Studia Quaternaria, vol. 21: 117–127.

SUBFOSSIL CHIRONOMID ASSEMBLAGES AS PALEOENVIRONMENTAL INDICATORS IN LAKE FAULERSEE (GERMANY)

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Abstract

Remains of chironomid larvae from cores of the ancient Lake Faulersee in northern Germany were examined. Pollen, radiocarbon datings, and geochemical data were used to develop the chronology of the Late-Glacial Period in Lake Faulersee and to validate interpretations made by chironomid data. Factors influencing the composition of the subfossil chironomid assemblages were assessed. Our data indicate fluctuations of temperature, lake-level, and trophic state in the Late-Glacial. Furthermore, we explain a discontinuous sequence found in the cores of Lake Faulersee pertaining to a refilling event about 5,800 cal years before present (BP).

Key words: Chironomidae, lake-level, temperature, shallow lake, trophic state

INTRODUCTION

Subfossil remains of chironomid larvae are produced as dead specimens and exuviae during each of the insects‘ four larval stages (Walker, Mathewes 1987). The advantage of chironomids over most other zoological palaeindicators is that they are ubiquitous, occurring in high concentrations in most freshwater habitats (Brooks *et al.* 1997), even in acidic ones (Rodrigues, Scharf 2001). Chironomids provide valuable information on the environmental conditions during lake ontogeny (Hofmann 1988), because various ecological factors determine the species composition of chironomid communities and are, in turn, reflected in the subfossil assemblages. To interpret successional changes, the influence of abiotic and biotic factors has to be considered (Hofmann 1988). However, it is very often not possible to separate the main influencing factor only by chironomid analysis. Therefore results obtained by chironomids should always be compared with other palaeolimnological data.

In our investigation we try to reconstruct environmental changes during the history of a shallow lake, Lake Faulersee. The main palaeolimnological tool is the interpretation of chironomid remains, with supporting evidence from pollen and geochemical data.

STUDY SITE

Lake Faulersee is located in the eastern part of Northern Germany (Fig. 1), 1.5 km east of Lake Arendsee, a deep lake which was formed in several steps since the last Late-Glacial due to the solution of a salt dome in the underground (Röhrig, Scharf 2002). Lake Faulersee was drained into Lake Arendsee in 1960 and is now used as a meadow for agriculture.

METHODS

Coring sites and sampling

Four sediment cores were collected in Lake Faulersee (Fig. 1, Fig. 2). Three sediment cores were taken 30 m from the former shoreline (FAU1b, FAU1c, FAU1e) and one in the deepest part of the lake (FAU2a). The 3 m long core of FAU1b was subsampled in regions of expected faunal change (clay/ gyttia/ silt; or changing colour). The cores FAU1c, FAU1e and FAU2a were divided into 2 cm slices. The distances between the sub-cores of site FAU1 (FAU1b, FAU1c, and FAU1e) were 1 m.

Geochemistry

Organic and carbonate content were determined by loss-on-ignition (LOI) at 550 °C and 880 °C for 2 hours, respectively. Elements were analysed using X-ray fluorescence (WDXRF).

Pollen analysis

Pollen analyses of cores FAU1c, FAU1e, and FAU2a were performed according to standard methods (Beug 1957). The objective of the pollen analysis was to establish the chro-

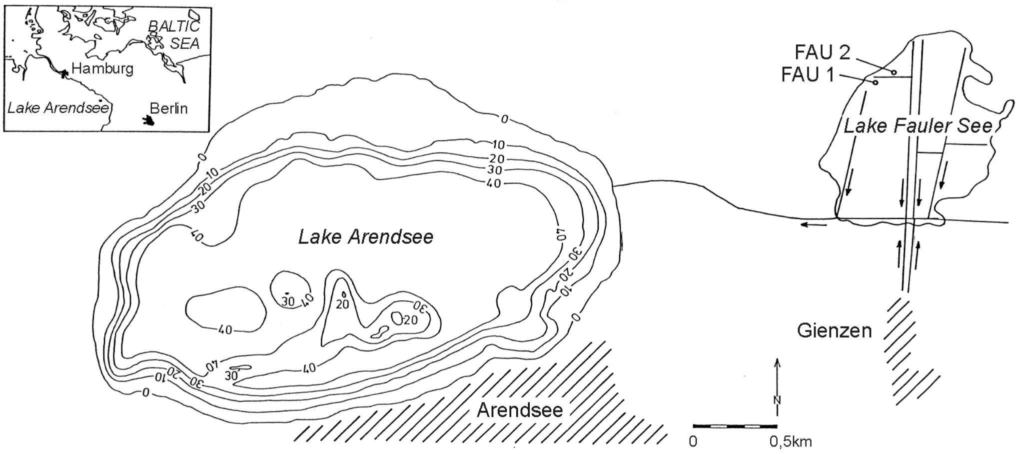

Fig. 1. Location of the ancient Lake Faulersee and sample sites.

nology of Lake Faulersee to identify major changes in the vegetation of the catchment during the ontogenesis of the lake.

Radiocarbon dating

Calibrated years before present (cal BP) were obtained by radiometric determination on bulk organic carbon. The carbon of the sample was extracted and dissolved into benzene, which was then prepared for liquid scintillation counting (LSC). Standard accelerator-mass-spectrometry (AMS) on algae mud and peat was used as a second dating technique (Leibniz-Labor for Radiometric Dating and Isotope Research, Kiel, Germany). Radiocarbon ages were calibrated by the Radiocarbon Calibration Program Rev 4.3 (Stuiver, Reimer 1993).

Chironomid analysis

1 to 9 ml samples were taken from the cores FAU1b, FAU1e, and FAU2a for treatment and further analysis. Chironomid remains were isolated by deflocculation in warm 5–10% KOH, and by sieving on 200 and 100 µm mesh sieves, respectively. The head capsules (hc) were separated from the sediment in a dish at a magnification of 35 x. A minimum of 50 specimens was selected in each sample, except

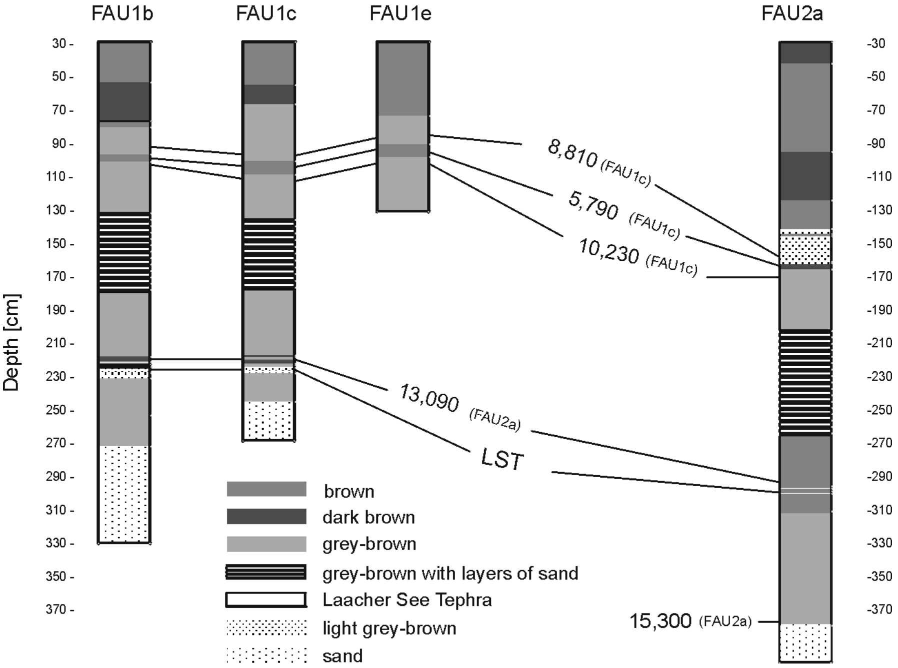

Fig. 2. Stratification of the cores collected from Lake Faulersee. The distances between the sample sites FAU1b, FAU1c, and FAU1e are about 1 m, respectively. Ages in cal BP. LST = Laacher See Tephra.

Table 1

Used chironomid indicators for lake temperature, trophic state, and lake-level of Lake Faulersee

Taxa	References
cold-water taxa:	
unidentified Orthocladiinae	(Lotter *et al.* 1999)
Sergentia coracina	(Brundin 1949, Brodin 1986)
Stictochironomus spec.	(Lotter *et al.* 1997)
Micropsectra spec.	(Lotter *et al.* 1997)
warm-water taxa:	
Cladopelma spec.	(Walker *et al*. 1997, Lotter *et al.* 1999; Larocque *et al.* 2001)
Lauterborniella agrayloides	(Lotter *et al.* 1997, 1999)
Parachironomus spec.	(Lotter *et al.* 1997, 1999)
Pseudochironomus spec.	(Lotter *et al.* 1997, 1999, Walker *et al.* 1997)
eutrophic taxa:	
Cricotopus spec.	(Brodersen 1998, Lotter *et al.* 1998)
Chironomus plumosus-type	(Dévai, Moldovan 1983, Francis, Kane 1995, Svensson 1998)
Endochironomus spec.	(Brodin 1986, Brodersen 1998, Lotter *et al.* 1998)
Glyptotendipes spec.	(Brodersen 1998, Lotter *et al.* 1998)
Lauterborniella agrayloides	(Lotter *et al.* 1998)
Parachironomus spec.	(Lotter *et al.* 1998)
oligo-/mesotrophic taxa:	
Pagastiella orophila	(Bayerisches Landesamt für Wasserwirtschaft 1992, Brundin 1949)
Micropsectra spec.	(Hofmann 1984, Lotter *et al.* 1998)
littoral taxa:	
Pentaneurini	(Hofmann 1971)
Corynoneura spec.	(Hofmann 1971)
Cricotopus spec.	(Brundin 1949, Hofmann 1971)
Psectrocladius spec.	(Hofmann 1971, Brodin 1986)
Endochironomus spec.	(Brundin 1949, Hofmann 1971)
Glyptotendipes spec.	(Hofmann 1971, Brodin 1986)
Lauterborniella agrayloides	(Hofmann 1971)
Pseudochironomus spec.	(Brundin 1949, Hofmann 1971, Brodin 1986)
Stenochironomus spec.	(Hofmann 1971)
Cladotanytarsus spec.	(Brundin 1949, Hofmann 1971)
Corynocera ambigua	(Hofmann 1971)
Paratanytarsus spec.	(Brundin 1949, Hofmann 1971)
profundal taxa:	
Chironomus anthracinus-type	(Brundin 1949, Hofmann 1971, Brodersen 1998)
Sergentia coracina	(Brundin 1949, Hofmann 1971, Little, Smol 2001)
Stictochironomus spec.	(Brundin 1949, Hofmann 1971)
Micropsectra spec.	(Brundin 1949, Hofmann 1971, Little, Smol 2001)

samples FAU 1e 94–96 cm (19 hc) and FAU1e 100–102 cm (29 hc). All *Chaoborus* mandibles were also picked. The remains were mounted in Hydromatrix® on microscope slides. Identifications were made at magnifications of 100 to 1000 x. Head capsules were counted following the instructions of Walker *et al.* (1991). Taxonomic literature used includes Hofmann (1971), Müller (1995), Sæther (1970), Schmid (1993), Walker (1988a), and Wiederholm (1983). It was not possible to provide all identifications at the generic level. Thus, several broader taxonomic categories, e.g. Pentaneurini, unidentified Orthocladiinae and Tanytarsini, have been designated. The following taxa were used as indicators for lake temperature, trophic state, and lake-level (Table 1).

Chironomid zones

Chironomid zones of core FAU2a were obtained using the software: ZONE (Version 1.2) which is written by Steve Juggins for the editing, transformation, and zonation of palaeoecological data.

RESULTS

Core-correlation

The color stratigraphies of the 4 cores of Lake Faulersee are shown in Fig. 2. Distinctive layers for core-correlations are the Laacher See Tephra (LST), the alternating sequence of grey-brown peat and sand, and a thin brown to dark-brown layer, dated 5,790 cal BP, 15 to 22 cm above the latter.

Loss-on-ignition (LOI)

10 LOI zones, Lake Fauler See LOI zone- (FSLOI-), could be distinguished in core FAU2a (Figs. 3, 9). The deposits of Lake Faulersee mainly consist of algae mud (Beug unpublished results) with varying proportions of sand. In core

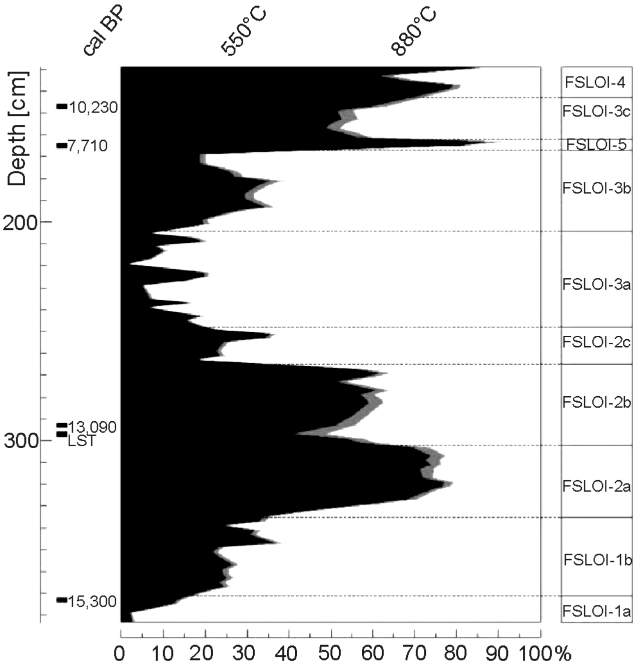

Fig. 3. Loss-on-ignition (LOI) from core FAU2a of Lake Faulersee.

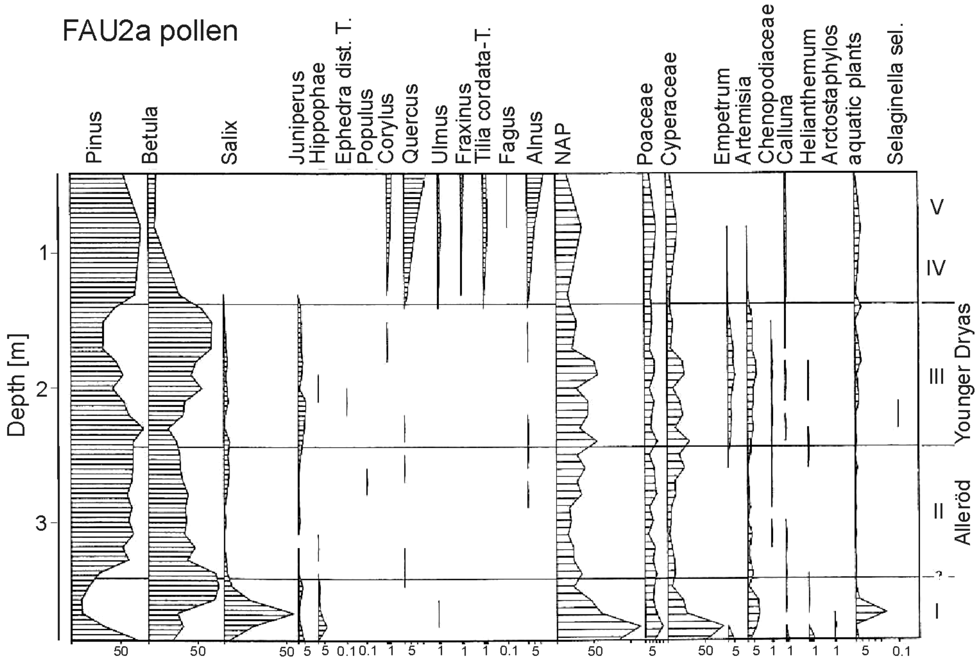

Fig. 4. Pollen diagram of Lake Faulersee for core FAU2a.

Table 2

Uncalibrated radiocarbon dates and calibrated ages for Lake Faulersee

Core	Depth [cm]	Dating method	Material	Radiocarbon age [BP]	Calibrated age [cal BP] in diagram (2σ range)
FAU1c	30-53	LSC	algae mud	5,467 ± 133	6,280 (6,498 - 5,931)
	55-63	LSC	algae mud	7,331 ± 139	8,120 (8,393 - 7,865)
	65-93	LSC	algae mud	7,981 ± 144	8,810 (9,395 - 8,426)
	97-103	LSC	algae mud	5,050 ± 128	5,790 (6,168 - 5,491)
	105-130	LSC	algae mud	8,867 ± 171	10,010 (10,396 - 9,528)
	105-130	AMS	algae mud	9,111 ± 67	10,230 (10,473 - 10,181)
	130-153	LSC	algae mud	9,152 ± 165	10,240 (10,732 - 9,872)
	155-173	LSC	algae mud	10,138 ± 159	11,720 (12,623 - 11,201)
	175-193	LSC	algae mud	10,374 ± 162	12,330 (12,900 - 11,439)
FAU2a	48-50	AMS	algae mud	5,242 ± 32	5,970 (6,169 - 5,924)
	146-148	AMS	algae mud	9,107 ± 41	10,230 (10,395 - 10,192)
	164-166	AMS	algae mud	6,917 ± 33	7,710 (7,815 - 7,667)
	292-294	AMS	algae mud	11,074 ± 48	13,090 (13,183 - 12,675)
	372-374	AMS	algae mud	12,665 ± 67	15,300 (15,524 - 14,281)

FAU2a (Fig. 3) high values of sand (98–62%) were found between 380 and 335 cm (FSLOI–1a/b) and between 265 and 168 cm (FSLOI–2c/FSLOI–3a–c). Organic rich sediments (88–49 %) occurred between 335 and 265 cm (FSLOI–2a/b), with a short decrease (41 %) at 297 cm, and between 168 and 130 cm (FSLOI–5/FSLOI–3c/FSLOI–4).

Pollen zones

5 pollen zones were distinguished from core FAU2a (Fig. 4). Pollen zone I is of pre-Allerød age and belongs to the Older Dryas. Zone I (390–340 cm) starts with high non arboreal pollen (NAP) values indicating open vegetation. This stage was succeeded by an expansion of *Salix* followed by high *Betula* values. Such a succession is a the transition from an open Tundra to forest cover which started at the beginning of zone II. In addition, zone I shows relatively high amounts of *Juniperus*, *Hippophae*, Cyperaceae, *Artemisia*, and other NAP. Furthermore, there is a high relative abundance of aquatic plant pollen, which is mainly caused by *Myriophyllum alterniflorum*.

Zone II (340–245 cm), which corresponds to the Allerød warm period, starts with increases of *Pinus* values and the decline of *Betula*, *Salix*, aquatic plants, and NAP. During this period, the area was covered by *Pinus* forests. The LST layer was found approximately in 295 cm depth which is middle Allerød.

Zone III (245–135 cm), the Younger Dryas cold period,

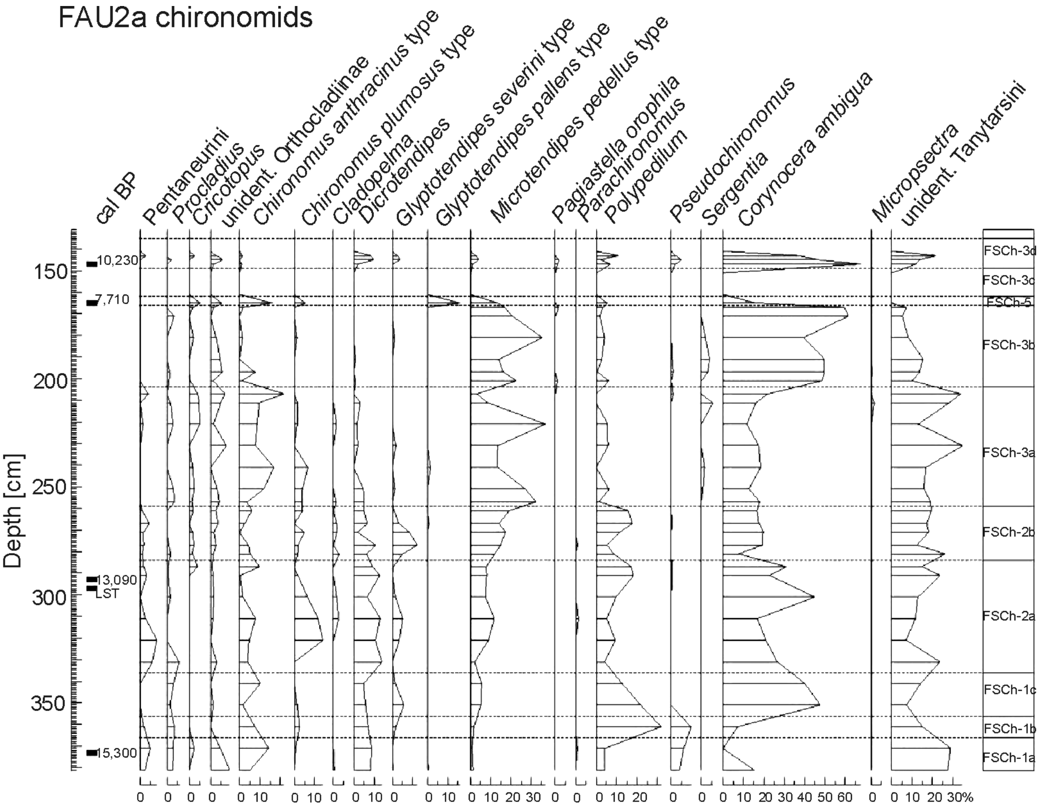

Fig. 5. Chironomid percentage diagram for Lake Faulersee core FAU2a. Chironomid zone boundaries were determined using the software: ZONE (Version 1.2).

is characterized by an increase of *Juniperus*, *Empetrum*, and *Artemisia*, by less *Pinus* and more *Betula*. Apparently, the climatic change created open forests with more shrub vegetation than before. The spread of *Empetrum* heaths is typical for the northwestern areas of Central Europe during the Younger Dryas interval.

The Younger Dryas is followed by the early Holocene pollen zone IV (Preboreal), but due to bad pollen preservation, interpretation of the pollen chronology is difficult.

Radiocarbon datings

6 accelerator mass spectrometry (AMS) radiocarbon datings and 8 liquid scintillation counting (LSC) radiocarbon datings (Table 2) were carried out.

Both dating methods provide comparable ages for section 105–130 cm in core FAU1c. The AMS-dating method attains a smaller range and a slightly older age than the LSC-dating method. With increasing depth the ages raise, except for the depths 97–103 cm in FAU1c and 164–166 cm in FAU2a. These sediments are several 1,000 years younger than the adjacent ones.

Chironomid zones

10 chironomid zones, Lake Fauler See chironomid zone-(FSCh-), could be distinguished in core FAU2a (Figs. 5–9).

The following 3 zones correspond mainly to pollen zone I. Therefore the zones were labelled FSCh–1a, FSCh–1b, and FSCh–1c.

Zone FSCh–1a

More than 75% of the 38 distinguishable chironomid taxa were already present at the beginning of the Lake Faulersee record (FSCh–1a). Around 15,000 cal BP cold-water taxa like unidentified Orthocladiinae began to disappear, whereas the warm-water taxon *Pseudochironomus* slightly increased in abundance (Fig. 5). In the middle of FSCh–1a profundal taxa reached their maximum (15%) in the lower part of the sediment core (Fig. 6). Littoral taxa decreased from 40 to less than 30%.

Zone FSCh–1b

In FSCh–1b warm-water taxa show their first maximum, while littoral taxa fell below 25%.

Zone FSCh–1c

The dominant taxon in FSCh–1c accounting for nearly 50% of the chironomid community was *Corynocera ambigua*. The warm-water taxa dominant in FSCh–1b decreased dramatically and disappeared in FSCh–1c.

The following 2 zones correspond mainly to the Allerød pollen zone. Therefore the zones were labelled FSCh–2a and FSCh–2b.

Zone FSCh–2a

In the beginning of chironomid zone FSCh–2a, Pentaneurini, *Dicrotendipes*, *Microtendipes pedellus*-type, and *Polypedilum* increased in abundance as compared to *Cory-*

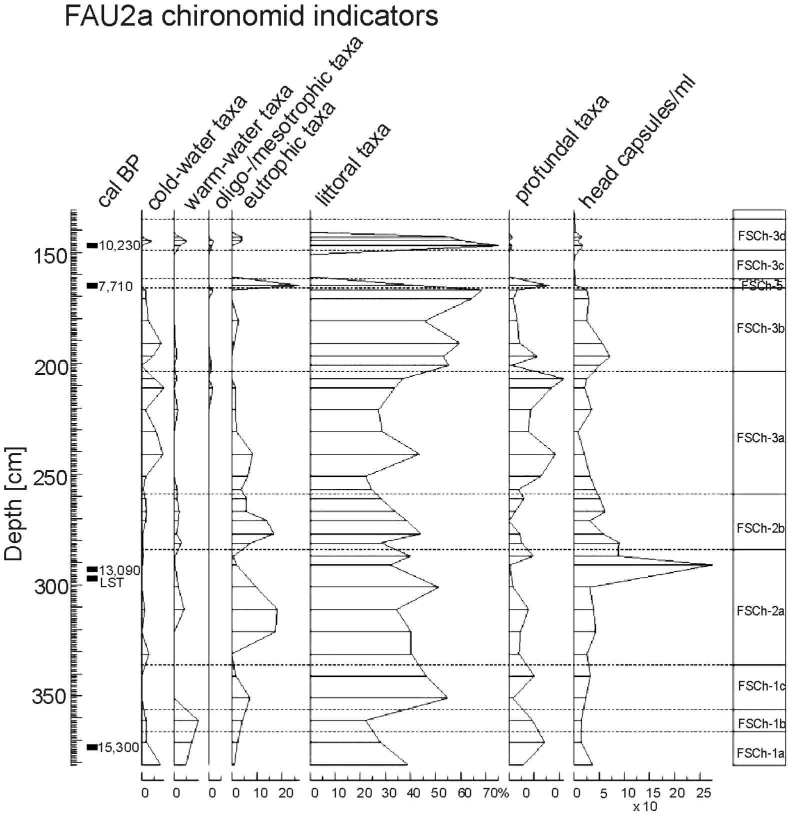

Fig. 6. Chironomid percentage diagram for Lake Faulersee core FAU2a showing changes of lake-level-, temperature-, and trophic state-dependent taxa. Chironomid zone boundaries were determined using the software: ZONE (Version 1.2).

nocera ambigua. Furthermore the eutrophic indicator *Chironomus plumosus*-type peaked.

Shortly before Laacher See eruption, new warm-water taxa such as *Cladopelma* and *Parachironomus* occurred, but decreased at the end of FSCh–2a.

Zone FSCh–2b

The littoral taxon, *Glyptotendipes severini*-type, showed its highest relative abundances with more than 12% in the middle of zone 2b. Warm-water taxa (< 5%) slightly decreased, and the relative abundances of *Corynocera ambigua* (20%) remained low, but stable.

The following 2 zones belong mainly to the Younger Dryas pollen zone. Therefore they were labelled FSCh–3a and FSCh–3b.

Zone FSCh–3a

The dominant taxa in FSCh–3a were *Microtendipes pedellus*-type and unidentified Tanytarsini. Furthermore, *Chironomus anthracinus*-type, unidentified Orthocladiinae, and *Cricotopus* increased their relative abundances. New taxa such as *Sergentia* and, at the end of FSCh–3a, *Micropsectra* occurred for the first time. On the other hand, *Polypedilum*, *Dicrotendipes*, and *Chironomus plumosus*-type decreased drastically. *Corynocera ambigua* remained stable around 20%. Cold-water and profundal taxa showed high values, but eutrophic taxa disappeared at the end of FSCh–3a, and oligo/mesotrophic indicators appeared for the first time.

Zone FSCh–3b

The transition from chironomid zone 3a to 3b was marked by a sharp increase in *Corynocera ambigua* abundance from 15 to 50%. Moreover, *Chironomus anthracinus*-type, *Cricotopus*, *Psectrocladius*, *Chironomus plumosus*-type, *Glyptotendipes severini*-type, *Dicrotendipes*, and Pentaneurini nearly disappeared. Profundal taxa declined from 22 to <5%, while littoral taxa increased by 25%. The cold-water taxa still showed high values with strong decrease at the end of FSCh–3b. Eutrophic indicators showed very low values (0–1%).

Zone FSCh–5

In FSCh–5, the chironomid assemblage changed completely. Taxa such as *Glyptotendipes pallens*-type, *Endochironomus*, *Chironomus anthracinus*-type, and *C. plumosus*-type showed distinct peaks. In general, profundal and eutrophic indicator taxa reached high values. In core FAU2a, chironomid zone FSCh–5 is only 2 cm thick, wherease in FAU1 (Figs. 2, 7) it is approximately 10 cm thick, enabling a more detailed analysis. In FAU1e, the chironomid assemblage of zone 5 mainly consisted of both *Glyptotendipes* types, both *Chironomus* types, *Endochironomus*, and *Phaenopsectra* (Fig. 7). New taxa such as *Potthastia*, *Paratendipes*, *Paracricotopus*, and remains of *Chaoborus* (Fig. 8) appeared for the first time. The formerly dominant taxa, *Corynocera ambigua* (60%) and *Sergentia* (12%), disappeared in zone 5 of core FAU1e. *Microtendipes pedellus*-type and unidentified Tany-

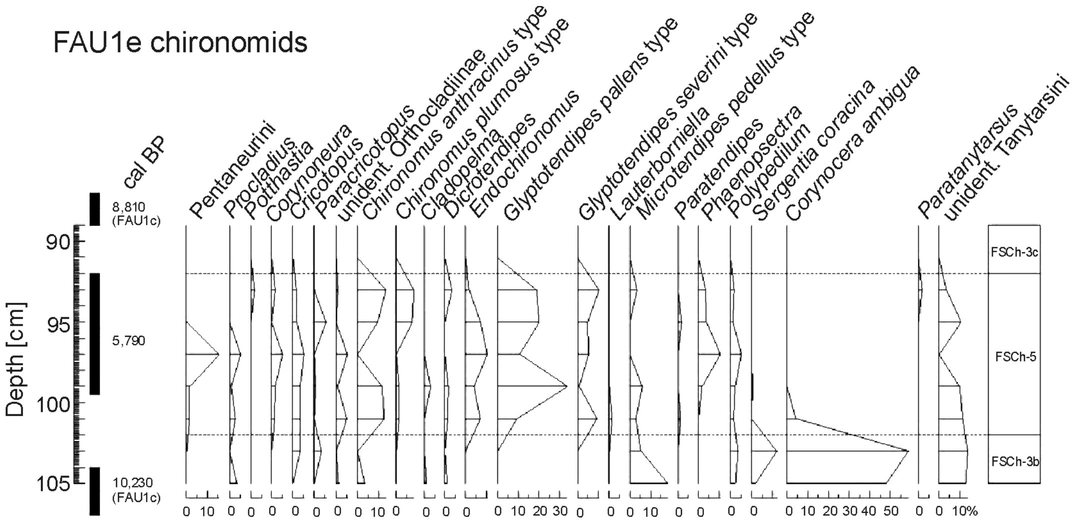

Fig. 7. Chironomid percentage diagram for Lake Faulersee core FAU1e. Chironomid zone boundaries were determined using the software: ZONE (Version 1.2).

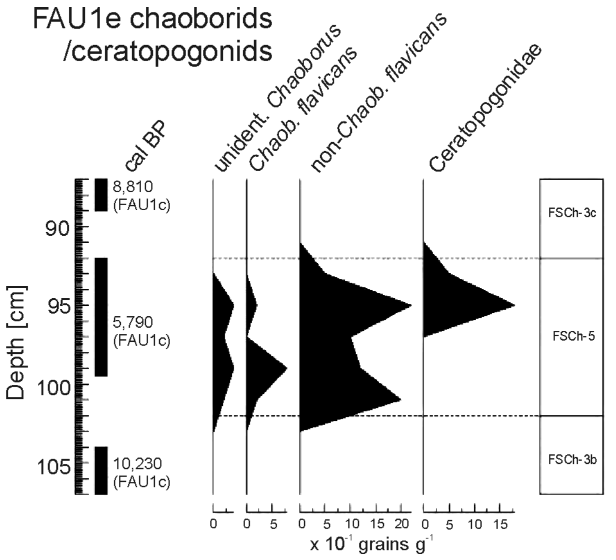

Fig. 8. Concentration diagram of chaoborid and ceratopogonid remains found in 10 ml fresh sediment of core FAU1e from Lake Faulersee. Chironomid zone boundaries were determined using the software: ZONE (Version 1.2).

tarsini decreased, while profundal, as well as eutrophic indicator taxa, and Ceratopogonidae showed an increase.

The following 2 zones also belong to the Younger Dryas pollen zone. Therefore these zones were labelled FSCh–3c and FSCh–3d.

Zone FSCh–3c

Between 164 and 148 cm in core FAU2a limnetic faunal remains were mostly absent.

Zone FSCh–3d

During FSCh–3d the numbers of headcapsules per ml rose. *Corynocera ambigua* and unidentified Tanytarsini dominated the assemblages. In general, littoral, eutrophic and both cold-water and warm-water taxa were abundant. Above FSCh–3d no chironomids could be found.

DISCUSSION

Factors influencing chironomids and their importance in Lake Faulersee

The subfossil composition of chironomids is affected by many factors, e.g. temperature, substrate, macrophytes, food availability, lake depth, trophic state, and oxygen content.

In summer, oxygen content probably had no limiting effect on chironomids in this shallow, polymictic lake, but in winter, permanent frost led to a thick layer of ice, thus we assume that the oxygen was depleted. Similar to oxygen content in winter, temperature was thought to be an important factor during late-glacial periods in Lake Faulersee determining the composition of the chironomid communities. Chironomids living in a polymictic lake, which never exceeds 5 to 6 m water depth, are not able to avoid extreme temperatures by downward migration and therefore are good temperature indicators. Substrate, macrophytes, trophic state, and water depth were also considered to potentially have had a major effect on chironomids in this shallow lake.

Relation of pollen, LOI, and chironomid zones

The pollen zones seem to correlate quite well with the LOI zones and chironomid zones of Lake Faulersee (Fig. 9). The zones of FSLOI–1, FSCh–1 correspond with pollen zone I, zones of FSLOI–2, FSCh–2 with pollen zone II, zones of FSLOI–3, FSCh–3 with pollen zone III, and FSLOI–5, FSCh–5 with pollen zone VI.

Nevertheless, chironomid zone FSCh–3a (Fig. 9) starts explicitly before pollen zone III, suggesting that chironomids respond more rapidly than vegetation to the climatic cooling at the beginning of Younger Dryas. But the chironomid changes at the zone FSCh–2b–FSCh–3a boundary are not caused by climatic cooling. They are caused by the abrupt decrease of *Polypedilum* and the change from Pentaneurini to

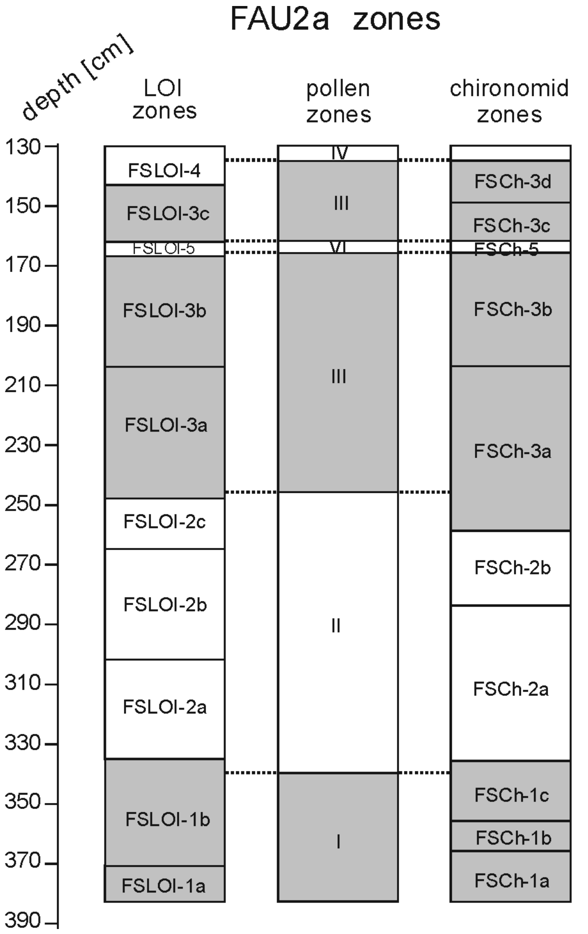

Fig. 9. Comparison of LOI, pollen, and chironomid zones from core FAU2a.

Procladius, indicating a shift in substrate and/or macrophyte composition. In additon, the cold-water chironomids increase not until the beginning of pollen zone III.

In general, chironomids, having up to 2 generations a year, can react very fast to environmental changes, whereas vegetation, especially trees with a generation time of decades, can not. In core FAU2a a possible time lag between vegetation and chironomid responses to environmental changes is hardly perceptible, because one sample (2 cm) represents approximately 25 to 35 years.

LOI zone FSLOI–4 starts a little earlier than pollen zone IV, because the organic content in the sediments rose drastically. This indicates most probably a higher production in Lake Faulersee, less windstorms, and/or a complete cover of vegetation in the area at the end of Younger Dryas. The increase of lake's production is maintained by a distinct peak of eutrophic indicators.

Temperature

In Lake Faulersee, cold periods of the Late-Glacial were indicated by

– cold-water chironomid taxa, such as *Micropsectra*, *Sergentia*, *Stictochironomus*, and unidentified Orthocladiinae,

– low loss-on-ignition and high amounts of sand.

The import of sand was most likely caused by heavy windstorms. The input of sand into Lake Faulersee was possible, because the land's surface was not sufficiently protected by the vegetation cover.

Warm phases were characterized by

– warm-water chironomid taxa, such the genera *Pseudochironomus, Parachironomus, Cladopelma, and Lauterborniella agrayloides*,

– high amounts of organic matter,

– low contents of sand.

The appearance of *Pseudochironomus* is noteworthy, because it is the first record of this genus in northern Germany during the Late-Glacial period, and it immediately occurred in high abundance.

The oldest limnetic sediments of Lake Faulersee (FSCh–1a, 382–366 cm) showed high abundances of both cold-water and warm-water taxa, indicating a rapidly changing climate. The occurrence of P*seudochironomus* points to a forest catchment (Walker, MacDonald 1995), which is confirmed by the pollen data. Zone FSCh–1b belongs to a warmer period; thus the first limnetic sediments were deposited during the transition from a cold (Oldest Dryas?) to a warm Late-Glacial Period (Bølling?). The following zone (FSCh–1c) involves the above mentioned characteristics typical of a cooler period (Older Dryas?).

The beginning of the Allerød as indicated by pollen is accompanied by low numbers of cold-water chironomids. However, warm-water taxa responded slowly to the warming of the climate, but disappeared quickly at the beginning of the Younger Dryas. The highest air and water temperature probably occurred before the Laacher See eruption. This conclusion is supported by the lowest values of NAP.

The Younger Dryas cold period is indicated by the great abundance of cold-water chironomids and NAP, and simultaneous low values of LOI and warm-water chironomid taxa. Higher abundances of warm-water chironomids at the end of the Younger Dryas (FSCh–3d) indicate a climate warming.

Substrate, macrophytes

Several of the recorded chironomid taxa are commonly reported in association with aquatic macrophytes (Brodersen 1998). *Microtendipes pedellus*-type and *Cricotopus*, for example, are often found on *Potamogeton* (Berg 1950, Brodersen 1998). *Corynocera ambigua* commonly lives in association with *Chara* (Walker 1988b), but the presence of specimens in lakes without Characeae argues against a strict dependence of *Corynocera ambigua* on *Chara* (Livingstone *et al.* 1958). If we disregard the last statement, the chironomid data imply a *Chara*-dominated lake during FSCh–1c, near the Laacher See eruption, and during the second half of the Younger Dryas. Similarly, Lake Faulersee was probably a *Potamogeton*-dominated lake during the second half of Allerød and the first half of Younger Dryas.

Trophic state

The chironomid communities in Lake Faulersee indicate eutrophic conditions throughout the lake's history, except for the middle of the Younger Dryas cold period. *Chironomus*

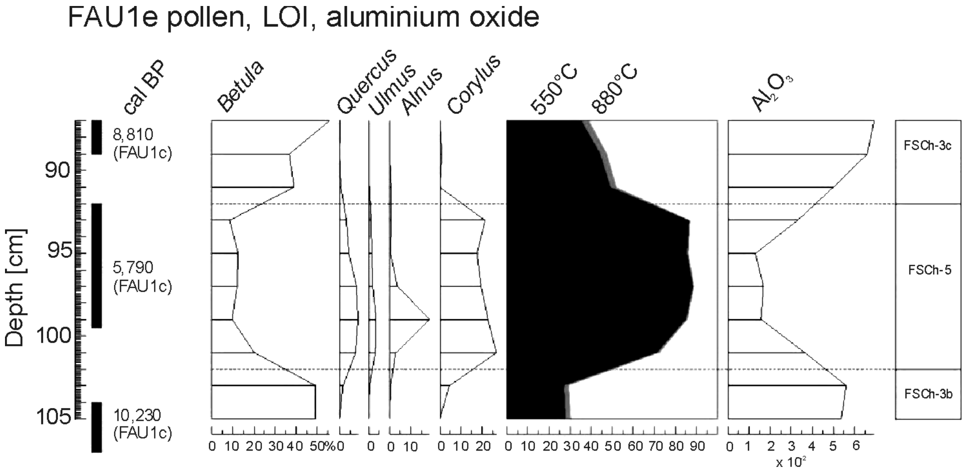

Fig. 10. Percentage diagram depicting major pollen and geochemical data from core FAU1e. Chironomid zone boundaries were determined using the software: ZONE (Version 1.2).

plumosus-type, dominating the first half of Allerød, reflect the soft, unstable and organic rich substrata characteristics (Dévai, Moldovan 1983, Francis, Kane 1995). The second half of Allerød was dominated by *Glyptotendipes* which prefers highly productive turbid lakes without submerged macrovegetation (Brodersen 1998).

In the middle of Younger Dryas an obvious oligotrophication occurred, because the first oligo/mesotrophic indicators established strong populations and eutrophic indicators partly disappeared. The oligotrophication was most likely caused by low temperatures, which reduced the autochthonous as well as the allochthonous production. In addition to this mechanism, a potential loss of vegetation cover in the catchment area facilitated minerogenic inputs from the dunes between Lake Faulersee and Lake Arendsee, thereby diluting the amount of organic matter in the sediments.

Discontinuous sedimentation

It is very likely, that chironomid zone FSCh–5 is an Atlantic layer (5,790 cal BP), that is sandwiched between Younger Dryas sediments. FSCh–5 was found in all cores of Lake Faulersee with varying thicknesses. The datings were taken from core FAU1c, which contains the thickest FSCh–5 layer of all Lake Faulersee cores. In FSCh–5 both cold-water and warm-water chironomids were found at low abundance. Most zone 5 taxa are known from warm-temperate and low-elevation lakes (Lotter *et al.* 1997) requiring forest catchment vegetation (Walker, MacDonald 1995). On the other hand warm-water indicators such as *Chaoborus* and Ceratopogonidae (Walker, MacDonald 1995, Walker *et al.* 1997) appeared for the first time, indicating a warm climate. Furthermore, *Chaoborus* mostly occurs after the late-glacial period (Brodin 1986, Hofmann 1978, Walker *et al.* 1991). Moreover, the high LOI- and low Al_2O_3-values indicate a reduced input of minerogenic material, confirming that FSCh–5 cannot belong to the Younger Dryas (Fig. 10). The pollen data for FSCh–5 indicate a late Boreal to early Atlantic age for this layer.

The chironomid assemblages indicate a highly productive lake without pronounced submerged vegetation.

After the Younger Dryas, a period of terrestrial sedimentation occurred. We explain the occurrence of this obvious Atlantic layer in older sediments by a refilling event of Lake Faulersee approximately 5,800 cal BP. We assume the following mode of action: The buoyant post-limnetic material, which was deposited between approximately 10,000 and 6,000 cal BP, floated as the lake filled and broke into pieces creating new small pools and perhaps floating islands. Atlantic pollen, faunal remains, *etc*. dropped between these islands and were deposited directly above the limnetic sediments of the Late-Glacial. A renewed drying up of Lake Faulersee re-deposited the post-limnetic material, which now covers the younger layer.

The refilling of Lake Faulersee was possibly caused by higher precipitation/lower evaporation or a sinking of the lake‘s ground near the salt dome, situated below Lake Arendsee.

Lake-level

We assume that from the time of the lake’s origin (15,300 cal BP) until the beginning of the Allerød, the water depth of Lake Fauler See was mostly less than 1 m, because no sediments were deposited at FAU1. The first pollen and chironomid records of FAU1 are of Allerød age (Beug unpublished results) and were found in 274 cm depths, approximately 1 m above the first records of FAU2 (Fig. 2). The assumed shallowness of Lake Faulersee at this time is only partially supported by the chironomid data. In addition to high amounts of littoral taxa, there are still records of profundal chironomids (Fig. 6). But it is well-known that in cold periods or cooler regions profundal taxa often appear even in the littoral (Brundin 1949, Hofmann 1988).

However, one cannot rule out the possibility that the lack of sediments at the beginning of FAU1 is caused by erosion. This is partly supported by the chironomid data that showed moderate amounts of profundal taxa in FAU2 at this time (Fig. 6). In addition, FAU1 is situated 30 m from the shore, which reduces the possibility of erosion. In our opinion, a low lake-level is the reason for the lack of sediment in FAU1. Regarding the depth of the prelimnetic ground of FAU1b and

FAU1c (Fig. 2), the lake-level rose at least 25 cm at the transition FSCh–1c/ FSCh–2a.

Another high lake-level was indicated during the first half of the Younger Dryas by high values of the "true" profundal taxon, *Chironomus anthracinus*-type (Brodersen 1998). But this indication is possibly an artefact due to a cooler climate as mentioned above. The high import of sand combined with a lowering of the trophic state probably disfavored *Chironomus anthracinus*-type in the second half of the Younger Dryas.

Furthermore, there are several periods in which littoral chironomids dominated the assemblages whereas profundal taxa were present only in low numbers indicating low lake-levels: First, at the beginning of FSCh–1c (end of Older Dryas?), second, shortly before the Laacher See eruption and finally, starting from the second half of the Younger Dryas cold period until the lake's demise. Zone FSCh–3c lying in between is interpreted as partial drying up of Lake Faulersee, because chironomid headcapsules were mostly absent. A lowering of the water level during the later part of the Younger Dryas has also been reported from a lake at Torreberga, Scania, South Sweden (Berglund, Digerfeldt 1970). Lake Torreberga is situated approximately 320 km north of the Lake Arendsee region. At the end of Younger Dryas Berglund, Digerfeld (1970) observed a radical shift to a macrophyte composition that inhabits shallower water depths.

The Younger Dryas ended in complete evaporation of Lake Faulersee because no remains of chironomids, cladocerans or other limnic taxa could be found.

CONCLUSIONS

Lake origin – end of Older Dryas

At the beginning of the Lake Faulersee record, the temperature and vegetation changed dynamically. The lake was only 1 m deep and dominated by *Corynocera ambigua*, which is commonly associated with Characeae.

Allerød

The Allerød is well-documented by loss-on-ignition and pollen data, but warm-water chironomids responded with delay. In the early Allerød a forest environment became established and the lake-level increased, which is probably the main factor responsible for the subsequent eutrophication. Immediately following the Laacher See eruption the climate cooled slightly.

Younger Dryas

At the beginning of the Younger Dryas Lake Faulersee was still in a meso- to eutrophic state. In the middle of the Younger Dryas until the end of the Late-Glacial, the lake changed to an oligotrophic state with low lake-levels.

Post-Glacial

At the beginning of the Post-Glacial, Lake Faulersee completely dried up, because limnic remains were absent. Around 5,800 cal BP an episodic refilling occurred. The Atlantic sedimentation led to a discontinuous sequence in all Lake Faulersee cores.

Acknowledgements

We would like to thank Mrs. Stams, UFZ Leipzig-Halle GmbH, Department of Hydrogeology, for performing the radiometric determination of the bulk organic carbon. This project is part of the DFG Priority Program "Wandel der Geo-Biosphäre während der letzten 15,000 Jahre" (grant SCHA 533/2–1 and 2–2).

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