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Response of littoral chironomid communities and organic matter to late glacial lake—level, vegetation and climate changes at Lago dell'Accesa (Tuscany, Italy)

Laurent Millet[1, 2], Boris Vannière[1], Valérie Verneaux[3], Michel Magny[1], Jean Robert Disnar[4], Fatima Laggoun-Défarge[4], Anne Véronique Walter-Simonnet[5], Gilles Bossuet[1], Elena Ortu[1] and Jacques-Louis de Beaulieu[6]

(1) Laboratoire de Chrono-Ecologie, UMR 6565 CNRS, UFR Sciences et Techniques, Université de Franche-Comté, 25030 Besançon cedex, France
(2) Laboratoire EDYTEM, UMR 5204, CISM, Université de Savoie, 73376 Le Bourget du Lac cedex, France
(3) Laboratoire de Biologie Environnementale, EA 3184 USC INRA, UFR Sciences et Techniques, Université de Franche-Comté, 25030 Besançon cedex, France
(4) Institut des Sciences de la Terre d'Orléans, UMR 6113 CNRS, Université d'Orléans, Géosciences, BP 6759, 45067 Orléans Cedex 2, France
(5) Laboratoire de Géosciences, UFR Sciences et Techniques, Université de Franche-Comté, 25030 Besançon cedex, France
(6) Laboratoire IMEP, UMR 6116, Europôle Méditerranéen de l'Arbois, Bat. Villemin, BP 80, 13545 Aix-en-Provence cedex 4, France

Abstract

This study focuses on the response of lacustrine littoral chironomid communities to late glacial changes in limnological, environmental and climate conditions in the Mediterranean context. Late glacial chironomid (Diptera: Chironomidae) assemblages, organic petrography and geochemistry were analysed in a sediment core from the littoral zone of Lago dell'Accesa (Tuscany, Italy), where the lake-level fluctuations and the vegetation history have been previously reconstructed. Comparison of the chironomid stratigraphy to other proxies (pollen assemblages, organic petrography and geochemistry, lake-level) and regional climate reconstruction suggested the predominant influence of lake-level changes on the littoral chironomid fauna. The main lowering events that occurred during the Oldest and the Younger Dryas were followed by higher proportions of taxa typical of littoral habitats. A complementary study of organic matter suggested the indirect impact of lake-level on the chironomids through changes in humic status and habitat characteristics, such as the type of substrate and aquatic macrophyte development. Several chironomid taxa, such as *Glyptotendipes*, *Microtendipes* and *Cricotopus* type *patens*, were identified as possible indicators of low lake-level in the late glacial records. Nevertheless, this study suggested that parallel analyses of organic matter and chironomid assemblages may be needed to circumvent misinterpretation of littoral chironomid assemblage stratigraphy. There was a weak response of the chironomid assemblages to small lake-level lowerings that corresponded to the Older Dryas and Preboreal oscillations. A higher level of determination, e.g. to the species group level, may be necessary to increase the sensibility of the indicators to lake-level changes.

Keywords Chironomids - Organic matter - Late glacial - Paleolimnology - Lake-level - Italy

Introduction

Subfossil chironomids are one of the most promising proxies of paleoenvironmental and paleoclimatic changes (Walker *2001*). The long persistence of larval remains (head capsules) in the sediment allows reconstructing past assemblages after extraction and determination. Changes in the composition of the chironomid fauna are interpreted in reference to ecological preferences of the taxa involved. A great variety of environmental factors are known to potentially affect chironomid communities such as oxygen conditions (Verneaux and Aleya *1998*), trophic level (Saether *1979*; Woodward and Schulmeister *2006*), humic status (Brinkhurst *1974*), type of substrate and habitat (Maitland *1979*; Gandouin et al. *2006*) and temperature (Walker et al. *1991*; Barley et al. *2006*). In mid-latitude and northern Europe, the late glacial period was marked by numerous and strong temperature changes (Magny et al. *2006b*). Here, chironomid studies of late glacial records have focused on quantitative reconstruction of temperature considered as the main driving factor of chironomid successions (e.g. Heiri and Millet *2005*). These reconstructions provided information on late glacial climate variability and its forcing mechanisms (Magny et al. *2006b*).

In the Mediterranean zone and in particular in Italy, while many late glacial lacustrine records are available, chironomid remains have rarely been used to reconstruct late glacial climate and environmental variability (e.g. Manca et al. *1996*). Recent high-resolution studies of marine and lacustrine sequences suggest close similarities in the timing of late glacial climate variability between the Mediterranean and the North Atlantic regions (Huntley et al. *1999*, Asioli et al. *2001*). Nevertheless, the magnitude of summer temperature changes during the major transitions of the last deglaciation was probably lower in southern Europe than in northern Europe (Renssen and Isarin *2001* and references therein). At Lago dell'Accesa (Tuscany, Italy), multiproxy reconstruction involving vegetation and lake-level changes suggested that hydrological changes were probably strong, especially for low-elevation Mediterranean sites (Magny et al. *2006a*). Velle et al. (*2005*) suggested that in times of low amplitude temperature changes, other environmental factors may control the chironomid response. In Mediterranean lake records, the predominant role of temperature changes on late glacial littoral chironomid fauna should then be carefully studied.

In this study, besides the chironomid assemblages, petrographic and geochemical analyses of the sediment organic matter (OM) were performed on a late glacial sediment core from Lago dell'Accesa (Tuscany, Italy), where lake-level variations and vegetation history already have been reconstructed (Magny et al. *2006a*; Drescher-Schneider et al. 2007). The aim of this work was to assess the response of the littoral chironomid communities to late glacial limnological, environmental and climate changes in a Mediterranean lake. We paid special attention to the lake-level impact on the littoral chironomid fauna through changes in humic status and habitat characteristics. The final goal was to provide some backgrounds for the interpretation of future late glacial chironomid works in Mediterranean lakes, and more specifically to define some valuable indicators of lake-level changes from chironomid and OM records.

Site description

Lago dell'Accesa is located in the Grosseto province (Tuscany, Italy, Fig. 1). The small catchment (5 km^2) lies at the southern margin of the Colline Metallifere (alt. max.: 1060 m

a.s.l.). The catchment is delimited by several low elevation hills (max alt. 352 m) and lies between three main geological formations: Permian schist to the north-east, highly karstified Rhaetian dolomite limestone to the north and west, and Eocene schist to the south and west (Merciai *1933*). The lake is of karstic origin and is fed by run-off from the catchment and by a small karstic inlet (Inferno spring, Fig. 1). The eastern outlet forms the source of the Bruna River. The maximum lake depth is 42 m and the mean depth is 21.3 m (Fig. 1). In 1912, the outlet floor was deepened by about 50 cm in order to extend the cultivated area around the lake (Merciai *1933*). The subsequent lake lowering led to the emergence of a large littoral platform (ca. 150 m wide).

Material and methods
Coring

The coring point is located on land 50 m from the present-day western lakeshore within the former littoral platform (Fig. 1). This site was chosen following several observations: (i) preliminary pollen analysis indicated that the sedimentary accumulation corresponding to the late glacial period is there around 5 m thick and can then provide a good temporal resolution for paleoenvironmental studies, (ii) the zone is fully accessible to a corer fixed on a caterpillar APAGEO®. Two overlapping cores series, 17.50 m long each, were retrieved using a Russian corer. Magnetic susceptibility was used to correlate stratigraphically the two sediment columns and build a synthetic record.

Chironomid analysis

Sampling intervals were 10 cm in the main part of the core and 5 cm in the 13.30–11.90 m section. In total, 84 samples, 2 cm thick, were used for subfossil chironomid analysis. Chironomid head capsules were extracted from sediment following the procedure described by Walker (*2001*). Identification of chironomid head capsules was performed according to Wiederholm (*1983*) and Klink and Moller-Pillot (*2003*), in most cases, to the genus or species group level. For the taxon names, the designation 'gr.' indicates that the taxon could be any species within the species group and the use of the designation 'type' indicates that the taxon is morphologically similar to a specific species. *Cricotopus* type *patens* was identified according to the description of the species given by Hirvenoja (*1973*). *Parakiefferiella* type *bathophila* was recognised from Wiederholm (*1983*). Specimens referred to as *Parakiefferiella* sp. A were described in Brooks et al. (*1997*). *Chironomus* type *plumosus* specimens were differentiated from other *Chironomus* from the combination of a long fourth lateral tooth of the mentum and three inner teeth on the mandibule (Hofmann *1971*).

Relative abundances of the taxa were calculated for each sample. Only chironomid taxa occurring in at least two samples, with a relative abundance of more than 2% in at least one sample, were included for further analysis. The Hill'N2 (Hill *1973*) diversity index was calculated for each sample. A stratigraphic diagram of taxon relative abundances was produced using the TILIA and TILIA-Graph software package (Grimm *1991*). The chironomid assemblage zones were defined from a stratigraphically constrained cluster analysis performed by Coniss (Grimm *1991*). The number of statistical zones was assessed by comparison with the broken stick model (Bennett *1996*).

To help the diagram interpretation, we cumulated the relative abundances of taxa usually considered in the literature as shallow-water living larvae: *Dicrotendipes*, *Glyptotendipes*,

Labrundinia, Limnophyes, Phaenopsectra, Polypedilum type *sordens, Stenochironomus* and *Xenochironomus* (Littoral biotope taxa in Fig. 3). The only Palaearctic species of *Labrundinia* is found in bogs (Fittkau and Roback *1983*). *Labrundinia* is one of the dominant chironomid taxa in the submerged vegetation of the littoral zone of Lago di Vico (Mastrantuono *1991*). *Polypedilum sordens, Glyptotendipes* and *Dicrotendipes* are widely recognised as being associated with aquatic macrophytes (Thut *1968*; Pinder and Reiss *1983*; Klink and Moller-Pillot *2003*). *Phaenopsectra* lives in very shallow zones in permanent lakes and ponds (Palomäki *1989*). *Limnophyes* is a terrestrial genus scattered in aquatic biotopes, *Stenochironomus* mine in submerged wood remains and *Xenochironomus* are obligate miners in freshwater sponges (Pinder and Reiss *1983*; Klink and Moller-Pillot *2003*).

Organic geochemistry and petrography

Total Organic Carbon (TOC) contents and Hydrogen Index (HI) values were determined by Rock-Eval$^{®}$ pyrolysis (Espitalié et al. *1985a, b*) with a model 6 device (Vinci Technologies). The analyses were carried out on 50–100 mg of crushed samples under standard conditions. TOC (%) accounts for the quantity of organic carbon present in the sediment. HI (mg HC g^{-1} TOC) is the amount of hydrocarbonaceous products (HC) released during pyrolysis (S2 signal intensity, in mg HC g^{-1} dry sediment) normalized to TOC

$$HI = [S2 \cdot TOC^{-1}] \times 100$$

TOC and HI indicate OM abundance and hydrogen richness, respectively. TOC contents depend not only on autochthonous OM productivity and allochthonous OM inputs, but also on oxygen conditions, which determine OM degradation in the water column and sediments. In stratigraphic records, TOC measurements can be affected by the sedimentation rate. For example, a high influx of minerogenic particles entails a dilution of OM contents.

The HI index is controlled by the type (i.e. the source) and the degree of degradation of the OM. It may be used to assess main variations in lacustrine-deposit OM quality (Talbot and Livingstone *1989*; Meyers and Lallier-Vergès *1999*; Jacob et al. *2004*). An HI decrease is mainly due to a larger contribution of terrestrial and littoral (e.g. aquatic macrophytes) organic material in the total sediment OM (Disnar et al. *2003*). However, OM oxidation also entails a decrease of the HI (Espitalié et al. *1985a, b*; Jacob et al. *2004*).

The petrographic study (palynofacies) of the Accesa record involved the microscopic examination under transmitted light of 26 samples after acid hydrolysis of organic remains. Organic residues were mounted as palynofacies slides and examined at 20 and 50× magnification. Chromatic and textural characteristics of organic remains were used to identify and quantify OM compounds. Organic remains were classified into two groups: material of phytoplanktonic origin and material from vascular plants. The first group is the authigenic fraction. It mainly consists of greyish amorphous OM and translucent membrane fragments (Lallier-Vergès et al. *1993*). The second group is composed of well-preserved ligno-cellulosic tissues, reddish amorphous OM, yellow-orange gelified particles and dark organic components. They belong to higher plants and likely originate from emergent plants or local vegetation growing around the lake. This material may represent the post-burial state of autochthonous higher plants when the system is functioning as a shallow lake or a peat swamp (Sifeddine et al. *1996*). It may also derive from the surrounding soil (Noël et al. *2001*). The surfaces of each OM particle type were counted with a grid reticle in the eye-piece of the

microscope. About 3000 items per sample were counted to calculate relative frequencies with an estimated error of about 10%.

Age–depth model

The age–depth model of the sequence (Fig. 2) was developed from a linear interpolation of five tephra layers and two radiocarbon dates (Table 1). More precise information about the age–depth model, including analysis and dating of tephra layers, can be found in Magny et al. (*2006a*). Age of tephra layers was determined with reference to the work of Wulf et al. (*2004*) in the laminated sediment of Lago di Monticchio. The pollen stratigraphy allowed the identification of the main late glacial climatic events: Oldest Dryas, late glacial Interstadial and Younger Dryas (Drescher-Schneider et al. 2007). The age of these events was obtained using our age–depth model (Fig. 2) and appeared to be in agreement with the age found in other Mediterranean terrestrial and marine records (Magny et al. *2006a*).

Results and interpretations
General comments

Twenty-seven chironomid taxa were identified from the entire core (Fig. 3). Despite the processing of large quantities of sediment (up to 50 g), less than 10 head capsules (h.c.) were recovered in 5 samples (16.20 m, 15.95 m, 14.51 m, 14.30 m, 14.09 m). These samples were removed from the data set for further analysis. Seven chironomid assemblage biozones (CAZ-Ac1 to 7) were identified throughout the diagram (Fig. 3).

TOC values fluctuate between 0.13 and 2.39% throughout the record (Fig. 4). However, most values are gathered in the 0.42–0.85% range (Fig. 4) that is relatively low in comparison to other late glacial lacustrine records (e.g. Ramrath et al. *1999*). This difference can tentatively be explained by the dilution of the OM by carbonate minerals that were produced in rather great abundance on the littoral platform, where were deposited the studied sediments. Minimum and maximum HI values reach 280 and 834 mg HC g^{-1} TOC, respectively. However, a S2 versus TOC diagram (Fig. 5) reveals that all the data points are gathered between two lines passing through the origin of the axes, the slope of these two lines corresponding to HI values of 300 and 750 mg HC g^{-1}, respectively. The fact that these two lines do not show any tendency to intersect the abscissa axis rules out any mineral matrix effect that would have lowered HI values (Espitalié et al. *1985b*; Langford and Blanc-Valleron *1990*). In addition, the total absence of points between the lower line and the abscissa axis reveals that no sample contains notably weathered OM that would be characterised by a rather low HI. The HI values 300 and 750 mg HC g^{-1} delineated by the two lines defined here above, are typical for well-preserved ligno-cellulosic debris and phytoplankton, respectively. At least in a first approach, in the absence of any notable mineral matrix effect and OM alteration, the gathering of all the data points between these two lines delineating HI values typical for the two major allochthonous/autochthonous OM end-members allow us to consider the HI of any sample as resulting from the mixing of variable proportions of these two materials (and thus is indicative of these proportions). However, in such an approach it must also be born in mind that in lacustrine environments and especially in sediments deposited near a palaeoshore, remains of aquatic macrophytes can add to the debris of woody land plants constituting the true allochthonous OM contribution (Meyers and Lallier-Vergès *1999*; Jacob et al. *2004*). The results suggest an overall dominance of

lacustrine remains in total sediment OM. This assumption is supported by the palynofacies analysis. The proportion of terrestrial or paludal OM (TOM, Fig. 4) represents between 4.9 and 47.4% throughout the whole record.

Changes in chironomid and OM can be compared with the vegetation history reconstructed from pollen analysis (Drescher-Schneider et al. 2007) and lake-level variations inferred from a specific sedimentological method (Magny et al. *2006a*).

Oldest Dryas

The Oldest Dryas pollen zone is represented by the CAZ-Ac1 within the chironomid record (Fig. 3). The chironomid community is dominated by *Parakiefferiella* type *bathophila*, *Paratanytarsus*, *Glyptotendipes* and *Microtendipes* (Fig. 3). The low lake-level reconstructed during this period (Magny et al. *2006a*) led to the development of a littoral habitat fauna composed of taxa like *Glyptotendipes*, *Dicrotendipes*, *Xenochironomus* and *Phaenopsectra* (Fig. 3). Development of the aquatic macrophyte flora near the coring site is suggested by the high relative abundance of *Glyptotendipes*, a vegetation mining taxon (Thut *1968*; Pinder and Reiss *1983*; Klink and Moller-Pillot *2003*). The high percentage of TOM and the low HI (Fig. 4) are most probably caused by a greater contribution of aquatic macrophytes remains in the sediment. A terrestrial origin of the OM remains would be in contradiction with the poor arboreal cover indicated by the high percentages of non-arboreal pollen (NAP curve in Fig. 6). High relative abundance of *Microtendipes* may be explained by the high proportion of carbonated concretions (Oncolites and Cawliflower morphotypes, Magny et al. *2006a*) and coarse organic particles in the sediment. A substrate preference of *Microtendipes* for similar littoral habitat was found by McGarrigle (*1980*).

The first part of the Oldest Dryas is marked by the only occurrence of *Stictochironomus* for the whole record (Fig. 3). *Stictochironomus* can be found in the littoral zone of cold lakes with low organic accumulation and well-oxygenated waters (Hofmann *1986*). Given the overall low water depth during the Oldest Dryas, cool conditions seemed to prevail. In the lower part of the Oldest Dryas, the lower abundance of *Glyptotendipes* (Fig. 3) and the higher HI (Fig. 4) points to a less developed aquatic macrophyte belt, probably limited by cold climate.

Late glacial Interstadial

The late glacial Interstadial is represented by CAZ-Ac2 and CAZ-Ac3 in the chironomid stratigraphy (Fig. 3). The transition from CAZ-Ac1 to CAZ-Ac2 is abrupt (Fig. 3). *Microtendipes*, *Glyptotendipes* and other littoral habitat taxa sharply decline in abundance. New dominant taxa (*Chironomus*, *Cricotopus* type *patens*, *Psectrocladius* type *sordidellus* and *Ablabesmyia)* characterise both CAZ-Ac2 and CAZ-Ac3.

The late glacial Interstadial is marked by a decrease in TOC contents (Fig. 4). This decline cannot be interpreted as a lower organic input to the sediment since the sedimentation rate is much higher than in the previous zone (Fig. 2). HI increases up to its maximum for the whole record, whereas TOM percentages decline. Several successive episodes of high lake-levels (Fig. 6) were reconstructed during the late glacial Interstadial (Magny et al. *2006a*).

Consequently to these higher water levels, the distance of the lake paleoshore from the coring site increases. The typical littoral habitats including wood and aquatic plant remains had then little influence on the chironomid fauna. The sediment OM was dominated by phytoplankton-like particles of pelagic origin. The higher proportion of fine OM in the sediment led to the dominance of taxa, such as *Ablabesmyia* and *Psectrocladius* type *sordidellus*.

Several episodes of lake-level lowering of similar magnitude as during the Oldest Dryas have been reconstructed during the late glacial Interstadial (Fig. 6, Magny et al. *2006a*). Nevertheless, responses of both the chironomid community and the OM to these low lake-level episodes were different than during the Oldest Dryas. The low lake-level event between 15.50 m and 15.85 m corresponds to a peak of *Chironomus* (Fig. 3). This period is also marked by higher TOM percentages as well as lower HI (Fig. 4). The low lake-level probably favoured the development of aquatic macrophytes in the vicinity of the coring site. Some members of *Chironomus* are known to survive under anoxia and are typical of the deep zone of eutrophic lakes, whereas others live in littoral habitats, such as aquatic macrophyte belts (Butler et al. *1999*). The high relative abundance of *Chironomus* observed between 15.50 and 15.85 m (Fig. 3) may then be linked to the development of these littoral-living *Chironomus*. The lake-level lowering identified at 13.65–14.05 m seemed to have no visible effect on OM, but corresponds to a high relative abundance of *Chironomus*, most probably littoral species (Fig. 3). Between 14.85 m and 15.10 m, a low lake-level event correlated with the Older Dryas pollen zone (Magny et al. *2006a*). It was followed by the dominance of *Cricotopus* type *patens* and the occurrence of *Xenochironomus* in the chironomid community (Fig. 3). In Fennoscandia, *Cricotopus patens* is found in submerged mosses in lakes and in smaller bodies of standing water (Hirvenoja *1973*).

Younger Dryas

The first part of the Younger Dryas (13.00–13.65 m) was marked by high lake-levels (Magny et al. *2006a*). Nevertheless, a short lowering event could have occurred between 13.30 and 13.45 m (lake-level curve in Fig. 6). In the OM record, this episode is characterised by notable TOM percentages and a drop in HI (Fig. 4). The low lake-level led to growth of aquatic macrophytes near the coring site as suggested by the increase in the remains of littoral aquatic macrophytes in the sediment OM. In the chironomid assemblages, this short event was followed by an increase in the assemblage diversity (Hill's N2 in Fig. 3) probably due to the diversification of the benthic habitat. A slight rise in relative abundance of littoral habitat taxa, such as *Labrundinia*, *Glyptotendipes* and *Polypedilum* type *sordens*, can also be recognised (Fig. 3).

The second part of the Younger Dryas (13.00–12.20 m) was characterised by a lacustrine regressive episode (Fig. 6, Magny et al. *2006a*). Impacts of this lowering were found in both the OM content and the chironomid stratigraphy. In the OM record, HI and TOM percentages reached similar values as during the Oldest Dryas (Fig. 4). An increase in allochthonous inputs of terrestrial plants and soil particles is inconsistent with the strongly reduced vegetation cover as indicated by the high NAP percentages in the pollen stratigraphy (Fig. 6). Thus, the observed trend was due to the accumulation of organic remains from the aquatic macrophytes belt that grew in the near vicinity of the coring site. The chironomid community (CAZ-Ac5 and CAZ-Ac6) was dominated by typical littoral taxa like *Polypedilum* type *sordens* and *Labrundinia*. The littoral environment favoured the development of *Microtendipes* and sustained a well diversified fauna as indicated by the higher assemblage diversity (Hill's N2 in Fig. 3).

Early Holocene

At the Younger Dryas/Holocene transition, a short hiatus was followed by a brief lake lowering (Fig. 6, Magny et al. *2006a*). Imprints of this event were found in both chironomid and organic records. The high relative abundance of littoral habitat taxa was maintained briefly posterior to the beginning of the Holocene (Fig. 6). This period was also marked by low HI and high TOM percentages as during the second phase of the Younger Dryas (Fig. 4).

The higher lake-level reconstructed after 12.10 m coincides with the transition CAZ-Ac6/CAZ-Ac7, which was characterised by the decline of littoral taxa combined to the dominance of *Chironomus*, *Cryptochironomus*, *Procladius* and *Tanytarsus* (Fig. 3). *Chironomus* specimens found during CAZ-Ac7 belong to the *plumosus*-group (Fig. 3), which is more common of deep zones in eutrophic polyhumic lakes with high phytoplanktonic production and high nutrient concentrations (Saether *1979*). This group is also known to live in anoxic conditions due to physiological and behavioural adaptations (Heinis and Crommentuijn *1992*). The OM stratigraphy indicates the dominance of autochthonous organic remains in the total OM in the sediment, as shown by high HI (Fig. 6). The age–depth model (Fig. 2) indicates a similar sedimentation rate as during the Younger Dryas. A higher organic influx might then be deduced from the increase in TOC contents. The higher lake-level, combined with a warmer climate as indicated by the pollen record (Drescher-Schneider et al. 2007), led to a large increase in lacustrine production. The excessive organic production led to OM accumulation in the sediment (Fig. 6). The following oxygen depletion, also possibly favoured by the increase in the lake-level, most likely induced the strong dominance of taxa resistant to hypoxia, such as *Chironomus* gr. *plumosus*, and a drop in the assemblage diversity (Hill's N2 in Fig. 3).

The high lake-level phase was interrupted at 11.60 m by a water lowering that possibly was correlated to the Preboreal Oscillation (Magny et al. *2006a*). The sharp peak of *Cricotopus* type *patens* and the presence of a few specimens of *Labrundinia* found at the time might be the result of the development of a littoral habitat.

Discussion
Controlling factors for the chironomid community and the sediment organic matter

Main shifts in chironomid and OM were concomitant with major lake-level changes. The low lake-level during the Oldest and Younger Dryas corresponded to the dominance of littoral habitat taxa in the chironomid community and higher proportions of aquatic macrophyte remains in the OM composition. Changes in chironomid and OM records were also synchronous with some major modifications in the pollen assemblages. Reduced arboreal cover (e.g. during Oldest Dryas and Younger Dryas) were concomitant with a high proportion of littoral remains in the OM (Fig. 6) so that there is probably no cause–effect relationship between vegetation on the watershed and OM in the sediment. Both respond in concert to changes in the water balance. During the Oldest and Younger Dryas, the decline of arboreal cover was driven by dry and probably cold conditions (Drescher-Schneider et al. 2007). Our work showed that dry phases (Fig. 6) followed by the reduction in arboreal cover and concurrently by the drop in lake-level (Magny et al. *2006a*) led to the consecutive development of aquatic macrophytes in the vicinity of the coring point. On the contrary, wet episodes led to a concurrent increase in vegetation cover around the lake (NAP decrease in

Fig. 6) and to a higher lake-level (Fig. 6) determining a higher contribution of algal organic remains in the sediment (HI increase in Fig. 6). Lake-level fluctuations have then a major impact on the chironomid assemblages. At the coring point, the influence of water depth oscillations on the chironomid assemblages was most probably indirect through multiple impacts on lake properties (Velle et al. *2005*). The proxies analysed in this study enlighted the influence of some benthic habitat characteristics (the humic status and the substrate type).

In mid-latitude and northern European lakes, a cold-adapted chironomid fauna dominated the Oldest and Younger Dryas (Brooks and Birks *2001*). At the late glacial Interstadial and the early Holocene, it was replaced by typical warm lake assemblages (e.g. Millet et al. *2003*). At Lago dell'Accesa, analogue changes in the chironomid community were not recorded. Chironomids living in temperate to warm environments maintained a high relative abundance throughout the late glacial period. A short event, coinciding with the first part of the Oldest Dryas could correspond to colder conditions, as indicated by the presence of *Stictochironomus* in the chironomid assemblage. This implies that temperature changes played only a minor role on the late glacial littoral chironomid succession at Lago dell'Accesa. In their climate quantifications for the two major warming phases of the last deglaciation at 14.7 and 11.5 ka cal. BP, Renssen and Isarin (*2001*) showed that in southern Europe, the increase in July temperature was less intense than in north-western Europe. Moreover, they suggested July air temperature around 17–20°C at sea-level during the Oldest and Younger Dryas in the area of Lago dell'Accesa. At this low elevation Mediterranean site (157 m a.s.l) summer temperature variations were probably too low to produce significant modifications in littoral fauna composition, whereas marked changes in benthic habitat characteristics were found as one of the main controlling factor of the chironomid assemblages.

Littoral chironomids and organic matter as lake-level indicators

Our study suggests that the chironomid assemblage and the OM were sensitive indicators to the major changes in lake-level. The results show that taxa such as *Microtendipes*, *Dicrotendipes*, *Glyptotendipes*, *Labrundinia*, *Limnophyes*, *Phaenopsectra*, *Polypedilum* type *sordens*, *Stenochironomus*, *Xenochironomus* and *Cricotopus* type *patens* should be considered as low lake-level indicators in littoral records. Korhola et al. (*2000*) already showed that *Microtendipes* and *Dicrotendipes* seemed to prefer shallower lakes in northern Fennoscandia. Barley et al. (*2006*) found also low water-depth optima for *Glyptotendipes*, *Dicrotendipes* and *Microtendipes* in their northwest North American training set. From our study, other taxa such as *Chironomus* type *plumosus* should be recognised as deeper water indicators. Taken alone, the indicator value of these chironomid taxa could be questioned. For example, *Glyptotendipes* may be associated with macrophytes, but this taxon also includes several species of collector-feeders that filter food materials from the water column (Armitage et al. *1995*). Parallel analyses of chironomids with organic geochemistry and petrology studies may circumvent this uncertainty. For example, a combination of high relative abundances of *Glyptotendipes* with a high proportion of OM remains from aquatic macrophytes provides less questionable indication of a low lake-level during the Oldest Dryas at Lago dell'Accesa. A dominance of *Chironomus* type *plumosus* concurring with a high accumulation of planktonic OM implies a higher water level, as was found during the early Holocene at Lago dell'Accesa.

Century-scale oscillation like the Older Dryas and the Preboreal Oscillation only had a minor impact on our chironomid and OM stratigraphy. There is probably a need for a higher taxonomic resolution of the chironomid head capsules. The indicator value of a taxon is better

at the species or species group level than at the genus level. For example, *Chironomus* includes many species with very different ecological preferences (Butler et al. *1999*). In the Lago dell'Accesa littoral record, high relative abundances of this genus was found both during high and low lake-level periods. Nevertheless, a high proportion of *Chironomus* type *plumosus* seemed to be linked to high lake-level events unlike the *Chironomus* type *anthracinus*, which may include typical species from the littoral environment.

Chironomid and OM analysis also provided original information on lake-level variations. In the first part of the Younger Dryas, brief changes in the relative frequency of carbonated concretion morphotypes were not interpreted as significant evidence of a low lake-level event (Magny et al. *2006a*). However, synchronous shifts in chironomid assemblages and OM, which occurred during this period, strengthened the hypothesis of a short but well marked low lake-level event.

Conclusion

Late glacial chironomid (Diptera: Chironomidae) assemblages, organic petrography and geochemistry were analysed in a sediment core from the littoral zone of a Mediterranean lake, Lago dell'Accesa (Tuscany, Italy), where lake-level and vegetation history previously have been reconstructed. We tried to assess the response of chironomid community and sediment OM to lake-level, vegetation and climate changes. The proxies analysed suggested that chironomid succession was influenced indirectly by lake-level variations through their impact on benthic habitat characteristics and more specifically on the humic status and substrate type. At this low elevation Mediterranean site, small temperature changes played only a minor role on the late glacial littoral chironomid fauna. In this geographical area, interpretation of future littoral chironomid stratigraphy should take into consideration the predominant influence of lake-level variations. Our results showed that littoral chironomid fauna can be used in combination with OM analysis as a useful indicator of past lake-level changes in Mediterranean lakes. These proxies give original and complementary information on lake-level variations independent of other approaches. Nevertheless, an improvement of the identification level of chironomid remains is needed to refine lake-level reconstruction.

Acknowledgements

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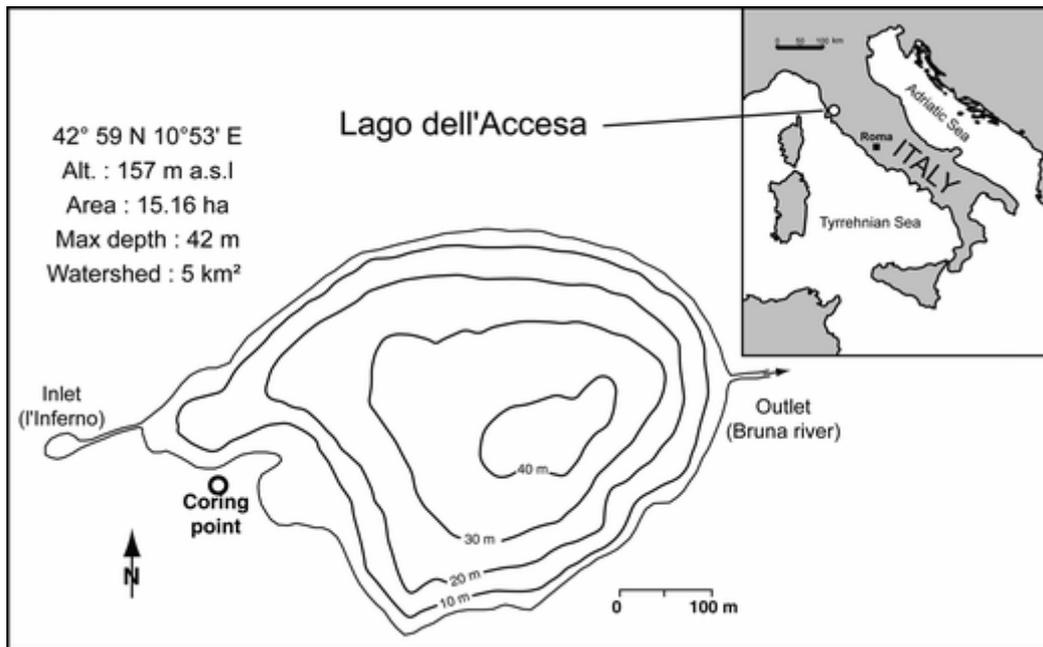
Figures

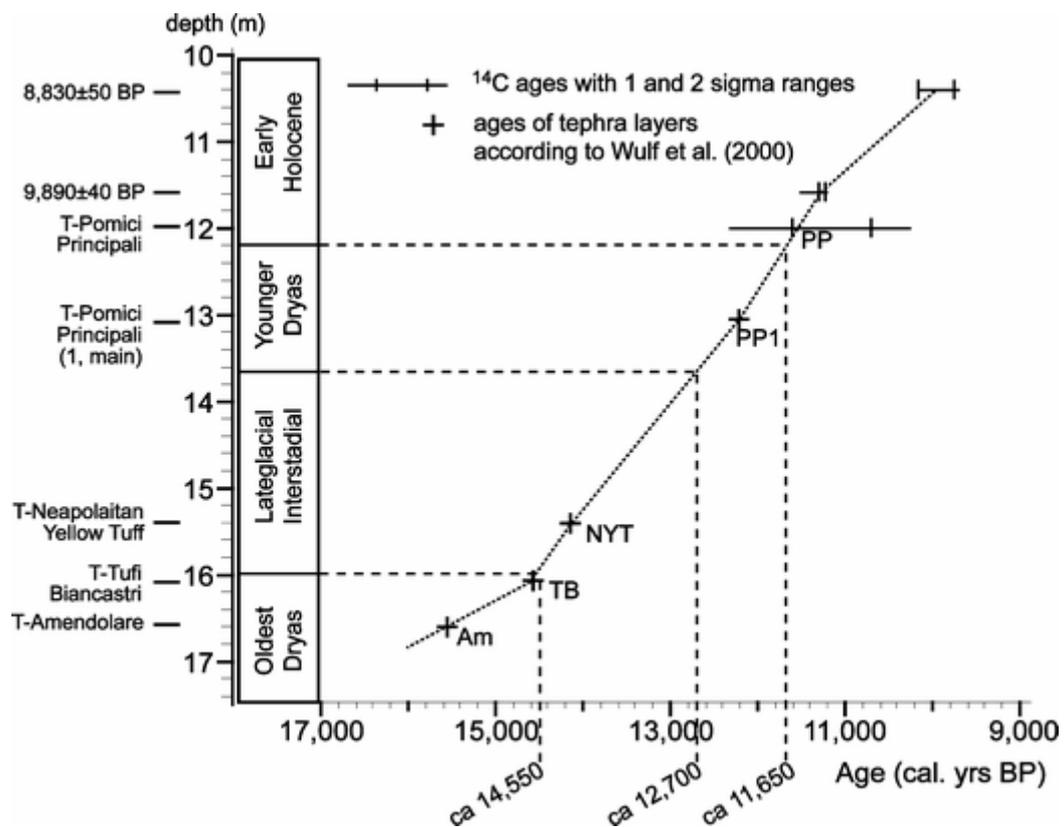Fig. 1 Study site location and Lago dell'Accesa main characteristics

Fig. 2 Age–depth model built from tephra layers and radiocarbon dates. The age of the main late glacial events identified from the pollen stratigraphy are also indicated
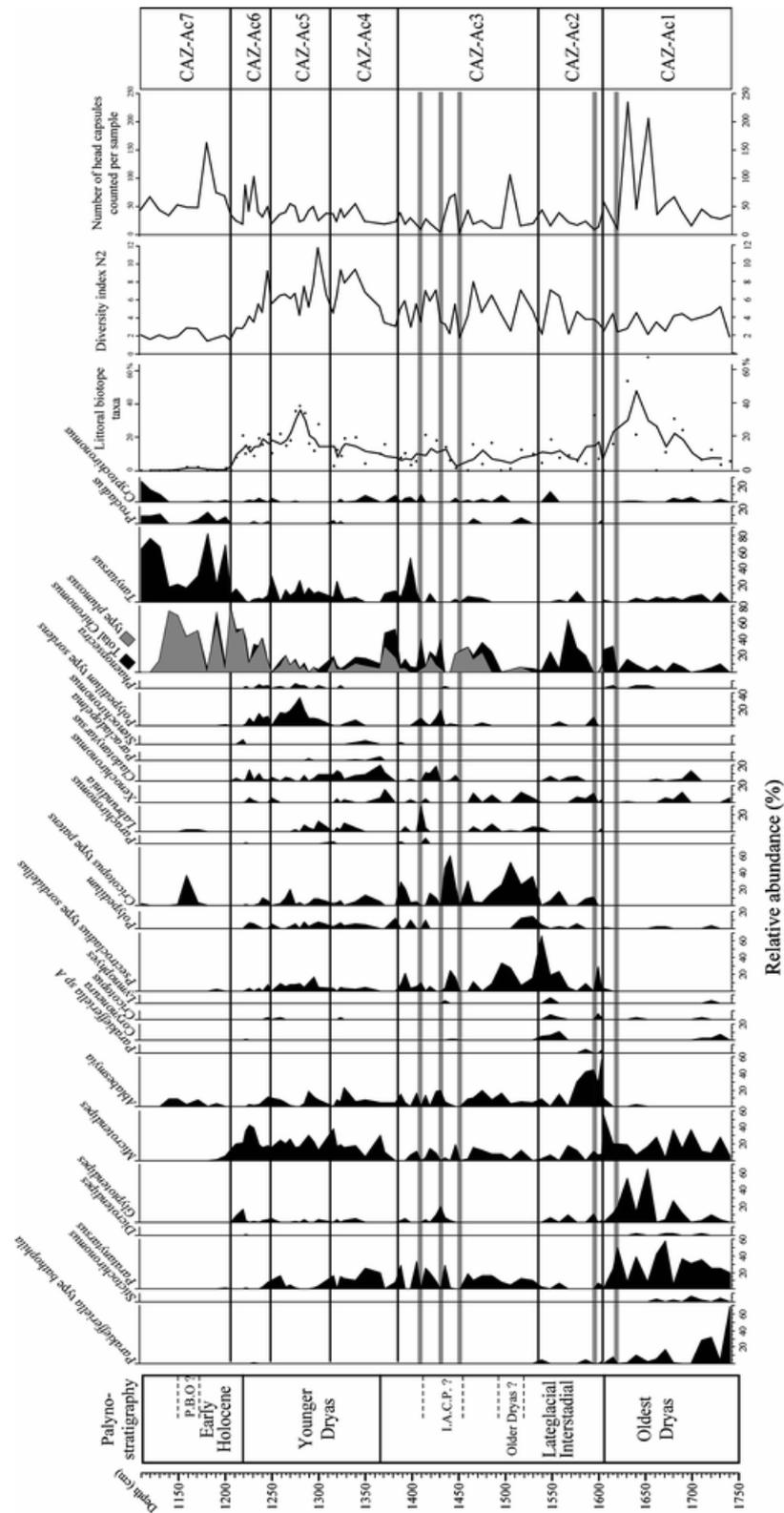
Fig. 3 Chironomid assemblage diagram from Lago dell'Accesa showing relative abundances and assemblage diversity (N2, Hill *1973*) relative to depth in the core. Percentages of littoral biotope taxa were cumulated (dark curve: three point running mean). The taxa are distributed from left to right according to the depth along the core of their maximum relative abundance. Grey bars indicate samples in which less than 10 head capsules were recovered. Stratigraphic

boundaries of the statistical significant biozones (CAZ-Ac: Chironomid assemblage zone of Accesa) are indicated. I.A.C.P = Intra Alleröd Cold Phase; P.B.O. = Preboreal Oscillation
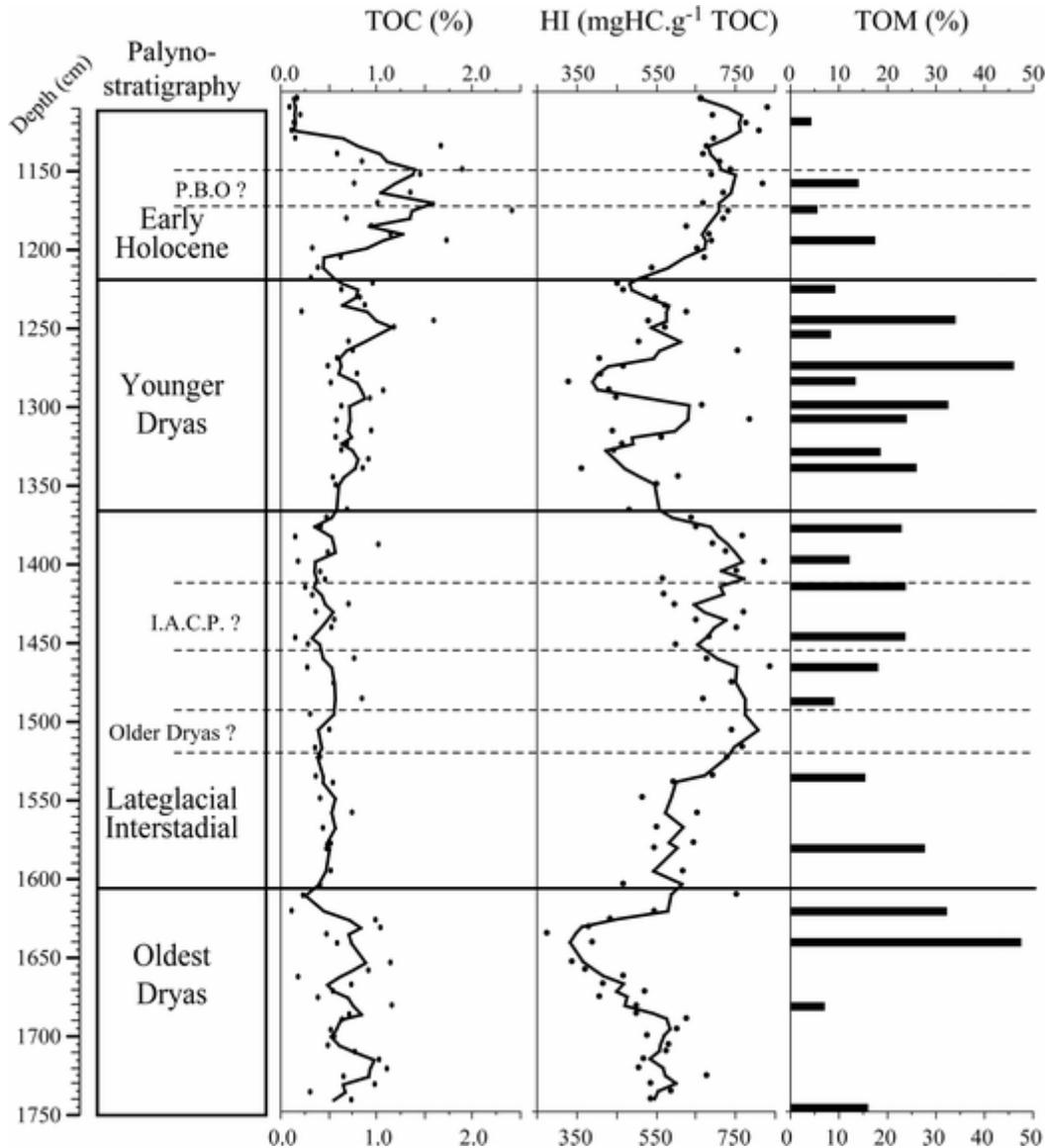

Fig. 4 Organic geochemistry and petrography diagram from Lago Dell'Accesa. TOC (Total Organic Carbon) in grams of carbon per gram of dried sediment (%) (dark curve: three-point running mean); HI: Hydrogen Index in milligrams of hydrocarbon per gram TOC (dark curve: three-point running mean); TOM (Terrestrial Organic Matter) in percentages of the palynofacies. I.A.C.P = Intra Alleröd Cold Phase; P.B.O. = Preboreal Oscillation
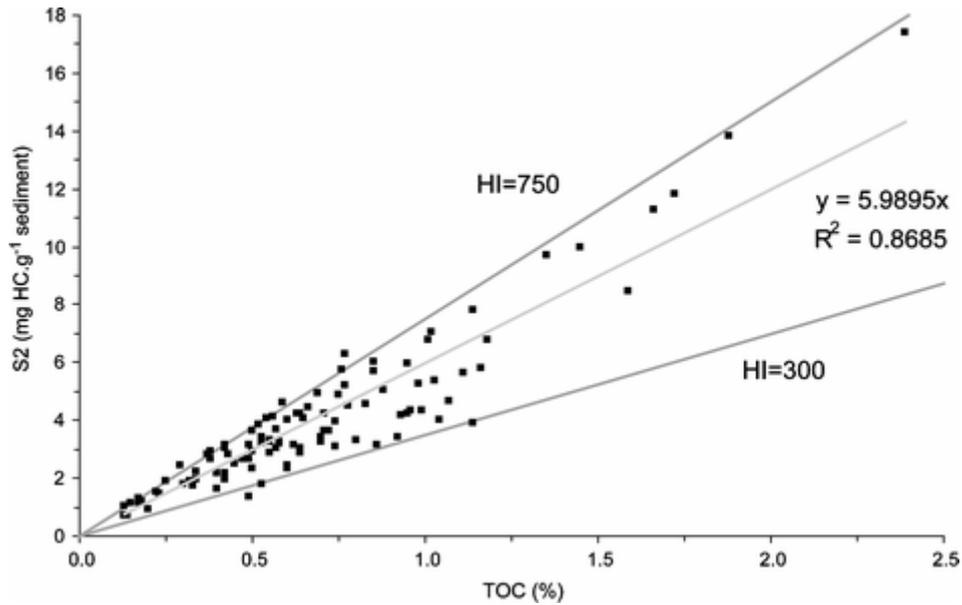
Fig. 5 S2 rock-Eval peak versus Total Organic Carbon. S2 in milligrams of Hydrocarbons released during pyrolysis per gram of dried sediment. HI = [S2 · TOC^{-1}] × 100
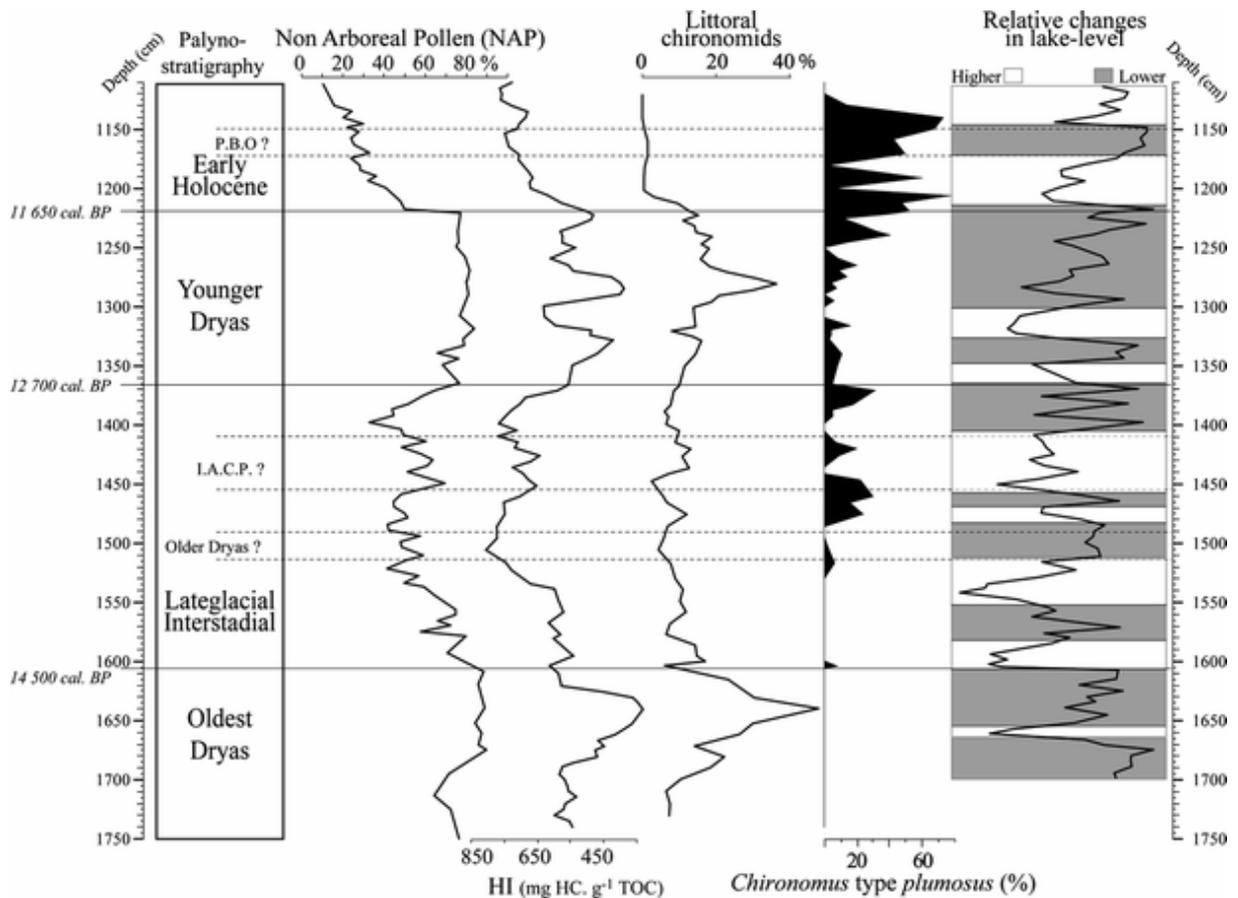

Fig. 6 Main results derived from pollen (NAP: Non-Arboreal Pollen, Drescher-Schneider et al. 2007), chironomid and OM analysis, and the lake-level events derived from Magny et al. (*2006a*). The age of the major late glacial events was determined by using the age–depth model (Fig. 2). See Figs. 3 and 4 for details

Tables

Table 1 Tephra layers and radiocarbon dates used to build the age–depth model

Depth (cm)		Age	Calibrated age (1sigma)	Laboratory number	References
1040.5	^{14}C from peat	8,830 ± 50 BP	9,775–10,147 cal. yrs BP	POZ-9970	
1158.5	^{14}C from wood fragments	9,890 ± 40 BP	11,296–11,226 cal. yrs BP	VERA-2807	
1200	Tephra: Pomici Principali	9,760 ± 300 BP			De vito et al. (*1999*)
1305	Tephra: Pomici Principali (1, main)	10,320 ± 50 BP 12,180 varve yrs BP			Wulf et al. (*2004*)
1542	Tephra: Neapolitan Yellow Tuff	12,300 ± 300 BP 14,120 varve yrs BP			Schmidt et al. (*2002*); Wulf et al. (*2004*)
1605	Tephra: Tufi Biancastri	14,557 varve yrs BP			Wulf et al. (*2004*)
1660	Tephra: Amendolare	15,550 varve yrs BP			Wulf et al. (*2004*)

Radiocarbon dates were calibrated using CALIB 4.3 (Stuiver et al. *1998*)