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Late-Glacial and Holocene vegetation history of Pavullo nel Frignano (Northern Apennines, Italy)

Elisa Vescovi [a,b,*], Petra Kaltenrieder [a], Willy Tinner [a]

[a] Institute of Plant Sciences and Oeschger Centre for Climate Change Research, University of Bern, Altenbergrain 21, CH-3013 Bern, Switzerland
[b] C.N.R. – Institute for the Environmental Dynamics, via Pasubio 5, 24044 Dalmine, Italy

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ABSTRACT

Until recently, pollen-stratigraphic research in the Northern Apennines (Northern Italy) provided only generalized pollen diagrams that lacked reliable chronologies, and few records provided complete and detailed postglacial sequences equipped with radiocarbon dates. We present a new Late-Glacial and Holocene pollen sequence from Pavullo nel Frignano in the Emilian Apennines (Modena, Italy). The chronology relies on AMS-radiocarbon-dated samples of terrestrial plant origin. Our pollen record suggests that open Late-Glacial *Pinus* and *Juniperus* dominated woodlands were established at the site before 14,000 cal. BP. Thermophilous trees such as *Quercus, Ulmus*, and *Tilia* as well as *Abies alba* expanded already during the Late-Glacial (ca. 14,000–13,000 cal. BP), but did not form closed forests. After climate cooling of the Younger Dryas *A. alba* re-expanded at the onset of the Holocene at ca. 11,500 cal. BP and remained the dominant species until at ca. 6000–5500 cal. BP. The decline of *A. alba* was associated with a marked opening of forests, and the expansion of deciduous trees such as *Fagus* and *Quercus*. Vegetational composition did not change substantially during the past 5000 years, and cultivated tree taxa such as *Juglans* and *Castanea* played only a transient or marginal role. Although the vegetation history of Pavullo is consistent with previous investigations in the study area, comparison is hampered by the absence of other records from the same vegetational (colline) belt. Our pollen-inferred human-impact history is in agreement with archaeological evidence. In addition, our results suggest a rather close link between vegetational change in the Northern Apennines and the Southern Alps. Common features between these two climatically-similar regions are the initial expansion of thermophilous trees and *Abies alba* at ca. 13,000 cal. BP, the mid-Holocene collapse of *A. alba* (probably as a consequence of human disturbance) as well as the subsequent expansions of *Quercus* and *Fagus*.

1. Introduction

The Northern Apennines are a mountainous region that extends from Liguria to Emilia Romagna and Tuscany, and separate Northern and Central Italy (Fig. 1). The northern slopes that descend gradually to the Po Plain are less steep than the southern slopes in Tuscany. Well-preserved lake or mire deposits are relatively rare in the region. Thus, high temporal and taxonomic resolution palaeo-environmental sequences from the Northern Apennines are still scarce and only a few diagrams are equipped with enough radiocarbon dates on terrestrial macrofossils to reach sufficient temporal precision.

Despite these limitations, several published records provide a baseline Holocene vegetation history for the Northern Apennines. For example, lake and mire sediments from the Ligurian Apennines, situated between 800 m a.s.l. and ca. 1500 m a.s.l., provide pollen records spanning from the early to the late Holocene (Table 1; Cruise, 1990a,b; Braggio et al., 1991; Branch, 2004; Cruise et al., 2009). In the northern part of the Tuscan–Emilian Apennines five sites at high elevation provide detailed Late-Glacial and early Holocene or Holocene records (Table 1; Chiarugi, 1936; Bertoldi, 1980; Lowe, 1992; Bertoldi et al., 2004; Bertoldi et al., 2007; Vescovi et al., in press). Three more sequences are available from lakes in the mountains of the Emilian Apennines that cover almost the entire Holocene (Watson, 1996). However, no records are available from the southern part of the northern Apennines (e.g. Tuscany) and sequences from low elevations are also scarce. Although two research programs that started in 1988 and 1999 provided valuable pollen diagrams such as the Prato Spilla, Lago Pratignano, Lago Padule, Ospitale and Lago Riane, Rovegno, Lago Rotondo, Lago Lagastro records, the chronology of these sequences are based on radiocarbon dates on bulk material, and thus lack sufficient chronological precision (Hajdas et al., 1998; Ravazzi, 2002). The aim of this paper is to present a new pollen

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* Corresponding author. Institute of Plant Sciences and Oeschger Centre for Climate Change Research, University of Bern, Altenbergrain 21, CH-3013 Bern, Switzerland. Tel.: +41 31 631 49 22; fax: +41 31 631 49 42.
E-mail address: elisa.vescovi@ips.unibe.ch (E. Vescovi).

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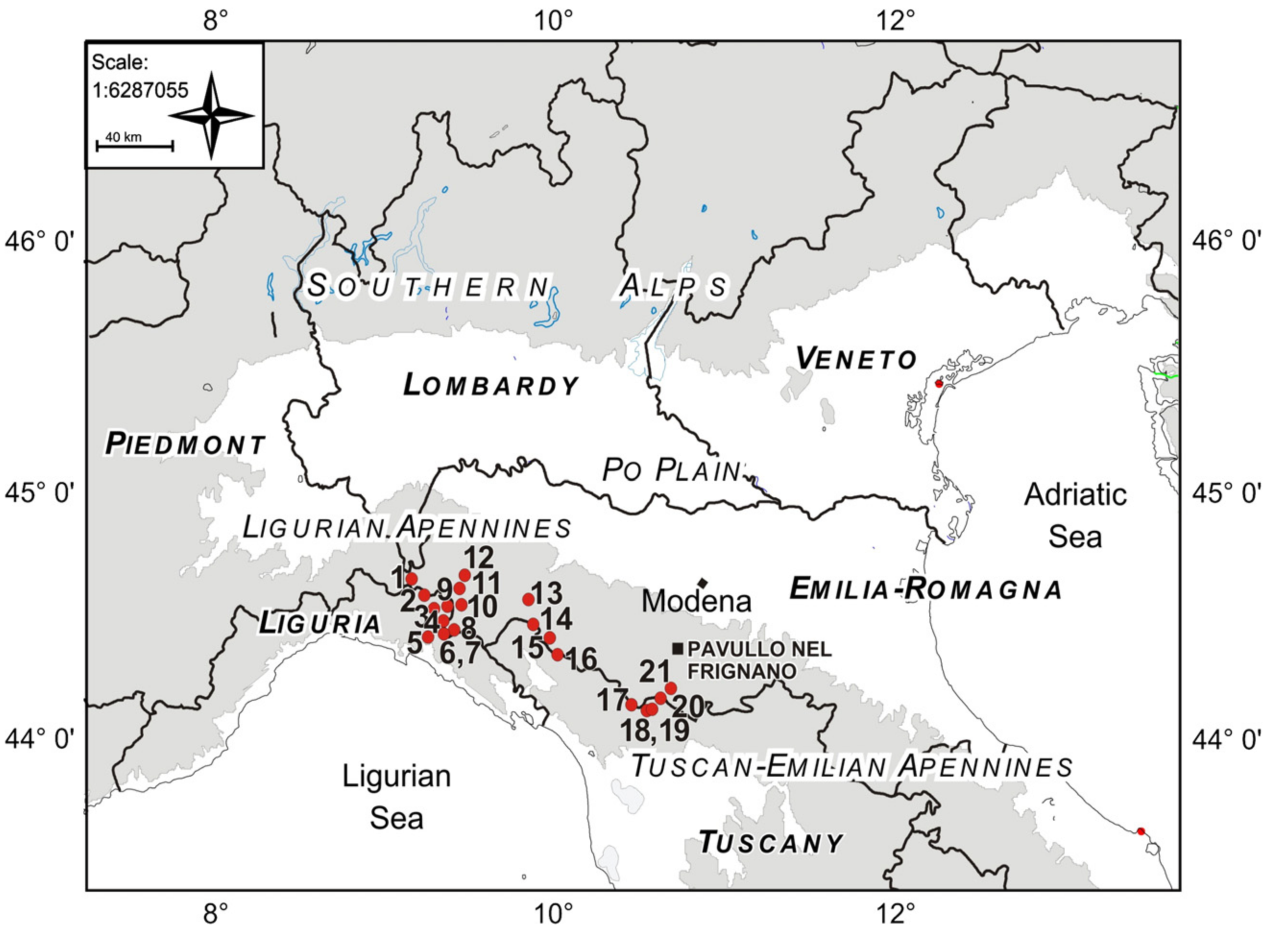

Fig. 1. Location of important sites in the Northern Apennines mentioned in the present paper. Grey area: elevation above 200 m. Sites: 1 — Rovegno, 2 — Casanova, 3 — Lago Riane, 4 — Lago delle Lame, 5 — Bargone, 6 — Lago Rotondo, 7 — Lago Lagastro, 8 — Prato Mollo, 9 — Agoraie, 10 — Lago Nero, 11 — Pramollo, 12 — Lago Moo, 13 — Berceto, 14 — Lagdei (I, II), 15 — Prato Spilla (A, B, D), 16 — Lago Padule, 17 — Lago Baccio, 18 — Lago del Greppo, 19 — Lago Baccioli, 20 — Ospitale, 21 — Pratignano.

diagram from Pavullo nel Frignano (675 m a.s.l., Modena) which may contribute to a better understanding of Holocene vegetational dynamics in the Northern Apennines, and allows us to place the vegetation history of the Northern Apennines within the context of vegetational change on a broader spatial scale. Thus, we compare our results with vegetation history records from the Southern Alps where climatic conditions are similar to those in the Northern Apennines (e.g. July means of 22 °C, January means of 2 °C and annual precipitation of 1000–1800 mm in the lowlands). We also contribute new information on the past distribution and dynamics of important taxa (e.g. expansion of *Abies alba*).

2. Study area and study site

In the Emilia Romagna Region peat deposits are mainly located in the depressed part of the Po Plain, especially towards the shore of the Adriatic Sea, while natural lakes are present almost exclusively above 1000 m of altitude, usually of glacial origin. Natural archives are rare in the foothills of the Northern Apennines and the vegetation history of low and intermediate elevation (100–1000 m a.s.l.) is still poorly studied.

On the northern slope of the Tuscan–Emilian Apennines, near the village of Pavullo nel Frignano (Province of Modena, Figs. 1 and 2) at ca. 670 m a.s.l., in a wide plain situated in a karstic landscape (poljie following Panizza, 1968) a series of depressions are occupied by peat-bogs or swamps. The peat deposits were discovered and partially exploited by man around AD 1860 in a vast area south of the village, near San Pellegrino. In the 1970s Bertolani Marchetti et al. (1977) recognized the palaeo-vegetational potential of the site and analysed pollen samples from cores taken in the swampy area of "la Chioggiola" north of the village. Subsequently new palynological investigations were made (Bertolani Marchetti et al., 1994) in the peat-bog of San Pellegrino. An additional site a few kilometres north of Pavullo (St. Antonio, unpublished data) contains a discontinuous record probably with spectra from the Last Glacial Maximum (LGM) to the early Holocene (Lowe and Watson, 1993).

Our new study site of Pavullo (44°19′198″ N, 10°50′307″ E, 675 m a.s.l.) is located near San Pellegrino, close to the coring spot of Bertolani Marchetti et al. (1994). Sandy, deeply fractured limestone bedrock of the Bismantova Formation underlies the site. The origin of the former lake is probably connected with the interruption of the deep karstic drainage. The successive shift of the lake in to a swamp or peat-bog may be related to an incision along the northern border that created a surface outlet. The site is presently occupied by an artificial pool (for fishing and tourism) with an area of 21.6 ha and a maximum depth of 4.7 m, without any major inlet and outlet.

The present climate regime is temperate (Cf, Pinna, 1977) and mean annual, mean July and mean January temperature are 10 °C, 19 °C, and 2 °C respectively. Mean annual precipitation is 969 mm, with a maximum in November. Slopes surrounding the mire are covered by a sub-Mediterranean type of vegetation with *Quercus pubescens*, *Sorbus torminalis*, *Acer monspessulanum*, *Acer campestre*, and *Fraxinus ornus*. On shady and cooler slopes, i.e. towards the southern part of the plateau, downy oak is associated with *Quercus cerris* and *Ostrya carpinifolia*. *Castanea sativa* and *Fagus sylvatica* are also present in the local vegetation.

Table 1
Lakes and bogs analysed in the Northern Apennines.

Site	Altitude m a.s.l.	Analysed fraction	^{14}C dates	Authors
Ligurian Apennines				
Rovegno	812	Peat	4380 ± 80	Branch (2004)
		Peat	11,690 ± 70	
Lago Bargone	831	Bulk sediment	7330 ± 70	Cruise (1990a);
		Bulk sediment	8450 ± 80	
		Peat	2375 ± 45	Cruise et al. (2009)
		Peat	4625 ± 50	
		Peat	6075 ± 45	
		Silty peat	10,690 ± 450	
		Peat	700 ± 60	
		Peat	5390 ± 60	
		Peat	8390 ± 110	
		Silty peat	10,870 ± 90	
Lago delle Lame	1029	Bulk sediment	3025 ± 50	Cruise (1990a)
		Bulk sediment	3510 ± 35	
Casanova	1056	Bulk sediment	5040 ± 100	Cruise (1990a,b)
Lago Moo	1106	/	/	Braggio et al. (1991)
Lago Riane	1279	Bulk sediment	4955 ± 130	
Lago Riane	1279	Peat	5280 ± 80	Branch (2004)
		Peat	9070 ± 70	
Lago Lagastro	1326	Wood	1790 ± 70	Branch (2004)
		Peat	2690 ± 60	
Agoraie	1328	Bulk sediment	2050 ± 50	Cruise (1990a,b), Braggio Morucchio and Guido (1975)
		Bulk sediment	3510 ± 60	
		Bulk sediment	4180 ± 60	
Lago Rotondo	1331	Wood	6410 ± 60	Branch (2004)
		Peat	7100 ± 80	
Pramollo	1375	Bulk sediment	5632 ± 130	Braggio et al. (1991)
Lago Nero	1475	Bulk sediment	4610 ± 30	Cruise (1990a)
Prato Mollo	1492	Bulk sediment	4130 ± 60	Cruise (1990a)
		Bulk sediment	4300 ± 60	
Tuscan–Emilian Apennines				
Berceto	870	Scraps of plant	11,150 ± 70	Bertoldi et al. (2004), Bertoldi et al. (2007)
		Scraps of plant/wood	14,480 ± 50	
		Organic matter	29,620 ± 290	
Lago Padule	1187	Organic mud	1165 ± 55	Watson (1996)
		Organic mud	2880 ± 50	
		Gyttja	5260 ± 55	
		Gyttja	7940 ± 50	
		Organic mud	8990 ± 65	
		Organic mud	9155 ± 55	
		Organic mud	9895 ± 50	
Ospitale	1225	Peat	1820 ± 45	Watson (1996)
		Organic mud	2790 ± 45	
		Organic mud	4760 ± 45	
		Organic mud	5430 ± 50	
Lagdei	1254	/	6840 ± 53	Bertoldi (1980), Bertoldi et al. (2007)
		/	8190 ± 70	
		/	9620 ± 70	
		Peat	9900 ± 80	
Prato Spilla D	1280	Bulk sediment	9590 ± 60	Lowe (1992), Lowe and Watson (1993), Lowe et al. (1994a,b), Ponel and Lowe (1992), Watson et al. (1994)
		Bulk sediment	10,165 ± 50	
		Bulk sediment	11,060 ± 50	
		Bulk sediment	11,770 ± 50	
Lago Baccioli	1295	/	/	Chiarugi (1936)
Lago Pratignano	1307	Fibrous peat	4450 ± 50	Watson (1996)
		Fibrous peat	4245 ± 50	
		Organic mud	5780 ± 40	
		Detrital peat	8715 ± 40	
Lago del Greppo	1442	Cone scale of *Abies*	170 ± 30	Vescovi (2007), Chiarugi 1936
		Twig of shrub	325 ± 30	
		Abies needles	2705 ± 35	
		Needles of *Abies*	3955 ± 35	
		Cone scale and needles of *Abies*	6600 ± 50	
		Needles of *Abies*	6990 ± 40	
		Needles of *Abies*	7010 ± 40	
		Needles of *Abies*	7660 ± 40	
		Needles of *Abies*	7860 ± 50	
		Needles of *Abies*	8900 ± 50	
		Twig of shrub	9540 ± 50	
		Needles of *Juniperus*	10,940 ± 60	
Prato Spilla A	1550	Bulk sediment	1400 ± 45	Lowe (1992), Lowe and Watson (1993), Lowe et al. (1994a,b), Ponel and Lowe (1992); Watson et al. (1994)
		Bulk sediment	3890 ± 45	
		Bulk sediment	5035 ± 50	
		Bulk sediment	7965 ± 45	
		Bulk sediment	10,300 ± 45	
		Bulk sediment	10,610 ± 45	
Lago Baccio	1554	/	/	Chiarugi (1936)
Lago Nero	1740	/	/	Chiarugi (1936)

3. Methods

3.1. Fieldwork

In 2001 two parallel cores (PV2 and PV3, 40 cm apart) were taken in the southern part of the former swamp (outside the modern artificial pool in a parking lot) with a modified Streif-Livingstone piston corer (Merkt and Streif, 1970). Before coring, the first meter (i.e. pavement and construction debris) was removed by digging with a shovel. A coring depth below ground of 16.42 m and 15.50 m was reached with cores PV2 and PV3, respectively. After fieldwork, sediments were accurately described, correlated by matching distinctive layers and lithological contacts and stored at 5 °C before subsampling. Only core PV2 was used for palaeobotanical analysis because it was most complete.

3.2. Chronology

Accelerator mass spectrometry (AMS) radiocarbon dates were obtained at the Poznan Radiocarbon Laboratory (Poznan, Poland) from terrestrial plant macroremains (Table 2). ^{14}C-dates were calibrated as calendar year before present (cal. BP) using the program CALIB 5.0.1 (IntCal04; Reimer et al., 2004).

3.3. Pollen and charcoal analysis

Pollen samples were prepared from 1 cm^3 of sediment subsamples following standard techniques including treatment with HCl, KOH, HF and acetolysis (Moore et al., 1991) and physical treatment (sieving at 500 µm and decanting). *Lycopodium* tablets (Stockmarr, 1971) were added to samples for estimation of pollen concentrations. A sum of at least 400 pollen grains was counted for each sample (excluding *Alnus*, wetlands plants, aquatic plants, spores and non-pollen palynomorphs (NPP)), at a standard magnification of ×400. Higher magnifications (×630 and ×1000) were used for difficult pollen determinations. Pollen grains were identified using keys, pollen atlases (Punt and Blackmore, 1976–1995; Moore et al., 1991; Reille, 1992–1998; Beug, 2004) and the reference collection of the Institute of Plant Sciences of the University of Bern. We identified fossil stomata following Trautmann (1953). NPP identification follows van Geel et al. (1989). Microscopic charcoal particles longer than 10 µm were identified and counted in the pollen slides following Tinner and Hu (2003) and Finsinger and Tinner (2005). Particle concentrations (charcoal particle cm^{-3}) were estimated with the same approach as for pollen. Pollen and charcoal diagrams were drawn using TILIA 1.12 and TiliaGraph. The results are presented as TgView 2.0.2 pollen diagrams

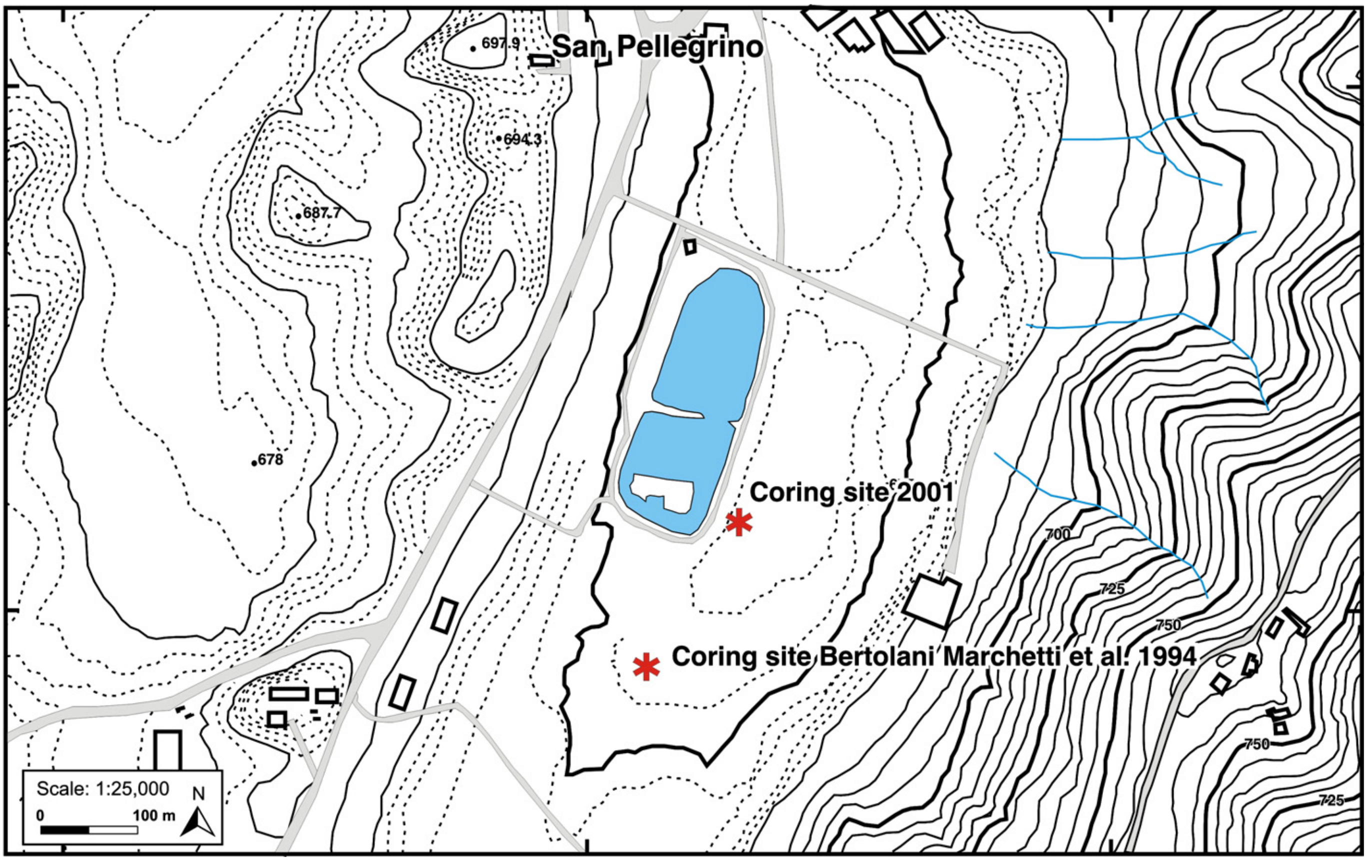

Fig. 2. Simplified map of the Pavullo-San Pellegrino area.

(Grimm, 1992–2005). To determine local pollen assemblage zones numerical zonation was carried out using the program ZONE 1.2 and selecting the optimal-sum-of-square partition (Birks and Gordon, 1985). Statistically significant pollen zone limits (SPZL) were determined by using the broken-stick model (Bennett, 1996). In addition, “subzones” as determined by ZONE (Birks and Gordon, 1985) have been used where necessary.

4. Results

4.1. Sediment description and depth–age model

The lithostratigraphy of the core PV2 is summarized in Table 3. The succession of layers of peat gyttja and minerogenic materials shows that the sediments were deposited in wetlands or aquatic environments, and that the basin was subject to several changes in the water level. Twelve dates were obtained from terrestrial plant remains from the PV2 core (Table 2). The depth–age model (Fig. 3) was built by linear interpolation of the dates. We rejected two dates from the core that are unreasonably old in comparison with the other dates of the Pavullo sequence and the radiocarbon-dated biostratigraphy in the region (Vescovi, 2007). These dates were obtained from wood, a substrate that can deliver ages that are older than surrounding sediments (Oswald et al., 2005).

4.2. Pollen analysis and vegetation history

The pollen diagram can be subdivided into four statistically significant local pollen assemblages (zones PV 1–4 Fig. 4a and b).

Table 2
AMS-radiocarbon dates from Pavullo nel Frignano.

Lab nr	Depth (cm)	Analysed fraction	Conv. ^{14}C yrs BP	Cal age BP (2σ range)	Age in diagram
Poz-19116	150–151	Wood	4180 ± 35	4584–4837	Rejected
Poz-19117	226–227	Wood	450 ± 30	472–535	509
Poz-20087	347–348	Cyperaceae rhizomes	1720 ± 30	1554–1704	1629
Poz-16181	472–473	Wood	3400 ± 30	3567–3718	3650
Poz-16182	606–607	Branch	5060 ± 40	5669–5911	5817
Poz-11238	690	Wood	5930 ± 40	6665–6878	6754
Poz-14770	775–776	Wood	7740 ± 40	8431–8590	8515
Poz-16184	866–870	Wood	9180 ± 50	10,238–10,493	10,344
Poz-19118	944–948	Cyperaceae rhizomes	9980 ± 50	11,252–11,700	11,442
Poz-16185	1005–1006	Wood	12,420 ± 60	14,149–14,853	Rejected
Poz-20089	1010–1011	Cyperaceae rhizomes	10,380 ± 50	12,054–12,578	12,256
Poz-16186	1086–1087	Wood	12,100 ± 60	13,806–14,095	13,951

Table 3
The sediments from Pavullo nel Frignano.

Depth (cm)	Sediment	Colour
112–160	Peat	Black–brown
160–203	Calcareous gyttja	Brown
203–682	Peat with gyttja and wood	Dark brown
682–815	Clayey–silty gyttja with macro (non carbonatic)	Bright brown
815–1119	Peat	Black brown
1119–1216	Silty gyttja (low carbonate)	
1216–1256	Silty clay (no carbonate) to silty–gyttja	
1256–1346	Silty–clayey fine sand with carbonate partly oxidated	Orange grey bright brown
1346–1414	Silty–clayey fine sand with carbonate partly oxidated	
1414–1472	Silty clay fine sand with carbonate	
1472–1482	Gyttja	
1482–1560	Silty fine sandy clay with carbonate	

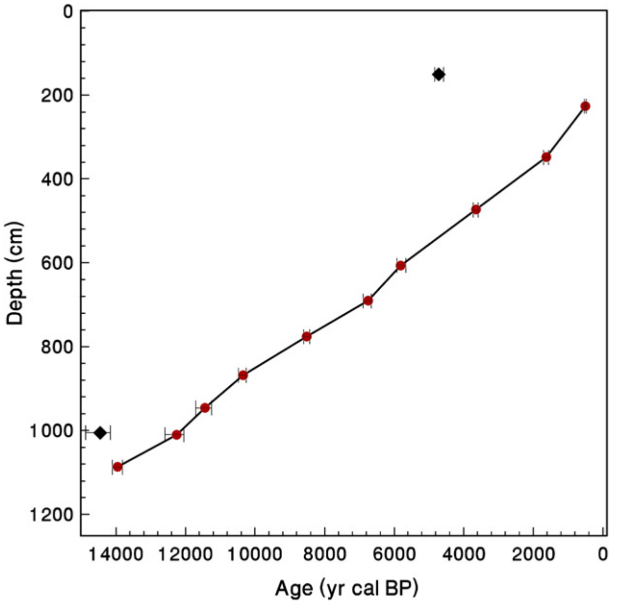

Fig. 3. Depth–age model for Pavullo nel Frignano based on linear interpolation of calibrated radiocarbon years BP. The dots represent the calibrated median ages and the bars the 95% confidence intervals according to CALIB 5.0.1 (Reimer et al., 2004).

The pollen record suggests that until ca. 14,500 cal. BP the landscape near Pavullo was open (PV-1). Shrubs (*Juniperus*, *Ephedra dystachia*, *Hippophaë*) were present together with light-demanding and pioneer herbaceous taxa (*Artemisia*, Chenopodiaceae, Poaceae, Asteroideae, Apiaceae and Cichorioideae). Higher *Pinus sylvestris*/*mugo* percentages of pollen and regular findings and/or increases of pollen of *Salix, Quercus, Ulmus, Tilia* and *Abies* pollen may reflect the presence of mixed coniferous–deciduous woodlands in the Pavullo area between ca. 14,500 and 12,500 cal. BP (PV-2a). Decreasing *Pinus* pollen (starting at ca. 13,500 cal. BP) suggests subsequent opening of the forests between ca. 12,500 and 11,500 cal. BP (PV-2b). At the same time pollen of *Juniperus*, *Artemisia*, and other steppic and alpine herbs and shrubs (e.g. Chenopodiaceae, Brassicaceae, *Galium* type and *Ephedra*) became far more frequent, indicating an expansion of steppe or alpine meadow vegetation. This subzone probably reflects the effects of the Younger Dryas cooling (ca. 12,650–11,500 cal. BP; Ammann et al., 2000) on vegetation.

At the onset of the Holocene, ca. 11,500 cal. BP, *Abies* populations re-expanded (PV-2c, ca. 11,500–10,700 cal. BP). Increasing pollen of *Corylus, Ulmus* and *Tilia* combined with a decrease of herbaceous taxa indicate a recovery and further expansion of mixed coniferous–deciduous woodlands, probably as a consequence of climatic warming at the Late-Glacial/Holocene transition. Pollen data suggest that vegetation remained rather stable until ca. 5800 cal. BP (PV-3, 10,700–5800 cal. BP), despite some fluctuations in the vegetation cover. For example, an abrupt but short decrease of *Abies* pollen percentages that is connected with an increase of *Corylus* around ca. 8500 cal. BP may suggest a weak opening in the vegetation cover. Our data indicate *Abies* forests collapsed ca. 5700 cal. BP. A weak increase of *Fagus* and *Corylus* pollen, followed by a clear increase of deciduous *Quercus* suggests open deciduous forests with *Quercus*, *Corylus*, *Ulmus* and *Fagus* replaced the mixed *Abies* forests (PV-4, ca. 5700–0 cal. BP). This process was accompanied by the presence or expansion of taxa indicative of human impact (e.g. Cerealia, *Plantago lanceolata, Rumex acetosella*) and disturbance (e.g. monolete spores) at ca. 4700 cal. BP. A further decline of *Pinus* pollen, the disappearance of *Tilia* pollen and the appearance of *Quercus ilex* pollen indicate forest composition changed slightly ca. 3000 cal. BP. These changes were almost concomitant with the establishment of the Terramare (3550–3100 cal. BP) culture, in the Po plain and on the neighbouring foothills of the Northern Apennines during the Middle and Late Bronze Age (Cremaschi et al., 2006; Mercuri et al., 2006). After ca.1500 cal. BP the presence of pollen of *Castanea* suggests the cultivation of this fruit tree in the Pavullo area. Our findings, contrast with Bertolani Marchetti et al. (1994) who recorded *Castanea sativa* since the Late-Glacial, with high values during the early and late Holocene. Given that *Castanea* is essentially absent from our record before 1500 ca. BP, we suggest that the previous interpretation of *Castanea* before this time possibly resulted from contamination or misidentification (confusion with *Filipendula*). In agreement with other sites in Northern Italy *Juglans* is present in the pollen assemblages of Pavullo since before the onset of the Roman period. This may indicate a natural presence or an earlier (Neolithic) introduction of this fruit tree (see discussion in Kaltenrieder et al., in press). The carbonatic soils around Pavullo are certainly better suited for *Juglans regia* than *Castanea sativa,* which has a strong preference for siliceous substrates (Conedera et al., 2004).

4.3. Microscopic charcoal and fire history

The microscopic charcoal record of Pavullo nel Frignano suggests pronounced changes in regional fire history. Regional fire activity reached maxima around 12,000, 10,500 and after 4500 cal. BP (Fig. 4b). High concentrations between ca. 12,500 and 11,500 cal. BP, with peaks of ca. 50,000 part/cm^3 correspond to microscopic charcoal influx peaks reaching values >2000 particles/cm^2/yr. Influx values show that fire activity slightly increased again after 4500 cal. BP than during the first part of the Holocene. However, charcoal values remain low (ca. 15,000 part/cm^3) and suggest only minor to moderate regional fire-peak activities in the Pavullo area.

5. Discussion

5.1. Vegetation history

5.1.1. Last Glacial Maximum and Late-Glacial

During the Last Glacial Maximum the Northern slope of the Tuscan–Emilian Apennines was partly covered by glaciers and the highest valleys of the Emilian slope sheltered ice tongues with northern orientation that reached elevations below 1000 m a.s.l. (Jaurand, 1998). No palaeo-environmental investigations are available to precisely date the regression of the glaciers in the area that induced the beginning of the formation of mire and lake basins in the Northern Apennines. Also scarce are sequences that recorded the early phase of afforestation after the Last Glacial Maximum in the Northern Apennines.

The pollen record of Pavullo nel Frignano (670 m a.s.l.) suggests that already before ca. 14,500 cal. BP some *Pinus* and *Betula* stands were present in the steppic environments of the foothills of the Northern Apennines. The first abrupt change in the vegetation composition occurred at around 14,500 cal. BP. The Pavullo sequence suggests that at lower altitudes (below 600–900 m a.s.l.), *Pinus* increased in the previously established *Pinus*–*Betula*–*Juniperus* woodlands. The pollen evidence from Berceto (820 m a.s.l.), in the Emilian Apennines (Bertoldi et al., 2004, 2007), and Rovegno (812 m a.s.l.), in the Ligurian Apennines (Branch, 2004), also suggest an expansion at ca. 14,500 cal. BP of *Pinus* and *Betula* in open early woods or shrublands. Only ca. 500 years after the *Pinus* expansion, deciduous shrubs and trees, such as *Salix, Quercus, Ulmus* and *Tilia* became established in the Pavullo area. This thermophilous vegetation type moved rapidly upslope, expanding at higher elevations in the *Juniperus*–*Hippophaë* shrublands (Lago del Greppo; Vescovi, 2007) or in open woodlands (Lagdei, Bertoldi, 1980). Similar increases of deciduous shrubs and trees (*Quercus* and *Corylus*) occurred at Berceto, but are not evident at Rovegno. However, dissimilarities may be the consequence of insecure chronologies and/or missing sediments (hiatus). For instance the Berceto succession is abruptly interrupted at ca. 13,300 cal. BP (Bertoldi et al., 2007). Well-dated records are very rare in the region and thus it is difficult to assess if the vegetational succession recorded at Pavullo and Lago del Greppo is typical for the Northern Apennines. However, vegetational change in the region probably reflects increasing temperatures at the beginning of the Bølling–Allerød interstadial (14,700–14,600 cal. BP; Ammann et al., 2000; Lowe et al., 2001; Heiri and Millet, 2005). Not far away (ca. 100 km) across the Po Plain, chironomid-inferred temperature reconstructions (Heiri et al., 2005; Larocque and Finsinger, 2008) suggest an abrupt temperature increase between 15,000 and 14,600 cal. BP. The warming at the onset of the Bølling triggered the development of dense pine birch forests with admixed thermophilous trees at low elevations, whereas pine-dominated woodlands expanded in the tundra and Alpine meadows above 1000 m a.s.l. forming a new treeline at about 1800 m a.s.l. (Wick, 1996; Tinner et al., 1999; Hofstetter et al., 2006; Finsinger et al., 2006; Vescovi et al., 2007). For this period non-pollen evidence of climatic change is not jet available for the Northern Apennines.

A transient but pronounced expansion of thermophilous or mesophilous trees such as *Quercus*, *Ulmus*, *Tilia* and *Abies* occurs ca. 13,000 cal. BP at Pavullo nel Frignano. This vegetational pattern is very similar to that recorded in the pollen records of the southern Alpine forelands (across the Po Plain) at 13,000 cal. BP (Lago di Avigliana, Annone, Origlio, Balladrum; Wick, 1996; Tinner et al., 1999; Hofstetter et al., 2006; Finsinger et al., 2006). In general, the expansion of thermophilous taxa was connected with a temporary decline of *Pinus* at 13,100–12,800 cal. BP, before the onset of the Younger Dryas (Vescovi et al., 2007). Palaeoclimatic series from Central Europe and the Alps suggest strong climatic fluctuations during this period (von Grafenstein et al., 1999; Ammann et al., 2000; Heiri and Millet, 2005; Heiri et al., 2005; Larocque and Finsinger, 2008). These records point to a pronounced cooling event in the Alps at around 13,100–12,900 cal. BP (the Gerzensee Oscillation; Eicher, 1987) that was followed by a pronounced warming between at ca. 12,900 and 12,600 cal. BP, before the onset of the Younger Dryas cooling (12,600–12,500 cal. BP; Ammann et al., 2000). We speculate that temperature increase after ca. 13,000 cal. BP may have triggered the transient expansion of thermophilous trees (e.g. *Quercus*, *Ulmus*, *Tilia*, and partly also *Abies*) in the lowlands south and north of the Po Plain, a development that was abruptly interrupted by the reversal of the Younger Dryas.

Several sequences in the Northern Apennines recorded a vegetation response to the Younger Dryas cooling (Bertoldi, 1980; Lowe, 1992; Ponel and Lowe, 1992; Lowe and Watson, 1993; Branch, 2004; Bertoldi et al., 2007; Vescovi, 2007; Cruise et al., 2009). However, some difficulties such as insufficient chronological precision and/or temporal resolution affect these sequences. As a consequence it is rather difficult to unambiguously identify the limits of the Younger Dryas cooling. For instance the important Prato Spilla sequence is possibly affected by reservoir effects or hiatuses (Lowe et al., 1994a; Ravazzi, 2002; Vescovi, 2007). Nevertheless, together these records suggest an opening of forests, a reduction of thermophilous trees (e.g. *Quercus*, *Tilia*, *Ulmus*) and a minor increase of steppic plants such as *Artemisia* (Prato Spilla C and D, Lagdei, Lago di Bargone; Bertoldi, 1980; Lowe, 1992; Lowe and Watson, 1993; Bertoldi et al., 2007; Cruise et al., 2009). Moreover, these vegetational responses to the Younger Dryas cooling are in perfect agreement with similar changes in the nearby Southern Alps (Wick, 1996; Tinner et al., 1999; Finsinger et al., 2006; Vescovi et al., 2007). Furthermore the contraction of forest cover and the re-expansion of steppe vegetation (e.g. *Artemisia*, Chenopodiaceae) in the Northern Apennines at low (Pavullo nel Frignano, Bargone, Rovegno) and at high elevations (Lagdei, Prato Spilla; Lowe, 1992; Lowe and Watson, 1993; Ponel and Lowe, 1992; Bertoldi et al., 2007) are consistent with Central European vegetational dynamics (e.g. Gerzensee, Soppensee; Lotter et al., 1992; Lotter, 1999). However, in Central Europe, thermophilous trees such as oak and elm expanded only after the onset of the Holocene.

5.1.2. Holocene

At the onset of the Holocene (ca. 11,600 cal. BP), oxygen isotope-inferred temperatures in Europe increased by ca. 3–4 °C in a few decades (Ammann et al., 2000; Schwander et al., 2000; von Grafenstein et al., 2000). In the Northern Apennines, abrupt climatic warming led to the re-expansion of thermophilous trees such a *Quercus, Ulmus, Tilia* and shrubs (e.g. *Corylus*), which was followed by the expansion (Lago del Greppo) or the re-expansion of *Abies* (Pavullo, Prato Spilla). During the early and mid-Holocene, between ca. 11,000 and 5500 cal. BP, forests were very dense in the Northern Apennines. Pollen records from the region suggest that the vegetation was dominated by *Abies alba* and trees and shrubs of the mixed deciduous forest such a *Quercus*, *Acer*, *Tilia*, *Ulmus, Corylus* and *Fraxinus*. *Abies* remained the dominant species in the forests of the Northern Apennines, for probably more than 5000 years (e.g. Prato Spilla, Lago Pratignano, Lago Padule, Rovegno, Bargone; Lowe, 1992; Watson, 1996; Branch, 2004, Cruise et al., 2009). Our new record unambiguously shows that *A. alba* was able to dominate even in the colline belts, where it is absent today. This is again a striking analogy with the Insubrian Southern Alps across the (continental) Po Plain, where lowland forests were also dominated by *Abies* ca. 9000 to 5000 cal. BP. This close link might be explainable by similar climatic conditions. Today the lowlands of both regions reach July means of 22 °C and January means of 2 °C and annual precipitation of 1000–1800 mm.

During the mid-Holocene, between ca. 6500 cal. BP and ca. 3000 cal. BP, *Abies* declined at most sites in the Northern Apennines. At low altitudes in the colline vegetation belt the *Abies* decline was followed or accompanied by the expansion of *Quercus* (Pavullo, Bargone and Rovegno; Cruise, 1990a; Branch, 2004; Cruise et al., 2009), whereas *Fagus* expanded in the mountain belt above ca. 900 m of elevation (e.g. Lago del Greppo, Prato Spilla A, Lago Padule; Lowe, 1992; Lowe and Watson, 1993; Watson, 1996; Vescovi, 2007). Even considering differences caused by imprecise chronologies (e.g. bulk radiocarbon datings), these vegetational changes were probably not synchronous in the region and the cause for the *Abies* decline and for the population expansions of *Quercus* and *Fagus* at different altitudes is not yet well-understood.

Different hypotheses have been put forward to explain the decline and the expansion of these taxa, including climatic changes, human impact, a combination of both or other factors (i.e. bedrock and soil factors; Cruise, 1990a; Lowe et al., 1994a,b; Watson, 1996). During the early Holocene peat or lake sediment accumulation ceased at most sites in the Northern Apennines (e.g. Lago Nero, Agoraie, Casanova, Lago delle Lame, Ospitale; Cruise, 1990a,b; Watson et al., 1994; Watson, 1996). Cruise (1990a) suggested that a mid-Holocene (ca. 8500–5000 cal. BP) climatic change towards cooler and moister conditions was probably responsible for the development of peat deposits in the study area as well as for the changes in forest composition at high altitudes. Watson (1996) supported this hypothesis suggesting that the most significant influence on the vegetation of the region for this period was climatic change. In fact, lake level and precipitation reconstructions from Northern and Central Italy (Giraudi, 2004; Baroni et al., 2006; Magny et al., 2007, 2009) point to increased humidity after a dry early Holocene. However, the climatic hypothesis is difficult to evaluate in the absence of local palaeoclimatic proxies. Furthermore, because most palaeo-vegetational series lack the temporal resolution and precision needed for a thorough comparison. Moreover, given the (oceanic to sub-oceanic) environmental preferences of *A. alba* it is very unlikely that the species would have suffered from a climatic change towards

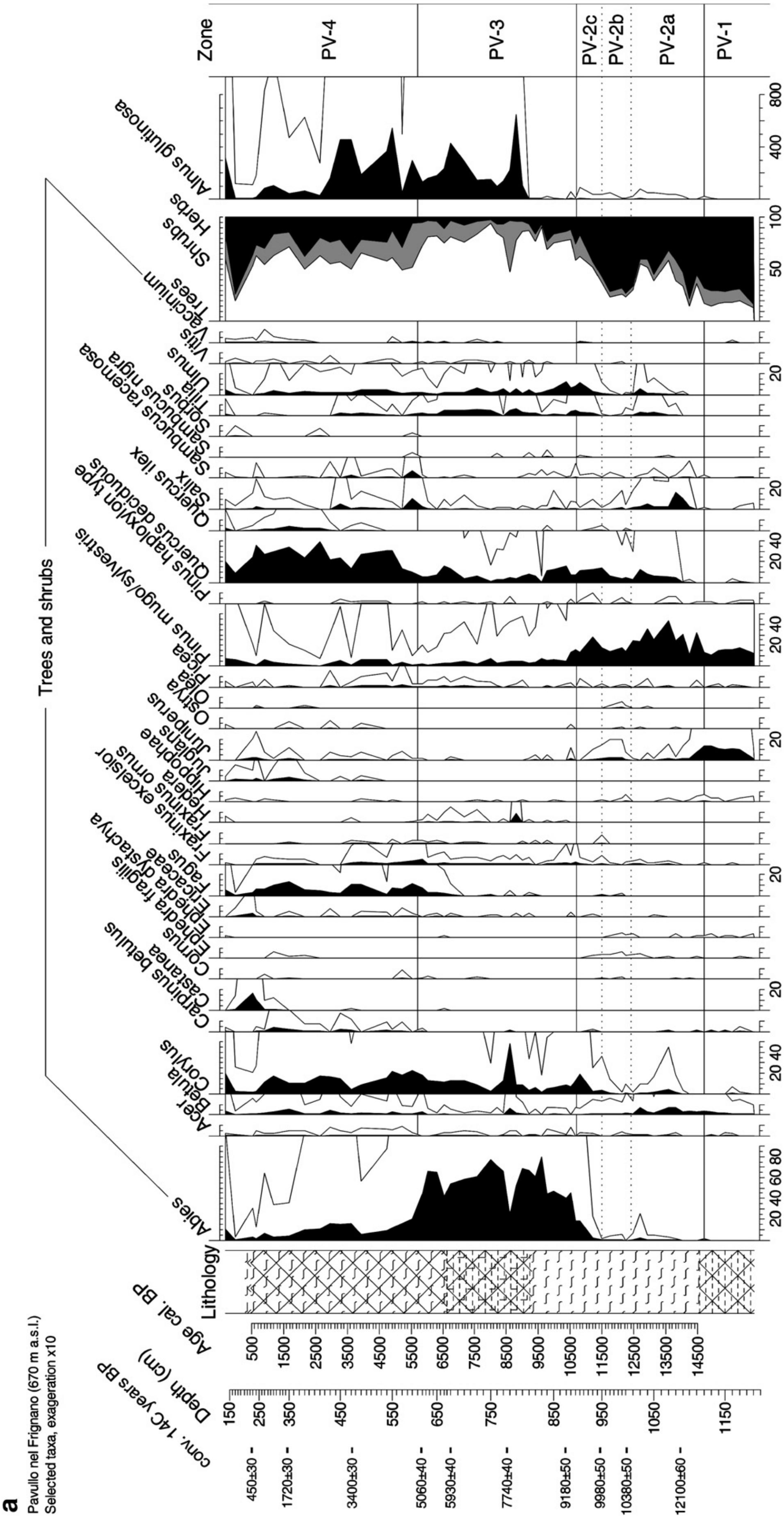

Fig. 4. Percentage pollen diagram of selected pollen taxa (exaggeration ×10) from Pavullo nel Frignano. (a) Trees and shrubs, (b) herbs, wetlands/aquatics and spores/extrafossils.

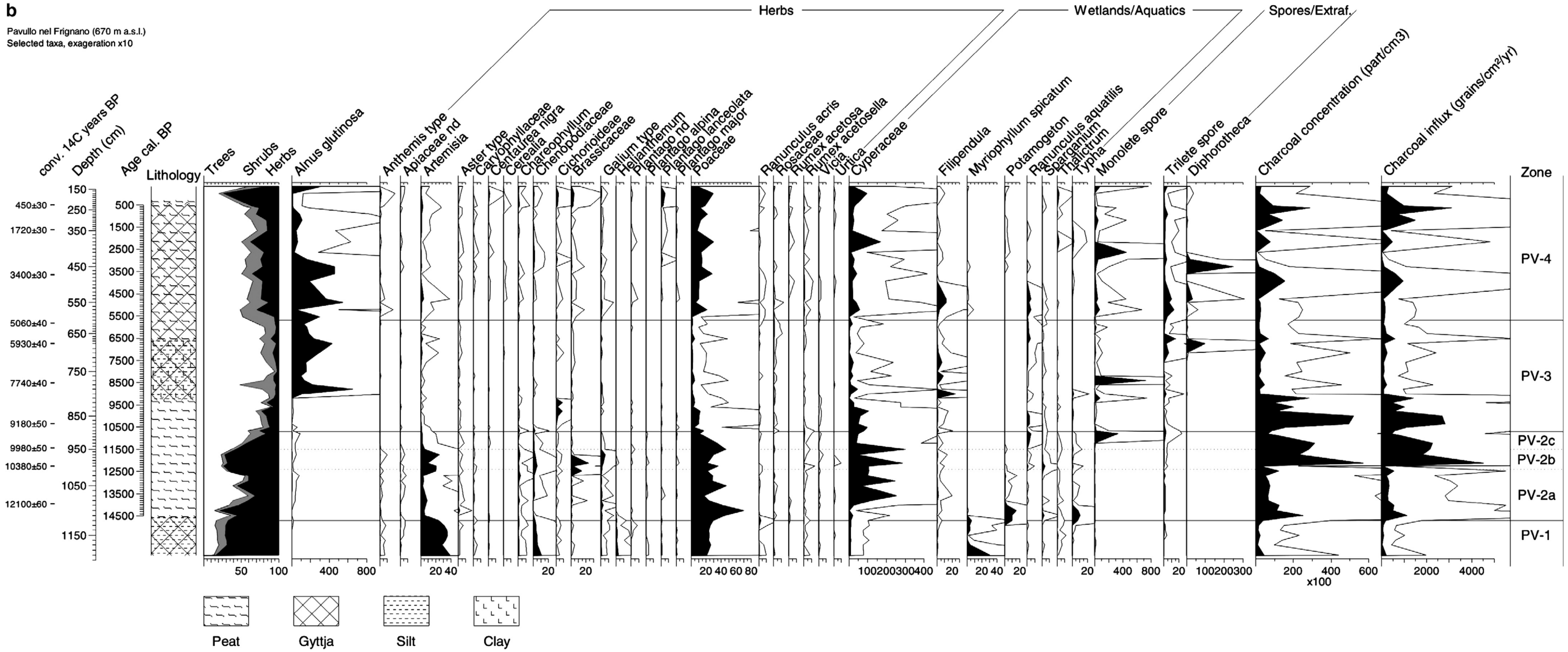

Fig. 4 (*continued*).

more humid or oceanic conditions (Ellenberg, 1988). On the other hand, it is noteworthy that this marked vegetational change occurred during the late Neolithic or Bronze Age, when archaeological findings suggest increased human impact. Macroscopic charcoal evidence from archaeological and camps sites at high altitudes (Castelletti et al., 1976, 1994) show that during Mesolithic time human visited mountain sites, while the region was perhaps less densely inhabited during the Neolithic (7500–5200 cal. BP, Pessina, 2000). Archaeological investigations in the nearby Liguria region however suggest that Neolithic groups probably spread inland from Mediterranean Seacoast settlements as early as 7200 cal. BP clearing forests and cultivating at low- to medium altitudes (e.g., <1000 m a.s.l.) in the Apennines (Maggi, 1984, 1990; Lowe et al., 1994a,b). Archaeological excavations also provide evidence of increased human activity during the Copper (ca. 4950–4250 cal. BP) and Bronze Age (ca. 4250–2800 cal. BP) at 400 to 800 m a.s.l. in the Ligurian Apennines (Maggi and Formicola, 1978; Maggi, 1983; Maggi et al., 1985), respectively below and above 500 and 1500 m a.s.l. in the Tuscan Apennines (Castelletti et al., 1994). As a consequence of increased human impact, fire disturbance and soil instability became widespread after the Late Neolithic–early-Copper Age transition in the western part of the region. Similarly, in the Tuscan–Emilian Apennines soil disturbance increased throughout the Copper and Bronze Age (Lowe et al., 1994a, b). In the Ligurian Apennines horizons of macro-charcoal were also found at the base of the Pramollo and Lago Nero pollen sequences and were related to finds of Copper Age flints and evidence of soil disturbances. These archaeological findings are in good agreement with our pollen record which suggests that the *Abies* decline at 5800 cal. BP was associated with a marked opening of the forested environments (AP decreased from ca. 95–98% to ca. 80%). Pollen of herbaceous taxa such as Poaceae, Cichorioideae, Brassicaceae, *Galium* t., and *Rumex acetosella* increased markedly, suggesting the establishment of pastures or meadows. Single finds of Cerealia pollen at ca. 5000 cal. BP may indicate crop plantations. Lowe et al. (1994a,b) identified this phase as a “marker” horizons M2, indicating an episode of significant human interference in the vegetation of the high part of the Apennines. Moreover, the charcoal record of Lago del Greppo (Vescovi, 2007) suggests an increase of fire activity around 6500 cal. BP, probably in connection of human activity. The microscopic charcoal record of Pavullo instead suggests that regional fire activity did not increase significantly during the decline of *Abies*. Scarce findings in this part of the Apennines for the Copper Age compared to the Bronze Age may suggest a seasonal use (gathering of material such as copper, steatite and flint) or the onset of transhumance (plain/Apennine divide; Ferrari et al., 2006). Human impact at medium elevation during the Eneolithic may those results from woodland exploitation for mining and pastoral activity (Ferrari et al., 2006).

Our results match similar evidence for mid-Holocene vegetational change in the Southern Alps. In the southern Alpine forelands, *A. alba* declined abruptly at ca. 5000 cal. BP after having been dominant for millennia. Palaeobotanical sequences and modelling studies suggest that this decline was closely connected to human impact and slash and burn activities (Tinner et al., 1999, 2000; Keller et al., 2002; Wick and Möhl, 2006). Interestingly, as documented for the Northern Apennines, in the Southern Alps and their forelands the collapse of *Abies* gave way to the expansions of *Quercus* (colline belt below 900 m) and *Fagus* (mountain belt above 900 m), leading to today's humanized vegetation types in both regions (Cruise et al., 2009). These two tree species are far more disturbance-tolerant than *A. alba*, which is very fire-sensitive and subject to intensive and selective browsing during the winter season (Tinner et al., 1999).

Human environmental impacts increased steadily during the Middle Bronze Age (3600–3300 cal. BP), when Northern Italy was influenced by different cultures. The colline and montane belts of the Emilia–Romagna region, were settled by two different cultures the Grotta Nuova and the Apennine facies (Cardarelli, 1992). These populations practised pastoralism and breeding, with extensive transhumance (Torelli, 1981). The Po plain, North to the Reno River was instead settled by the Terramare culture (3600–3100 cal. BP; Mercuri et al., 2006; Cremaschi et al., 2006), a more complex society whose subsistence was based on agriculture, pastoralism, handicraft and long-distance trade. Terramare settlements, banked and ditched villages, were generally not larger than 2 ha in area during early phases of Middle Bronze Age and increased in density and dimensions (7–22 ha) in the Recent Bronze Age due to a significant demographic growth (Cremaschi et al., 2006). Palaeobotanical and archaeological investigations provide evidence for intensification of forest clearings around the settlements during this period. This is important because archaeologically the Pavullo area has been assigned to the Grotta Nuova/Apennine facies for the first part and to the Terramare culture for the second part of the Middle Bronze Age (Cardarelli, 1992, 2006). Thus it is likely that the vegetation of our study site was also influenced by increasing anthropogenic activities (Cardarelli, 2006; Cremaschi et al., 2006). This is underscored by the position of Pavullo on an important pathway to the Apennines pass which might have resulted in economic and political power for local societies. In fact, pollen indicative of human activities such as *Plantago lanceolata* increased significantly at around 3500 cal. BP at Pavullo nel Frignano. However, *Quercus*, at low elevations, and *Fagus*, in the upper belt, continued to dominate the forest vegetation in the Northern Apennines (e.g. Cruise, 1990a,b; Lowe, 1992; Vescovi, 2007; Cruise et al., 2009) throughout the late Holocene.

Further opening in the forest occurred during Iron Age (around ca. 2500 cal. BP) when Friniates (a Ligurian Tribe) and Etruscan cohabitated in this region of the Apennines before Roman conquest at ca. 2000 cal. BP (Malnati, 2006). Trees commonly associated with Roman agricultural activities such as *Olea*, *Castanea* and *Juglans* are not common as in other regions (e.g. Southern Alps) in the pollen sequences of the Northern Apennines (Watson 1996). However, the records of Lago del Greppo, Lago Riane, Lago Rotondo, and Lago Lagastro (Branch, 2004; Vescovi, 2007) in the mountain belt as well as Pavullo nel Frignano and Bargone (Cruise et al., 2009) at lower elevations in the colline belt consistently recorded these taxa. Scattered pollen of *Castanea* probably indicates long-distance transport from cultivation in valley bottoms below and also recorded in the pollen sequences of Rovegno, Casanova, Ospitale and Lago Pratignano (Cruise, 1990b; Watson, 1996; Branch, 2004). Recent archaeological evidence supports the concept that rural settlements were scattered along the Apennine chain below ca. 1000 m of elevation during the Roman and early Medieval periods (Lowe et al., 1994b). The Pavullo pollen record is consistent with this concept, but shows that agricultural activities during the Roman and early Middle Ages were not substantially more intense than during the Copper and Bronze Ages. Agricultural intensification is however hinted in the uppermost samples of the Pavullo pollen record suggesting that land use became more relevant during the past 1000 years.

6. Conclusions

The pollen record of Pavullo nel Frignano provides new insights into the Late-Glacial and Holocene vegetation history of the Northern Apennines. Despite ecologically relevant differences between the vegetation belts (e.g. different abundances of species) and local differences within the mountain range (e.g. Ligurian vs. Tuscan–Emilian Apennine), the general patterns of vegetation history are consistent within the entire region. Moreover, our new site suggests that (palaeo-) biogeographically the northern slope of the Northern Apennines belongs to the same domain as the forelands and the foothills of the Insubrian Southern Alps. Common vegetational developments in the two areas persisted since the Late-Glacial. Of particular relevance are the local expansions of *Abies alba* during the Late-Glacial (see also Liepelt et al., 2009), its dominance in the pre-Neolithic forests, and the subsequent expansion of disturbance-tolerant *Quercus* and *Fagus* during the mid and late Holocene in the colline and montane belt, respectively. In agreement with previous studies from the Insubrian Southern Alps (e.g. Tinner et al., 1999, 2000; Gobet et al., 2000; Keller et al., 2002; Tinner and Lotter, 2006) we assume that vegetational shifts towards more disturbance-adapted late-successional trees mainly reflect increased land-use activity. This result is in agreement with recent partly multi-proxy studies from Italy (e.g. Colombaroli et al., 2007, 2008, 2009; Vanniére et al., 2007; Noti et al., 2009; Tinner et al., 2009), suggesting that the main cause of vegetation change during the mid and late Holocene was land use.

Additional high-resolution and precision pollen, macrofossils and charcoal records are needed from the Northern Apennines to refine our knowledge of the regional vegetation and fire history of the area, mainly in regard of some time periods (e.g. Younger Dryas) and of some important taxa (e.g. *Abies*, *Fagus*). Comparison with non-pollen palaeoclimatic series and archaeological evidences from the Apennines are also needed to more thoroughly disentangle the effects of climate and human impact on ecosystems.

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