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Lateglacial summer temperature in the Trentino area (Northern Italy) as reconstructed by fossil chironomid assemblages in Lago di Lavarone (1100 m a.s.l.)

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SUMMARY - *Lateglacial summer temperature in the Trentino area (Northern Italy) as reconstructed by fossil chironomid assemblages in Lago di Lavarone (1100 m a.s.l.)* - Fossil chironomid assemblages and other aquatic invertebrate remains in the sediments of Lago di Lavarone were studied in order to reconstruct the summer temperature development from ca. 15,000 to 11,000 calibrated radiocarbon years BP. Analyses indicate assemblages adapted to low oxygen conditions during the entire sequence. Major changes in the chironomid fauna were inferred (1) at the beginning of the Lateglacial Interstadial, when taxa adapted to oligo-mesotrophic northern and mountain lakes disappeared from the record, (2) at the beginning of the Younger Dryas cold phase when chironomid concentrations declined, suggesting increased anoxia in the lake, and many taxa typical for temperate lowland lakes disappeared from the record, and (3) at the end of the Younger Dryas when most taxa adapted to temperate conditions returned. A chironomid-July air temperature transfer function from Central Europe was applied to the record and reconstructed July air temperatures of 10.5-10.8 °C before the Lateglacial Interstadial, 13.8-13.9 °C during most of the Interstadial with a slight increase to 15.3 °C just before the Younger Dryas, variable temperatures of 11.7-14.5 °C during the Younger Dryas and temperatures of 15.8-16.4 °C during the earliest Holocene. Inferences during the Younger Dryas cold episode were based on a low number of specimens and therefore remain uncertain.

RIASSUNTO - *Temperature estive del Tardoglaciale in Trentino (Nord Italia) ricostruite dalle comunità di chironomidi fossili del Lago di Lavarone (1100 m s.l.m.)* - Le comunità dei chironomidi fossili e di altri resti di invertebrati acquatici nei sedimenti del Lago di Lavarone sono state studiate per ricostruire l'andamento della temperatura estiva da 15.000 a 11.000 anni calibrati BP. Le analisi indicano comunità adattate a condizioni di ossigeno scarso lungo l'intera sequenza. I maggiori cambiamenti nella fauna dei chironomidi sono stati individuati in alcuni periodi: all'inizio dell'Interstadiale del Tardoglaciale, quando taxa adattati a condizioni oligo-mesotrofiche tipici di laghi alpini e nordici scompaiono dal record; all'inizio della fase fredda del Dryas recente, quando la concentrazione dei chironomidi diminuisce, suggerendo un aumento dell'anossia nel lago, e molti taxa tipici di laghi temperati di pianura scompaiono dal record; alla fine del Dryas recente, quando riappare la gran parte dei taxa adattati a condizioni temperate. Una funzione di trasferimento per ricostruire la temperatura dell'aria di luglio dai chironomidi dell'Europa Centrale è stata applicata al record, e ha riportato temperature dell'aria di luglio di 10,5-10,8 °C per il periodo antecedente all'Interstadiale Tardoglaciale, di 13,8-13,9 °C per la gran parte dell'Interstadiale con un leggero aumento a 15,3 °C appena prima del Dryas recente, di 11,7-14,5 °C durante il Dryas recente, e di 15,8-16,4 °C durante l'inizio dell'Olocene. Le ricostruzioni durante l'episodio freddo del Dryas recente sono basate su un numero basso di esemplari, e rimangono dunque incerte.

Key words: fossil chironomids, Late Glacial, temperature reconstruction, transfer function, paleolimnology, Trentino
Parole chiave: chironomidi fossili, Tardoglaciale, ricostruzioni di temperature, funzioni di trasferimento, paleolimnologia, Trentino

1. INTRODUCTION

The Chironomidae are a family of the true flies (Diptera) whose larvae are found in freshwater habitats ranging from small temporary water bodies to large lakes and streams. The family is species rich with presently 1194 species reported from Europe (Saether & Spies 2004). A single lake can contain more than 100 different chironomid species (e.g. Harper & Cloutier 1986) and, since many lacustrine chironomid species are considered indicative for lake nutrient conditions, the Chironomidae have a long tradition as indicator organisms in lakes (e.g., Saether 1979; Wiederholm 1980).

Remains of chironomid larvae, especially the strongly sclerotized head capsules, preserve well in lake sediments. Chironomid head capsules remain identifiable, usually at least to genus level, although many subgeneric morphotypes can be recognized as well (e.g., Brooks *et al.* 2007). Surveys studying subfossil chironomid assemblages in lake surface sediments have revealed that the distribution of many chironomid taxa in temperate and subarctic regions is strongly related to summer air and water temperature (e.g., Walker *et al.* 1991; Heiri & Lotter 2005; Brooks 2006). This relationship is strong enough that chironomid-temperature transfer functions can be developed to reconstruct past summer temperatures based on fossil chironomid assemblages. In Europe, chironomid-based temperature transfer functions are now available from Scandinavia and Central Europe (e.g., Lotter *et al.* 1997; Larocque *et al.* 2001; Korhola *et al.* 2002; Heiri & Lotter 2005) and these inference models typically reconstruct summer temperatures with a prediction error of 1-1.5 °C.

The Lateglacial period, ca. 14,700-11,500 calibrated radiocarbon years BP (cal. yrs BP), was an episode of changing environmental conditions in Europe, in which the climate system shifted from the glacial to the interglacial mode (e.g. Björck *et al.* 1998; Magny *et al.* 2006). In the North Atlantic region the Lateglacial is characterized by a rapid increase in temperatures at the start of the Lateglacial Interstadial (ca. 14,700 cal. yrs BP; e.g. Brooks and Birks 2000; Johnsen *et al.* 2001; Magny *et al.* 2006). In the following ca. 2000 years the climate stayed comparatively warm before temperatures reverted back to cooler values during the Younger Dryas cold period, ca. 12,650-11,500 cal. yrs BP (e.g., Birks & Ammann 2000; Lotter *et al.* 2000). At the end of this cold phase, at the Younger Dryas/Holocene transition, temperatures increased again to values comparable to the modern climatic conditions.

In Italy, the few palaeoclimate and palaeovegetation reconstructions available record a similar sequence of climatic events as recorded from Northern and Central Europe, i.e. a warm Lateglacial Interstadial followed by the Younger Dryas cooling before climatic conditions reach comparatively stable and warm Holocene values (e.g., Leroy *et al.* 1996; Lowe *et al.* 1996). A number of these studies are from the southern Alps (e.g., Frisia *et al.* 2005; Pini 2002). However, only few quantitative climate reconstructions for the Lateglacial are available from this region (e.g. Ortu *et al.*, 2006).

Here we present a Lateglacial chironomid record and a chironomid-based July air temperature reconstruction from Lago di Lavarone, a small lake in the Trentino region, North-East Italy. The lake has been the focus of a multi-proxy study with the aim of reconstructing the palaeoenvironmental history of the region and has provided a continuous sediment record reaching from shortly after deglaciation to the present. Within this article we present and discuss chironomid remains identified in the lateglacial part of the sequence which was characterized by a number of distinct and clearly interpretable shifts in the chironomid assemblages. Parts of the late Holocene record of Lago di Lavarone have also been analyzed and the results are presented in a companion paper (Filippi *et al.* 2007).

2. STUDY AREA

Lago di Lavarone is situated at ca. 1100 m a.s.l. on a karstic plateau (Altopiano di Folgaria e Lavarone, Trentino, NE Italy; 45°56′10″N/11°15′10″E). It has a surface area of 0.05 km^2 and a maximum depth of 17 m. Although the lake presently experiences two overturns per year, bottom waters stay almost permanently anoxic. For more details on the physico-chemical properties of the lake water we refer to the paper of Corradini *et al.* (2007).

3. METHODS

In 2003 two up to 10 m long sediment cores were obtained from the deepest part of Lago di Lavarone using an UWITEC piston corer. The cores were correlated using lithological marker layers and physico-chemical properties (magnetic susceptibility, water content, see Filippi *et al.* 2007, for details). 19 terrestrial plant remains were submitted for ^{14}C AMS dating. Four of these dates were rejected: Two measurements provided age estimates obviously too young, and two further dates clearly came from a turbidite and were therefore eliminated from age-depth modeling. The remaining 15 ^{14}C dates, together with an age estimate near the core top based on ^{210}Pb dating, provided an age assessment of the record down to 5.14 m sediment depth (dated to a 1 σ age interval of 12,990-13,150 cal. yrs BP). Below this depth a tentative age estimate has been assigned to the chironomid samples based on a linear extrapolation of the sedimentation rate of the lowermost part of the dated sediment sequence. Further details on the coring effort, the sediment lithology, the dating of the record and the development of the age-depth relationship for the sediments using mixed effect regression are provided in Filippi *et al.* (2007).

Sediment samples for chironomid analysis were sieved using a 100 μm mesh size sieve. The sieve residue was examined at 25-40x magnification using a stereo microscope. Chironomid head capsules and other invertebrate remains of interest were mounted in Euparal mounting medium and identified under the compound microscope at 100-400x magnification. Fossil chironomid taxonomy largely follows

Wiederholm (1983), Schmid (1993), Rieradevall & Brooks (2001) and Brooks *et al.* (2007). Other invertebrate remains were identified by comparison with complete, mounted invertebrate specimens and with reference to Sweetman & Smol (2006), Francis (2001), Walker (2001) and Rumes *et al.* (2005).

Numerical analyses (transfer function development and quantitative reconstruction) were implemented using the program C2 (Juggins 2003) version 1.4.3.

4. RESULTS

4.1. Chironomid assemblages

The Lateglacial sequence was identified within the Lago di Lavarone record at ca. 490-550 cm sediment depth based on the available radiocarbon dates, on lithological changes and on the palynological results (Filippi *et al.* 2007). Over this time window, and including the oldest part of the Pleniglacial and the earliest Holocene, a total of 52 horizons were analyzed for fossil chironomid assemblages. Chironomid concentrations in the Lago di Lavarone sediments were very low in parts of the record, ranging from 0.5 to 22 chironomid head capsules per cm^3. Since chironomid count sums were far below the numbers recommended for chironomid analysis (Heiri & Lotter 2001; Larocque 2001; Quinlan & Smol 2001) adjacent samples were amalgamated where necessary to reach more reliable counts. This amalgamated dataset contained a total of 17 chironomid samples based on 2.2 to 16.4 cm^3 of analyzed sediment per sample.

In the lowest part of the analyzed sequence chironomid concentrations were comparatively high (6-17 head capsules cm^{-3}). Chironomid assemblages were dominated by taxa such as *Heterotrissocladius grimshawi*-type, *Stictochironomus*, *Tanytarsus lugens*-type, *Micropsectra insignilobus*-type, *Chironomus anthracinus*-type and *Paracladius* (Fig. 1). The earliest occurrence of mandibles of the phantom midge *Chaoborus flavicans* was at ca. 550 cm depth. An abrupt change in chironomid assemblages is recorded at ca. 546 cm sediment depth (Fig. 1). Many of the taxa present in the earliest part of the record disappear and new taxa such as *Paratanytarsus penicillatus*-type, *Tanytarsus pallidicornis*-type /type VI, *Polypedilum nubeculosum*-type, *Psectrocladius sordidellus*-type, *Corynoneura arctica*-type, or *Dicrotendipes nervosus*-type colonized Lago di Lavarone. However, other taxa, e.g. *Procladius*, *C. anthracinus*-type and *Parakiefferiella* type L – a *Parakiefferiella* morphotype with only 5 lateral teeth on the mentum – did not show major changes in abundance at this sediment depth.

At ca. 515-520 cm depth another group of taxa appears in the record, e.g. *Ablabesmyia*, *Paramerina* and *Einfeldia*. At ca. 508 cm depth, the chironomid concentrations in the Lago di Lavarone record decrease abruptly and between 493 and 508 cm only 16-19 head capsules were available per sample (Fig. 1). At the same time many chironomid taxa that occurred regularly in the earlier part of the record (e.g., *Ablabesmyia*, *Corynoneura edwardsi*-type, *D. nervosus*-type) disappeared, whereas other chironomids persist in this part of the record (e.g. *Glyptotendipes*, *Paratendipes albimanus*-type, *Microtendipes*, *P. penicillatus*-type). *C. anthracinus*-type dominates assemblages for most of the Lago di Lavarone sequence. However, between 493 and 508 cm it reaches some of the highest abundances in the entire record.

At ca. 493 cm many of the chironomids already present between 510-545 cm sediment depth reappear in the record, and between ca. 493 and 487 cm chironomid concentrations increase again to ca. 7-11 head capsules cm^{-3}. Chironomid assemblage composition remains similar for the rest of the analyzed sequence (470-493 cm). However, a distinct increase in bryozoan statoblasts is registered at ca. 478-483 cm sediment depth. *Plumatella*-type statoblasts are present in the Lago di Lavarone sediments from 555 cm onwards. However, at 483-478 cm their abundance relative to the number of chironomids increases significantly. Furthermore, *Cristatella*-type statoblasts are only found in this interval of the Lago di Lavarone sequence.

4.2 Quantitative summer temperature reconstruction

For the reconstruction of July air temperatures based on the Lago di Lavarone sequence a calibration dataset was available consisting of 118 chironomid assemblages from lake surface sediments obtained from the Central Swiss Alps, the Northern Swiss Alps, the Swiss Plateau and the Jura mountains (Lotter *et al.* 1997; Heiri 2001; Heiri & Lotter 2005; Bigler *et al.* 2006). Samples from 3 lakes were excluded from further modeling because they did not contain sufficient chironomids for quantitative analysis, 7 were excluded because the lakes were affected by unusual hydrologic conditions or were heavily modified by human activity, and 7 were deleted as outliers because they were strongly affected by shading or unusually deep in relation to the remaining sites in the calibration dataset. The remaining 101 sites were used to produce a chironomid-July air temperature transfer function that predicts temperature based on chironomid assemblage composition. Calculations were based on Weighted averaging-partial least squares regression (WA-PLS; ter Braak & Juggins 1993; ter Braak *et al.* 1993) and square root transformed chironomid percentage data. Only chironomid taxa with at least 3 occurrences in the calibration data were retained in the inference model. If assessed in the 101-lake modern calibration data-

Fig. 1 - Chironomids and other aquatic invertebrate remains in the sediments of Lago di Lavarone. Abundances are given as percentages relative to the total number of chironomids per sample, except where indicated otherwise.

Fig. 1 - Chironomidi e altri resti di invertebrati acquatici trovati nel sedimento del Lago di Lavarone. Le abbondanze sono espresse in percentuale relativa al numero totale di individui per campione, eccetto dove indicato diversamente.

set using leave-one-out cross-validation, this transfer function – which covers a July air temperature range of 5.0-18.4 °C – infers July air temperature with a root mean square error of prediction (RMSEP) of 1.31 °C and a coefficient of determination (r^2) of 0.89 (Fig. 2).

Of the 49 chironomid taxa identified in the Lateglacial and early Holocene Lago di Lavarone sequence 45 were represented in the calibration dataset. Three of the taxa not represented in the calibration data (*Nilothauma*, *Psectrocladius barbimanus*-type and an unknown Orthocladiinae head capsule type) occurred only once, as a single complete or split head capsule. In contrast, *Parakiefferiella* type L occurred regularly in the sequence (Fig. 1). However, the maximum abundance of this fourth head capsule type which was not represented in the calibration dataset was 6.3% in any given sample. Chironomid-inferred July air temperature in the lowest part of the record ranged from 10.5 to 10.8 °C (Fig. 3). At ca. 546 cm sediment depth a distinct increase in inferred temperatures is registered and between ca. 530 and 546 cm July air temperatures of 13.8-13.9 °C are inferred. Starting at ca. 520 cm the temperatures increase gradually to reach 15.3 °C at 510 cm. A period of cooler summer temperatures is inferred from ca. 493-508 cm although temperatures are very variable in this part of the record and range from 11.7 to 14.5 °C. At ca. 493 cm chironomid-inferred July air temperatures increase again and remain between 15.8 and 16.4 °C for the rest of the analyzed sequence. Sample-specific standard errors of prediction were estimated for the samples based on 100 bootstrapping cycles (Birks *et al.*, 1990). These sample specific prediction errors ranged from 1.36 to 1.47 °C in the Lavarone sequence (Fig. 3).

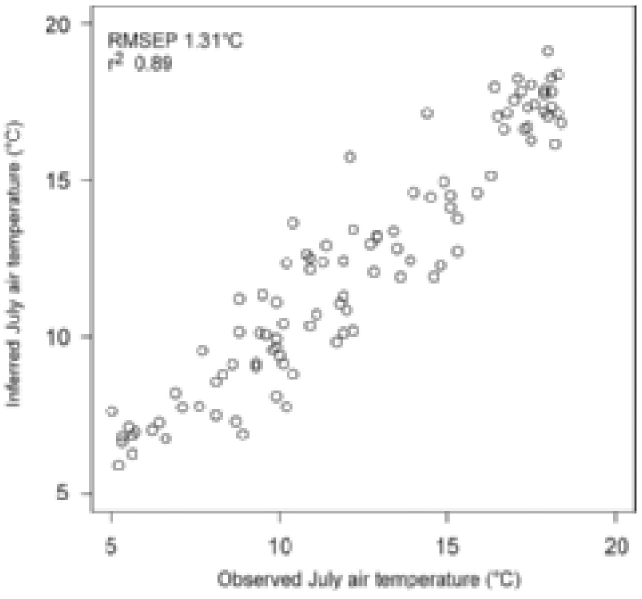

Fig. 2 - Performance of the applied chironomid-July air temperature inference model. Chironomid-inferred temperatures are plotted versus the observed July air temperature values for all the lakes in the model. Inferred values are calculated based on a leave-one-out cross-validation procedure.

Fig. 2 - Performance del modello di inferenza applicato, riguardante la temperatura dell'aria di luglio. Le temperature dedotte dai Chironomidi sono confrontate nel grafico con i valori delle temperature dell'aria nel mese di luglio osservate per tutti i laghi del modello. I valori dedotti sono calcolati sulla base di una procedura di tipo leave-one-out cross-validation.

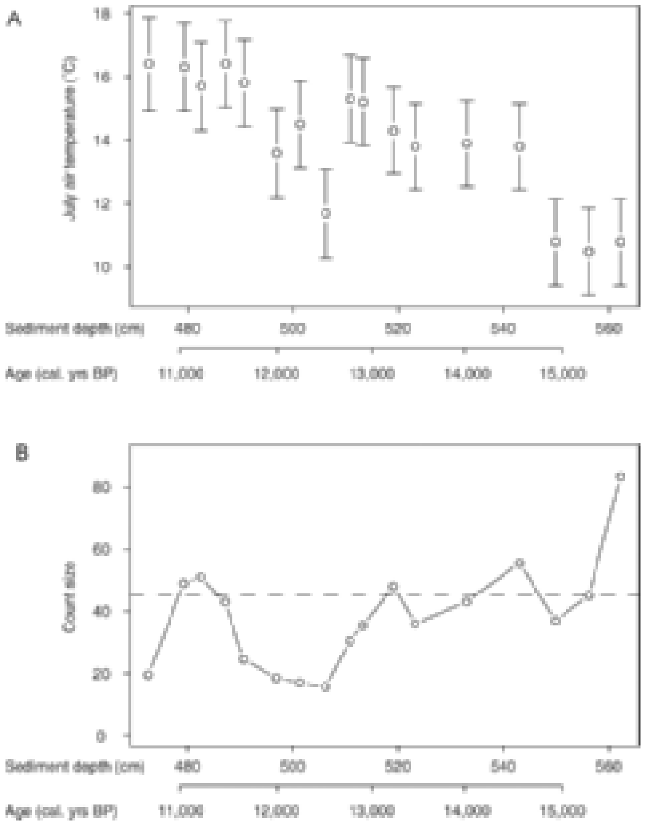

Fig. 3 - Chironomid-inferred July air temperatures and sample count size in the Lago di Lavarone record. A) Chironomid-inferred July air temperatures with sample specific standard errors. B) Counts per sample in the Lavarone record. The dashed line indicates the threshold of 45 chironomid head capsules per sample which is usually recommended for quantitative analysis (Heiri & Lotter 2001; Larocque 2001; Quinlan & Smol 2001).

Fig. 3 - Temperature dell'aria del mese di luglio dedotte dai chironomidi e numero di individui contati per campione nel record del Lago di Lavarone. A) Temperature dell'aria del mese di luglio dedotte dai chironomidi con barra di errore specifica per campione. B) Individui contati per campione nel record di Lavarone. La linea tratteggiata indica il limite di 45 capsule cefaliche di chironomidi per campione, numero normalmente raccomandato per le analisi quantitative (Heiri & Lotter 2001; Larocque 2001; Quinlan & Smol 2001).

A comparison of the chironomid-inferred temperatures with the count size of the samples (Fig. 3) reveals that the count sum is slightly above or below the value of 45 head capsules per sample that is commonly recommended for chironomid analysis (Heiri & Lotter 2001; Larocque 2001; Quinlan & Smol 2001) for most of the sequence. However, in two parts of the record, at ca. 490 to 508 cm and at 473 cm, chironomid counts are below 25 specimens per sample. The variability of chironomid-based inferences increases disproportionately at count sums below ca. 30 head capsules (Heiri & Lotter 2001) and reconstructions based on these parts of the Lago di Lavarone chironomid record should therefore only be interpreted with caution.

5. DISCUSSION

5.1. Chironomid and aquatic invertebrate assemblages

The isolated fossils of chironomid larvae and other aquatic invertebrates suggest that during the entire analyzed sequence Lago di Lavarone was susceptible to anoxia in the hypolimnion. *Chironomus* larvae of the *C. anthracinus*-type are typical inhabitants of standing waters with low oxygen conditions (e.g., Hamburger *et al.* 1994). Similarly, *C. flavicans* is usually abundant in lakes with hypoxic conditions in the hypolimnion (e.g., Liljendahl-Nurminen *et al.* 2002). During the earliest part of the record, from ca. 563 to 550 cm, *Chaoborus* was largely absent and a number of chironomids typically found in oligo- to mesotrophic northern and mountain lakes were present in Lago di Lavarone. For example, *Micropsectra*, *Heterotrissocladius* and larvae of the *T. lugens*-type are all typical for oligo-mesotrophic lakes in Scandinavia (e.g., Saether 1979; Wiederholm 1984) or for high altitude lakes in the Alps (Bretschko 1974; Heiri 2001; Boggero *et al.* 2006). This suggests that at this time Lago di Lavarone was an oligotrophic-mesotrophic lake with a tendency to anoxic conditions in the hypolimnion, possibly as a consequence of the lake's comparatively low surface to depth ratio.

At ca. 550 cm the first remains of *C. flavicans* are found in the record and between 555 and 543 cm sediment depth many of the taxa typical for cool oligo-mesotrophic lakes disappear and are replaced by chironomids more typical for shallow lakes and littoral conditions in temperate climates, e.g. *P. sordidellus*-type, *D. nervosus*-type, *Glyptotendipes* or *T. pallidicornis*-type/tipe VI (see e.g. Heiri 2001). *C. anthracinus*-type and *Procladius*, taxa present in this part of the record, are among the profundal chironomids most resistant to anoxic conditions. Most of the other chironomids found in Lago di Lavarone between 543 and 510 cm are typical inhabitants of the littoral zone, although *Paratendipes*, *Psectrocladius*, *Pagastiella* and *Polypedilum* are occasionally found in the profundal of lakes (see e.g. Moog 1995). This suggests that a large part of the chironomids deposited in the centre of Lago di Lavarone in this part of the sequence have been transported from the littoral and the sublittoral region of the lake, whereas the lake centre only supported comparatively low densities of chironomids adapted to hypoxic conditions. Hence, Lago di Lavarone seems to have been a meso-eutrophic lake during this period with a strong susceptibility to anoxia.

Between ca. 510 and 493 cm chironomid concentrations decrease significantly. Since sedimentation rates do not show a major change during this period (Filippi *et al.*, this issue), this suggests that chironomid densities in the lake's hypolimnion decreased even further and that anoxic conditions became more severe, leading to a decline in overall chironomid abundances. This episode in Lago di Lavarone's history is marked by the disappearance of many chironomid taxa typical for warm lowland lakes (Fig. 1). Furthermore, a comparison with the available pollen results for Lago di Lavarone indicates that this was a phase of more open landscapes in the region (Filippi *et al.* 2007) and, based on the ^{14}C dating of this part of the record, equivalent to the Younger Dryas cold phase. A possible explanation for reduced chironomid concentrations is, therefore, that cooler temperatures led to prolonged winter ice-cover and reduced the overturning of the lake during early spring or late autumn. At ca. 493 cm many of the chironomids that were eliminated from the record reappear again and at ca. 487 cm depth chironomid concentrations reach higher values than before the Younger Dryas, suggesting again higher oxygen levels in Lago di Lavarone. At 487-482 cm an abrupt increase in bryozoan statoblasts is registered in the sediments (Fig. 1), although no clear coeval change in chironomid assemblages is apparent. Statoblasts of the *Plumatella*-type increase distinctly and statoblasts of the *Cristatella*-type show their first and only appearance in the record. Bryozoan statoblasts have previously been interpreted as indicating the relative extent of the littoral zone in lakes, lake level fluctuations, and past temperature and trophic state changes (Francis 2001). However, due to lacking data on their distribution in lacustrine sediments it is presently not possible to interpret bryozoan records in a straightforward manner (e.g., Crisman *et al.* 1986), especially in cases such as the Lago di Lavarone record where the statoblasts have not been identified to species level. Nevertheless, the distinct increase in statoblast abundance and the occurrence of *Cristatella*-type statoblasts at 487-482 cm do suggest a distinct change in the limnological conditions in Lago di Lavarone. This is especially intriguing since the timing of this episode (11,200-11,000) shows a reasonably close temporal agreement with the Preboreal Oscillation reported from Central and Northern Europe (e.g., Lotter *et al.* 1992; Björck 1997).

5.2. *Chironomid-inferred temperature reconstruction*

During a significant part of the Lago di Lavarone record count sums were below 45 specimens per sample which is commonly considered an appropriate minimum count sum for chironomid-based palaeoenvironmental reconstruction. However, the chironomid-based July air temperature reconstruction (Fig. 3) shows a clear sequence of climatological events. In the earliest part of the record July air temperatures of 10.5-10.8 °C are reconstructed. Between 550 and 545 cm (ca. 15,000-14,600 cal. yrs BP) temperatures increase abruptly to 13.8-13.9 °C. We correlate this increase with the Oldest Dryas/Bølling transition, which has been reported, amongst other regions, from the Northern Alpine area (Lotter *et al.* 1992), the Jura mountains (Heiri & Millet 2005; Magny *et al.* 2006) and the Greenland ice cores (e.g., Johnsen *et al.* 2001), and has been dated to approximately 14,700 cal. yrs BP (Johnsen *et al.* 2001; Magny 2001). To our knowledge this temperature increase has not previously been quantified in the region of Lago di Lavarone. Nevertheless, the July air temperature increase of ca. 3 °C inferred at Lavarone is slightly lower but of similar amplitude as the rise in July temperatures inferred in the Jura mountains by chironomids (ca. 3-3.5 °C; Heiri & Millet 2005; Magny *et al.* 2006), whereas a pollen-based reconstruction from the Jura mountains reconstructs a more distinct increase of 5 °C in the temperature of the warmest month for this transition (Peyron *et al.* 2005).

During the first part of the Lateglacial Interstadial inferred temperatures in the Lavarone record remain comparatively stable. In the younger part of the interstadial temperatures increase slightly to reach values around 15.3 °C. A similar pattern of interglacial temperature increase has been reconstructed by Heiri and Millet (2005) for the Jura Mountains. In this reconstruction temperatures increase gradually in the first few centuries of the interstadial after the intial abrupt temperature rise at the Oldest Dryas/Bølling transition. In contrast, the temperature rise at Lago di Lavarone takes place later in the interstadial at ca. 13,000 cal. yrs BP. However, it has been previously noted that in North Italy the end of the Lateglacial Interstadial is marked by the expansion of thermophilous tree-species (Finsinger 2004) and the Lago di Lavarone record suggests that this expansion may be related to an increase in local summer temperatures.

At ca. 12,650 cal. yrs BP temperatures decrase abruptly in the Lago di Lavarone record. During the next ca. 1000 years inferred temperatures are very variable, most likely due to the very low count sums in the chironomid samples. Nevertheless, the Lavarone record clearly indicates a distinct cooling which, as indicated above, can be correlated with the Younger Dryas cold phase. The average July air temperature of 13.3 °C of the three Younger Dryas samples in the record (range: 11.7-14.5 °C) would suggest a ca. 2 °C difference to the Lateglacial interstadial and a 2.5 °C difference in comparison with the earliest Holocene. This would be slightly higher than the increase of July air temperatures of ca. 1.5-2 °C inferred by chironomid records for this latter transition to the north of the Alps (Heiri *et al.* 2003; Heiri *et al.* 2004; Heiri & Millet 2005). However count sums are so low in this part of the record that the results should only be interpreted with caution.

Chironomid inferred temperatures increase to 15.8-16.4 °C during the earliest Holocene. A very minor decrease in chironomid-inferred temperature is reconstructed at ca. 11,200 cal. yrs BP and synchronous with the increase in bryozoan statoblasts in the Lago di Lavarone sediments. However, this decrease of ca. 0.5 °C is well within the prediction error of the chironomid-temperature inference model.

6. CONCLUSION

Chironomid head capsules and other aquatic invertebrate remains in the sediments of Lago di Lavarone were analyzed in order to reconstruct Lateglacial palaeoenvironmental conditions and summer temperature at the lake. The fossil invertebrate assemblages contained taxa adapted to low oxygen conditions during the entire analyzed sequence. Before the Lateglacial Interstadial (>ca. 14,700 cal. yrs BP) these taxa were supplemented by a group of chironomids typically found in oligo- to mesotrophic northern and mountain lakes. At the transition to the Interstadial most of these cold adapted taxa disappeared and, in the following ca. 2000 years, chironomids typical of lowland lakes in temperate latitudes dominated in Lago di Lavarone. During the Younger Dryas cold episode many of these lowland taxa disappeared from the sediments and chironomid concentrations decreased significantly, suggesting that anoxic conditions in the lake may have become more severe, possibly due to prolonged periods of ice cover on the lake. After the Younger Dryas chironomid assemblages rapidly reverted to an assemblage composition similar to the one during the Lateglacial Interstadial.

A chironomid-July air temperature transfer function based on chironomid assemblages from Central Europe reconstructs cool July air temperature of 10.5-10.8 °C before the Lateglacial Interstadial, temperatures of 13.8-13.9 °C during most of the interstadial with slightly higher inferred values shortly before the Younger Dryas, very variable temperatures of 11.7-14.5 °C during the Younger Dryas cool episode and temperatures of 15.8-16.4 °C in the earliest Holocene. Although the number of analyzed chironomids per sample was low for a significant part of the Lago di Lavarone record the reconstructed temperatures were in good agreement with the Lateglacial temperature development expected for the region. However, the very variable temperatures reconstructed during the Younger Dryas cold interval were probably affected by the very low count size in this part of the record.

The Lago di Lavarone chironomid record provides the first quantitative Lateglacial summer temperature reconstruction for the Trentino area and indicates that chironomid-temperature transfer functions developed in the Northern and Central Alpine region can be successfully applied to chironomid records from the Southern Alps. The reconstruction suggests small but significant differences with available summer temperature reconstructions from Central Europe, e.g. the warming at the end of the Lateglacial interstadial. Additional records in the region are necessary to corroborate these differences in temperature developments. However, the present results suggest that distinct shifts in Lateglacial temperature gradients may have taken place across the Alpine region and these spatial patterns in temperature development may well provide important information on the nature and cause of Lateglacial temperature change in Europe.

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