Holocene temperature and environmental reconstruction from lake sediments in the Søndre Strømfjord region, southern West Greenland

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Instrumental temperature records indicate that the mean annual surface-air temperature of the Earth has risen approximately 0.6°C since 1860 (IPCC 2001). Increased global warming can have considerable influence at high latitudes, and among the major concerns are the effects on the sensitive arctic ecosystems and the possible reduction in the diversity of regional flora and fauna. Arctic organisms are highly adapted to extreme environmental conditions and have difficulties coping with any additional stresses or disturbances.

In the ongoing palaeolimnological projects in West Greenland (Anderson & Bennike 1997; Brodersen & Anderson 2000) we address to what extent climate variation has influenced the low-arctic West Greenland lakes during the Holocene. Palaeolimnological data provide independent information on the recent warming, and also place the 19th to 20th century (instrumental temperature records) warming in a long-term context. The sedimentary records allow us to look at the lake-specific ecological response to regional temperature fluctuations over the last several centuries to millennia. This perspective is an important capability in any aim to predict the possible outcome of late 20th century global warming. An important prerequisite, however, is to have good knowledge of the present lake-ecological conditions and the regional climate variability in southern West Greenland, keeping in mind that West Greenland regionally has experienced a decline in average temperature in the second half of the 20th century (Heide-Jørgensen & Johnsen 1998; see also Mikkelsen *et al.* 2001, this volume).

Recent limnology and palaeolimnology

Most groups of plants and animals respond more or less directly to the ambient temperature and climate conditions. The non-biting midges (Diptera: Chironomidae)

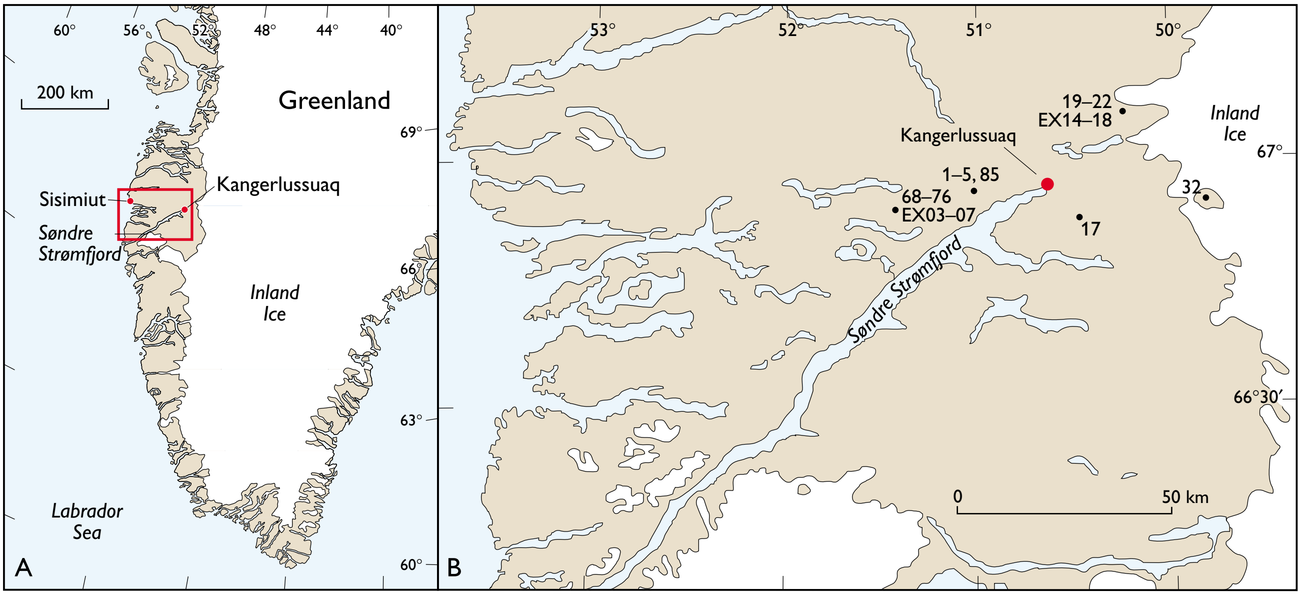

Fig. 1. **A**: Map of southern Greenland showing the location of the study area. **B**: Map of the area at the head of Søndre Strømfjord showing the location of lakes and ponds mentioned in the text and in Table 1. Modified from Anderson *et al.* (2000).

Table 1. Lakes and ponds sampled for chironomid exuviae from 14–24 June 2000

Lake code	N lat.	W long.	Lake type	Conductivity (µS cm-1)	Total nitrogen (mg l-1)	Altitude (m)
SS05	66°59.400′	51°05.300′	B	4072	0.77	175
SS03	66°59.900′	51°01.700′	B	3601	0.80	175
SS17	66°59.400′	50°35.900′	B	2798	1.26	215
SS04	66°59.300′	51°02.800′	B	2636	0.96	170
SS71	66°57.600′	51°31.950′	B	1465	1.86	240
SS85	66°58.900′	51°03.400′	B	616	1.12	178
SS75	66°56.390′	51°33.330′	B	226	0.05	340
SS70	66°57.260′	51°34.950′	D	2443	0.40	235
SS68	66°56.730′	51°35.070′	D	376	0.35	240
SS76	66°56.300′	51°33.300′	D	346	0.36	345
SS72	66°57.802′	51°31.860′	D	311	0.37	255
SS73	66°57.920′	51°29.810′	D	268	0.13	270
SS74	66°56.360′	51°34.510′	D	234	0.00	330
SS02	66°59.800′	50°58.200′	C	321	0.65	185
SS69	66°56.950′	51°35.930′	C	211	0.63	230
SS21	67°09.500′	50°20.400′	C	148	0.37	470
SS01	66°59.200′	50°55.700′	C	128	0.75	120
SS22	67°10.000′	50°19.900′	C	113	0.26	470
SS20	67°09.100′	50°19.500′	C	107	0.41	445
SS19	67°08.500′	50°18.300′	C	85	0.45	470
EX14	67°10.004′	50°19.735′	C	*	*	450
EX04	66°56.539′	51°33.938′	A	423	*	318
EX03	66°56.605′	51°33.800′	A	398	*	318
EX05	66°57.052′	51°31.676′	A	*	*	381
EX06	66°56.828′	51°33.532′	A	*	*	321
EX07	66°56.631′	51°31.020′	A	*	*	380
EX17	67°10.116′	50°20.432′	A	*	*	479
EX18	67°09.950′	50°20.929′	A	*	*	472

Lakes are arranged according to lake type and decreasing conductivity. Lake types are defined from the ordination of species compositions in Fig. 4. SS-lakes are lakes included in the surface sediment sampling program. EX-ponds are additional ponds only sampled for exuviae in June 2000.

* Water chemistry data are not available for the shallow ponds.

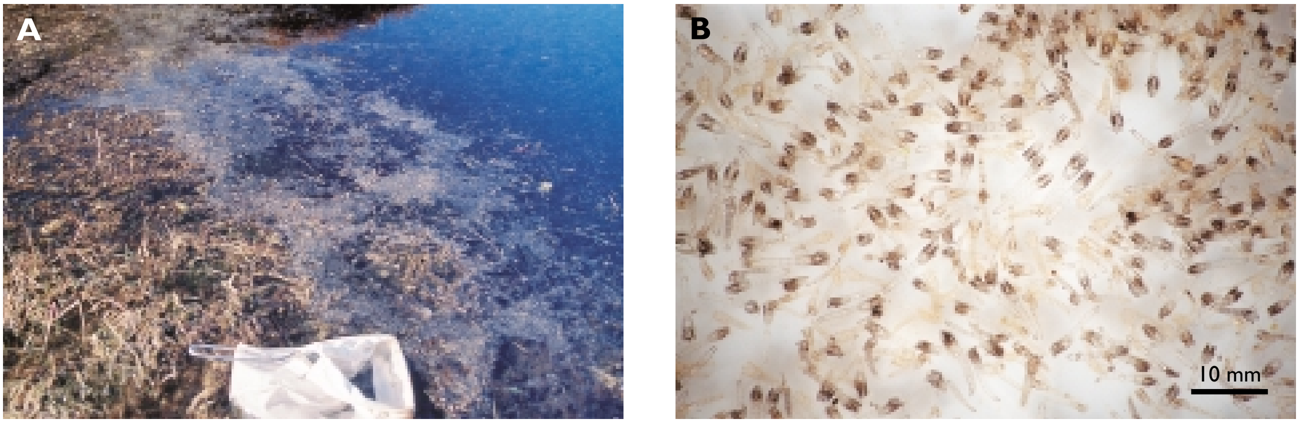

Fig. 2. **A**: Large numbers of floating chironomid exuviae (pale-coloured patches) along the shore of a shallow pond (EX05). For location, see Fig. 1. **B**: Close-up of exuviae, primarily *Chironomus* sp. 3 and *Procladius* sp. 1.

are now accepted as being one of the best biological palaeoclimate proxies (Walker *et al.* 1991; Lotter *et al.* 1999; Olander *et al.* 1999; Battarbee 2000; Brooks & Birks 2000). Subfossil chironomid head capsules are well preserved in lake sediments and by numerical modelling of the relationship between recently deposited subfossil assemblages and the contemporary lake conditions (physics, chemistry and biology) it is possible to quantitatively infer palaeotemperature and to reconstruct past climate variation in the region (Brodersen & Anderson 2000).

Chironomid exuviae

In June 2000, surface sediments were sampled, lake temperature and conductivity profiles were measured and chironomid exuviae collected from 20 of the study lakes initially sampled by Anderson *et al.* (1999) and from eight additional shallow ponds (Fig. 1; Table 1). Exuviae are the cast skins left from the pupae when the aquatic larvae metamorphose into the terrestrial winged adult stage. The exuviae are collected from the lake shores and can sometimes be found in very large numbers when a synchronised mass swarming has occurred, often during or immediately after ice-melt (Fig. 2). The chironomid exuviae can be identified to genera (Wiederholm 1986) and many Palaearctic taxa can be identified to species level (Langton 1991). The knowledge gained from identification of recent exuviae improves our ability to correctly identify the subfossil larval remains from the lake sediments (Fig. 3).

Twenty-two chironomid taxa were registered (Table 2), and several appear to be intermediate types between Palaearctic and Nearctic species. Collected and described material from Greenland is still scarce and the application of West Palaearctic identification literature is problematical.

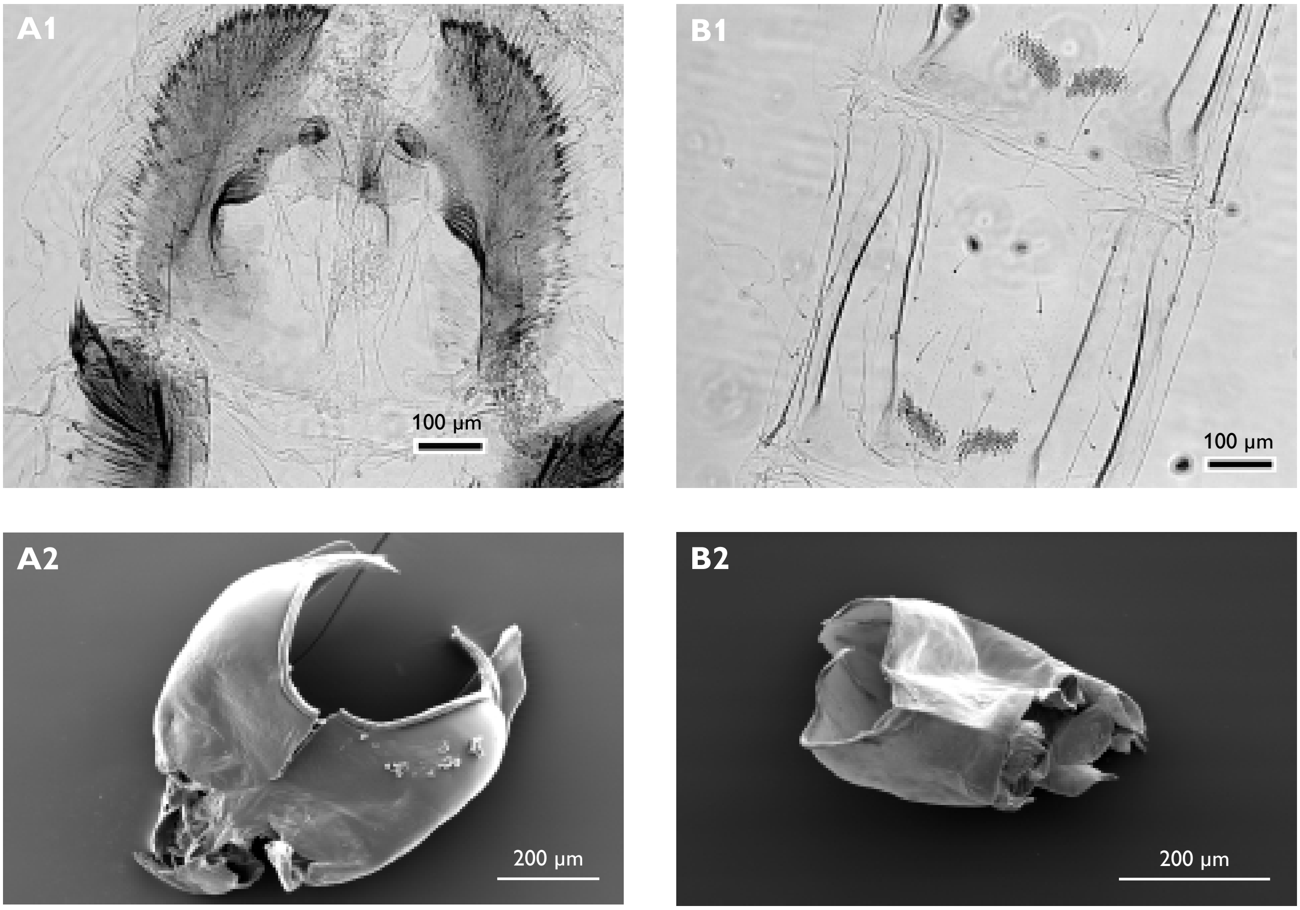

Fig. 3. **A1**: Posterior abdominal segment of *Chironomus* sp. 1 pupae (from pond EX18); **A2**: Larval head capsule of subfossil *Chironomus* sp. (from Lake SS32). **B1**: Abdominal segments of *Micropsecta brundini* (from Lake SS19); **B2**: Larval head capsule of subfossil *Micropsectra* sp. (from Lake SS32). A1 and B1 are light micrographs; A2 and B2 are scanning electron micrographs. For lake locations, see Fig. 1 and Table 1.

Table 2. Chironomid exuviae collected in West Greenland lakes and ponds from 14–24 June 2000

Taxon	Number of lakes	Lake type
Ablabesmyia pulchripennis (Lundbeck 1898)	4	B
Arctopelopia melanosoma (Goetghebuer 1933)	1	B
Procladius sp. 1	7	A
Procladius sp. 2	7	B
Chaetocladius sp.	1	D
Corynoneura arctica Kieffer 1923	12	BC
Heterotrissocladius sp.	7	CD
Psectrocladius barbimanus (Edwards 1929)	14	ABC
Psectrocladius limbatellus (Holmgren 1869)	3	DC
Psectrocladius octomaculatus Wülker 1956	1	C
Orthocladius olivaceus Kieffer 1911	1	C
Chironomus sp. 1	8	AB
Chironomus sp. 2	6	AB
Chironomus sp. 3	3	AB
Dicrotendipes modestus (Say 1823)	8	AB
Micropsectra brundini Säwedal 1979	13	CD
Micropsectra groenlandica Andersen 1937	1	C
Micropsectra lindrothi Goetghebuer 1931	1	D
Paratanytarsus laccophilus (Edwards 1929)	1	A
Tanytarsus gracilentus (Holmgren 1883)	7	BC
Tanytarsus norvegicus (Kieffer 1924)	1	C
Tanytarsus sp. 2	1	C

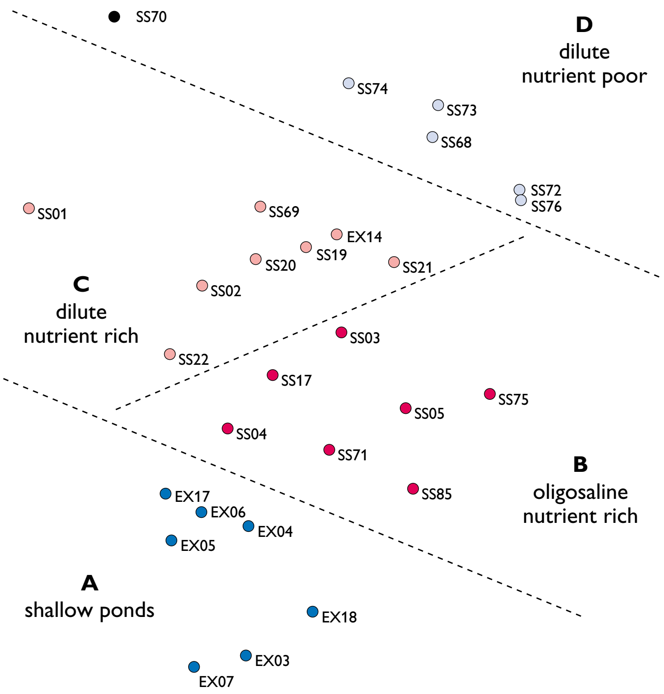

Fig. 4. Non-metric multidimensional scaling (NMDS) of 28 chironomid exuviae samples from southern West Greenland. Lakes in the ordination diagram are plotted along arbitrary axes according to their similarity in species composition. High proximity reflects high species similarity. Lakes (**dots**) are coloured according to lake groups. For lake locations, see Fig. 1 and Table 1.

Non-metric multidimensional scaling (NMDS; Clarke & Warwick 1994) based on similarities in species composition in the 28 lakes and ponds clearly demonstrates the value of chironomids as environmental indicators (Fig. 4). Lakes (and ponds) that group close together in the ordination diagram have high similarity in chironomid assemblages and the preference lake types for the 22 taxa are given in Table 2. The ponds (group A) and the 'oligosaline nutrient-rich' lakes (group B) were characterised by warm-water species that inhabit shallow lakes or the littoral zone of deep lakes (*Chironomus* sp., *Ablabesmyia pulchripennis*, *Procladius* spp., *Dicrotendipes modestus*). The meromictic oligosaline lakes (group B) are almost permanently stratified (Brodersen & Anderson 2000) and species that characterise the deep profundal zone are absent in these lakes due to low oxygen levels (Anderson *et al.* 1999). The dilute lakes (groups C and D) are relatively nutrient-poor and less productive and characteristic species are *Heterotrissocladius* sp. and *Micropsectra* spp. The oligotrophic Lake SS75 was misclassified because a few exuviae of *Chironomus* sp. 3 were found in the sample. Two different non-named species of *Procladius* appear to show significantly different lake type preference, suggesting that subfossil *Procladius* head capsules should be carefully identified and separated in palaeolimnological analysis, which is still not possible. In contrast, three species of *Chironomus* did not differentiate significantly in this preliminary numerical analysis.

Subfossil chironomids

Lake surface sediments were collected from a range of lakes and the training set with subfossil chironomid data now constitutes 48 lakes and 28 taxa. High-resolution water temperature data are available for 21 of the lakes and there is a good correlation between the chironomid assemblages and the mean July surface-water temperature ($r = 0.80$, Fig. 5). However, even though temperature is the strongest variable to describe the chironomid distribution, both lake total-nitrogen concentration (TN) and maximum lake depth are also strong environmental parameters ($r = 0.69$ and $r = 0.66$, respectively; authors' unpublished data).

Holocene climate reconstruction

A dated Holocene sediment core from a lake near the harbour at Kangerlussuaq has been analysed and clear stratigraphic signals are recorded (unpublished data). Quantitative temperature reconstructions using the preliminary 21-lake model reveal the same patterns in Holocene cold/warm fluctuations as interpreted through ice cores from the Greenland Inland Ice. The rapid cold event at 8200 ice core years B.P. (Alley *et al.* 1997; Willemse & Törnqvist 1999) is clearly reflected in the sediment core by extreme low chironomid diversity and by dominance of the cold-water indicator *Micropsectra* (Fig. 3). The warmer periods around 2500 B.P. and 3500 B.P. are characterised by warm-water genera such as *Chironomus* (Fig. 3). The sediment cores from West Greenland have been studied by a multiproxy approach that includes diatom-inferred conductivity, plant pigments, zooplankton, stable isotopes and macrofossils (Anderson *et al.* 2000) and the preliminary results show good agreement between the different proxies. This approach allows assessment of lake ontogeny along environmental gradients other than temperature. By addressing the same question simultaneously with different proxies it is possible to identify artifacts of each of them, and the aim of reaching a reasonable *ecological* reconstruction is more conceivable. A common problem in palaeolimnological temperature reconstruction is to partial out the effect of inter-relation between lake temperature and lake productivity. The low productive, oligotrophic lakes are usually also cold, high altitude and deep lakes with small catchment areas, whereas the warm lakes are nutrient-rich and productive lowland lakes often with high organic sediment content (cf. Lotter *et al.* 1997; Müller *et al.* 1998; Olander *et al.* 1999). In the West Greenland data set, strong secondary environmental gradients are also found (TN and lake depth) and one of the aims of this project is to highlight and include these variables in the inference models rather than to discard them.

Long-term lake monitoring and assessment

Compared to the ongoing intensive lake monitoring programs in European countries (Kristensen & Hansen 1994), collection of limnological and environmental data from the sensitive and pristine low-arctic West Greenland lakes must be considered as limited. However, biological remains (i.e. chironomid head capsules and exuviae) from the lake sediments and surface waters integrate information on lake conditions over years and decades and can therefore be used as a long-term monitoring tool in these remote areas where frequent data registration is difficult and where existing environmental records do not exist (Smol 1992). The data collected during this project can thus provide a standard of reference in future evaluation of changes in lake conditions and typology on decadal time scales (Brodersen *et al.* 1998). The studies of collected exuviae samples from West Greenland, presented here for the first time, are also valuable for verification of identified subfossil material.

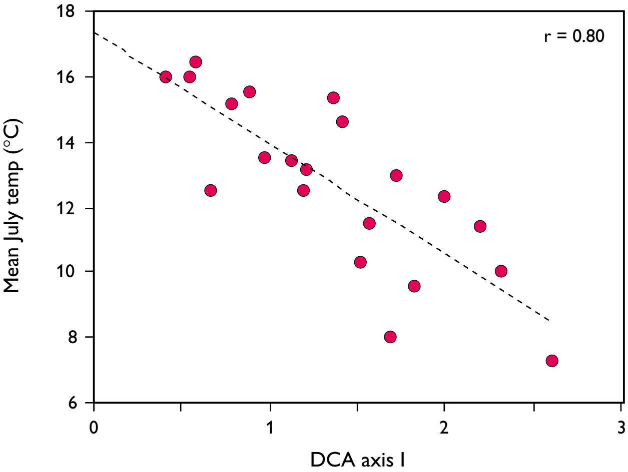

Fig. 5. Correlation between subfossil chironomid assemblages and the mean July surface-water temperature (°C) from 21 lakes. Chironomid assemblages are expressed as the axis one scores of a detrended correspondence analysis (DCA; Hill & Gauch 1980).

Future work

In future field seasons we intend to expand the calibration data set in the low end of the temperature gradient by including glacier-near lakes (late-glacial analogues) and also lakes at higher altitudes, although the latter might introduce new ecological assumptions that need to be taken into account. The ecological responses gained from the lake sediments in southern West Greenland can be compared to ice core data from the Greenland Inland Ice more readily than results from lakes elsewhere. Analyses of Holocene sediment cores from closely located lakes, but with different typology (e.g. salinity and productivity; Fig. 4), will give an idea of similarities in inter-lake overall climate impact as compared to the differences in in-lake dynamic processes. The long time-series provided by the palaeolimnological data therefore not only give an independent idea of past environmental and climate conditions, but also help to assess the natural variability of the biotic and abiotic systems.

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