequencies of broad bean and common vetch drop thereafter, they are less rare at the latest sites

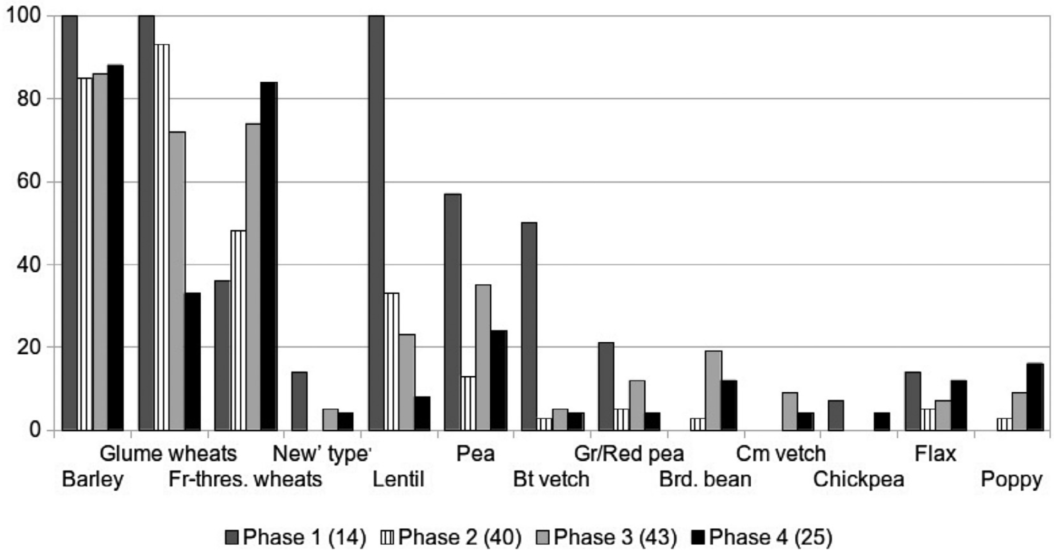

Fig. 4. Ubiquity values by phase for the crops included in the study.

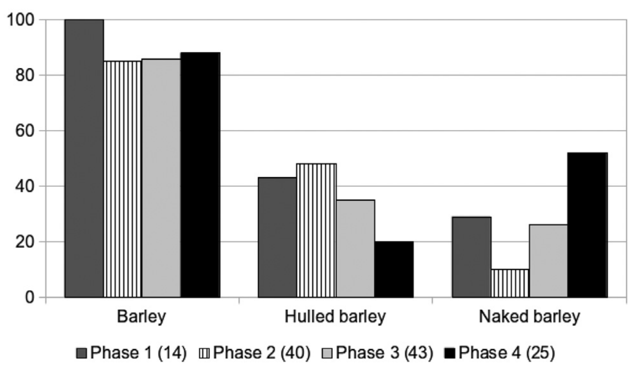

Fig. 5. Ubiquity values by phase for hulled and naked barley.

than at earlier sites from Dalmatia and southern Italy (Phase 2).

Flax is present in low frequencies throughout the westward expansion of farming, though it is rarest from sites dating to the sixth millennium BC (Phases 2 and 3). Although relatively rare, poppy is the only crop to show a continuous increase in frequency from Phase 2 onwards. It is present across the western Mediterranean where it is recorded from central Italy (site 33), France (sites 78 and 85), Switzerland (sites 90 and 91) and up to Andalusia in Spain (sites 96, 108, 116 and 117). It is worth stressing that both these taxa are likely to be under-represented, not only due to their propensity to burst when heated (Märkle and Rösch, 2018) but also to their small size. The use of 1–2 mm sieving/floating meshes for the recovery of plant remains creates a bias against small seeded crops, as well as cereal chaff and wild plant seeds.

5. Simpson's diversity index and correspondence analyses

The highest diversity is seen in Phase 1, in which taxa are most evenly distributed along axes 1 and 2 of Fig. 8. All Phase 1 sites contain glume wheats, barley and lentil, and about half have pea and bitter vetch. Free-threshing wheat is less common (found in 36% of sites, n = 5), as is grass/red pea (found in 21% of sites, n = 3). Flax is found at Servia and Otzaki Magoula, the latter being the only site with chickpea. The most significant drop in diversity is seen between Phases 1 and 2. Phase 2 sites plot closer to the core Neolithic 'package' of glume wheats, barley, lentil and pea, with the exception of a few outliers that contain rare finds of flax (sites 18 and 33), bitter vetch (site 38), grass/red pea (sites 18 and 29) and two new crops: broad bean (site 42) and opium poppy from La Marmotta on the West coast of Italy (site 33) (Figs. 6 and 8). Barley and glume wheats continue to be the most frequent crops, though the presence of free-threshing wheat increases by 12%. There is a significant drop in the ubiquity scores of lentil (33%, n = 13) and pea (13%, n = 5) (Fig. 4). The diversity increases into Phase 3, with values of Simpson's index of diversity spanning a large range. Indeed, the sites of Phase 3 are the most evenly distributed across the CA space, showing not only the highest range in diversity but also the largest geographical coverage (from North Italy to Andalusia). The high ubiquity of barley is maintained, but free-threshing wheats are now as common as hulled wheats (74%, n = 32 and 72%, n = 31 respectively). Whereas pea and grass/red pea are more frequent than in Phase 2, the drop in the frequency of lentil continues and it is now found in fewer sites than pea. Common vetch is found for the first time in Phase 3 (sites 59, 60, 64, 96 and 108), and broad bean has the highest ubiquity score of all phases (19%, n = 8). Flax and opium

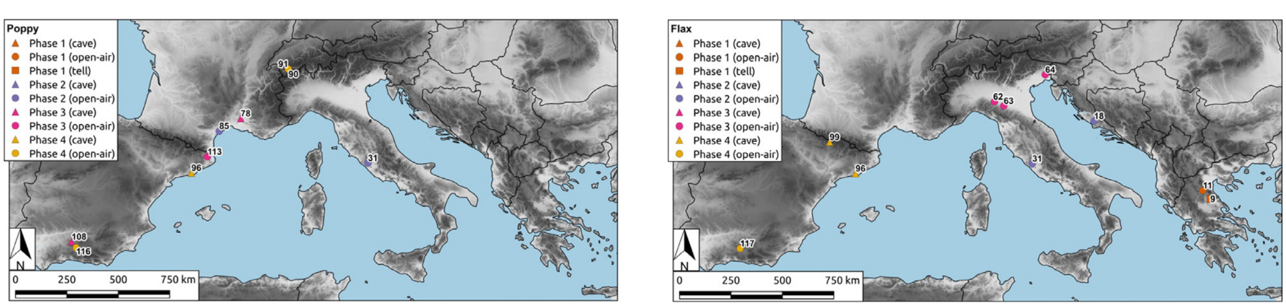

Fig. 6. Location of sites with poppy (left) and flax (right). Distribution maps for all the other crops can be found in the electronic supplementary information.

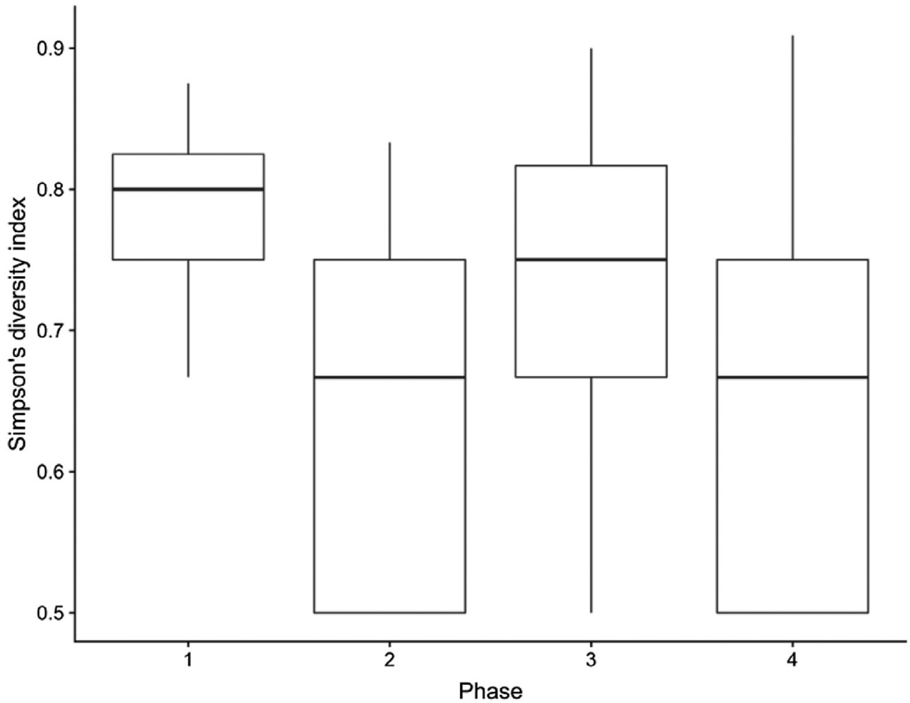

Fig. 7. Simpson's diversity index by phase.

poppy are slightly more common than in the previous phase. Phase 4 has the same diversity index and range of values as Phase 2, although the species richness and abundance differ. Barley is still very common but the high ratio of hulled to free-threshing wheats evident in the first two phases is reversed. Free-threshing wheat is now more frequent, as can be seen by the greater number of Phase 4 sites plotting in the top left quadrant of Fig. 8. All the pulses are present, although their ubiquity scores are reduced compared to Phase 3, particularly for lentils which falls by 15%. The exception constitutes the only other find of chickpea from the research area (site 96). The frequencies of flax and opium poppy are slightly higher than in Phase 3, and higher than those of lentil, grass/red pea and both vetches.

6. Discussion

6.1. Testing the patterns

The crop distribution patterns evidenced during the initial neolithisation of the Adriatic and north-western Mediterranean show spatio-temporal variations in both the range and the ubiquity of crops. In order to test the significance of these patterns, and before the latter can be discussed, phenomena which may have altered the true distribution of crop taxa were tested for. Fig. 2 indicates that the range of crop taxa by site is not strongly influenced by the number of samples processed. Sample numbers were only available for 47% of sites, and volumes were rarely specified. Sample volumes and other details such as the description and number of features/contexts would have made for a more accurate comparison between sites. It is worth stressing that this result does not affirm that comprehensive sampling strategies are not more likely to obtain representative assemblages of archaeobotanical remains. Instead, it reassures that the variable presence (not absolute counts) of the twelve crops of interest to this study does not appear to be a direct outcome of variable sample numbers. Similarly, the inclusion of sites whose records of plant remains were obtained solely from impressions within ceramic, plaster and/or daub, does not negatively affect the diversity of crop packages by phase. The range of crops utilised at any particular site is likely to be under-represented in the record of impressions, as pulses and seeds from oil and fibre crops are seldom recovered. However, at the scale of our analyses, the inclusion of impressions does not appear to bias against non-cereal crops, and allows for a more complete record of cereal finds. Results from the analyses performed to evaluate the obtained patterns of crop distribution are specific to the scale of our observations and our research agenda. They were limited by the available data, and we take this opportunity to urge archaeobotanists to include in their reports and publications as many details from excavations, sample strategies, recoveries and processing as possible. These factors can severely bias the plant record, and lead to inappropriate analyses with erroneous interpretations.

Overall cave sites did not contain a restricted range of crops. The number of taxa found in caves/rockshelters is comparable to that from open-air settlements (Fig. 3), suggesting that the same diet of cultivated plants is represented across both site types (*cf.* Antolín et al., 2018). Although aspects of cultivation and crop processing cannot be addressed here, the presence of charred seeds in caves suggests crops were not (uniquely) transported as flour or fully cooked foods. Raw crops may have been an easier and more durable product to transport if caves were only seasonally or occasionally used. Conversely, large quantities of cereal remains could be an indication of more perennial occupations and the cultivation of surrounding soils (Antolín et al., 2018; Martin et al., in press).

The range of taxa found at the Greek tell sites is very consistent. The rapid build-up of tell sites and the dense accumulation of waste tend to lead to better preservation of charred botanical remains (Bogaard and Halstead, 2015: 391; Valamoti, 2005). These hypotheses are supported by our results which show that no fewer than four crop taxa were frequently recovered from the tell sites. Only one site contained more than six crops: Otzaki Magoula with the only find of chickpea as well as flax (present at only two Greek sites). Opium poppy, broad bean and common vetch were not found at any of the Greek sites. The absence of the latter two crops is curious, considering they were present at earlier sites in SW Asia (Caracuta et al., 2017; Zohary et al., 2012: 89-92).

7. Taxa frequencies and crop distributions

A spatio-temporal shift is evident from the preference of emmer,

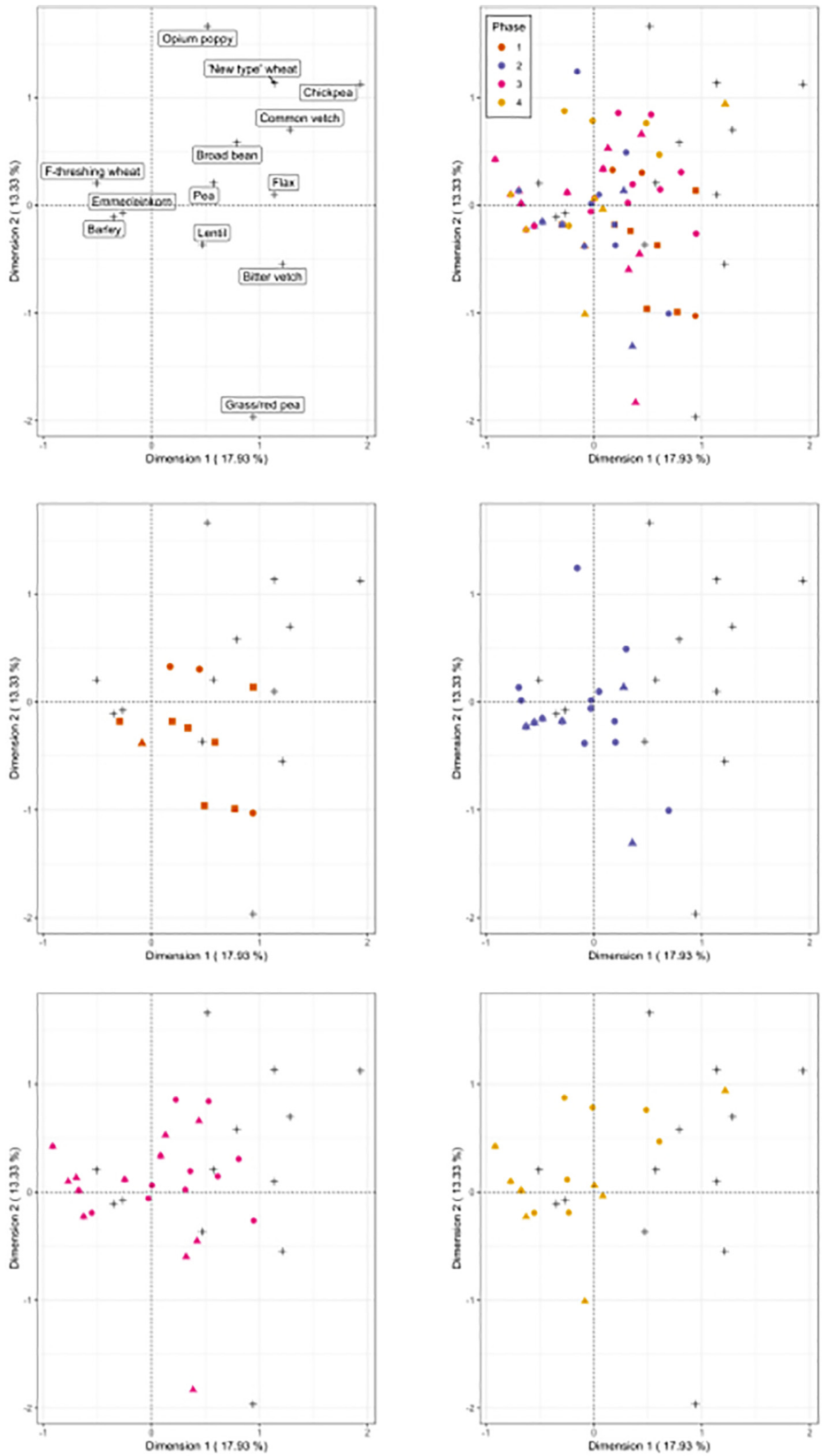

Fig. 8. Correspondence analyses of crops by phase. Crop labels and individual phases are presented separately for ease of viewing.

einkorn and hulled barley to free-threshing wheat and naked barley. Records of naked barley are currently unsatisfactory although our results suggest it became more common towards the end of the Early Neolithic. At some sites in Andalusia and the region of Valencia (Spain) it was already an important crop during Phase 3 (sites 97, 108, 109, 116 and 121) (Pérez-Jordá et al., 2017). Further East in Catalonia its cultivation was not prominent until the Middle Neolithic (*c.*4500–3200 cal BC) (Antolín et al., 2015). Free-threshing wheat is initially thought to have been a minor crop, or a weed of glume wheats during the first spread of farming through the Balkans and into southern Italy and central Europe (Bogaard, 2011: 38; Filipović & Obradović, 2013; Reed, 2015; Rottoli and Pessina, 2007; Valamoti and Kotsakis, 2007). In northern Italy, during our Phase 3, free-threshing wheats become as frequent as the glume ones. However, emmer and einkorn are still found in greater quantities and it seems that free-threshing wheat remained insignificant (Rottoli and Castiglioni, 2009: 95-97). It is only in the western Mediterranean where free-threshing wheat is found in greater frequencies and quantities than the glume wheats (Peña-Chocarro et al., 2018; Pérez-Jordá et al., 2017). Glume wheats were not completely abandoned but persisted at some sites (Antolín et al., 2015; Zapata et al., 2004). Both tetraploid (*Triticum durum/turgidum*) and hexaploid (*T. aestivum*) free-threshing species have been found, though the former is thought to have been the main wheat of the Early Neolithic along the Iberian coast (Peña-Chocarro et al., 2018).

Hulled cereals are more labour intensive but can grow in poor soils and are more resistant to pests and diseases during growth as well as storage (Nesbitt and Samuel, 1996). Additionally, emmer and einkorn straw are known to have been important products, being used as fuel, for thatching, bedding, basketry and in numerous other ways (Peña-Chocarro and Zapata Peña, 2014; Peña-Chocarro et al., 2009). Free-threshing cereals are easier to process since the grains are not firmly encased within their glumes. Pioneer farming communities tended to be small (e.g. Jover Maestre et al., 2019; Porčić, 2018), and lack of labour may have led to a preference in cereals that required less time and energy to process. Although little information is available for the western Mediterranean, entomological analyses suggest that cereal pests existed during the Early Neolithic in the Balkans and central Europe, but then seem to disappear quite early in the neolithisation process (Panagiotakopulu and Buckland, 2018). Contrary to the latitudinal gradient experienced during the inland spread into Europe, the neolithisation of the Mediterranean would not have been subject to significant climatic and seasonal variations. Consequently, and as emmer, einkorn and tetraploid free-threshing wheats are all suited to a Mediterranean climate, farmers may have been able to focus on crops that were better suited to their labour capacities. A reduced threat of pests, along with possible adaptations in storage facilities (Prat et al., submitted), may also have encouraged a focus on free-threshing wheat. The rise in naked cereals in the western Mediterranean pre-dates evidence for larger settlements and woodland clearings (Badal García et al., 1994; López Sáez et al., 2011; Jalut et al., 2000), suggesting that the change in focus was not caused by a possible shift from an intensive agricultural system to an extensive one based on a restricted range of cultivars. This is also suggested by multi-proxy site-scale analyses such as at the lake dwelling site of La Draga, where naked wheat is one of the main crops (Antolín et al., 2014; Revelles et al., 2014). Nevertheless, naked cereals, together with hulled barley, may have facilitated large-scale cultivation and the rise of settlement densities during the Bronze and Iron Ages, as they are easier/faster to process and store for later redistribution (e.g. Bouby, 2014; Alagich et al., 2018; Alonso, 1999; Alonso and Bouby, 2017).

Lentil and pea were part of the original suite of cultivated crops and were the two most common pulses in the Neolithic diet of southern Europe and SW Asia (Zohary et al., 2012: 77-87). They are found during all four phases, although they become less frequent during the westward migration of farming, particularly lentil. Modern cultivars of lentil are more tolerant of drought and heat, and have a slightly longer growing season than peas (Andrews and McKenzie, 2007; Ecocrop). Summer and particularly winter average temperatures during the Early Neolithic of the research area are calculated to have been one to two degrees lower than today's (Mauri et al., 2015: Figs. 3 and 4), perhaps creating climatic conditions which were more suitable to pea. The most important stage in a crop's development is its flowering time, and in pulses flowering is sensitive to both temperature (accumulated degree-days) and photoperiod (light duration, quality and radiant energy) (Craufurd and Wheeler, 2009; Iannucci et al., 2008; Weller and Ortega, 2015). Modern pea and lentil varieties have the shortest growing seasons (pea more so than lentil whose cultivation area is more restricted; Cubero, 1981: Fig. 2), suggesting that their cultivation over other pulses may have been determined by shorter growing seasons (they would still have had time to fruit if flowering had been delayed by colder temperatures and/or shorter light hours). Nevertheless, it is surprising that some pulses (e.g. broad bean) could be grown in southern Italy (site 42) but not in Dalmatia or Greece, and it seems that climatic adaptations were not the only parameters to determine the selection of crops. Historically, vetches and grass pea are known to have been grown for fodder (e.g. Bouby and Léa, 2006; Jones and Halstead, 1995: 103; Zapata et al., 2004: 297). Despite their high protein content, the seeds are toxic to humans and cannot be consumed without lengthy pre-treatments (Bouby and Léa, 2006: 978). Their under-representation in the archaeobotanical record may be related to their secondary economic role (as fodder) or to their lower importance as a food resource. Similarly, the patchy appearance of chickpea may be due to its specific use as an animal food (Antolín and Schafer, submitted).

Findings of the 'new' glume wheat are becoming more common as the taxa is better represented across research laboratories. Indeed, it's overall low presence and complete absence from Dalmatia and southern Italy (Phase 2) may be more an artefact of developments in the discipline than real prehistoric crop use, as 60% of Phase 2 sites were published before the formal identification of the 'new type' (Jones et al., 2000; Kohler-Schneider, 2003). At present, our results suggest that the 'new type' was probably present across the research area though rare in both frequency and absolute quantities.

Oil plants are equally poorly represented in the studied area, which is most likely due to their difficult preservation by charring (particularly poppy which can be abundant in waterlogged deposits, such as at La Draga or La Marmotta) (Märkle and Rösch, 2018; Wilson, 1984). Such a bias in the representation of charred remains of oil plants has been repeatedly observed in the Neolithic lakeshore settlements found in the Alpine foreland (Jacomet et al., 1989). Despite this fact, there is a significant difference between the distribution of flax and opium poppy in our maps. While flax is present in sites located all across the studied region (except southern Italy), poppy is only found in central Italy and the Western Mediterranean region. There are only very scanty references to the presence of poppy in the Near East (Kislev et al., 2004; Rössner et al., 2018), leaving the question open for a domestication of this crop in the western Mediterranean region (Salavert et al., 2018). This phenomenon could have started in central Italy and quickly spread westwards with the first farming settlements found in the NW Mediterranean region. From there it could have spread northwards (Salavert, 2010). Flax was virtually absent from the carpological record in the Iberian Peninsula until relatively recently (Stika, 2005; Rovira, 2007), but it is more commonly found in recent studies thus showing a possible methodological bias that may also account for its absence in southern Italy. Both crops would have been demanding for early farmers and they may have been grown at a very small scale like the small plots of poppy that have traditionally been grown in the house gardens of South Tyrol (Schilperoord, 2017).

8. Exploring diversity

When a fraction of a farming population leaves to colonise new areas a drop in the diversity of their crop package is expected (Conolly et al., 2008; Drost and Vander Linden, 2018; Pérez-Losada and Fort, 2011). The loss of taxa through founder effects such as neutral drift and homophily is unpredictable, as is the time required for these taxa to be re-introduced. The drop in the diversity of crop packages during the first westward maritime spread mimics the same phenomena seen along the inland route into Europe (Colledge and Conolly, 2007; Coward et al., 2008; McClatchie et al., 2014), where impacts of founder effects are hard to separate from those of rising latitudes and climate change. Conversely, the latter two conditions are less likely to have resulted in the abandonment of particular crops within the Adriatic and

Mediterranean zone, suggesting that a drop in diversity, observed in reducing values of Simpson's index, particularly in Phase 2, is more likely an outcome of the process of migration. Changes in diversity indices between Phase 1 and 4 are testimony to the arrhythmic nature of the migration (Guilaine, 2001), which included pauses for establishing settlements and perhaps building networks with other communities across the Mediterranean or further inland. For example, the presence of common vetch in Phase 3 may point to destinations beyond Greece as the pulse is not known within the Adriatic or Aegean at that time (Marinova and Valamoti 2014; de Vareilles, unpublished). Similarly, broad bean is present in Phase 2 but currently absent from the Greek Neolithic (Marinova and Valamoti, 2014). The signal is further complicated by the increased rate of expansion into the western Mediterranean, and the possible inclusion of fifth millennium sites into Phase 3 (see methodology). As such, we may not have captured the very first migration out of southern Italy, but show the effects of regular, multi-directional movements across the research area. The drop in Simpson's diversity index in Phase 4 appears to illustrates the increased focus on a narrower range of cereals in the western Mediterranean.

9. Conclusion

Changes in both the frequency of taxa and in the diversity of crop packages are evident during the first maritime neolithisation of the Adriatic and north-western Mediterranean. The core group of barley, wheats, lentil and pea are found throughout, though significant changes in the frequency of hulled to naked cereals, and of lentil to pea occurred during the second half of the sixth millennium. Other pulses, such as bitter vetch, grass/red pea and chickpea, appear to have been almost abandoned, whilst some were introduced at later dates. Poppy seems to have held an important role within the western Mediterranean agricultural system, although the precise locale of its domestication currently remains enigmatic. Explaining such diversity is complicated, not least because of the numerous natural and cultural factors that would have shaped the agrarian model. Nevertheless, we suggest that climatic and environmental changes had minor consequences, and that crop packages were more influenced by founder effects and the nature of maritime trajectories. Our results support other archaeological evidence in depicting regional details and multi-directional maritime trajectories, within a broader westward maritime expansion of the Neolithic.

Collation of the dataset for this article has revealed large geographical gaps where further research is clearly needed. Additionally, there is a large disparity between different countries in the levels of published details. Presence/absence data is informative, and we concur with previous examples in demonstrating that such data is suitable for documenting the dispersal of domesticated crops. Nevertheless, our understanding of the first farming communities would be much enhanced by improvements in the recording and publishing of archaeobotanical remains. Seeds should be dated directly wherever possible, particularly the rarer pulses and oil crops. Our use of Simpson's diversity index has shown that outcomes of random processes like founder effects can be tested for. We urge researches to include diverse statistical approaches to test for processes known from theoretical models, which might explain patterns evident in large-scale data. We acknowledge that our results only stand true until further investigations refute them, though we hope that the 'big picture' presented here encourages more detailed and robust data acquisition and manipulation.

CRediT authorship contribution statement

A. de Vareilles: Conceptualization, Data curation, Investigation, Methodology, Project administration. **L. Bouby:** Data curation. **A. Jesus:** Data curation. **L. Martin:** Data curation. **M. Rottoli:** Data curation. **M. Vander Linden:** Data curation, Funding acquisition, Methodology, Software, Validation, Visualization. **F. Antolín:** Conceptualization, Data curation, Investigation, Funding acquisition, Methodology, Project administration.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2019.102140.

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