Chapter 1: Introduction / Summary

1.1 Climate change

1.1.1 Introduction

During the last decade, there has been an increase in both the attention for and the awareness of global climate change. Predictions of future climate change as the result of increased human-induced levels of carbon dioxide and methane are alarming (IPCC 2007). However, even without the influence of mankind, earth's climate has always been dynamic and the processes driving these changes are still acting, thus complicating the analysis of the effects of anthropogenic forcing on the climate system.

To disentangle the natural variability in the climate system and the human-induced effects on the global climate, a critical analysis of climate change in the past may offer an understanding of the processes acting on the earth's surface and driving the global climate system. However, the period for which there are historical records of changes in, for instance, precipitation or temperature is (in geological terms) relatively short. In most regions instrumental records do not start earlier than the 19th century. In order to reconstruct processes driving climate change on a longer timescale, we have to use indirect measurements of relevant parameters of the climate system, so called climate proxy-indicators.

A wide range of proxies and techniques is available to study past changes in the climate system, and sediment, ice or even trees provide natural archives in which these proxies are preserved. The knowledge of both pattern and timing of climatic changes in the past is a prerequisite in order to understand the causes of changing climate at various time scales (Vandenberghe et al. 1998a).

This study focuses on the last ice age (known in northwestern Europe as the Weichselian) during which abrupt climate changes have been reconstructed (see section 1.1.2) and applies chironomid analysis, a relatively new method, to infer past July air temperatures from fossil insect (chironomid) remains (section 1.2.3).

1.1.2 Palaeoclimatology

The Quaternary (covering the last 2.6 million years of earth's history (Gibbard et al. 2005)) is characterised by numerous repetitive oscillations in climate (e.g. Crowhurst 2002)). A periodicity of ~41 ka dominates in palaeoclimate records between 2.6 and 1 Ma ago, whereas a 100 ka cycle strongly characterizes climate change over the last 600 ka (Figure 1.1a). Stable oxygen isotope records from deep sea sediments (e.g. Crowhurst 2002), deuterium records from Antarctic ice cores (e.g. Epica community members 2004) and evidence on global sea level changes from e.g. fossil remains of

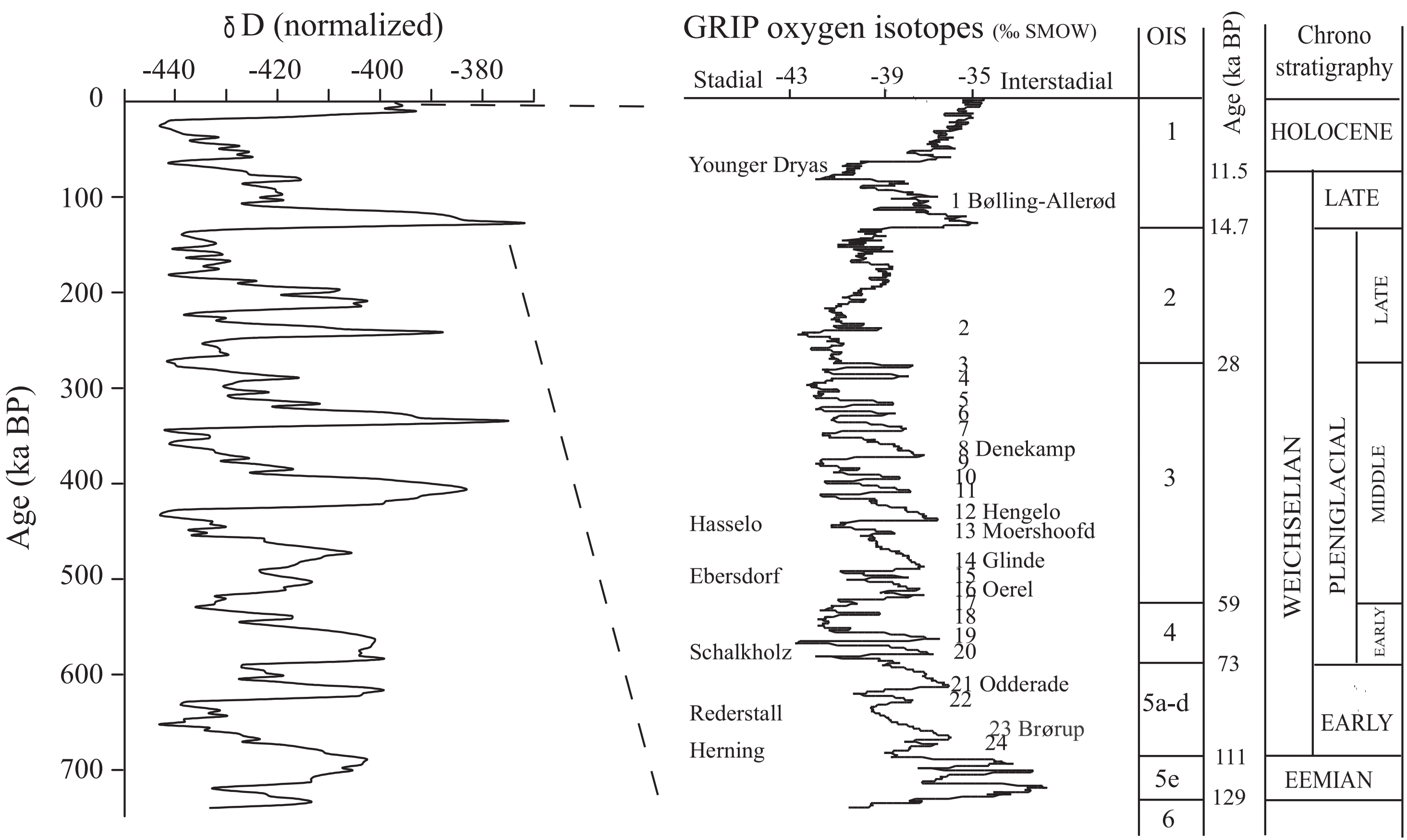

Figure 1.1: a) EPICA Dome C deuterium record, spanning the last 700 ka (after EPICA community members 2004) and illustrating the 100 ka cyclicity in temperature over Antarctica over the past 600 ka; **b)** The GRIP oxygen isotope record, showing the (numbered) abrupt climate oscillation known as the Dansgaard/ Oeschger events (Johnsen et al. 1992).

coral reefs (e.g. Lambeck and Chappell 2001) show that the Quaternary has been a period characterized by numerous changes between ice-ages (glacials) and interglacials. All these changes are primarily attributed to variations in incoming solar radiation, as the result of variations in the eccentricity, axial tilt, and precession of the Earth's movement (Milankovitch 1941).

Abrupt climate oscillations can be discerned superimposed on this long-scale Milankovitch-dominated signal, as for instance evident in the δ^{18}O record of marine and ice-core records covering the last 110 ka (e.g. NGRIP members 2004). Within a matter of a few years, air temperatures could shift by more than 12 ^{o}C in the high latitudes (Huber et al. 2006). During the glacial periods, these warm phases were however generally short (see Figure 1.1b), and followed by a step-wise return to colder conditions (e.g. Ganopolski and Rahmstorf 2001; Rasmussen and Thomsen 2004). These abrupt climate oscillations are known as Dansgaard/ Oeschger (D/O) events (e.g. Johnsen et al. 1992; Dansgaard et al. 1993). Although the exact origin of these millennial-scale cycles is still under debate, there is a relationship between the climate events witnessed in the Greenland ice-cores and past ocean circulation (e.g. Bond et al. 1993). D/O events seem to be centred on the North Atlantic region (Rasmussen and Thomsen 2004 and references therein), and changes in the North Atlantic thermohaline circulation most likely played a key-role in changing the amount of energy being delivered to the North Atlantic region (e.g. Ganopolski and Rahmstorf 2001).

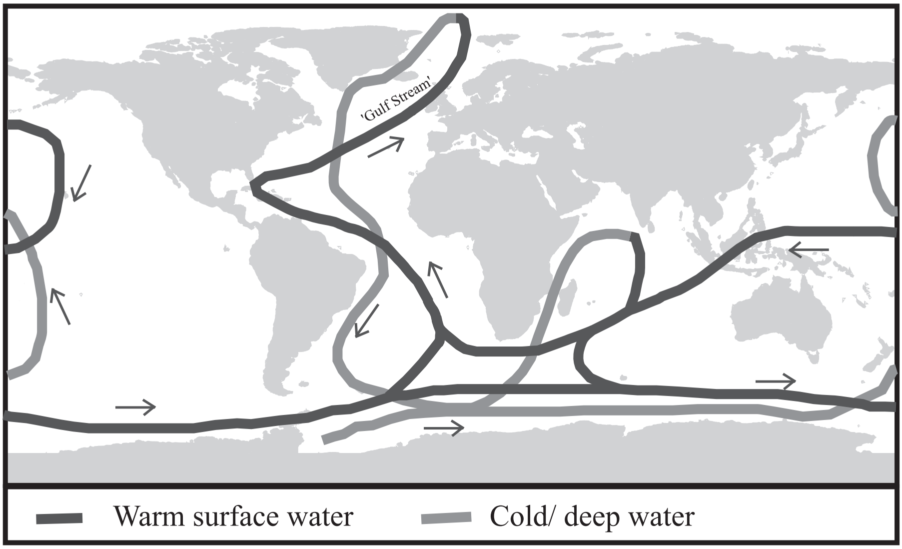

Figure 1.2: Schematic outline of the thermohaline circulation in the present interglacial mode (after Rahmstorf 2006), illustrating the energy brought to mid and high northern latitudes around the Atlantic Ocean by the so-called 'warm gulfstream'.

1.1.3 European climate during Oxygen Isotope Stage-3 (59-28 ka BP)

The modern climate of the European continent is strongly influenced by the energy brought to mid and high northern latitudes by the so-called 'gulfstream', which forms part of the larger thermohaline circulation (Figure 1.2). Former variations in the strength of this circulation, which are proposed as a driving mechanism for D/O-events, should therefore be evident on the European continent. Considering the generally westerly atmospheric circulation over western Europe this makes this area a key region for studying the D/O climate variability on land (Helmens et al. 2007).

Early palaeoclimatological studies focussing on the Weichselian climatic evolution on the European continent produced records in which the Early Glacial was characterized by the Amersfoort, Brørup and Odderade interstadials (e.g. Zagwijn 1961). The following Pleniglacial was considered as a generally cold period, consisting of a gradual expansion towards the maximum of the glacial (Van der Hammen 1952). The Late-Glacial period was characterized by the two warm periods Bølling and Allerød (Iversen 1942, Van der Hammen 1957). This general subdivision was used up to the end of the 1980s (Vandenberghe 1992). Subsequently, the Pleniglacial was subdivided into three periods: the "cold" Lower and Upper Pleniglacial and the "cool" Middle Pleniglacial, with the latter period characterized by several warm interstadials (Florschütz 1957; Van der Hammen et al. 1967; Zagwijn 1974; Vandenberghe 1992). This general subdivision of the Weichselian was correlated to the deep sea stratigraphical zonation (i.e. Oxygen Isotope Stages 2-5) by Woillard and Mook (1982), Vandenberghe (1985) and Guiot et al. (1989).

The publications by Johnsen et al. (1992) and Dansgaard et al. (1993) showed that numerous abrupt short-term climate oscillations occurred over Greenland during OIS-3, and higher-resolution studies were performed in Europe, with the objective of determining whether the abrupt climate changes during OIS-3 as witnessed in the marine and ice-core records were also evident on the European continent.

To be able to reconstruct the short and abrupt climate oscillations as known from the marine and ice-core records in a terrestrial setting, long, continuous sediment records are essential. The number of terrestrial records in Europe registering climate change over OIS-3 is, however, limited. Continuous pollen records from France, including records from the Velay Region, Les Echets and La Grande Pile (Figure 1.3), show oscillations in the relative abundance of arboreal pollen which are assumed to be linked to D/O-like climate variability (e.g. Reille and De Beaulieu 1990; Reille et al. 2000). Furthermore, recent high-resolution studies by Veres (2007) on new cores taken from the Les Echets lake basin show new multi-proxy based evidence for the impact of D/O-events on the lake system.

Spötl and Magnini (2002) published a speleothem record from the Central Alps (Austria), showing fluctuations in $\delta^{18}O$ that are remarkably similar to Greenland interstadials 15-12 as recorded in the Greenland ice cores. A second speleothem record was recovered from the same cave, and the results published by Spötl et al. (2006) again showed a strong resemblance to the Greenland records.

The loess sequence of Nussloch (Germany) spans the time interval between 19 and 31 ka BP (Rousseau et al. 2002). It shows 8 successive tundra-gley/loess units which have a periodicity of 1487.5 years, corresponding to the duration of Bond cycles or D/O-events, and the grain size variations in the Nussloch loess sequence show a strong similarity to the atmospheric dust content over Greenland (Rousseau et al. 2002).

Vandenberghe et al. (1998b) recorded five cycles of cold phases (characterised by high sedimentation rates of coarse loess) and warmer intervals (during which gleysols were formed) in an exposure near Kesselt (Belgium). Using radiocarbon dates, these five cycles are placed in the time-interval between 41 and 27 ka.

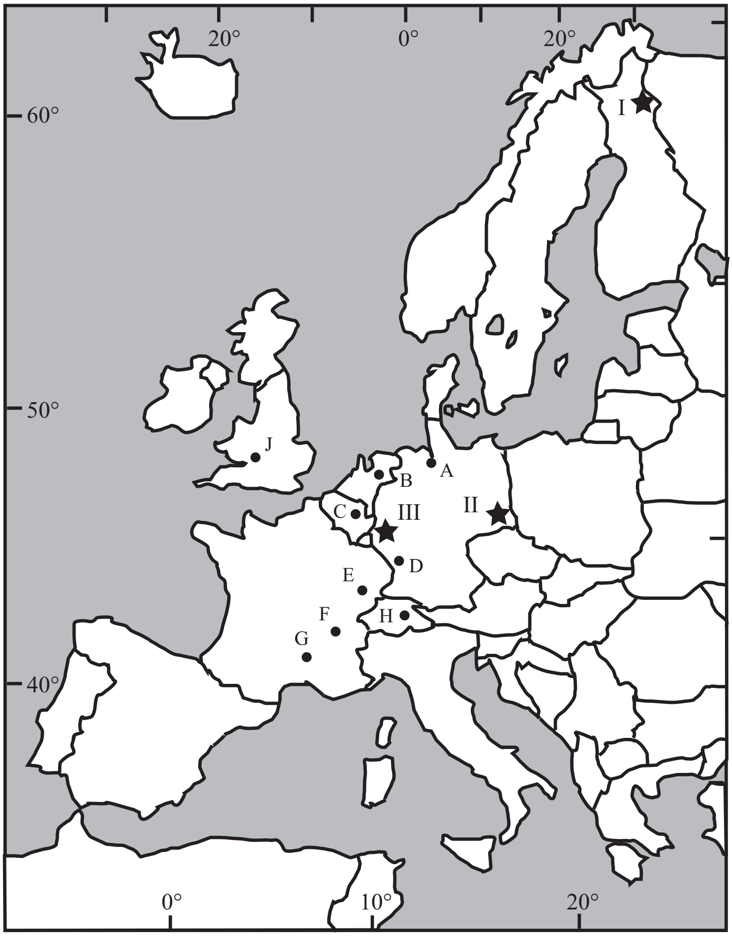

Figure 1.3: Study sites in northwestern and central Europe (stars; I = Sokli, II = Reichwalde/ Nochten, III = Oberwinkler Maar), covering (parts of) Oxygen Isotope Stage 3. Closed circles indicate the location of other records discussed in this chapter (A= Oerel, B= Denekamp/ Hengelo, C = Kesselt, D = Nussloch, E = La Grande Pile, F = Les Echets, G = Lac du Bouchet, H= Gossau, J = Upton Warron).

Many sites have registered only part (-s) of OIS-3, and several interstadial periods have been reconstructed in northwestern and central Europe using fragmentary records from different sites. Locations from Great-Britain show coleopteran assemblages that indicate a temperate oceanic climate during OIS-3 with July air temperatures reaching values at least as warm as those of the present day (Coope 2002).

Investigations of lacustrine and peat deposits intercalated in clastic fluvial and aeolian deposits in the Netherlands and northern Germany allowed for the identification of 5 different interstadials (e.g. Van der Hammen et al. 1967; Van der Hammen 1971; Zagwijn 1974; Behre 1989; Van Huissteden 1990; Behre and van der Plicht 1992). The opencast brown coal mines in eastern Germany and Poland provide additional sites where fragmentary records covering parts of OIS-3 are identified (e.g. Mol 1997; Bos et al. 2001; Kasse et al. 2003; Hiller et al. 2004).

In the lignite mines at Gossau (Switzerland), Preusser et al. (2003) reconstructed several distinct interstadial periods in the middle Weichselian, some of which were characterized by a steppe vegetation with pine, and others by an open coniferous (*Picea*) vegetation. Beetle analysis suggests mean July air temperatures around 10 $^{\circ}$C for the steppe-dominated phases, and around 12-13 $^{\circ}$C for the coniferous-phases (Jost-Stauffer et al. 2001).

However, quantitative data on both interstadial and stadial climate conditions during OIS-3 are still scarce, and the analysis of chironomid-remains provides for a new tool to obtain palaeotemperature estimates.

1.2 Chironomids

1.2.1 Introduction

Chironomids are a diverse group of insects (Arthropoda: Insecta: Diptera: Chironomidae), including more than 5000 species worldwide (Cranston and Martin 1989). As other Diptera, chironomids have 4 life stages: egg, larva, pupa and imago (or adult). Most people will be familiar with chironomids as the black swarms of midges that occur near the rim of a lake on a warm day. The larvae of these insects mostly live in water and are typically among the most abundant invertebrates found in lakes and rivers (e.g. Cranston 1995). In the past 15 years, a new method has been developed through which the remains of the larvae of these animals can be used to reconstruct past temperatures. Below, information about the chironomid life cycle and ecology is presented, mostly based on the work by Pinder (1986), Armitage et al. (1995), and Porinchu and MacDonald (2003; see section 1.2.2). The latter part of this section focuses on the development of chironomids as a proxy for July air temperature (section 1.2.3).

1.2.2 Chironomid life cycle

Adult male chironomids (Figure 1.4) form swarms, most often at dusk or dawn, and females enter this swarm to find a mate. After mating, the female deposits a gelatinous egg mass on or near the water surface of lakes, rivers or streams, often attaching it to

Figure 1.4: Picture of an adult male specimen of *Chironomus anthracinus*, picture taken by K.P. Brodersen at Lake Esrum, Denmark (source: http://www.zi.ku.dk/personal/kpbrodersen/Chiropics.htm). Used with kind permission of Klaus Brodersen.

hard substrates such as rocks or water plants. A single batch of eggs can contain from 20 to 2000+ eggs. Hatching of the eggs occurs after a number of days, although the range of time involved can be between a few hours and several weeks. Timing of hatching is species-dependent, as is the preferential temperature at which hatching occurs.

When hatching is successful, the newly emerged larvae swim vigorously (living planktonic in lakes) until they sink to the bottom of lakes, streams and rivers to find a suitable habitat for larval development. During the larval stage, chironomids moult (shed their cuticle) when they have outgrown their exoskeleton. The four different larval stages between the successive moults are called “instars”. The sclerotized parts of these molted cuticles (especially the head capsules of the exoskeleton) are deposited and preserved in lake sediment.

The larval stage is the most important life-stage of a chironomid, and can last between a number of days in tropical rock-pool dwellers to 7 years for certain arctic taxa. Most chironomid species that occur in subarctic and temperate environments are uni- to bivoltine, i.e. having 1 respectively 2 generations per year. The larvae inhabit a large suite of habitats, including lotic and lentic freshwater bodies, but they also occur in brackish to saline aquatic habitats, wet soils, soft substrates such as lake sediments, thermal springs, ephemeral pools, plant-held waters and in connection with aquatic macrophytes, hard substrata and submerged wood.

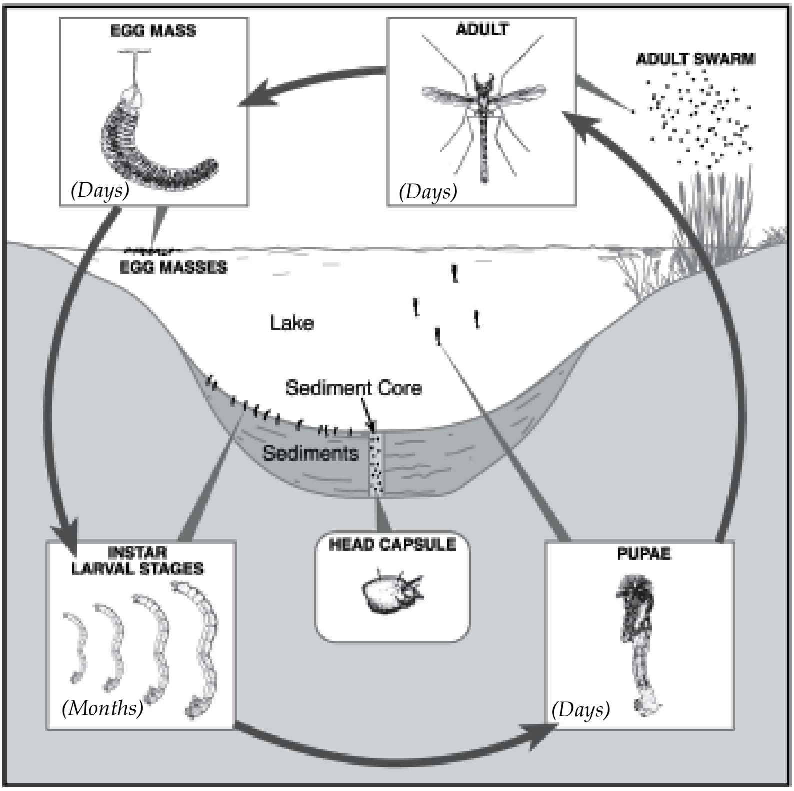

Figure 1.5: Schematic representation of the life cycle of chironomids. Modified after Porinchu and MacDonald (2003), with kind permission of Dave Porinchu and SAGE publications

Feeding strategies of the individual species are also diverse, and can be roughly classified into six groups, although most chironomids are not restricted to one mode of feeding:

- Collector-gatherers: Feed on accumulated organic material, mostly fine particulate organic matter and algal remains. The larvae can be both tube-dwelling and free-living chironomids. This is the most common feeding pattern.
- Collector-filterers: Suspension-feeders filter food from the water column with the use of silk nets.
- Scrapers: Many Diamesinae, Orthocladinae, and a few Chironominae belong to this group, which use their mandibles to scrape food from rocks, plants, submerged wood or sediments.
- Shredders: Chironomids of this group mine, chew, gouge or rasp their food, which mostly consists of coarse particulate organic matter.
- Engulfers: Attack and ingest all or parts of their prey. Many Tanypodinae feed in this manner.
- Piercers: Pierce their prey and suck the fluids out of it. This feeding strategy is mostly applied by some Orthocladinae.

When an optimal temperature is reached (possibly in combination with a critical day-length or preferred light-conditions), the larvae pupate. Free pupae occur for maximally 72 hours, and most pupae are mobile, being able to swim. Some stay at the water surface, some only rise from time to time for oxygen and some only rise for emergence. After successful emergence, the male chironomids again form monospecific swarms. Most species prefer a particular time and location for swarming, although the preferred place varies depending on local factors. Swarming occurs in calm weather and at low wind speeds.

1.2.3 Chironomids as a temperature proxy

Initial palaeolimnological studies in the 1960s applying chironomids as a proxy focussed on the reconstruction of the trophic state of the lake system, based on a lake classification system introduced by Thienemann in 1922 (Brooks (2006) and references therein). Walker (1987) and Walker and Matthewes (1987) were the first authors to suggest that midge (chironomid) fossils might be useful palaeoclimatic indicators. The authors proposed this relationship as they recognised the decline of *Heterotrissocladius*, a chironomid genus often associated with cold-oligotrophic lakes, following deglaciation in North America and Europe (Walker and Cwynar 2006). Furthermore, they realized that the best analogues for the late-glacial assemblages dominated by *Heterotrissocladius* are found in present-day Arctic and Alpine settings (e.g. Walker and Matthewes 1987; Walker et al. 1991; Walker and Cwynar 2006).

The idea that a strong relationship exists between temperature and chironomid abundances was tested through surface sample collections of midge communities and multi-variate statistical analysis (Walker et al. 1991; Walker and Cwynar 2006). In these initial studies, the relationship between summer temperature and chironomids was shown to be strong. As a consequence, a number of modern datasets were developed, containing environmental information on lakes distributed over altitudinal or latitudinal gradients, and their associated chironomid faunas (the so-called training sets). In Europe, available training sets include those developed for the Swiss Alps (Heiri and Lotter 2005), Norway and Svalbard (Brooks and Birks 2001; unpublished data), northern Sweden (Larocque et al. 2001), and northwest Finland (Nyman et al. 2005). Application of these training sets initially focussed on the Late Glacial period (approximately 15-11.7 ka BP) and on the Holocene (11.7 ka BP – present). Battarbee et al. (2002) already indicated the considerable potential of chironomids as a proxy for reconstructing past climate, and chironomids are now seen as an essential component in many multi-proxy palaeoenvironmental studies based on lake sediment (Brooks 2006). Chironomid-based temperature reconstructions on Weichselian lake sediment sequences predating the late-glacial seemed a promising way to obtain reliable palaeotemperature estimates for a time-interval where such data is scarce (section 1.1.3).

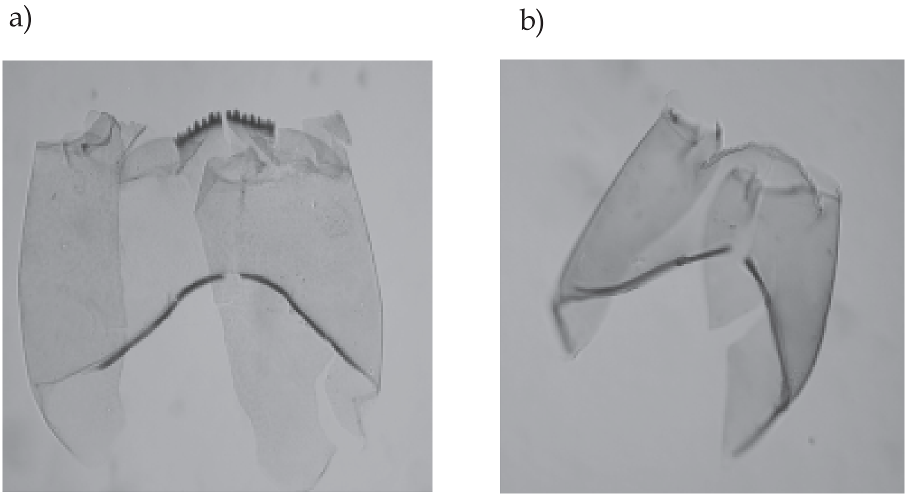

Figure 1.6: Typical chironomid head capsules as encountered in lake sediments; a) *Endochironomus albipennis*-type, a taxon typically encountered in meso- to eutrohic water bodies (Brodin 1986), and b) *Paracladius,* a genus typical of cold, oligotrophic conditions (Walker et al. 1991). Source: O. Heiri

Chironomids are a useful proxy because they are present in high concentrations in most freshwater bodies in the world. They often show diverse assemblages and have a good preservation potential. Furthermore, it is possible to identify preserved head capsules to species/ genus- level (Figure 1.6). As the adult chironomids are able to fly, and the chironomid life cycle is short, they are able to readily move from site to site, thus being able to rapidly respond to changes in environment or climate (e.g. Brooks et al. 2007).

A large number of chironomids strongly depend on particular environmental conditions for their development, and using numerical techniques, quantitative estimates of environmental parameters that are important for chironomid survival (including oxygen availability, trophic state, salinity or July air temperature) may be derived from fossil chironomid assemblages (e.g. Brodersen and Quinlan 2006; Brooks 2006; Eggermont et al. 2006; Langdon et al. 2006).

1.3 Research objectives and results

1.3.1 Aim and research questions

The processes driving the abrupt climate changes during OIS-3 are still poorly understood, and knowledge of the pattern of climate change over Europe during this period might improve our understanding of the climate dynamics and possible forcing mechanisms. The generally discontinuous nature of continental sedimentation and repeated erosion combined with poor dating control and a scarcity of high-resolution records presently hamper a detailed study of the Last Glacial climate in Europe (Helmens et al. 2007). The number of sites with a continuous registration of climate change during OIS-3 is limited (see section 1.1.3) and inferences of past changes in environment and climate are often only available for one or several interstadial intervals. As such, the magnitude and extent of climate change on the European continent during OIS-3 remains uncertain. This study aims to provide quantitative data on climate change during OIS-3 from key locations in Europe by employing chironomids as a new proxy for past summer temperatures during the Weichselian glaciation. Since many of the sediment records available for this time-window originate from floodplain lakes, an important aspect of this work was to explore the potential of sediments from floodplain lakes for chironomid-based quantitative climate inferences.

At the onset of this project, the general aim was to study the impact of D/O-like climate variability on the fluvial system of the Niederlausitz area in eastern Germany and on similar locations in northwestern and central Europe. During the project, opportunities to study D/O-climate variability on other key-locations in Europe arose (i.e. Eifel (Germany), Sokli (Finland)). The analyses of the lacustrine sediments derived from these localities provided information on past climate conditions for regions where such information was previously not available, as is the case in Sokli, or where no earlier studies using chironomids as a proxy were performed. Furthermore, a non-analogue situation between the former lakes from eastern Germany and the available modern training sets was studied in Finnish Lapland, and provided essential information on the influence of flooding by rivers on the chironomid fauna of floodplain lakes.

Specific questions addressed in this study include:

- What is the potential of using chironomid remains that are preserved in lake sediments from OIS-3 for quantitative reconstructions of July air temperatures?
- Can the abrupt climate oscillations (D/O-events) as documented in the marine and ice-core records, be recognized on the European continent by applying fast-migrating proxies such as chironomids? To what extent is the chironomid fauna of deep lakes influenced by D/O-like climate variability?
- Are shallow floodplain lakes suitable archives for quantitative climate reconstructions based on chironomids?
- Was the formation of thaw lakes during the Weichselian Pleniglacial in eastern Germany climate driven?

1.3.2 Thesis outline

Apart from this introduction (Chapter 1), this thesis contains 6 papers which have either been published or which have been submitted for publication in peer-reviewed international scientific journals (Chapter 2-7). Due to the multi-proxy nature of palaeoenvironmental studies of lake sediments, all the papers presented here have a number of co-authors. I am the principal author of Chapters 2, 5, 6 and 7. Co-authors contributed to these papers in the form of data, ideas or contributions to the text. Two papers to which I contributed as a co-author provide a broader overview, summary or interpretation of the research projects my PhD-work provided a significant contribution to. For these two papers, I produced the chironomid data and their interpretation, and contributed to the writing of the text. They are therefore also included in this thesis (Chapter 3 and 4).

Chapter 2: Chironomid-based palaeotemperature estimates for northeast Finland during Oxygen Isotope Stage 3

The long sediment record from Sokli (northeast Finland) spans multiple glaciation-cycles, and includes a lacustrine sediment body covering part of OIS-3. The chironomid fauna encountered in these lacustrine sediments indicates that a shallow lake was present at the study site throughout the analyzed period. Using a Norwegian calibration data set (Brooks and Birks 2001, unpublished data), mean July air temperatures were reconstructed based on the chironomid assemblages. The palaeotemperature estimates are in the order of 10.5 – 14 °C, which is similar to the current temperature at the study site of 13.1 °C. As these reconstructed temperatures were unexpectedly high, the results were critically reviewed. Numerical analyses were performed to test the representation of the fossil Sokli-samples in the modern training set, various possible mechanisms that could have influenced the chironomid-inferred temperatures are discussed in this chapter, and the chironomid-based results were compared to other proxy-based reconstructions from the Sokli sequence and to temperatures derived from climate model simulations.

Chapter 3: Present-day temperatures in northern Scandinavia during the Last Glaciation

Chapter 3 presents an overview of all proxy-data that was developed for the Sokli site by different project participants, including the work presented in Chapter 2, new pollen data, and quantitative pollen and macrofossil-based inferences of past climate change. Climate model-results are discussed in detail, and a possible mechanism to explain the high reconstructed July air temperatures is proposed.

Chapter 4: Rapid climatic events as recorded in Middle Weichselian thermokarst lake sediments

A ~40 cm thick thermokarst deposit, recovered from the opencast lignite mine of Reichwalde (Germany), was analysed for pollen, macro-remains and chironomids and the results are presented in this chapter. Cryogenic features underlying the horizontally laminated lake sediments suggest cold conditions prior to the formation of the lake. During the initial infilling of the lake, July air temperatures were high, as is suggested by both the chironomid assemblages and the macro-remains. Based on botanical data, a minimum mean July air temperature of 12-14 °C is reconstructed. The sharp decrease to lower temperatures (as reconstructed through semi-quantitative reconstruction of July air temperature based on the chironomid assemblages), together with the sudden drop in organic content of the sediment and the return to permafrost conditions (inferred from sedimentological features) all suggest a return to cold climate conditions during the deposition of the youngest part of the sediment record.

The combined evidence suggests a D/O-like climate evolution forcing the formation and termination of the lake system.

Chapter 5: Intraregional variability in chironomid-inferred temperature estimates and the influence of river inundations on lacustrine chironomid assemblages

Lakes on river floodplains are strongly affected by the regular inundations that occur in a natural environment. Flooding might have a distinct impact on the chironomid fauna living in a lake, as it might affect nutrient availability and water transparency, introduce new species, and influence habitat availability for chironomid larvae. For this reason, floodplain lakes are usually not included in modern training sets. However, the lake sediments presented in Chapter 4 were formed on a river floodplain, thus creating a non-analogue situation between our fossil samples and the modern lakes used in the training sets used to examine the relationship between chironomids and temperature. In order to assess the possible influence of river inundations on lacustrine chironomid-assemblages, 33 lakes were sampled during a 3-week fieldwork in Finnish Lapland. Of these lakes 13 were situated on a floodplain and thus prone to regular flooding, whereas the other 20 lakes were located outside the reach of the river, and thus did not experience any riverine influence.

Only minor differences in the physical and chemical conditions in these two groups of lakes (inundated lakes versus lakes isolated from riverine influence) were detected although the environmental conditions were more variable in the group of isolated lakes. The chironomid fauna of the two groups did show differences, both with respect to taxon richness and chironomid concentration and in relative abundances of the different taxa. Using a Finnish calibration data set (Nyman et al. 2005), quantitative temperature estimates were derived from the 33 lakes. The results show surprisingly low variation in inferred temperatures, and imply that chironomid-assemblages derived from floodplain sediments can be used to quantitatively reconstruct July air temperatures, even when the training set that is used to calibrate the inference model is based on lakes that are isolated from riverine influence.

Chapter 6:Environmental inferences and chironomid-based temperature reconstructions from fragmentary records of the Weichselian Early Glacial and Pleniglacial periods in the Niederlausitz area (eastern Germany)

In this chapter the sedimentary history of the opencast lignite mines of Nochten and Reichwalde, East Germany, is discussed. A chronology is obtained through optically stimulated luminescence (OSL)- and radiocarbon dating, and compared to previously existing chronologies published in other studies. A discrepancy between our chronology and earlier published records, concerning deposits formed in either OIS-4 or early OIS-3, is discussed.

Two fragmentary lacustrine records, dated back to the Weichselian Early Glacial and to the Early Pleniglacial, are analysed for their chironomid content. The chironomid fauna of both records indicates that the former lakes were probably very shallow and mesoto eutrophic, and were situated on a floodplain. Using a Central European calibration data set (Heiri and Lotter 2005), quantitative palaeotemperature estimates were derived from the chironomid samples. The results are first compared to other proxy-records from the same cores, including temperature estimates based on macro-remains of botanical aquatic taxa. The chironomid-based temperature estimates are thereafter compared to other climate reconstructions from the Niederlausitz region, and finally placed in the larger framework of northwest and central European climatic history.

Chapter 7: The lacustrine archive of Oberwinkler Maar (Eifel, Germany): chironomid-based inferences of environmental changes during Oxygen Isotope Stage 3

There are only several lacustrine records available in Europe that continuously registered local and regional environmental and climatological change during the last ice-age, the northernmost of which is the Oberwinkler Maar record. The sediment record of the Oberwinkler Maar covers the entire OIS-3, and shows an alternation of organic-rich and clastic sediment intervals. The lower part of this record has been analysed for chironomids, and in this paper the results of these analyses and methodological problems associated with analyzing these sediments are discussed. The chironomid fauna of Oberwinkler Maar indicates that during the stadials, the former lake was relatively deep and oligotrophic. Cold-stenothermic taxa were abundant and show a surprisingly diverse assemblage. During the interstadial intervals, the number of chironomid remains encountered in the sediments decreases to very low numbers. The presence of different taxa belonging to the tribe Chironomini might indicate higher summer temperatures during these time-windows, but might also be the result of changes in oxygen-availability, trophic state or a combination of these factors. As count sums were generally low in this record, no attempt was made to quantitatively infer past changes in July air temperatures.

Chapter 8: Synthesis / Epilogue

Chapter 8 concludes this thesis and the first sections focus on the potentials and problems associated with the application of chironomids as a proxy for past climate change. First, the relationship between chironomids and air temperature is discussed, and several factors that might influence this relationship are considered. The chironomid-based temperature inferences obtained in this study are compared with the results of the other proxies discussed in this thesis. Second, the palaeoclimatological data obtained in this study are placed in the broader framework of northwestern and central Europe, and the pattern that emerges from this comparison is briefly discussed. Finally, some concluding remarks concerning possible ways forward in the study of chironomids and their applications in palaeoclimatology, as well as some points concerning the progress in the study of D/O-events, are provided.

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