

2019-05-01

From influence to impact: the multifunctional land-use in Mediterranean prehistory emerging from palynology of archaeological sites (8.0-2.8 ka BP)

Mercuri, AM

<http://hdl.handle.net/10026.1/12228>

10.1177/0959683619826631

The Holocene

SAGE Publications

All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.

**From influence to impact: the multifunctional land-use in
Mediterranean prehistory emerging from palynology of
archaeological sites (8.0-2.8 ka BP)**

Journal:	<i>The Holocene</i>
Manuscript ID	HOL-18-0100.R1
Manuscript Type:	Paper
Date Submitted by the Author:	18-Jul-2018
Complete List of Authors:	Mercuri, Anna Maria; University of Modena and Reggio Emilia, Museum of Palaeobiology and Botanic Garden Florenzano, Assunta; University of Modena and Reggio Emilia, Museum of Palaeobiology and Botanic Garden Burjachs, Francesc; Institutio Catalana de Recerca i Estudis Avancats, Humanities; IPHES, Archaeobotany Giardini, Marco; Sapienza University, Biologia Ambientale Kouli, Katerina; National and Kapodistrian University of Athens, Faculty of Geology and Geoscience Masi, Alessia ; Universita degli Studi di Roma La Sapienza Facolta di Scienze Matematiche Fische e Naturali, of Environmental Biology Picornell, Llorenç; Universitat de les Illes Balears, Departament de Ciències Històriques i Teoria de les Arts Revelles, Jordi; Universitat Autònoma de Barcelona, Departament de Prehistoria Sadori, Laura; Sapienza University, Biologia Vegetale Servera-Vives, Gabriel; Universitat de les Illes Balears, Ciències Històriques i Teoria de les Arts Torri, Paola; University Modena and Reggio Emilia, Laboratorio di Palinologia e Paleobotanica, Dipartimento di Scienze della Vita Fyfe, Ralph; University of Plymouth,
Keywords:	sustainable farming, pollen, charcoal, Holocene, Neolithic, Bronze Age
Abstract:	Archaeobotany is used to discover details on local land uses in prehistoric settlements developed during the middle and beginning of late Holocene. Six archaeological sites from four countries (Spain, Italy, Greece, Turkey) have pollen and charcoal records showing clear signs of the agrarian systems that had developed in the Mediterranean basin during different cultural phases, from pre-Neolithic to Recent Bronze age. A selected list of pollen taxa and sums, including cultivated trees, other woody species, crops and annual or perennial synanthropic plants are analysed for land use reconstructions. In general, cultivation has a lower image in palynology than forestry, and past land uses became visible when oak woods were affected by human activities. On-site palynology allows us to recognise the first influence of humans even before it can be recognised in off-site sequences, and off-site

1
2
3
4 sequences can allow us to determine the area of influence of a site.
5 Neolithic and Bronze Age archaeological sites show similar land use
6 dynamics implying oak exploitation, causing local deforestation, and
7 cultivation of cereal fields in the area or around the site. Although a
8 substantial difference makes the Neolithic influence quite distant from the
9 Bronze Age impact, mixed systems of land exploitation emerged
10 everywhere. Multiple land use activities exist (multifunctional landscapes)
11 at the same time within the area of influence of a site. Since the Neolithic,
12 people have adopted a diffused pattern of land use involving a combination
13 of diverse activities, using trees-cereals-domesticated animals. The most
14 recurrent combination included wood exploitation, field cultivation and
15 animal breeding. The lesson from the past is that the multifunctional land-
16 use, combining silvo-pastoral and crop farming mixed systems, has been
17 largely adopted for millennia being more sustainable than the monoculture
18 and a promising way to develop our economy.

18
19
20 Note: The following files were submitted by the author for peer review, but cannot be converted to
21 PDF. You must view these files (e.g. movies) online.

22
23 Fig. 4 corretta.jpg
24 Mercuri et al Fig. 8 new.jpg
25

26
27
28 SCHOLARONE™
29 Manuscripts

30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
Review

From influence to impact: the multifunctional land-use in Mediterranean prehistory emerging from palynology of archaeological sites (8.0-2.8 ka BP)

A.M. Mercuri¹, A. Florenzano¹, F. Burjachs², M. Giardini³, K. Kouli⁴, A. Masi³, L. Picornell-Gelabert⁵, J. Revelles⁶, L. Sadori³, G. Servera-Vives⁵, P. Torri¹, R. Fyfe⁷

¹Laboratorio di Palinologia e Paleobotanica, Dipartimento di Scienze della Vita, Università di Modena e Reggio Emilia, Italy

²Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Spain; Institut Català de Paleoeologia Humana i Evolució Social (IPHES), Tarragona, Spain; Universitat Rovira i Virgili (URV), Tarragona, Spain

³Laboratorio di Paleobotanica e Palinologia, Dipartimento di Biologia Ambientale, Università di Roma La Sapienza, Italy

⁴Department of Geology and Geoenvironment, National and Kapodistrian University of Athens, Greece

⁵ArqueoUIB Research Group. Departament de Ciències Històriques i Teoria de les Arts, Universitat de les Illes Balears. Carretera de Valldemossa Km 7,5, CP07122, Mallorca, Spain

⁶Departament de Prehistòria, Universitat Autònoma de Barcelona, Bellaterra, Spain

⁷School of Geography, Earth and Environmental Sciences, University of Plymouth, Drake Circus, Plymouth PL48AA, UK

Abstract:

Archaeobotany is used to discover details on local land uses in prehistoric settlements developed during the middle and beginning of late Holocene. Six archaeological sites from four countries (Spain, Italy, Greece, Turkey) have pollen and charcoal records showing clear signs of the agrarian systems that had developed in the Mediterranean basin during different cultural phases, from pre-Neolithic to Recent Bronze age. A selected list of pollen taxa and sums, including cultivated trees, other woody species, crops and annual or perennial synanthropic plants are analysed for land use reconstructions. In general, cultivation has a lower image in palynology than forestry, and past land uses became visible when oak woods were affected by human activities.

On-site palynology allows us to recognise the first influence of humans even before it can be recognised in off-site sequences, and off-site sequences can allow us to determine the area of influence of a site.

Neolithic and Bronze age archaeological sites show similar land use dynamics implying oak exploitation, causing local deforestation, and cultivation of cereal fields in the area or around the site. Although a substantial difference makes the Neolithic *influence* quite distant from the Bronze age *impact*, mixed systems of land exploitation emerged everywhere. Multiple land use activities exist (multifunctional landscapes) at the same time within the area of influence of a site. Since the Neolithic, people have adopted a diffused pattern of land use involving a combination of diverse activities, using trees-crops-domesticated animals. The most recurrent combination included wood exploitation, field cultivation and animal breeding. The lesson from the past is that the multifunctional land-use, combining silvo-pastoral and crop farming mixed systems, has been largely adopted for millennia being more sustainable than the monoculture and a promising way to develop our economy.

Key words: sustainable farming, pollen, charcoal, Holocene, Neolithic, Bronze age

INTRODUCTION

According to FAO/UNEP, the United Nations Environment Programme, and the Intergovernmental Panel on Climate Change *Special Report on Land Use, Land-Use Change and Forestry* (IPCC, 1999), land-use is 'the total of arrangements, activities, and inputs that people undertake in a certain land cover type' (FAO/UNEP, 1999). Land use is thus a concept that depends on both plant cover (Nature) and human activities (Culture). The availability of natural resources relies on ecological and phytogeographical diversity. At different latitudes, species distributions are controlled by moisture availability, nutrient supply and light exposure. Each environment has distinct geomorphological characteristics and soil types which can influence land cover. Each of these features allows, or may trigger, a certain type of land use. As in the suggestive title "Fields of Change" edited by Cappers (2005), it is evident that our (cultural – agrarian) land uses have been, and still are, subjected to transformations under environmental-climatic as well as socio-economic changes. Several categories of land-use are identified by the IPCC report that point to an Increasing Intensity of Use (IIU): from deserts, non-forest wooded lands or wetlands, to forestry, land under shifting cultivation, temporary fallow, permanent pastures, permanent or temporary crops and the modern (residential/industrial/transportation) facilities.

In the past, and even today, our behaviour must have been determined by the primary needs of our species (*sensu* Maslow, 1943) including water, food, clothing and shelter. Plants have been especially responsible for the development and success of different land-use strategies, from hunting and gathering to crop cultivation to farming and forestry, to the management and shaping of landscapes. From an ecological approach (Faegri et al., 1989), the direct and indirect consequences of human activities on the environment are expected to drive changes in vegetation cover on a long-term perspective. Mercuri et al. (2010: 861) observed that land uses might have low *influence* or high *impact* depending on the scale (space) and duration (time) of the human presence/action in a given territory; this produces different effects on the environment. As a result of this human influence or impact on plant cover may be variable and not always detectable over a large area, far from settlements or productive areas.

Succession from simple to complex forms of land exploitation, local and regional differences, and intensity of use are often obtained by the comparison between on-site and off-site pollen records. The terms have a general meaning of 'local' or 'regional' study, respectively, but their use may have different nuances in different cases.

The degree of understanding of the ecological, formal and cognitive levels of cultural landscapes depends on the chronology and contexts (Mercuri, 2014). Classically, the synanthropic and cultural plants from archaeological sites (on-site) provide local signals of the human role in past vegetation history (Mercuri and Sadori, 2014; Sabato et al. 2015), with intermediate contexts (Mercuri et al., 2002; Pepe et al., 2013), while off-site palynology is used as a measure of this role over large areas (Jahns, 1993, 2005; Mercuri et al., 2002; Colombaroli et al., 2008; Kouli and Dermitzakis, 2008; Vanni re et al., 2008; Vescovi et al., 2010; Marinova et al., 2012; Pepe et al., 2013; Mercuri and Sadori, 2014; Weiberg et al., 2016; Sabato et al. 2015; Revelles et al., 2018).

Human action is evident from archaeology, and human-induced changes in flora composition and vegetation cover should have occurred earlier near settlements and in the places that today we call 'archaeological sites', and then spread to the surrounding area leaving increasingly visible traces in sedimentary archives (Mercuri et al., 2012). Hence, the study of land-uses may be notably improved by archaeopalynology: the analysis of pollen from archaeological sites (Faegri et al., 1989). From the *one-site* to *one-area* approach, if the interdisciplinary study of one archaeological site shows local space-time events and the behaviour of a few people, the integration of data from many sites enables regional and cross-cultural landscape reconstructions (Mercuri, 2008; see also the *multi-point* and *multi-site* sampling concepts of palynology in Mercuri et al., 2015c: 237; on pollen sampling strategy see also Fig. 2 in Mercuri, 2014).

It is often assumed that there are many taphonomical problems associated with on-site palynology, both in terms of pollen transport and post-depositional decay. In some archaeological layers, the poor state of

Formatted: No widow/orphan control, Don't adjust space between Latin and Asian text, Don't adjust space between Asian text and numbers

preservation of pollen grains, especially due to oxidation or the local use of fire, discourages analysts to carry out such analyses. However, the palynology of archaeological sites has been utilized for many decades and can be considered as an important part of archaeobotany (e.g. Mercuri et al. 2015a). Today, it is clear that the correct sampling strategy, well-studied stratigraphy and chronology, and interdisciplinary interpretation are basic to obtain robust data from these special archaeo-environmental contexts.

Pollen as 'land-use' evidence

Starting from general knowledge on botany and ecology, pollen taxa are commonly grouped into sums useful for environmental and land-use reconstructions. ~~Particular pollen taxa whose presence or abundance is linked to human presence and land uses have been identified as~~ The Anthropogenic Pollen Indicators ~~by Behre (1981). They~~ are a substantial, intrinsic part of past pollen diagrams in the Mediterranean area, because people generated impressive patterns of landscape complexity, and the flora/vegetation have pervasively been transformed by cultural waves during the Holocene (Zohary and Hopf, 2000; Mercuri et al., 2011; Roberts et al., 2011). The main sums for environmental reconstructions are the arboreal or woody plant (~~AP, with~~ upland forest, mixed deciduous forest, Mediterranean forest or shrubland and macchia), and the wetland plants (~~with~~ riverine wood and hydro-hygrophilous herbs) (for a review of sums see Kouli et al., in press). The sum of steppic indicators showing open landscapes, dominated by grasses and steppe elements (Non-Arboreal pollen, NAP) is quite ambiguous as most taxa can be regarded as composed of wild steppe and grassland vegetation types or wild synanthropic, i.e. anthropogenic, species (Mercuri et al., 2013b). For example, the presence of steppe indicators (*Artemisia*, *Chenopodiaceae*, *Apiaceae*) during the Younger Dryas cool-oscillation, despite the recovery of many settlements in the Italian peninsula (Mussi and Peresani, 2011), may reasonably be regarded as evidence of natural vegetation favoured by both the climate and presence of large herds of herbivores needing and maintaining open grasslands until the Pleistocene/Holocene transition (Burney and Flannery, 2005). Similarly, the AP curve can be a result of climate (e.g. Sadori et al., 2016) or human action in the case of trees exploitation to wood management (Mercuri and Sadori, 2014; and see, for example, the wood management of the Terramare culture: Mercuri et al. 2006a, 2015a). However, unlike off-site records, trends in wild anthropogenic taxa and the AP pollen sum from archaeological sites can be used as unambiguous indicators of human actions (Mercuri et al., 2013b: 150).

The main sums for land-use reconstructions are the cultivated plants (trees and other woody species, and annual or perennial herbs) and the synanthropic plants. Weeds and ruderals growing within farming contexts and open disturbed ground are the main contingent of ~~wild~~ synanthropic plants (secondary anthropogenic indicators *sensu* Behre, 1990).

Altogether, pollen from cultivated and synanthropic species form the sum of Anthropogenic Pollen Indicators (API) associated with human activities (Behre, 1981; Lopez-Saez et al., 2006; see Mercuri et al., 2013b for ubiquitous pollen taxa in archaeological sites of Italy).

The OJC group, including *Olea*, *Juglans* and *Castanea* pollen, is an important marker of increasing anthropization in the Mediterranean area (Mercuri et al., 2013a; Florenzano et al., 2017) being sometimes constituted by the three curves (as in central Italy: Mercuri et al., 2002; Stoddart et al., this issue), or coinciding with only one or two of these tree pollen. Other woody plants, such as *Vitis* and *Corylus*, when cultivated, may be important cultural markers while the woody plants collected in the wild may be significant even if rare (e.g. *Cornus*, *Prunus* and *Rubus*).

Cereals (cereal-type; primary anthropogenic indicators *sensu* Behre, 1990) are considered among the clearest signal of agrarian land use. As many cereals are low pollen producers, they indicate crop fields and agricultural systems in a site/region even if under-represented in pollen spectra. Other sums are more focused on reconstructing pastoral and breeding activities. The Local Pastoral Pollen Indicators (LPPI) and Regional Human Activities Pollen Indicators (RHAPI) are indices that are used to infer local pastoral activities and background human activities respectively (Mazier et al., 2009). The Pollen Disturbance Index (PDI) includes selected pollen taxa that have been correlated with pastoral activities in the Hellenic peninsula (e.g. some *Sarcopoterium*, *Plantago* and *Polygonum* species; Bottema, 1982; Bottema and Woldring, 1990; Kouli, 2012, 2015). Field observations on the current distribution of Cichorieae have demonstrated that, although the cichory tribe is common in many habitats of southern Italy, its abundance

1
2
3
4
5
6
7 increases in open habitats including pastures, and the smallest size pollen belongs to species typical of
8 secondary pastures (Florenzano et al., 2015). High percentages of this pollen in the spectra is thus regarded
9 as a good indicator of grasslands used for pasture in land-use reconstructions. Increases in other API taxa
10 can reflect enhanced trampling (*Plantago*), excrement deposition (*Urtica*), weeds (*Aphanes*), fodder and
11 breeding/pastoral practices (Fabaceae, Asteroideae).

12 13 **Aim of this paper**

14
15 The aim of the paper is to show how the anthropogenic pollen indicators may fruitfully be used to obtain
16 detailed reconstructions on the local land-use types. Prehistoric sites have been selected that cover phases
17 of the mid and late Holocene (c. 8000-2800 years cal BP), the period that saw the rise and fall of cultures
18 from pre-Neolithic to Neolithic, Chalcolithic up to the Middle and Recent Bronze ages in the
19 Mediterranean. The Neolithic to Bronze ages saw the passage from the adoption of agriculture to advanced
20 farming cultures. New relationships between human societies and environment were accompanied by
21 profound changes. The ability to cultivate domesticate species gave to the early farmers an increase of
22 control on natural events, a new opportunity they obtained also by means of a different type of knowledge
23 on plants (Mercuri and Sadori, 2014: see the table at p. 508).

24 Archaeobotany has great potentiality for environmental and palaeoethnobotanical purposes, with samples
25 collected from almost every type of archaeological item/context (Kouli and Dermitzakis, 2003; Pearsall,
26 2016; Cappers and Neef, 2012; Mercuri et al., 2015a; Riera et al., 2018). In this synthesis we focus on data
27 from palynology and vertical sampling. Vertical sampling provides a biostratigraphical analysis and allows
28 changes in plant assemblages to be identified across long-term sequences. This gives the opportunity to
29 reconstruct land transformations in a diachronical palaeoecological perspective. Horizontal sampling (not
30 fully considered here) uses many samples/points from one chronological phase or archaeological site, and
31 is more helpful to understand intra-site patterns in plant uses such as processing or storage (e.g., Van der
32 Veen, 2007 for macroremains; Rattighieri et al., 2013 for pollen).

32 In this paper, the pollen data from archaeological sites represent different types of Intensity of Use across
33 four countries within the Mediterranean Basin (Spain, Italy, Greece and Turkey; **Fig. 1**). Where pollen
34 preservation is poor and thus low numbers of pollen samples are available (as in Closos de ca'n Gaià and
35 Arslantepe) anthracological data is added to aid interpretation (Sadori et al. 2010). The sites were settled in
36 very different environmental contexts, from the shore of Lake Banyoles in NE Iberia (La Draga) to the
37 western Mediterranean Balearic Islands (Closos de ca'n Gaià), to the alluvial plain of North Italy (terramaras
38 of Montale and Santa Rosa di Poviglio) to the shore of Lake Orestias or Kastoria (Dispiliò) and the tableland
39 of eastern Anatolia (Arslantepe) in the eastern Mediterranean. In this synthesis, the archaeological sites
40 have been considered for their common features that allow general to detailed archaeo-environmental
41 descriptions, the reconstruction of land-uses in the Mediterranean basin and the general comparison with
42 off-site pollen data over five millennia.

43 **METHODS**

44
45 Six prehistoric settlements from four countries facing to the Mediterranean basin have been selected to
46 present archaeobotanical data from archaeological sites (**Tab. 1**). The sites located in Italy are part of the
47 database BRAIN, and the others have been now added in the special section of 'Extra-Italy' records
48 (<https://brainplants.unimore.it/>). The settlements preserved pollen and macrobotanical remains and have
49 been studied within interdisciplinary archaeological research programmes. Most of the archaeobotanical
50 study was carried out on samples taken during archaeological fieldwork: pollen samples were collected
51 from stratigraphic sequences/trenches or cores, distinguishing between on-site (from the settlement
52 excavation) and near-site (just next to the site but known to be in the site's *area of influence*, the territory
53 visited every day by the inhabitants). Samples for macrobotanical remains were taken from occupation
54 layers discovered during the excavations. A charcoal sample includes all the wood fragments corresponding
55
56
57
58
59
60

to one single wood, or those recovered from the fill of small features or single structure (Masi et al., 2018). Pollen taxa and sums from 227 pollen samples, from 13 sequences/trenches/cores, have been drawn with Tilia diagrams (Grimm, 2015) plotted against samples or chronology. The list of taxa includes the main elements of natural land cover (*Pinus*, *Abies*, *Quercus*, *Corylus*, *Alnus*; Poaceae), and the known anthropogenic taxa. The latter include woody plants as OJC (*Olea*, *Juglans*, *Castanea*), and possibly *Vitis* although *Vitis* has different reproductive features, and therefore different pollen production, in wild and domesticated subspecies. Anthropogenic taxa also include herbaceous plants such as cereals, Cichorieae, *Artemisia*, *Centaurea*, *Plantago*, *Trifolium* type, *Urtica*. Pollen sums were calculated for Mixed oakwoods, Sclerophyllous vegetation, Shrubland, Grassland, Wetland, and Weeds/Anthropogenic environments. Samples were grouped into 90 time-slots from c. 8000 to c. 2800 cal yrs BP to compare the trends of the main pollen taxa and sums. The time slots are contiguous but not of equal duration. Time-slots were established on the basis of radiocarbon dates, stratigraphy-sedimentation rate and cultural attributions of the layers of each site. Each sample was attributed to one time-slot, and each time-slot includes samples with a similar age from different sites. Harmonising the pollen data into time-slots was necessary as the pollen sequences had variable temporal resolution (from c. 9 to c. 200 years), depending on the archaeological deposits, with the highest resolution observed in the Terramara's Bronze age stratigraphies (9-12 years).

Pollen data were ordinated by Principal Component Analysis (using XLSTAT). The PCA uses the percentage values of taxa that are included in the groups described above and was performed using the sampling points as variables. Pollen data were ordinated by Principal Component Analysis (using XLSTAT). The PCA uses the percentage values of taxa and was performed using the sampling points as variables. The percentage calculations are made in terms of percentages of the total pollen sum (including all pollen types) for the taxa grouped into main sums useful for landscape reconstructions described above. The dataset analysed is composed of 226 pollen spectra.

RESULTS THE CASE STUDIES

The case studies

The datasets selected for this synthesis show evidence of land uses, including changes in arboreal taxa (Fig. 2), and diachronic evolution of cultural landscape along about 5000 years of human activities crossing different cultural periods. From the West to East, the sites include La Draga and Closos de ca'n Gaià from Spain, the terramaras of Montale and Santa Rosa di Poviglio from Italy, Dispiliò in Greece and Arslantepe in Turkey. Below, after a short description of the archaeological deposits, and the main results from pollen collected from both on-site and near-site layers, general trends in land uses in the different Mediterranean regions are reported.

Western Mediterranean: La Draga (Girona)

NE Spain, Catalonia

Early Neolithic Cardial - 7270-6750 cal BP

Settlement sites (open-air pile-dwelling on a lake shore)

Sampling: pollen, NPPs; macroremains: seeds/fruits, charcoal

39 pollen samples from 3 on-site profiles (trenches in archaeological layers)

Key events: AP higher before the settlement and water-rich environment near the Lake Banyoles; exploitation of woods and cereal field cultivation

The first Neolithic farming societies in the Lake Banyoles area settled in a humid and densely forested region (predominantly deciduous *Quercus* and *Corylus avellana*). The settlement of La Draga was established in a lacustrine carbonate-sand beach, with alkaline soils poor in nutrients. The dominant vegetation within and in the near surroundings of the settlement would have been aquatic (*Potamogeton coloratus*, Characeae) with hygrophytes (Cyperaceae, *Typha latifolia*, *Typha-Sparganium*, *Juncus articulatus*-type, *J. effusus*-type, *Cladium mariscus* and *Mentha* cf. *aquatica*) in a land with high water availability. A riparian forest formed by ash (*Fraxinus*), willow (*Salix*), elm (*Ulmus*), alder (*Alnus*), poplar (*Populus*), elder (*Sambucus nigra*), laurel (*Laurus nobilis*) and wild grape (*Vitis vinifera* subsp. *sylvestris*) surrounded the beach. Ferns (mainly *Pteridium aquilinum*) lived in humid environments. Close to surrounding slopes, oak forests grew in deep humid soils, with dominance of deciduous *Quercus*, and the presence of hazel (*Corylus*), lime (*Tilia*), pines in the clearances (*Pinus*), yew in shaded spots (*Taxus*) and boxwood in the underbrush and colonising degraded areas (*Buxus*). Conifer forests existed in the mountains (*Pinus* and *Abies*) and at regional scale Mediterranean sclerophyllous forests would have been developed in drier substrates, with evergreen oaks (*Quercus ilex-coccifera*), wild olive tree (*Olea europaea* var. *sylvestris*), *Phillyrea*, heather (*Erica*) and rockrose (*Cistus*; Revelles, 2017).

At the onset of the settlement, oak was exploited for firewood and raw material for construction (attested by charcoal and wood remains, with > 1000 oak posts recovered in the 800 m² of the excavated area; Revelles et al., 2014). Considering the fact that the total extension of the site is estimated to c. 8000 m², thousands of poles must have been cut for the construction of the settlement, with moreover the period of occupation (Revelles et al., 2014; López-Bultó, 2015). The trunks were cut (with adzes, as shown by traces of the tools Bosch et al., 2008), and dragged to the settlement. This resulted in significant deforestation, caused soil erosion (Revelles et al., 2016) and the scale of impact was such that it was visible in off-site records some 500 m from the archaeological site (core SB2 in Revelles et al., 2015), and in off-site records that reflect the regional vegetation (Lake Banyoles: Pérez-Obiol and Julià, 1994).

A high presence of cereals (Cerealia-type pollen) is documented in the two occupation phases described at La Draga. Crop fields could not be in the immediate surroundings of the settlement as the site was established in a swampy area unsuitable for cultivation. Cereal fields would have been far enough away to prevent Cerealia-type pollen from reaching the nearby off-site (thus, near site) SB2 core (Revelles et al., 2014, 2015). The high concentrations of Cerealia-type pollen within the settlement reflects on-site storage of crops (mixed cereal grains and chaff suggesting domestic storage were studied by Antolín et al., 2014) and are a by-product of on-site plant processing: at La Draga spatial association between the highest values of cereal pollen and grinding stones identified an area of cereal processing (Revelles et al., 2017). The comparison of the pollen records from this area (Fig. 1) suggests that farming itself caused a limited impact on the landscape locally, and that firewood and timber supply was responsible for major landscape transformations at the extra-local scale (reflected in the near/off-site records: Revelles, 2017).

Western Mediterranean: Closos de ca'n Gaià (Mallorca)

Insular Spain, Balearic Islands

1
2
3
4
5
6
7 *Bronze age (Naviform BA) to Iron age - 3650-2800 cal BP*

8 *Settlement, megalithic navetiform house (Navetiform 1)*

9 *Sampling: pollen, NPPs; macroremains: charcoal*

10 *7 pollen samples from on-site horizontal sampling; anthracological record from 7 archaeological*
11 *layers*

12 Key events: land transformation since c. 3350 cal BP related to the agropastoral expansion in
13 Mallorca; *Olea* wood resource management

14
15 The Naviform culture developed in the Balearic Islands during the Bronze age (from c. 3650/3550
16 to c.2800 cal BP; Lull et al., 2013). Naviform society constitutes the first sedentary megalithic
17 culture established on the archipelago, occupying all the islands biotopes. The productive
18 economy was based on cultivation of cereals and pulses (Pérez-Jordà et al., 2017) and on
19 sheep/goat, pigs and cattle husbandry, being the former the most numerous livestock (Ramis,
20 2017). The Closos de ca'n Gaià settlement included at least five domestic structures (navetiforms),
21 and some of them continued to be occupied throughout Iron Age (Oliver et al., 2017). Navetiforms
22 were monumental domestic spaces, consisting of large buildings with an elongated floor plan,
23 were inhabited by domestic groups and represented the *locus* in which the social life was
24 centralized (Fornés et al., 2009). In Closos de ca'n Gaià, the Navetiform 1 has been completely
25 excavated and presents four archaeological phases, ranging from a first occupation previous to the
26 building (Phase 1, c. 3650/3550 – 3350 cal BP), two subsequent building layers (Phase 2, c. 3350-
27 2950 cal BP; Phase 3, c. 2950-2800 cal BP) to the abandonment and subsequent roof collapse
28 (Phase 4, just after c. 2800 cal BP; Javaloyas et al., 2011). Archaeobotanical data show
29 agropastoral and wood management strategies at the site.
30

31 During the Bronze age the Balearic Islands had predominance of sclerophyllous vegetation (*Olea*,
32 *Pistacia*, Cistaceae, etc.; Fyfe et al. this volume) and crop and pasture fields (Burjachs et al., 2017;
33 Servera-Vives et al., 2018). The general picture of the plant landscape, as shown by both
34 anthracological and palynological records from the excavation, is consistent with off-site pollen
35 records from the Gymnesics (Mallorca and Menorca) for this period, with a mosaic landscape
36 dominated by macchia/garrigues and open areas (Figs. 2,3). The pre-megalithic occupation of the
37 site (Phase 1) was perpetuated by the construction of the Navetiform building (Phase 2), a
38 monumental house that was continuously occupied for several centuries (Javaloyas et al., 2011,
39 2013; Oliver et al., 2017).

40 Starting at c. 3350 cal BP there was a general decrease of arboreal pollen matching the expansion
41 of weeds, synanthropic taxa and grasslands. This correlates with archaeological data for increasing
42 land use. The exploitation of forest resources for firewood became quite specialized: (wild-)olive
43 dominates the charcoal assemblages whilst shrubs such as *Rhamnus/Phillyrea* and *Pistacia*
44 *lentiscus* become less used or available compared to the previous phase.

45 The integration of pollen and charcoal data mainly suggests that before the building (Phase 1)
46 landscape exploitation strategies were focussed around use of olive tree and understory forest
47 species for firewood provisioning and moderate agropastoral activities in a semi-open
48 environment surrounding the site. Following a noticeable landscape disruption associated with
49 Phase 2 (c. 3350 cal BP) pastoral activities expanded and (wild-)olive wood exploitation intensified
50 for firewood collection. Then, data show a variability in Phase 3 that probably reflects the spatial
51 distribution of samples within the house, reaching higher values of anemophilous tree pollen in
52 the front area, near the only entrance to the building (SU 9), compared to the inner one (SU 35;
53 [and see the charcoal from these SU in Fig. 3](#)).

The high values of anthropogenic pollen indicators and *Olea* charcoal fragments, found also in the roof collapse sample (Phase 4), testify to the land uses of the last occupation phase. This sediment is likely the result of the roof construction/maintenance and the subsequent post-collapse sedimentation in a context where the neighboring navetiforms of the settlement were still inhabited after the Bronze age.

The overall picture is that the Navetiform culture had a visible impact on the local lands, as well as regional impact that became therefore visible in the only off-site record available for Mallorca in the Albufera d'Alcúdia record (Fig. 1; Burjachs, 1994; Burjachs et al., 2017). This sequence shows the prevalence of thermophilous and sclerophilous taxa (e.g., *Olea*, *Pistacia*, etc.) during Bronze Age chronologies. Moreover, the increase of *Artemisia*, the high values of *Plantago* and the presence of *Rumex* highlights the existence of noticeable human activities in the area during this period.

Central Mediterranean: Terramara di Montale-Modena and Terramara Santa Rosa di Poviglio (Reggio Emilia, North Italy)

N Italy, Emilia Romagna: Terramara di Montale-Modena, Terramara Santa Rosa di Poviglio-Reggio Emilia

Middle to Recent Bronze Age – 3600-3170 cal BP

Settlement sites (open-air pile-dwelling, and then villages, in river meanders)

Sampling: pollen, NPPs; macroremains: seeds/fruits, charcoal

83 pollen samples from 3 on-site and one near-site series (trenches)

Key events: AP higher before the settlement of Montale, and water-rich environment near the rivers in the Po Plain; exploitation of woods and cereal field cultivation

The Terramare civilization developed in the Po Plain during the Middle and Recent Bronze Age (1650 – 1170 BC; Bernabò Brea et al., 1997), in a *quasi* open-land with fertile soils, rich of water and nutrients from the river floods. Before the onset of terramara settlements the landscape was largely natural with a fairly sparse, open canopy, forest growing in the area. Woods mainly consisted of deciduous *Quercus* and *Carpinus betulus* prevailing in mixed oak forests with *Acer*, *Fraxinus excelsior* type, *Ostrya carpinifolia*, *Tilia*, *Ulmus*, and *Corylus avellana*. They were also mixed with conifer (*Pinus* and *Abies*), whose woods were abundant during the early Holocene and were partly replaced by *Fagus* in the hills and mountains, and by mixed oak woods in the lower belts. At the onset of settlements, a sudden decrease of trees in pollen spectra mark the impressive use of woods for construction of houses (*Quercus* for piles, and *Fraxinus* and other trees for house walls) and palisades (*Carpinus betulus*; Mercuri et al., 2006a). Thousands of poles and posts, including charred trunks, have been discovered at the base floor of these archaeological sites (e.g. Rottoli, 1997). Reduction of *Alnus* pollen, alongside an increase in hydro-hygrophytes, has been interpreted as the clearance of river banks and construction of ditches (Mercuri et al., 2006a:56). The deforestation in the Po Plain was so extensive that it is visible even in off-site records (e.g. Adriatic Sea core RF93-30 which received sediments from the Po valley: Mercuri et al., 2012).

Each terramara consisted of a fortified village, with rows of houses surrounded by an embankment and a ditch. Its area of influence (the territory exploited and/or cultivated) was dependant on the size of the settlement, its distance from other sites and the chronological phase (Cardarelli, 1988). Terramaras were close to each other (> 220 sites have been discovered only in the province of Modena), one per 9-10 km, and sometimes per 2 km, with population estimates of c. 150,000

people in the later phase (Cremaschi, 1997; Cardarelli, 1997). Terramara di Montale is amongst the best studied sites. It had eleven occupational phases, with houses often destroyed by fire, and was settled in a south-eastern position, near the Apennines. Terramara Santa Rosa di Poviglio had two main phases, developing from a 'small village' (Villaggio Piccolo-VP) to a 'large village' (Villaggio Grande-VG).

A high presence of cereals (Cerealia-type pollen) is documented in all the sites (Mercuri et al., 2006b). Cereals were grown close to each village as their pollen records (Cerealia-type) are always detected in near-site sequences, and high values in on-site sequences are connected with plant transport and processing near the houses (Fig. 4). Some plots were cultivated for fodder (Fabaceae, including *Lotus*, *Medicago*, *Melilotus*, *Trifolium*) or left for fallow/grazing in the area of influence; the area of influence was surrounded by forests supplying wild fruits and defensive functions (Mercuri et al., 2015c). Comparison of on-site and near-site (P3) pollen records suggests that cereal fields were mostly cultivated towards the west around Montale, possibly in rotation or intercropping with legume fields (Mercuri et al., 2006b) whereas domestic animals were kept inside the settlement (presence of dung, and archaeozoological remains) and browsed grasses and fodder plants in small parcels and pastures rich of Cichorieae, all within the area of influence. Trees and wood management have a special role in this society, and first signals of *Vitis* cultivation emerged (Mercuri et al., 2006a, 2015a; Cremaschi et al., 2016). At the end of the Recent Bronze Age, this society rapidly vanished, probably forced by a combination of climatic, environmental and socioeconomic causes (Cremaschi et al., 2016).

Eastern Mediterranean: Dispiliò (northern Greece)

N Greece; Neolithic-Chalcolithic – 7750-5150 cal BP
Settlement site (on lake shore)

Sampling: pollen, NPPs, phytoliths; macroremains: seeds/fruits, charcoal
86 pollen samples from 2 on-site and one near-site series (cores)

Key events: exceptional location and long-time continuative occupation, at the shore of Lake Orestiás; cereal field cultivation in a diversified kind and intensive exploitation of natural resources

Dispiliò, near Lake Orestiás, also known as Lake Kastoria, is the first lake settlement systematically investigated in Greece. According to joint archaeological and radiocarbon data (Facorellis et al., 2014), the site was occupied for about 2000 years, from the Middle Neolithic (7500 cal BP) to the Chalcolithic (5500 cal BP) representing one of the earliest locations with unambiguous evidence of human disturbance in Greece. Earlier agropastoral activities associated with the Early Neolithic communities have been observed starting from at least 8300 cal BP in eastern Macedonia (Glais et al., 2016).

The establishment of the Dispiliò settlement (c. 7500 cal BP) took place within a landscape characterised by dense woodland cover. Mountainous coniferous forest and smaller areas with *Fagus* forest existed on the higher altitudes around the lake basin, whereas mixed deciduous oak forests with *Carpinus orientalis/Ostrya* type, *Corylus*, *Crataegus monogyna* and *Ulmus* covered intermediate and lower altitudes. Human activities resulted in the development of a mosaic of habitats in the surrounding area, reflected by local pollen assemblages that correspond to different kinds, or intensity, of exploitation of natural resources in space and time (Kouli and Dermitzakis 2008; Kouli, 2015).

Three periods of retreat of natural woodland and of major anthropic disturbance have been recognized, especially at intermediate altitudes. These are correlated with the three periods of

major constructing activities described by the archaeological study (Hourmouziadi and Yagoulis, 2002; Sofronidou, 2008). Two of them, corresponding to the Middle Neolithic (c. 7200 cal BP, ending with the destruction by fire of the settlement; Karkanis et al., 2011) and Late Neolithic II to Chalcolithic (c. 6000 cal BP) show evidence of intensive cultivation. Two episodes of woodland recovery are characterized by decrease of anthropogenic indicators in pollen spectra, representing a pause of pastoral activities between the major construction phases.

The inhabitants of Dispiliò were both agriculturalists and animal herders, but the kind and intensity of those activities were not consistent through time. Following the establishment of the settlement, cultivation produced abundant cereal pollen in the deposits, and cultivation remained one of the major activities of the Neolithic society. Pastoralism seems to have been a significant and diachronic activity, more intensively practiced in the first phases of the settlement. The peak of animal breeding is recorded at c. 6400 cal BP, reducing in importance afterwards while the peak in evidence for cereal cultivation is during the final occupation period of the Late Neolithic II-Chalcolithic. The on-site / near-site comparison demonstrated that cereal fields were cultivated in the close vicinity of the houses, in "garden-like" fields (Mangafa, 2002), whereas herds were kept around the settlement and not inside (Kouli, 2015).

Eastern Mediterranean: Arslantepe (Anatolia)

E Turkey; Late Chalcolithic, Late Uruk, Early Bronze Age – 6650-3950 cal BP

Settlement site (layered tell)

Sampling: pollen; macroremains: seeds/fruits, charcoal

12 pollen samples from on-site (short trenches); anthracological record from 7 archaeological layers

Key events: several sudden changes of populations followed one another in the settlement, implying continuous changes in occupation patterns and land-use

Arslantepe is located in the modern Malatya plateau, a region characterized by low precipitation both today and during prehistory. A large hydrogeological karst catchment supplies water to the plain allowing extensive agriculture since at least the Chalcolithic age (Masi et al., 2014). The site was settled several times at the same place, forming a tell in an open landscape characterized by trees such as deciduous and semi-deciduous oaks (*Quercus* sp.), elms (*Ulmus*), ashes (*Fraxinus*), and shrubs as junipers (*Juniperus*). The presence of a spring at the base of the tell and of a number of others in the close surroundings, favoured the growth of alders and poplars.

The palynological data comes from seven archaeological phases ranging from Late Chalcolithic 1–2 (6500 cal BP, VIII period) to Early Bronze Age III (4000 cal BP, VID2 phase). Contrasts between the charcoal and pollen records for tree taxa reveal important aspects of landscape exploitation. The pollen rain/human mounds show only low quantities of arboreal pollen. The human selection of timber appears to be quite clear: the charcoal record shows a dominance of deciduous *Quercus* followed by hydrophilous (*Alnus*, *Populus*, *Tamarix*) and hygrophilous (*Fraxinus*, *Ulmus*) trees (Fig. 3; Sadori et al., 2006). These abundant taxa are either poorly represented in the pollen record (deciduous *Quercus*) or not present at all (*Alnus*). *Castanea*, *Juglans* and *Corylus*, present in the pollen samples, are not found either in the charcoal or seed records.

The results indicate that woody plants were mainly exploited from woody steppe / shrubland in which Rosaceae played an important role, and from the riparian vegetation. Mountain taxa such as *Juniperus*, and *Pinus* play only a minor role. The selection of the timber appears mainly linked to the different cultural and socio-economic traits of the Arslantepe communities. Palaeoclimatic

1
2
3
4
5
6
7 reconstruction based on stable carbon isotope demonstrated that environmental changes played
8 only a marginal role in the different wood exploitation (Masi et al., 2013a,b; Vignola et al., 2017,
9 2018). Charcoal analysis shows important changes in plant use not matching the environmental
10 changes. The different occurrence of taxa according to the depositional context highlights that the
11 hydrophilous plants prevail in building structures, with the exception of the c. 4900–4500 cal BP
12 period: isotope data demonstrate that during this period there was an increased humidity;
13 nevertheless, there was a prevalent use of woodland-steppe plants (Masi et al., 2018).
14 There are no off-site pollen records for reconstructing extra-local or regional vegetation. The
15 closest is the lake Van record (300 km far from Arslantepe) with tree pollen between 40 and 50%
16 during Chalcolithic and early Bronze Age levels (Wick et al., 2003).

17 18 | **RESULTS AND DISCUSSION**

19 20 **Comparing data, sites and land-uses**

21
22 The detailed data from the archaeobotanical studies described here provide information about
23 the ‘small histories’ of land use in single sites from different regions. However, major common
24 themes in plant exploitation can be revealed by the comparison of the main pollen curves from all
25 sites, and show the variability of this history at a regional scale.

26
27 The percentages of total AP and *Quercus* pollen (**Fig. 2**) outline the role of trees in prehistory as a
28 substantial and indisputable natural resource (for fuel, construction, metallurgy, tools and
29 ploughs, and wild fruit picking). The different diagrams show similar general patterns: a) the
30 trends of decrease of woodland cover (also possibly reflecting climatic changes?); b) declines in
31 trees at the onset of settlement; c) notable declines in oaks in particular within the deforestation
32 events (e.g. at La Draga and in the terramare); d) alternative cycles of retreat and recovery of
33 woodland depending on intensity of human activities (e.g. at Dispiliò); e) elevated local
34 representation of oak pollen due to the transport of wood into the site (e.g. Arslantepe, where
35 oaks prevails also in the anthracological record: **Fig. 3**). Human-related declines in AP/*Quercus*
36 match usage for house/palisade buildings and fuel for metallurgy, while other activities, such as
37 fruit collection, may rely on tree survival and wood management. Care for the survival of trees
38 may have been the case of high pollen values of *Juglans* at Arslantepe, or of *Corylus* and *Vitis*
39 at the Terramara Santa Rosa di Poviglio. The different local availability of the Mediterranean
40 vegetation caused the large use of *Olea* wood at Closos de ca’n Gaià (**Fig. 3**).

41
42 The trends of both the OJC tree sum and the Cereals vs. Cichorieae herb sums are among the best
43 indicators of land use (**Fig. 4**). There are signals of cultivation and pastoral activities in all the sites,
44 but their representation is variable. OJC are present but sporadic, fragmentary evidence in the
45 archaeological sites (except the only *Olea* in Closos de ca’n Gaià). This seems to be in contrast with
46 what may be visible in some off-site records (Mercuri et al., 2013a; Stoddart et al., this issue).
47 Cultural trees were grown or cultivated far from the settlements: they were cared for, managed
48 but not transplanted near the sites, and sites seem to have not been settled near stands of these
49 (even wild) trees. At a regional scale, the increase of the OJC curve appears later, around 3000-
50 2700 cal BP in off-site records, when arboriculture begins in central Italy (Mercuri et al., 2002;
51 Stoddart et al., this issue; [Langgut et al., this issue](#)).

52 Instead of trees, crop fields were established and cultivated close to the sites. Representation of
53 cereals in on-site records can be very high due to plant processing from the very start of use of the

1
2
3
4
5
6
7 site (as at La Draga and Montale), or during the life of the settlements (e.g. Dispiliò and
8 Arslantepe). The regularly opposite trends of cereal and cichory pollen (at La Draga, Montale,
9 Dispiliò; **Fig. 4**) marks the alternation (either replacement or rotation) of crop fields and pastures
10 as alternative/complimentary land uses over these prehistoric times in different contexts and
11 countries. Whilst increases in cichory may suggest abandonment of fields, it appears to
12 correspond to a real alternative (pastoral) land-use. This practice, even if casually introduced and
13 then maintained, had the advantage of adding manur to soils (from the dung of browsing animals)
14 following some years of high nitrogen-demanding cereal cultivation.
15 All the sites were settled near wet environments, surrounded by grasslands and mixed oakwoods,
16 and with variable amount of synanthropic taxa (**Figs. 5,6**).

17
18 The PCA, based on individual taxa, besides all the sums considered above, provides further data
19 comparison showing that the wild and synanthropic pollen taxa cluster differently along the Axis 1
20 and Axis 2 principal component functions (**Fig. 7**). The samples are organized mainly by vegetation
21 types and fall along a forested to an opened landscape gradient. Interestingly, the samples of each
22 site cluster within the ordination plot, with little overlap between sites. This shows that sites have
23 their own features and suggests that Neolithic and Bronze age sites have different focuses on land
24 uses and cultural skills.

25 The sites with a higher number of samples (La Draga, Poviglio, Dispiliò and Montale) show an
26 elongated distribution in relation to Axis 1, representing the highest variability probably related to
27 the long term vegetation and land-uses changes. As described, the gradient along Axis 1
28 represents a transition from more forested (lower values) to more open vegetation (higher
29 values). The Neolithic lakeshore sites of La Draga and Dispiliò cluster along more forested
30 landscapes according a gradient ranging from the more wooded environments (especially La
31 Draga) towards more opened landscape (Dispiliò). Both sites are linked to crops and forested
32 landscapes according to their position on Axis 2, rather than pasturelands. The Italian Bronze Age
33 sites of Poviglio and Montale cluster differently: on Axis 2 the first site is linked to pastureland and
34 wetlands while the second mainly to grasslands and anthropic environments. The position of their
35 samples on Axis 1 shows a predominantly open landscape. Closos and Arslanstepe show positive
36 values in Axis 1 indicating their relation to more opened areas. Both sites are characterized by
37 open woodlands with scattered pasturelands and crops.

38 The PCA confirms the different relationships with the environment during the Neolithic and the
39 Bronze age, underlying an increasing importance given to wood exploitation over time.
40

41 **From Neolithic to Bronze age land use**

42
43 In the earliest times, hunter-gatherers had a 'less permanent' interference with vegetation
44 dynamics because both humans and plants were part of the same ecosystems. Although
45 intermediate forms of environment exploitation between gathering and food production have
46 been recognised in the Levant and the Sahara (Willcox et al., 2012; Clarke et al., 2016; Mercuri et
47 al., 2018), evidence for this in Mediterranean records is weak and still hard to investigate. The
48 increase of sedentism resulted in communities exploiting the same territory over long periods of
49 time, agriculture expansion and technological development, causing a deeper transformation of
50 the landscape (Mercuri et al., 2011).

51 Despite the different chronological phases and social organization, and based on the
52 morphological and botanical geographical features, the trend of landscape transformation in the
53 different Mediterranean regions may be regarded as having some similar trends. First,
54
55
56
57
58
59
60

1
2
3
4
5
6
7 anthropogenic influence on plant cover, soils and waters firstly occurred in the vicinity of
8 settlements, and all archaeological sites preserve evidence of anthropogenic pollen indicators.
9 Second, actions on the environment and development of forestry alongside agriculture caused the
10 expansion of human influence on the environment, and the local pressure expanded toward a
11 regional impact, becoming recognisable in off-site records more distant from the archaeological
12 sites (Mercuri et al., 2010; Kouli, 2015). Human impact at a regional scale depends on the cultural
13 variables, demography, distance from the settlement sites and the intensity of activities
14 undertaken. Holocene climate variability and instability, forest clearance and management, wood
15 exploitation for metallurgy, crop cultivation, animal breeding and pastoralism are the primary
16 agents that have transformed land cover in the Mediterranean landscape. Palynology from
17 archaeological sites (so-called on-site palynology) is essential to recognise the first influence of
18 humans, as activities begin in/close/next to the occupied/settled sites. It also allows us to
19 recognise and categorise the type of land-use activities undertaken, sometimes also inferring its
20 intensity by combining archaeobotanical data with archaeo- and geo-data.

21
22 The sites of La Draga (7270-6750 cal BP) and Terramara di Montale (3550-3200 cal BP) show
23 similar land-use dynamics implying oak exploitation, causing local deforestation, and cultivation of
24 cereal fields in the area or around the site. Despite the different chronology and culture, tree
25 decreases and the subsequent soil erosion were so extensive that evidence can be found even
26 beyond the sites (Oldfield et al., 2003; Revelles et al., 2015). Nevertheless, there are clear
27 differences between the Neolithic influence and the Bronze age impact.

28
29 According to Revelles (2017:441) Early Neolithic human actions have been recorded at different
30 degrees of intensity on local and extra-local scales in the area of Lake Banyoles (the region in
31 which La Draga is situated). The signal of farming is only identifiable in on-site records, confirming
32 the limited impact of cereal cultivation by the first farmers. Whilst deforestation is not visible in
33 the core from Lake Banyoles, it is in core SB2, closer to La Draga (**Fig. 8**). The core SB2 can thus
34 reflect the scale of the area of influence of the settlement and can be considered as a 'near-site'
35 core. This mirrors different pollen production, distance of the pollen sources from the site,
36 transport of plants into the site and intensity of the human action in transforming the landscape
37 (Mercuri, 2014). The process of deforestation was not monotonic, as broadleaf deciduous forests
38 recovered during the later Neolithic after the end of human pressure in northeast Spain (Revelles,
39 2017; Fyfe et al., this issue). In north Greece, similar woodland dynamics occurred during the
40 settlement development and Neolithic land-use at Dispiliò, following occupation and temporary
41 abandonment phases but again the process is not visible in the off-site core of Lake Dojran (**Fig. 8**;
42 Kouli, 2015), or in the woodland vegetation clusters of northern Greece (Weiberg et al., this issue).

43
44 Three thousand years later, in eastern Anatolia, groups of people at Arslantepe exploited the oaks
45 and hydro-hygrophilous trees, not only searching for the most available (those arid highlands were
46 almost treeless or covered by shrublands), and were highly selective of the timber most suitable
47 for building and fire. In northern Italy, the terramare villages settled on the Po Plain. Because
48 settlements need space and houses, considerable deforestation supplied timber for houses,
49 palisades, furnaces and tools. Population levels and technological skills gave this culture both the
50 motivation and ability to deeply shape the landscape, changing the river courses and the
51 distribution of woods and open spaces (Cremaschi, 1997; Cardarelli, 1997). This transformation
52 became irreversible leaving traces in off-site pollen diagrams distant from the area (Mercuri et al.,
53 2012). Terrestrial cores such as lakes of Albano and Nemi show evidence of rapid forest changes,
54 probably reflecting the proximity of other archaeological sites present in the peninsula (as shown
55
56
57
58
59
60

1
2
3
4
5
6
7 by BRAIN). These lakes can be, therefore, classified as near-sites as, for example, the Bronze age
8 'Villaggio delle Macine' is still visible at the shores of Lago Albano.
9 In the later Bronze age phases, the people of Closos de ca'n Gaià selectively exploited (wild) olive
10 wood and other sclerophyll maquis species for different purposes, confirming that local wood was
11 a very good, versatile, natural resource and the inhabitants of Mallorca learned how to exploit it
12 (Picornell-Gelabert & Servera-Vives, 2017), possibly also spreading plants.
13 Transport of trunks might have been a hard task, and thus may be reasonably considered a local
14 (near-site) activity and, as mentioned above, the manipulation of trees has left marked signals in
15 pollen diagrams. In the Mediterranean, however, off-site records often contain anthropogenic
16 pollen indicators and archaeological survey demonstrate that human traces are spread all over
17 entire regions (Mercuri et al., 2011; Roberts et al. *this issue*; Weiberg et al. *this issue*). From the
18 Neolithic onwards, it is difficult to find records that are wholly 'natural'. Traces of human influence
19 or impact can be found even in sequences collected at 30-40 km distance from one particular site,
20 both because of the proximity of other sites, and of the regional spread of the impact in the areas
21 of influence of the archaeological sites which increases through time.

22 The off-site records are useful in demonstrating that natural sequences in the Mediterranean area
23 are rare due to the long history of presence and land-use by the civilizations that occupied these
24 territories even before the Neolithic. For example, off-site records can intercept anthropic signals
25 when i) the sites are close to archaeological sites (e.g., lake shores settled by pile dwellings: Lago
26 Lucone, Valsecchi et al., 2006; Lago Mezzano, Sadori, submitted), ii) the human action is
27 extensively spread in the area, and iii) the cores collect sediments from regions modified by
28 human activities (Adriatic RF93-30 shows unambiguous signs of land-use in the Po valley; Mercuri
29 et al., 2012), iv) the land-use is definitively turned to a land-cover transformation at regional scale
30 (e.g., Mensig et al., 2018). All considered, the archaeological sites discussed in this paper testify to
31 a diversified set of land uses at each cultural phase. At La Draga people practised forest
32 exploitation and cereal cultivation, at Dispiliò people performed husbandry and farming, whilst
33 people at Arslantepe stored impressive quantities of cereals and exploited oaks. The terramare
34 culture was able to manage the forest, and performed a diversified agriculture with crop
35 cultivation and animal breeding at the same site, while the Navetiform groups practised a
36 combined activity of understory and olive tree exploitation with pastoral activities.
37
38
39

40 CONCLUSIONS

41
42 Archaeobotany and the interpretation of data from on-site studies demonstrate that land use has
43 been a multifaceted process involving original and repetitive human behaviour. Since the Neolithic
44 and into the Bronze age people have adopted a diffused pattern of land use involving a
45 combination of diverse activities performed in the same territory. The most recurrent
46 combinations included wood exploitation, field cultivation and animal breeding, and the set of
47 activities provided the ensemble of timber/fuel, crops/food, milk/meat, respectively. Considering
48 that land-use is a subsector of the human impact, this conclusion confirms that "human impact is a
49 collective concept including the ensemble of adaptive strategies, technological outputs and
50 interferences between cultural needs and natural ecosystem dynamics" (Mercuri et al.,
51 2015b:136).

52 The presence of cultures in Mediterranean lands is impressive. Each lived in different territories
53 with their own characteristics and identity. The archaeological approach tends to consider one
54
55
56
57
58
59

activity – one type of economy – one adaptation strategy prevalent over others in a way that each culture seems to have been centred on one type of land-use. However, pollen and other plant records tell us that different land-uses co-existed at the same site in the Mediterranean. Although it is true that different land use activities were performed by different cultures, archaeobotanical data show that different uses of natural resources have been performed by the same culture (and we can also argue that possibly different people, as today, were involved in different works, depending on the social organization and degree of specialisation within communities). This skilful way allowed communities to exploit the full spectrum of natural resources offered by the Mediterranean biodiversity, and helped people to cross the environmental instability of the mid and late Holocene. Local signals of the different land-uses are evident at each site, confirming that this has been an ancient and common pattern, even when they are not evident or soft/thinner in the off-site records where we cannot be sure that the same land space was used for different purposes.

Agriculture and forestry have become progressively more specialised and intensive in the Mediterranean, and are facing global environmental and economic challenges in common with many other regions of the world. The lesson from the past - [here the prehistory](#) - is that the multifunctional land-use, combining silvo-pastoral and crop farming mixed systems, is probably more sustainable than monoculture and a promising way to develop the rural economy. Multifunctional land use is not only recognisable at regional scale (where may be ambiguous because plant records in one point synthesize a large area) but it is especially evident in pollen and charcoal/macrobotanical records at the site scale. The multifunctional exploitation of the area of influence in each site can be regarded as a clever strategy that acted on reducing the pressure on the environment of permanent settlements facilitating the life of sedentary people. What is generally considered a recent and just lost strategy of traditional agriculture, in use during the last two centuries, seems to have been an important practice and very adaptive human behaviour in the instability of the mid and early-late Holocene of the prehistoric Mediterranean.

Acknowledgements

A.M.M. planned with A.F. and wrote the main text; J.R. and J.B. studied La Draga; K.K. studied Duspiliò; L.S., A.M., M.G. studied Arslantepe; L.P.G. and G.S.V. studied Closos de ca'n Gaià; A.M.M., P.T., A.F. studied terramaras; R.F. promoted the teamwork, and improved the English; A.F., L.P.G. and G.S.V. elaborated data; A.M.M., L.S. and G.S.V. prepared the diagrams. All authors shared data, wrote the relevant parts of the text, read and approved the final manuscript.

The research on the terramare culture is part of the activity of the project SUCCESO-TERRA (Human societies, climate/environment changes and resource exploitation/sustainability in the Po Plain at the Mid-Holocene times: the Terramaras; Ministero dell'Istruzione, dell'Università e della Ricerca PRIN-20158KBLNB; coord. Mauro Cremaschi, University of Milan) entrusted to A.M.M.

The research at Closos de ca'n Gaià has been founded by Ajuntament de Felanitx, Consell Insular de Mallorca and the research project financed by the Spanish Ministry of Economy and Competitiveness: "Archipelagos: landscapes, insular prehistoric communities and connectivity strategies in the western Mediterranean. The case of the Balearic Islands during the recent prehistory (2500–123 BC) (HAR2015, 67211-P)". The work of G.S.V. has been founded by "Programa Vicenç Mut d'Incorporació de Personal R+D+I (Pla de Ciència, Tecnologia, Innovació i Emprenedoria 2013-2017) de la Vicepresidència i Conselleria d'Innovació, Recerca i Turisme del Govern de les Illes Balears i el Fons Social Europeu (PD-018-2017)". The work of L.P.G. has been funded by the Ministry of Economy and Competitiveness of Spanish Government (Juan de La Cierva Program: IJCI-2015-24550).). The work of K.K. was funded by EU & GSRT/Greece (PENED95ED1983) and NKUA project (KA14168).

A.M., M.G. and L.S. wish to acknowledge Marcella Frangipane and Francesca Balossi Restelli for the continuous advice in the study of the plant remains from Arslantepe; a special thank is due to Cristiano Vignola for his help in pollen sampling.

References

- Antolín F, Buxó R, Jacomet S, Navarrete V and Saña M (2014) An integrated perspective on farming in the early Neolithic lakeshore site of La Draga (Banyoles, Spain). *Environmental Archaeology* 19 (3): 241-255.
- Behre KE (1981) The interpretation of anthropogenic indicators in pollen diagrams. *Pollen et Spores* 23: 225-245.
- Behre KE (1990) Some reflections on anthropogenic indicators and the record of prehistoric occupation phases in pollen diagrams from the Near East. In: Bottema S, Entjes-Nieborg G and van Zeist W (eds.) *Man's Role in the Shaping of the Eastern Mediterranean Landscape*. Rotterdam: Balkema, pp.219-230.
- Bernabò Brea M, Cardarelli A and Cremaschi M (eds) (1997) *Le Terramare, la più antica civiltà padana*. Milano: Elemond Editori Associati, Electa.
- Bosch A, Chinchilla J, Tarrús J, Lladó E and Saña M (2008) Uso y explotación de los bóvidos en el asentamiento de la Draga Banyoles, Catalunya. In: *IV Congreso del Neolítico Peninsular* (eds MS Hernandez, JA Saler y JA Lopez), Alicante 27-30 de noviembre de 2006, pp.326–331. Alicante: MARQ y Deputacion Provincial de Alicante.
- Bottema S (1982) Palynological investigations in Greece with special reference to pollen as an indicator of human activity. *Palaeohistoria* 24: 257–288.
- Bottema S and Woldring H (1990) Anthropogenic indicators in the pollen record of the eastern Mediterranean. In: Bottema S, Entjes-Nieborg G, van Zeist W (eds) *Man's role in the shaping of the eastern Mediterranean Landscape*. Rotterdam, Boston: AA Balkema, pp.231–264.
- Burjachs F (1994) Palynology of the upper Pleistocene and Holocene of the north-east Iberian Peninsula: Pla de l'Estany (Catalonia). *Historical Biology* 9, 17–33.
- Burjachs F, Pérez-Obiol R, Picornell-Gelabert L, Revelles J, Servera-Vives G, Expósito I *et al.* (2017) Overview of environmental changes and human colonization in the Balearic Islands and their impacts on vegetation: a review. *Journal of Archaeological Science: Reports* 12: 845-859.
- Burney DA and Flannery TF (2005) Fifty millennia of catastrophic extinctions after human contact. *Trends in Ecology & Evolution* 20, 395-401.
- Cappers RTJ (ed) (2005) *Fields of change: progress in African archaeobotany*. Groningen: Barkhuis & Groningen University Library.
- Cappers RTJ and Neef R (2012) *Handbook of Plant Palaeoecology*. Groningen: Barkhuis & Groningen University Library.
- Cardarelli A (1988) L'eta del Bronzo: organizzazione del territorio, forme economiche, strutture sociali. In: Cardarelli A (ed) *Modena dalle origini all'anno Mille. Studi di archeologia e storia I*. Modena: Edizioni Panini, pp.86–127.
- Cardarelli A (1997) The evolution of settlement and demography in the Terramare culture. In: Rittershofer K-F (ed) *Demographie der Bronzezeit. Paläodemographie-Möglichkeiten und Grenzen. Internationale Archäologie* 36: 230-237.

- 1
2
3
4
5
6
7 Clarke J, Brooks N, Banning EB, Bar-Matthews M, Campbell S, Clare L *et al.* (2016) Climatic changes and
8 social transformations in the Near East and North Africa during the 'long' 4th millennium BC: A comparative
9 study of environmental and archaeological evidence. *Quaternary Science Review* 136: 96-121.
- 10 Colombaroli D, Vannièrè B, Emmanuel C, Magny M and Tinner W (2008) Fire-vegetation interactions during
11 the Mesolithic-eolithic transition at Lago dell'Accesa, Tuscany, Italy. *The Holocene* 18(5): 679-692.
- 12
13 Cremaschi M (1997) Terramare e paesaggio padano. In: Bernabò Brea M, Cardarelli A, Cremaschi M (eds) *Le*
14 *Terramare. La piu` antica civiltà padana*. Milano: Elemond Editori Associati, Electa, pp.107-125.
- 15
16 Cremaschi M, Mercuri AM, Torri P, Florenzano A, Pizzi C, Marchesini M *et al.* (2016)
17 Climate change versus land management in the Po Plain (Northern Italy) during the Bronze Age: New
18 insights from the VP/VG sequence of the Terramara Santa Rosa di Poviglio. *Quaternary Science Reviews*
19 136: 153-172.
- 20 Facorellis Y, Sofronidou M and Hourmouziadis G (2014) Radiocarbon Dating of the Lakeside Settlement of
21 Dispilio, Kastoria, Northern Greece. *Radiocarbon* 56(2): 511-528.
- 22
23 Faegri K, Kaland PE and Krzywinski K (eds) (1989) *Textbook of Pollen Analysis*. IV edn. Wiley & Sons.
- 24 [Food and Agriculture Organization/United Nations Environmental Programme FAO/UNEP](#)
25 [\(1999\) Terminology for Integrated Resources Planning and Management. Rome, Italy and Nairobi, Kenya.](#)
- 26
27 [Fornés J, Javaloyas D, Salvà B, Belenguer C, Mates F, Servera G *et al.* \(2009\) Más que una casa. Los](#)
28 [navetiformes en el Bronce Balear. In: Belarte C \(ed\) *El espacio doméstico y la organización de la sociedad en*](#)
29 [la protohistoria del Mediterráneo occidental \(Ier milenio aC\) ArqueoMediterrània 11, Tarragona: ICAC.](#)
- 30
31 Florenzano A, Marignani M, Rosati L, Fascetti S and Mercuri AM (2015) Are Cichorieae an indicator of open
32 habitats and pastoralism in current and past vegetation studies? *Plant Biosystems* 149(1): 154-165.
- 33
34 Florenzano A, Mercuri AM, Rinaldi R, Rattighieri E, Fornaciari R, Messori R *et al.* (2017) The
35 Representativeness of *Olea* Pollen from Olive Groves and the Late Holocene Landscape Reconstruction in
36 Central Mediterranean. *Frontiers in Earth Science* 5:85-96.
- 37 [Food and Agriculture Organization/United Nations Environmental Programme FAO/UNEP](#)
38 [\(1999\) Terminology for Integrated Resources Planning and Management. Rome, Italy and Nairobi, Kenya.](#)
- 39
40 [Fornés J, Javaloyas D, Salvà B, Belenguer C, Mates F, Servera G *et al.* \(2009\) Más que una casa. Los](#)
41 [navetiformes en el Bronce Balear. In: Belarte C \(ed\) *El espacio doméstico y la organización de la sociedad en*](#)
42 [la protohistoria del Mediterráneo occidental \(Ier milenio aC\) ArqueoMediterrània 11, Tarragona: ICAC.](#)
- 43
44 Fyfe R, Woodbridge J, Palmisano A, Bevan A, Shennan S, Burjachs F *et al.* (this issue) Eastern Iberia: regional
45 land cover, vegetation and settlement.
- 46
47 Glais A, Antonio López-Sáez J, Lespez L and Davidson L (2016) Climate and humane environment
48 relationships on the edge of the Tenaghi-Philippou marsh (Northern Greece) during the Neolithization
49 process. *Quaternary International* 403: 237-250.
- 50
51 Grimm, E.C., 2015. Tilia/TGView 2.0.41. Illinois State Museum, Research and Collections Center, Springfield,
52 IL.
- 53
54 Hourmouziadis A and Yagoulis T (2002) Problems and methods concerning the spatial characteristics. In:
55 Hourmouziadis GH (ed) *Dispilio 7.500 years after*. Thessaloniki: University Studio Press, pp.37-74.
- 56
57
58
59
60

- 1
2
3
4
5
6
7
8 IPCC - Intergovernmental Panel on Climate Change (2000) Land use, land-use change, and forestry. Special
9 Report. Available at: www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=45
- 10 Jahns S. (1993) On the Holocene vegetation history of the Argive Plain (Peloponnese, southern Greece).
11 *Vegetation History and Archaeobotany* 2: 187-203.
- 12
13 Jahns S. (2005) The Holocene history of vegetation and settlement at the coastal site of lake Voukaria in
14 Acarnania, western Greece. *Vegetation History Archaeobotany* 14: 55-66.
- 15
16 Javaloyas D, Fornés J, Salvà B, Oliver LI and Servera-Vives G (2011) Concepcions espacials a l'Edat del
17 Bronze. Els navetiformes: entre l'espai públic i el privat. In: III Jornades d'arqueologia de les Illes Balears.
18 (coord. Gual J.) Maó 3-4 octubre 2008, pp.23-34. Maó : Consell Insular de Menorca.
- 19
20 Javaloyas D, Fornés J, Oliver LI and Salvà B (2013) Informe de la campanya d'excavació de 2011 del jaciment
21 dels Closos de Can Gaià (Portocolom, Felanitx). In: F Tugores and A Lozano (Coord.) Memòria del Patrimoni
22 Cultural. Intervencions autoritzades pel Consell de Mallorca. 2010-2011. Palma de Mallorca: Direcció
23 Insular de Cultura i Patrimoni
- 24
25 Karkanis P, Pavlopoulos K, Kouli K, Ntinou M, Tsartsidou G, Facorellis Y *et al.* (2011) Paleoenvironment and
26 site formation processes of the Neolithic lakeside site of Dispilio, Kastoria, Northern Greece.
27 *Geoarchaeology* 26: 83–117.
- 28
29 Kouli K (2012) Vegetation development and human activities in Attiki (SE Greece) during the last 5000
30 years. *Vegetation History and Archaeobotany* 21: 267–278.
- 31
32 Kouli K (2015) Plant landscape and land use at the lake settlement of Dispilió (Macedonia, Northeastern
33 Greece). *Plant Biosystems* 149(1): 195-204.
- 34
35 Kouli K and Dermitzakis MD (2003) Archaeopalynology and Cultural landscape. In: Proceeding of the
36 Archaeological Symposium "The Prehistoric research in Greece and its perspectives: Theoretical
37 and Methodological considerations", Thessaloniki-Kastoria, 26-28 November 1998, pp. 129-137
- 38
39 Kouli K and Dermitzakis MD (2008) Natural and cultural landscape of the Neolithic settlement of Dispilió:
40 palynological results. *Hellenic Journal of Geosciences* 43: 29-39.
- 41
42 Kouli K, Masi A, Mercuri AM, Florenzano A and Sadori L (in press) Regional vegetation histories: an overview
43 of the pollen evidence from the Central Mediterranean. In: Izdebski A and Mulryan M (eds) *Environment
44 and Society in the first millenium AD*. Late Antique Archaeology 13. Leiden: Brill.
- 45
46 López-Bultó JO (2015) *Processos d'obtenció, transformació i ús de la fusta en l'assentament neolític antic de
47 la Draga (5320-4800 cal BC)* PhD Thesis, Universitat Autònoma de Barcelona.
- 48
49 López-Sáez JA, Burjachs F, López Garcia P and López Merino L (2006) Algunas precisiones sobre el muestreo
50 e interpretación de los datos en arqueopalinología. *Polen* 15: 17–29.
- 51
52 Lull V, Micó R, Rihuete Herrada C and Risch R (2013) The Bronze age in the Balearic Islands. In: Fokkens H
53 and Harding A (eds.) *The Oxford Handbook of the European Bronze Age*. Oxford University Press.
- 54
55 Mangafa M (2002) Archaeobotanical study of the Dispilio lake settlement. In: Hourmouziadis GH, (ed)
56 *Dispilio 7.500 years after*. Thessaloniki: University Studio Press, pp.115–134.
- 57
58
59
60

1
2
3
4
5
6
7 Marinova E, Tonkov S, Bozilova E and Vajsov I (2012) Holocene anthropogenic landscapes in the Balkans:
8 the palaeobotanical evidence from southwestern Bulgaria. *Vegetation History and Archaeobotany* 21: 413-
9 427.

10 [Masi A, Sadori L, Balossi Restelli F, Baneschi I and Zanchetta G \(2014\) Stable carbon isotope analysis as crop
11 management indicator at Arslantepe \(Malatya, Turkey\) during the Late Chalcolithic and Early Bronze Age.
12 *Vegetation History and Archaeobotany* 23: 751-760.](#)

13
14 [Masi A, Balossi Restelli F, Sabato D, Vignola C and Sadori L \(2018\) Timber exploitation during the 5th-3rd
15 millennia BCE at Arslantepe \(Malatya, Turkey\): environmental constraints and cultural choices.
16 *Archaeological and Anthropological Sciences* 10: 465-483.](#)

17 Masi A, Sadori L, Baneschi I, Siani AM and Zanchetta G (2013a) Stable isotope analysis of archaeological oak
18 charcoal from eastern Anatolia as a marker of mid-Holocene climate change. *Plant Biology* 15 (Suppl 1): 83-
19 92.

20
21 Masi A, Sadori L, Zanchetta G, Baneschi I and Giardini M (2013b) Climatic interpretation of carbon isotope
22 content of Mid-Holocene archaeological charcoals from eastern Anatolia. *Quaternary International* 303: 64-
23 72.

24 [Masi A, Sadori L, Balossi Restelli F, Baneschi I and Zanchetta G \(2014\) Stable carbon isotope analysis as crop
25 management indicator at Arslantepe \(Malatya, Turkey\) during the Late Chalcolithic and Early Bronze Age.
26 *Vegetation History and Archaeobotany* 23: 751-760.](#)

27
28 [Masi A, Balossi Restelli F, Sabato D, Vignola C and Sadori L \(2018\) Timber exploitation during the 5th-3rd
29 millennia BCE at Arslantepe \(Malatya, Turkey\): environmental constraints and cultural choices.
30 *Archaeological and Anthropological Sciences* 10: 465-483.](#)

31
32 Maslow AH (1943) A Theory of Human Motivation. *Psychological Review* 50: 370-396.

33
34 Mazier F, Galop D, Gaillard MJ, Rendu C, Cugny C, Legaz A *et al.* (2009) Multidisciplinary approach to
35 reconstructing local pastoral activities- an example from the Pyrenean Mountains (Pays Basque). *The
36 Holocene* 19: 171-188.

37 Mensig SA, Shoolman EM, Tunno I, Noble PJ, Sagnotti L, Florindo F, Piovesan G (2018) Historical ecology
38 reveals landscape transformation coincident with cultural development in central Italy since the Roman
39 Period. *Scientific Reports* 8: 2138.

40
41 Mercuri AM (2008) Plant exploitation and ethnopalynological evidence from the Wadi Teshuinat area
42 (Tadrart Acacus, Libyan Sahara). *Journal of Archaeological Science* 35 (6): 1619-642.

43
44 Mercuri AM (2014) Genesis and evolution of the cultural landscape in central Mediterranean: The 'where,
45 when and how' through the palynological approach. *Landscape Ecology* 29: 1799-1810.

46
47 Mercuri AM and Sadori L (2014) Mediterranean culture and climatic change: Past patterns and future
48 trends. In: Goffredo S, Dubinsky Z (eds) *The Mediterranean Sea: Its history and present challenges*.
Dordrecht: Springer, pp.507-527.

49
50 [Mercuri AM, Allevato E, Arobba D, Bandini Mazzanti M, Bosi G, Caramiello R *et al.* \(2015a\) Pollen and
51 macroremains from Holocene archaeological sites: A dataset for the understanding of the bio-cultural
52 diversity of the Italian landscape. *Review of Palaeobotany and Palynology* 218: 250-266.](#)

1
2
3
4
5
6
7 Mercuri AM, Accorsi CA and Bandini Mazzanti M (2002) The long history of *Cannabis* and its cultivation by
8 the Romans in central Italy, shown by pollen records from lago Albano and lago di Nemi. *Vegetation History*
9 *and Archaeobotany* 11 (4): 263-276.

10
11 Mercuri AM, Accorsi CA, Bandini Mazzanti M, Bosi G, Cardarelli A, Labate D *et al.* (2006a). Economy and
12 environment of Bronze Age settlements–Terramaras–on the Po Plain (Northern Italy): First results from the
13 archaeobotanical research at the Terramara di Montale. *Vegetation History and Archaeobotany* 16 (1): 43-
14 60.

15 Mercuri AM, Accorsi CA, Bandini Mazzanti M, Bosi G, Trevisan Grandi G, Cardarelli A *et al.* (2006b) Cereal
16 fields from the Middle-Recent Bronze Age, as found in the Terramara di Montale, in the Po Plain (Emilia
17 Romagna, Northern Italy), based on pollen, seeds/fruits and microcharcoals. In: Morel JP, Tresseras Juan J
18 and Matamala JC (eds), *The Archaeology of Crop Fields and Gardens*. Centro Studi Europei per i Beni
19 Culturali, Edipuglia, pp.251-270.

20 ~~Mercuri AM, Sadori L and Blasi C (2010) Archaeobotany for cultural landscape and human impact~~
21 ~~reconstructions. *Plant Biosystem* 144: 860–864.~~

22
23 ~~Mercuri AM, Sadori L and Uzquiano Ollero P (2011) Mediterranean and north-African cultural adaptations~~
24 ~~to mid-Holocene environmental and climatic changes. *The Holocene* 21(1): 189–206.~~

25
26 Mercuri AM, Bandini Mazzanti M, Torri P, Vigliotti L, Bosi G, Florenzano A *et al.* (2012) A marine/terrestrial
27 integration for mid-late Holocene vegetation history and the development of the cultural landscape in the
28 Po Valley as a result of human impact and climate change. *Vegetation History and Archaeobotany* 21: 353–
29 372.

30 Mercuri AM, Bandini Mazzanti M, Florenzano A, Montecchi MC, Rattighieri E (2013a) *Olea*, *Juglans* and
31 *Castanea*: The OJC group as pollen evidence of the development of human induced environments in the
32 Italian peninsula. *Quaternary International* 303: 24–42.

33
34 Mercuri AM, Bandini Mazzanti M, Florenzano A, Montecchi MC, Rattighieri E and Torri P (2013b)
35 Anthropogenic Pollen Indicators (API) from archaeological sites as local evidence of human-induced
36 environments in the Italian peninsula. *Annali di Botanica* 3: 143–153.

37 ~~Mercuri AM, Fornaciari R, Gallinaro M, Vanin S, di Lernia S (2018) Plant behaviour from human imprints and~~
38 ~~the cultivation of wild cereals in Holocene Sahara. *Nature Plants* 4: 71-81.~~

39
40 ~~Mercuri AM, Marignani M and Sadori L (2015b) - Palaeoecology and long-term human impact in plant~~
41 ~~biology. *Plant Biosystems* 149(1): 136-143.~~

42
43 ~~Mercuri AM, Allevato E, Arobba D, Bandini Mazzanti M, Bosi G, Caramiello R *et al.* (2015a) Pollen and~~
44 ~~macroremains from Holocene archaeological sites: A dataset for the understanding of the bio-cultural~~
45 ~~diversity of the Italian landscape. *Review of Palaeobotany and Palynology* 218: 250-266.~~

46
47 ~~Mercuri AM, Marignani M and Sadori L (2015b) - Palaeoecology and long-term human impact in plant~~
48 ~~biology. *Plant Biosystems* 149(1): 136-143.~~

49
50 Mercuri AM, Montecchi MC, Pellacani G, Florenzano A, Rattighieri E, Cardarelli A (2015c) Environment,
51 human impact and the role of trees on the Po plain during the Middle and Recent Bronze Age: Pollen
52 evidence from the local influence of the *terrामare* of Baggiovvara and Casinalbo. *Review of Palaeobotany*
53 *and Palynology* 218: 231-249.

1
2
3
4
5
6
7 [Mercuri AM, Fornaciari R, Gallinaro M, Vanin S, di Lernia S \(2018\) Plant behaviour from human imprints and the cultivation of wild cereals in Holocene Sahara. *Nature Plants* 4: 71-81.](#)

8
9
10 [Mercuri AM, Sadori L and Blasi C \(2010\) Archaeobotany for cultural landscape and human impact reconstructions. *Plant Biosystem* 144: 860-864.](#)

11
12 [Mercuri AM, Sadori L and Uzquiano Ollero P \(2011\) Mediterranean and north-African cultural adaptations to mid-Holocene environmental and climatic changes. *The Holocene* 21\(1\): 189-206.](#)

13
14
15 Mussi M and Peresani M (2011) Human settlement of Italy during the Younger Dryas. *Quaternary International* 242: 360-370.

16
17
18 Oldfield F, Asioli A, Accorsi CA, Mercuri AM, Juggins S, Langone L *et al.* (2003) A high resolution late Holocene palaeo-environmental record from the central Adriatic Sea. *Quaternary Science Reviews* 22: 319-342.

19
20
21 Oliver LI, Salvà B, Javaloyas D. and Fornés J. (2017). La intervenció arqueològica a la naveta doble dels Closos. In: IV Jornades d'Estudis Locals de Felanitx, pp.1-14.

22
23
24 Pearsall DM (2016) *Paleoethnobotany: A Handbook of Procedures*. 3rd edn. New York: Routledge.

25
26
27 Pepe C, Giardini M, Giraudi C, Masi A, Mazzini I and Sadori L (2013) Plant landscape and environmental changes recorded in marginal marine environments: The ancient Roman harbour of Portus (Rome, Italy). *Quaternary International* 303: 73-81.

28
29
30 Pérez-Jordà G, Peña-Chocarro L, Picornell-Gelabert L and Carrión Marco Y (2017) Agriculture between the third and first millennium BC in the Balearic Islands: the archaeobotanical data. *Vegetation History and Archaeobotany* 27(1): 253-265.

31
32
33 Pérez-Obiol R and Julià R (1994) Climatic change on the Iberian Peninsula recorded in a 30,000-yr pollen record from Lake Banyoles. *Quaternary Research* 41: 91-98.

34
35
36 [Picornell-Gelabert LI and Servera-Vives G \(2017\) Landscape practices and everyday life in domestic spaces in Bronze Age Mallorca \(Balearic Islands\): perspectives for and archaeology of fuel and firewood. *Quaternary International* 431: 73-89.](#)

Formatted: Font: Italic

37
38
39 Ramis D (2017) Animal exploitation in the Early Prehistory of the Balearic Islands. *The Journal of Islands and Coastal Archaeology* 13(2): 269-282.

40
41
42 Rattighieri E, Rinaldi R, Mercuri AM and Bowes K (2013) Land use from seasonal archaeological sites: the archaeobotanical evidence of small Roman farmhouses in Cinigiano, south-eastern Tuscany - central Italy. *Annali di Botanica* 3: 207-215.

43
44
45 Revelles J (2017) Archaeoecology of Neolithisation. Human-environment interactions in the NE Iberian Peninsula during the Early Neolithic. *Journal of Archaeological Science: Reports* 15: 437-445.

46
47
48 Revelles J, Antolín F, Berihuete M, Burjachs F, Buxó R, Caruso L *et al.* (2014) Landscape transformation and economic practices among the first farming societies in Lake Banyoles (Girona, Spain). *Environmental Archaeology* 19 (3): 298-310.

49
50
51 [Revelles J, Cho S, Iriarte E, Burjachs F, van Geel B, Palomo A *et al.* \(2015\) Mid-holocene vegetation history and Neolithic land use in the Lake Banyoles area \(Girona, Spain\). *Palaeogeography Palaeoclimatology Palaeoecology* 435: 70-85.](#)

1
2
3
4
5
6
7
8 | Revelles J, Burjachs F and van Geel B (2016) Pollen and non-pollen palynomorphs from the Early Neolithic
9 settlement of La Draga (Girona, Spain). *Review of Palaeobotany and Palynology* 225: 1-20.

10
11 | Revelles J, Burjachs F, Morera N, Barceló JA, Berrocal A, López-Bultó O *et al.* (2017) Use of space and site
12 formation processes in a Neolithic lakeside settlement. Pollen and non-pollen palynomorphs spatial
13 analysis in La Draga (Banyoles, NE Iberia). *Journal of Archaeological Science* 81: 101-115.

14
15 | Revelles J, Burjachs F, Palomo A, Piqué R, Iriarte E, Pérez-Obiol R *et al.* (2018). Human-environment
16 interaction during the Mesolithic-Neolithic transition in the NE Iberian Peninsula. Vegetation history,
17 climate change and human impact during the Early-Middle Holocene in the Eastern Pre-Pyrenees.
Quaternary Science Reviews 184, 183-200.

18 | [Revelles J, Cho S, Iriarte E, Burjachs F, van Geel B, Palomo A *et al.* \(2015\) Mid-holocene vegetation history
19 and Neolithic land-use in the Lake Banyoles area \(Girona, Spain\). *Palaeogeography Palaeoclimatology
20 Palaeoecology* 435: 70-85.](#)

21
22 | Riera S, Servera-Vivas G, Picornell-Gelartbert L, Cabanis M, Boi M and Miras Y (2018) Pollen Signatures of a
23 Ritual Process in the Collective Burial Cave of Cova des Pas (Late Bronze Age, Minorca, Balearic Islands,
24 Spain). In: Livarda A, Madgwick R, Riera Mora S (eds) *The Bioarchaeology of Ritual and Religion*. Oxbow
25 Book

26 | [Roberts N, Fyfe R, Shennan S, Bevan A, Woodbridge J and Palmisano A \(this issue\) The changing face of the
27 Mediterranean: inter-regional comparisons.](#)

28
29 | Roberts N, Warren JE, Kuzucuoglu C, Fiorentino G and Caracuta V (2011) Climatic, vegetation and cultural
30 change in the eastern Mediterranean during the mid-Holocene environmental transition.
31 *The Holocene* 21 (1): 131-146.

32
33 | [Roberts N, Fyfe R, Shennan S, Bevan A, Woodbridge J and Palmisano A \(this issue\) The changing face of the
34 Mediterranean: inter-regional comparisons.](#)

35
36 | Rottoli M (1997) I legni della terramara di Castione Marchesi (PR). In: Bernabò Brea M, Cardarelli A and
37 Cremaschi M (eds.) *Le Terramare. La più antica civiltà padana*. Milano: Elemond Editori Associati, Electa,
38 pp.481-486.

39 | [Sabato D, Masi A, Pepe C, Ucchesu M, Peña-Chocarro L, Usai A *et al.* \(2015\). Archaeobotanical analysis of a
40 Bronze Age well in Sardinia: a wealth of knowledge. *Plant Biosystems* 149\(1\): 205-215.](#)

41
42 | Sadori L, Koutsodendris A, Panagiotopoulos K, Masi A, Bertini A, Combourieu-Nebout N *et al.* (2016) Pollen-
43 based paleoenvironmental and paleoclimatic change at Lake Ohrid (south-eastern Europe) during the past
44 500 ka. *Biogeosciences* 13: 1423-1437.

45 | [Sabato D, Masi A, Pepe C, Ucchesu M, Peña-Chocarro L, Usai A *et al.* \(2015\). Archaeobotanical analysis of a
46 Bronze Age well in Sardinia: a wealth of knowledge. *Plant Biosystems* 149\(1\): 205-215.](#)

47
48 | [Sadori L, Mercuri AM and Mariotti Lippi M \(2010\). Reconstructing past cultural landscape and human
49 impact using pollen and plant macroremains. *Plant Biosystems* 144: 940-951.](#)

50
51 | [Sadori \(submitted\) The Lateglacial and Holocene vegetation and climate history of Lago di Mezzano \(central
52 Italy\). *Quaternary Science Reviews*](#)

1
2
3
4
5
6
7 Sadori L, Susanna F and Persiani C (2006) Archaeobotanical data and crop storage evidence from an early
8 Bronze Age 2 burnt house at Arslantepe, Malatya, Turkey. *Vegetation history and archaeobotany* 15(3):
9 205-215.

10 ~~Sadori (submitted) The Lateglacial and Holocene vegetation and climate history of Lago di Mezzano (central~~
11 ~~Italy). *Quaternary Science Reviews*~~

12
13 Servera-Vives G, Riera S, Picornell-Gelabert L, Moffa-Sánchez P, Llergo Y, Garcia-Molsosa A *et al.* (2018)
14 The onset of islandscapes in the Balearic Islands: A study-case of Addaia (northern Minorca, Spain).
15 *Palaeogeography, palaeoclimatology, palaeoecology* 498(1): 9-23.

16 ~~Sofronidou M (2008) The prehistoric lakeside settlement of Dispilio, Kastoria. *Anaskamma* 1: 9–26.~~

17
18 Stoddart S, Woodbridge J, Palmisano A, Mercuri AM, Mensing S, Colombaroli D *et al.* (this issue) Tyrrhenian
19 central Italy: regional land cover, vegetation and settlement.

20 ~~Sofronidou M (2008) The prehistoric lakeside settlement of Dispilio, Kastoria. *Anaskamma* 1: 9–26.~~

21
22 Valsecchi V, Tinner W, Finsinger W and Amman B (2006) Human impact during the Bronze Age on the
23 vegetation at Lago Lucone (northern Italy). *Vegetation History and Archaeobotany* 15: 99-113.

24
25 Van der Veen M. (2007) Formation processes of desiccated and carbonised plant remains - the
26 identification of routine practice. *Journal of Archaeological Science* 34: 968-990.

27
28 Vannièrè B, Colombaroli D, Chapron E, Leroux A, Tinner W and Magny M (2008) Climate versus human-
29 driven fire regimes in Mediterranean landscapes: the Holocene record of Lago dell'Accesa (Tuscany, Italy).
30 *Quaternary Science Reviews* 27: 1181-1196.

31
32 Vescovi E, Ammann B, Ravazzi C and Tinner W (2010) A new Late-glacial and Holocene record of vegetation
33 and fire history from Lago del Greppo, northern Apennines, Italy. *Vegetation History and Archaeobotany*
34 19: 219-233.

35
36 Vignola C, Masi A, Balossi Restelli F, Frangipane M, Marzaioli F, Passariello I *et al.* (2017) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ from
37 ^{14}C -AMS dated cereal grains reveal agricultural practices during 4300–2000BC at Arslantepe (Turkey).
38 *Review of Palaeobotany and Palynology* 247: 164-174.

39
40 Vignola C, Masi A, Balossi Restelli F, Frangipane M, Marzaioli F, Passariello I *et al.* (2018) $\delta^{13}\text{C}$ values in
41 archaeological ^{14}C -AMS dated charcoals: assessing mid-Holocene climate fluctuations and human response
42 from a high-resolution isotope record (Arslantepe, Turkey). *Rapid Communications in Mass Spectrometry*.
43 Epub ahead of print 12 April 2018. Doi 10.1002/rcm.8137.

44 ~~Weiberg E, Bevan A, Kouli K, Katsianis M, Woodbridge J, Bonnier A, Finné M *et al.* (this issue) Long-term~~
45 ~~trends of land use and demography in Greece: a comparative study.~~

46
47 Weiberg E, Unkel I, Kouli K, Holmgren K, Avramidis P, Bonnier A *et al.* (2016) The socio-environmental
48 history of the Peloponnese during the Holocene: Towards an integrated understanding of the past.
49 *Quaternary Science Reviews* 136(15): 40–65.

50 ~~Weiberg E, Bevan A, Kouli K, Katsianis M, Woodbridge J, Bonnier A, Finné M *et al.* (this issue) Long-term~~
51 ~~trends of land use and demography in Greece: a comparative study.~~

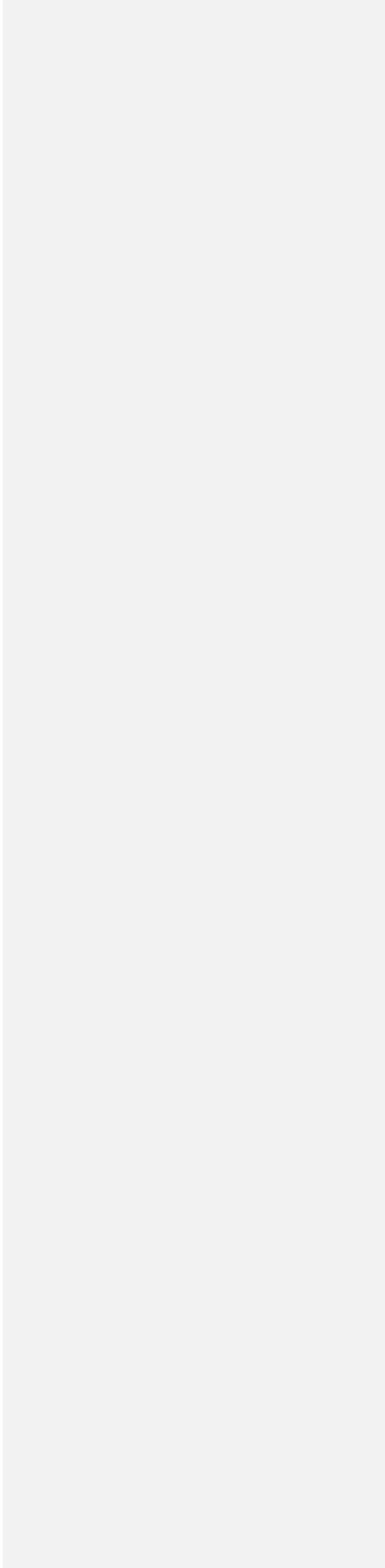
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Wick L, Lemcke G and Sturm M (2003) Evidence of Late glacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. *The Holocene* 13: 665–675.

Willcox G, Nesbitt M and Bittmann F (2012) From collecting to cultivation: transitions to a production economy in the Near East. *Vegetation History and Archaeobotany* 21: 81–83.

Zohary D and Hopf M (2000) *Domestication of Plants in the Old World*. 3rd edn, New York: Oxford University Press.

For Peer Review



Legends

Tab. 1 – List of the archaeological sites reported as case studies in this paper.

Fig. 1 – Location map showing the sites reported in this paper (*) including six archaeological sites: 1) La Draga, 2) Closos de ca'n Gaià, 3) Poviglio, 4) Montale, 5) Duspiliò, 6) Arslantepe, and ten off/near-sites: A) Lake Banyoles; B) SB2 Banyoles; C) Les Palanques; D) Sobrestany; E) S'Albufera d'Alcúdia; F) Lake Mezzano; G) Lake Nemi; H) Lake Albano; I) RF93-30; J) Lake Dojran

Fig. 2 – Percentage pollen diagrams from the six archaeological sites: AP and Quercus % (time scale at the top, depth scale at the bottom).

Formatted: Font: Not Italic

Fig. 3 – Anthracological diagrams based on anthracological analysis of the sites of Arslantepe, Turkey (Masi et al., 2018), and Closos de can Gaià, Mallorca (Picornell-Gelabert and Servera-Vives 2017). Results at Closos de can Gaià are presented with percentage (%) of charcoal fragments per taxon at every archaeological layer (Stratigrafic Units) and occupation phase of the Navetiform 1 building. Results at Arslantepe are presented with percentage (%) of charcoal weight per taxon at every archaeological layer of the site. Dots represent values <3%."

Fig. 4 – Percentage pollen diagrams from the six archaeological sites: OJC, Cereals and Cichorieae

Fig. 5 – Percentage pollen diagrams from the archaeological sites: pollen sums of the two Neolithic sites La Draga and Dispiliò describe the mixed oakwoods, sclerophyllous, shrubland, grasslands and wetlands as mainly natural component of the landscape, and weeds/anthropic plants as signs of human-influenced environment (time scale at the top, depth scale at the bottom).

Formatted: Font: Not Italic

Fig. 6 – Percentage pollen diagrams from the archaeological sites: pollen sums of the four sites with samples of the Bronze age showing samples mixed oakwoods, sclerophyllous, shrubland, grasslands and wetlands as mainly natural component of the landscape, and weeds/anthropic plants as signs of human-influenced environment (time scale at the top; the depth scale at the bottom shows better resolution for the Bronze age samples).

Fig. 7 – Principal Component analysis (PCA) of selected pollen taxa and sums from the six archaeological sites included in this paper (samples are plotted as variables). Axis 1 separates the samples along a woody landscape gradient (from forested towards more open environments), while Axis 2 groups them mainly by vegetation types (pasturelands and riparian forests against more forested environments and crops). Each site is well separated to the others and shows own features.

Fig. 8 – The AP% trends of off-sites may be useful to observe the regional effect of the local human activities inferred from on-sites (the archaeological sites) of the same area; these AP curves show oscillations that have ambiguous/dual natural-anthropogenic causes (references in the text). They depend on human activities only if the sampling sites lies in the area of influence (near-site) of the archaeological settlements where people was exploiting woods. A: beginning of Dispiliò; B: lifetime of La Draga; C: Bronze age at Closos (beginning) and Arslantepe (end phase); D: Terramare culture.

BRAIN ID	Location		Site name	Chronology			Archaeology			Sampling		References
	Country / Region	Area		Number of radiocarbon dates	Chronology of the records (cal vs BP)	Chronology of the culture (BC)	Culture	Context	Plant records	Pollen	Samples in this system (pollen, charcoal)	
EX1	Northeast Spain	Lake Banyoles	La Draga	28	7270-6930	5320-4800	Early Neolithic	Settlement (pile dwelling)	pollen, NPPs, woods/charcoals, seeds/fruits	on-site, 3 archaeological profiles from Sector D (trenches)	39 ps	Revelles et al. 2016; Revelles 2016
EX4	Balearic Islands	Mallorca	Navetxorn 1, Clovis de can Gaà	39	c.3650-2850/2800	c.1700-900/850	Bronze Age	Settlement (megalithic dwelling)	pollen, NPPs, charcoals	on-site, stratigraphic units pre-building and occupation layers of the building	7 ps + 7 cs	Picornell-Gelabert and Servera-Vives 2017; this study
NER68 (Montale), NER92 (Poviglio)	North Italy	Po Plain	Terramara di Montale, Terramara Santa Rosa di Poviglio	8 in Montale; 3 in core DG2	c.7000-3100	1550-1170	Middle to Recent Bronze Age	Settlement sites (Terramara)	pollen, NPPs, seeds/fruits, woods/charcoals	(on-site) trenches: Montale Profile 1, Montale Profile 2; Poviglio (near-site) core: Montale Profile 3	83 ps	Mencari et al. 2006; Cremaschi et al. 2015
EX12	North Greece	Lake Orestiás (Kastoria)	Dogalió	3 in core G25; 3 in core DG2	7500-5500	5550-3550	Middle Neolithic to Early Chalcolithic	Lake settlement	pollen, NPPs, phytoliths, seeds/fruits, woods/charcoals	(on-site) cores: G26 and D52; (near-site) core: G25	86 ps	Kouli 2015
EX13	Turkey	Eastern Anatolia	Arslantepe (Tell site)	112	c.6650-3950	c.4700-700	Late Chalcolithic/ Early Bronze Age	Settlement (layered tell)	pollen, NPPs, seeds/fruits, woods/charcoals	on-site stratigraphic units	12 ps + 1027 cs	Sadori et al. 2006; Masi et al. 2018; this study

Tab. 1 – List of the archaeological sites reported as case studies in this paper.

297x209mm (150 x 150 DPI)

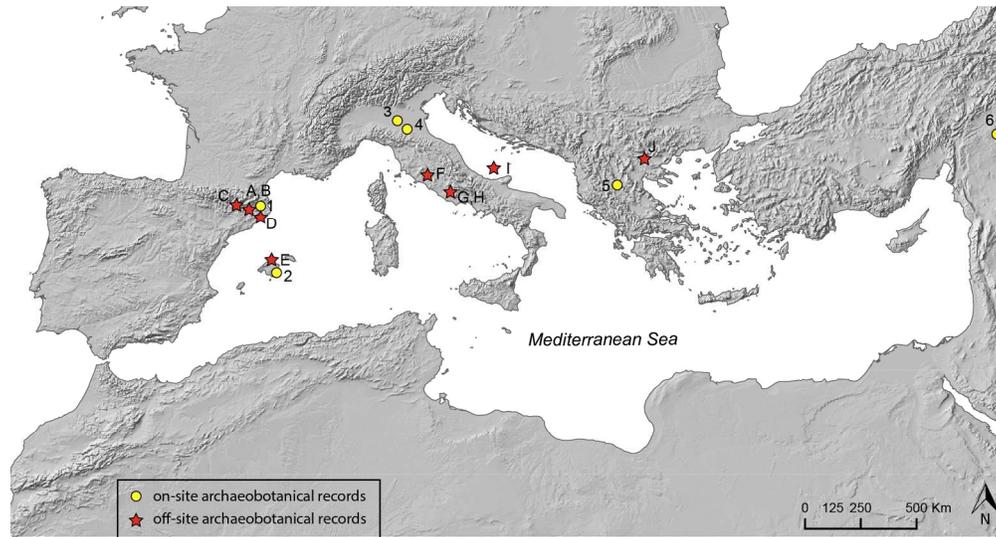


Fig. 1 – Location map showing the sites reported in this paper (*) including six archaeological sites: 1) La Draga, 2) Closos de ca'n Gaià, 3) Poviglio, 4) Montale, 5) Duspiliò, 6) Arslantepe, and ten off/near-sites: A) Lake Banyoles; B) SB2 Banyoles; C) Les Palanques; D) Sobrestany; E) S'Albufera d'Alcúdia; F) Lake Mezzano; G) Lake Nemi; H) Lake Albano; I) RF93-30; J) Lake Dojran

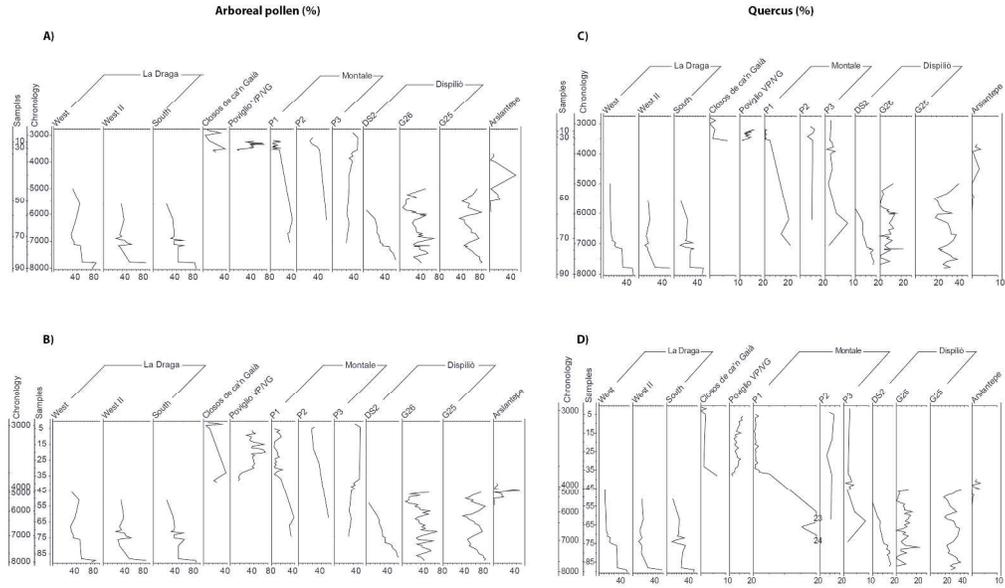


Fig. 2 – Percentage pollen diagrams from the six archaeological sites: AP and Quercus %

289x169mm (300 x 300 DPI)

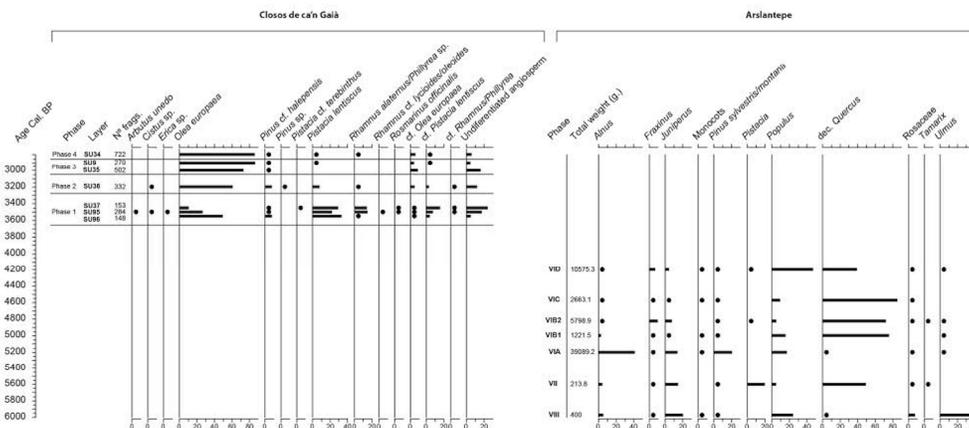


Fig. 3 – Anthracological diagrams based on anthracological analysis of the sites of Arslantepe, Turkey (Masi et al., 2018), and Closos de can Gaià, Mallorca (Picornell-Gelabert and Servera-Vives 2017). Results at Closos de can Gaià are presented with percentage (%) of charcoal fragments per taxon at every archaeological layer (Stratigraphic Units) and occupation phase of the Navetiform 1 building. Results at Arslantepe are presented with percentage (%) of charcoal weight per taxon at every archaeological layer of the site. Dots represent values <3%."

250x176mm (300 x 300 DPI)

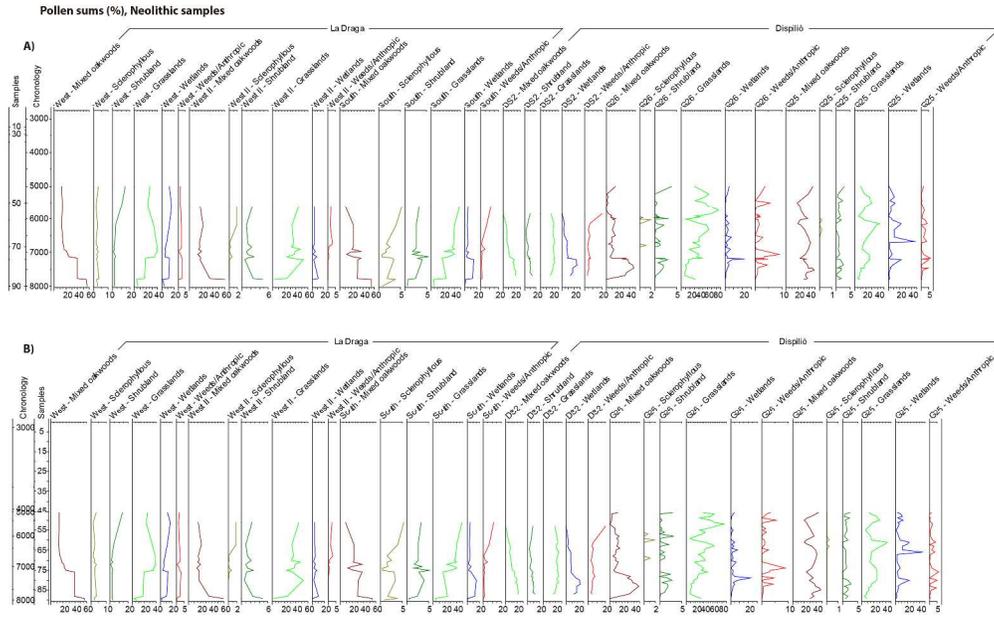


Fig. 5 – Percentage pollen diagrams from the archaeological sites: pollen sums of Neolithic sites

292x179mm (300 x 300 DPI)

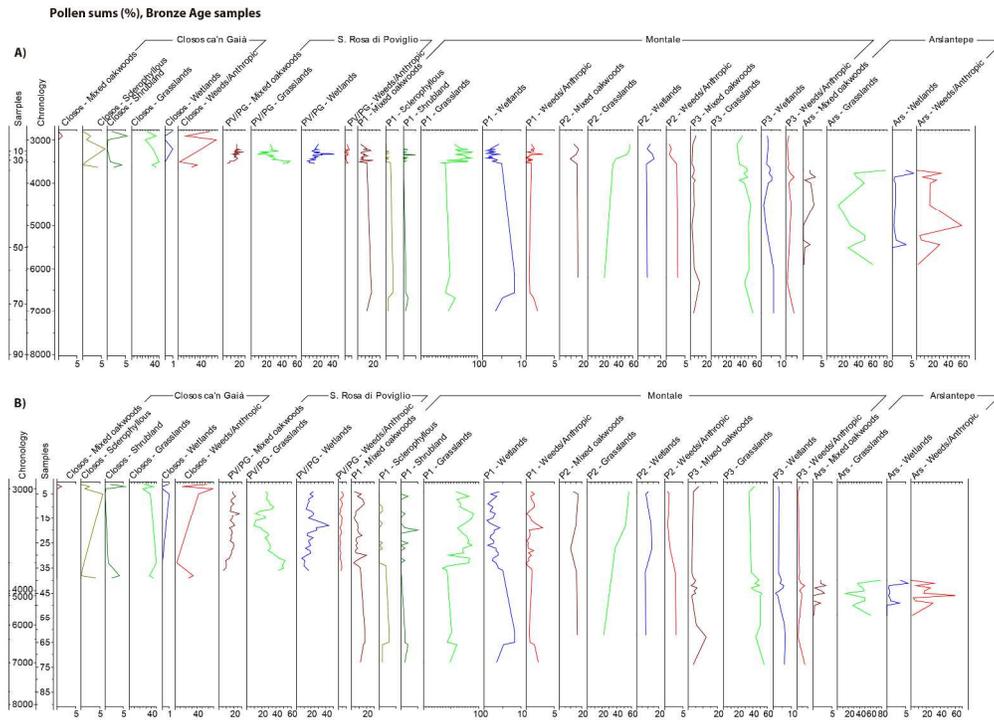


Fig. 6 - Percentage pollen diagrams from the archaeological sites: pollen sums of Bronze samples

273x196mm (300 x 300 DPI)

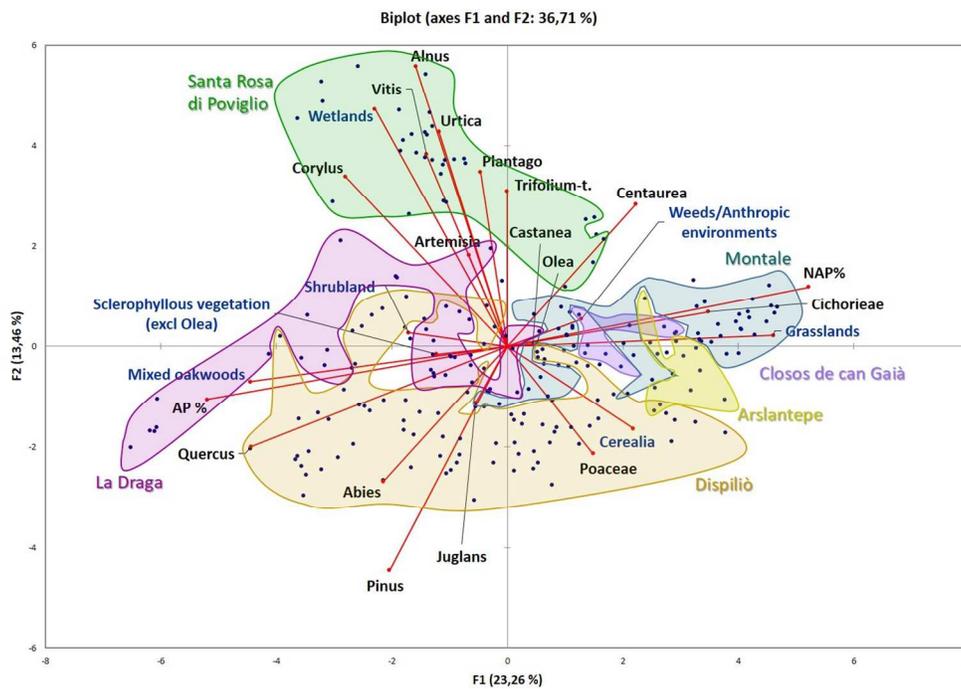


Fig. 7 –Principal Component analysis (PCA) of selected pollen taxa and sums from the six archaeological sites included in this paper (samples are plotted as variables). Axis 1 separates the samples along a woody landscape gradient (from forested towards more open environments), while Axis 2 groups them mainly by vegetation types (pasturelands and riparian forests against more forested environments and crops). Each site is well separated to the others and shows own features.

254x185mm (150 x 150 DPI)