

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

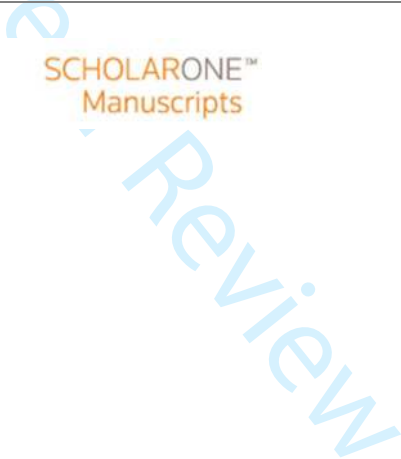
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Keywords:	sustainable farming, pollen, charcoal, Holocene, Neolithic, Bronze Age
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sequences can allow us to determine the area of influence of a site. Neolithic and Bronze Age archaeological sites 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-cereals-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.

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

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### 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; Vannièrè 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

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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

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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**

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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**

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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  
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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 m<sup>2</sup> of the excavated area; Revelles et al., 2014). Considering the fact that the total extension of the site is estimated to c. 8000 m<sup>2</sup>, 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*



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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*

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

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

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

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

12 A high presence of cereals (Cerealia-type pollen) is documented in all the sites (Mercuri et al.,  
13 2006b). Cereals were grown close to each village as their pollen records (Cerealia-type) are always  
14 detected in near-site sequences, and high values in on-site sequences are connected with plant  
15 transport and processing near the houses (Fig. 4). Some plots were cultivated for fodder  
16 (Fabaceae, including *Lotus*, *Medicago*, *Melilotus*, *Trifolium*) or left for fallow/grazing in the area of  
17 influence; the area of influence was surrounded by forests supplying wild fruits and defensive  
18 functions (Mercuri et al., 2015c). Comparison of on-site and near-site (P3) pollen records suggests  
19 that cereal fields were mostly cultivated towards the west around Montale, possibly in rotation or  
20 intercropping with legume fields (Mercuri et al., 2006b) whereas domestic animals were kept  
21 inside the settlement (presence of dung, and archaeozoological remains) and browsed grasses and  
22 fodder plants in small parcels and pastures rich of Cichorieae, all within the area of influence.  
23 Trees and wood management have a special role in this society, and first signals of *Vitis* cultivation  
24 emerged (Mercuri et al., 2006a, 2015a; Cremaschi et al., 2016). At the end of the Recent Bronze  
25 Age, this society rapidly vanished, probably forced by a combination of climatic, environmental  
26 and socioeconomic causes (Cremaschi et al., 2016).

### 27 **Eastern Mediterranean: Dispiliò (northern Greece)**

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

31 *Sampling: pollen, NPPs, phytoliths; macroremains: seeds/fruits, charcoal*  
32 *86 pollen samples from 2 on-site and one near-site series (cores)*  
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34 Key events: exceptional location and long-time continuative occupation, at the shore of Lake  
35 Orestiás; cereal field cultivation in a diversified kind and intensive exploitation of natural resources  
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37 Dispiliò, near Lake Orestiás, also known as Lake Kastoria, is the first lake settlement systematically  
38 investigated in Greece. According to joint archaeological and radiocarbon data (Facorellis et al.,  
39 2014), the site was occupied for about 2000 years, from the Middle Neolithic (7500 cal BP) to the  
40 Chalcolithic (5500 cal BP) representing one of the earliest locations with unambiguous evidence of  
41 human disturbance in Greece. Earlier agropastoral activities associated with the Early Neolithic  
42 communities have been observed starting from at least 8300 cal BP in eastern Macedonia (Glais et  
43 al., 2016).

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

52 Three periods of retreat of natural woodland and of major anthropic disturbance have been  
53 recognized, especially at intermediate altitudes. These are correlated with the three periods of  
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7 major constructing activities described by the archaeological study (Hourmouziadi and Yagoulis,  
8 2002; Sofronidou, 2008). Two of them, corresponding to the Middle Neolithic (c. 7200 cal BP,  
9 ending with the destruction by fire of the settlement; Karkanis et al., 2011) and Late Neolithic II to  
10 Chalcolithic (c. 6000 cal BP) show evidence of intensive cultivation. Two episodes of woodland  
11 recovery are characterized by decrease of anthropogenic indicators in pollen spectra, representing  
12 a pause of pastoral activities between the major construction phases.

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

### 23 ***Eastern Mediterranean: Arslantepe (Anatolia)***

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

26 *Settlement site (layered tell)*

27 *Sampling: pollen; macroremains: seeds/fruits, charcoal*

28 *12 pollen samples from on-site (short trenches); anthracological record from 7 archaeological*  
29 *layers*

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31 Key events: several sudden changes of populations followed one another in the settlement,  
32 implying continuous changes in occupation patterns and land-use  
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34 Arslantepe is located in the modern Malatya plateau, a region characterized by low precipitation  
35 both today and during prehistory. A large hydrogeological karst catchment supplies water to the  
36 plain allowing extensive agriculture since at least the Chalcolithic age (Masi et al., 2014). The site  
37 was settled several times at the same place, forming a tell in an open landscape characterized by  
38 trees such as deciduous and semi-deciduous oaks (*Quercus* sp.), elms (*Ulmus*), ashes (*Fraxinus*),  
39 and shrubs as junipers (*Juniperus*). The presence of a spring at the base of the tell and of a number  
40 of others in the close surroundings, favoured the growth of alders and poplars.

41 The palynological data comes from seven archaeological phases ranging from Late Chalcolithic 1–2  
42 (6500 cal BP, VIII period) to Early Bronze Age III (4000 cal BP, VID2 phase). Contrasts between the  
43 charcoal and pollen records for tree taxa reveal important aspects of landscape exploitation. The  
44 pollen rain/human mounds show only low quantities of arboreal pollen. The human selection of  
45 timber appears to be quite clear: the charcoal record shows a dominance of deciduous *Quercus*  
46 followed by hydrophilous (*Alnus*, *Populus*, *Tamarix*) and hygrophilous (*Fraxinus*, *Ulmus*) trees (Fig.  
47 3; Sadori et al., 2006). These abundant taxa are either poorly represented in the pollen record  
48 (deciduous *Quercus*) or not present at all (*Alnus*). *Castanea*, *Juglans* and *Corylus*, present in the  
49 pollen samples, are not found either in the charcoal or seed records.

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

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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

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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**).

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

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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,  
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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.

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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  
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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  
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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.

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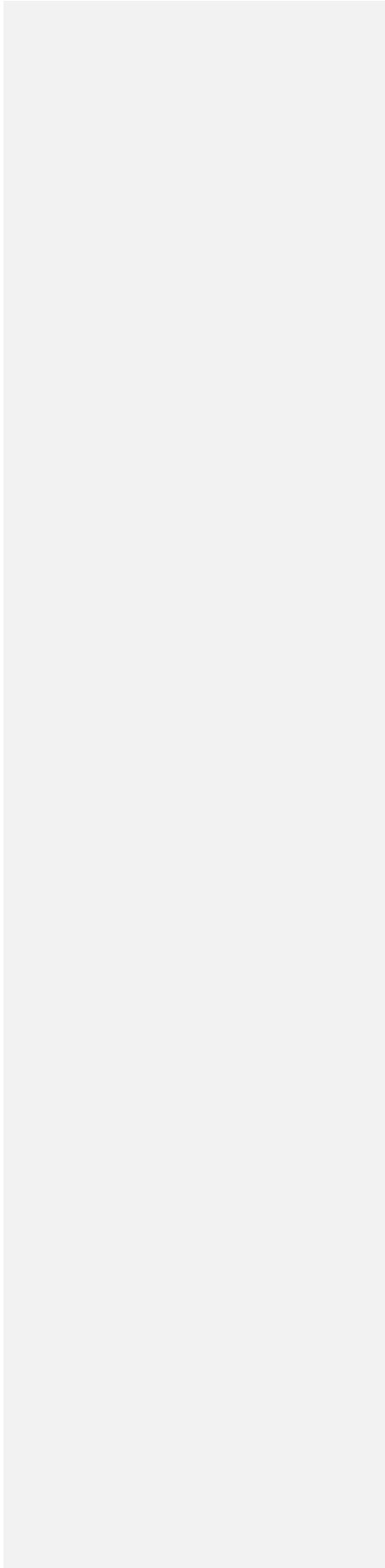
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For Peer Review



## 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).

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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).

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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			Samples (a min. maximum value)	References	
	Country / Region	Area		Number of radiocarbon dates	Chronology of the records (a BP)	Chronology of the culture (aC)	Culture	Context	Plant records			Pollen
EX1	Northeast Spain	Lake Banyoles	La Darga	28	9270-6930	3320-4800	Early Neolithic	Settlement (pile-dwelling)	pollen, NPPs, macrocharcoal, seeds/fruits	on-site, 3 stratigraphical profiles from Sector D (interfau)	39 ps	Reveres et al. 2016, Dowd et al. 2016
EX3	Riverine (Spain)	MaBorca	MaBorca I. El yacimiento de la Gasa	39	~3450-2850/2300	~3700-900/850	Bronze Age	Settlement (negative pile-dwelling)	pollen, NPPs, charcoal	on-site, stratigraphical units from building and non-building spaces of the building	7 ps + 7 cs	Plaza-Irigoin et al. 2017, this study
NE138 (Morales), NE140 (Voz) (B)	North Italy	Po Plain	Monte Moro, The ancient Sella Rotta di Piavazzo	8 in Morales; 3 in Voz	~7000-5000	~550-1170	Middle to Recent Bronze Age	Settlement sites (open-air)	pollen, NPPs, seeds/fruits, wood/charcoal	on-site, trenches: Morales Profile 1, Morales Profile 2; Piavazzo Profile 1; core: Morales Profile 3	83 ps	Morales et al. 2006; Cremaschi et al. 2004
EX2	North Greece	Lake Orestiada (Kochistra)	Orkida	2 in core G25; 3 in core G62	3500-5500	5550-3550	Middle Neolithic to Early Chalcolithic	Open-settlement	pollen, NPPs, phytoliths, seeds/fruits, wood/charcoal	on-site, cores: G25 and ES2; tree-ring core: G25	86 ps	Kouli 2015
EX1	Turkey	Eastern Anatolia	Arborena (Talat)	113	~5650-3000	~4700-700	late Chalcolithic/Early Bronze Age	Settlement (excavated)	pollen, NPPs, seeds/fruits, wood/charcoal	on-site stratigraphical units	22 ps + 2027 cs	Saizel et al. 2006; Akad et al. 2012; this study

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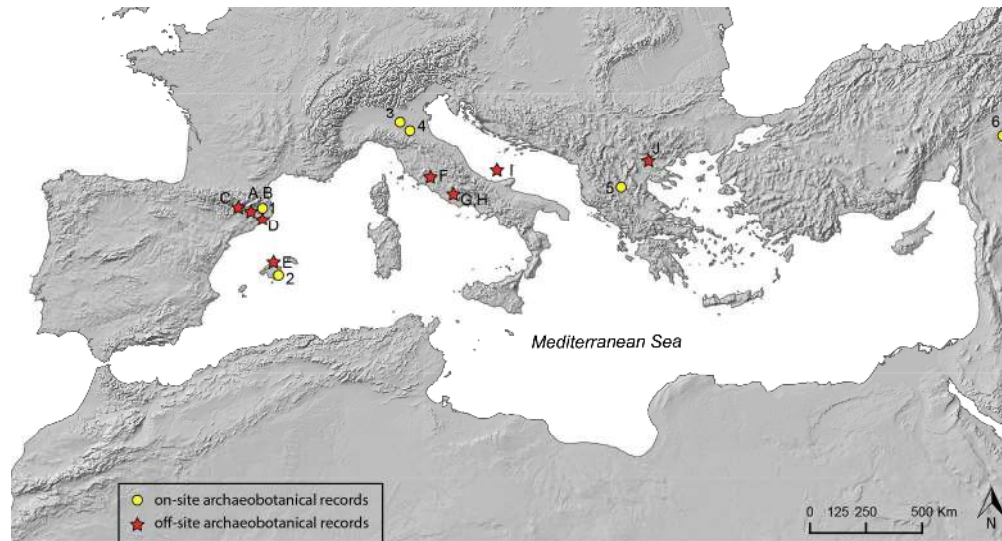


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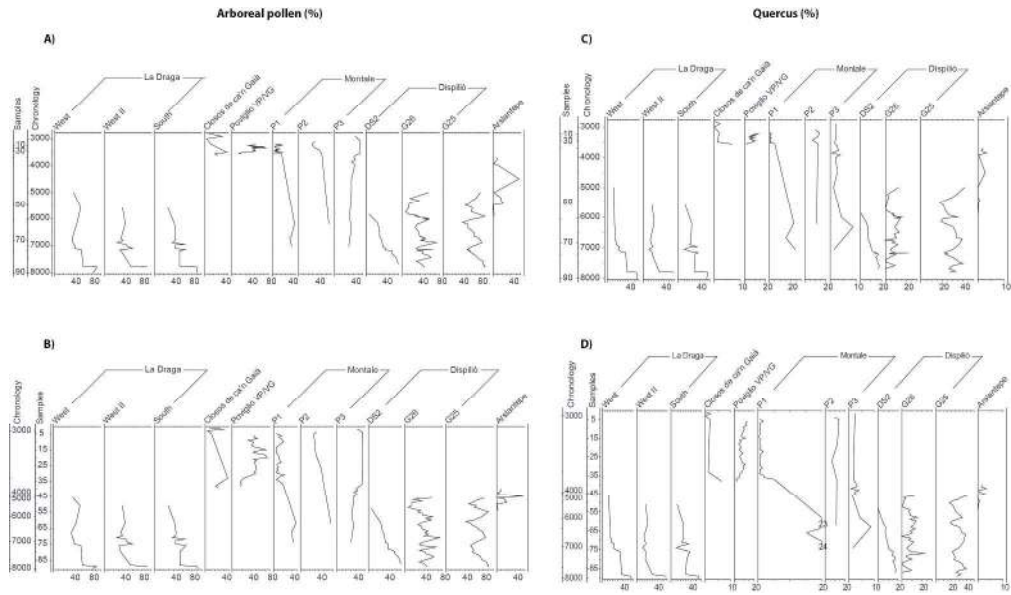


Fig. 2 – Percentage pollen diagrams from the six archaeological sites: AP and Quercus %

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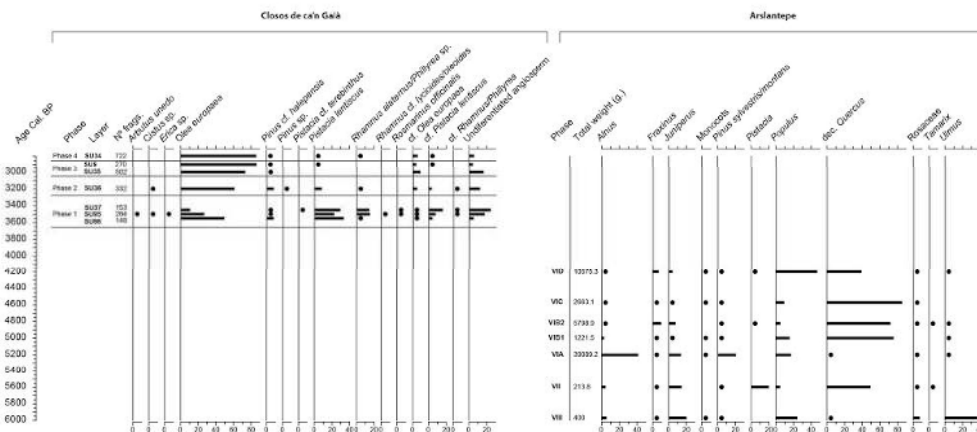


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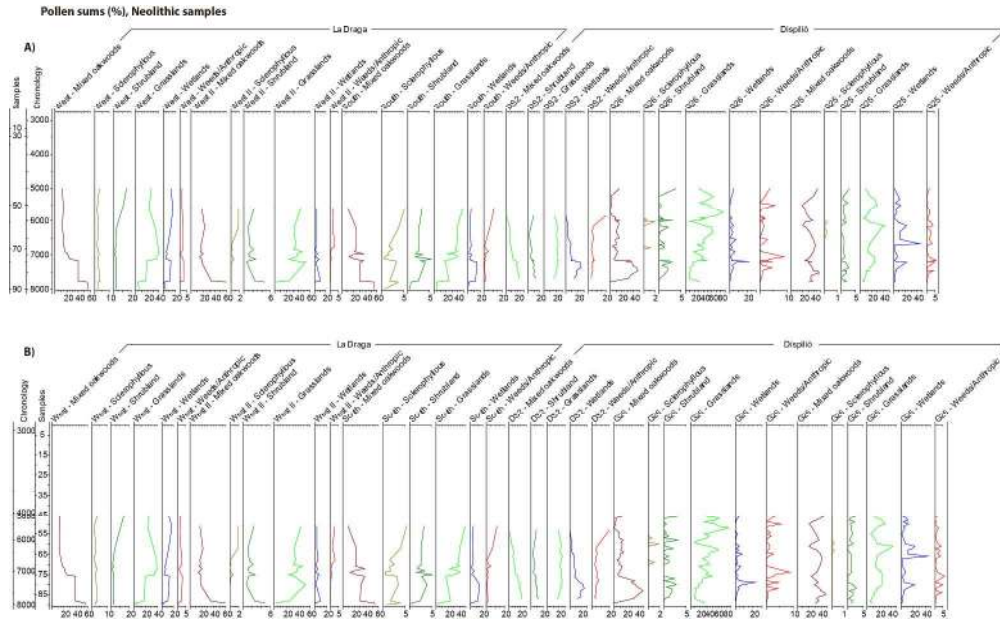


Fig. 5 – Percentage pollen diagrams from the archaeological sites: pollen sums of Neolithic sites

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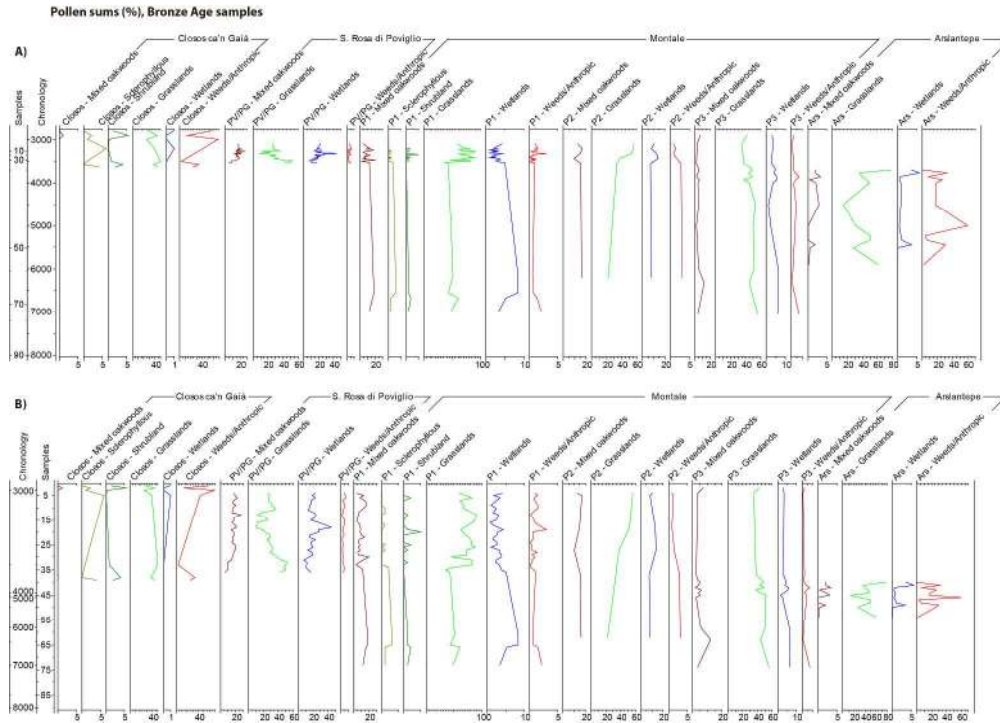


Fig. 6 - Percentage pollen diagrams from the archaeological sites: pollen sums of Bronze samples

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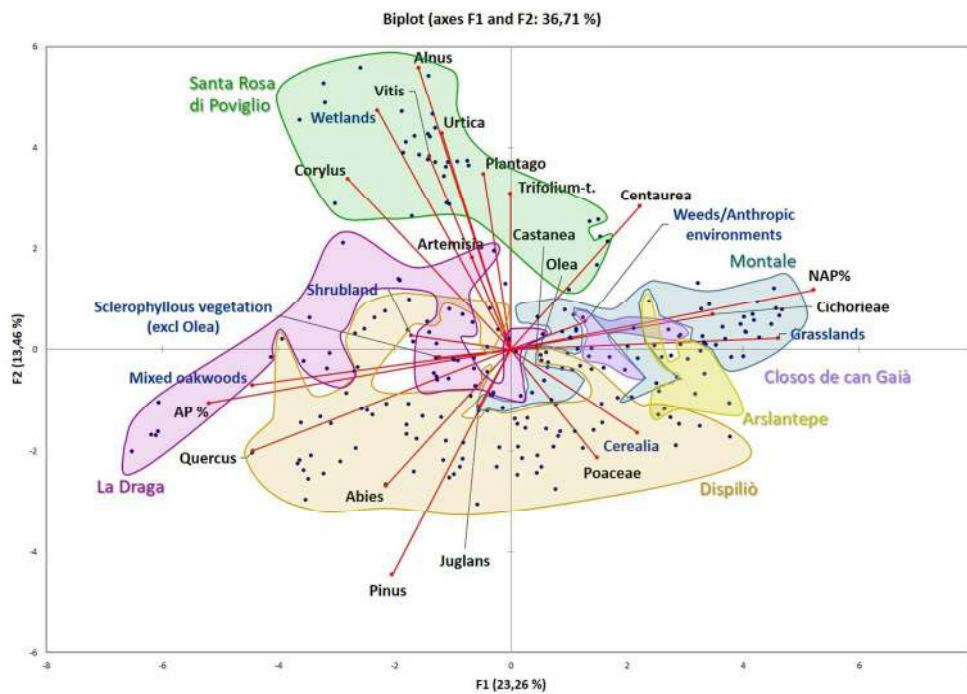


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254x185mm (150 x 150 DPI)