Upper Pleistocene and Late Holocene vegetation belts in western Liguria: an archaeopalynological approach

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Abstract

This study presents a new approach of local vegetation history based on pollen analyses of four sediment profiles from two archaeological sites located in western Liguria (northwest Italy). Statistical analyses (principal components analyses: PCA) were used to provide four theoretical patterns on vegetation distribution in Mediterranean belts during the Upper Pleistocene and the Late Holocene. PCA were mainly applied to elaborate vegetation assemblages such as Mediterranean pre-forest unit, evergreen woodland, or alluvial forest, and to replace these groups in a local area according to edaphic factors. The pollen data showed 10 vegetation assemblages, extending from the seashore arid zone to the Ligurian mountains humid/per-humid zones. These groups are distinct arboreal or non-arboreal formations and give pictures of the vegetation from the arid coastal herbs located on the seashore to the deciduous forest developed at low altitude. The statistical data were also used to develop PCA synthetic pollen diagrams (PCAsd). In Liguria, PCAsd showed the weight of Mediterranean vegetation during the last Interglacial whereas the early Weichselian glacial is marked by the extent of the steppe landscape. From the last Interglacial to the Lower Pleniglacial, the climate was characterized by a significant increase of drought from the coastal zone to the Ligurian relief, together with an increase of moisture in altitude. The coastal warm and dry Interglacial climate turned to cool and humid during the beginning of the Weichselian glacial, and to colder and drier during the Lower Pleniglacial.

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1. Introduction

Archaeopalynology is described by several workers (Couteaux, 1977; Pons, 1984; Reille, 1990) as a method with many limitations (selective transport, differential dispersion, reworking, contamination by intrusive pollen or undetected sedimentary hiatuses), and it is generally assumed that palaeoenvironmental reconstructions based on palynological investigations of cave sediments cannot provide a regional history of vegetation (Cushing, 1967; Dimbleby and Evans, 1974; Havinga, 1974, 1984; Farbos, 1985; Turner, 1985; Coles

et al., 1989; Davis et al., 1991; Carrión et al., 1998). However, archaeopalynology is a potentially important source of information regarding the Quaternary palaeoecology in the vicinity of the sequence investigated (Havinga, 1974; Carrión et al., 1998, 1999; Navarro et al., 2001). In order to interpret such data in terms of past vegetation, it is a necessary basic assumption that it is not only the climate that governs the distribution of species (Pons and Quézel, 1998). In fact, in the western Mediterranean area, the reconstruction of Pleistocene palaeovegetation must take into account the heterogeneity of vegetation and the respective roles of climate, soils and geographical hazard in plant distribution (Pons and Quézel, 1998). In order to determine these parameters in western Liguria according to the pollen analyses of archaeological sites, multivariate analyses

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were applied to selective taxa and allowed an approach of plants distribution on Mediterranean belts. Multivariate analyses are often used in sedimentology (Guerzoni et al., 1996), in diatom studies (Hausmann and Lotter, 2001) and in palynology (Kovach, 1989; Gervais and MacDonald, 2001; Yu, 2003) but these methods were never applied before in archaeological sites in order to elaborate vegetation assemblages (Quézel, 1999) in Mediterranean belts.

In this paper, we provide theoretical patterns of palaeovegetation terracing in the Ligurian belts during four periods between the Upper Pleistocene (Middle Palaeolithic) and the Late Holocene (Gallo-roman period). Terrestrial pollen assemblages from two Ligurian sites, Madonna dell'Arma (San Remo) and Santa Lucia superiore (Toirano), were used to reconstruct past vegetation. The resulting pollen spectra were studied statistically in order to elaborate vegetation assemblages and to establish soil parameters. These data were compared to the works of phytogeographers and botanists on actual vegetation in the northwestern Mediterranean area (Barbero et al., 1973; Ozenda, 1975; Quézel, 1999; Ozenda and Borel, 2000). These comparisons are intended to determine if Upper Pleistocene and Late Holocene palaeovegetation assemblages have modern counterparts or no close modern analogues. These data were also used to establish a new type of synthetic pollen diagram that allowed study of the evolution of vegetation according to three parameters: vegetation assemblages, soil parameters and altitude. These reconstructions of Ligurian vegetation allow detection of local particularities, and permit a proposed schematic view of the plant distribution in an area where data on palaeovegetation are scarce.

2. Geographic location, climate, present vegetation and archaeological sites

Western Liguria (Fig. 1), located in the northern Mediterranean area, belongs to the Ligurian Alps biogeographical zone (Barbero et al., 1973). Mainly consisting of steep promontories, sandy coves and cliffs, northwest Italy is characterized by a calcareous stony coast perpendicularly striated by deep and narrow valleys (Socio Marino Marini, 2001). The Mediterranean region has been free from continental ice sheets that covered northern Europe, which allowed the settlement of *Homo neanderthalensis* populations in many caves (Del Lucchese et al., 1985). Madonna dell'Arma and Santa Lucia superiore, two caves located in the coastal zone of western Liguria, are suitable for reconstructing the local history of Mediterranean vegetation.

Madonna dell'Arma cave (43°N 7°E, +8 m a.s.l.) is located in Imperia province, western Liguria, near the

seaside resorts of San Remo and Taggia at the top of the ancient Via Aurelia, very close to the coastline. Inserted in a context bordered in the west by Argentina torrent and in the east by the mouth of Armea (Fig. 1), this cave is an erosion cavity established in an upper Pliocene littoral conglomerate outcrop (Isetti et al., 1962). The elevation of the cave is about +8 m above sea level. The cave opening faces southeast. The climate of the Ligurian coast is typically Mediterranean with mean summer temperatures between 29.1 and 35.5 °C, a mean of the coldest month between 1.3 and 8.8 °C. The mean precipitation for summer is less than 10 mm (June–August), increasing to 208.2 mm during the winter (total annual precipitation ca. 660.4 mm) (Fayard et al., 1999; Giammarino, 2004). This area is placed in the thermo-Mediterranean belt characterized by *Ceratonia*, *Myrtus communis*, *Pistacia lentiscus* and *Pinus halepensis* (Barbero et al., 1973; Ozenda, 1975). The lower Ligurian slopes have been currently disturbed by human activities and support an artificial exotic garden with acclimatized species which belong to Cactaceae, Crassulaceae, Fabaceae, Liliaceae and Polygalaceae (Alziar, 1984; Kaniewski, 2002).

The lower part of Madonna dell'Arma profile, located in the cave (Fig. 2), was dated between $149,000 \pm 15,000$ BP (Laurent, 1993) and $95,000 \pm 5000$ BP (Stearns and Thurber, 1967) by U/Th applied on shells. This first unit (Tyrrhenian seabed) contains *Strombus bubonius* associated with many Senegalese species such as *Conus testudinarius* (Blanc-Vernet in Isetti et al., 1962; Keraudren, 2000). Located upon the Tyrrhenian seabed, a thin layer contains an Archaic-type Mousterian assemblage (de Lumley-Woodyear, 1969). The main archaeological levels were dated between $91,000 \pm 5200$ and $73,100 \pm 4400$ yr BP (Blanchin, 1999) by U/Th and electronic spin resonance applied on bones. These layers enclose a Levallois-type Mousterian assemblage with many scrapers and numerous faunal remains such as *Cervus elaphus*, *Bos primigenius*, *Rhinoceros mercki*, *Elephas antiquus*, *Hippopotamus amphibious*, *Sus scrofa* and *Hyaena crocuta spelaea* (Isetti et al., 1962). This unit also contains human remains (four pieces of skull) attributable to *Homo neanderthalensis*.

The upper part of the profile (outside slopes) is not yet dated by radiometric methods but was deposited after $73,100 \pm 4400$ BP according to the stratigraphical relationship between the inside and the outside layers (Kaniewski, 2002). These upper layers enclose many lithic Levallois-type Mousterian tools with many nuclei and scrapers (Cauche, 2002), attributed to the Ligurian Mousterian culture between OIS 5 and OIS 3 (Del Lucchese et al., 1985). Faunal remains are marked by the absence of *Elephas antiquus*, *Hippopotamus amphibious* and the presence of *Cervus elaphus*, *Bos primigenius* and *Rhinoceros mercki*.

Fig. 1. Geographical and topographical location of the two Ligurian sites (from de Lumley-Woodyear, 1969; Lorenz, 1971; Brotot and Despointes, 2002).

The Gallo-Roman assemblage is characterized by a house wall and by many fragments of amphora (de Lumley, 1997). This house could have been used as a refuge along the Via Aurelia between the town of Albingaunum (Albenga) (Della Corte, 1984) and the military camp of Albintimilium (Ventimiglia) (Arobba et al., 1998a) between the first and the third century AD (Kaniewski, 2002; Kaniewski et al., 2004b). The chronological hypothesis came from an archaeological integration of data in a local area (Arobba, 1976; Arobba et al., 1983, 1998a, b) and from the preliminary results of potteries studies (Kaniewski et al., 2004b).

Santa Lucia superiore cave (44°N 8°E; +211 m a.s.l.) is located in Savone province, western Liguria, on the Monte San Pietro slopes, north Toirano (Fig. 1). Situated near Borghetto S. Spirito seashore, this cave is located on Torrente Varatello left bank, a tributary of Varatiglia, below the Monte Ravinet level (Tozzi, 1963; de Lumley-Woodyear, 1969). *Santa Lucia superiore* cave is a Miocene erosion cavity developed in a Triassic dolomitic limestone (Tongiorgi and Lamboglia, 1963). The climate of the lower mountain is typically Mediterranean, with mean summer temperatures between 21

and 29.1 °C, and a mean of the coldest month between −0.5 and 3.5 °C. The mean precipitation for summer is less than 37.9 mm (June–August), increasing to 347 mm during the winter (total annual precipitation ca. 750 mm) (Fayard et al., 1999; Giammarino, 2004). This area is located in the lower mēso-Mediterranean belt (200–400 m a.s.l.) characterized by *Pinus halepensis*, *Rosmarinus* and cultivated *Olea* (Barbero et al., 1973; Ozenda, 1975).

The site was divided into eight stratigraphical layers (Fig. 2). The lower part of the profile contains lithic tools attributable to a Levallois-type Mousterian assemblage with few scrapers. No faunal remains have been found (Tozzi, 1963; de Lumley-Woodyear, 1969). The upper part of the profile includes Levallois-type Mousterian tools with many scrapers and numerous faunal remains such as *Capra ibex*, *Perdrix sp.*, *Canis lupus*, *Vulpes vulpes* and *Capreolus capreolus* (Tozzi, 1963; de Lumley-Woodyear, 1969). This part also contains human remains attributable to *Homo neanderthalensis* (a left femur and a foot phalanx). These eight layers are attributable to OIS 4 (Kaniewski, 2002; Kaniewski et al., 2004c).

Fig. 2. Madonna dell'Arma and Santa Lucia superiore (from Isetti et al., 1962; Tozzi, 1963; de Lumley, 1997; Kaniewski, 2002; Kaniewski et al., 2004a, b, 2005).

3. Methods

3.1. Criteria used in pollen analyses of the two sites

Laboratory treatment was performed following the protocol of Sittler (1955) and Funkhouser and Evitt (1959). Samples were weighed (15–20 g/sample) and

chemically treated to remove the unwanted organic and mineral fractions. Acetolysis was not used, to avoid destruction of cell cytoplasm (a decisive factor in the case of actual pollen contamination). A minimum of 300 pollen grains, excluding spores (Cushing, 1967), and 20 taxa were counted at each level analysed (McAndrews and King, 1976; Reille, 1990). Taxa denominations were

referred to the International code of Botanical Nomenclature (Greuter et al., 2000). The pollen percentages for taxa are based on a main pollen sum which excludes spores, indeterminable and unknowns. *Pinus* was not excluded despite its over-representation in littoral deposits. *Pinus* release large amounts of pollen in the air, leading to relatively high numbers in the spectra compared to other taxa. In order to study statistically the significance of this genus in the profiles, we kept this taxon as a normal element in pollen analyses. Evaluation of pollen concentrations as grains per gram has been undertaken following Cour (1974). Pollen concentration was used as a criterion to evaluate the degree of alteration and the reliability of pollen spectra from sandy soils. Low pollen concentrations, fewer than 1000 grains/g, indicated deteriorated pollen assemblages (Hall, 1981). The detailed and synthetic pollen diagrams for each section mentioned in this paper are presented in Kaniewski (2002) and Kaniewski et al. (2004a, b, 2005).

3.2. Statistical analyses

Multivariate analyses have often been used in ecology since 1972 (Gauch and Whittaker, 1972; Fasham, 1977) and have proved to be useful in plant palaeoecology and palynology (Kovach, 1989; Gervais and MacDonald, 2001). Elaboration of theoretical patterns for the distribution of Upper Pleistocene and Late Holocene vegetation was realized by statistical treatments of spectra (multivariate analyses) and by comparisons of the results with actual data of the Mediterranean vegetation groups (Barbero et al., 1973; Ozenda, 1975, 1981, 1994; Noirfalise, 1987; Pons and Quézel, 1998; Quézel, 1999; Ozenda and Borel, 2000). Principal components analyses (PCA) of pollen percentages were undertaken to interpret the pollen profiles using the statistical program Statistica (from Eyzies software). The use of a linear method such as PCA was chosen to provide a better representation of “ecological distances” between taxa (Yu, 2003). PCA has been frequently applied to pollen data sets, as the analysis is easy to implement on large data sets and the results can be displayed graphically (Caseldine and Gordon, 1978; Prentice, 1980; MacDonald and Ritchie, 1986). PCA, in these studies, use a covariance matrix calculated from data that have been centred on the origin of the coordinate system. This is useful when it is desirable to reduce the effects of dominant taxa (*Pinus*, Cupressaceae) so that rare genera (*Myrica*, *Cistus*, *Myrtus*) play a greater role in the resulting configuration (Kovach, 1989). Moreover, PCA allow processing of raw quantitative variables (Kovach, 1989; Escofier and Pagès, 1998) when the results of detrended correspondence analysis (DCA) are quite linear (Ter Braak, 1987; Yu, 2003). The statistical matrices only contain the percentages of 23–26 pollen types that were considered

significant in each diagram (two-dimensional matrices: individuals and quantitative variables). These selective taxa have all an ecological signification and a particular altitude localisation. In each PCA, the herbaceous taxa that do not provide any information about the soil parameters, the climate, the situation in altitude or the vegetation groups have not been taken into account. So, there is no bias in the subset selection process or no influences in the way PCA are interpreted, because all taxa with ecological meaning were included in each PCA. These pollen types correspond mainly to the Mediterranean taxa (*Olea*, *Pistacia*, *Phillyrea*, *Carpinus orientalis*, evergreen *Quercus*, *Myrtus*, *Cistus* and *Rhamnus*), hygrophilous and mesophilous trees (deciduous *Quercus*, *Alnus*, *Betula*, *Corylus*, *Fraxinus* and *Salix*), arid and semi-arid herbs (*Artemisia*, *Centaurea*, *Ephedra*, Poaceae, Asteraceae, Chenopodiaceae), Gymnosperms (*Abies*, *Picea*, Cupressaceae, *Pinus*). Underneath each PCA (Figs. 3–6) are placed the synthetic pollen diagrams (PCAsd), which were elaborated according to the statistical analyses of the initial detailed pollen diagrams (Kaniewski, 2002; Kaniewski et al., 2004a, b, 2005). The vegetation groups mentioned in each synthetic diagram (Figs. 3–6) were established according to the distribution of dots (taxa) on the PCA two principal axes. The clusters were compared with the modern Mediterranean vegetation assemblages to correlate past and present vegetation and to define the ecological meaning (edaphic parameters, altitude, moisture requirements) of each group. The vegetation assemblage frequencies in PCAsd came from the sum of each taxon frequency included in this group. As an example, the pre-forest unit frequencies (Fig. 3) came from the sums of *Pinus*, Cupressaceae, *Olea* and *Pistacia* frequencies for each spectrum. The taxa frequencies (detailed pollen diagrams) are available in Kaniewski (2002) and Kaniewski et al. (2004a, b, 2005). Synthetic diagrams allowed estimation of the extent of each vegetation assemblage in a local area and interpretation of these assemblages according to the altitude.

4. Palynological diagrams

4.1. Madonna dell'Arma

The detailed pollen diagram from *the cave* has been divided in four pollen zones (Mad. 1–4), which reveal a woody landscape (percentages of AP: 60–83%). The main arboreal taxa represented are *Pinus* and the Cupressaceae (*Cupressus* and *Juniperus* type) with several Mediterranean elements including evergreen *Quercus*, *Olea*, *Pistacia*, *Phillyrea*, *Cistus* and *Myrtus*. The other trees correspond to deciduous *Quercus*, *Fraxinus* and *Corylus* and several hygrophilous taxa such as *Alnus*, *Betula* and *Salix*. Asteraceae, Poaceae

Fig. 3. PCA and PCAsd—Madonna dell'Arma (San Remo, Liguria)—between $91,000 \pm 5200$ and $73,100 \pm 4400$ yr BP.

and Chenopodiaceae are the main herbs with occasional increases of Brassicaceae and *Centaurea*. Zones Mad. 1 and Mad. 3 are quite similar with numerous Mediterra-

nean trees and shrubs, which indicate a warm-temperate climate. An increase of moisture in zone Mad. 2 generates an extension of hygrophilous and caducifoliate

ALN : <i>Alnus</i>	Cori : <i>Carpinus orientalis</i> type	POA : Poaceae
AST : Asteraceae Asteroideae	CUP : Cupressaceae	Qdec : deciduous <i>Quercus</i>
BET : <i>Betula</i>	FRA : <i>Fraxinus</i>	Qevr : evergreen <i>Quercus</i>
Cbet : <i>Carpinus betulus</i> type	MYRI : <i>Myrica</i>	RHA : <i>Rhamnus</i>
CEN : <i>Centaurea</i>	MYRT : <i>Myrtus</i>	SAL : <i>Salix</i>
CHE : Chenopodiaceae	OLE : <i>Olea</i>	TIL : <i>Tilia</i>
CIC : Asteraceae Cichorioideae	PHI : <i>Phillyrea</i>	ULM : <i>Ulmus</i>
CIS : <i>Cistus</i>	PIN : <i>Pinus</i>	
COR : <i>Corylus</i>	PIS : <i>Pistacia</i>

Fig. 4. PCA and PCAsd—Madonna dell'Arma (San Remo, Liguria)—later than $73,100 \pm 4400$ yr BP.

trees whereas Mediterranean taxa decline. The beginning of the pleniglacial (zone Mad. 4), colder and drier, is indicated in the sequence by increases of *Pinus*,

Cupressaceae and *Artemisia* in the context of a decline in the thermophilous components (Kaniewski et al., 2004a).

Fig. 5. PCA and PCAsd—Santa Lucia superiore (Toirano, Liguria)—early Weichselian glacial.

Three pollen zones (Mad. 6–8) have been defined from the *outside slopes*. Although the AP curve reaches 89%, it is mainly due to *Pinus* and Cupressaceae, with (respectively) high values of 57% and 33%. The other major taxa are deciduous *Quercus*, *Fraxinus*, *Alnus*, *Betula* and *Salix*. Occasional increases of Mediterranean taxa are noticed as well (zone Mad. 8). Asteraceae, Poaceae and Chenopodiaceae are still the main herbs (Kaniewski, 2002). The cool and

humid conditions in the lower layers generate high percentages of needle-leaved trees and deciduous broad-leaved trees (zone Mad. 6). An increase of evergreen *Quercus* and decreases of broad-leaved trees in zone Mad. 7 indicate a fall of moisture. A drier climate in the upper layers generates increases of needle-leaved trees and Mediterranean taxa such as *Olea* and *Pistacia* whereas evergreen *Quercus* decrease (zone Mad. 8).

Fig. 6. PCA and PCAsd—Madonna dell'Arma (San Remo, Liguria)—Gallo-roman period.

The Gallo-roman diagram is rather homogeneous with a large number of Mediterranean taxa such as evergreen *Quercus*, *Olea*, *Pistacia*, *Phillyrea* and *Carpinus orientalis* while the frequencies of *Pinus* and Cupressaceae decline. The Gallo-roman herbaceous formations are rich from a floristic point of view. Cultivated plants (Poaceae *cerealia* type, Brassicaceae, Fabaceae), pastoral indicators (*Plantago*, *Centaurea*) and pioneering herbs (Asteraceae, Poaceae) are the main formations. The

Gallo-Roman climate seems to be warm and dry (Kaniewski, 2002; Kaniewski et al., 2004b).

4.2. Santa Lucia superiore

The diagram has been divided into five pollen zones (SL. 1–5), which reveal woodlands (AP: 55%) alternating with open vegetation (NAP: 94%). The open vegetation is characterized by *Artemisia*, *Ephedra*,

Centaurea with families like Apiaceae, Asteraceae, Caryophyllaceae, Chenopodiaceae and Poaceae. The arboreal taxa are mainly represented by *Alnus*, *Betula*, *Corylus* and *Ulmus* with lesser increases of deciduous *Quercus* and *Fraxinus* (*Pinus* reaches 17% and Cupressaceae never exceed 9%). Among the herbs, the Cyperaceae and the Ranunculaceae increased when the trees expanded. The dry and cold phases (zones SL. 1, SL. 3 and SL. 5) caused the establishment of a steppe-landscape (NAP 92%). In zone SL. 2, the increase of moisture generated a first arboreal extension (*Pinus*, *Betula*, *Corylus*, *Ulmus*), which engendered the formation of an open-forest landscape (AP 43%). The second arboreal extension (zone SL. 4, AP 55%) was due to an increase of moisture and higher temperatures, which allowed the development of Mediterranean trees and shrubs (evergreen *Quercus*, *Olea*, *Phillyrea*) (Kaniewski, 2002; Kaniewski et al., 2005).

5. PCA results

In each PCA, axis 1 (*Olea* and *Betula* in Fig. 3) and axis 2 (deciduous *Quercus* and Asteraceae Cichorioideae in Fig. 4) are generated by the factorial weight of two distinct taxa. Axis 1 separates taxa according to their moisture requirements. Positive values indicate humid to per-humid zones and negative values show semi-arid to sub-humid zones. Axis 2 illustrates vegetation terracing from Ligurian coastal zone (negative values) to low relief (high positive values) (Kaniewski, 2002; Kaniewski et al., 2004a, b, 2005). These distributions also show the influence of precipitation variations with altitude (Fayard et al., 1999). Landscapes with low precipitation and high temperature range occupy the littoral. Low relief areas show the first perturbations, which increase with altitude (Barbero et al., 1973). Distribution of taxa on the two principal axes of each PCA generates seven distinct clusters.

5.1. [Aa]: Xerophytic and halophytic herbs (Figs. 3 and 4)

The first group includes only xerophytic herbaceous taxa such as Asteraceae Asteroideae, Asteraceae Cichorioideae, *Centaurea*, Brassicaceae and Poaceae. This structure could represent a coastal arid vegetation similar to those actually found on the sandy soils of the northwestern Mediterranean area. *Artemisia* and *Ephedra*, principal components of steppe landscapes (Quézel, 1999; Subally and Quézel, 2002), were not included in this first group. The low percentages of these markers (Kaniewski, 2002; Kaniewski et al., 2004a) do not permit interpretation of the assemblage to represent a coastal arid steppe. On the other hand, the position of Chenopodiaceae on axis 2 allows inclusion of this taxon

in the coastal zone, with xerophytic herbs. Chenopodiaceae, defined as a halophytic marker, spreads in sandy-salt soils or in the dry banks of rivers (Dajoz, 1971). The vegetation assemblage deduced from the PCA principally results from high soil salinity and important moisture deficits.

5.2. [Ab]: Steppe-landscape (Fig. 5)

The major difference between Aa and Ab is the expansion of the two steppic markers *Artemisia* and *Ephedra* (Quézel, 1995, 1999; Subally and Quézel, 2002) with a halophytic indicator, Chenopodiaceae (Dajoz, 1971). The other main taxa remain unchanged. An incursion of Caryophyllaceae with numerous families or genera not mentioned in the PCA, including Apiaceae, *Helianthemum* and *Thalictrum* (Kaniewski, 2002; Kaniewski et al., 2005) was noted. This assemblage is an advanced form of group Aa and could represent an arid steppe-landscape (Quézel, 1999) expanding on dry or undeveloped soils. This group seems to have extended to cover low altitude areas during the early Weichselian glacial, probably following the dry banks of Torrente Varatello.

5.3. [B]: Semi-arid shrubs (Figs. 3, 4 and 6)

This group includes *Cistus*, *Myrtus*, *Rhamnus* and characterizes a semi-arid vegetation (Noirfalise, 1987) settled landward of the coastal arid group. These semi-arid shrubs are similar to those found in the thermo-Mediterranean vegetation belt (Barbero et al., 1973; Noirfalise, 1987). This structure has grown on surface soils behind the arid coast, on Pliocene conglomerates during the Middle Palaeolithic.

5.4. [C]: Sub-humid vegetation (Figs. 3, 4 and 6)

The sub-humid vegetation assemblages are subdivided into three groups.

(a) The first group reflects a sub-humid thermophilous vegetation with Cupressaceae (*Cupressus* and *Juniperus*), *Olea*, *Pistacia*, and could represent a Mediterranean pre-forest unit (Quézel, 1999). With the exception of the early Weichselian glacial (Fig. 5), *Pinus* sp. was located on the lower slopes and could be a component (Quézel, 1999). Pre-forest units are currently situated in the thermo-Mediterranean vegetation belt and precede evergreen woodlands from the méso-Mediterranean vegetation belt (Ozenda, 1975; Quézel, 1999). This assemblage seems to have extended up the lower slopes, in sub-humid zones (Quézel, 1999) behind semi-arid shrubs and arid herbs. *Pistacia* and *Olea* are also present in a méso-Mediterranean maquis with *Rhamnus* (Noirfalise, 1987).

(b) The second group represents a maquis assemblage with *Phillyrea* and *Carpinus orientalis*, or only *Phillyrea* (Noirfalise, 1987). Maquis grew on thin or stony soils, in sub-humid zones.

(c) The third group corresponds to evergreen woodland (Barbero et al., 1973; Ozenda, 1975). Evergreen *Quercus* (*Q. ilex*, *Q. coccifera*) and *Carpinus orientalis* grew on deep calcareous soils in the sub-humid zone (Quézel, 1999).

Carpinus orientalis, native to the eastern Mediterranean (Quézel and Barbero, 1985), is current in southern Italy and penetrates north to Tuscany. This species is incorporated in eastern Greece evergreen *Quercus* matorrals, in north Anatolian *Quercus coccifera* formations, and in several groups in northern Greece (Quézel and Barbero, 1985). *Carpinus orientalis* is also associated with *Phillyrea media* in the Black Sea coastal zone (Noirfalise, 1987). According to statistical analyses, two possibilities can be considered in western Liguria.

The similarity between *Carpinus orientalis* and evergreen *Quercus* (Figs. 4 and 6) in statistical analyses could suggest evergreen woodland (Barbero et al., 1973; Pons and Quézel, 1998) similar to a north Anatolian or a matorral similar to eastern Greece (Noirfalise, 1987). Alternatively, the similarity between *Carpinus orientalis* and *Phillyrea* (Fig. 3) in statistical analyses could suggest a maquis similar to that near the Black Sea (Noirfalise, 1987).

Moreover, the relationship between evergreen *Quercus* and *Olea* (Fig. 5) indicates an inclusion of olive trees into woodland. This specific assemblage of vegetation can be compared to the modern eastern Provençal oak grove, south France, located in the thermo-Mediterranean vegetation belt (Noirfalise, 1987).

5.5. [D]: Alluvial forest (Figs. 3, 4 and 6)

The fourth group includes several hygrophilous trees including *Alnus*, *Betula*, *Salix* and *Ulmus* probably located in marshy zones near the banks of the Armea and Argentina streams. This group corresponds to an alluvial forest (azonal type) developed in the per-humid zones (Quézel, 1999). *Corylus* and *Fraxinus*, incorporated in this group, could have been situated behind a per-humid zone. The decrease of arboreal taxa and the increase of hygrophilous herbs including Cyperaceae and Ranunculaceae (Fig. 5) indicate a ripisylve located in marshy zones near the banks of Torrente Varatello.

5.6. [E]: Caducifoliate forest (Figs. 3–6)

The fifth group incorporates deciduous trees including *Quercus* (*Q. pedunculata*, *Q. pubescens*), *Carpinus betulus*, *Corylus*, *Fraxinus* and *Tilia*. This forest structure, similar to those actually present in the supra-Mediterranean vegetation belt (Ozenda, 1975;

Quézel and Bonin, 1980; Quézel, 1999), constitutes a caducifoliate forest widespread in Ligurian low altitude humid zones. *Carpinus betulus* is actually located outside the Mediterranean area, apart from the Esterel and Tanneron massifs in southern France, where this species can be found in ripisylves or integrated in mesophilous forests (Barbero and Loisel, 1970; Noirfalise, 1987). During the Middle Palaeolithic, the expansion of *Carpinus betulus* in Liguria resulted from an increase of soil humidity at low altitude. This hypothesis seems to be corroborated by the nearness of *Fraxinus* and *Myrica* (Figs. 3 and 4).

5.7. [F]: Mountain forest (Fig. 5)

The sixth gathering includes three caducifoliate elements (*Betula*, *Corylus*, *Ulmus*) and a Coniferous, *Pinus* (Fig. 4). As *Betula* is not a common taxon in the Mediterranean area, apart from one species, *Betula pendula* (Quézel, 1995), the researches of similar vegetation were carried out in boreal or temperate Europe. The southern forests in northern Europe are characterized by the expansion of *Betula*, *Corylus* and *Ulmus* with two major components, *Pinus* and *Picea* (Noirfalise, 1987). Although it is proscribed to transpose this forest structure to the Mediterranean area, the assemblage of *Pinus*, *Betula*, *Corylus* and *Ulmus* suggests a Ligurian mountain forest similar to the northern Europe southern forest. The expansion of the mountain forest in Ligurian relief was due to the oscillation of precipitations at altitudes. This assemblage was probably located in humid to per-humid zones near the marshy banks of Torrente Varatello or Varatiglia River.

5.8. [G]: Human impacted assemblage (Fig. 6)

This assemblage is only detected during the Gallo-roman period between the first and the third Century AD, and includes pastoral elements (*Centaurea*, *Plantago*), pioneering taxa (Poaceae, Asteraceae) and cultivated plants including Poaceae *cerealia* type, Brassicaceae and Fabaceae (Behre, 1981). This group mainly represents a fallow land (Behre, 1981) due to cessation of agricultural practices near the Gallo-roman house. The herb assemblage corresponds to azonal type vegetation, extension of which depends on human activities.

A small group containing two conifers, *Abies* and *Picea*, appears in Fig. 5. These two taxa are located in the Ligurian relief at an altitude higher than the other groups. *Abies* and *Picea* are actually situated in the subalpine vegetation belt (Barbero et al., 1973; Ozenda, 1975). The very low percentages of *Abies* and *Picea* in all the pollen diagrams (Kaniewski, 2002) are probably due to the huge distance between these trees and the two sites (Heim, 1971; Coles et al., 1989; Ruffaldi, 1994).

6. Discussion

6.1. Vegetation assemblages

A schematic view of the evolution of vegetation groups in western Liguria between $91,000 \pm 5200$ yr BP and the early Weichselian glacial is represented in Fig. 7. Three distinct phases are discerned from the multi-variate analyses.

Fig. 7. Schematic view of the evolution of arid to mountain zones between $91,000 \pm 5200$ yr BP and the Weichselian glacial.

The first vegetation terracing [A] could represent a Mediterranean garrigue with a large pre-forest unit spread on the lower slopes. Located on the seashore, arid herbs are the main components on dry and saline soils. Behind, a semi-arid group colonized the superficial soils of the coast. Maquis settled on stony soils interrupt the evergreen woodland. Alluvial and caducifoliate forests are situated near Argentina and Armea Torrente, in marshy zones, and extend in altitude depending on the enlargement of the banks. The hypotheses based on vegetation indicate a dry Mediterranean temperate climate with a significant increase of humidity from the seashore to low altitude. The presence of several thermophilous taxa shows warm temperatures during long periods. The taxa in this first PCA denote an interglacial or an interstadial episode.

In order to validate the presence of certain taxa in the Ligurian area, we compared our results with local archaeo pollen records and Italian continuous pollen records using the Grande Pile terminology (Woillard, 1978, 1979; Woillard and Mook, 1982; Beaulieu and Reille, 1992). During the Upper Pleistocene, the increase of thermophilous taxa started during the Eemian episode in Italy (Follieri et al., 1988, 1989, 1998). After the Eemian episode, thermophilous taxa decreased but they were present during St Germain I and St Germain II episodes in northwest Liguria (Balzi Rossi) at La Grotte du Prince (Renault-Miskovsky, 1971, 1972; Kharbouch, 1990), in the Valle di Castiglione (Follieri et al., 1988, 1989, 1998) and in Lagaccione (Magri, 1999). According to the radiometric dating of the pollen sequence (between $91,000 \pm 5200$ and $73,100 \pm 4400$ yr BP) from which the PCA was undertaken, the first vegetation fits with the St Germain II episode and is well correlated with the archaeo and continuous pollen records from the Mediterranean basin.

The second vegetation terracing [B] represents an extension in altitude of the arid herbs, which could be interpreted as increased extent of dry soils due to a decrease of precipitation and reduction of river flow. The draining of soils generated an expansion of arid to semi-arid zones up to lower slopes. Drying forced the alluvial and caducifoliate forests upward, closer to humid/per-humid zones, into a restricted area. Likewise, the sub-humid zone tended to increase in altitude. This change could result from the end of St Germain II interglacial mentioned above. Despite an increase of AP to 89% of the pollen sum (mainly due to *Pinus* and Cupressaceae), the other trees decreased. The climate was dry and cool with a concentration of humidity at altitude.

The end of St Germain II episode is indicated in southeast France (Nice) at La Grotte du Lazaret (Gauthier, 1992) and in Lagaccione (Magri, 1999) by an increase of *Pinus* and Cupressaceae. The other trees such as evergreen *Quercus*, deciduous *Quercus*, *Alnus*

and *Betula* persisted, albeit in small proportions (Gauthier, 1992; Magri, 1999). As the beginning of the Pleniglacial is marked by an increase of steppic markers (*Artemisia*, *Ephedra*, *Chenopodiaceae* etc.) and an important decrease of trees, the second PCA (later than $73,100 \pm 4400$ yr BP) is strongly correlated with the end of the St Germain II episode.

The third vegetation terracing [C] mainly shows a huge variation in taxa distribution due to a shift in edaphic and climatic parameters. The PCA indicates open vegetation due to an extension of the steppe-landscape in altitude. The steppe extended, probably following the dry riverbanks and was widespread in an area where a huge draining of soils tended to enlarge the arid-zones. The lower size of the humid to per-humid zones confined the caducifoliate and hygrophilous trees to the tiny marshy riverbanks. The sub-humid zones are reduced and located near the humid zones. The climate was drier and colder, with a persistence of weak moisture conditions in certain parts of the Ligurian mountains.

During the early Weichselian glacial, the Mediterranean landscape was covered by an open herb-dominated vegetation with reduced stands of trees as indicated by generally low percentages of AP (Magri, 1999). A clear rise in *Artemisia*, *Ephedra*, *Chenopodiaceae*, *Asteraceae* and *Poaceae* is mentioned in the Mediterranean basin at this time (Follieri et al., 1988; Magri, 1999; Allen and Huntley, 2000; Allen et al., 2000; Watts et al., 2000). Several weak expansions of caducifoliate arboreal taxa (AP < 50%) were noticed in Lagaccione (Magri, 1999) and in Monticchio (Allen et al., 2000). These trees are mainly *Alnus*, *Betula*, deciduous *Quercus*, *Corylus*, *Ulmus* and in very low proportions *Carpinus betulus*. Mediterranean taxa such as evergreen *Quercus*, *Olea* and *Cistus* were mentioned in southeast France (Toulon) at Cap Sicié (Bernard, 1972). In Lagaccione, the first expansion of trees after the last interglacial is termed the Lazio complex episode I (Magri, 1999). According to the PCA, the third vegetation fits with episode I of the Italian Lazio Complex (during OIS 4).

The PCA (Fig. 8) derived from the Gallo-Roman pollen diagram [D] is similar to that from the St Germain II episode [A]. However, several differences are clear. The Gallo-roman period differs from the others in the presence of pastoral, pioneering and cultivated plants, mainly due to human activities. According to axis 2, this group extended over the lower slopes, in sub-humid to humid zones near the caducifoliate forest. Thus, the fourth PCA shows that the human impact has generated a type of vegetation that only partly reflects the parameters of soil and climate. The climate was warm and dry, with an increase of moisture with altitude.

Despite some increases of *Poaceae cerealia* type (Isola del Giglio, first–third century AD) (Arobba et al., 1983)

Fig. 8. Schematic view of the evolution of arid to per-humid zones during Gallo-roman period.

and *Vitis vinifera* due to maritime transport of resins (Punta Ala, third century AD) (Arobba, 1976), the arboreal vegetation notified in each pollen diagram from Liguria and Toscana is quite similar. In each site, the main arboreal taxa are evergreen *Quercus*, *Olea*, *Pistacia*, *Phillyrea* with several caducifoliate and hygrophilous trees including deciduous *Quercus*, *Ulmus*, *Alnus* and *Salix*. Numerous Mediterranean shrubs (*Cistus*, *Myrtus*, *Rhamnus*) are also noted. On the other hand, each Gallo-roman site had a specific herb composition. In Albintimilium Roman graves (fourth–fifth century AD) (Arobba et al., 1998a), the funeral rites (flower offerings) have disrupted the picture of vegetation by some increases of Lamiaceae, Liliaceae and Primulaceae. In Del Golfo Dianese (first century AD) (Arobba et al., 1998b), samples came from several amphora found in a Roman wreck near the Imperia coast (western Liguria). Thus, the major components of pollen diagrams are cultivated plants (e.g. *Poaceae cerealia* type, *Triticum*). Despite several NAP differences between all these sites, the Gallo-roman PCA correlated well with the arboreal cover mentioned in northwestern Italy between the first and the fifth century AD.

6.2. Synthetic pollen diagrams

The vegetation assemblages established, according to PCA, were integrated in detailed pollen sequences to construct synthetic diagrams. PCA synthetic diagrams (PCA sd) allowed us to interpret taxa according to three parameters: vegetation assemblages, soils, and altitude. PCA sd showed the extent of each assemblage in a local

area. Thus, it is easy to detect some irregularities due to the relationship between vegetation and archaeological sequences. The over-representation of the Mediterranean pre-forest unit (Figs. 3 and 4) could be initially interpreted by the relationship between this unit and the archaeological sequences. In a same way, the over-representation of the ripisylve (Fig. 5) is mainly due to the proximity of Torrente Varatello to Santa Lucia superiore cave. After establishing the altitude of each vegetation assemblage and estimating the distances between these assemblages and the archaeological site, a decline in pollen representative of their assemblages appears clearly when the distance increases. This hypothesis is similar to those obtained by several authors from actual pollen distributions (Heim, 1971; Coles et al., 1989; Ruffaldi, 1994; Navarro et al., 2001). Data interpretations must consider that the representation of each vegetation assemblage would have been completely different if the two archaeological sites were located at higher altitudes.

Moreover, the development of a littoral-relief curve (Figs. 3 and 4) allowed us to estimate the significance, in pollen diagrams, of vegetation assemblages placed at the same level as the archaeological sequences. In the same way, the development of a moisture curve (Fig. 5) and a human activities curve (Fig. 6) allowed us to assess the importance of these vegetation groups in pollen sequences. Therefore, the archaeopollen sequences offered several pictures of vegetation that must be assessed in a local area (altitude, soils, proximity) before giving any climatic conclusions.

6.3. On the presence of Mediterranean taxa in Liguria

Apart from the early Weichselian glacial, the PCAsd (Figs. 3, 4 and 6) showed a major representation of the littoral vegetation (especially from the lower slopes where Madonna dell'Arma is located). Thus, it shows Mediterranean assemblages as pre-forest units and evergreen woodlands. Semi-arid Mediterranean shrubs are in lower proportions. The first two PCAsd indicated that Mediterranean taxa were still present in western Liguria during the St Germain II episode up to the end of the last interglacial. In contrast, the PCAsd from the early Weichselian glacial (Fig. 5) only showed two small increases of Mediterranean vegetation. Therefore, between the last interglacial and the Pleniglacial, the Mediterranean taxa declined from a floristic point of view. During St Germain II, the main thermophilous taxa were evergreen *Quercus*, *Olea*, *Pistacia*, *Phillyrea*, *Carpinus orientalis*, *Cistus*, *Myrtus* and *Rhamnus*, with additional genera (not mentioned in this paper) including *Coriaria* and *Matthiola*. Since the early Weichselian glacial, the only thermophilous taxa were evergreen *Quercus*, *Olea*, and *Phillyrea*.

7. Conclusion

Statistical analyses from two archaeological sites located in western Liguria were used to reconstruct the vegetation terracing in the Mediterranean belts and to discuss vegetation distribution according to edaphic factors. The edaphic parameters are as important as the climatic factors in Liguria: caducifoliate trees often colonized the deep alluvial soils whereas sclerophyllous elements can extend over superficial or stony substrates (Pons and Quézel, 1998). Ordination of the main taxa by PCA shows that the vegetation assemblages defined from archaeological sequences are confirmed by the studies of actual vegetation in the same local area. Research by phytogeographers and botanists in the northwestern Mediterranean area (Barbero et al., 1973; Ozenda, 1975; Quézel, 1999; Ozenda and Borel, 2000) has produced a huge database, which has allowed us to estimate by comparison the coherence of vegetation and ecological assemblages identified in archaeological sites. These comparisons aim to reduce the uncertainties about the palaeoecological value of cave pollen assemblages. Pollen data from Madonna dell'Arma and Santa Lucia superiore cave indicate distinct pre-forest unit/evergreen woodland to steppe-landscape/ripisylve landscapes between the last interglacial and the early Weichselian glacial. The data indicate a significant increase of drought from the coastal zone up to the Ligurian relief and an increase of moisture with altitude. These hypotheses established according to the pollen sequences are corroborated by the faunal remains and well integrated in the multidisciplinary studies of each site.

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