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Olea europaea L. in the North Mediterranean basin during the Pleniglacial and the Early–Middle Holocene

Yolana Carrión [a, *], Maria Ntinou [b], Ernestina Badal [c]

[a] *Centro de Investigaciones sobre Desertificación (CIDE), CSIC, Camí de la Marjal s/n, 46470 Albal, Valencia, Spain, e-mail: Yolanda.carrion@uv.es*

[b] *Agg. Sikelianou 2, 45221 Ioannina, Greece, e-mail: Maria.Ntinou@uv.es*

[c] *Universitat de València, Av. Blasco Ibáñez 28. 46010 Valencia, Spain, e-mail: Ernestina.badal@uv.es*

* Corresponding author. Tel.: +34 961220540; Fax: +34 961270967

ABSTRACT

The paper aims to define the natural distribution of *Olea europaea* L. var. *sylvestris* (Miller) Lehr. in the North Mediterranean basin during the Pleniglacial and the Early–Middle Holocene by means of the identification of its wood-charcoal and/or wood at prehistoric sites. For this purpose we have reviewed the previously available information and we have combined it with new wood-charcoal analyses data. We have taken under consideration the presence and frequency of *Olea europaea* L. in the available wood-charcoal sequences, the characteristics of the accompanying flora, the associated chrono-cultural contexts, the broader biogeographical context and the AMS dates provided by *Olea* wood-charcoal or endocarps. According to the available evidence, during the Middle and Late Pleniglacial (c. 59–11,5 ka cal. BP), *Olea* would have persisted in thermophilous refugia located in the southern areas of the North Mediterranean basin, the southern Levant and the north of Africa. The Last Glacial Maximum (c. 22–18 ka cal. BP) probably reduced the distribution area of *Olea*. During the Preboreal and the Boreal (c. 11 500–8800 cal. BP) the species started to expand in the thermomediterranean bioclimatic level. In the western Mediterranean, during the Atlantic period (c. 8800–5600 cal. BP), the species became very abundant or dominant in the thermophilous plant formations and expanded to favorable enclaves outside the limits of the thermomediterranean level.

Key words: *Olea* wood-charcoal, Mediterranean, AMS dates, pleniglacial refugia, Early Holocene, thermomediterranean

1. Introduction

Olea europaea L. var. *sylvestris* (Miller) Lehr. (the oleaster, the wild olive) is a prominent feature of present-day Mediterranean vegetation. The species is considered a sensitive thermal bioindicator for the definition of the thermomediterranean bioclimatic level and its natural distribution has been confined to the coastal areas of the Mediterranean basin below latitude 41°/39° N as one moves from west to east (Fig. 1 and 5A) (Ozenda, 1975; Rivas-Martinez, 1987).

The origins and the natural distribution of wild olive populations have been a focus of multidisciplinary research largely on aspects of its domestication and cultivation (Liphschitz et al., 1991; Terral, 1996; Zohary and Hopf, 2000; Contento et al., 2002; Besnard et al., 2002; Terral et al., 2004, 2005; Breton et al., 2006). The cultivation of the olive tree since late prehistory, in the Bronze Age, has turned it into an emblematic and genuine plant of the Mediterranean cultures that has both domestic and symbolic uses. Cultivation has caused the species to surpass its natural bioclimatic limits and to be grown at higher altitudes and latitudes, with the result that the distribution of the olive tree scarcely reflects that of the wild variety. Nevertheless, macroremains of *Olea* that have been recovered at archaeological sites from periods far predating its cultivation, i.e. the Palaeolithic to the Neolithic, may contribute to a reconstruction of the history and the distribution of the wild olive from the Pleniglacial to the Early and Middle Holocene.

One such category of archaeobotanical macroremains is wood-charcoal. In the last 30 years, wood-charcoal analyses that have been carried out at archaeological sites across the Mediterranean basin have provided abundant evidence on the plant taxa used by human groups for fuel (Vernet, 1992; Thiébault, 2002; Dufraisse, 2006; Fiorentino and Magri, 2008). *Olea* wood-charcoal macroremains constitute the most adequate category of archaeobotanical remains for assessing both the presence of the species in Pleniglacial vegetation and the genesis of the Holocene plant formations in which the species played a key role. Based on the idea that wood-charcoal remains at an archaeological site reflect the local flora that has been collected for firewood (Chabal, 1988), *Olea* wood-charcoals may be considered relatively safe indicators of the species' local growth, particularly in comparison to endocarps, whose presence may be due to human transport of the fruit over wide areas, and also in comparison to pollen grains found in natural deposits, which may have been carried by natural agents over variable distances. In addition, through wood-charcoal analysis, the species becomes an integral part of the charcoal assemblages that reflect the palaeoecological conditions of the area under study, in particular the local flora and the characteristics of the local vegetation,

which respond to the specific climatic parameters of temperature and precipitation (Chabal et al., 1999). Finally, because wood-charcoal *Olea* remains can be directly AMS dated, they can aid in documenting the first appearance and expansion of the species in a region and in detecting taphonomic problems.

In this paper we present evidence of the presence of *Olea* that derives from wood-charcoal analyses carried out at prehistoric sites of the North Mediterranean basin that date from the Palaeolithic to the Neolithic. The chronological framework in this paper extends from the Middle Pleniglacial to the end of the Atlantic period (for the chronological boundaries of each period, see Fig. 2). The earlier chronological limit is set by the occasional finds of early wood-charcoal while the later roughly coincides with the end of the Neolithic, when the cultivation of the olive started and new parameters affecting its distribution were introduced. Our aims are a) to evaluate the presence of the species and the location of refugia during the Middle and Late Pleniglacial on the evidence of the new data, b) to trace the formation of thermophilous vegetation and the presence of *Olea* since early postglacial times and c) to define the role of *Olea* in the plant formations of the Atlantic *optimum* and its relationship to human activity.

The role of local oleaster populations in the domestication of the olive and in agricultural practices has been broadly discussed in numerous papers (e.g., Besnard et al., 2002; Contento et al., 2002; Breton et al., 2006). Although the data presented here may help to define those populations, discussion concerning the origin(s) of olive domestication and its cultivation during the Bronze Age in the eastern Mediterranean, and during the Iron Age in the western Mediterranean, is beyond the scope of this paper given that such processes are related to complex cultural phenomena.

2. Setting

The olive in the Mediterranean basin, in the present day, constitutes a complex of wild type, cultivated varieties and secondary feral forms. *Olea europaea* L. var. *sylvestris*, the oleaster, tends to take a shrubby form, whereas *Olea europaea* L. var. *europaea* is treelike. Both are evergreen with discrete hermaphrodite flowers that cluster in the axils of leaves. The olive fruit is fleshy and globe-shaped, with a single stone, and is green when unripe and black upon maturity. The oleaster occupies the warmest areas of the Mediterranean, coinciding approximately with the thermomediterranean bioclimatic level or with the lower mesomediterranean (Fig. 1 and 5A) (Ozenda, 1975; Rivas-Martínez, 1987). In the western Mediterranean, it forms part of the *Oleo-Ceratonion* plant association (Braun-Blanquet et al.,

1951), which extends over low warm lands with a mean annual temperature of between 17 and 19º C. A limiting factor for its development is the mean temperature of the coldest month, which should not be below 6º C (Rubio et al., 2002, fig. 1). In terms of altitude, the upper limit for *Olea* in the Iberian Peninsula is around 500 m. In the eastern Mediterranean, the oleaster forms part of the *Ceratonion-Pistacion lentisci* association (Zohary and Orshan, 1959; Browics, 1983). In the plant associations of both the western and the eastern Mediterranean, thermophilous elements including *Pistacia lentiscus* L., *Quercus* sp. evergreen, *Nerium oleander* L., *Myrtus communis* L., *Rhamnus lycioides* L. and *Rosmarinus officinalis* L. accompany *Olea*. In areas that have been subjected to little human activity, these species may form well-structured woodlands with trees up to 15 m in height, as is the case at Serra d'Arrabida in Portugal (Costa et al., 2001).

The olive has been grown for its oil-rich fruit since late prehistoric times. The cultivated variety, *Olea europaea* L. var. *europaea*, has become more adaptable to a wider range of climatic and environmental conditions and it extends beyond the previously described area (Fig. 1). It penetrates toward higher, colder and more continental lands, growing mainly on calcareous soils, terra rossa and sandy marls.

3. Materials and methods

Olea wood-charcoal macroremains that have been recovered at prehistoric sites across the North Mediterranean basin are used in the present study to trace the natural distribution of *Olea* during the Pleniglacial and the Holocene. On the basis of new wood-charcoal analyses and previously available data, we report where *Olea* has been identified (Table 1). Not all regions and chronological periods are represented by sufficient and comparable data, a circumstance that has to be taken into consideration in interpreting the evidence. The longer tradition of wood-charcoal studies in the western and central Mediterranean probably accounts for the more extensive documentation from sites in those regions than in the eastern Mediterranean. The relative scarcity of *Olea* data for the Pleniglacial in comparison with the Early–Middle Holocene is probably related to the continuous climatic oscillations during the former and the optimal environmental conditions that characterized the latter.

Despite these limitations, the wide array of information now available affords a reconstruction of the history of *Olea* in the North Mediterranean basin. In pursuit of that goal, we assess the presence and frequency of *Olea* wood-charcoal remains in each site, the characteristics of the accompanying flora, the associated chrono-cultural sequence, the

broader biogeographical context and the AMS dates provided by *Olea* wood-charcoal and endocarps.

The prehistoric sites of the North Mediterranean basin that preserve *Olea* wood-charcoal remains are shown in Table 1. Available *Olea* frequency data are cited and discussed in the text. In relation to frequencies, we believe that it is important to distinguish, in the present paper, between the simple presence of *Olea* at certain sites, represented by isolated fragments, and its abundance at others (e.g., where it constitutes 10% or more of the wood-charcoal); the latter allows us to document the expansion or dominance of the species. The frequency values of taxa identified in statistically meaningful wood-charcoal assemblages are measured as a percentage of fragment counts (for an example, see Fig. 4). On the hypothesis that during firewood collection all species were gathered in direct proportion to their occurrence in the vegetation that surrounded the habitat, the frequency of individual taxa in any given assemblage can be considered an accurate reflection of their proportion in the vegetation at the time of human presence in the area (Chabal, 1988; Chabal et al., 1999; Asouti and Austin, 2005).

Concerning the flora that accompanied *Olea*, we consider as thermophilous formations the association of species that usually accompanies the oleaster nowadays, which includes *Pistacia lentiscus*, *Rosmarinus officinalis*, *Rhamnus*, *Phillyrea*, *Pinus halepensis*, *Pinus pinea*, *P. pinaster*, and *Quercus* sp. evergreen.

All reference to vegetation zonation follows the system of vegetation levels of Ozenda (1975) and Rivas-Martinez (1987). Their classification distinguishes a five-level schematic bioclimatic arrangement of species and vegetation types in the Mediterranean region, essentially corresponding to thermal criteria that vary in relation to altitude and latitude (for an example of the above, see Fig. 5A). We consider this classification method the most suitable for describing migration of the species in the Mediterranean area in terms of altitude and latitude.

All dates mentioned in this paper are in calendar years BP. Dates published in other formats in the cited references have been calibrated to 2 sigma using the CalPal-2007 program (Weninger et al., 2009) and the CalPal-2007-Hulu calibration data set (Weninger and Jöris, 2008), and are reported in Table 2-B. Figure 2 presents a chronological correlation of the marine record with the Pleniglacial and the Holocene chrono-zones as well as with the cultural periods mentioned in the text.

Three maps show the distribution of the oleaster —at the present time (Fig. 1) and during the Middle–Late Pleniglacial (Fig. 3A) and the Early–Middle Holocene (Fig. 3B) — in

order to delimit its biogeographical affinities now and in the past. The sites mentioned in the text are accompanied by a number which allows locating them in both Table 1 and Figure 3. The information presented on the maps and Table 1, the evaluation of the flora accompanying *Olea* in the wood-charcoal sequences and the AMS dates of *Olea* macroremains (Table 2-A) provide our bases for reassessing the location of thermophilous tree refugia and the postglacial distribution and expansion of oleaster populations in the sclerophyllous vegetation of the North Mediterranean basin. Evidence from the pollen record and from archaeobotanical seed macroremains is cited where relevant.

4. Results

4.1. The Pleniglacial

The presence of the olive in the Mediterranean basin during the Pleniglacial is documented at a few Middle and Upper Palaeolithic sites, ascribed to the Marine Isotope Stage (MIS) 3 (58–23 ka BP) and MIS 2 (23–11,5 ka BP) (Table 1, Fig. 3A).

During the MIS 3, the earliest *Olea* wood-charcoal finds in the eastern Mediterranean come from the Palaeolithic sites of Klissoura Cave 1 (2) and Boker (53). At the former, an AMS *Olea* wood-charcoal date (using ABOX pre-treatment)[1] places the earliest presence of the species to 61 440–55 320 cal. BP (Table 2-B). At Boker (53) two charcoal samples (Liphschitz et al., 1991) originate from transitional Middle/Upper Palaeolithic levels that have been dated to c. 49 ka cal. BP (for the date see Mellars, 2006). *Olea* wood-charcoal was also recovered on the island of Thera (Santorini) (5) in the Aegean, in palaeosols dating to c. 47 and c. 41 ka cal. BP (Friedrich, 1978). Of later date, but still within the MIS 3, *Olea* wood-charcoal has again been identified at Klissoura Cave 1 (2), in levels dating to between c. 37 ka and 32 ka cal. BP (Ntinou, unpublished) and at Boker (53) in Upper Palaeolithic strata dating to between c. 32 ka and 27 ka cal. BP (Liphschitz et al., 1991). The taxon at Klissoura Cave 1 (2) is associated to open woodland formations with *Prunus* t. *P. amygdalus/P. webii* and other thermophilous and mesophilous taxa such as evergreen and deciduous *Quercus*, *Acer* sp. and *Ulmus* sp. (Ntinou, unpublished).

Further evidence for the presence of *Olea* during the MIS 3 comes from Palaeolithic sites in the Iberian Peninsula (Table 1, Fig. 3A). The earliest dated find is an olive nutshell

[1] ABOX (acid-base-oxidation) is a chemical pre-treatment method that involves wet oxidation and step-heating of samples to be dated by AMS. The ABOX method eliminates a substantially larger percentage of recent contaminants and it can be used to produce reliable 14C dates on charcoal up to at least 50 ka (Bird et al., 1999: 127).

recovered at the Higueral de Valleja Cave (4). The age of the specimen is placed at 42 630–41 390 cal. BP (Jennings et al., 2009, table 4), indicating the local presence of the taxon during the Middle Pleniglacial. At Gorham's Cave (1), the presence of *Olea* in Middle Palaeolithic layers coincides with the dominant presence of *Pinus pinea-pinaster* whereas *Pinus nigra-sylvestris* is very rare (Carrión et al., 2008). At Abric Romaní (41), the presence of the olive is rare in a wider floristic/vegetation context with cold characteristics in which *Pinus nigra-sylvestris* dominates and thermophilous taxa are absent (Allué, 2002). At the Portuguese site of Buraca Grande (42), *Olea* reaches frequencies of 9% in the Upper Palaeolithic layer 9B dated to 29 730–27 970 cal. BP (Table 2-B) (Figueiral and Terral, 2002). Although the dominance of *Pinus* type *sylvestris* and *Buxus sempervirens* indicates mountain-type habitats with cool and dry climatic conditions, the presence of *Olea*, deciduous *Quercus* and *Arbutus* suggests that the limestone hills of the Portuguese Estremadura constituted a refuge for thermophilous and mesophilous taxa (Figueiral and Terral, 2002). However, Buraca Grande (42) presents certain problems: the AMS date of an *Olea* wood-charcoal fragment recovered from level 9B gave an age of 7970–7770 cal. BP (Table 2-A). The aberrant date and the fact that the species is very abundant (60–80%) in the overlying Holocene levels (Figueiral and Terral, 2002) suggest the intrusive character of *Olea* in these Pleniglacial contexts.

During the MIS 2, *Olea* wood-charcoal remains are scarce (Table 1, Fig. 3A) despite the fact that many Palaeolithic sites of relevant dates have been excavated across the Mediterranean. Furthermore, at a number of sites, the AMS dates of *Olea* specimens provided irrelevant Holocene ages (Table 2-A).

In the eastern Mediterranean, in the Levantine area, there are no reports for *Olea* wood-charcoals in Late Pleniglacial contexts. However, the presence of *Olea* may be deduced from the finding of olive stones at the Upper Palaeolithic site of Ohalo II (23 500–22 500 cal. BP) (Kislev et al., 1992; for the date see Nadel et al., 2006) and at Late Natufian (12 500–12 000 cal. BP) contexts at Nahal Oren (Noy et al., 1973). Further to the north, at Öküzini Cave (9), two possible (cf.) *Olea* wood-charcoal fragments were identified in Upper Palaeolithic levels dated to 20 170–19 170 and 15 370–14 570 cal. BP and characterized by "steppe forest" vegetation with *P. amygdalus*, *Pistacia* and *Juniperus*, as well as mesophilous (deciduous oak, *Acer*), thermophilous (*Phillyrea*) and riverine (tamarisk, ash, willow/poplar) taxa (Emery-Barbier and Thiébault, 2005). Also at Öküzini Cave (9), *Olea* pollen is recorded in spectra probably corresponding to the levels where olive wood-charcoals have been found (Emery-Barbier and Thiébault, 2005). Finally, at Klissoura Cave 1 (2), *Olea* wood-charcoal is included in Upper Palaeolithic assemblages dated to 17 780–17 140 cal. BP (Table 2-B)

(Koumouzelis et al., 2001) and characterized by open parkland vegetation with *Prunus amygdalus*. However, the presence of *Olea* in those contexts is questionable since the AMS date of an *Olea* wood-charcoal fragment provided a Holocene age (4660–4220 cal. BP; Table 2-A).

The Iberian Peninsula offers additional data concerning the presence of *Olea* during the MIS 2. At the Portuguese site of Buraca Grande (42) (Figueiral and Terral, 2002), *Olea* reaches frequencies of 22% in the Upper Palaeolithic layer 9A dated to 21 840–20 920 cal. BP (Figueiral and Terral, 2002). However, the aberrant AMS dates of *Olea* from earlier Upper Palaeolithic levels (see above) raise reasonable doubts as to the taxon's presence in any pre-Holocene context. At Cova de les Cendres (10), *Olea* wood-charcoal has been identified in an Upper Palaeolithic level, coexisting with mountain taxa (*Pinus nigra-P. sylvestris*) (Badal and Carrión, 2001). The AMS date of an *Olea* specimen (7620–7460 cal. BP, Table 2-A) at Cova de les Cendres (10) raises questions similar to those in the case of Buraca Grande (42) and Klissoura Cave 1 (2). At La Ratlla del Bubo (8), *Olea* charcoal and that of other thermophilous taxa that have been identified at levels dated to 21 310–20 390 cal. BP (Table 2-B), associated with plant formations dominated by *Juniperus* and including some *Pinus nigra* and *Ephedra*. The presence of thermophilous taxa has been interpreted by Badal (1995) to be a result of charcoal infiltration from the overlying Holocene contexts.

To the south, at Gorham's Cave (1), the presence of *Olea* in Upper Palaeolithic levels (earlier than 12 500 cal. BP) is coherent with that of other thermophilous taxa, such as *Pistacia lentiscus* and *Rhamnus alaternus-Phillyrea*, identifying Gibraltar as a reservoir of temperate and thermophilous phytodiversity during the cold stages of the Late Glacial (Carrión et al., 2008, p. 2125). At Cueva de Nerja (6), a continuous *Olea* curve is documented from the end of the Late Glacial (13 100–12 580 cal. BP –Table 2-B) and onward, parallel to the expansion of thermophilous Mediterranean vegetation dominated by Leguminosae, *Pinus pinea*, *Pinus halepensis*, *Pistacia lentiscus* and *Rosmarinus officinalis* (Badal, 1998).

On this evidence of the *Olea* wood-charcoal from Middle and Upper Palaeolithic sites in the northern Mediterranean basin, the species is seen to have survived the Pleniglacial climatic deterioration in refugia located in coastal areas or in hinterland locations with favorable microclimates. Corroborative evidence is provided by various palynological analyses in the eastern and western Mediterranean. *Olea* pollen has been present in the Ghab, northwestern Syria, for at least the last 50 000 years (Niklewski and van Zeist, 1970, cited in Bottema and Sarpaki, 2003) and occurs in the Hula, northern Israel, throughout the whole core of the last 17 000 years (Baruch and Bottema, 1999, cited in Bottema and Sarpaki, 2003).

Pollen analyses at the Natufian sites of Salibiya XII and I and Fazael IV, located in the lower Jordan valley, document abundance of *Olea* in the local vegetation already during the Late Glacial (Darmon, 1987). The Megali Limni cores, Lesvos Island, Greece (Margari et al., 2009), show that *Olea* was important in the Aegean during the early part of MIS 3 (c. 53–51 ka cal. BP) and its expansions with evergreen *Quercus* suggest warm conditions especially during winter and increased seasonality of precipitation. Moreover, the presence of *Olea* and other thermophilous taxa is documented in the I-284 pollen core, Ioannina lake basin, Greece, during the interstadial prior to 24 380 cal. BP (Galanidou et al., 2000; Tzedakis et al., 2002). In the southern Iberian Peninsula, early *Olea* curves are present at Bajondillo, dated to 39 218 ± 1643 cal. BP (Cortés-Sánchez et al., 2008), at Siles Lake from c. 20 276 cal. BP onward (Carrión et al., 2003), at the Middle Palaeolithic levels of Carihuela Cave and Cueva Negra (Carrión et al., 2003), at the Middle and Upper Palaeolithic levels of Gorham's Cave (1) (Carrión et al., 2008) and at the Upper Palaeolithic levels of Algarrobo Cave (Carrión et al., 1999). At Cueva Perneras, *Olea* pollen has been sporadically identified during the Pleniglacial and the Late Glacial in spectra where pine and steppic plants (*Artemisia* and Chenopodiaceae) dominate (Carrión et al., 1995). According to the pollen evidence, short episodes of *Olea* expansion, which would have left hardly any trace in the charcoal record, might have occurred during the warm intervals of the last glaciation. Wild olive populations would have been constrained in refugial lowland areas and it is probably for this reason that *Olea* is not detected in Late Pleniglacial pollen sequences from locations at higher altitudes, such as the Padul peat bog (Pons and Reille, 1988).

4.2. The Holocene

The location of the Pleniglacial thermophilous plant refugia would have played an important role in the distribution, expansion and abundance of the oleaster in different areas of the Mediterranean during the earlier part of the Holocene and until the Atlantic. It is after the latter period that human activities became the principal agent in the transformation of the landscape and vegetation.

4.2.1. The eastern Mediterranean

The earliest *Olea* finds in the eastern Mediterranean come from sites located in the thermomediterranean level (Table 1, Fig. 3B). At the Pleistocene/Holocene transition, the presence of *Olea* wood-charcoal is attested in the southern Levantine area at the Pre-pottery Neolithic (PPN) A levels (11 700–10 500 cal. BP) of Jericho (56) (Western, 1971) and Abu

Salem (54), Negev (Liphschitz et al., 1991). During the PPNB and C (10 500–8250 cal. BP), the species was present at the sites of Horvat Galil (19) (Liphschitz, 1997) and Nahal Divshon (55) (Liphschitz et al., 1991) and also at the now submerged settlement of Atlit Yam (18) (Galili et al., 1993). The distribution of *Olea* (wood and charcoal) findings indicates that the species was present in a variety of habitats ranging from the coastal areas to the western Upper Galilee [Atlit Yam (18), Horvat Galil (19)] and the Negev [Nahal Divshon (55)], coinciding approximately with the area of the Pleniglacial presence of the species [Nahal Oren, Ohalo and Boker (53)]. The oleaster would have formed part of the Mediterranean vegetation in the Levantine coastal areas, and it would have probably also grown in regions that are presently characterized by irano-turanian and saharo-arabian formations. Its wood and fruit would have been collected for fuel and consumption by the PPN and PN communities as indicated by the early presence of olive stones at Tell Ras Shamra (Syria) at levels dating to between the early 10th and 9th mill. cal. BP (Colledge, 2001) and at various submerged sites off the northern Carmel Coast (Kfar Samir, Kfar Galim, Tel Hreiz, Megadim) dating to the 8th mill. cal. BP (Galili et al., 1988, 1989). An exceptional find highlighting the human factor as an agent for the dispersal of *Olea* are two olive-stone fragments from the transitional PPNA/PPNB levels of Dja'de and the PPNB levels of Halula (Table 2-B), both located at the Euphrates valley and outside the area of the natural oleaster distribution (Willcox, 1996).

The presence of *Olea* in Cyprus is well documented as early as the mid-11th mill. cal. BP at Shillourokambos (12), where during the 10th mill. cal. BP (Table 2-B) the taxon became the dominant feature in the local vegetation (50%) together with *Pistacia* sp. (Thiébault, 2003). *Olea* was also present during the 9th and 8th mill. cal. BP at Khirokitia (16) (Table 2-B), participating in formations dominated by *Pistacia*, and later by *Pinus brutia* (Thiébault, 2003). The wood-charcoal results are supported by the finding of a few olive stones in PPN and Late Neolithic contexts at Khirokitia (16) (Hansen, 1991, 1994), Cape Andreas-*Kastros* (van Zeist, 1981, cited in Hansen, 1991) and Ayios Epiktitos-Vrysi (Kyllo, 1982, cited in Hansen, 1991). This evidence from Cyprus indicates a continuous and locally abundant presence of *Olea* in the vegetation from the Preboreal and until the Atlantic period.

In the Aegean area and Greece the history of the olive during the Holocene is quite obscure due to the scarcity of data. The low presence of the species in the wood-charcoal record is probably related to the fact that most of the available results come from northern sites (Ntinou, 2002) that lay outside the area of the natural oleaster distribution, which is confined to the south of latitude 39º N (Ozenda, 1975). However, even in the few southern or Aegean sites where the olive could be expected to have grown, it has rarely been identified in

Early-Middle Holocene wood-charcoal sequences. The earliest *Olea* wood-charcoal finds in the Aegean area have been identified at the Cave of the Cyclops (52), Youra, Northern Sporades, Greece (Ntinou, in press). The Mesolithic/Neolithic sequence of the cave shows that *Olea* was conspicuously absent from the Early Holocene evergreen Mediterranean plant formations (c. early 11th and 10th mill. cal. BP –Table 2-B) and appeared, in low percentages, only after 8640–8480 cal. BP (Table 2-B), mainly coinciding with the Neolithic period (Fig. 4C).

In Crete, the absence or late appearance of the olive during the Holocene contrasts with the Cypriot and the Levantine data. At the site of Knossos, wood-charcoal analysis (Badal and Ntinou, unpublished) failed to detect the presence of the olive in any of the Neolithic layers despite the fact that typically thermomediterranean formations with evergreen oaks and other sclerophyllous taxa would have grown in the area. The only wood-charcoal evidence of *Olea* being present in Crete before the Bronze Age derives from Final Neolithic contexts (6th mill. cal. BP) at the Kephala-Petras (39) settlement in Eastern Crete (Ntinou, unpublished). The absence of the olive during the first half of the Holocene is also attested by other lines of evidence. The oldest olive archaeobotanical remains on Crete date to the Subboreal, particularly the Early Bronze Age (Bottema and Sarpaki, 2003), while the taxon is absent from the lower spectra of all the pollen sequences of the island (Bottema, 1980; Moody et al., 1996; Bottema and Sarpaki, 2003). It appears for the first time in the Delphinos core (Bottema and Sarpaki, 2003) at c. 7230–6990 cal. BP and shows a continuous closed curve only after 6530–6450 cal. BP (Table 2-B). According to Bottema and Sarpaki (2003), the olive was a late introduction to the island through overseas contacts, sometime after the Middle Neolithic. However, Moody et al. (1996) suggest that the olive was a natural element of the Pleistocene vegetation of Crete that survived in refugia somewhere on the island, from where it spread at a slow rate with the onset of the Holocene.

To the west of mainland Greece, *Olea* wood-charcoal has been found in the Late Neolithic levels (early 8th mill. cal. BP) of Drakaina Cave (40), Kefalonia (Ntinou, unpublished). The presence of the species in mixed evergreen and deciduous formations in the gorge environment of the cave may be seen in agreement with the hypothesis put forward by Moody et al. (1996) for Crete (see above). It is thus possible that the species grew in small numbers in special microenvironments, such as gorges, and became a prominent feature of the vegetation only much later through cultivation.

In mainland Greece, *Olea* remains are either absent or very sporadic until the end of the Atlantic period or later. Isolated olive stones are reported from Neolithic contexts in central

and northern Greece (Renfrew, 1966; Margariti, 2004), but their interpretation is far from clear. In the pollen record from central and southern Greece, *Olea* is quite sporadic before the Subboreal, when the taxon starts to display continuous curves attributed to the cultivation of the tree (Wright, 1972; Turner and Greig, 1975; Bottema, 1990, 1994; Jahns, 1993).

4.2.2. The central Mediterranean

In the central Mediterranean, the presence of *Olea* wood-charcoal has been documented at sites that concentrate in Sicily, in the southernmost areas of the Italian Peninsula and in the Liguro-Provençal region, all of them confined to the thermomediterranean bioclimatic level (Table 1, Fig. 3B).

The earliest *Olea* wood-charcoal finds in the central Mediterranean are reported from the Mesolithic levels at Grotta dell' Uzzo (11) in Sicily, dating between 12 060–11 220 and 9560–9080 cal. BP (Table 2-B) (Costantini, 1989). The presence of *Quercus* cf. *ilex* and *Phillyrea* sp. in the same levels has led Costantini (1989) to the conclusion that the vegetation of the area was a xerophyll maquis. At the same site, the first appearance of wild olive stones dates back to the Mesolithic/Neolithic transition.

The early presence of the oleaster in Sicily is confirmed by various pollen sequences. At Gorgo Basso, southwestern Sicily (Tinner et al., 2009), and at Lago di Pergusa, central Sicily (Sadori and Narcisi, 2001), *Olea* trees or shrubs expanded between 8500 and 8000 cal. BP. Despite an abrupt decline observed at Gorgo Basso at 8200 cal. BP, the species reexpanded at c. 7300–7000 cal. BP, being also documented in the pollen sequence from Biviere di Gela, southern Sicily (Noti et al., 2009). After 7000 cal. BP, *Olea europaea* and *Quercus ilex* would have formed rather dense evergreen forests on the coastal areas of the island (Noti et al., 2009; Tinner et al., 2009).

In the Italian Peninsula, Early Holocene *Olea* wood-charcoal finds are rather rare. To the south, at Piana di Curinga (38), *Olea* is documented as early as 7910–7630 cal. BP (Table 2-B) with percentages of around 5% (Badal, 2002) (Fig. 4B). Evergreen *Quercus* dominates throughout the whole sequence, while other thermophilous taxa, such as *Pistacia lentiscus* and *Daphne gnidium*, as well as species of cooler environments, namely *Ostrya carpinifolia*, are also present (Badal, 2002). Wood-charcoal analyses conducted at Grotta Latronico 3, did not reveal the presence of *Olea* remains (Castelletti, 1978). We may postulate that the rapid transition between successive bioclimatic levels throughout the Italian Peninsula, along with the restricted thermomediterranean belt, might have been a limiting factor for the Early Holocene expansion of *Olea*. In line with such a suggestion is the pollen evidence from the

Italian Peninsula that mainly points to an *Olea* expansion during the Atlantic period. On the western side of central Italy, the pollen sequences from Lagaccione (Magri, 1999) and Lago di Vico (Magri and Sadori, 1999) in Lazio and from Lago dell'Accesa (Drescher et al., 2007) in Tuscany document an early (c. 9000 cal. BP at Lagaccione) though rare and discontinuous presence of *Olea* in a deciduous oak-dominated landscape. It was after 6500 cal. BP that a mixed forest was established, including deciduous elements together with evergreen oaks and *Olea* (Magri, 1999); however, *Olea* would not have been an important component of the sclerophyllous woodland (Drescher et al., 2007). Unfortunately, the pollen sequences from eastern central Italy, i.e. from Lago di Battaglia (Caroli and Caldara, 2007) and Lago Alimini Piccoli (Di Rita and Magri, 2009) in Apulia, do not record the earliest part of the Holocene. However, they confirm that *Olea* was present and quite abundant from 5950 cal. BP at the former and from c. 5600–5200 cal. BP at the latter, forming part of a dense Mediterranean evergreen vegetation with *Quercus ilex*, *Phillyrea* and *Pistacia* (Caroli and Caldara, 2007; Di Rita and Magri, 2009).

Further to the north, in the Liguro-Provençal region, *Olea* wood-charcoals are reported at Caucade (35), Giribaldi (36) (Thiébault, 2001) and Arene Candide (37) (Nisbet, 1997) in levels corresponding to the Atlantic period and later (Table 1). The taxon reaches high frequencies and is accompanied by other thermophilous species, such as the lentisc and the Aleppo pine. The available wood-charcoal data indicate the existence of a restricted warm coastal area corresponding to the present-day thermomediterranean niches found in the Liguro-Provençal region (Thiébault, 2001).

In Corsica, wild olive stones dating back to the Middle Neolithic (Magdeleine and Ottaviani, 1984) were found at Scaffa Piana, but there are no reports of *Olea* wood-charcoal finds on the island. The pollen record of Corsica gives evidence for the sporadic Early Holocene presence of *Olea* both at high-altitude and lowland areas of the western coast while it is absent from the eastern plain (Reille, 1992). High-altitude sites show the rare presence of *Olea*, from the Boreal onward at Lac de Greno and only after the Atlantic period at Bastani 1 and 2. During the Atlantic period on the western coast of Corsica (at Saleccia and Le Fango), among the trees that characterize the thermophilous zone today, *Olea* was only irregularly recorded while *Pistacia* and *Phillyrea* were more frequent (Reille, 1992).

4.2.3. The western Mediterranean

The Holocene marks the beginning of a massive *Olea* expansion that is attested in most of the wood-charcoal sequences from the warmest western Mediterranean areas. The large

number of wood-charcoal analyses that have been carried out in this region has enabled a mapping of the wild olive distribution in this setting (Table 1, Fig. 3B).

4.2.3.1. Olea in the thermomediterranean level

The earliest Holocene *Olea* finds in the western Mediterranean are reported from prehistoric sites located in the thermomediterranean level. During the Preboreal, the presence of the taxon is still scarce and this may be partly related to the hiatuses reported in some sequences coinciding with this period. However, at Cueva de Nerja (6), a continuous *Olea* wood-charcoal curve is detected as early as the end of the Pleistocene and throughout the Holocene sequence (Badal, 1998). The presence of *Olea* wood-charcoal has also been documented during the Pleistocene/Holocene transition at Cova de Santa Maira (13) (Aura et al., 2006) and during the Early Holocene at Boquete de Zafarraya (3) (Terral et al., 2005) (Table 2-B). At the former, other thermophilous taxa, such as *Pistacia*, also appear quite sporadically. At the Neolithic levels of this cave, *Olea* becomes co-dominant with *Pinus halepensis*, thus attesting a change in vegetation composition during the Atlantic, when thermophilous species become dominant (Badal, 1999).

In the southernmost areas of the Iberian Peninsula, *Olea* pollen is seen to trace a continuous curve from the beginning of the Late Glacial and onward (Pantaleón-Cano et al., 2003; Cortés-Sánchez et al., 2008). In the lower Guadiana valley, the CM5 core shows a continuous pollen curve for *Olea* from c. 9200 cal. BP, but a sporadic presence of the species is already documented from c. 13 600 cal. BP, a sign of the early development of the "thermomediterranean forest fringe" (Fletcher et al., 2007). An "echo" of these lowland populations of *Olea*, given the ease with which its pollen disperses, would have reached the mesomediterranean level, as reported in the pollen record of Padul peat bog (Pons and Reille, 1988).

The Atlantic period saw the expansion of *Olea* in the western Mediterranean basin. There are numerous wood-charcoal sequences on both the Mediterranean and Atlantic façade of Iberia where *Olea* is continuously present and abundant. The largest collection of *Olea* findings for the Atlantic period is recorded to the south of parallel 40º N. Along the eastern coastline, at Cova de les Cendres (10), Cova Bolumini (25), Cova Ampla del Montgó (26), Cova de la Recambra (28) and Cova del Llop (27), *Olea* is present from the beginning of the Neolithic sequence (c. 7500 cal. BP) along with other thermophilous taxa (Vernet et al., 1983; Badal et al., 1994), a situation also seen in the rest of the thermomediterranean level. This is the case of Los Murciélagos de Albuñol (23) and Río Palmones (17), located in the mouth of

the Guadalquivir River, Vale Pincel I (20) at Alentejo (Carrión, 2005), Abrigo da Pena d'Água (14) in the Tajo valley (Figueiral, 1998) and Castelejo (15) in the Portuguese Algarve. New wood-charcoal data from Castelejo (15) are exceptional in that *Olea* is the prevailing taxon from a very early stage (the Mesolithic level, 9070–8590 cal. BP –Table 2-A) and throughout the whole sequence at percentages of between 40-60% (Fig. 4A). On the Atlantic façade, *Olea* is usually accompanied by *Pinus pinea*, *P. pinaster* and *Quercus suber* (Carrión, 2005).

Notably, *Olea* wood-charcoals have been recovered at very few sites located near or above parallel 41º N. In Catalonia, the wild olive has been documented only at the sites of Can Sadurní (32) and Can Tintorer (33) (Ros, 1985), despite the numerous anthracological analyses carried out in this region. One of the most northerly pieces of evidence for the abundant presence of *Olea* was found at Cova de l'Espérit (34) in the east Pyrenees. Here, the presence of wild olive is documented from the end of the Mesolithic period, reaching values of around 30% after 7620–7380 cal. BP (Table 2-B), when it is accompanied by other thermophilous indicators such as lentisc and *Rhamnus-Phillyrea* (Solari and Vernet, 1992). The presence of *Olea* in such northern areas is an indication that, as in the Liguro-Provençal region (see above), warm enclaves beyond the continuous thermomediterranean belt (coinciding with their present-day configuration) might have existed earlier than the Middle Holocene. This hypothesis is corroborated by pollen data, specifically the continuous curve of *Olea* in Catalonia dated from 9500 cal. BP onward (Pantaleón-Cano et al., 2003) and in the Gulf of Lions from 7346 cal. BP (Jalut et al., 2009).

4.2.3.2. Olea in the mesomediterranean level

Wood-charcoal sequences in the Iberian Peninsula document the presence of *Olea* also in the mesomediterranean level, particularly in its lower part. In this level, the distribution of the species, its dynamics and the accompanying taxa differ significantly from those reported for the thermomediterranean level.

In the lower mesomediterranean level, the presence of *Olea* seems to be strongly linked to favorable orographic conditions, having been reported primarily in areas such as sunny slopes and valley bottoms that are warm and protected from continentality. Such is the case at Cova de l'Or (47), located on a south-facing slope, where *Olea* is present with values of around 10 to 15% (Badal et al., 1994). In more interior enclaves, such as at La Falguera (48), its presence is more sporadic (Carrión, 2002; García and Aura, 2006). The presence of *Olea* in the Guadalquivir valley, where it has been documented at Cueva del Toro (44), Murciélagos

de Zuheros (45) and Polideportivo de Martos (46), is probably to be explained as inland penetration of warm conditions and thermophilous vegetation along river courses (Rodríguez-Ariza and Montes, 2005).

Buraca Grande (42) and Montou (51) (Fig. 3B) document the northernmost presence of *Olea* in the mesomediterranean level. At the former, the species is present from 9290–8890 cal. BP (Table 2-B) and throughout the Holocene sequence (Figueiral and Terral, 2002), while at Montou (51) it appears at a single level dating to 6180–5780 cal. BP (Table 2-B) (Heinz et al., 2004).

The poor frequency of *Olea* in the mesomediterranean sites, generally well below 10% of the remains, is comparable to that of other thermophilous taxa. The dominant taxon is *Quercus*, both evergreen and deciduous. The higher the latitude, the scarcer thermophilous taxa become. The exception to this pattern is, once again, Buraca Grande (42), where *Olea* frequency is around 80% (Figueiral and Terral, 2002, p. 551).

In the absence of evidence that *Olea* was present in the mesomediterranean bioclimatic level during the Preboreal and the Boreal, the appearance of the taxon in this level should be linked to its expansion during the Atlantic period. In continental pollen sequences, *Olea* is sporadic even during the expansion of Mediterranean-type species around 5000 cal. BP (Carrión et al., 2001). The wood-charcoal remains indicate that its presence was restricted to favorable enclaves in the lower mesomediterranean belt.

5. Discussion

The distribution of *Olea* in Pleniglacial and Holocene contexts in the North Mediterranean basin can be more fully documented on the evidence of the available *Olea* AMS dates, the accompanying flora, the continuity of the species' presence in wood-charcoal and in certain pollen sequences and the biogeographical situation of the sites with *Olea* remains.

5.1. The Olea dates

The available AMS *Olea* wood-charcoal dates (Table 2-A) provide a framework for discussing the distribution of the species during the Pleniglacial and the Holocene.

In general terms, the Middle Palaeolithic, the Mesolithic and the Neolithic contexts closely correlate with the corresponding AMS dates (Table 2-A). The correlated dates appear to substantiate the presence of *Olea* in certain areas under the favorable environmental conditions of the MIS 3 interstadials and the Holocene. Some of the *Olea* AMS dates,

however, particularly those from Upper Palaeolithic sequences, are not coherent with the associated chrono-cultural context and have provided Holocene ages. Infiltration or mixing of Pleistocene/Holocene contact levels seems to be responsible for the presence of *Olea* in Pleniglacial contexts at Buraca Grande (42), Cova de les Cendres (10) and Klissoura Cave 1 (2). At other sites where Pleistocene/Holocene contact levels are present, and where *Olea* usually acquires low percentages in Pleistocene contexts and higher frequency in Holocene levels, similar explanations may be considered. Discrepancies between *Olea* dates and chrono-cultural contexts indicate the existence of taphonomic problems at some sites and may cast doubt on the identifications of some *Olea* refugia during the Pleniglacial.

As a further means of evaluating the presence of *Olea* during the Pleniglacial, we have reconsidered the plant taxa that accompany this species in wood-charcoal sequences, specifically by assessing the presence and abundance of the thermophilous taxa that usually accompany *Olea*, and also the cold-environment ones, whose presence in assemblages together with the wild olive is divergent in ecological terms (Fig. 5A). The resulting pattern observed at some sites with Pleistocene and Holocene levels, where *Olea* (and occasionally other thermophilous taxa) and *Pinus nigra-sylvestris* are associated (Fig. 5B), is instructive. In most of the Pleniglacial records that document the presence of *Olea*, the taxon appears in low percentages and in a floristic context otherwise dominated by cold-environment or pioneer taxa (*Pinus nigra-P. sylvestris*, *Juniperus*). Another apparently inconsistent association is seen in the persistence of *Pinus nigra-sylvestris* at Holocene levels, when thermophilous taxa are already dominant. In these two cases, the presence of thermophilous and cold-environment taxa could be explicable as an intrusion from Holocene and Pleistocene levels, respectively (Fig. 5B). Such intrusion is demonstrated in the case of Cova de les Cendres (10), where AMS dates of an *Olea* fragment from Upper Palaeolithic levels gave a Holocene date and a *Pinus nigra-P. sylvestris* fragment from the Neolithic levels provided a Pleistocene date (Badal, 2006) (Table 2-A).

Considering these findings, we suggest that taphonomic processes may account for the coexistence of *Olea* (in low relative abundance) and cold-environment taxa in Late Pleniglacial assemblages, as for example at Abric Romaní (41), la Ratlla del Bubo (8) and Santa Maira (13). It is recommended that the role of *Pinus nigra-sylvestris* in the mesomediterranean vegetation during the Holocene be clarified, particularly in light of the reported persistence of that taxon in Portuguese sites (Figueiral and Carcaillet, 2005). For the accomplishment of that goal, and in awareness of the ecological complexity of the

Mediterranean area, possibly attenuated during glacial times, new AMS dates of the above-mentioned species and contexts are essential.

5.2. The Pleniglacial refugia and the distribution of Olea during the Early and Middle Holocene

The hypothesis for the existence of thermophilous refugia in the Pleniglacial has been based on AMS *Olea* dates and the presence of the species together with other thermophilous taxa in various chrono-cultural contexts (Figueiral and Terral, 2002; Carrión et al., 2008; Tzedakis et al., 2002).

The presence of *Olea* during the Middle Pleniglacial is confirmed by two direct AMS dates, from Klissoura Cave 1 (2) and from Higueral de la Valleja Cave (4) (Table 2-A). These, together with *Olea* wood-charcoal from the southern Levant, the Aegean area and the southern Iberian Peninsula, may indicate the permanence of the species in these regions during the milder periods of the MIS 3. Supporting evidence comes from pollen data in the same regions (Niklewski and van Zeist, 1970; Pantaleón-Cano et al., 2003; Carrión et al., 2007; Margari et al., 2009).

During the Late Pleniglacial, the presence of *Olea* wood-charcoal remains is sporadic despite the numerous sequences corresponding to the Upper Palaeolithic. On the evidence of the available wood-charcoal results, we suggest that the Late Pleniglacial *Olea* refugia would have been located in those areas where: a) *Olea* is accompanied by other thermophilous taxa that are dominant [as at Gorham's Cave (1) and Cueva de Nerja (6)], b) continuous *Olea* curves are documented from the Late Glacial and continuing throughout the Holocene [as at Cueva de Nerja (6)] and c) the taxon is present in the Early Holocene (Preboreal) [as in the southern Levant close to the Mediterranean, on Cyprus, and at Grotta dell' Uzzo (11)]. On this hypothesis, thermophilous refugia with *Olea* would have existed in the southern Levant, the southern parts of the Iberian Peninsula and most probably in Cyprus and Sicily. North Africa would have constituted another such area, given the presence of *Olea* at Rhafas Cave at the start of the Last Glaciation (Wengler and Vernet, 1992) and at Grotte des Pigeons in the Late Glacial (Santa, 1958–1959, cited in Wengler and Vernet, 1992). The existence of refugia in southern Spain and the Levant is supported by pollen data: the beginning of continuous curves of *Olea* date to 20 298–19 799 cal. BP for southern Spain (Pantaleón-Cano et al., 2003) and to 17 000 cal. BP for the Levant (Baruch and Bottema, 1999, cited in Bottema and Sarpaki, 2003).

The survival of *Olea* and other thermophilous taxa in Pleniglacial refugia in the Mediterranean basin would have favored their early expansion in the Holocene. The Preboreal and the Boreal constitute a pioneer phase that implies the establishment of a biogeographical configuration similar to that of the present day (Fig. 1), as is documented by *Olea* wood-charcoal (Table 1) and pollen finds from the Near East, Cyprus, Sicily and south Iberia (Sadori and Narcisi, 2001; Pantaleón-Cano et al., 2003; Fletcher et al., 2007; Noti et al., 2009; Tinner et al., 2009).

The Atlantic period marks the expansion of *Olea* as well as differentiation in its distribution and dynamics between the western and eastern areas of the basin. The biogeographical patterns are better understood in the western Mediterranean, where there is a large number of wood-charcoal sequences. In the Iberian Peninsula, *Olea* appears during the Atlantic at virtually all sites presently situated in the thermomediterranean and lower mesomediterranean bioclimatic levels. The presence of *Olea* in the lower mesomediterranean should be linked to the maximum representation and expansion of the species in the thermomediterranean, as well as to the favorable orography of particular areas such as south-facing slopes [as at Cova de l'Or (47)] and valley bottoms [as at La Falguera (48)]. Outside this setting, the presence of *Olea* is much scarcer, and is restricted to sporadic enclaves such as Cova de l'Espérit (34) in the eastern Pyrenees and the Liguro-Provençal sites [Caucade (35), Giribaldi (36) and Arene Candide (37)] (Solari and Vernet, 1992; Nisbet, 1997; Thiébault, 2001).

In attempting to assess the causes of the rapid expansion of *Olea* during the Atlantic period, we may consider two possibly complementary factors, namely climatic change and anthropogenic activities:

a) The wild olive and other thermophilous taxa were favored by the climatic optimum of the Atlantic period that enabled their spread in the thermomediterranean level. Major expansion of *Olea* occurred during the 7000–5500 cal. BP interval, which according to Jalut et al. (2009), corresponds to a transitional period of the Holocene between the previous mostly humid one (11500-7000 cal. BP) and the following phase (5500 cal. BP to the present) at various sites in the Mediterranean (southeast Spain, the Peloponnese, Central Italy, Sicily, the Gulf of Lions). On the evidence of the available *Olea* charcoal data and of the pollen sequences from south Iberia and Sicily (Carrión et al., 2003; Pantaleón-Cano et al., 2003; Fletcher et al., 2007; Noti et al., 2009; Tinner et al., 2009), it is probable that humid conditions in the southern areas of the North Mediterranean basin favored the expansion and density of sclerophyllous vegetation with *Olea*. By the end of the mentioned humid period,

aridification processes would have caused the expansion of sclerophyllous vegetation in the lower mesomediterranean belt to the detriment of mesophilous forests (Pons and Quézel, 1998; Jalut et al., 2000).

b) The human factor, specifically farming activities and the early manipulation of the wild olive, played a fundamental role in the expansion process of *Olea*. Evidence in support of such a hypothesis comes from *Olea* macroremains across the Mediterranean that show intensive use of the species in thermomediterranean contexts (Terral, 1997; Badal, 1999; Terral el al., 2004; Galili et al., 1989). The cultivation of the olive in later periods resulted in that it became more resistant to continental conditions and even to those prevailing at the Atlantic façade of the Iberian Peninsula.

5.3. Olea in the sclerophyllous woodland

During the Atlantic period, *Olea* formed part of the typical sclerophyllous woodland in the Mediterranean basin. If we take into account its frequency and the accompanying taxa in the available wood-charcoal sequences, three distinct behaviors of the *Olea* populations can be described:

A) *Olea* dominates: *Olea* charcoal represents more than 50% of the remains and *Pistacia lentiscus*, *Quercus* sp. evergreen, *Phillyrea* and/or *Rhamnus* play a key role in the plant formations as it can be seen at Castelejo (15) (Fig. 4A). This situation is observed in coastal sites to the south of latitude 40º N during the Boreal and the Atlantic. On the eastern coast of the Iberian Peninsula, *Pinus halepensis* is an important element of the vegetation, while *P. pinaster* and *P. pinea* are abundant on the western coast.

B) *Olea* accompanies species with a similar ecology: In some cases, *Olea* reaches significant percentages, but it is not dominant in the wood-charcoal assemblages. The dominant taxa are evergreen *Quercus* sp., *Pinus halepensis*, *P. pinaster* and *P. pinea*. In these formations, *Pistacia lentiscus*, *Rhamnus* and/or *Phillyrea*, *Arbutus unedo*, Leguminosae, etc. are usually present. This situation is represented at Cova de l'Or (47) and the Liguro-Provençal sites (see Fig. 4B).

C) *Olea* shows low frequency: The species represents less than 10% of the remains. The charcoal assemblages are dominated by evergreen *Quercus* sp., *Phillyrea* and deciduous taxa. *Pistacia lentiscus* is less represented in such contexts and together with the scant presence of *Olea*, indicates the ecological upper limits for the development of thermophilous Mediterranean woodland. Such conditions can be observed at La Falguera (48) and the Cave of the Cyclops (52) (see Fig. 4C), for example, both of which are located in the

mesomediterranean level, probably at the limits of what would have been the optimal oleaster distribution area.

The available data reveal the importance of *Olea* as part of the genuine sclerophyllous Mediterranean vegetation, and its particular relevance in the western part of the Mediterranean basin. We propose that the thermomediterranean *Olea*-dominated formations (case A) that were present before the intensive anthropization of the landscape should be recognized as distinct phytogeographical entities and that they should be differentiated from open plant formations with *Olea* that result from aridification coupled with intense human activity (Yll et al., 1997).

The data presented here imply that the early presence of *Olea* in several parts of the Mediterranean should be taken into account in assessments of the domestication processes of this species and the origin of the cultivated varieties. Genetic research on the relationship between the wild and the cultivated olive populations has indicated a multiple origin for the cultivated varieties from wild, local populations, a process in which human manipulation has seemingly been fundamental (Contento et al., 2002; Besnard et al., 2002). The *Olea* refugia and the Early-Middle Holocene distribution of the species proposed in this paper overlap with some of the origin areas of the wild populations from which cultivars emerged (Breton et al., 2006, p. 1925).

6. Conclusions

In this paper we have presented the wood-charcoal analyses data concerning the presence of *Olea* in North Mediterranean archaeological sequences dating to the Pleniglacial and the Early Holocene. A combined evaluation of the relevant available information on past vegetation of the Mediterranean basin, AMS *Olea* dates and the biogeographical context has led us to the following conclusions:

a. During the Pleniglacial, *Olea* might have persisted in thermophilous refugia located in the southern areas of the North Mediterranean basin and the southern Levant while the north of Africa would have also played a fundamental role in the survival of the species.

b. The presence of the species is scarce during the MIS 2. The Last Glacial Maximum probably caused the distribution area of *Olea* to shrink. Moreover, in some of the Late Pleniglacial contexts in which the taxon has been identified, there is no agreement between the *Olea* AMS dates (Holocene) and the chrono-cultural contexts

to which these correspond (Upper Palaeolithic); therefore, the presence of *Olea* should be interpreted with caution.

c. In light of the total lack of secure *Olea* remains dated to the MIS 2, we suggest the need to perform more AMS dates directly on the remains of this species recovered from Pleniglacial contexts in order to delimit its presence in this period and to provide more solid bases for discussing the existence of refugia.

d. *Olea* appears early in the Holocene, already during the Preboreal and the Boreal, in southern Iberia, Sicily, Cyprus and the southern Levant. This early distribution pattern may be explained by the existence of Late Pleniglacial thermophilous refugia in these areas that favored the early expansion of the species.

e. During the Early Holocene, *Olea* is more abundant in coastal areas of the Iberian Peninsula than in the other peninsulas of the Mediterranean basin. Setting aside the biases resulting from unequal numbers of data sets in the different regions, it is probable that the smoother geomorphology and orography of the Iberian Peninsula and the greater extension of the thermomediterranean belt along its coasts, when compared to the Italian or the Greek Peninsula, favored the early expansion of sclerophyllous formations with *Olea*.

f. The emergence and development of the sclerophyllous formations, probably dominated by *Olea*, took place in the Atlantic period and within the thermal, altitudinal and latitudinal limits of the thermomediterranean level, coinciding approximately with their present-day distribution (Fig. 1). The climatic *optimum* of this period would have enabled this species to spread to lower mesomediterranean areas with a strong determining orographic thermicity.

g. The formations in which the oleaster was an important element of the natural vegetation would have constituted the basis for the implantation of its cultivation.

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Figure captions

Figure 1. Present-day distribution area of the wild and cultivated olive (*Olea europaea* L.) in the Mediterranean basin.

Figure 2. Chronological correspondence of the marine, climatic and cultural terminology for the sequences discussed in the paper (after Lowe and Walker, 1997; Kuijt et al., 2002; Ravazzi, 2003; Walker et al., 2009.).

Figure 3. Distribution of sites with *Olea europaea* wood-charcoal finds in the North Mediterranean for A) the Pleniglacial, and B) the Early–Middle Holocene. A key to the site identities is given in Table 1.

Figure 4. Frequency of *Olea europaea* and accompanying taxa in wood-charcoal sequences of A) Castelejo, Vila do Bispo, Portugal, B) Piana di Curinga, Calabria, Italy and C) Cave of the Cyclops, Youra, Northern Sporades, Greece.

Figure 5. *Olea europaea* and *Pinus nigra* as bioclimatic and taphonomic markers: A) Current ecological divergence between *Olea europaea* and *Pinus nigra* (after Costa et al. 2001 and Ozenda 1975). B) Coexistence of *Olea europaea* and *Pinus nigra-sylvestris* as a result of intrusion/infiltration in archaeological Pleistocene/Holocene contact levels (simplified theoretical model).

Table 1. Sites with *Olea* wood-charcoal finds in the North Mediterranean. New data appearing in this paper are designated "unpublished". Country codes are those of the *International Organization of Standardization* (ISO). (* Contexts with irrelevant AMS dates on *Olea* macroremains; see Table 2).

Table 2. Radiocarbon dates of A) *Olea* and *Pinus nigra-sylvestris* archaeological macroremains; the dates considered "irrelevant" present a chronological divergence between the AMS age and the cultural context, and B) archaeological contexts containing *Olea* macroremains.

Table 1

Site		Country	Biocl. Level	Climatic period					Cultural context	References
				MIS3	MIS2	Prebor.	Boreal	Atlantic		
1	Gorham's Cave	ES	Thermomed.	X	X				Middle, Upper Palaeolithic	Carrión et al., 2008
2	Klissoura Cave 1	GR	Thermomed.	X	X*				Middle, Upper Palaeolithic	Ntinou, unpublished
3	Boquete de Zafarraya	ES	Thermomed.	X		X	X		Middle Palaeol., Mesol.	Terral et al., 2005
4	Higueral de Valleja	ES	Thermomed.	X					Middle, Upper Palaeolithic	Jennings et al., 2009
5	Thera (Santorini)	GR	Thermomed.	X					Palaeosol	Friedrich, 1978
6	Cueva de Nerja	ES	Thermomed.		X	X	X	X	Epipalaeol., Neol.	Badal, 1990, 1996
7	Cabeço de Porto Marinho	PT	Thermomed.		X				Upper Palaeolithic	Figueiral, 1993, 1995
8	Ratlla del Bubo	ES	Thermomed.		X				Upper Palaeolithic	Badal and Carrión, 2001
9	Öküzini	TR	Thermomed.		X				Upper Palaeolithic	Emery-Barbier and Thiébault, 2005
10	Cova de les Cendres	ES	Thermomed.		X*			X	Upper Palaeol., Neol.	Badal et al., 1994
11	Grotta dell'Uzzo	IT	Thermomed.			X	X	X	Mesolithic, Neolithic	Costantini, 1989
12	Shillourokambos	CY	Thermomed.			X	X		Neolithic	Thiébault, 2003
13	Cova de Santa Maira	ES	Thermomed.			X*	X	X	Upper Palaeolithic, Mesol.	Badal, 1999; Carrión, 2005
14	Abrigo da Pena d'Água	PT	Thermomed.				X	X	Epipalaeol., Neol.	Figueiral, 1998
15	Castelejo	PT	Thermomed.				X	X	Epipal., Mesol., Neol.	Badal, unpublish.
16	Khirokitia	CY	Thermomed.				X	X	Neolithic	Thiébault, 2003
17	Río Palmones	ES	Thermomed.				X	X	Epipalaeolithic	Rodríguez-Ariza, 2004
18	Atlit Yam	IL	Thermomed.				X		pre-Pottery Neolithic	Galili et al., 1993
19	Horvat Galil	IL	Thermomed.				X		pre-Pottery Neolithic B	Liphschitz, 1997
20	Vale Pincel I	PT	Thermomed.					X	Epipalaeol., Neol.	Carrión, 2005
21	Rocha das Gaivotas	PT	Thermomed.					X	Mesolithic	Figueiral and Carvalho, 2006
22	Vale Boi	PT	Thermomed.					X	Early Neolithic	Figueiral and Carvalho, 2006
23	Murciélagos de Albuñol	ES	Thermomed.					X	Neolithic	Rodríguez-Ariza and Montes, 2005
24	El Retamar	ES	Thermomed.					X	Neolithic	Arnanz and Uzquiano, 2002
25	Cova Bolumini	ES	Thermomed.					X	Neolithic	Badal, 1990
26	Cova Ampla del Montgó	ES	Thermomed.					X	Neolithic	Vernet et al., 1983
27	Cova del Llop	ES	Thermomed.					X	Neolithic	Vernet et al., 1983
28	Cova de la Recambra	ES	Thermomed.					X	Neolithic	Vernet et al., 1983
29	Tossal de les Basses	ES	Thermomed.					X	Neolithic	Carrión, unpublish.
30	La Vital	ES	Thermomed.					X	Neolithic	Carrión, unpublish.
31	Costamar	ES	Thermomed.					X	Neolithic	Carrión, unpublish.
32	Can Sadurní	ES	Thermomed.					X	Neolithic	Ros, 1992
33	Can Tintorer	ES	Thermomed.					X	Neolithic	Ros, 1992
34	Cova de l'Espérit	FR	Thermomed.					X	Mesolithic, Neolithic	Solari and Vernet, 1992
35	Caucade	FR	Thermomed.					X	Neolithic	Thiébault, 2001
36	Giribaldi	FR	Thermomed.					X	Neolithic	Thiébault, 2001
37	Arene Candide	IT	Thermomed.					X	Neolithic	Nisbet, 1997
38	Piana di Curinga	IT	Thermomed.					X	Neolithic	Badal, 1988
39	Kephala-Petras	GR	Thermomed.					X	Neolithic	Ntinou, unpublished
40	Drakaina Cave	GR	Thermomed.					X	Late Neolithic	Ntinou, unpublished
41	Abric Romaní	ES	Mesomed.	X					Middle Palaeolithic	Allué, 2002
42	Buraca Grande	PT	Mesomed.	X*	X		X	X	Upper Palaeol. to Neolithic	Figueiral and Terral, 2002
43	Gruta do Caldeirão	PT	Mesomed.		X				Upper Palaeolithic	Figueiral, unpublished
44	Cueva del Toro	ES	Mesomed.					X	Neolithic	Rodríguez-Ariza, 2004
45	Murciélagos de Zuheros	ES	Mesomed.					X	Neolithic	Rodríguez-Ariza, 1996
46	Polideportivo de Martos	ES	Mesomed.					X	Neolithic	Rodríguez-Ariza, 1996
47	Cova de l'Or	ES	Mesomed.					X	Neolithic	Badal et al., 1994
48	La Falguera	ES	Mesomed.					X	Mesolithic, Neolithic	Carrión, 2002; García and Aura, 2006
49	Barranc de l'Encantada	ES	Mesomed.					X	Epipalaeolithic	Carrión, unpublish.
50	Cova de les Tàbegues	ES	Mesomed.					X	Late Neolithic	Badal and Carrión, unpublished
51	Montou	FR	Mesomed.					X	Middle Neolithic	Heinz et al., 2004.
52	Cave of the Cyclops	GR	Mesomed.					X	Neolithic	Ntinou, in press
53	Boker	IL	Saharo-arabic	X	X				Middle, Upper Palaeolithic	Liphschitz et al. 1991
54	Abu Salem	IL	Saharo-arabic			X			pre-Pottery Neolithic A	Liphschitz et al. 1991
55	Nahal Divshon	IL	Saharo-arabic				X		pre-Pottery Neolithic B	Liphschitz et al. 1991
56	Jericho	PS	Irano-turanian			X			pre-Pottery Neolithic A	Western 1971; Willcox, 1991, 1992

Table 2

A) AMS dates on *Olea* and *Pinus nigra-sylvestris* macroremains

	Site	Species	Cultural context	Lab. ref.	References	AMS B.P.	Cal. yr. BP
Relevant	Klissoura Cave 1	*Olea europaea*	Middle Palaeolithic	AA 75630	Kuhn et al., n. d.	56 140 ± 1450	61 440 - 55 320
	Higueral de Valleja	*Olea europaea*	Middle Palaeolithic	ORAU-12272	Jennings et al., 2009	37 220 ± 290	42 630 - 41 390
	Castelejo	*Olea europaea*	Mesolithic	ICEN - 211	Soares, pers. comm.	7970 ± 60	9070 - 8590
	La Falguera	*Olea europaea*	Mesolithic	AA-2295	García and Aura, 2006	7410 ± 70	8400 - 8080
	Cova de les Cendres	*Olea europaea*	Neolithic	GifA-101354	Bernabeu and Fumanal, in press	5860 ± 80	4933 - 4536
	Cova de les Cendres	*Olea europaea*	Neolithic	GifA-101356	Bernabeu and Fumanal, in press	5930 ± 90	5035 - 4556
	Vale Pincel I	*Olea europaea*	Early Neolithic	Beta-165793	Badal and Carrión, unpubl.	6350 ± 50	7440 - 7160
	Cova de les Tàbegues	*Olea europaea*	Late Neolithic	Beta-187433	Fernández, 2006	4530 ± 40	5390 - 4990
Irrelevant	Klissoura Cave 1	*Olea europaea*	Upper Palaeolithic	AA 75622	Stiner and Pigati, pers. comm.	3980 ± 70	4660 - 4220
	Buraca Grande	*Olea europaea*	Upper Palaeolithic	T18816A	Figueiral, pers. comm.	7022 ± 41	7970 - 7770
	Cova de Santa Maira	*Olea europaea*	Mesolithic	Beta-158013	Aura et al., 2006	420 ± 40	590 - 310
	Cova de les Cendres	*Olea europaea*	Upper Palaeolithic	Beta-118025	Villaverde, 2001	6660 ± 50	7620 - 7460
	Cova de les Cendres	*Pinus nigra-sylvestris*	Early Neolithic	Beta-116625	Badal, 2006	20 430 ± 170	24 860 - 23 900

B) Dates of contexts with *Olea* macroremains

Site	Cal. yr. BP date	Published C14 date	References
Thera	49 530 - 45 610	44 500 BP	Friedrich, 1978
Thera	42 300 - 41 220	36 700 BP	Friedrich, 1978
Öküzini	20 170 - 19 170	16 400 ± 160 BP	Emery-Barbier and Thiébault, 2005
Öküzini	15 370 - 14 570	12 540 ± 110 BP	Emery-Barbier and Thiébault, 2005
Klissoura Cave 1	17 780 - 17 140	14 280 ± 90 BP	Koumouzelis et al., 2001
Dja'de	11 390 - 10 470	9610 ± 170 BP	Willcox, 1996
Dja'de	10 380 - 9780	8990 ± 100 BP	Willcox, 1996
Halula	9860 - 9460	8655 ± 75 BP	Willcox, 1996
Halula	9590 - 8110	7930 ± 310 BP	Willcox, 1996
Shillourokambos	10760 - 10240	9310 ± 80 BP	Guilaine et al., 1996
Shillourokambos	10290 - 9530	8824 ± 100 BP	Guilaine et al., 1996
Shillourokambos	9840 - 9480	8665 ± 65 BP	Guilaine et al., 1996
Khirokitia	9140 - 8460	7930 ± 130 BP	Thiébault, 2003
Khirokitia	8090 - 7570	7000 ± 150 BP	Thiébault, 2003
Khirokitia	7960 - 7600	6930 ± 90 BP	Thiébault, 2003
Delphinos	7230 - 6990	6200 BP	Bottema and Sarpaki, 2003
Delphinos	6530 - 6450	5700 BP	Bottema and Sarpaki, 2003
Cave of the Cyclops	10 580 - 10 260	9252 ± 31 BP	Sampson, 2008
Cave of the Cyclops	8640 - 8480	7779 ± 32 BP	Sampson, 2008
Cave of the Cyclops	5640 - 5440	4814 ± 25 BP	Sampson, 2008
Grotta dell'Uzzo	12 060 - 11 220	10 070 ± 90 BP	Costantini, 1989
Grotta dell'Uzzo	9560 - 9080	8330 ± 80 BP	Costantini, 1989
Piana di Curinga	7910 - 7630	6930 ± 60 BP	Badal, 2002
Buraca Grande	29 730-27 970	23 920 ± 300 BP	Figueiral and Terral, 2002
Buraca Grande	21 840 - 20 920	17 850 ± 200 BP	Figueiral and Terral, 2002
Buraca Grande	9290 - 8890	8120 ± 70 BP	Figueiral and Terral, 2002
Santa Maira	11 260 - 11 140	9760 ± 40 BP	Aura et al., 2006
Santa Maira	10 720 - 10 480	9370 ± 40 BP	Aura et al., 2006
Ratlla del Bubo	21 310 - 20 390	17 360 ± 180 BP	Badal, 1995
Cueva de Nerja	13 100 - 12 580	10 860 ± 160 BP	Aura et al., 2002
Boquete de Zafarraya	10 240 - 9560	8805 ± 60 BP	Terral et al., 2005
Boquete de Zafarraya	9470 - 9030	8255 ± 55 BP	Terral et al., 2005
Cova de l'Espérit	7620 - 7380	6590±70 BP	Solari and Vernet, 1992
Montou	6180 - 5780	5190 ± 70 BP	Heinz et al., 2004

Figure 1

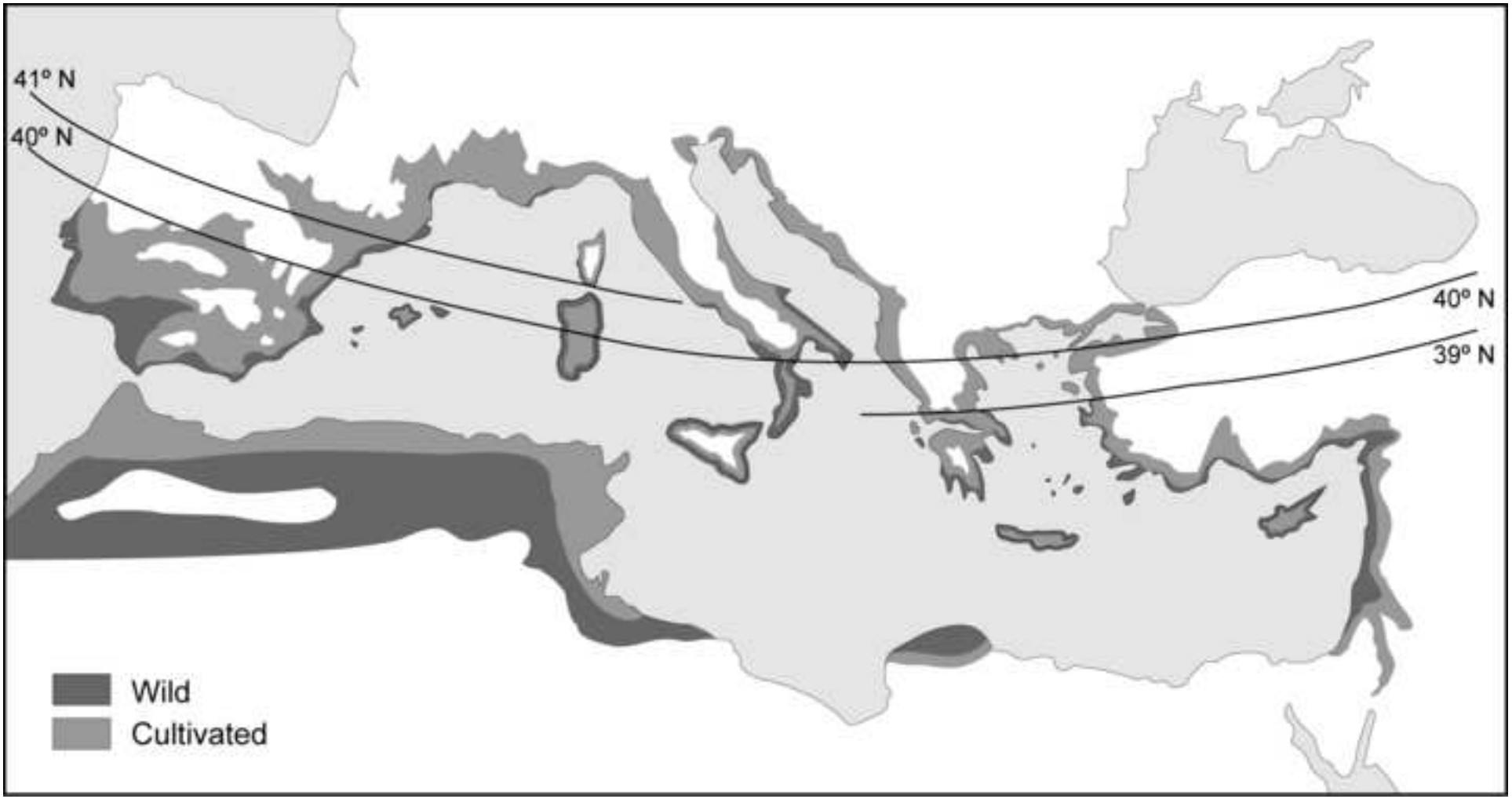


Figure 2

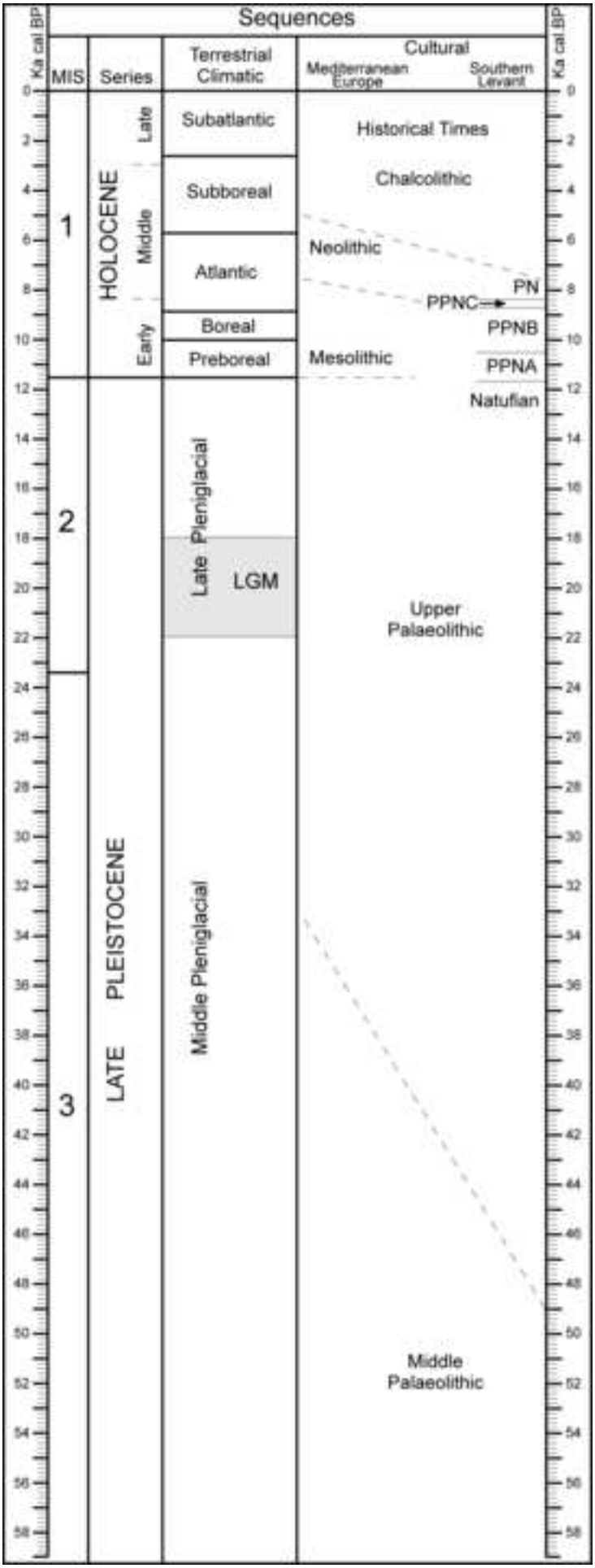

Sequences
Ka cal BP
MIS
Series
Terrestrial Climatic
Cultural
Mediterranean Europe
Southern Levant
HOLOCENE
Late
Middle
Early
PLEISTOCENE
LATE
Subatlantic
Subboreal
Atlantic
Boreal
Preboreal
Late Pleniglacial
LGM
Middle Pleniglacial
Historical Times
Chalcolithic
Neolithic
Mesolithic
PN
PPNC
PPNB
PPNA
Natufian
Upper Palaeolithic
Middle Palaeolithic
1
2
3

Figure 3

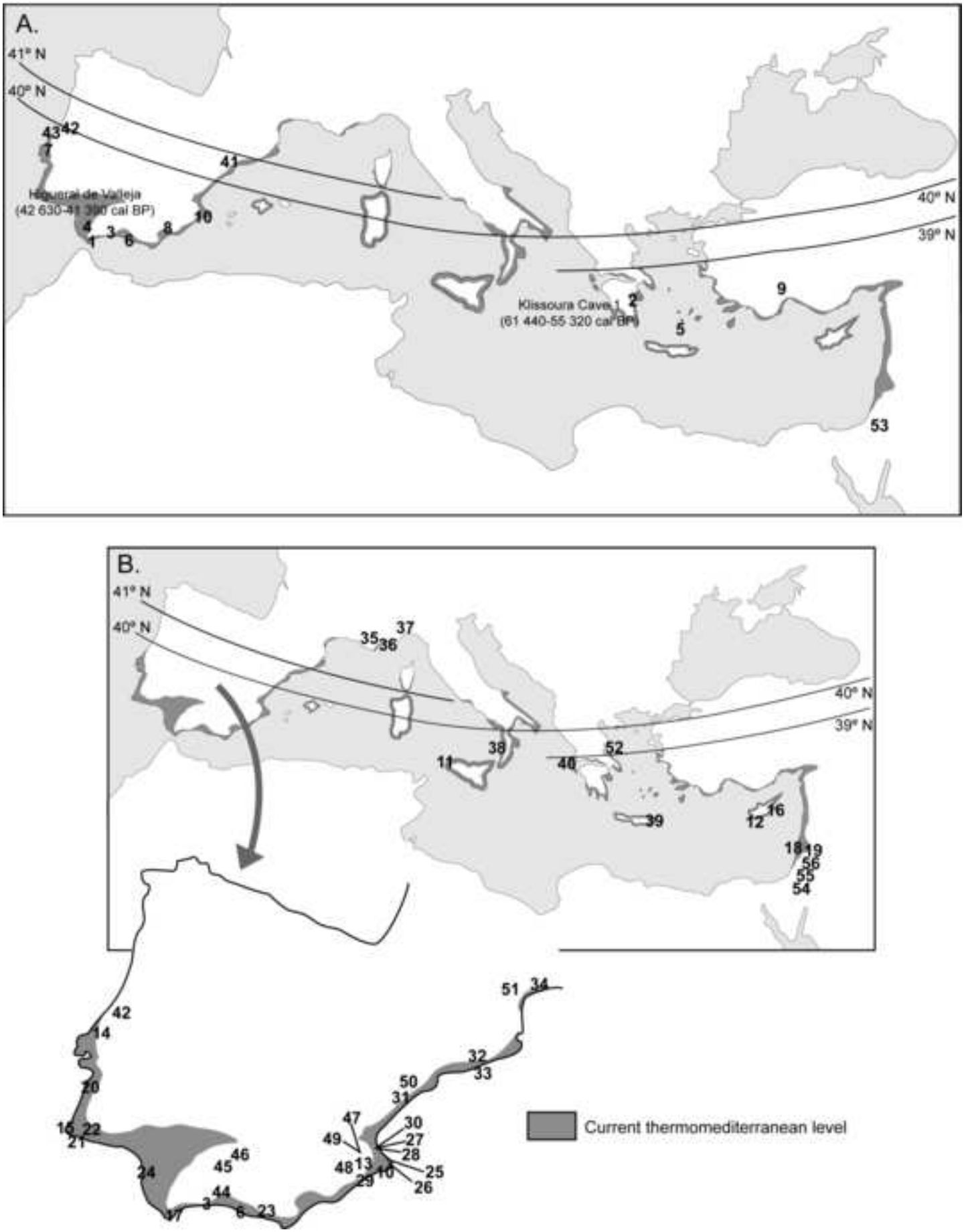

A.
41° N
40° N
39° N
Higueral de Valleja
(42 630-41 300 cal BP)
Klissoura Cave 1
(61 440-55 320 cal BP)
B.
41° N
40° N
39° N
Current thermomediterranean level

Figure 4

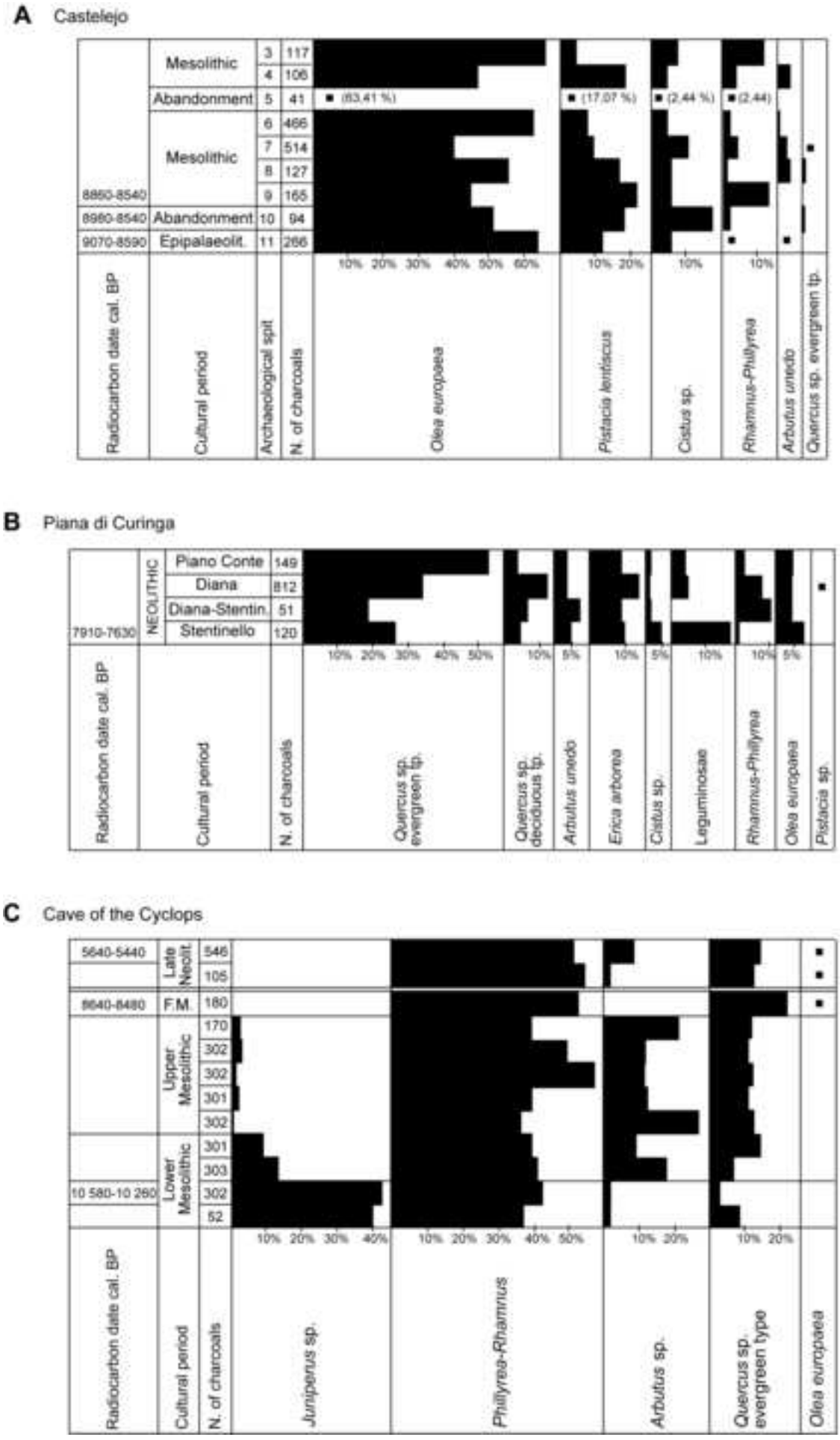
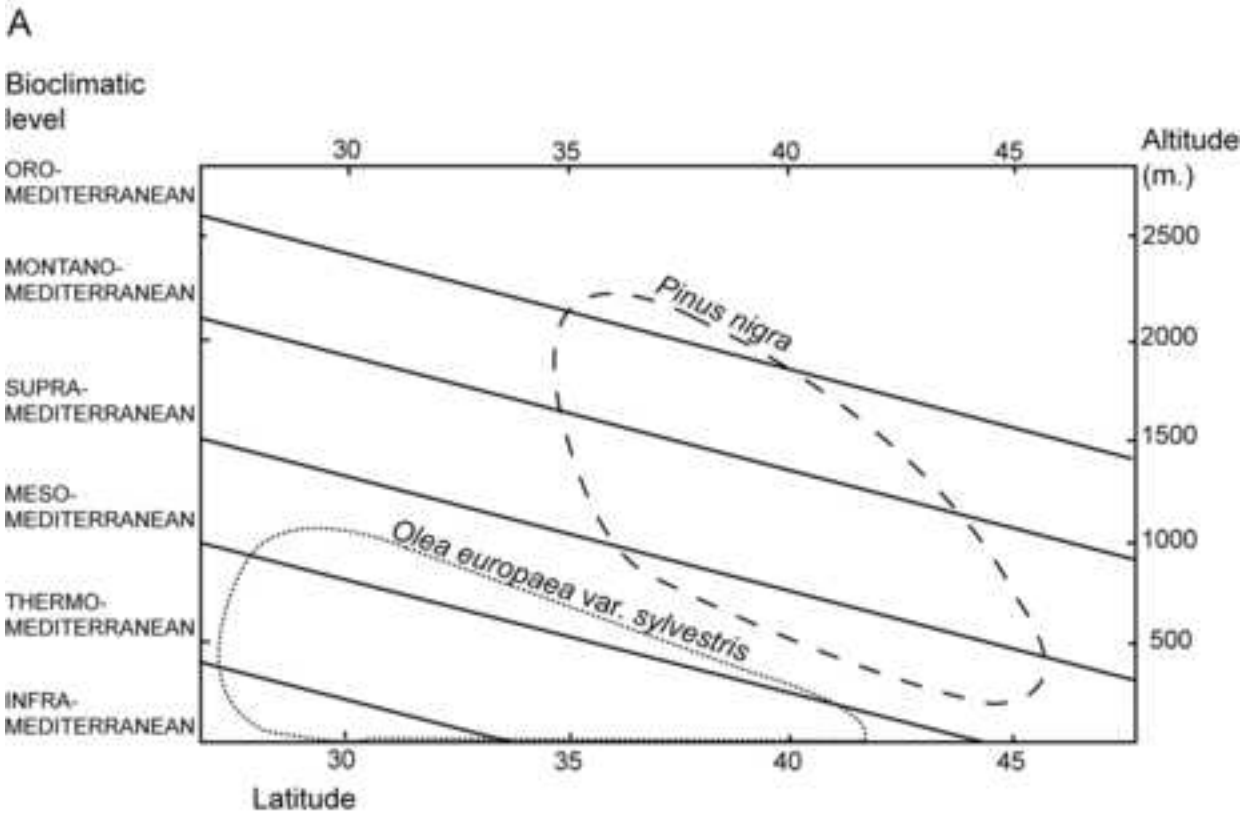
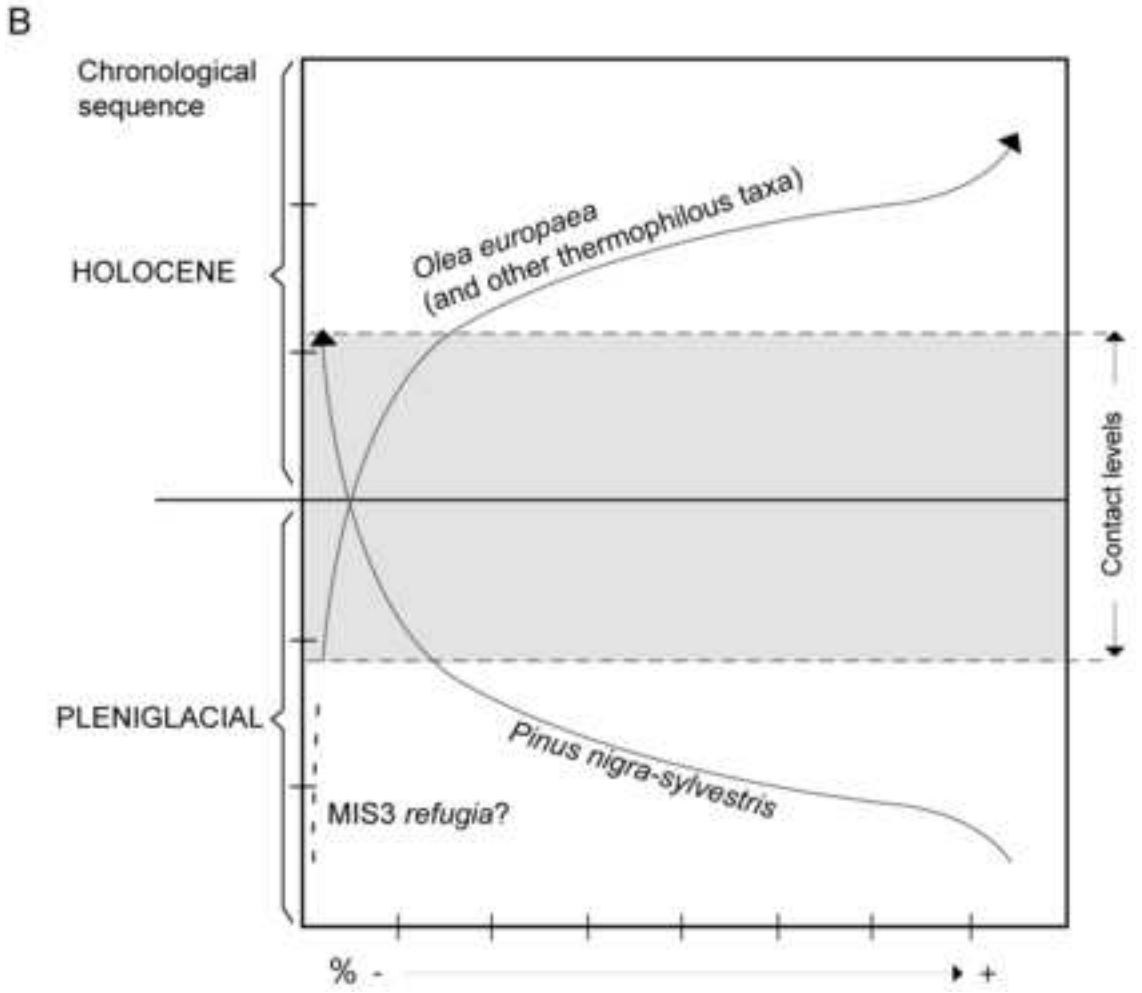

A Castelejo
Mesolithic
Abandonment
Mesolithic
Abandonment
Epipalaeolit.
8860-8540
8960-8540
9070-8590
3
4
5
6
7
8
9
10
11
117
106
41
466
514
127
165
94
266
(63,41 %)
(17,07 %)
(2,44 %)
(2,44)
Radiocarbon date cal. BP
Cultural period
Archaeological spit
N. of charcoals
Olea europaea
Pistacia lentiscus
Cistus sp.
Rhamnus-Phillyrea
Arbutus unedo
Quercus sp. evergreen tp.
B Piana di Curinga
NEOLITHIC
Piano Conte
Diana
Diana-Stentin.
Stentinello
7910-7630
149
812
51
120
Radiocarbon date cal. BP
Cultural period
N. of charcoals
Quercus sp. evergreen tp.
Quercus sp. deciduous tp.
Arbutus unedo
Erica arborea
Cistus sp.
Leguminosae
Rhamnus-Phillyrea
Olea europaea
Pistacia sp.
C Cave of the Cyclops
5640-5440
8640-8480
10 580-10 260
Late Neolit.
F.M.
Upper Mesolithic
Lower Mesolithic
546
105
180
170
302
302
301
302
301
303
302
52
Radiocarbon date cal. BP
Cultural period
N. of charcoals
Juniperus sp.
Phillyrea-Rhamnus
Arbutus sp.
Quercus sp. evergreen type
Olea europaea

Figure 5


A
Bioclimatic level
ORO-MEDITERRANEAN
MONTANO-MEDITERRANEAN
SUPRA-MEDITERRANEAN
MESO-MEDITERRANEAN
THERMO-MEDITERRANEAN
INFRA-MEDITERRANEAN
30
35
40
45
Altitude (m.)
2500
2000
1500
1000
500
Pinus nigra
Olea europaea var. sylvestris
Latitude


B
Chronological sequence
HOLOCENE
PLENIGLACIAL
Olea europaea (and other thermophilous taxa)
Contact levels
Pinus nigra-sylvestris
MIS3 refugia?
% - +