Subfossil insect remains (Chironomidae) and lake-water temperature inference in the Sisimiut–Kangerlussuaq region, southern West Greenland

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Climate and water temperature have an important influence on the functioning of lake ecosystems. From limnological and palaeolimnological studies of lakes, information on biological diversity and climate variability in time and space can be gleaned from physical, chemical and biological indicators preserved in the lake sediments. The lakes in southern West Greenland are particularly useful for this purpose – they are numerous, diverse and have minimal anthropogenic impact (Anderson & Bennike 1997). Palaeolimnological data are fundamental for understanding the functioning and development of modern lakes and for understanding the causes of climatic change as well as the effect on lake biota.

Larvae of the aquatic non-biting midges (Diptera: Chironomidae) are sensitive indicators of lake-water temperature (Lotter *et al.* 1999; Olander *et al.* 1999). As a part of a multi-proxy palaeoecological project (Anderson *et al.* 1999; 2000, this volume), models for quantitative reconstruction of climatic-induced limnological changes are being developed using subfossil remains of chironomid larvae. The quality of such quantitative inference models depends on good knowledge on autecology and ecological optima for the individual species, and hence good estimates of the environmental variables in question, here lake-water temperature.

High-resolution temperature data

In 1998 littoral surface temperatures were measured in 17 lakes (Anderson *et al.* 1999). In summer 1999 the intention was to extend this data-set and to include temperature depth profiles. High-resolution lake-water

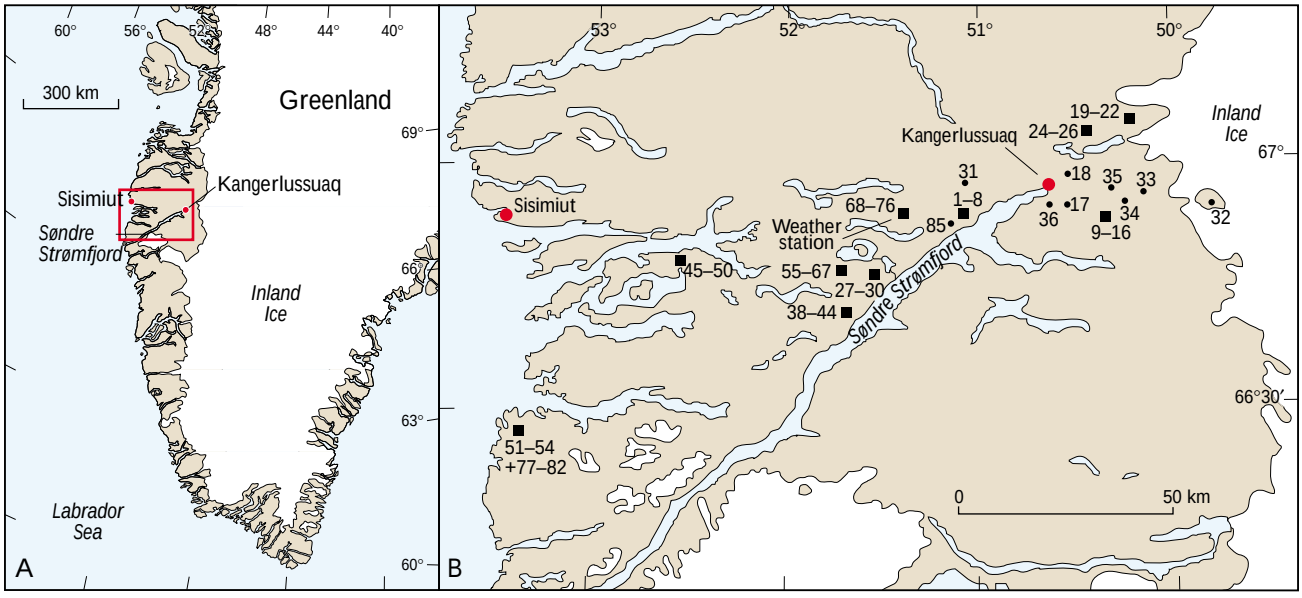

Fig. 1. **A**: The study area in southern West Greenland. **B**: Location of the Sisimiut–Kangerlussuaq transect from the Inland Ice margin to the outer coast. Numbers correspond to individual lakes, lake groups and to the lakes mentioned in the text. ■ = group of lakes; • = individual lake. Modified from Anderson *et al.* (1999).

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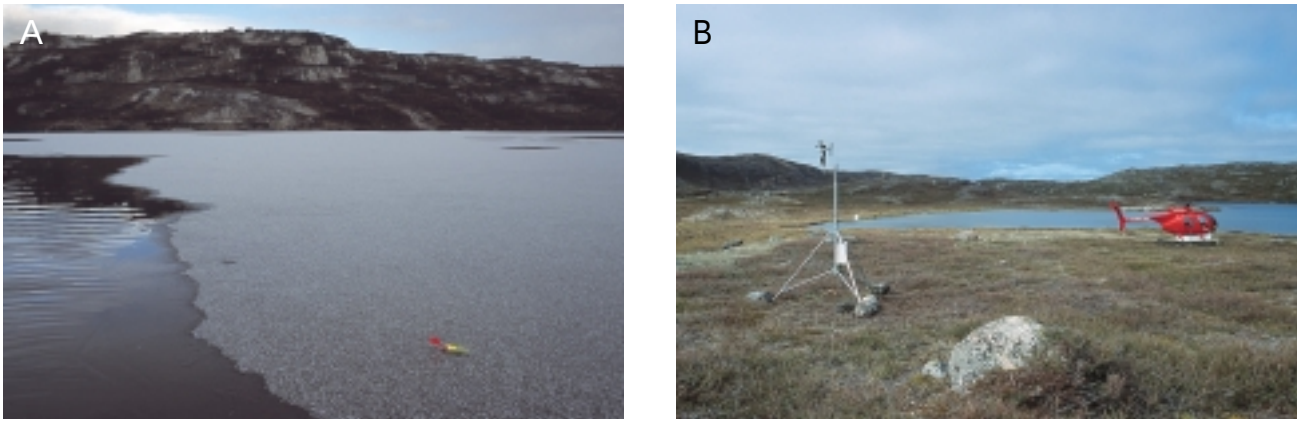

Fig. 2. **A**: Float and thermistor in Lake 49, 5 September 1999. Thermistors were removed just before new ice cover. **B**: The weather station near Lakes 75 and 76 in the centre of the transect. For locations, see Fig. 1.

temperatures were recorded in 31 lakes along a transect from the Inland Ice near Kangerlussuaq (Søndre Strømfjord) to the outer coast south of Sisimiut (Holsteinsborg) (Fig. 1). Thermistors were set to record temperature every 30 minutes from mid-June (ice-melt) to mid-September. Individual data loggers were put out in the littoral water of 22 lakes (Fig. 2A) and in 14 lakes thermistor strings of 4–6 loggers set at different depths were set out in the lake centre to measure thermal stratification in the water column. In five lakes, both littoral thermistors and strings were deployed to permit comparison of the two data-logging strategies. Air temperature, wind velocity and wind direction were measured every hour from an extra weather station located in the centre of the transect (Figs 1, 2B). The high-resolution data provides good information on: (1) the seasonal variation in surface water temperatures; (2) how to derive the best estimate of mean temperature as opposed to using spot measurements as is normal in very remote areas; (3) development and extent of thermal and density gradients in the stratified lakes; (4) how to correlate and model water temperatures from air temperature data obtained from nearby meteorological stations; and (5) the differences in total energy input among lakes, calculated as e.g. sum of day-degrees.

When and how the lakes warm up depends on their location, altitude, landscape morphometry, mean lake depth and the lake surface to volume ratio. Although the mean air temperature only varies by 2–3°C from the maritime climate at Sisimiut to the more continental cli-

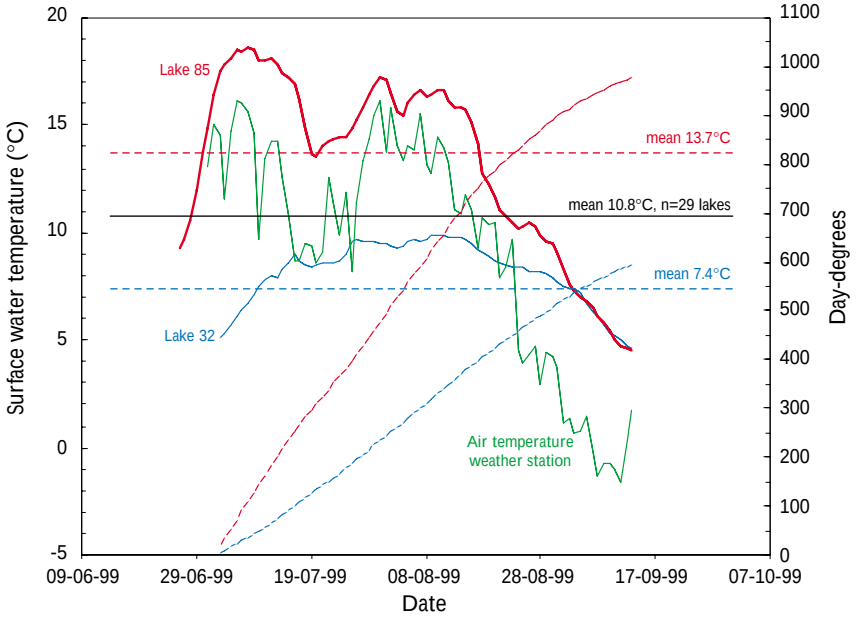

Fig. 3. Littoral surface water temperature in 1999 for the warmest lake (Lake 85, **red line**) and the coldest lake (Lake 32, **blue line**) in the study programme. Summer mean temperatures and the total number of day-degrees, accumulated from 3 July to 13 September are shown for both lakes (same colour code). **Black line** is the summer mean temperature for all study lakes in 1999 (10.8°C, n=29). **Green line** is the daily mean air temperature obtained from the weather station (see Fig. 2B).

mate at Kangerlussuaq, considerable differences were seen in the lake thermal patterns and temperature regimes. Figure 3 shows the 1999 littoral surface water temperatures for the warmest and coldest lakes in the study region (Lake 85 and the nunatak Lake 32) (locations in Fig. 1). The shallow Lake 85 warmed up rapidly in the spring and reached a maximum temperature of 18.5°C already by 6 July. The lake on the nunatak warmed up very slowly and did not reach its maximum temperature of 9.8°C until 10 August. The mean summer temperature for the two lakes differed by 6.3°C and the average summer temperature of all 29 lakes sampled during the 1999 study was 10.8°C (Fig. 3). The total sum of day-degrees varied from 978°C to 594°C between the shallow central lakes (near the weather station) and Lake 32, respectively (Fig. 3).

Three examples of thermal stratification are shown in Fig. 4 by means of depth–time–temperature diagrams. Isotherms connect points of equal temperature; vertical lines indicate homogenous temperature down the water column and possible complete mixing. Horizontal lines indicate a greater temperature gradient and a stronger stratification. Three types of stratification were found in 1999 with the *dimictic* lake type (Lake 41) the most common. The water in these dilute lakes circulates freely all the way to the bottom twice a year (spring and fall) and it is stratified during the summer. Mean lake-water conductivity, which is a good proxy for lake salinity, is close to 90 µS cm^{-1} for these lakes (median for 74 lakes). The nunatak lake (Lake 32) was only weakly stratified when it warmed up and it showed no strong stratification during the summer (almost *monomictic*). Lake 4 (Brayasø) is a *meromictic* saline lake with a strong stratification enhanced by a steep salinity gradient (*chemocline*) with a conductivity of 2,378 µS cm^{-1} in the surface and 3,640 µS cm^{-1} at the bottom. The upper water mass probably never mixes with the lower portion and the bottom water is permanently oxygen free (Anderson *et al.* 1999).

The pattern of seasonal variation was the same for all lakes, except for Lake 32, and the water temperature data correlates perfectly with meteorological data obtained from the area (Fig. 3). The lakes showed considerable differences in initial warming in the spring but

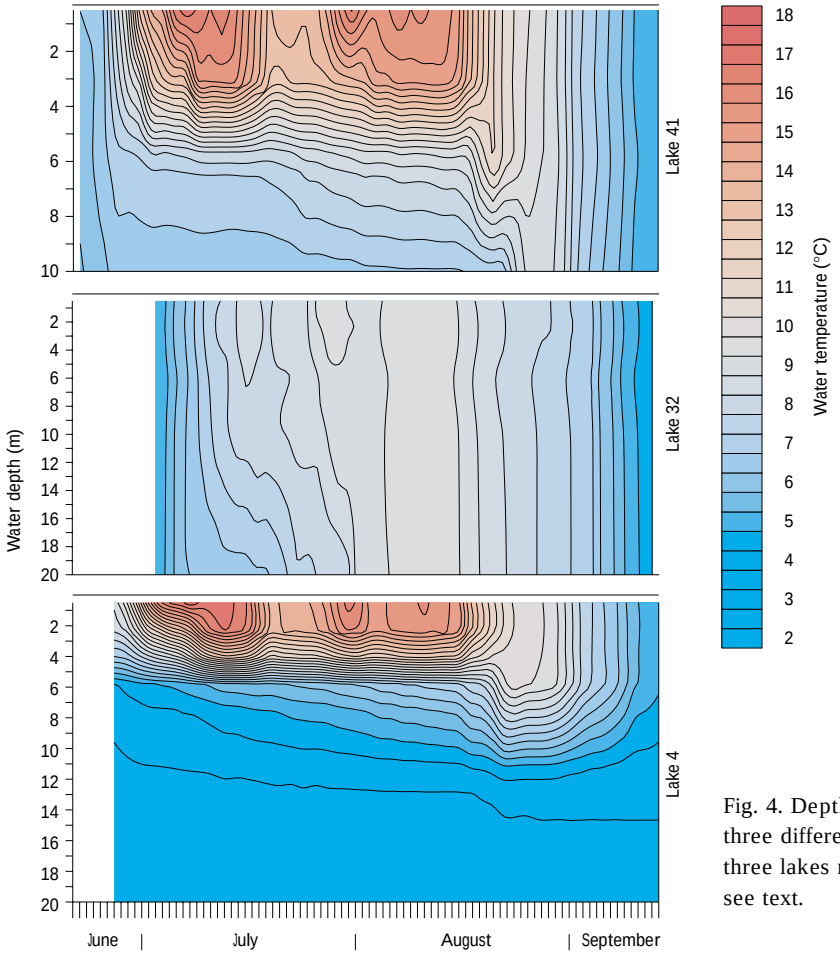

Fig. 4. Depth–time–temperature diagrams showing the three different types of thermal stratification found in three lakes near Kangerlussuaq, 1999. For explanation, see text.

the turnover in the autumn occurred on 22 August for all lakes (Fig. 4) due to decrease in air temperature and a pronounced increase in average wind speed from 2 to 8 m sec^{-1} for several days.

Linking water temperature and aquatic insect remains

Many aquatic insects live close to their limit of existence in the arctic and subarctic regions of Greenland. A few groups, however, have species that are highly adapted to surviving the long cold winters in the deep-water zones. Some species of non-biting midges (Chironomidae) are reasonably well adapted to cope with low temperature, short growth season, temporally restricted emergence period and low food supply in the nutrient-poor (unproductive) lakes, silty substrates and varying oxygen availability. As a result, the relative species composition of the chironomid communities closely reflects the environment in which they live. The head capsules of the 3rd and 4th instar larvae are well preserved as subfossil remains in the lake sediments (Figs 5, 6) and are therefore good indicators of both present and past environmental variables in the lake habitat, such as salinity (Walker *et al.* 1995), oxygen (Quinlan *et al.* 1998), temperature (e.g. Lotter *et al.* 1999) and lake trophic state (Brodersen & Lindegaard 1999).

The chironomid larvae living in subarctic lakes show a direct physiological response to climate/temperature changes, i.e. the ability to survive and complete a life cycle at very low temperatures and limited number of day-degrees. An indirect response comes from the important influence that thermal- and density-induced stratification of the water column has on the physical and chemical cycles in lakes and hence also on the production and decomposition of organic matter. Increased temperature will enhance the production in the upper water column (assuming no nutrient limitation) resulting in an increased sedimentation and a decrease in bottom water oxygen concentration due to the following biological degradation/respiration. In such a scenario, the changes in chironomid communities will be a response to combined effects of many interfering limnological processes.

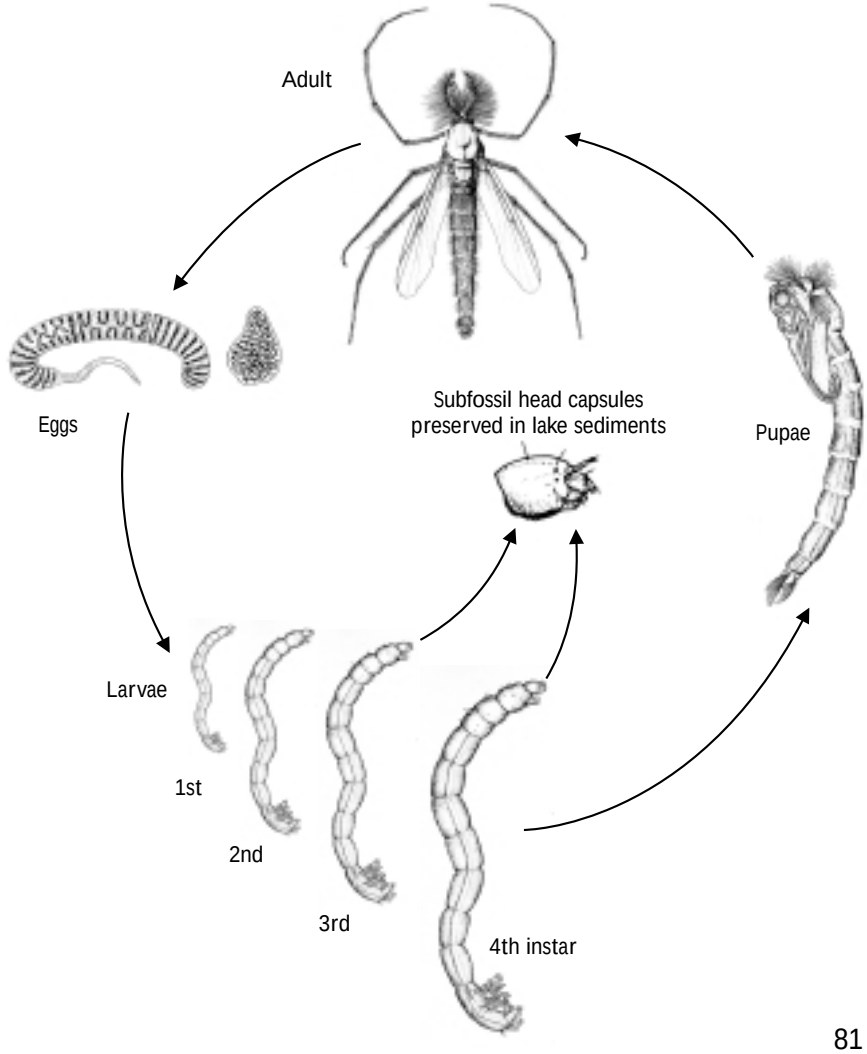

Fig. 5. Life cycle of non-biting midges (Chironomidae). The chitinised head capsules of 3rd and 4th larval instars are preserved in the lake sediments. Different chironomid species have different temperature optima and the subfossil remains in the sediments thus reflect the lake-water temperature at the time of deposition.

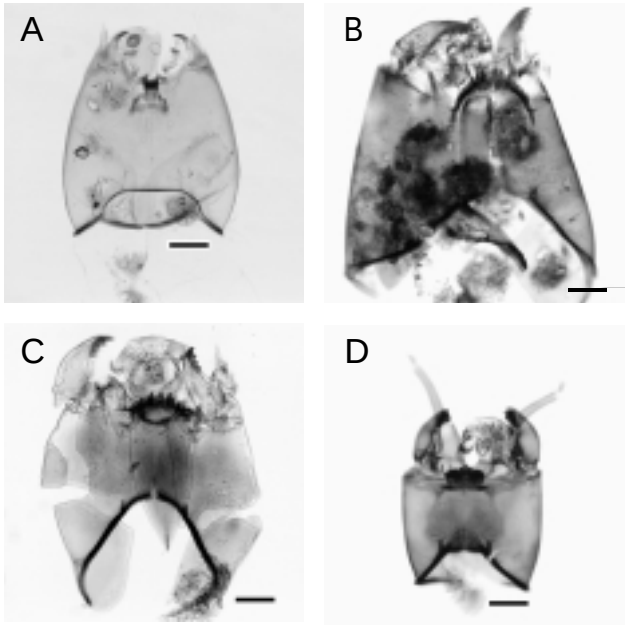

Fig. 6. Microphotographs of subfossil chironomid remains from lakes in the Sisimiut–Kangerlussuaq region. Head capsules of the four most common subfamilies/tribes are shown. **A**: Tanypodinae; **B**: Orthocladiinae; **C**: Chironominae (tribe Chironomini); **D**: Chironominae (tribe Tanytarsini). Scale bar is 100 µm.

Conclusions

The results reported here are part of the ongoing project to decipher how different limnological variables and environmental gradients influence the invertebrate communities in West Greenland lakes. There is no doubt that temperature is among the most important controlling factors, and the great variation in thermal patterns in the lakes in the Sisimiut–Kangerlussuaq region offers excellent opportunities for both limnological and palaeolimnological studies. The good quality of high-resolution temperature data obtained during 1999 from subarctic lakes makes it possible to relate the chironomid communities quantitatively to their optimal temperature regimes. The species-specific temperature optima are fundamental for understanding of lake development and for quantitative reconstruction of Holocene temperature and climate change in subarctic regions.

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