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A high-resolution Late-Glacial - Holocene pollen diagram from Pian di Gembro (Central Alps, Northern Italy)

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Abstract. The local and regional history of vegetation and climate, from the Late Glacial to the present, is represented in a new, high-resolution pollen diagram from Pian di Gembro (1350 m asl), ten ^{14}C dates providing a reliable time control. An open pioneer vegetation dominated by *Artemisia*, Gramineae, and Chenopodiaceae followed the retreat of the glaciers after the Last Glacial Maximum. Shrub vegetation with *Juniperus*, *Alnus viridis*, and *Salix* expanded soon after. Denser *Betula-Pinus* forests were present in Pian di Gembro around 12,320 B.P. Their extent was greatly reduced by the climatic cooling of the Younger Dryas, when open vegetation spread again. The beginning of the Holocene was marked by a considerable expansion in mixed oak taxa. *Corylus* immigrated to the site at 9,250 B.P. *Picea* and *Abies* expanded at 7,370 B.P., recording an abrupt change in the structure of the vegetational belts. A coeval climatic change is evidenced in the GRIP records and also detectable through oscillations of the timberline. Signs of human impact are present since late Atlantic, becoming more intense around 2,200 B.P. As pasture lands increased, *Abies* and *Fagus* slowly disappeared. The introduction of *Castanea* and *Juglans* is dated to Roman times, and *Secale* to the Middle Ages.

Keywords: N Italy – Late Glacial/Holocene – Immigration – 8,200 cal B.P. event – Human impact

Introduction

Several alpine and pre-alpine glaciers formed numerous lakes and mires in the Italian Central Alps at different altitudes. In the last 20 years various efforts have been made to reconstruct past vegetation and climate by means of multidisciplinary investigations of these lacustrine and peaty sediments (Burga 1987; Wick 1994; Fedele and Wick 1996). Nevertheless the Late Glacial and Holocene history of this area is so complex that only high-resolution analysis can reveal climatic oscillations in an alpine environment. Recent investigations have shown that during the Holocene several climatic phases occurred in the Alps (Orombelli and Pelfini 1985; Orombelli 1996; Orombelli and Mason 1997). Zoller et al. (1966) and Zoller (1967) described climatic and glacial oscillations (named Misox, Piora, Göschenen) in the Gotthard region. Correlations with glacial advances in Austria and North America were also discussed. Patzelt and Bortenschlager (1973) brought further confirmation and improvement to the knowledge of these oscillations. Other climatic phases (Venediger, Frosnitz, Rotmoos, Löbben) were indicated for the Eastern Alps. In the last decades new investigations were made which confirmed the existence and the amplitude of the oscillations previously proposed (Wick and Tinner 1997). Detailed palaeobotanical analysis is thus required to investigate the reactions of vegetation to cold and warm periods.

The aim of this paper is to present a new high-resolution pollen diagram from Pian di Gembro (1350 m asl, Val Camonica, Central Alps), a key site for understanding the past vegetation and climate in Central Northern Italy. The high resolution of this palynological investigation, together with reliable ^{14}C dates, can be used for tracing the history of an area which, for biogeographic reasons, represents a junction point of early tree migration. Furthermore, the climate of this part of the Alps is influenced by the Insubric regime, the sub-Mediterranean regime (typical of the region of Lago di Garda) and the continentality of the valley floor of inner Valtellina. Val Camonica is an important study area where several factors could have influenced the history of the vegetation.

Because of the large data set available, this paper is only a descriptive overview of the local and regional history of vegetation and climate. Specific topics will be discussed in future papers.

A palaeobotanical investigation of 5 localities in Val Camonica was carried out by Gehrig (1997), pollen percentage and influx diagrams, together with several ^{14}C dates providing a detailed picture of the vegetation and climate during the Late Glacial and Holocene.

A previous palynological study of the site investigated here was made by Zoller et al. (University of Basel) between 1973 and 1975, and two detailed pollen profiles provided with ^{14}C dates were presented at the ALPQUA meeting in 1977. Because of the discrepancies between pollen stratigraphy and ^{14}C chronology during the Late Glacial and early Holocene, these were never published in

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a regular journal. The date for the deepest organic material from the cores (13,490 cal B.P.: Zoller et al. 1977) indicates that the Pian di Gembro succession extends from the early Late Glacial through the entire Holocene. It is therefore a useful site for the reconstruction of vegetation history and climate during this time interval. A collaboration between the Universities of Milano and Bern made it possible to again undertake the study of the stratigraphical sequence of Pian di Gembro.

The study area (geographical and geological setting, climate)

The Pian di Gembro peat mire (1350 m asl) is located in the Italian Central Alps (province of Sondrio, Lombardy), a few km north of the Aprica Pass (Fig. 1a,b). It is one of the largest peat mires in Italy: its longest axis is 2.5 km long, while the shortest one is 250-300 m long (Figs. 2, 3, 4). The mire is located in a saddle deeply cut into the bedrock (metamorphic rocks of the Scisti di Edolo Formation) at the watershed of Val Camonica and Valtellina. This depression is filled by glacial, lacustrine, and peaty sediments. Two coalescent debris cones (Fig. 2) divide the peat mire in two sectors. Accumulation of peat has occurred mainly in the western sector, the drainage of which is controlled by the activity of the debris cones. The smaller eastern sector has a small outlet draining towards Valtellina.

The origin of the complex morphology of this area is not yet clear, but it is unlikely that the erosion of the Adda glacier during the Last Glacial Maximum was itself responsible for the excavation of the depression of Pian di Gembro, which already existed. This is revealed by the great depth down to the bedrock in the W part of the mire (more than 35 m: Dal Piaz 1929). Tectonic activity linked to the presence of the Insubric fault probably played an important role in the genesis of the depression of Pian di Gembro.

It has been well known since the 1970s that the Pian di Gembro mire contains one of the more complete stratigraphical successions found in the Italian Central Alps. As revealed by radiocarbon dating it is a natural archive covering at least the last 15,000 years (ETH, Zurich, Zoller et al. 1977).

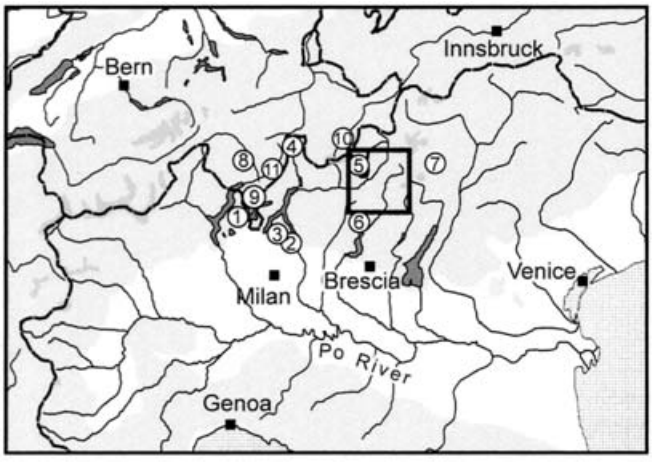
Climate strongly shows the effects of continentality, typical of the valley floor of inner Valtellina. Nevertheless, many local factors (mainly the high daily evapotranspiration and the related humidity) modify the macro- and meso-climate, making these peculiar and difficult to resolve into rigorous patterns.

Present-day vegetation and alterations to the peat mire

A composite mosaic of vegetation characterises the peat mire, showing features that are commonly present in intermediate bogs (*Phragmitetea*, *Utricularietea*, *Scheuchzerio-Caricetea fuscae*, *Oxycocco-Sphagnetea*, *Rhynchosporetum albae*: Andreis and Rodondi, 1982). Mostly during the last century, up to the end of the Second World War, the peat mire of Pian di Gembro suffered from severe environmental alterations caused by intense anthropic pressure. *Sphagnum* and Ericaceae were harvested largely as litter for cowsheds. An area of about 2.5 ha in the western part of the peat mire has been severely damaged by *Sphagnum* and peat exploitation leaving pools 2.5 m deep as traces of past activities. Re-colonizing vegetation communities began to grow after the end of these activities (Andreis et al. 1999). In 1983 Pian di Gembro became a Natural Reserve of Lombardy.

Regional vegetation

Nowadays the slopes surrounding the peat mire are covered by forests dominated by *Picea abies*, *Larix decidua*, and *Pinus sylvestris* (Fig. 5). *Betula alba*, *Populus*



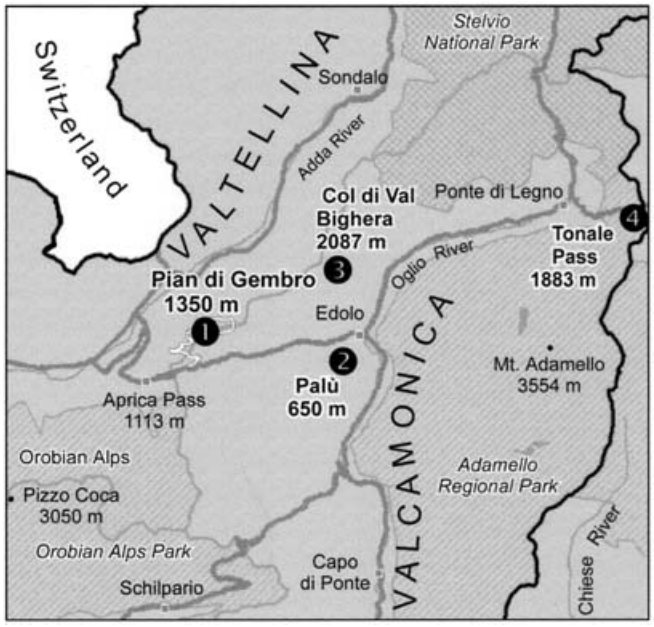


Fig. 1. Map **A** shows Northern Italy, neighbouring countries, and sites mentioned in the text:
1 - Lago di Ganna (Schneider and Tobolski 1985); 2 - Lago di Annone (Wick 1996); 3 - Lago del Segrino (Wick 1996); 4 - Pian dei Cavalli (Wick 1994); 5 - Selva (Burga 1987); 6 - Cerete (Orombelli and Ravazzi 1995); 7 - Val di Sole (Speranza et al. 1996); 8 - Bedrina (Zoller 1960); 9 - Gola di Lago (Zoller 1960); 10 - Chanoua (Zoller et al. 1996); 11 - Pian di Signano (Zoller 1960)
Map **B** illustrates the study region and locations of sites mentioned in the text: 1 - Pian di Gembro (this paper); 2 - Palù di Edolo ; 3 - Col di Val Bighera; 4 - Passo del Tonale (2 - 4, Gehrig 1997)

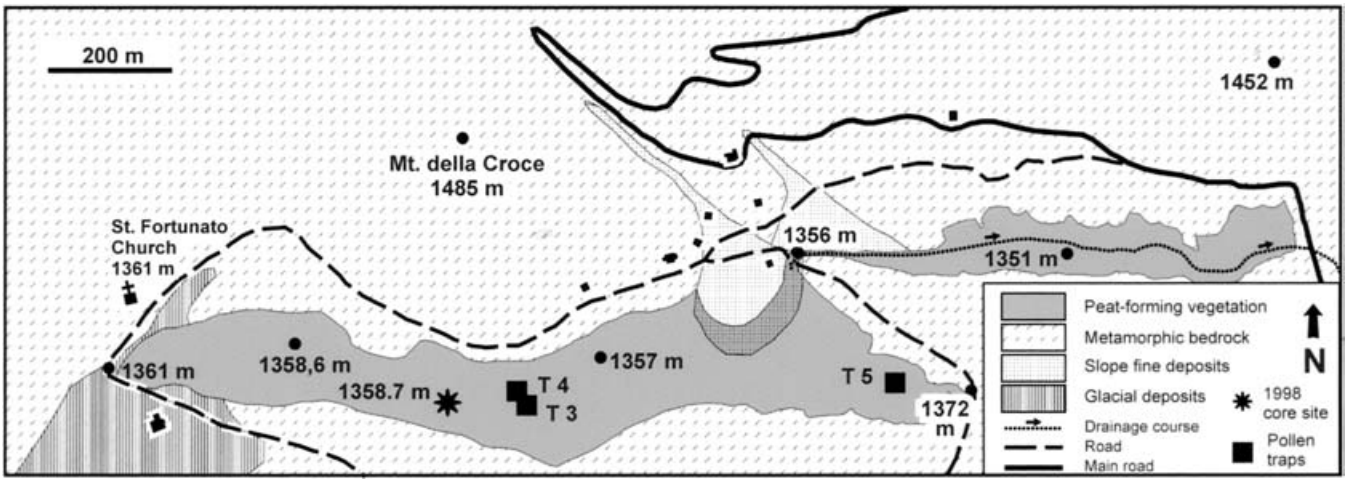


Fig. 2. Geological and geomorphological sketch of the peat mire of Pian di Gembro. The 1998 coring site is indicated by an asterisk. Positions of pollen traps are indicated by black squares

tremula, *Juniperus communis*, and *Vaccinium* spp. are present, the latter often dominating the understorey. *Quercus petraea* and *Corylus avellana* occur sporadically.

The main features of the vegetation of the nearby valleys (Val Camonica and Valtellina) are described here, based on existing literature (Valtellina: Credaro and Pirola 1975) and on original observations (Val Camonica: Ravazzi and Pini, June 2002, see Fig. 5). Later in this paper the modern vegetation will be compared with new data on modern pollen rain from pollen traps placed in Pian di Gembro. This comparison may help to interpret the vegetational history of the study area.

The vegetation of the valley floor of Val Camonica is dominated by *Fraxinus excelsior* and sporadic *Alnus incana*. On south-facing slopes below 1000 m asl, *Quercus petraea* is abundant, together with *Fraxinus excelsior, Corylus avellana*, *Populus tremula*, *Larix decidua* and *Prunus avium*. Conifer forests, dominated by *Larix decidua* and *Picea abies*, are present on north-facing slopes. Moving towards higher altitudes, *Fraxinus excelsior* decreases, being limited to moister sites together with *Salix capraea*, *Alnus incana*, *Sambucus nigra* and sporadic *Acer pseudoplatanus*, *Sorbus aucuparia* and *Tilia* spp. *Quercus petraea* is the dominant tree up to 1300 m asl, accompanied by *Betula alba*, *Populus tremula*, *Corylus avellana*, *Pinus sylvestris*, *Frangula alnus* and *Rhamnus saxatilis*. *Pteridium aquilinum* is very abundant. At about 1300 m asl mixed forests dominated by conifers (mostly *Larix decidua* and *Picea abies*) take the place of the *Quercus* forests. At higher altitudes, between 1600-1900 m asl, large areas are alpine pasture land. *Larix* parklands occur on low-energy slopes, with sporadic *Picea abies* and *Pinus sylvestris*. *Alnus viridis* dominates the vegetation above 1900 m asl.

Credaro and Pirola (1975) have described the vegetation of Valtellina. The natural vegetation of the submontane belt has been largely modified by anthropic pressure. Forests of *Fraxinus ornus* and *Ostrya carpinifolia*, showing affinities with some Mediterranean mixed-oak forests, can be regarded as traces of the 'climax vegetation'. The lower montane belt is made up of mixed-oak forests with *Fagus sylvatica*, *Fraxinus excelsior*, *Tilia cordata*, *Quercus petraea*, *Quercus pubescens*, etc. *Picea abies* is widely distributed in the upper montane belt and in the lower subalpine belt, *Pinus cembra* and *Larix decidua* being present in the latter. *Pinus cembra*, *Pinus mugo*, and *Larix decidua* characterise the upper subalpine belt. Finally, the alpine belt is dominated by pasture lands and shrubs.

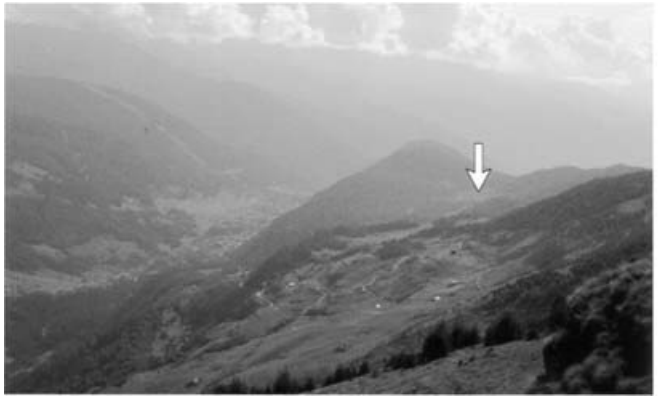


Fig. 3. View of the peat mire of Pian di Gembro as seen from Mt. Padrio

Fig. 4. The peat mire of Pian di Gembro and the Adamello Massif

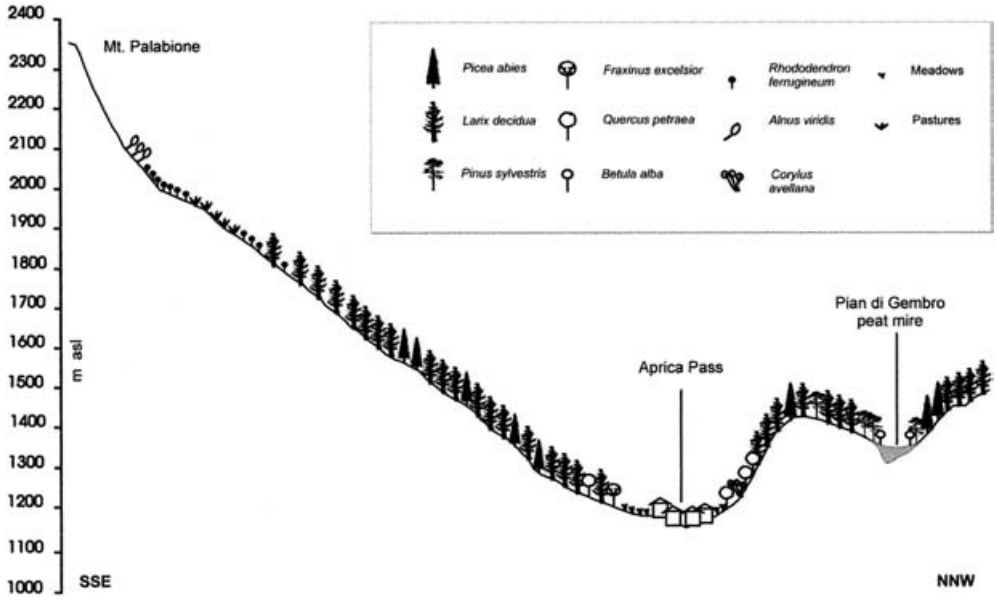


Fig. 5. Scheme of the present-day vegetation along a NNW-SSE transect through Val Camonica. The vertical scale is exaggerated x2

The use of pollen traps to monitor modern pollen rain

Seven pollen traps were placed in different sectors of the peat mire of Pian di Gembro to evaluate modern pollen deposition. Only three of them recorded the pollen rain over two years (1996-1998) and data from selected taxa are summarised here (Table 1; Pini and Mangili 1998; Pini and Mangili, unpubl.). Nevertheless, these data can be used as a tool to understand and interpret the picture of vegetation revealed by the pollen diagram.

Table 1. Pollen pecentage data from selected taxa found in the pollen traps at Pian di Gembro

	Trap nr. 3		Trap nr. 4		Trap nr. 5	
Taxa	96-97 p %	97-98 p %	96-97 p %	97-98 p %	96-97 p %	97-98 p %
P. sylvestris/mugo	33.3	13.3	15.2	6.3	16.3	17.0
Picea	8.6	0.5	1.6	0.4	2.1	0.3
Larix	1.6	0.5	0.2	1.1	0.3	0.1
Acer	-	-	-	0.1	-	0.1
Alnus glutinosa t.	6.6	11.7	7.4	6.5	4.6	1.8
Betula	13.6	16.6	15.4	13	7.6	2.4
Carpinus betulus	0.9	0.1	1.0	0.6	0.5	-
Castanea	3.6	8.6	4.9	7.2	6.1	3.6
Corylus	1.0	4.6	0.5	4.0	0.2	0.1
Fagus	0.3	0.1	0.1	0.1	0.3	-
Fraxinus excelsior	3.6	5.6	1.1	5.3	1.2	0.3
Hedera	-	0.1	-	-	-	-
Juglans	0.9	0.3	0.3	1.0	0.1	-
Ostrya	1.9	8.5	0.4	7.9	0.2	0.7
Quercus	2.3	1.9	2.2	1.0	1.6	0.2
Tilia	0.3	0.1	-	-	0.1	0.1
Ulmus	0.3	0.1	0.3	0.1	0.3	0.1
Vitis	-	0.1	-	-	-	-
Arboreal pollen	76.9	75.8	46.8	60.9	43.5	27.2
Non-arboreal pollen	23.1	24.2	53.2	39.1	56.5	72.8

Pollen trap no. 3 was placed in the northern sector of the peat mire, 70 m inside its border. The surrounding vegetation is dominated by *Sphagnum* spp., *Rhynchospora alba* and *Lycopodiella inundata*. Pollen trap no. 4 was placed in the northern sector of the mire, surrounded on three sides by *Phragmites*-dominated vegetation. *Sphagnum* spp., *Calluna vulgaris*, *Andromeda polifolia*, *Molinia* spp. and *Carex* spp., etc. are present. Pollen trap no. 5 was placed in the SE sector of the mire, where the vegetation is dominated by *Trichophorum caespitosum*, and *Molinia coerulea*. Dense forests containing *Picea abies*, *Larix decidua*, *Pinus sylvestris* and *Betula alba* grow in the vicinity of the site. For the location of the pollen traps see Fig. 2.

The comparison of present-day vegetation and pollen found in the pollen traps reveals that, among the trees growing around the peat mire, *Larix* and *Picea* are underrepresented. On the other hand, the pollen rain from *Pinus sylvestris*, *Betula* and *Alnus glutinosa* t. reflects the presence of these taxa in the vegetation quite well. Pollen from mixed oak taxa (especially deciduous *Quercus*), which are very abundant up to 1300 m asl, is scarce in the pollen traps. The abundance of these trees in the vegetation is not reflected by their image in the pollen rain. The case of *Castanea* is notable. The nearest trees grow up to 900 m asl on the Val Camonica side, 450 m below Pian di Gembro. *Castanea* is well represented in the modern pollen rain at Pian di Gembro (mean value > 5.6 %), more than the other abundant pollen producers (*Quercus* and *Corylus*) growing at shorter distance from Pian di Gembro.

Material and Methods

In September 1998 three cores were drilled in the SW part of Pian di Gembro using a Streif Livingstone piston corer. The main core, which was used for pollen analysis and ^{14}C dating, was 9.5 m long. Coring operations were performed in an area that had never been affected by peat exploitation, so a complete stratigraphy was obtained (Table 2).

Table 2. Lithostratigraphy of core PGB1, taken at Pian di Gembro

Depth (cm)	Sediment description
0 – 4	*Sphagnum* peat
4 – 200	brown peat, from medium to high degree of decomposition, rich in Cyperaceae macroremains. Conifer needles and wood fragments are rare.
200 – 343	brown peat with very few macroremains
343 – 440	brown peat with abundant macroremains (Cyperaceae rootlets and stems, conifer needles, *Equisetum* plants, seeds, etc.)
440 – 450	wood layer, with sparse matrix
450 – 570	brown peat, extremely rich in macroremains (mainly Cyperaceae)
570 – 805,5	soft but compact gyttja, which becomes lighter in colour with greater depth, poor in macroremains. Sharp lower limit.
805,5 – 830	light brown silt-gyttja. Sharp lower limit.
830 – 850	grey clay, without macroremains
850 – 855	coarse sand
855 – 950	grey clay, without macroremains

Preparation of samples for pollen analysis followed standard methodology (including HF and acetolysis). 283 samples were analysed, a sum of at least 1,000 pollen grains (with a few exceptions for pollen-poor Late Glacial clay) being counted. *Lycopodium* tablets (Stockmarr 1971) were added to the sediment samples for estimation of pollen concentration (grains/cm^3). Identifications were made with reference to Moore et al. (1991), Punt and Blackmore (1976-1995), Reille (1992-1995) and the reference collection of the Institute of Plant Sciences of Bern. Nomenclature of pollen types follows ALPADABA (Alpine Palynological Database) and the spelling of plant names is according to Pignatti (1982). Identification of fossil stomata follows Trautmann (1953). Determination of species of *Pediastrum* is according to Komárek and Fott (1983).

Pollen diagrams (Fig. 7 and 8) were drawn using the program TILIA 1.11 (Grimm 1992). Pollen percentages are based on a pollen sum which includes trees, shrubs and upland herbs (Cyperaceae, aquatics and spores are excluded). The diagrams were then divided in LPAZ (local pollen assemblage zones).

Holocene chronozones follow Welten (1982), valid for the Alps and based on Mangerud et al. (1974). The Late Glacial is subdivided in Late Glacial Interstadial (LGI) and Younger Dryas. The interval preceding the LGI is, however, unnamed.

Radiocarbon dating

AMS ^{14}C dates on terrestrial plant remains were determined at the R.J. Van de Graaff Laboratorium (Faculteit Natuur- en Sterrenkunde, University of Utrecht, The Netherlands). The results, calibrated with the program CALIB 4.3 (Stuiver et al. 1998) are summarised in Table 3 and plotted in Figs. 7 and 8.

The age-depth curve can be roughly divided into three parts. The interval 801-701 cm covers about 3,600 years, during which the sedimentation rate was rather low (average of 0.28 mm/year). The interval 701-161 cm covers about 6,900 years; the sedimentation rate is higher than before (average of 0.87 mm/year) and apparently does not seem to have been influenced by the change of sediment type from gyttja to peat that occurred at 570 cm depth. A lower sedimentation rate (average of 0.55 mm/year) characterises the last 2 millennia. Unfortunately no ^{14}C dates are available for the interval between 945-801 cm, but the low pollen concentration values recorded here point to a rather high sedimentation rate.

Results and discussion: vegetational development and climate history at Pian di Gembro

The data are presented in Fig. 7 and are interpreted and compared with neighbouring sites in the following sections which correspond to the pollen assemblage zones in the diagram.

LPAZ PGB-1 (up to 895 cm)

After the retreat of the LGM glaciers, during the Alpine deglaciation, a pioneer vegetation typical of a cold and steppic environment started to spread on the raw soils of Pian di Gembro. Herbaceous, anemophilous taxa (*Artemisia*, Chenopodiaceae, Gramineae, Asteroideae, and

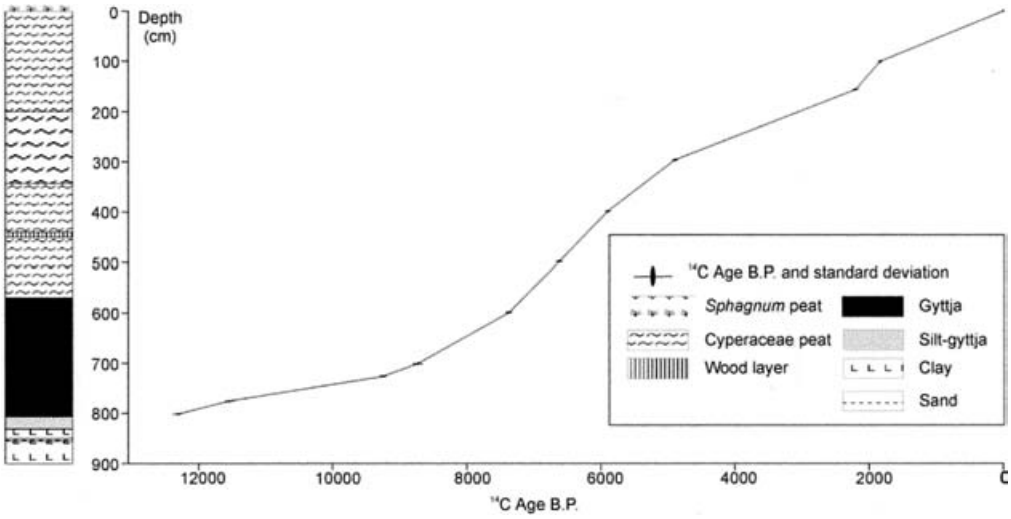


Fig. 6. Lithostratigraphic log of the core PGB1 taken at Pian di Gembro and age-depth model

Table 3. AMS dates from Pian di Gembro

Lab nr	Depth (cm)	Analysed fraction	δ ^{13}C ‰	^{14}C yrs B.P.	Calendar Age (1σ range)
UtC-9084	101-103	4 leaves of *Andromeda*	-26.9	1,835 ± 35	1,821-1,712
UtC-9083	157-161	wood of Ericaceae	-26.7	2,200 ± 45	2,309-2,221; 2,210-2,148; 2,135-2,132
UtC-9082	297-303	needles of *Picea*	-26.7	4,895 ± 40	5,654-5,594
UtC-9081	399-401	needles of *Picea*	-28.0	5,901 ± 45	6,780-6,772; 6,755-6,666
UtC-9080	497-499	needles of *Picea*	-28.9	6,620 ± 50	7,568-7,524; 7,513-7,457; 7,451-7,432
UtC-9079	599-601	2 fruits of *Tilia platyphyllos*	-27.9	7,371 ± 50	8,274-8,274; 8,192-8,159; 8,136-8,132; 8,119-8,112; 8,079-8,059
UtC-9078	701-703	twig of *Betula*	-29.8	8,730 ± 70	9,889-9,878; 9,869-9,845; 9,835-9,830; 9,824-9,805; 9,799-9,554
UtC-9077	726	1 fruit of *Tilia platyphyllos*	-25.9	9,250 ± 50	10,500-10,435; 10,433-10,360; 10,344-10,328; 10,320-10,306; 10,306-10,285
UtC-9076	775-781	fragments of bark and 1 seed of *Pinus*	-26.1	11,540 ± 60	13,793-13,666; 13,507-13,425
UtC-9075	801-803	twig of *Betula*	-28.8	12,320 ± 60	15,301-14,646; 14,367-14,136

Cichorioideae, etc.) were present, together with a few shrubs (*Ephedra distachya* and *E. fragilis* type). *Galium*, *Armeria*, and *Caltha* were also present. A few pollen grains of *Picea* in the deepest part of the profile can be attributed to long-distance transport (Ravazzi 2002). The absence of conifer stomata and very low pollen concentration values of *Pinus sylvestris/mugo* and *Pinus cembra* suggest that transport from the pre-alpine valleys below is probably responsible for the presence of pine pollen in Pian di Gembro: at that time the timberline was still lower than 1350 m asl.

LPAZ PGB-2 (895-838 cm)

Pioneer herbaceous taxa still dominated the vegetation (e.g. *Helianthemum*, *Saxifraga oppositifolia* type, *Plantago alpina*, and *P. lanceolata* type). In addition, other taxa appeared in the pollen flora: *Rumex acetosa* type, Brassicaceae, Labiatae, Apiaceae (*Anthriscus sylvestris* type, *Peucedanum palustre* type, *Carum carvi* type). This higher biodiversity may indicate soil development (enrichment in organic matter) and possibly early climatic warming. *Juniperus* appeared in the vegetation. At lower altitudes reforestation started around 13,000 B.P., when *Betula* and *Larix* immigrated and spread (Gehrig 1997).

Percentages of birch pollen are quite low (0-3.3%). *Betula* is well represented in the modern pollen rain at Pian di Gembro (between 7.6 and 16.6%, only one sample records *Betula* pollen as low as 2.4%: Table 1). According to these values, the local presence of *Betula* during this pollen zone is excluded.

The alpine belt, dominated by grasslands, extended above 1600 m (Gehrig 1997).

LPAZ PGB-3a (838-800 cm)

Several species of algae were present in the lake of Pian di Gembro (*Pediastrum boryanum* ssp. *longicorne*, *Pediastrum integrum*, rarely *Pediastrum orientale*, and *Botryococcus pila*): they suggest that the lake water was cold, clean, and oligotrophic/distrophic. *Isoetes lacustris* started. Among the aquatic and wetland species *Thalictrum, Typha latifolia, Myriophyllum alterniflorum*, *Potamogeton*, and *Nymphaea* were present.

The comparison of percentage values of *Betula* in the pollen diagram (2.4-27%) with those in the modern pollen rain at Pian di Gembro (mean value = 11.4%) indicates that birch had reached the plain of Pian di Gembro, developing a shrub vegetation together with *Hippophae* and *Salix*. The occurrence of *Betula* near the basin is also demonstrated by a fragment of twig found between 801-803 cm and dated to 12,320±60 B.P.

The rise of NAP values during this pollen zone may indicate the development of species-rich meadows. The percentage rise is mainly due to *Artemisia* (which reaches 40%) and to a lesser extent to Gramineae, Asteroideae (*Aster* type, *Centaurea scabiosa*, *Cirsium*) and Cichorioideae. The phase recorded between 830-804 cm at Pian di Gembro could have been induced by a climatic change that favoured the expansion of herbaceous vegetation. This phase predates the Bighera oscillation, defined by Gehrig (1997) as a recession of *Pinus* values, rise of NAP pollen, and increase of minerogenic components in the sediment. The Bighera oscillation is not clearly recognizable in the pollen diagram from Pian di Gembro. The climatic phase recorded at Pian di Gembro could be correlated with the moderate expansion of *Pinus cembra* and *Betula* recorded before 12,340 B.P. at Lago di Annone (226 m asl, N Italy), just before the strong expansion of pine documenting the beginning of the Late Glacial interstadial including the Bølling and Allerød (Wick 1996).

Alnus viridis spread earlier in Val Camonica than in localities situated north of the Alps (for instance in Engadine and in the Grisons), suggesting the occurrence of green alder south of the Alps during the Alpine deglaciation. In pollen diagrams from Engadine and

Fig. 7. Percentage pollen diagram of selected taxa from Pian di Gembro. Pollen percentages are based on a pollen sum which includes trees, shrubs and upland herbs (Cyperaceae, aquatics and spores are excluded). Pollen influx, pollen concentration, and charcoal concentration curves are also plotted. Unless otherwise stated, curves are exaggerated x5: exaggeration is indicated by stippling. Curves of *Pediastrum*, *Isoetes*, *Sphagnum*, *Tilletia sphagni*, and *Amphitrema* are exaggerated x3

Pian di Gembro (1350 m asl). % pollen diagram, selected curves

Grisons (Burga 1980, Burga 1987; Zoller et al. 1996), *Alnus viridis* is recorded only from the Atlantic onwards with the continental climate of central alpine valleys playing an important role in controlling its spread. However, *Alnus viridis* never reached high percentage values in Pian di Gembro (< 5%), probably due to the relatively low elevation of this site, while on the contrary, at Col di Val Bighera (2087 m asl; Gehrig 1997) it reached values of 10-20%.

LPAZ PGB-3b (800-790 cm, 12,300-12,000 B.P., beginning of Late Glacial interstadial)

This pollen zone is characterised by the arrival and subsequent mass expansion of *Pinus sylvestris/mugo* and *Pinus cembra,* dated to 12,320±60 B.P., as indicated by the presence of stomata and high percentage and concentration values. *Betula* and *Larix* were also present. Heliophilous taxa (*Artemisia*, Chenopodiaceae, and Ephedraceae), previously abundant, decreased locally and moved to higher altitudes.

At Palu' di Edolo, 700 m below Pian di Gembro and 10 km away, the immigration of *Pinus sylvestris/mugo* and *Pinus cembra* occurred around 13,000 B.P. (Gehrig 1997). The presence of *Pinus sylvestris/mugo*, *Pinus cembra*, and *Larix* was observed for the pre-alpine belt by Orombelli and Ravazzi (1995) and at Cerete Basso (440 m asl, Val Borlezza, prov. of Bergamo) conifer forests were already established at 13,025±150 B.P. A certain delay in the altitudinal expansion of *Larix* is seen in most of the pollen diagrams from the Grisons (Switzerland: Burga 1982), where it appeared at 1900-2000 m asl during the Preboreal.

LPAZ PGB-3c (790-768 cm, 12,000-11,000 B.P., second part of the Late Glacial interstadial)

During this period pine, larch and birch forests were present in Pian di Gembro. The pollen diagram records the presence of pollen of *Quercus* (0.4-2.8%), *Tilia* (0-1%), *Ulmus* (0-1.3%) and *Fraxinus excelsior* (0-0.8%). The comparison of the percentage values of these mesic taxa and the modern pollen rain at Pian di Gembro are compatible with the presence of *Quercus*, *Tilia* and *Ulmus* at lower altitude, in the montane belt. *Fraxinus excelsior* must have been either still very far from Pian di Gembro or represented in the lowlands by few trees.

Heliophilous shrubs (e.g. *Juniperus*, Ephedraceae, and *Hippophae*) quickly decreased. These features point to an improvement of the environmental conditions.

As already stated for *Alnus viridis*, *Pinus cembra* spread later in Engadine than in Val Camonica. In the pollen diagram from Chanoua (1590 m asl; Zoller et al. 1996) the species is recorded from the Allerød onwards. Thus the reimmigration into Engadine from northern Italy, postulated by Zoller et al. (1996), does seem probable.

LPAZ PGB-4 (768-754 cm, 11,000-10,000 B.P., Younger Dryas)

In this zone rapid cooling had strong effects on the vegetation: *Pinus sylvestris/mugo* (but not *Pinus cembra*) quickly decreased, and the steppe vegetation, typical of the Oldest Dryas, spread again. *Artemisia*, Chenopodiaceae, *Helianthemum*, *Saxifraga oppositifolia* type, Brassicaceae and other herbaceous taxa that had moved to higher altitudes during the Allerød, moved downwards again and colonized the open areas. A reduction phase in mixed oak taxa also testifies to the cooling and the dryness of this period. The climatic deterioration of the Younger Dryas is also well represented in the pollen zone DA 3 of the diagram from Selva (Poschiavo, 1440 m asl; Burga 1987), where the strong expansion of steppic elements led to a reduction in former pine stands.

Pollen diagrams from the south pre-alpine border (Lago di Annone and Lago del Segrino, Brianza; Wick 1996) testify to a tripartite structure for the Younger Dryas, probably representing different climatic conditions affecting thermophilous taxa (*Ulmus*, *Tilia*, *Quercus*, etc), which did not have the same significance at the altitude of Pian di Gembro.

In the stratigraphical sequence from Pian di Gembro, the Younger Dryas is represented by only 14 cm (754-768 cm), thus indicating a low sedimentation rate. The thin layer representing the Younger Dryas in Pian di Gembro makes it difficult to investigate in detail whether the above-mentioned tripartite structure is present or not, but it seems rather probable that the division is missing. Low sedimentation rate during the Younger Dryas is common to several pollen records from Northern Italy (Palù di Edolo, Tonale, Col di Val Bighera, Gehrig 1997; Cerete Basso, Orombelli and Ravazzi 1995; Lago di Ganna, Schneider and Tobolski 1985) and is usually related to low precipitation and reduced detrital supply to lacustrine basins.

LPAZ PGB-5a (754-710 cm, 10,000-9,000 B.P., Preboreal)

The Preboreal is marked by a large expansion of mixed oak forest taxa. Forests of *Quercus*, *Tilia* (*T. cordata* and *T. platyphyllos*), *Ulmus* and *Acer* developed at the altitude of Pian di Gembro. This hypothesis is corroborated by the comparison of percentage pollen data from this pollen zone and the modern pollen rain. Pollen of these mesic trees is poorly represented in the pollen traps placed at Pian di Gembro (*Quercus* is between 0-2.3%, *Tilia* 0.1-0.3%, *Ulmus* 0.1-0.3% and *Acer* 0-0.1%), although these species are very abundant in the lower vegetational belts. The higher percentage values recorded in this pollen zone could therefore be compatible with the presence of *Quercus*, *Tilia*, *Ulmus* and *Acer* at the altitude of Pian di Gembro during this period. The occurrence of *Tilia platyphyllos* near the basin is demonstrated by a fruit found at 726 cm depth and dated to 9,250±50 B.P. *Betula*, *Pinus sylvestris/mugo*, *Pinus cembra*, and *Larix* (whose stomata were found in the sediment) were also present in the nearby forests. *Calluna*, *Vaccinium*, and *Lonicera coerulea* were part of the local vegetation; *Juniperus* became more and more discontinously present. Among the herbs, species belonging to *Potentilla* type, *Rumex acetosa* and *R. acetosella* type, *Rhinanthus* type, *Filipendula*, *Phyteuma*, and several of the Apiaceae grew around the lake.

LPAZ PGB-5b (710-602 cm, 9,000-7,400 B.P., Boreal/Atlantic)

Corylus expansion is dated to about 9,250±50 B.P., even though its maximum spread took place later, during the Boreal. *Frangula* and *Sorbus* made up part of the forest composition. The constant presence of *Hedera* points to mild winters. Among the herbaceous taxa, *Rumex acetosa* and *R. acetosella* type, *Vicia* type, *Phyteuma*, and *Rhinanthus* type were still rather abundant. *Potamogeton*, *Sparganium erectum* type, *Nuphar*, and *Nymphaea* grew in the lake of Pian di Gembro. *Pinus sylvestris/mugo* declined, although still present (stomata). *Pinus cembra* had definitively left Pian di Gembro moving to higher altitudes near the timberline as its presence is recorded in the pollen diagram from Col di Val Bighera (Gehrig 1997), where it formed dense forests together with larch and birch. Nowadays *Pinus cembra* is present in restricted areas in Val Camonica and the northern side of the Orobian Alps (Arietti 1978; Armiraglio et al., in prep.) and is more abundant in the nearby Valtellina, where it forms mixed stands with *Picea abies* and *Larix decidua* (Piussi 1992).

LPAZ PGB-6 (602-554 cm, 7,400-7,000 B.P., early Atlantic)

A rapid and simultaneous expansion of *Picea* and *Abies* is dated to 7,371±50 B.P. (8,059-8,274 cal B.P.) around Pian di Gembro, and competition between mixed oak taxa and conifers caused a slight but general decrease of the former. A similar immigration pattern for *Picea* and *Abies* can be recognized in the pollen diagram of Selva (Burga 1987).

The strong resemblance between the curves of *Picea* and *Abies*, their sudden expansion, and the related vegetational changes that occurred in less than 100 years are astonishing. This event, which cannot be considered an artifact of the percentage decrease in other taxa (cf. concentration curve, Fig. 8), involves two species that have different biogeographic histories. At 7,300 B.P./8,200 cal B.P. a sharp and irreversible transition from a dry to a wetter Holocene took place on a global scale (Blunier et al. 1995). Increasing humidity at Pian di Gembro favoured the expansion of *Picea* and *Abies*, which found new areas for colonization, forming a new altitudinal vegetational belt, the montane coniferous forests. *Picea* forests were already established at higher altitudes (Col di Val Bighera, Gehrig 1997) at 8,300 B.P.; from these, *Picea* moved to colonize the areas at the montane altitude of Pian di Gembro.

Abies was already present in the lowland at around 9,000 B.P., being part of the local forests at around 7,600 B.P. (Lago di Annone: Wick 1996). The increasing humidity at 8,200 cal B.P. gave these the chance to expand at middle altitudes, thus reaching Pian di Gembro (1350 m asl, 7,370 B.P.) and Palu' di Edolo (650 m asl, 7,285 B.P.).

LPAZ PGB-7 (554-400 cm, 7,000-5,900 B.P., middle Atlantic)

During early Atlantic, the development of the lake of Pian di Gembro into a peat mire took place. The change from fine detritus gyttja to peat, the decrease in pollen from aquatic taxa (*Myriophyllum alterniflorum*, *Nuphar*, *Nymphaea*) and the increase in pollen of mire species (*Menyanthes*, *Drosera intermedia*) suggest the transition from a limnic to a telmatic environment. The rise in the curve of *Potentilla* type (probably *P. erecta* or *P. palustris*) indicates the local development of fen peat. Nowadays *Potentilla erecta* and *P. palustris* are largely scattered in the local vegetation at Pian di Gembro, occurring respectively in *Molinia*- and *Trichophorum*-dominated vegetation (*P. erecta*) and *Carex*- and *Sphagnum*-dominated vegetation (*P. palustris*). An important change in the algal assemblage indicates this transition: different species of *Pediastrum* and *Botryococcus* (*Pediastrum angulosum* var. *angulosum* and *Botryococcus neglectus*) replaced the previous ones, indicating mesotrophic waters and a change to mire conditions. The first important peaks in *Sphagnum* and *Tilletia sphagni* occurred at around 6,620±50 B.P. Gramineae and Cyperaceae quickly colonized the borders of the peat fen.

During middle Atlantic the slopes surrounding Pian di Gembro were covered by conifer forests, which probably reached to the margins of the peat mire (abundant stomata were found in the sediment). A long phase dominated by *Alnus glutinosa* type started at 6,620±50 B.P., ending at 5,901±45 B.P.; *Betula* expanded, even if not as rapidly as *Alnus*. *Hedera* was often present. *Viscum* pollen is recorded from one sample; this could be an indication of rather warm summers (around 16 - 18 °C) and quite cold winters (no colder than -6°C).

LPAZ PGB-8a (400-307 cm, 5,900-5,000 B.P., later Atlantic)

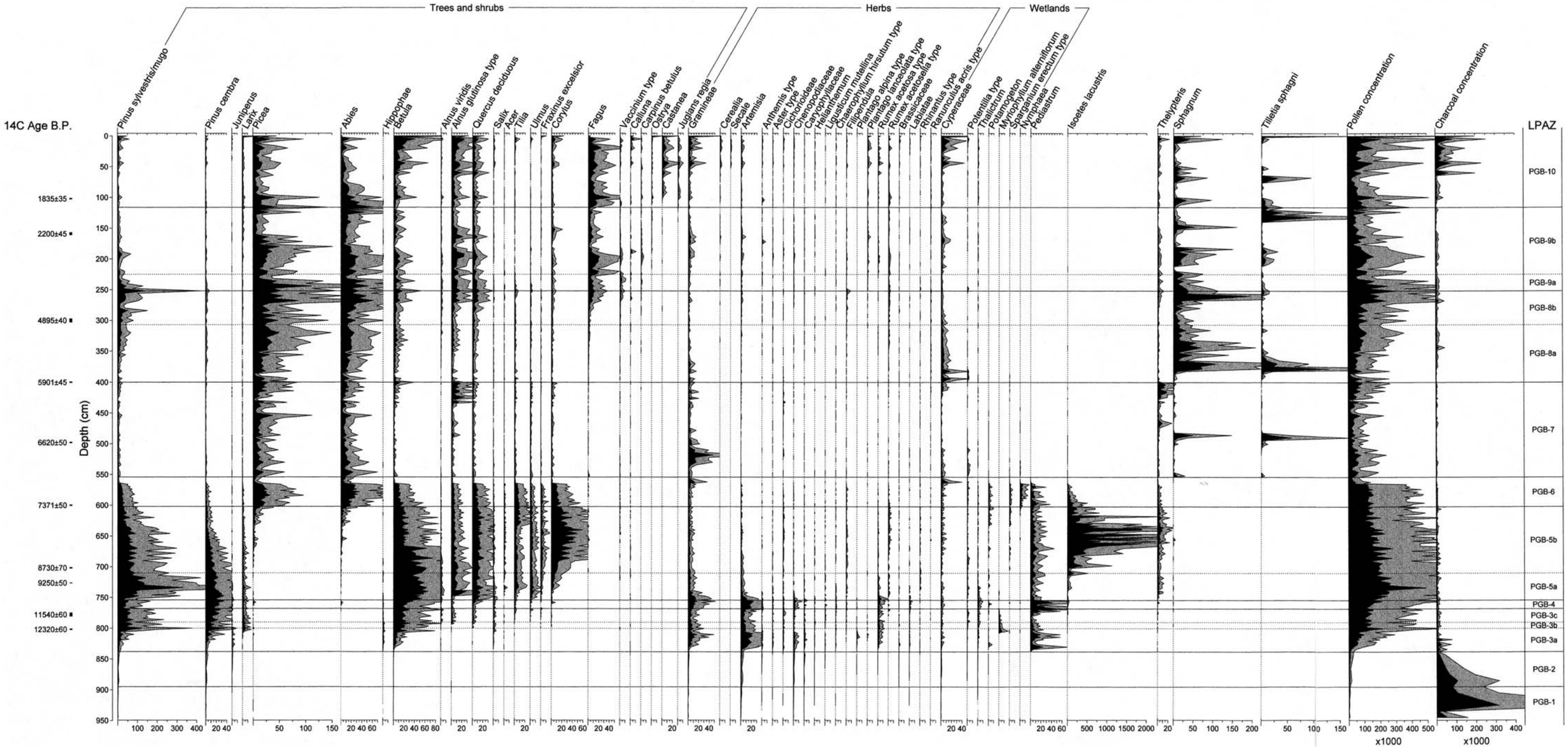
During the middle Neolithic the first signs of human activity had already appeared. The presence of meadows and pastures around the mire of Pian di Gembro is suggested by the percentages curves of *Rumex acetosa* and *R. acetosella* type, and *Ranunculus acris* type. Clear proofs of stable human settlements in the vicinity of Pian di Gembro are missing, but the existence of these, probably not too far from the site, is indicated by findings of Cerealia pollen grains. The nearest coeval populations were the Camuni, several settlements of whom were found along Val Camonica (the name of which is derived from this ancient population). Their rock engravings cover a long period of time, from the Epipalaeolithic to the Roman Conquest (1st cent. AD) (Anati 1975; De Marinis 1989).

LPAZ PGB-8b (307-252 cm, 5,000-4,100 B.P., early Subboreal)

The first occurrence of single pollen grains of *Fagus* in the pollen diagram from Pian di Gembro is dated to approximately 8,500 B.P. The percentage curve is discontinuous for about 2,600 years (705-398 cm), eventually becoming continuous at 398 cm, thus underlining the gradual but progressive approach of *Fagus* to Pian di Gembro. The expansion of *Fagus* in the vicinity of Pian di Gembro is dated to 4,895±40 B.P., and took about 900 years (300-250 cm, 4,895-4,000 B.P.). Beech immigration took place

Fig. 8. Pollen concentration diagram of selected trees, shrubs, herbs, spores, and other microfossil types from Pian di Gembro. Exaggeration x3 is indicated by stippling. A charcoal concentration curve is also plotted

Pian di Gembro (1350 m asl). Pollen concentration, selected curves



extremely slowly, but once established the species was able to thrive for several millennia. Similar results were obtained at Gola di Lago (Zoller and Kleiber 1971).

Fagus-dominated forests were growing in the plain of Pian di Gembro during the Subboreal and included *Sambucus nigra* type and *Sorbus*. Conifer forests (*Picea*, *Abies*, and *Pinus sylvestris/mugo*) covered the slopes at higher altitudes. *Pinus cembra* was absent in the local vegetation, very low pollen percentage values suggesting long-distance transport.

LPAZ PGB-9a (252-225 cm, 4,100-3,700 B.P., later Subboreal)

During the Bronze Age an increase in charcoal particles in the sediment seems to suggest an increase in human activities, with forest clearance starting locally in order to provide new areas for settlements, cultivation, grazing and wood for construction and fuel. *Larix* meadows (a form of grazed forest important in the central and southern Alps) started to spread. It is interesting to compare the relatively late human impact on vegetation, as seen in Pian di Gembro, with earlier anthropic activities. At Chanoua (1590 m asl, lower Engadine; Zoller et al. 1996), the spread of *Larix* meadows is dated to 4,820 B.P., simultaneous with a phase of anthropic cutting of *Picea*. *Larix* suddenly rose, reaching the highest pollen percentage within the whole section. In the following LPAZ, *Picea* quickly recovered, but *Larix* was still well represented (always about 10%).

In Pian di Gembro the opening of the forests due to human activities led to a new expansion of herbs, typical of naturally open areas (*Potentilla* type, *Filipendula*, *Rumex acetosa* and *R. acetosella* type, Brassicaceae, Ranunculaceae, *Rhinanthus* type, etc.). *Thelypteris*, *Polypodium vulgare*, and *Pteridium aquilinum* were constantly present. Although clearly visible, the rise of NAP in Pian di Gembro is not really comparable with those observed in the vicinity of archaeological sites, where NAP can reach 40-50% of the whole pollen assemblage and where charcoal layers are found (e.g. Bedrina Leventina, 1235 m asl, Tessin, Zoller 1960; lower Engadine, Zoller et al. 1996).

LPAZ PGB-9b (225-116 cm, 3,700-1,900 B.P., Subboreal/Subatlantic)

Human impact increased during the Subatlantic. During the Iron Age, the slopes surrounding Pian di Gembro were used as pastures for cattle, as shown by the rise of shrubs and NAP (mainly *Plantago lanceolata* type, *Rumex acetosa* and *R. acetosella* type, *Ranunculus acris* type, *Urtica*, *Cannabis*, *Humulus* – all indicators of cultivation, grazing and ruderal communities). Cereal cultivation developed. Deforestation led to the reduction of arboreal taxa such as *Abies*, *Fagus*, *Ulmus*, *Tilia* and, to a lesser degree, *Acer* and *Fraxinus excelsior*. These events can be easily correlated with the increasing curve of charcoal concentration. The decline in elm, lime, maple, ash, and ivy simultaneously with the evidence of farming activity points to the interference of humans with the vegetation. The wood from these taxa could be used for fuel and construction, and the flowers, leaves, and twigs for fodder (Troels-Smith 1960).

At around 2,200±40 B.P., larch meadows extended in the vicinity of Pian di Gembro, taking the place of the former pine stands; Ephedraceae and *Juniperus* appeared again in the pollen flora. The rising anthropic influence on the natural environment at lower altitudes is recorded by the expansion of taxa that could better withstand it. Thus *Carpinus betulus* showed its maximum abundance in early Subatlantic, and also *Corylus*, even if for a short period, took advantage of this situation. The spread of *Ostrya* was also influenced by human activity. The same pattern is described by Küster (1997) for central Europe.

LPAZ PGB-10 (from 116 cm and 1,900 B.P. up to the present time, Subatlantic)

The introduction of *Castanea* and *Juglans*, dated to 1,835±35 B.P., marked the beginning of the Roman period. The continuous curves of *Larix* and anthropogenic indicators point to intensive grazing. The forests were not yet heavily exploited; only the percentage values of *Abies* decreased sharply, followed by an increase of charcoal particles in the sediments. The question as to whether such southern-alpine *Abies* declines were caused by fire or by other factors (the fires occurring soon after) is currently under study (Mohl and Wick, in prep.; Keller et al., in prep.).

Intensive clearings are documented since the Middle Ages at every altitude, not only for agricultural purposes and fuel. The existence of several iron-smelting sites in Val Camonica and its lateral valleys (Cucini Tizzoni and Tizzoni 1996; Gehrig 1997; Marziani and Citterio 1999) could explain the urgent need for wood. *Abies* and *Fagus* decreased, and the concentration of charcoal particles in the sediments increased. Indicators of grazing and pasture were still well represented. Cereal cultivation increased, the record of *Secale* starting here. In the last 50-100 years *Pinus sylvestris/mugo* has spread again, probably due to the reduction in other woody taxa such as *Abies*, *Picea*, and *Fagus*.

Other microfossil analysis

Several microfossil types (according to van Geel 1978) were identified in the pollen slides (Fig. 7). The records of some Protozoa offer additional information on the environment and the trophic state of the water.

Remains of *Amphitrema* and *Assulina* (types 31A and 32; van Geel 1978) appear in the pollen record from Pian di Gembro after the development of the lake into a peat mire had taken place. Both are indicators of oligotrophic conditions, their abundance pointing to locally wet conditions, low values indicating locally dry conditions. The rhizopod *Arcella* (type 352; van Geel 1978) is also a low-nutrient indicator, however it is incompletely recorded due to its destruction by acetolysis. Loricae of *Callidina angusticollis* (type 37; van Geel 1978) are found in the uppermost 550 cm of the section; this species of Rotifera seems to prefer birch carr as a habitat (van Geel et al. 1981).

Accumulation rates

In order to estimate the sedimentation rates correctly, a comparison between the age-depth model and the pollen concentration curve is needed. In fact, the numerical val-

ues obtained by dividing the $\Delta^{14}C$ yrs B.P. and the Δdepths for every stratigraphic interval are simply mean values, not taking into account differences in the accumulation processes which are better described by the pollen concentration curves (Figs. 7, 8). Middeldorp (1982) showed that in peat bogs under densely forested conditions (e.g. early Holocene succession in Central and Southern Europe) the AP influx is fairly constant so this feature may be used for a detailed evaluation of the sedimentation rate through lithological changes.

Considering in particular the interval 500-600 cm in the sequence from Pian di Gembro, the estimated sedimentation rate is about 1.3 mm/year (100 cm in 750 years). The total pollen concentration curve (Fig. 7) for the same interval shows high values from 570-600 cm and then decreases sharply by a factor of 3. Assuming that AP pollen concentration during this forested interval is dependant on the sedimentation rate (and the latter on the different accumulation processes), we can infer a sedimentation rate for the interval 500-570 cm that was about 3 times higher than that at 570-600 cm (1.95 mm/year and 0.65 mm/year). This pattern perfectly fits with the lithological sequence; at a depth of 570 cm, lake gyttja is replaced by peat, this generally accumulating faster than gyttja.

During LPAZ PGB-1 and PGB-2 pollen concentration shows the lowest values (between 887-5,809 grains/cm^3). In these cases, both a high sedimentation rate and a poor pollen influx (mainly of herbaceous taxa) could explain such low values. Pollen concentration rises during LPAZ PGB-3, when reforestation took place with the increased vegetation cover leading to increased pollen production and influx. *Pinus sylvestris/mugo* and *Pinus cembra* present in Pian di Gembro strongly contribute to pollen concentration in the sediment; this can quickly rise to around 200,000 grains/cm^3.

Pollen concentration shows high values in LPAZ PGB-4 (corresponding to the Younger Dryas: 134,000-211,000 grains/cm^3) and PGB-5 (constantly above 100,000 grains/cm^3 with a peak of 490,000 grains/cm^3 recorded at 734 cm depth). During LPAZ PGB-6 pollen concentration and influx decrease sharply at 570 cm, reaching minimum values of 30,000 grains/cm^3. As previously stated, these parameters are influenced by the change of sediment (from lake gyttja to peat) occurring here, which has the effect of 'diluting' pollen. In LPAZ PGB-7 and PGB-8 (up to 280 cm) pollen concentration shows values lower than 80,000 grains/cm^3. At 280 cm it rises quickly, due to a local expansion of *Pinus sylvestris/mugo* (the stomata of which were abundant in pollen slides); the same pattern can be observed in the influx curve. In LPAZ PGB-9 high values of pollen concentration are recorded up to 188 cm, above this they decline to between 20,000-80,000 grains/cm^3. Only in the upper 20 cm (LPAZ PGB-10) are high values of pollen concentration (108,000-253,000 grains/cm^3) again recorded.

The increase in pollen concentration recorded in LPAZ PGB 3b is influenced by the change of sediment type that occurred at 830 cm. However increasing pollen concentration in LPAZ PGB 5a is instead the reaction of the vegetation to the climatic warming that marks the beginning of the Holocene. This climatic amelioration led to phases of both denser vegetation and higher pollen productivity.

The event at 8,200 cal B.P.

It is possible to see a striking correspondence between the simultaneous expansion of *Picea* and *Abies* at Pian di Gembro and the major Holocene climatic change recorded in the GRIP ice core from central Greenland as a strong fluctuation of atmospheric methane concentration (Blunier et al. 1995). The GRIP curve of methane concentration shows a sharp decrease at around 8,200 cal B.P., which equals about 7,500 B.P.; a similar feature is also present in the isotope record. Chappellaz et al. (1993) supposed that low-latitude moisture fluctuations could be partly responsible for the changes of atmospheric methane concentration. Blunier et al. (1995) underline that during the Holocene the lowest methane concentrations are contemporaneous with droughts in the tropics. Atmospheric methane concentration increased during late Holocene, probably due to a larger contribution from northern wetlands.

Stable oxygen isotope ratios in ostracods from Lake Ammersee (southern Germany; von Grafenstein et al. 1998) indicate a 200-year long negative excursion which is contemporaneous with the $\delta^{18}O$ excursion in the GRIP ice core dated 8,200 cal B.P. Von Grafenstein et al. (1998) interpreted this isotopic signal as induced by a perturbation of the North-Atlantic thermohaline circulation, possibly triggered either by a weak forcing or by a freshwater pulse due to the decay of the Hudson Bay Ice Dome.

In the pollen diagram from Pian di Signano (1540 m asl, Switzerland: Zoller 1960) strong depressions of the *Abies* belt, occurring between 7,500-6,500 B.P., were interpreted as being caused by the 'Misox cold phase'. Zoller et al. (1966) postulated that such a climatic phase was not limited to the Alps and proposed a correlation with glacier advances in North America. The strong climatic deterioration referred to as 'Misox oscillation' is represented in the palaeobotanical investigations at Lago Basso (2250 m asl) and Gouillé Rion (2343 m asl) (respectively Italy and Switzerland; Wick and Tinner 1997) as marked timberline oscillations, and at Wallisellen-Langachermoos (Switzerland; Haas 1996) as the abrupt decline in the frequency of *Najas* seeds.

Data indicate the presence and the stability of *Picea,* between 8,500-9,000 B.P., at altitudes near or above 1800 m asl in the Central Alps (Fig. 1a) (Ravazzi 2002). At 9,000 B.P. *Picea* was at Pian Venezia (2270 m asl, Val di Sole; Speranza et al. 1996); at 8,300 B.P. *Picea* was present at Col di Val Bighera (2087 m asl; Gehrig 1997); at 8,200 B.P. it was at Passo del Tonale (1883 m asl; Gehrig 1997) and not far from Pian dei Cavalli (2250 m asl; Wick 1994). These data suggest that during this time interval, *Picea* remained at high altitudes, where climatic and edaphic conditions were favourable for its survival and spread.

There are also indications of the early presence of *Abies* in the lowlands of Lombardy. At 10,500 B.P. the percentage curve of *Abies* at Lago di Annone and Lago del Segrino (226 m and 374 m asl; Wick 1996) became continuous. *Abies* was present as single trees up to 7,600 B.P., when it started being part of the local forests.

Methane concentration is correlated to air humidity: changes of humidity can modify the amplitude of a vegetational belt, thus favouring the immigration and expansion of taxa already present in nearby belts. An increase in humidity that occurred at 8,200 cal B.P. could

therefore be responsible for the spread, at middle and low altitudes of *Picea*, which reached Pian di Gembro at 7,370 B.P. (this work) and Palu' di Edolo at 7,285 B.P. (Gehrig 1997). The same mechanism could explain the expansion of *Abies* from the lowlands toward middle and high altitudes.

This transition occurring at 8,200 cal B.P. marked the end of the continental climatic regime and led to moister climatic conditions. Tinner and Ammann (2001) suggest that the transition was probably caused by an increase in the amount of humid air masses coming from west and north-west, resulting in the lowering of summer and winter temperatures and increased precipitation.

It is difficult to say if the sudden spread of *Picea* and *Abies*, as documented by the pollen record of Pian di Gembro, is just a response to a climatic change. Modern knowledge about migration routes after the LGM can be still improved, offering additional elements to answer this question. Several other factors should be mentioned as having played a role in determining the spread of *Picea* and *Abies* at the altitude of Pian di Gembro. These are the presence of soils already developed under forest cover, the absence of viable competitors and humidity and temperature conditions.

Conclusions

A high-resolution pollen analysis at Pian di Gembro (1350 m asl, Central Alps, Northern Italy) documents the history of vegetation and climate in detail, allowing comparisons with neighbouring sites at different altitudes. ^{14}C chronology offers a reliable time resolution. The results of this research can be summarised as follows:

1. After the retreat of glaciers after the Last Glacial Maximum, pioneer plants (mainly herbaceous taxa) spread in the plain of Pian di Gembro. The first shrub vegetation (*Juniperus*, *Alnus viridis*, *Salix*, Ephedraceae) seems to have expanded well before the beginning of the Late Glacial Interstadial, despite the lack of a chronological frame for this event.
2. The arrival and expansion of *Pinus sylvestris/mugo* and *Pinus cembra* in Pian di Gembro are dated to 12,320 B.P.
3. The rapid cooling of the Younger Dryas strongly reduced the extent of *Betula-Pinus* forests, and a fresh expansion of steppe vegetation occurred. Low precipitation and reduced detrital supply into the lacustrine basin could explain the low sedimentation rate during this event.
4. The large and rapid expansion of mixed oak forest taxa in Pian di Gembro took place during the Preboreal. Broad leaved trees reached higher altitudes suggesting milder winter temperatures at the beginning of the Holocene.
5. The sudden and simultaneous expansion of *Picea* and *Abies* is dated to 7,370 B.P., about 8,200 cal B.P., recording a clear, abrupt change in the structure of vegetational belts. This climatic change as evidenced in the polar ice cores was also detected through oscillations of the timberline (Zoller 1960; Wick and Tinner 1997). Pian di Gembro offers the first palynological evidence of the wide impact of this climatic change on a middle-altitude environment.
6. The development of the lake of Pian di Gembro into a peat mire, which took place during early Atlantic, is revealed by sedimentological and local pollen-assemblage changes.
7. Human impact is well documented since the middle Neolithic, and increased during the Iron Age and Roman Period, when pasture lands were present in the surroundings of Pian di Gembro. From the Middle Ages onwards, the activity of iron smelting sites, wide-spread in Val Camonica, led to heavier exploitations of the forests.
8. In the last century the decrease of *Abies*, *Picea*, and *Fagus* led to a new expansion of pine forests.

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