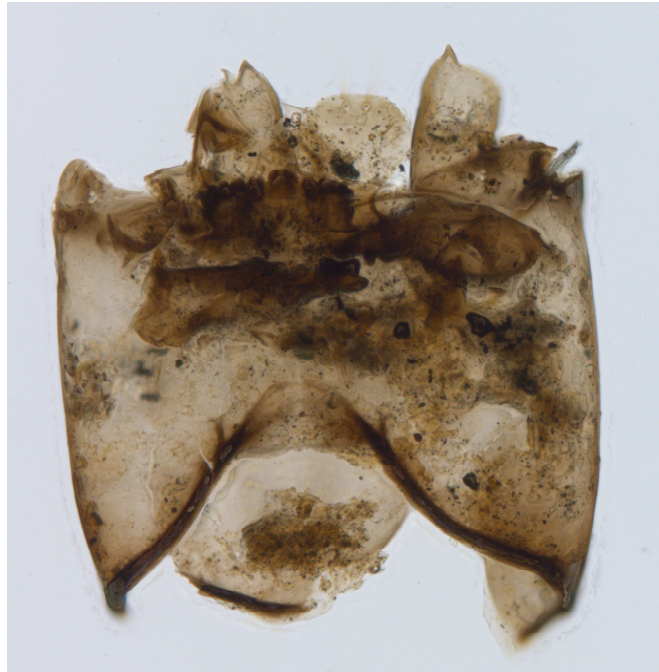# Climate History of the Arctic:
Temperature reconstruction of an arctic lake on Spitsbergen based on chironomid

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Front page:
Micropsectra insignilobus-type.
Photo: Kari Fadnes.

Acknowledgments.

During this project there are many that deserve appreciation.

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Abstract.

The increase in global climatic changes seen in recent years is debated to be a result from expanding anthropogenic activity. The aim for the study is to contribute to the climatic history at western Spitsbergen mainly focusing on the last 2000 years and recent climatic events.

Palaeoecoloogical studies investigates the climatic history of the past, assessing the speed and direction of future climate changes, and suggest how much of the changes are man made or based on natural forces. Chironomids are a good indicator for temperature changes in the past and were in this study used for a temperature reconstruction in lake Tjørnskardet on western Spitsbergen.

The sediment cores were dated back to ~ 6000 years BP. From the chironomid assembly, a temperature reconstruction was established based on reduced modern training set. A total of 26 taxa were found, with *Micropsectra, Hydrobaenus* and *Oliveridia* showing a considerable higher abundance compared to the rest of the taxa in the assemblage. The inferred temperature based on full modern training set and the reduced training set were compared to the results from the neighbouring lake, Skardtjørna together with the chironomid assemblage.

The reconstructed temperature gradient shows an overall temperature decline from ~ 6000 years BP to present, in correspondence to Skardtjørna and other sites at Svalbard.
Some major aberrant trends in the results indicate that there might be a strong correlation between the temperature and other environmental variables, which will influence the chironomid composition and weaken the reconstructed temperature.
The comparisons of the temperature from the training sets reveal that the inferred temperature based on the full training set showed more resemblance between the lakes.

TABLE OF CONTENTS.

1. INTRODUCTION.

1.1 Climate change.

Global climate change.

As a consequence of intensified occurrence of extreme climatic conditions, issues concerning global climate change have gained more public and political attention. The definition of climate change can be stated as changes in the climate due to natural or anthropogenic influence over a period of time, and research has lead to evidence that the climate is warming. Both air- and ocean temperatures are rising, and the amount of ice and snow melting around the poles contribute to materialize the seriousness of the situation (IPCC 2007). Human impact on the environment has increased dramatically since the industrial revolution and most likely contributes toward the recent climate change already commenced by natural factors (IPCC 2007).

Changes in atmospheric composition affect the natural energy flow and results in a shift in the global average temperature. Greenhouse gases like CO_2, CH_4, O_3, N_2O and water vapour traps infrared radiation effectively. Increasing amounts of greenhouse gases enhances the greenhouse effect and thereby the surface temperature on earth. As a result of enlarged human activity, the atmospheric concentration of these gases is increasing and enhances the natural greenhouse effect (Wigely 2001). This increase is mostly connected to population growth, expanding industrial (fossil fuel, land fillings) and agricultural (rice paddies, farming) activity, which all contributes to an increase of greenhouse gases in the atmosphere (Reay et al. 2007). Climate change or global warming affects the physical and biological systems in the Earth's ecosystems (Vitousek 1994). The most important physical changes are reduction of glaciers and early snowmelt with reduced snow-pack in arctic (Overpec et al. 1997) and alpine regions (Haeberli and Beniston 1998). The increasing temperatures lead to changes in temperature gradients and light intensity in water columns of lakes and streams (Schindler 1997). Marine systems experience sea level rise and changes in salt concentration, which in turn may cause a different halocline (Hugthon 2005).

Changes in biological systems include alterations of species composition, distribution and abundance. Altering of the environmental conditions in an ecosystem leads to reduction or extinction of native species and introduction of invasive species. Warmer climate would also affect seasonal events like blooming, migration and reproduction (Root et al. 2003)

1.2 The Arctic.

1.2.1 Arctic Climate.

The Arctic is defined to encompass areas with a summer mean below 10 °C and include the Arctic Ocean and the land areas north of the tree line (McGuire et al. 2006). These regions encompass approximately 5% of the total land area on earth (Chapin and Kørner 1996). The seasons in the Arctic consist of long winters (7 -10 months) with small amounts of solar radiation, low temperatures and little snow coverage. The summers are short with warmer temperatures and continuous daylight, which provides a short and hectic growing season (only 6-8 weeks in some areas) (Karplus 1952, Birks et al. 2004).

Arctic regions show a considerable sensitivity to climate change, and they acts as an early indicator for global change (Corell 2006). Arctic environments are in particular sensitive to increasing temperatures and experience a faster warming compared to other regions on Earth (Alexandrov and Maistrova 1998). While the Earth in general has suffered an average temperature rise of 0.6 °C since 1960 (Hansen et al. 1999), the equivalent rise in arctic environments has been 2-5 °C (Serreze et al. 2000).

Resulting from climate change, arctic ecosystems will experience alterations in UV-radiation and decreasing snow pack, retreating glaciers, reduced sea ice formation, reduced permafrost and increased precipitation (McGuire et al. 2006). Changes in the Arctic will play a significant part in changes in the global climate system through feedbacks, mainly affecting the ocean circulation, the amount of absorbed solar radiation and the amount of greenhouse gases in the atmosphere. In the ocean the sea level and fresh water concentration are affected by melting of glaciers and sea ice.

Snow- melt and reduced snow cover leads to decreased surface albedo thus increasing the absorption of solar radiation (AICA 2005, McGuire et al. 2006).

The Arctic is a key area for research on climatic change because of the enhanced effect of climate change, limited influence from both anthropogenic activity and atmospheric pollution and how feedback from the changes in the Arctic affect the global climate (Birks et. al 2004, Corell 2006).

1.2.2 Arctic ecosystems.

The Arctic ecosystems constitute the northern part of the global ecosystems characterized by extreme environmental conditions like low temperatures, no light during winters, snow, glaciers, permafrost and sea ice (ACIA 2005).

The biodiversity and productivity in the Arctic is limited to approximately 2- 3 % of the world's total biodiversity and productivity. These are strongly influenced by the temperature gradient and decreases with increasing latitude (Challaghan et al. 2004). Due to extreme environmental variables in the Arctic, species have evolved to survive their surroundings through adaptations. This makes them capable to take advantage of the environmental characteristics in the Arctic for survival (ACIA 2005). Organisms show adaptations to the environmental conditions through alterations of lifecycles, postponed stages in lifecycles waiting for optimal conditions, or through physical and morphological adjustments (Marchand 1996). Though adapted to harsh regions on earth, arctic organisms are sensitive to changes in environmental conditions and their survival rate depends on their adaptability to adapt to new conditions (Callaghan et al. 2004).

1.3 Paleoclimatic data.

The understanding of past climate change concerning its speed and direction is fundamental in order to give a sensible prediction on future climate change. It is important to separate anthropogenic influences from natural forces in terms of understanding their significance to climatic change (Jones and Mann 2004). Palaecological data provide information needed for constructing models for long-term climate change and play a key role in the understanding of past ecosystems and the changes within (Anderson et al. 2006).

Because data based on instrumental records only cover the last two centuries or so, other methods must be considered to obtain information on earlier climatic events. The use of natural indicators on climatic variability, or "proxies" found in the sediments, contributes to detect climate-related changes in the past (Jones and Mann 2004). Palaeoecology is the study and reconstruction of life and the habitats to organisms and the environment, based on physical, chemical, and biological information found in the sediment (Smol and Glew 1992). Fossils found in sediments can be used as a proxy or an indicator for past environmental changes if their biological and ecological tolerances are known. The environmental preferences are obtained through a modern assemblage of the fossil organisms (Birks and Birks 1980). Such assemblages of modern organisms compose a modern training set, which apply the environmental preferences to the fossil assemblages from the sediment core (Birks et al. 2000). Reconstruction of past environmental changes can be done by combining a temperature model developed from the modern training set and calibration techniques of the fossil assemblage (Brooks and Birks 2001).

1.4 General Circulation Models (GCMs).

General Circulation Models (GCMs) are the key for understanding climate and the factors behind climatic changes (Walsh and Crane 1992). They are models developed to simulate the earth's climate system. Such models are based on equations that describe the physics and dynamics of the movements and processes in the atmosphere, the sea, the ice and on land surface (Houghton 2005). Effects from climate change are more evident on a regional scale and in higher latitudes. Regional climate models (RCMs) provide regional simulations of climatic factors such as precipitation (Houghton 2005).

Most of the development of GCM`s are based on present day climatology, but present climatic data will not always provide a realistic prediction of future climatic events. To develop models that will make more reliable predictions about future climate, data of palaecological climate change prove to be useful (Arnell 1996). Data from mid-Holocene and Last Glacial Maximum (LGM) are shown to provide good predictions of future climate because reconstructed data of climatic changes in these periods indicate significant climatic differences from present conditions (Hargreaves and Annan 2009).

1.5 Chironomids.

Chironomidae is a family of non- biting midges belonging to the insect order Diptera. They are the most abundant and diverse insects in fresh water and can be found in most ecosystems (Cranston 1995). Chironomids are holometabolous insects developing from eggs to a larvae stage consisting of 4 instars before developing into adults through pupation (Johannson 1980). During the larvae stages, chironomids possess a heavily chitinized head capsule that they shed by moulting after each instars. The capsules settle down into the sediment and are preserved as sub-fossils. Due to the increased amount of chitin during the instars, most of the preserved capsules originate from the two last instars. The chitin leads to well preserved fossils in the sediment, and most of the specimens can be identified to genus level and species groups. In some cases it is possible to identify to species level (Brooks et al. 2007).

Chironomids spend their larval stages in the lake and closely reflect the environmental conditions in the habitat (Brodersen and Anderson 2002). This close relation causes them to show sensitivity to environmental stress related to changes in air- and water temperature (Brooks and Birks 2001), water depth (Heiri 2004), salinity (Walker et. al 1997), total phosphorus (Brooks et al. 2001), oxygen (Lotter et al. 1998) and pH (Brodin 1993).

Chironomids are good environmental indicators because they are abundant in lake biotopes, they are stenotopic and they respond quickly to changes (Brooks 2000). Their increased sensitivity to temperature compared to other aquatic insects makes them particularly interesting in temperature reconstructions (Ferrington 2008). When fossil chironomid assemblages are used in temperature reconstructions, modern chironomid- temperature training sets are used. This information is combined with the fossil assemblage to determine past temperature (Brooks and Birks 2001).

The abundance of chironomids in arctic lakes (Walker 1995), make a reliable temperature reconstruction possible (> 50 head capsules is sufficient) (Heiri and Lotter 2001, Quinland and Smol 2001). The use of chironomids as an indicator of environmental changes in palaeoecological studies has received increased attention (Brodersen and Anderson 2002, Brooks 2006). Despite promising results, recent studies have questioned the use of chironomids as a proxy for Holocene climate. Other environmental variables, at times, seem to have an overriding influence in chironomid assemblages, resulting in inaccurately climate reconstructions (Brodersen and Anderson 2002, Velle et al. 2005, Velle et al. in press). Since different proxies show sensitivity to different variables in the environment, a multi- proxy study with use of more than one proxy would provide a more extensive and accurate reconstruction (Birks et al. 2000, Velle et al 2005b). By comparing results from neighbouring lakes, the reliability of the temperature based on chironomid assemblages increases.

1.6 Previous studies.

Minimal anthropogenic influence and the Arctic localization, makes Svalbard a suitable area for climate research. (Rose et al. 2004)

The use of lake sediment cores has shown to provide valuable and effective records of climate and environmental changes on a broad time- scale (Jones and Birks 2001). Information from biological, chemical and/or physical indicators in sediment records from lakes at Svalbard have been used in a variety of projects connected to past climate and environmental questions. Brooks and Birks (2004) used the composition of chironomid assemblages in sediments from lakes on western Svalbard to detect and investigate environmental changes during the last 700 years. The response of chironomids to environmental changes has also been used to infer temperature changes from the last 1700 years in lake Skardtjørna on western Spitsbergen (Kongshavn 2009, Velle et al, submitted). Cores from lake Skardtjørna and lake Tjørnskardet have been collected to analyse changes in diatom assemblages and geochemical records to map out environmental changes during the 20th century

(Holmgren 2008). The composition of lake sediments has also been used to determine the sources of depositions of atmospheric pollutants on Svalbard (Rose et al. 2004). Svendsen and Mangerud (1997) examined the history of glacial variation during the Holocene period around Linnèdalen by structural and sedimentological studies.

Lake sediments have also been used for climatic research based on plant macrofossils. A study by Birks (1991) used macrofossils from Skardtjørna to explore the vegetation and climatic history of Western Spitsbergen.

1.7 Aims.

The aim for this project is to expand on the knowledge on arctic climate history.

The main focus of the thesis will be a temperature reconstruction from approximately the last 6000 years focusing on the last 2000 years by use of fossil chironomid head capsules, and compare the results to similar projects in the same area on western Spitsbergen. This will hopefully contribute to expand our knowledge on the magnitude, speed and the direction of global warming, focusing on temperature. This master thesis will be part of the Norwegian Research Council project "Magnitude and impact of Arctic climate change inferred from aquatic ecosystem (AQUACLIM)" managed by Gaute Velle. The project is based on validation of results from lakes in different arctic areas like Svalbard and arctic Canada, where the results provide an overall understanding of climate history. Svalbard and arctic Canada are interesting sites for climatic research because of the climatic variation with respect to their common latitude positions. Svalbard experiences a milder climate than arctic Canada, partially due to the North Atlantic Current (NAC), which transports warm water from the gulf -stream to northern European latitudes (Rossby 1996). The current branches off to form the West Spisbergen Current, providing mild climate to the Svalbard archipelago (Holmgren 2008) than on similar latitudes elsewhere in the Arctic.

2. MATERIAL AND METHODS.

2.1 Study area.

Svalbard is situated at 74°- 81° N and 10°- 30° E surrounded by the Barents Sea, the Greenland Sea and the Arctic Ocean. It is a high arctic archipelago with an area of 62 500 km^2, where Spitsbergen is the largest island with an area of 39 000 km^2. Because of south – west winds and the west Spitsbergen current, branching of from the North Atlantic Current, the climate is milder than expected compared to arctic areas at the same latitudes (Figure 2.1) (Holmgren 2008). Spitsbergen experience a mean temperature of 4.8°C in the summer (July temperature) and a mean temperature of -11.9 °C in the coldest winter months measured at Isfjord Radio (www.met.no).
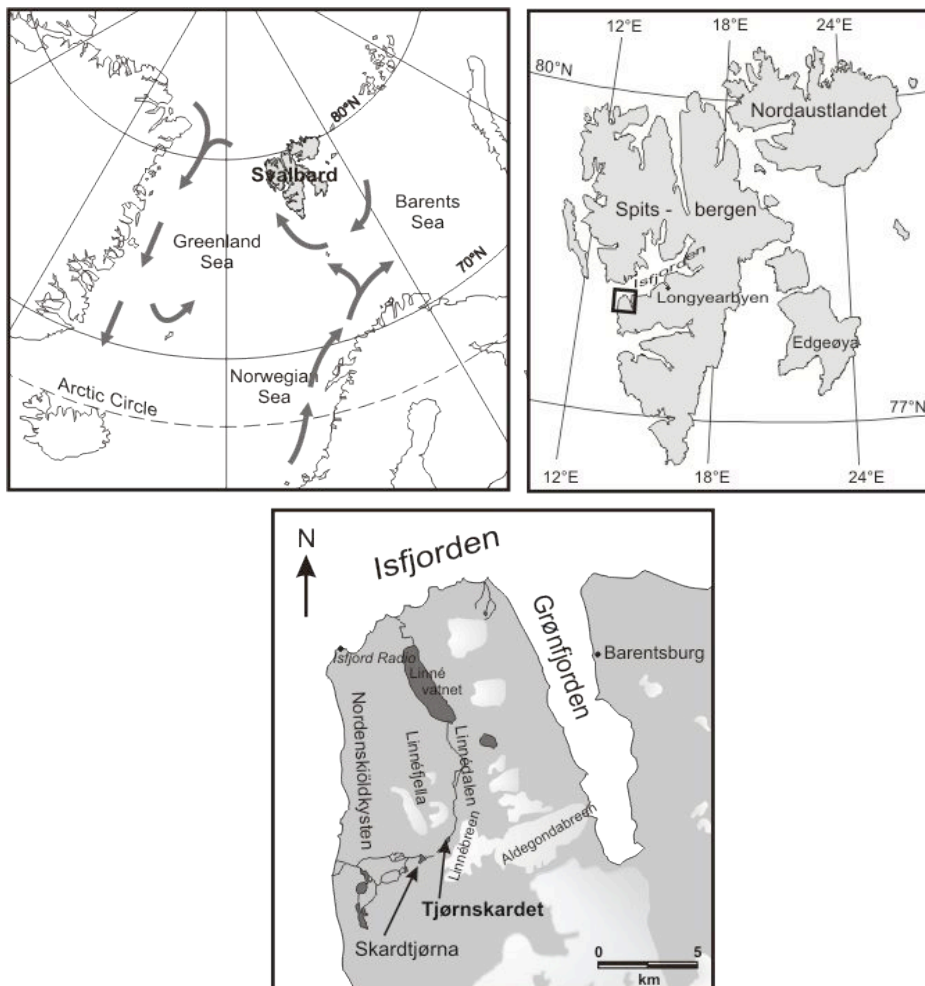
Figure 2.1. *Map of the Svalbard archipelago including the main water currents of the North Atlantic Current. The study site, Tjørnskardet is illustrated together with the neighbouring lake, Skardtjørna (modified from Holmgren et al. (2009).*

2.2 Study site:

Tjørnskardet is situated in the Tjørnskardet pass on the Nordenskiöld coast of western Spitsbergen (Figure 2.1), more precisely at the upper end of the pass (77°58′N, 13°52′E, 120 m a.s.l). Tjørnskardet is a narrow and elongated lake with a maximum depth of 2.45 m, a surface area of 0.081 km^2 and a catchment area of 2.2 km^2 (Figure 2.2) (Holmgren et al. 2009). It is situated in a non- glacial catchments area, most likely deglaciated around 12 500 years BP (Svendsen and Mangerud 1991). Thin discontinuous drift and erratics in the surroundings suggest Weichselian glaciations. Postglacial colluvium like talus and rock glacier on the valley slopes indicates Holocene permafrost (Holmgren et al. 2009). The area lies in the *Dryas octopetala* zone of the mid- arctic region and has a poor vegetation structure, dominated by *Salix Polaris* and bryophytes (Birks 1991).

Figure 2.2. *Tjørnskardet at the upper part of Tjørnskardet Pass*. Photo: G.Velle

2.3 Sediment sampling.

2.3.1. Sediment coring.

A short sediment core was obtained from Tjørnskardet in 2001 using a modified Kajak- Brinkhurst gravity device, which is a short sample corer used for sampling the upper 50 cm of sediment (Holmgren et al. 2009). Four long sediment cores were collected in 2003 by use of a Russian peat corer, resulting in 3.6 m of sediments (Figure 2.3).

2.3.2. Sediment samples.

A total of 73 samples were analysed from the collected sediment cores. Ten layers were used from the short core, which represents the first 19 cm of the upper and youngest sediment layers. The short core was parted in advance into 0.5 cm layers and freeze- dried for optimal storage. Layers of 0.5 cm to 1 cm were extracted with an interval of 0.5 cm to 10 cm down to 3.32 m in the long sediment core. Head capsules were sorted for temperature reconstruction while plant macrofossils were collected for dating.
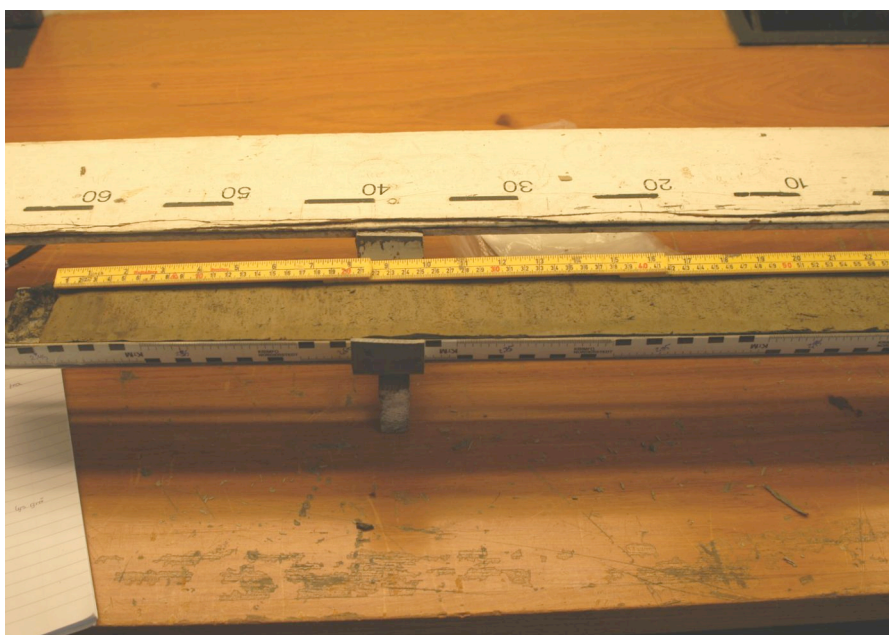
Figure 2.3. Sediment core from Tjørnskardet. Photo G. Velle

Because of low abundance of chironomid head capsules in some of the sediment levels, samples with <30 head capsules were pooled together to obtain enough capsules (>50) in the levels to provide a more reliable temperature reconstruction (Heiri and Lotter 2001, Quinlan and Smol 2001).

2.4 Sediment analysis.

2.4.1. Sediment chronology.

The age model for the short core was dated based on ^{210}Pb analysis (Holmgren 2009). By use of alpha spectroscopy the ^{210}Pb ($t_{1/2}$ = 22.3 years) activity, were interpreted, and the ^{210}Pb age was determined by applying the constant rate of supply (CRS) model to the unsupported ^{210}Pb inventory (Appleby and Oldfield 1978). The long cores were dated using ^{14}C analysis based on aquatic plant macrofossils by use of advent accelerator mass spectrometry (AMS) by BETA analytic. The age model of the sediment in this study was rearranged from radiocarbon age to calibrated years BP (BP= 1950) by CALIB version 6.0 (Stuiver et al. 2005).

The age model of the long core was made by estimating the relationship between the core depth and the radiocarbon age. This was done by polynomial regression, which from testing with a 2-order trendline had the highest significance and proved to be the best statistical model. The radiocarbon ages from the Tjørnskardet long core appeared much older than corresponding ages based on ^{210}Pb of the short core. One potential source of bias with carbon dating is that the radiocarbon age can be too old. This is due to the "hard-water effect" where old carbonates from the calcareous components in the sediment lower the radiocarbon activity in the lake. The old ^{14}C will then be assimilated instead of the atmospheric ^{14}C by the organisms in the lake and the dating will be erroneous (Barnekow et al. 1998). To provide an accurate dating of the core, the ^{14}C calibrated age were re-calculated on the basis of the ^{210}Pb age from the overlapping small core. The difference between the age models based on ^{210}Pb dating and on ^{14}C dating was subtracted from the calibrated ^{14}C age, providing a new radiocarbon age on the long core.

2.4.2. Chironomid analysis.

Analysis of the sediment was done by standard preparation techniques according to Brooks et al. (2007).

The samples collected from the core were weighed and sieved through a 100µm mesh under warm water. The head capsules were sorted individually from a sorting tray under 25-50x magnification by using fine forceps. The head capsules were then added to a small vessel filled with 96 % or absolute ethanol for dehydration before mounted on microscope slides. Euparal and Canada balm were used as mounting media. Euparal is quick drying, permanent and provide a gentle dehydration for delicate objects. The headcapsules were covered by a cover slide where one cover slide can contain up to 15 head capsules and each microscope slide can contain around 60 head capsules. The head capsules were mounted ventral side up to show critical mouthparts for the identification process (Brooks et. al. 2007).

2.4.3. Chironomid classification.

For identification, the head capsules were examined under 100-600x magnification and the identification of chironomid head capsules was done by use of a technical guide (Brooks et al. 2007). The identification is based on number of teeth on mandibles, premandibles and mentum, the shape of the ventromental plates and the spur on the antenna pedestals. The mandibles and premandibles are in most cases absent from the head capsules. In some species under *Micropsectra* the post- occipital plate will provide some diagnostic support (Figure 2.4). The colour and pigmentation of the head capsules may also contribute, but this is indistinct because the colour may change according to larvae instars. These features can easily be distinguished in the main taxa found in the sediment from Tjørnskardet.

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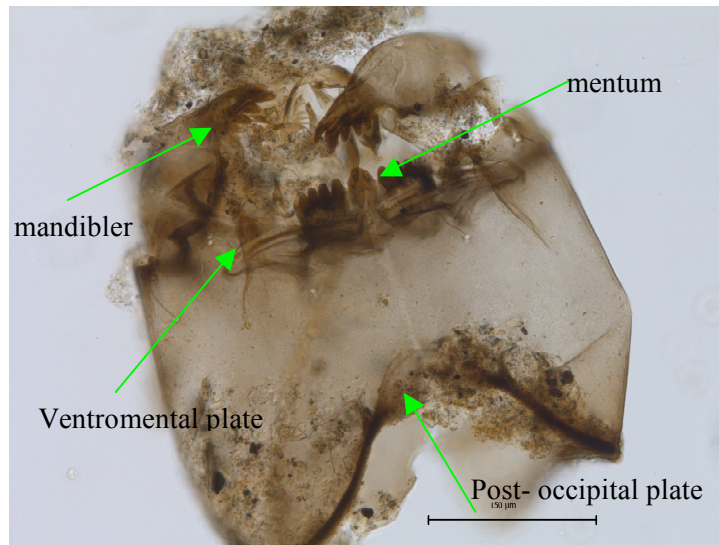
Figure 2.4. *Morphological characteristics.*
Micropsectra insignilobus-type.

2.5 Numerical analysis.

2.5.1. Zonation.

Zonation is a method to detect variation in the composition of fossil taxa in the sediment, where a zone can be defined as a stratigraphical area where the fossil composition varies in type and frequencies compared to other levels in the sediment (Birks 1972). Based on the optimal sum of squares partitioning on percentage data, the statistical significant changes in the chironomid composition was defined by use of the program ZONE (Juggins 1991). The number of statistical significant zones was assessed using the broken- stick model (Bennett 1996) in BSTICK (Line and Birks, unpublished software).

2.5.2. Ordination.

Gaussian response curve.

There is a close relationship between taxa and the environmental conditions in the habitats. The taxa have defined environmental optima and tolerances and will not be able to survive if the value of the different environmental variables changes to a certain extent (Birks 1995). This results in a non- linear relationship between taxa and environmental variables, and tends to show a unimodal distribution (Birks 1998). To express this unimodal relationship between taxa and environmental variables, a Gaussian response curve is used, illustrating the species maximum, optimum and tolerance towards an environmental variable (Figure 2.5.1) (Birks 1995). The taxa tolerance (1 SD) in the response curve is determined as standard deviation units of turnover (SD), and the environmental variable axis or gradient length for single taxa is 4 SD units long.
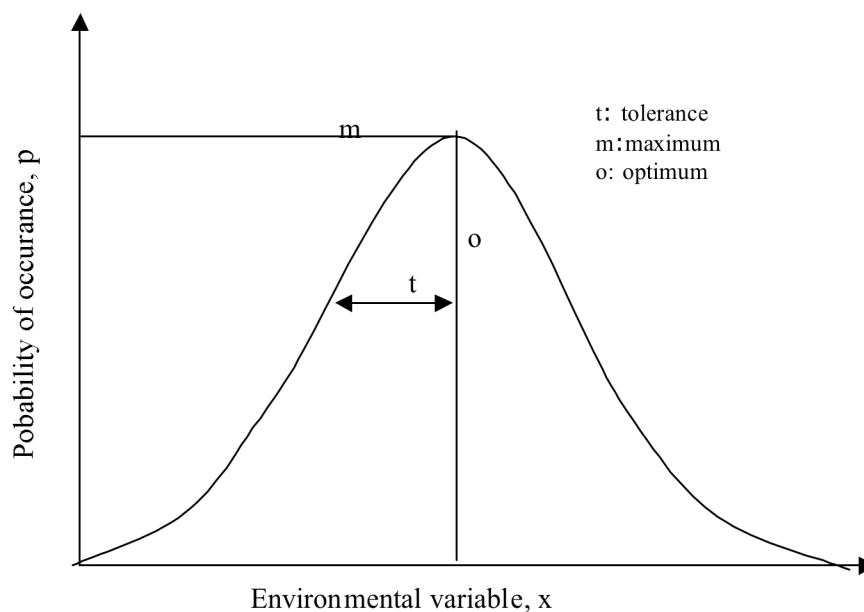
Figure 2.5. *A species response towards an environmental variable can be explained by a Gaussian response curv*e.

Detrended correspondence analysis (DCA).

Correspondence analysis (CA) is based on unimodal response curves to explain species response to environmental variables (ter Braak 1995). Detrended correspondence analysis (DCA) is a modified version of CA to prevent the arch effect, which makes it difficult to interpret the ordination diagram (Hill and Gauch 1980). In quantitative environmental reconstruction, detrended correspondence analysis (DCA) is used to determine if unimodal or lineal models are the most suited statistical models in relation to the taxa in question (Birks 1995).

Principal component analysis (PCA).

PCA is a linear model appropriate for analysis when the species data are quantitative abundances, and the range of environmental variation in the sample is confined (ter Braak and Prentice 1988). The objective with PCA is to reduce the number of predictor variables (chironomid taxa) and focusing on the major patterns of variation to the first components (first axis), and the patterns less coherent to the later components (Birks 1995) and by so identifying new possible underlying variables to explain the distribution. This model was chosen because the gradient length was estimated to be under 2SD. This means that there is a monotonic relationship between taxa and the environment variable, and the most appropriate ordination method is the linear model (Birks 1995).

Both DCA and PCA, from square- root transformed percentage data were carried out using the software CANOCO version 4.5 (ter Braak and Smilauer 2002). The PCA figure was made using CanoDraw, where rare taxa with N2 values (species score) less than 4 were excluded.

N2 diversity measure.

Hill`s N2 diversity index is a measure of diversity (Hill 1973). It represents the effective number of taxa in a sample, focusing on the most abundant taxa. N2 was measured in DCA by CANOCO (ter Braak and Smilauer 2002) and was estimated for each sample (layers with <30 head capsules were pooled with neighbouring layers).

<u>2.5.3. Transfer function.</u>

<u>Analogue matching.</u>

To infer an environmental variable accurately, a good analogue matching between the modern taxa assemblage and the fossil assemblage is favourable (ter Braak 1995). Testing for analogue matching is to detect the taxa representation in the modern training set compared to the fossil assemblage (Birks 1998). The analogue match is considered good of the assemblage lies within the 5% percentile. In the present study, this was done on square root transformed percentage data using the software C2 version 1.5 (Juggins 2007).

<u>Traning set for transfer function.</u>

The training set used in this project is based on chironomid taxa from surface sediment samples collected in lakes from Norway and Svalbard and contemporary environmental variables (Brooks and Birks 2000, 2001, unpublished). To perform the temperature reconstruction, two sub-sets of the modern training set were tested. The full training set included 157 lakes and a reduced training set excluding lakes with temperature above 9°C included 53 lakes.

The intention of testing training sets is to evaluate which of the sub-sets provides the most accurate palaeotemperature to the lake of interest (Velle et al. submitted). This is because the statistical edge effect is a potential problem when working with lakes at the cold end of the temperature gradient. The edge effect increases the predicted mean temperature values by pulling the predicted values towards the mean of the temperature gradient of the training set. By shortening the temperature gradient in the training, the values of the estimated variables will be more accurate (Birks 1998).

The modern transfer functions for July temperature were generated by the inverse regression approach of weighted-averaging partial-least-square regression (WA-PLS) (ter Braak and Juggins 1993). From testing of several inference models, (Velle et al.

submitted), WA-PLS is the most appropriate model for the lake in question. Usually WA-PLS is more appropriate for gradient length over 2 SD, but prove to be adequate for cased with short gradient lengths (<2 SD) because it need fewer components than PLS-1, which is the general model. It will also provide more reliable results when there is a poor analogue between the modern training set and the fossil assemblage (Birks 1995). For the full and reduced modern training set, 5 component models were developed, where the optimal number of components to include in the WA-PLS model was assessed by leave- one –out cross validation (ter Braak and Juggins 1993, Birks 1995). The best inference model is the one with the lowest maximum bias and low RMSEP (root mean square error of prediction), highest value of R^2 (coefficient of determination) and with the smallest number of useful partial- least-square components (Birks 1998).

<u>Temperature smoothing.</u>

Smoothing is a method for removing discrete and noisy data. This is to detect the major trends in the sediment levels, and to exclude levels that entail less meaningful information (Velle et al. 2005). The smoothing fit is dependent on the number of neighbouring points that participate in the calculation of the predicted value. More points make the fit smooth and more resistant to changes, while few points provide a less smooth fit and changes are more likely to occur.

The span (*f*) decide how many adjacent points (*q*) are used in the regression where *f=q/n, n* being the total sample size. This means that a large number of points provide a large *f* and the smoothest fit (Velle 2003). In the present study, smoothed lines with span 0.2 and 0.1 were used to highlight the major trends, where the smaller span include less points in the smoothing, providing a more detailed line. The transfer functions and LOESS scatter plot were developed using C2 version 1.5 (Juggins 2007).

3. RESULTS.

3.1 Sediment chronology.

The dating based on ^{14}C turned out to have an aberration leading to imprecise dating of the sediment compared to the results from the ^{210}Pb-dating.

Most likely due to the hardwater effect (see section 2.4) the resulting ^{14}C calibrated ages were offset compared to the ^{210}Pb ages. Hence, the core was dated by using the ^{210}Pb results to estimate new ages from the ^{14}C dating (Table 3.1).
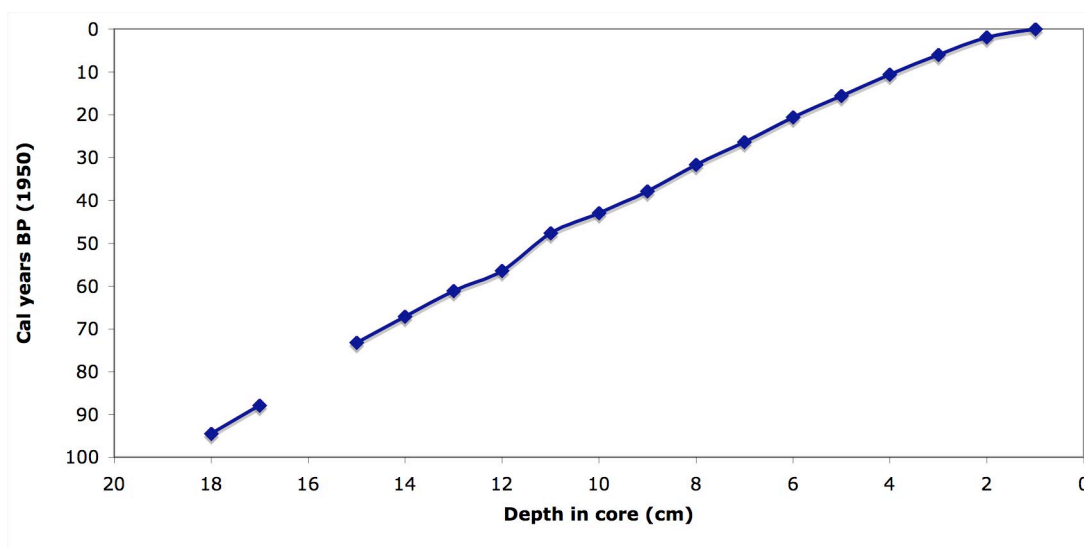
Figure. 3.1. *Calibrated years based on ^{210}Pb from the short sediment core.*

Figure 3.1 show the ^{210}Pb years of the short core. The calibrated age is extending from approximately 100 cal BP to present, while table 3.1 shows that the calibrated years from the long core show a time span from ~ 6244 cal BP to 935 cal BP. This gave a difference of ~1000 years of corresponding core layers. From the polynomial regression described in paragraph 2.4 the age of the long sediment core is ~6000 cal years (Figure 3.2).
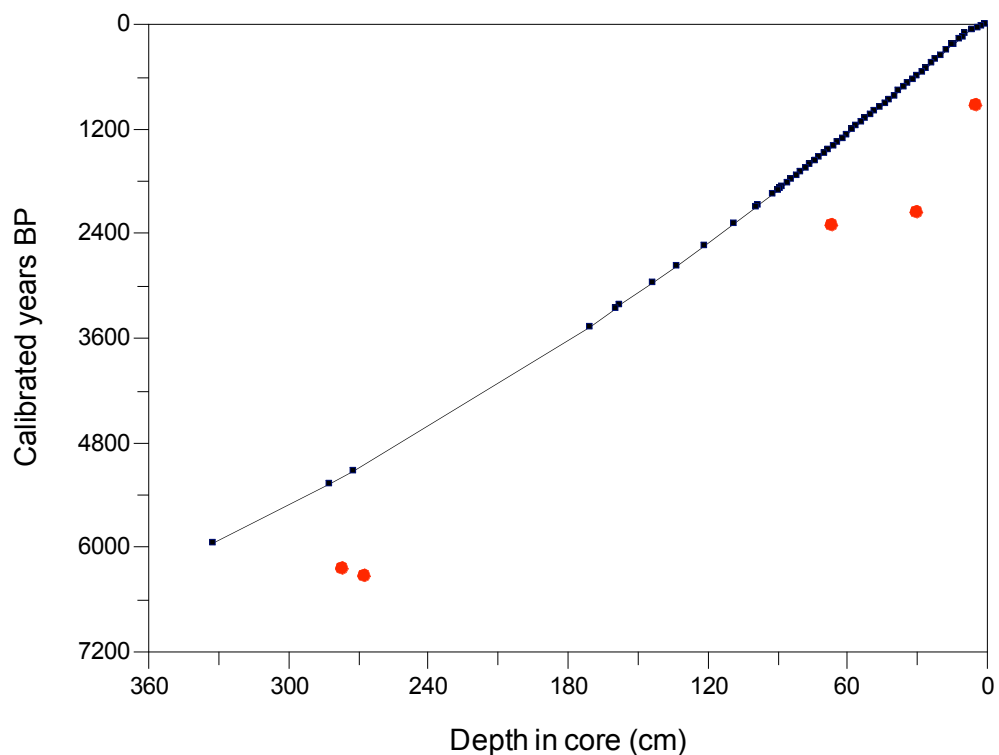
Figure 3.2. *New ^{14}C calibrated age estimated from the ^{210}Pb dates from Holmgren (2008). The red marks show the original age calibrated from the radiocarbon analysis (Table 3.1).*

Table 3.1. *Results from the radiocarbon dating analysis*

Depth (cm)	Conventional Radiocarbon Age	Cal. age BP	Material dated
4.5	1010+/- 40 BP	935	Drepanocladus sp.
30.5	2210 +/- 40 BP	2170	Drepanocladus sp.
66.5	2260 +/- 50 BP	2315	Drepanocladus sp.
267	5560 +/- 40 BP	6328	Drepanocladus sp.
277	5420 +/- 40 BP	6244	Head capsule

3.2 Chironomid analysis.

There were collected 79 layers from the sediment cores with a total of 4529 chironomid head capsules. There was great variation in the number of head capsules among levels giving an average of 57.9, with a maximum amount of 294 and a minimum of 5. Layers consisting of less than 30 capsules were pooled with the neighbouring layers to exceed the limit of > 50 capsules per layer, resulting in 60 layers. A total of 26 taxa were found in the sediment from Tjørnskardet including:

Procladius:
Thrive in mesotrophic and eutrophic lakes, not common in the coldest lakes (Brodin and Gransberg 1993).

Diamesa aberrata-type and *Diamesa zernyi/cinerella*-type:
Stenothermic larvae, living in cold flowing water or the littoral of lakes (Oliver 1983).

Brillia:
Holarctic genus that lives in the littoral and hygropetric zones (Cranston et al. 1983).

Chaetocladius:
Holoarctic taxa that can be found in arctic and subarctic lakes despite their preference for running water and vegetation (Cranston et al. 1983).

Eukiefferiella:
Eurythermic genera that exist in the surf zone in the lake (Lindegaard 1992).

Hydrobaenus conformis-type*, Hydrobaenus johanseni*-type and *Hydrobaenus lugubris*-type:
Cold stenotherms that occur in oligotrophic lakes (Cranston et al. 1983).

21

Limnophyes:

Common in shallow water, streams and in the littoral of lakes (Kansanen 1985). Most common in temperate lakes (Cranston et al. 1983).

Metriocnemus eurynotus-type and *Metriocnemus fuscipes*-type*:*

Common in temperate lakes and streams, and some species can be located in the Arctic (Cranston and Judd 1987). Can be found in the littoral of temperate lakes and stream (Cranston et al. 1982, 1983), and live among plants (Brodin 1986).

Orthocladius type 1, Orthocladius oliveri-type and *Orthocladius trigonolabis*-type*:*

Eurytopic taxa living in flowing and standing waters.

Most live in temperate, eutrophic conditions (Cranston et. al 1983), but some species are cold stenothermic (Saether 1979), occurring in oligotrophic arctic and subarctic lakes.

Paracladius:

Cold Stenothermic genus common in artic lakes and in deeper habitats of large temperate lakes (Walker et al. 1997).

Thienemaniella:

Usually in temperate lakes, in streams and rivers. (Cranston et al. 1983).

Corynoneura:

Abundant in arctic and alpine lakes, also found in warmer lakes. They live in the littoral zone (Brodersen et al. 2001).

Micropsectra radialis-type and *Micropsectra insignilobus*-type:

Cold stenothermic, acidophobic and live in ultraoligtrophic, cold arctic and alpine lakes. *Micropsectra insignilobus*-type has a higher temperature optimum than *Micropsectra radialis*-type (Brundin 1956). Occur in the profundal but move into the littoral of lakes (Lindegaard 1992).

Paratanytarsus austriacus-type and *Paratanytarsus penicillatus-type:*
Abundant in both warm and cold lakes. *Paratanytarsus austriacus*-type lives in cold oligothrophic lakes at high latitude or altitude. *Paratanytarsus penicillatus*-type thrives in warmer conditions (Brodersen et al. 2001).

Oliveridia tricornis:
Lives in cold oligotriphic lakes (Cranston et al. 1983).

Some of the capsules could not be identified to species level due to worn or lack of characteristic parts. Specimen with only half of the head capsule in some cases confined the identification. These specimens were placed in broader taxonomic unit of supra-specific taxa; *Paratanytarsus* sp*., Tanytarsini* sp. and *Orthocladiinae* sp.

Some of the taxa in the fossil assemblage were not included in the modern training set and was unified in groups present in the training set.
Diamesa aberrata-type and *Diamesa zernyi/cinerella*-type formed one *Diamesa* group*,* while *Oliveridia tricornis* and *Hydrobaenus lugubris*-type were placed in one group, mostly because worn specimens sometimes are undistinguishable. The median tooth is the most distinguishable feature in these species, where *Hydrobaenus lugubris*-type possess two median teeth, and *Oliveridia tricornis* has one. In worn specimens, this difference is not easily detected. *Orthocladius* type 1*, Orthocladius oliveri*-type and *Orthocladiinae* sp. formed one other group and *Metriocnemus eurynotus*-type and *Metriocnemus fuscipes*-type were also pooled.
The tree most abundant taxa in the sediment from Tjørnskardet was *Micropsectra radialis*-type, *Micropsectra insignilobus*-type and *Oliveridia tricornis* (Figure 3.3, 3.4 and 3.5)

Figure 3.3. *Micropsectra insignilobus. Photo: K. Fadnes*

Figure 3.4. *Micropsectra radialis. Photo K. Fadnes*
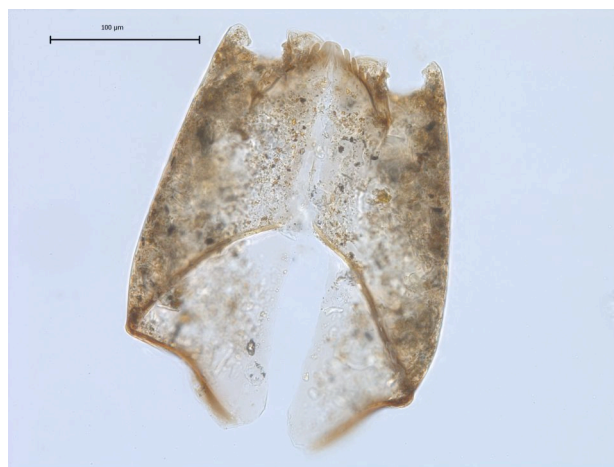
Figure 3.5. *Oliveridia tricornis. Photo: K. Fadnes*

3.3 Statistical analysis.

3.3.1 Ordination.

From the DCA the total inertia of species data (the gradient length) was 0.80 standard deviation units. This value entails the use of PCA for further ordination analysis. From the PCA, the eigenvalues were estimated to 0.445 and 0.118 for the first and the second axis, respectively. The first and second axis were statistical significant, however the second axis did not have any effect on the distribution of the chironomid assemblage. The N2 diversity measure had a minimum value of 3.07 and a maximum value of 10.21. The average value was 5.94 (Table 3-1 appendix).

Figure 3.6 show the results from the PCA and figure 3.7 show the distribution of species in Tjørnskardet along the significant PCA axes. The species with the lowest N2 score (<4) were excluded from the analysis (Table 3-2 appendix).
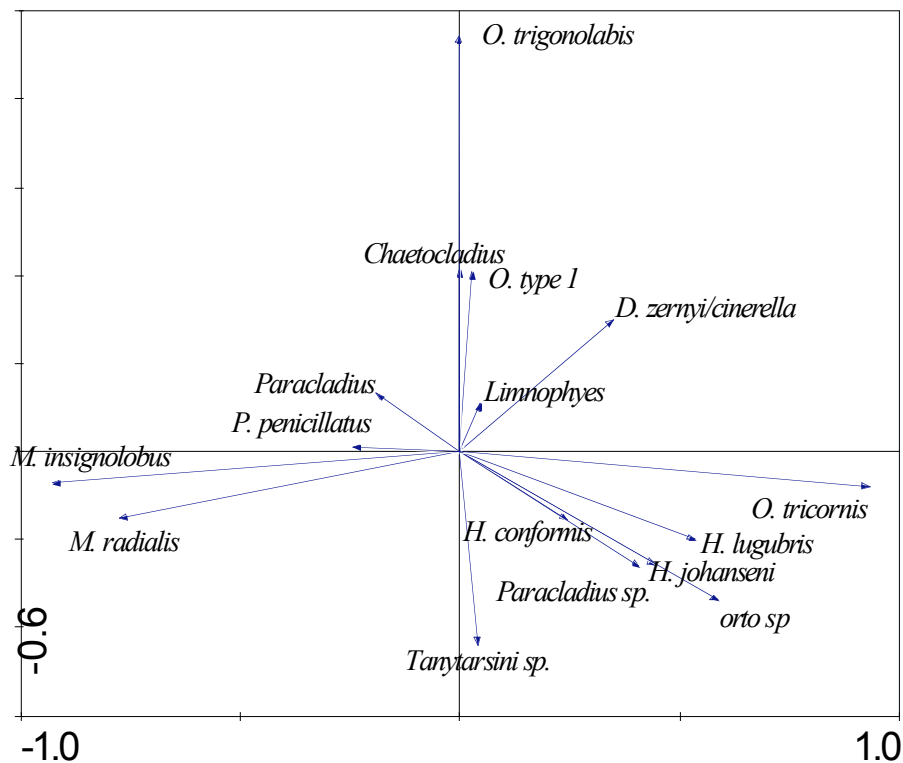
Figure 3.6. *PCA species scatter plot.*

Figure 3.6 shows that *Micropsectra radials-type* and *Micopsectra insignilobus*-type in almost all samples occur together, and are clearly correlated to the first PCA- axis. *Oliveridia tricornis* and *Hydrobaenus lugubris*-type also show a correlation with the first axis, and rarely occur together in sediment samples with *Micropsectra radials-type* and *Micropsectra insignilobus*-type. Figure 3.7 shows the species distribution along the first PCA- axis. The dispersion of taxa along the gradient indicates that temperature may explain the distribution because the temperature optima (Brooks and Birks 2000, 2001, unpublished) to the taxa decrease along the axis. However, some of the taxa with close resemblances in temperature optima are distributed differently along the axis, which may indicate that other environmental variables can have an influence on the chironomid assemblage in the lake.
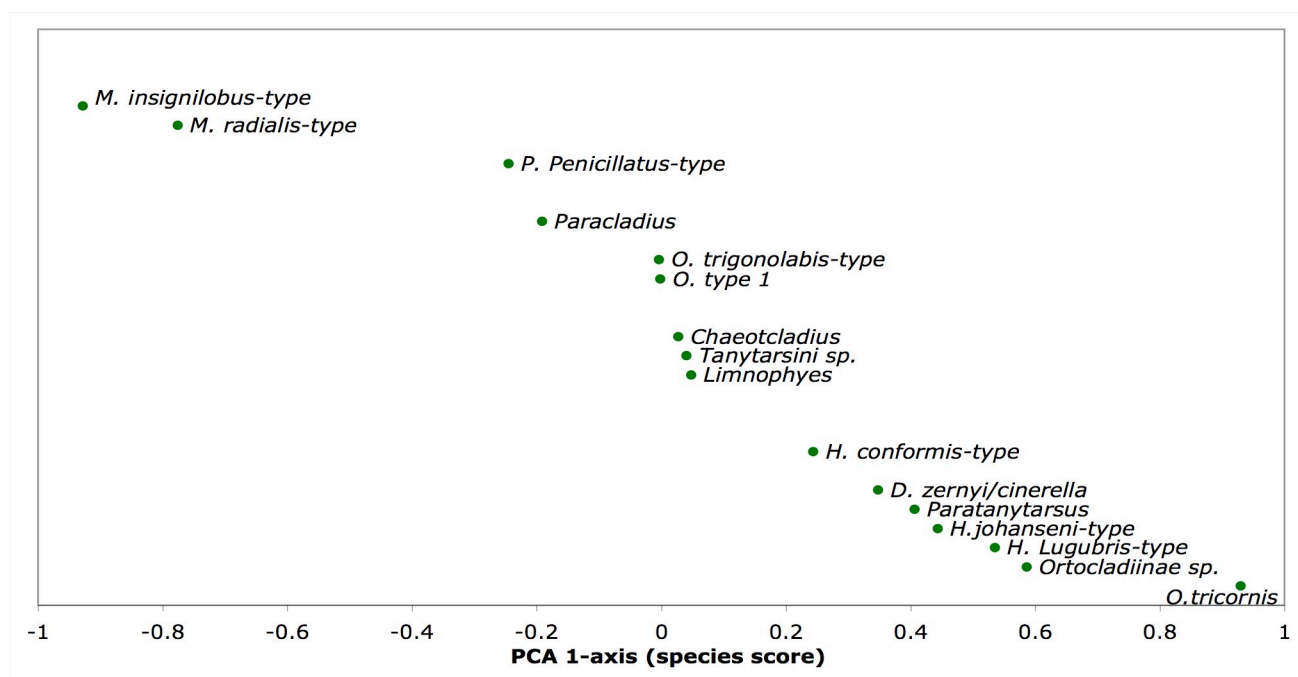
Figure 3.7. *Species score along PCA 1- axis. Only taxa with N2 score >4 are shown.*

3.3.2. Chironomid assemblages and zonation.

From the zonation analysis, there was one statistically significant change in the chironomid stratigraphy parting the core in two zones. There are five taxa that dominate throughout the core, *Hydrobaenus lugubris*-type*, Orthocladius trigonolabis*-type*, Oliveridia tricornis, Micropsectra radialis*-type and *Micropsectra insignilobus*-type (Figure 3.8). The other taxa found in the lake occurred in smaller numbers. From the temperatures listed for the 9°C modern training set, they all had temperature optimum and tolerance under 9°C (Table 3.2).

Table 3.2. *Taxa temperature optima and tolerance based on WA inference model from the reduced modern training set.*

Taxon	Tolerance	Optimum	WA-PLS beta coefficients
Hydrobaenus conformis	1.47	4.83	3.38
Mircopsectra radialis	1.64	5.50	4.40
Micropsectra insignilobus	1.17	7.57	8.08
Hydrobaenus lugubris + Oliviridia tricornis	1.89	4.45	2.70
Dimeza zernyi/cinerella	0.52	3.76	1.27
Orthocladius trigonolabis	1.7	5.2	3.8
Orthocladiinae sp.	2.0	6.6	6.5
Tanytarsini sp.	1.1	7.4	7.8

Zone 1: (0- 60 cm) age: BP present - 1261 cal BP:

Zone 2 includes the first 60 cm of the sediment core and represents the period from present year to 1261 cal BP.

Dominant taxa in zone 1 include *Hydrobaenus lugubris*-type*, Oliveridia tricornis and Hydrobaenus conformis*-type*,* which is cold stenotermic species. *Orthocladiinae* sp.*, Orthocladius trigonolabis*-type and *Diameza zernyi/cinerella*-type have a frequently occurrence in this zone compared to zone 2.

Zone 2: (62- 332.5 cm) age: ~1304 cal BP – 6000 cal BP:

Zone 2 ranges from 62 cm to 332.5 cm at the end of the core. This zone encompasses the years from ~1304 cal BP to 6000 cal BP.

Micropsectra radialis-type *and Micropsectra insignilobus*-type are the dominating taxa in this zone. This zone has a lower taxonomic diversity compared to zone 1.
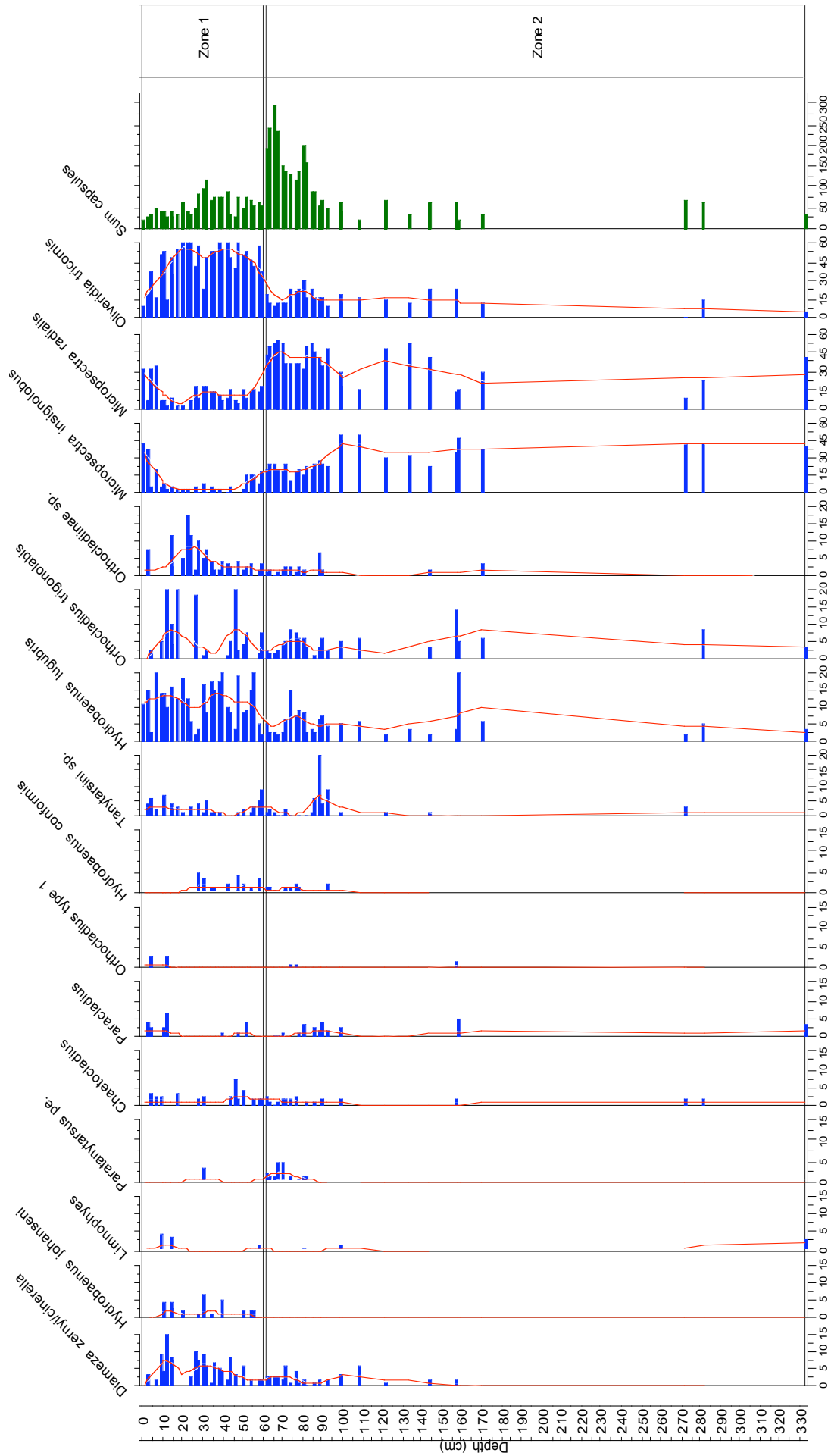
Figure 3.8. Core depth and percentage abundance of the most abundant taxa from Tjørnskardet. The taxa was included according to their N2 value (species score). Note different values on the x-axis in accordance to the taxa abundance in the sediment.

3.3.2. Transfer function.

Analogue matching.

There were no good analogues in the modern training set compared to the fossil assemblages. The average prosentile was 42.3% from 5 prosentile. 28 layers in the core had good analogues to the modern training set, and the layers in the lower section of the core had poor modern analogues.

Training set.

Testing of the 5 component models for each of the training sets indicate that the WA-PLS model with 2 components was most appropriate for the full modern data set, while for the reduced training set, the best model was the simplest one- component model. Table 3.3 shows that the reduced training set is the more appropriate modern training set with the lowest RMSEP, lowest maximum bias, the highest R^2 and with fewer WA-PLS components. The inferred temperature range in the two training sets are shown in figure 3.9.

Table 3.3. *Testing of the modern training sets by WA-PLS model.*

	9°C training set	Full training set
No. lakes	53	157
No taxa	86	141
Range (°C)	9-3.5	16- 3.5
RMSEP (°C)	0.73	1.22
R^2	0.88	0.88
Maximum bias (°C)	0.58	1.16
WA- PLS components	1	2
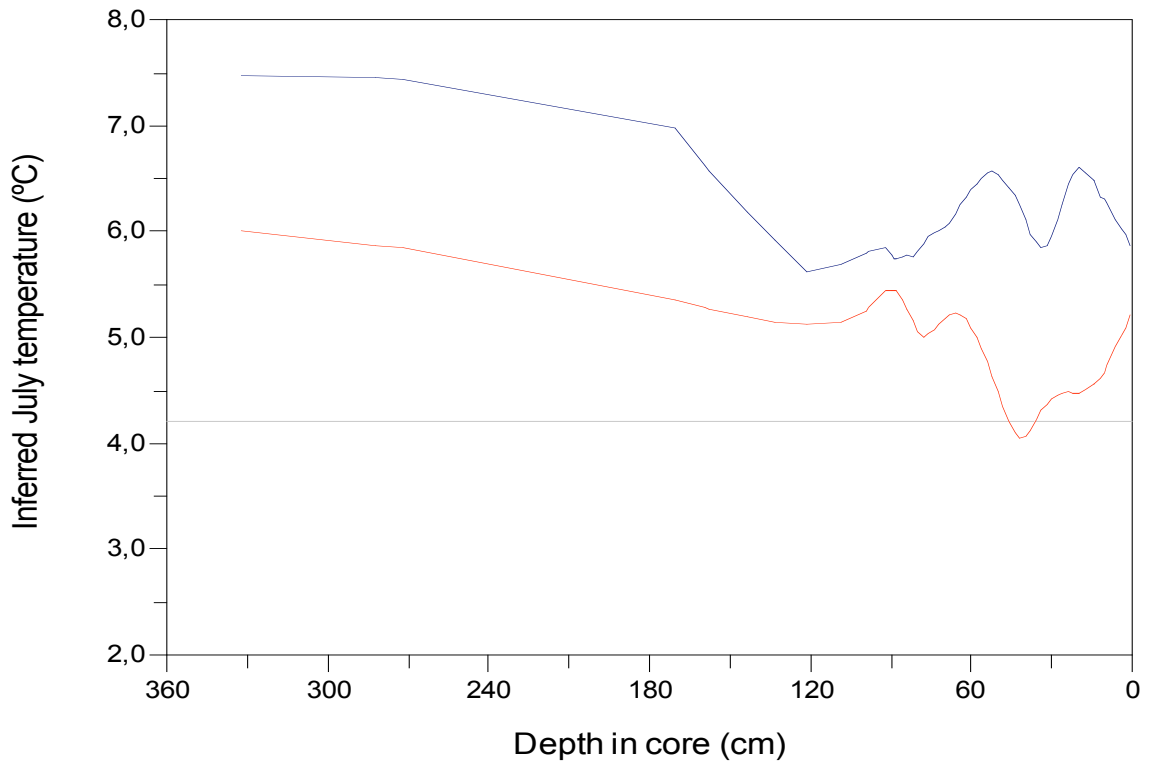
Figure 3.9. *Inferred temperatures based on the different training sets, the LOESS smoothed lines (span= 0.2) represents the reduced 9°C set (red line) and the full training set (blue line).*
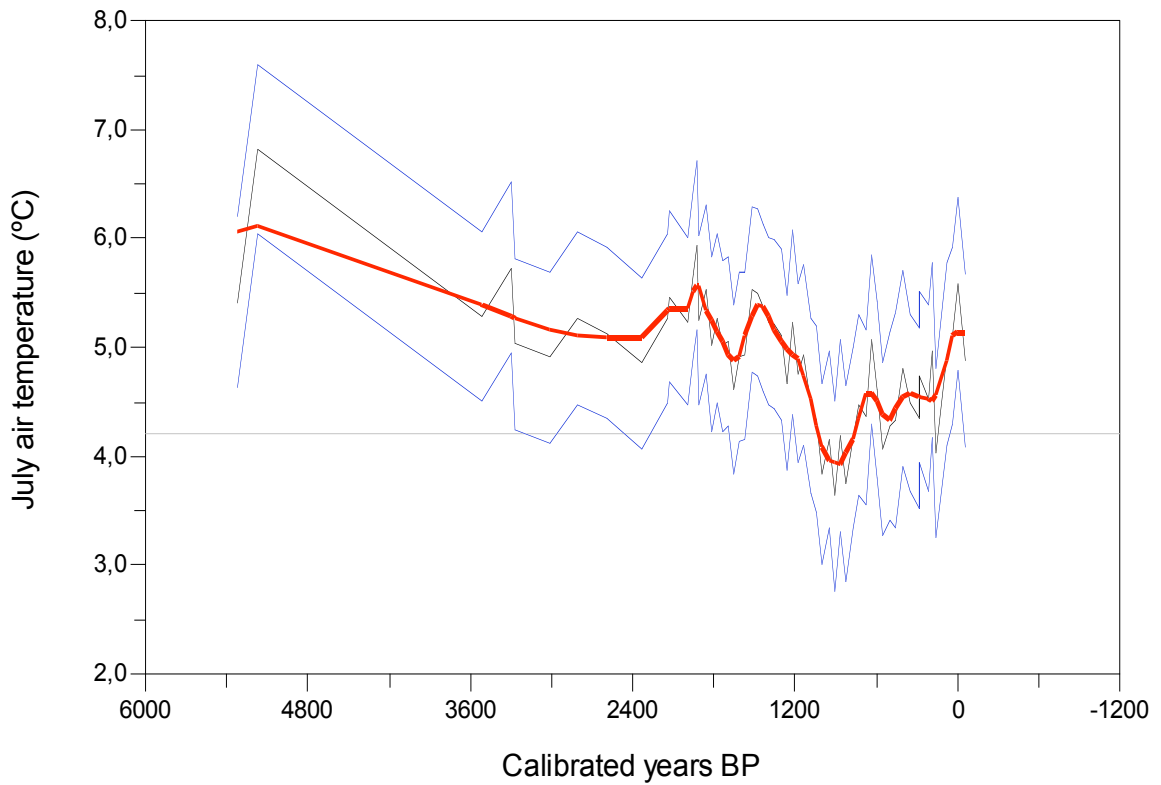
Figure 3.10. *Inferred temperature based on the reduced 9°C training set estimated by WA- PLS. Sample specific error estimates are added in blue and reconstructed July air temperature added LOESS smoother (red line, span= 0.1). Mean July temperature for the present (1961-1990) at Tjørnskardet is added with grey line (www.met.no).*

Figure 3.10 shows the calibrated temperature for the whole sediment core extending back to 6000 cal BP, while figure 3.11 shows the major changes that occurs at 1800 cal BP towards the present. The figure is smoothed with a 0.1 span to highlight the smaller shifts in the temperature. To see the estimated range of error in the temperature, the error estimates are added to the figure.
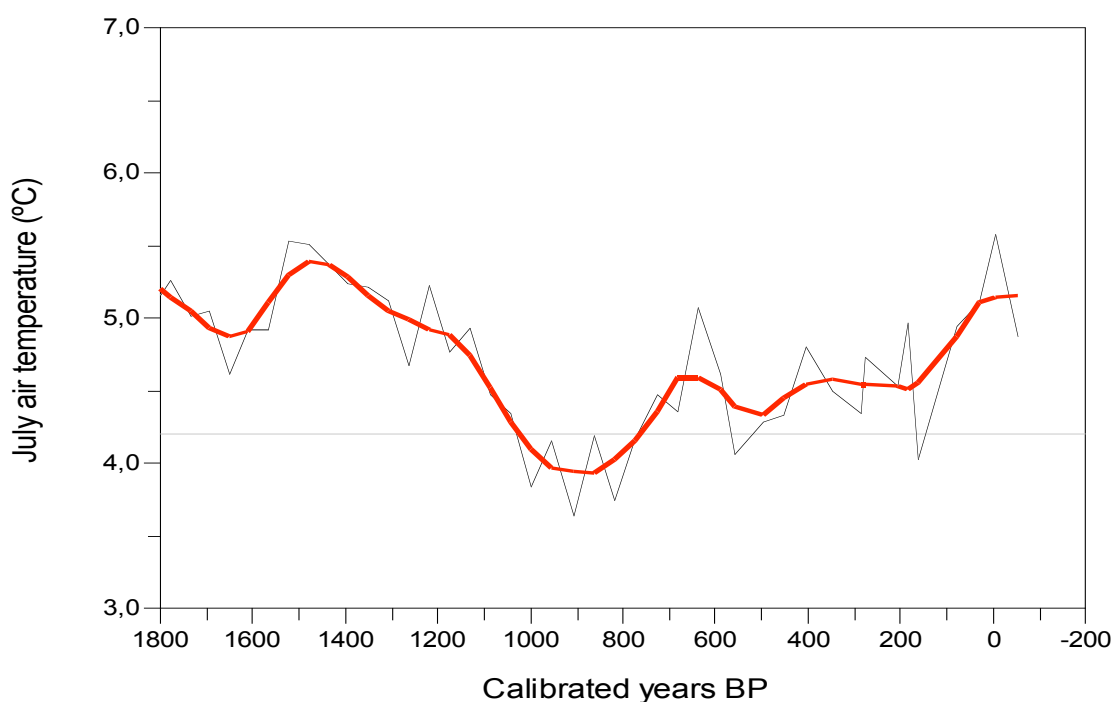
Figure 3.11. *Reconstructed July air temperature from the last 2000 years. LOESS smoothed with span= 0.1. Mean July temperature for the present (1961-1990) is added with grey line (www.met.no).*

The July air temperature estimated from the reduced 9 °C training set had a temperature range between 3.6 °C to 6.8 °C with a mean temperature of 4.9 °C.
From the smoothed line, there was detected some major temperature trends, described below.
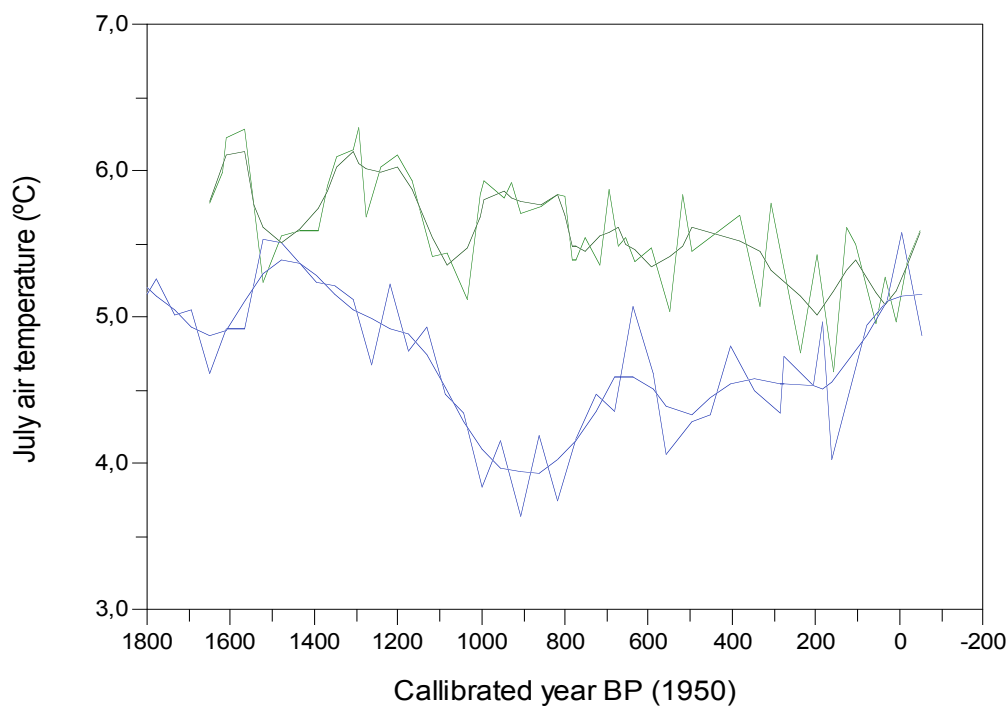
Figure 3.12. *July air temperature from Skardtjørna (green line)(Kongshavn 2009)*
and Tjørnskardet (blue line) based on the reduced training set. The lines are
smoothed by LOESS (span= 0.1)
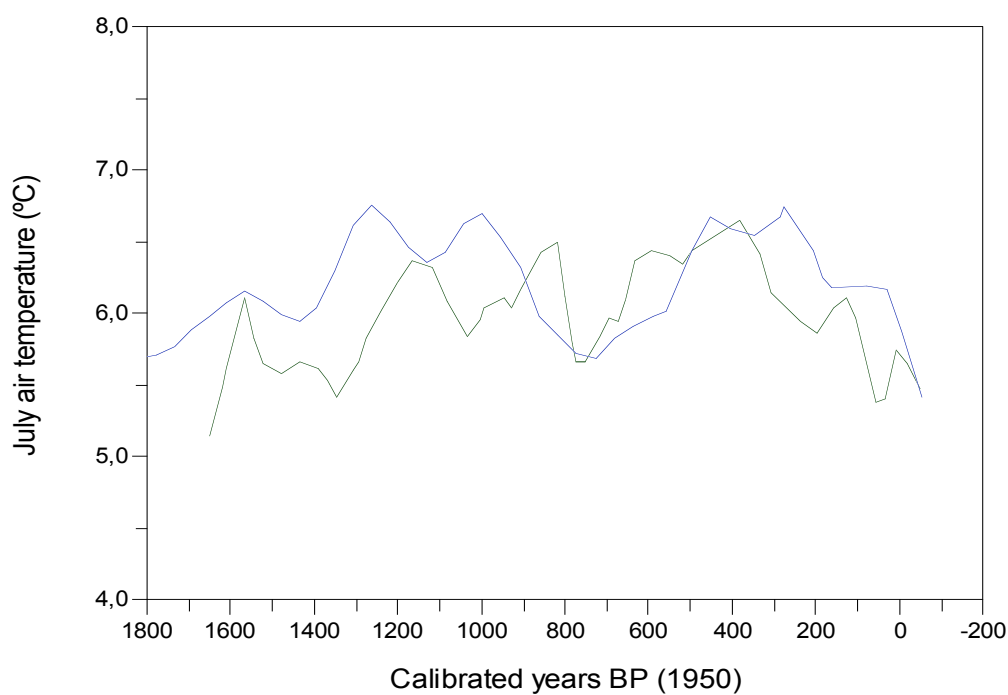
Figure 3.13. *Comparison of July air temperature from Skardtjørna (green line)*
(Kongshavn 2009) and Tjørnskardet (blue line) based on the full training set. The
lines are smoothed by LOESS (span= 0.1)

The July air temperature reconstruction from Tjørnskardet based on the reduced training set (Figures 3.10 and 3.11) revealed an overall decline in temperature from 6000 cal BP to present. From 6000 cal BP to 5200 cal BP a warming period occurred with a temperature rise of 2°C. A continuous cooling of 1.6 °C followed from 5200 to 2000 cal BP followed by a small increase by 0.5°C between 2000 cal BP and 1820 cal BP. From 1820 cal BP to 1650 cal BP there was a small cooling period followed by a rise from 1650 cal BP to 1450 cal BP. From 1450 cal BP to 850 cal BP there was a long cooling period with temperatures down to 3.6°C. A small warming period occurred from 850 cal BP to 690 cal BP before the temperature dropped by approximately 0.5°C. from 690 cal BP to 500 cal BP. There was a warming period from 500 cal BP to the present with an increase by 1.0 °C, only interrupted by a slight cooling around 400 cal BP to 180 cal BP.

Figure 3.12 and 3.13 show that there are some differences in the reconstructed temperature between Skardtjørna and Tjørnskardet, mostly concerning the reconstructed temperature based on the modified 9°C training set. The comparison of the July air temperature based on the original full training set show more analogous trends. However there are several factors that interfere and make a reliable comparison of the temperature reconstruction from the two lakes difficult. This will be discussed below.

4. DISCUSSION

The objective this study was to investigate the climate history of Svalbard focusing on temperature. This was done by use of chironomids as indicator for temperature changes. In the study a comparison was done of the neighbouring lake Skardtjørna. This discussion will be focusing on the uncertainties of the methods, comparison of temperatures inferred at Tjørnskardet with temperatures inferred Skardtjørna and Tjørnskardet with regards to chironomid composition and testing of training sets before the general temperature trends on Svalbard will be discussed in accordance to the results from present study.

4.1 Confounding factors.

The use of chironomids as temperature indicators is dependent on the species response to temperature. A good correspondence between a chironomid taxon and the temperature in the modern training set indicates that the taxon is a reliable temperature indicator. However, if there is a weak correspondence between the temperature and the taxa assemblage, other environmental variables (e.g. pH and water depth) may influence the chironomid composition in the lake and can result in inaccurate temperature reconstructions.

Arctic lakes have in general low diversity and abundance of chironomid taxa compared to other regions because of the extreme environmental conditions in the Arctic. Downcore, this leads to low counts of head capsules and few dominating taxa. In cases with low taxa diversity it is decisive to have taxa that are reliable temperature indicators in the sediment. Samples with few taxa that are more sensitive to other environmental factors reduce the reliability of the reconstructed temperature (Heinrichs 2005, Velle et al. in press). Low chironomid abundance in arctic lakes will also lead to inaccurate results from temperature reconstructions because low taxonomic resolution, due to ecological obstacles, will have an higher influence on lakes with few dominating taxa.

Part of the study was to do a comparison of the chironomid assemblage between the two lakes, Skardtjørna (Kongshavn 2009) and Tjørnskardet. Geographical, physical and geological factors can also contribute to altering in the chironomid composition between lakes and complicate the comparison of the inferred temperature. In arctic regions the presence of glaciers or snow patches providing a constant supply of cold melt water into the lakes during summers, which will influence the relationship between air temperature and water temperature. The relationship is normally close to 1:1 (Livingstone and Lotter 1998), but previous studies have discussed that water temperature has more influence on the chironomid composition in the lake (Velle et al. 2005, Brooks 2006, Brooks and Birks 2001). Cold melt water influence the inferred temperature by providing a habitat for taxa with a colder temperature optima, leading to under-estimated air temperatures (Brooks and Birks 2001). Other factors influencing the air- and water temperature relationship are wind exposure, the size and depth of the lake.

4.2 Sediment chronology.

To perform a good and reliable palaeoecological study it is important to provide the best and most reliable age-depth model of the sediment. In most palaeolimnological studies the models are based on AMS radiocarbon dating. However, radiocarbon dating is not without sources of errors and due to the "hard water effect", where dating based on ^{14}C lead to uncertainties in radiocarbon dates by presenting the sediments with older carbon (MacDonald et al. 1987). If the dating is based on aquatic plant macrofossils, the problem lies in deficient incorporation of ^{14}C- carbon by the plants. For aquatic plants, this occurs because the plants incorporate ^{14}C- deficient carbon from the lake sediments. Terrestrial plants absorb carbon from atmospheric CO_2, which give a younger and more correct calibrated age (MacDonald et al. 1987, Barnekow et al. 1998).

In arctic lake sediments the low amount of terrestrial plant material makes it difficult to find sufficient material for dating, which leads to an increased risk of dating errors. Chronology bias is evident in the present study where sediment from Tjørnskardet

contained low amount of plant macrofossils, which consisted of aquatic plants leading to dating errors (Figure 3.2). The sample from 277 cm in the core (Table 3.1) indicates a younger radiocarbon age than the sample from 267 cm. The radiocarbon age of the level from 277 cm in the core was dated based on chironomid head capsules that provide a younger radiocarbon age (Fallu et. al 2004, Francis et al. 2006). Diatoms are the main food source to chironomid larvae in this level and diatoms absorb carbon from the water. The carbon absorbed by the diatoms is in closer equilibrium with atmospheric CO_2 than ^{14}C- deficient carbon in the sediment incorporated through the root system of aquatic plants.

The timing of reconstructed temperature events for this study shows an overall coherence to earlier work on Svalbard. In the comparison between the inferred temperatures from Tjørnskardet and the neighbouring lake, Skardtjørna, the age models do, however, indicate a displacement of 100-150 cal BP in the temperature trends (Figure 3.12 and 3.13). Inadequate chronologies suggest that a comparison of the climatic history between the lakes should be performed with care.

4.3 Chironomid composition.

Results from the chironomid analysis show that the chironomid stratigraphy in Tjørnskardet consists of 26 taxa (Figure 3.8, Table 3-2 appendix). With an average of 57.9 head capsules per sediment sample, Tjørnskardet has a sufficient fossil abundance for temperature reconstruction. The relative distribution of taxa and the PCA results (Figure 3.6 and 3.7) reveals a chironomid composition consisting of taxa with ecological preferences indicating cold and oligotrophic conditions in Tjørnskardet. These taxa include *Hydrobaenus lugubris*-type*, Hydrobaenus conformis*-type*, Oliveridia tricornis, Micropsectra radialis*-type and *Micropsectra insignilobus*-type.

The temperature preferences of the taxa generally agree during the Holocene so that the coldest and the warmest taxa co-occur. However the period with the lowest inferred temperature in the core (~ 1300- 800 cal BP) (Figure 3.8 and 3.11) show a

tendency that the chironomid assemblage are influenced by other variables than temperature. This period is dominated by *Hydrobaenus lugubris*-type and *Oliveridia tricornis,* which are oligotrophic cold-water taxa. There is also occurrence of *Micropsectra radialis*-type*, Micropsectra insignilobus*-type and *Tanytarsini* sp. with higher temperature optima than the inferred temperature during the period. This suggests that temperature may not be the sole variable affecting the taxa composition at the time. From the PCA the first axis explained 44.5% of the taxa composition while the second axis explained 11.8% (Figures 3.6 and 3.7). The increase of the supra-specific taxa *Tanytarsini* sp. and *Orthocladiinae* sp., with a broad geographical distribution and a wide temperature tolerance and optimum will increase the uncertainties in the temperature reconstruction (Velle et al. 2005, Velle et al. in press).

Previous studies have discussed the difficulties in comparing inferred temperatures between lakes (Bigler et al. 2003, Rosenberg et al. 2004, Velle et al. 2005, Velle et al. in press). Skardtjørna and Tjørnskardet are situated in the same area of western Spitsbergen and because of this localization the lakes are expected to experience similar climatic conditions. The taxa composition in Skardtjørna and Tjørnskardet is then anticipated to show a certain degree of resemblance, however, geographical and physical differences might still result in some differences in the chironomid composition. The lakes are separated by a distance of 1.5 km and Skardtjørna is situated at 61 m a.s.l while Tjørnskardet is located at 120 m a.s.l (Holmgren et al. 2009). The difference of 59 m in altitude between the neighbouring lakes provides an adiabatic temperature difference of 0.35°C (Figure 3.12). The lakes show some differences in size where Skardtjørna have a surface area of 0.097 km^2 while Tjørnskardet is smaller with 0.081 km^2. The water depth in Skardtjørna is 7.3 m while Tjørnskardet is 2.45 m deep providing a difference of 4.85 m (Holmgren et al. 2009).

When comparing the chironomid analysis from Skardtjørna (Kongshavn 2009) and Tjørnskardet the two lakes show a corresponding trend in the dominating taxa composition, consisting of *Micropsectra radialis*- type*, Micropsectra insignilobus*-type*, Hydrobaenus lugubris*-type and *Oliveridia tricornis*. Skardtjørna have a higher occurrence of *Diamesa aberrata*-type*, Paratanytarsus* sp. and Tanytarsini sp., while Tjørnskardet includes *Orthocladiinae* sp. and *Diamesa zernyi/cinerella*-type. The abundance of rare taxa that differs between the lakes is most likely too low to have an

influence on the inferred temperature. The zonation of the chironomid stratigraphies in the lakes revealed that both had a significant change in the taxa assemblage around 1200 cal BP. The taxa composition shows an overall similarity, however, there was some variations in the upper zone where Skardtjørna has a rather constant presence of *Micropsectra radialis*-type*,* while Tjørnskardet has a reduction of *Micropsectra radialis*-type and *Micropsectra insignilobus* and an increase of *Hydrobaenus lugubris*-type and *Oliveridia tricornis.* This is in accordance to the temperature differences in the Medival Warm Period (MWP) explained below. The chironomid assemblage shows a similar trend during the last 200 years with in reduction of the coldest taxa *Hydrobaenus lugubris*-type and *Oliveridia tricornis* and an increase of *Micropsectra radialis*-type and *Micropsectra insignilobus*-type*,* which have warmer temperature optima.

4.4 Temperature reconstruction.

The modern training set was modified to reduce the potential problem of the statistical edge effect (Kongshavn 2009, Velle et al, submitted). The inferred temperatures from the two lakes have a higher degree of correlation using the full training set compared to the results obtained using the reduced training set (Figure 3.12 and 3.13), even though the reduced model was evaluated to provide the best result for the area of interest (Table 3.3). The reconstructed temperature from Tjørnskardet is higher than the present mean July temperature measured at Isfjord radio (Figure 2.1 and 3.11). This may partly be due to the statistical edge effect and further testing to reduce this edge effect can be done by include colder lakes to the temperature gradient. These results establish a foundation for more research to evaluate the method of trimming training sets in order to provide a more accurate inferred temperature in areas at the end of the temperature gradient in the modern training set.

Previous studies on past climate in arctic areas have indicated an overall decline in temperature during the Holocene. This epoch consists of tree periods, namely the Early Holocene (9300- 7300 cal BP), the Mid-Holocene (7300- 3900 cal BP), and the Late Holocene (3900 – present) (Rosén et al. 2000). The calibrated age of the

sediment core from Tjørnskardet extends to the middle of Mid- Holocene from ~ 6000 calibrated years BP based on the ^{210}Pb modified model. The temperature reconstruction based on the reduced modern training set describes an overall temperature decline towards the present (Figure 3.10). A study by Birks (1991) indicates that the summer temperature at Spitsbergen might have been around 1.5 °C higher from 8900 to 4500 cal BP (8000 -4000 BP) than during the present. The average July temperature on Spitsbergen is 4.7 °C and the mean July temperature from the area of the present study is 4.2 °C, measured at Isfjord Radio (Figures 2.1 and 3.11) (www.met.no). This temperature decline through the Holocene can be seen in the temperature reconstruction (Figure 3.10) where the period ~ 6000 cal BP had the highest temperature at 6.8 °C and the present has a temperature of ~ 5°C. Similar temperature trends were found at Skardtjørna (Kongshavn 2009) and from the changes in chironomid composition during the epoch (Figure 3.8).

The temperature reconstruction from Tjørnskardet shows a temperature decline from 5200 cal BP, suggested to represent the end of a long ice -free period (Svendsen and Mangerud 1997), and until 2400 cal BP. This cooling is analogue to data from the neighbouring lake, Skardtjørna (Birks 1991, Kongshavn 2009) and is confirmed by studies on glacial variation from the Linné glacier where glacial maxima occurred during the periods 3000 - 2950 cal BP (2800-2900 BP), ~ 2600 - 2500 cal BP (2500-2400 BP), 1400 - 1300 cal BP (2500- 2400 BP) and during the Little Ice Age (Svendsen and Mangerud 1997).

The inferred temperatures from Tjørnskardet in the period between 1100-750 cal BP show a rather extensive cooling period with a minimum temperature of 3.6 °C, illustrated in the zonation analysis where a significant change in taxa composition to more colder taxa occurred in this period (Figure 3.8). Previous work from the same area (Kongshavn 2009) and other sites at Svalbard describe the Medieval Warm Period (MWP) between 1010 - 680 cal BP (900 -1250 AD) (Grove and Switsur 1994), as a warmer period with temperatures close to present-day temperatures. Equivalent trends have been described in studies in other arctic regions like the Greenland shelf, where data from sediment cores revealed temperature cycles similar to the cycles of the MWP (Jennings et al. 2002), and in Europe where proxy records and climate models suggested temperatures confirming a MWP (Goosse et al. 2006). This period

was followed by a cooling trend where the temperature declined by approximately 0.5 ºC (Figure 3.10). The divergence in the temperature trend from Tjørnskardet in this period implies a disturbance of the chironomid composition in the lake. The chironomid assemblage during this period consist of taxa assemblages with a lower temperature optima than at Skardtjørna, suggesting that there has been a cooling of the lake providing a optimal habitat for cold taxa. The lake is connected to a snow patch throughout some summers (Figure 2.2), which will disturb the relationship between the air – and water temperature by leading to a constant supply of cold melt water into the lake. The amount of snow cover during summers and supply of cold water are both dependent on the specific annual precipitation in the area, and will not be a constant factor. This means that the snow patch will change in size and alter the timing of ice and snow melt. This suggests that winters with heavy snow-fall may have caused too cold inferred summer air temperatures during this period despite the warm temperatures presumed from other studies.

Based on C: N records, Holmgren (2009) indicated a temperature decrease in the period 700 cal BP - 250 cal BP, only interrupted by a small warming period around 600 cal BP to 400 cal BP. Trends from this period shows resemblance to the reconstructed temperatures from Tjørnskardet. An increase in glaciers at Svalbard introduced the Little Ice Age (LIA) during the Late Holocene (~ 400 – 100 cal BP). The exact beginning of LIA is debated, but climatic data show tendencies to a cooling period around 750 cal BP (1200 AD) as a relation to LIA (Jones and Birks 2004, Svendsen and Mangerud 1997). Jennings et al. 2002 suggested that the cooling trend connected to the LIA resulted from increased sea ice extent. The period stated as the LIA is in the present study is in agreement to previous studies at Svalbard. Goosse et al. (2005) address the question of climate changes in MWP and LIA by use of three-dimensional model of intermediate complexity GMS model. Their results describe an increase of the temperature in the MWP 1010-710 cal BP (1000-1200 AD) in the Northern Hemisphere and a cooling period described by other studies as the LIA. The studies show that these cooling- and warming trends have their maximum at different times on different continents, confirming the uncertainty of when the periods started.

During the last 200 years the Arctic have experienced a temperature increase (Overpec et al. 1997, Jones and Birks et al. 2004, Goosse et al. 2006). The climate change during the 20th century at Tjørnskardet is in agreement to work by Holmgren et al. (2009), where an increase in algae production and diatoms abundance are partly a result from an increase in temperature. Axford et al. (2009) suggested similar trends from lake sediments on Baffin Island, arctic Canada. Their chironomid record showed a change in the taxa composition from cold tolerant taxa to more warm tolerant taxa in the period from the end of LIA and to the present. The warming trend is similar to the present study with a warming from ~ 200 cal BP to the present which is in accordance with results from Skardtjørna by Kongshavn (2009). This increased warming can be a result of the increased global warming caused by anthropogenic activity.

5. CONCLUSIONS.

The aim of the project was to perform a temperature reconstruction from the Holocene based on chironomids, or non –biting midges, as biological proxy to enlighten a part of the climatic history at Svalbard. The sediment core was sampled from Tjørnskardet on western Spitsbergen. The depth-age model of the sediment profile was determined by AMS radiocarbon dating, extending from ~ 6000 cal BP to present. The inferred July air temperature was calculated based on a the full Norwegian training set and a reduced 9°C Norwegian training set because results from previous studies have shown that this model provide a higher training set performance by reducing the statistical edge effect to cold lakes at the end of the temperature gradient.

The results from the study follow the general trends described in previous work for western Spitsbergen and in other areas at Svalbard. The temperature reconstruction indicated an overall cooling trend from the mid- Holocene to the present with an increase in temperature during the last 200 years. However this study reveals the method is prone to weaknesses, which confines the reliability of the reconstructed temperature. In this study the main uncertainties include the "hard water" effect of the dating-method and the confounding influence of precipitation and duration of snow cover on the chironomid composition. The uncertainties was described by comparing inferred temperature from the reduced training set at Tjørnskardet with similar temperatures inferred at neighbouring Skardtjørna, and from the chironomid composition between Skardtjørna and Tjørnskardet. In addition, there were distinct temperature discrepancies during the MWP compared with other work from Svalbard and studies from Europe. Comparison of the inferred temperature from the full training set and the reduced training set between the two lakes showed more analogue temperatures based on the full training set. This confirms that more research is needed to develop optimal training sets for the coldest lakes at the end of the temperature gradient.

From previous studies of Holocene climate reconstruction, chironomids are shown to not always be a reliable proxy (Velle et al. 2005, Velle et al. in press), and this study

show that to rely on one proxy for reconstruction of environmental variables not always is sufficient to obtain reliable results.

Future work.

Results from several sites will be combined in future studies to expand on the climatic history of Svalbard. Results are available in studies by Brooks and Birks (2004) that sampled chironomid assemblages from Ossian Sarsfjellet, Ytertjørna and Tenndammen. The results will also be compared to other ongoing research on Svalbard. At Tjørnskardet multi-proxy studies are planned to detect the influence of other environmental variables on the fossil midge assemblage and is favourable to obtain a more extensive climatic history of the lake. The diatom composition in the core is planned to be analysed by Sofia Holmgren, and will be valuable for improving the interpretation by the chironomid assemblages.

To evaluate the method of trimming training sets in order to reduce the statistical edge effect, extensive research is needed. Including more lakes for comparison of training set is important and the effect of trimming the training sets will be evaluated by comparison with studies from the Norwegian mainland. Due to the warmer temperatures on the mainland compared to Svalbard, the results will be compared to temperature reconstructions from the Late- Glacial period with temperatures close to those of Svalbard. More efforts are planned to find terrestrial macrofossils in sediments from Svalbard. Because the radiocarbon dates were performed on aquatic macrofossils, the resulting radiocarbon age was 1000 years too old. It would be interesting to see if this is a general trend in the core that can reliably be used in depth-age modelling.

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APPENDIX.
Part 1: Chironomid composition.

Level	Sum	procladi	diam cz	diam ab	birilia	chaeto	eucle cl	hydro co	hydro j	hydro lu	limno	metri fu	orto ty	orto oliv	orto tri	parcl	thiema	orto sp	coryno	micro in	micro ra	para au	para pe	para sp	tany sp	oliv tr	metri eu
0.5	19	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	8	6	0	0	0	0	1	2
2.5	26	0	0	1	0	0	0	0	0	4	0	0	0	0	1	1	1	2	0	10	2	0	0	0	0	0	5
4.0	35	0	0	1	0	1	0	0	0	10	0	0	0	0	1	1	1	0	0	2	11	0	0	0	0	2	13
6.0	46	0	1	0	0	1	0	0	0	6	0	0	1	0	0	2	0	0	1	9	16	0	0	0	0	1	8
9.5	43	0	4	0	0	1	0	2	2	6	0	0	0	0	0	0	0	0	0	2	3	0	0	0	0	0	22
10.5	43	0	2	4	0	0	0	0	0	3	0	0	0	0	0	0	1	3	0	3	3	0	0	0	0	3	23
11.5	30	0	6	0	0	0	0	1	1	4	1	0	0	0	0	1	0	1	0	1	1	0	0	0	0	1	4
14.5	25	0	2	0	0	1	0	0	0	5	0	0	0	0	0	4	0	0	0	2	2	0	0	0	0	1	9
14.8	40	0	3	0	0	0	0	0	0	4	0	0	0	0	0	4	0	3	0	2	4	0	0	0	1	1	19
17.5	33	0	0	0	0	0	0	0	1	11	0	0	0	0	0	7	0	1	0	1	1	0	0	0	1	1	18
20.0	61	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	3	0	1	2	0	0	1	0	0	41
22.0	40	0	0	1	0	0	0	0	0	2	0	0	0	0	0	0	0	7	0	1	0	0	0	1	0	1	27
24.0	34	0	1	0	0	0	0	0	1	1	0	0	0	0	0	9	0	4	0	0	2	0	0	1	0	1	22
26.5	49	0	5	0	0	0	1	0	1	3	0	0	0	0	0	9	0	1	0	2	9	0	0	0	0	0	21
28.0	81	0	6	0	0	1	0	4	1	3	1	0	0	0	0	0	0	8	0	1	7	0	0	1	0	3	46
30.0	95	0	9	1	0	2	0	3	6	16	0	0	0	0	0	1	0	5	0	8	17	0	3	0	0	1	22
32.0	115	0	7	1	0	1	0	1	1	10	0	0	0	0	0	3	0	9	0	1	21	1	1	0	0	6	55
34.0	69	0	1	0	0	0	0	1	1	12	0	0	0	0	0	0	0	3	0	3	10	1	0	0	0	1	36
36.0	73	0	5	1	0	1	0	1	0	11	0	0	0	0	0	0	0	1	0	2	10	0	0	2	0	1	38
38.0	75	0	4	0	0	0	0	0	0	13	0	0	0	0	0	0	0	1	0	1	9	0	0	0	0	0	46
40.0	75	0	3	1	1	0	0	4	4	16	0	0	0	0	0	0	0	3	0	0	5	0	0	0	0	5	42
42.0	90	0	2	0	0	1	0	2	0	9	0	0	0	0	0	1	0	3	0	1	9	0	0	0	0	3	63
44.0	37	0	3	0	0	1	0	0	0	3	0	0	0	0	0	2	0	1	0	2	6	0	0	0	0	5	18
46.0	28	0	1	0	0	2	0	0	2	1	0	0	0	0	0	11	0	0	0	0	2	0	0	0	0	4	11
48.0	77	0	3	0	0	1	0	3	1	15	0	0	0	0	0	2	1	3	0	0	4	0	0	0	0	0	47
50.0	49	0	0	0	0	2	1	1	0	4	0	0	0	0	0	2	1	1	0	1	8	0	0	0	0	1	25
52.0	76	0	8	0	0	0	0	0	0	7	0	0	0	0	0	6	3	2	0	11	7	0	0	0	0	1	40
54.0	66	0	1	0	0	0	0	1	0	10	0	0	0	0	0	0	0	2	0	10	9	0	0	0	0	1	30
56.0	58	0	0	0	0	1	0	1	1	12	0	0	0	0	0	0	0	0	0	9	9	0	0	0	0	2	24
58.0	62	0	1	0	0	1	0	2	0	3	1	0	0	0	0	1	0	1	0	5	8	0	0	0	3	3	36
60.0	56	0	1	0	0	1	0	0	0	1	0	0	0	0	0	4	0	2	0	10	10	0	0	0	5	5	21
62.0	190	0	5	0	0	5	0	2	2	10	0	0	0	0	0	5	0	2	0	40	81	0	3	0	3	3	34
64.0	240	0	7	0	0	1	0	2	2	6	0	0	0	0	0	3	0	3	0	57	123	0	3	0	5	5	30
66.0	295	0	7	0	0	1	0	0	0	7	0	0	0	0	0	4	1	1	0	75	157	0	4	0	4	4	32
68.0	234	0	6	0	0	2	0	0	0	4	0	0	0	0	0	5	1	1	0	46	129	0	11	0	1	1	27
70.0	148	0	3	0	0	2	0	0	0	4	0	0	0	0	0	6	1	1	0	25	77	0	7	0	1	1	18
72.0	136	0	8	0	0	3	0	2	0	9	0	1	0	0	0	7	0	3	0	35	50	0	2	0	3	3	17
74.0	133	0	1	0	0	0	0	0	0	20	0	0	0	1	0	11	0	3	0	13	47	0	0	0	1	1	30
76.0	115	0	5	0	0	1	0	0	0	9	0	0	0	0	0	9	1	3	0	20	41	0	0	0	0	0	24
78.0	136	0	1	0	0	0	0	0	0	12	0	0	0	0	0	8	1	4	0	27	49	0	1	0	1	1	31
80.0	201	0	3	0	0	0	0	1	1	17	1	0	0	0	0	12	7	4	0	29	66	0	2	0	1	1	59
82.0	158	0	2	0	0	0	0	0	0	4	0	0	0	0	0	5	0	0	0	37	80	0	2	0	1	1	26
84.0	87	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	1	0	0	17	46	0	0	0	1	1	20
86.0	89	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	23	40	0	0	0	5	5	14
88.0	57	0	1	0	0	0	0	0	0	1	0	0	0	0	0	2	0	0	0	16	24	0	0	0	2	2	10
89.0	15	0	3	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	0	4	5	0	0	0	3	3	1
90.0	69	0	0	0	0	0	0	1	0	5	0	0	0	0	0	4	3	1	0	17	23	0	0	0	3	3	12
92.0	47	0	1	0	0	1	0	0	0	2	0	0	0	0	0	1	1	0	0	10	22	0	0	0	4	4	5
98.5	41	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	20	12	0	0	0	5	5	11
99.5	61	0	2	0	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	28	11	0	0	0	1	1	3
109.0	18	0	1	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	9	3	0	0	0	0	0	11
121.5	71	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	22	34	0	0	0	1	1	4
133.0	33	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	11	17	0	0	0	0	0	14
143.5	61	0	1	0	0	1	0	0	0	1	0	0	0	0	0	2	0	1	1	14	25	0	0	0	0	1	15
157.5	64	0	1	0	0	1	0	1	0	2	0	0	0	0	0	9	0	0	3	23	9	0	0	0	0	0	9
159.0	19	0	0	0	0	1	0	0	0	4	0	0	1	0	0	0	1	0	1	9	3	0	0	0	0	0	3
170.5	34	0	0	0	0	1	0	0	0	2	0	0	0	0	0	2	0	0	2	13	10	0	0	0	0	4	4
272.0	67	3	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	24	29	6	0	0	0	0	1	1
282.0	60	0	0	0	0	1	0	0	0	3	0	0	0	0	0	5	0	0	4	26	13	0	0	0	0	8	8
332.5	32	0	0	0	0	1	0	0	1	1	1	0	0	0	0	1	1	0	0	13	13	0	0	0	0	0	2

Table 1-1 - Chironomid abundance in the sediment levels.

I

Level	Sum	procladi	diam cz	diam ab	birilia	chaeto	eucie cl	hydro co	hydro j	hydro lu	limmo	metri fu	orto ty	orto oliv	orto tri	parcl	orto sp	thiema	orto sp	coryno	micro in	micro ra	para au	para pe	para sp	tany sp	oliv tr	metri eu
0.5	19	0	0	5	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	42	32	0	0	0	4	11	0
2.5	26	0	4	0	0	0	0	0	0	15	0	0	0	0	0	4	0	0	8	0	38	8	0	0	0	6	19	0
4.0	35	0	0	3	0	3	0	0	0	3	0	0	3	0	3	3	0	0	0	0	6	31	0	0	0	2	37	0
6.0	46	0	2	0	0	2	0	0	0	22	0	0	0	0	3	0	0	0	0	2	20	35	0	0	0	0	17	0
9.5	43	0	9	0	0	2	0	0	5	14	0	0	0	0	5	2	0	0	0	0	5	7	0	0	0	7	51	0
10.5	43	0	5	0	0	0	0	0	5	14	0	0	3	0	20	7	0	0	0	0	7	7	0	0	0	0	53	0
11.5	30	0	8	0	0	0	7	0	4	10	0	0	0	0	4	0	0	0	0	0	3	3	0	0	0	4	13	0
14.5	25	0	20	13	0	0	0	0	3	16	0	0	0	0	10	0	0	0	12	0	4	8	0	0	0	3	36	0
14.8	40	0	8	0	0	0	0	0	2	13	0	0	0	0	21	0	0	0	3	0	5	10	0	0	0	3	48	0
17.5	33	0	0	0	0	3	0	0	0	12	0	0	0	0	0	0	0	0	0	0	3	3	0	0	0	2	55	0
20.0	61	0	0	0	0	0	0	0	1	18	0	0	0	0	0	0	0	0	5	0	2	3	0	0	0	0	67	0
22.0	40	0	0	0	0	0	0	0	6	13	0	0	0	0	18	0	0	0	18	0	3	3	0	0	0	3	68	0
24.0	34	0	3	3	0	0	2	0	1	6	0	0	0	0	0	0	0	0	12	0	0	0	2	2	0	3	65	0
26.5	49	0	10	0	0	0	0	5	1	2	0	0	0	0	1	0	0	0	2	0	4	6	3	0	3	4	43	0
28.0	81	0	7	0	0	1	0	3	0	4	0	0	0	0	3	2	0	0	10	0	1	18	1	3	0	1	57	0
30.0	95	0	9	1	0	2	0	1	0	17	0	0	0	0	0	0	0	0	5	0	8	9	1	0	1	5	23	0
32.0	115	0	6	1	0	0	0	1	5	9	0	0	0	0	0	0	0	0	8	0	1	18	0	1	1	1	48	0
34.0	69	0	1	0	0	0	0	1	0	17	0	0	0	0	0	0	0	0	4	0	4	14	0	0	3	1	52	0
36.0	73	0	7	1	0	0	0	0	0	15	0	0	0	0	1	1	0	0	1	0	3	14	0	1	0	0	61	0
38.0	75	0	5	0	0	0	0	0	5	17	0	0	0	0	5	0	0	0	1	0	1	12	0	0	0	0	56	0
40.0	75	0	4	0	0	0	0	2	0	21	0	0	0	0	39	0	0	0	4	0	0	7	0	3	0	0	70	0
42.0	90	0	2	0	0	0	0	0	0	10	0	0	0	0	3	0	0	0	3	0	1	10	0	0	0	1	49	0
44.0	37	0	8	0	0	3	0	0	2	8	0	0	0	0	4	0	0	0	3	0	5	16	0	0	0	2	39	0
46.0	28	0	4	0	0	7	0	4	2	4	0	0	0	0	8	0	0	0	3	0	0	7	0	0	0	1	61	0
48.0	77	0	0	0	0	0	0	2	2	19	0	0	0	0	0	0	0	0	4	0	0	5	0	5	0	3	51	0
50.0	49	0	6	0	0	1	0	2	3	8	0	0	0	0	2	4	0	0	2	0	2	16	0	0	0	5	53	0
52.0	76	0	2	0	0	0	0	2	0	9	0	0	0	0	7	0	0	0	3	0	14	9	0	0	0	9	45	0
54.0	66	0	2	0	0	0	0	3	1	15	0	0	0	0	3	0	0	0	3	0	15	14	0	0	0	2	41	0
56.0	58	0	0	0	0	2	0	1	1	21	0	0	0	0	1	2	0	0	2	0	16	16	0	2	0	2	58	0
58.0	62	0	2	0	0	2	0	1	0	5	0	0	0	0	2	0	0	0	2	0	8	13	0	1	0	1	38	0
60.0	56	0	2	0	0	3	0	1	1	2	0	0	0	0	7	0	0	0	4	0	18	18	0	5	0	6	18	0
62.0	190	0	3	0	0	0	0	0	0	5	0	0	0	0	3	0	0	0	1	0	21	43	0	0	0	4	13	0
64.0	240	0	3	0	0	0	0	1	0	3	0	0	0	0	1	0	0	0	1	0	24	51	2	2	0	20	11	0
66.0	295	0	3	0	0	0	0	0	0	2	0	0	0	0	2	0	0	0	1	0	25	53	0	0	0	4	13	0
68.0	234	0	3	0	0	1	0	1	1	2	0	0	0	0	4	0	0	0	0	0	20	55	5	1	0	9	11	0
70.0	148	0	2	0	0	0	0	2	0	3	0	0	0	0	5	0	0	0	1	0	17	52	0	0	0	12	12	0
72.0	136	0	6	0	0	1	0	0	0	7	0	0	0	0	8	0	0	0	2	0	26	37	0	1	0	13	12	0
74.0	133	0	1	0	0	2	0	0	0	15	1	0	0	0	8	0	0	0	1	0	10	35	0	0	0	23	21	0
76.0	115	0	4	0	0	3	0	0	0	8	0	0	0	0	6	0	0	0	1	0	17	36	0	0	0	21	23	0
78.0	136	0	1	0	0	0	0	1	0	9	0	0	0	0	6	0	0	0	2	0	20	36	1	0	0	1	29	0
80.0	201	0	1	0	0	0	0	0	0	8	0	0	0	0	6	0	0	0	0	0	14	33	1	0	0	1	16	0
82.0	158	0	1	0	0	0	0	2	0	3	0	0	0	0	3	0	0	0	0	0	23	51	0	0	0	1	23	0
84.0	87	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	20	53	0	0	0	6	16	0
86.0	89	0	1	0	0	1	0	0	0	2	0	0	0	0	1	2	0	0	2	0	26	45	0	0	0	4	18	0
88.0	57	0	2	0	0	1	0	0	0	2	0	0	0	0	4	2	0	0	1	0	28	42	0	0	0	18	7	0
89.0	15	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	7	0	27	33	0	0	0	4	7	0
90.0	69	0	0	0	0	1	0	0	0	7	0	0	0	0	6	0	0	0	1	1	25	48	0	0	0	20	17	0
92.0	47	0	2	0	0	0	0	2	0	4	0	0	0	0	2	0	0	0	0	0	21	52	0	0	0	4	11	0
98.5	41	0	2	0	0	2	0	0	0	5	0	0	0	0	7	0	0	0	0	0	49	41	2	0	0	9	12	0
99.5	61	0	3	0	0	0	0	0	0	5	0	0	2	0	6	0	0	0	0	0	46	29	1	0	0	2	18	0
109.0	18	0	6	0	0	0	0	0	0	6	0	0	0	0	6	0	0	0	0	0	50	18	0	0	0	6	17	0
121.5	71	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	31	48	0	0	0	1	15	0
133.0	33	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	33	52	0	0	0	2	12	0
143.5	61	0	2	0	0	2	0	0	0	2	0	0	0	0	3	0	0	0	2	0	23	41	0	0	0	2	23	0
157.5	64	0	0	0	0	0	0	0	0	3	0	0	0	0	14	0	0	0	0	5	36	14	0	0	0	1	23	0
159.0	19	0	0	0	0	0	0	0	0	21	0	0	0	0	5	0	0	0	3	5	47	16	0	0	0	0	0	0
170.5	34	0	0	0	0	1	0	0	0	6	0	0	0	0	6	0	0	0	0	6	38	29	0	0	0	3	12	0
272.0	67	4.5	0	0	0	0	0	0	0	1	0	0	0	0	8	0	0	0	0	36	43	9	0	0	0	0	1	0
282.0	60	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	7	43	22	0	0	0	3	13	0
332.5	32	0	0	0	0	0	0	0	0	3	0	0	0	0	3	0	0	0	0	0	41	41	0	0	0	0	6	0

Table 1-2- Percentage of chironomid assemblage in the sediment levels.

Part 2: Zonation analysis.

Zonation analysis:

```
Program ZONE version 1.2 Aug 91

Tue Apr 20 10:39:00 2010

Input file: Species.dat
Title    : roduced data file
Data are Percentages, converted to Unchanged

Output from optimal sum of squares partition


Total SSQ = 62445.90234


Optimal division of objects into     2 groups

SSQ =  30889.1904297  which is 49.47 percent

Optimal division of objects into     3 groups

SSQ =  24924.3359375  which is 39.91 percent

Optimal division of objects into     4 groups

SSQ =  20458.0053711  which is 32.76 percent

Optimal division of objects into     5 groups

SSQ =  19306.9252930  which is 30.92 percent

Optimal division of objects into     6 groups

SSQ =  17942.2050781  which is 28.73 percent

Optimal division of objects into     7 groups

SSQ =  16791.1250000  which is 26.89 percent

Optimal division of objects into     8 groups

SSQ =  15643.9892578  which is 25.05 percent

Optimal division of objects into     9 groups

SSQ =  14821.8388672  which is 23.74 percent

Optimal division of objects into    10 groups

SSQ =  13688.3935547  which is 21.92 percent
```

```
Number of groups     2  3  4  5  6  7  8  9 10


Sample    Level

Number

   1      0.5
   2      2.5
   3      6.0

                         -- -- -- -- -- -- -- --
   4     10.5

                                     --     --
   5     11.5

                                     --     --
   6     14.5

                              --     --     --
   7     17.5
   8    249.0
   9    254.5
  10    259.5
  11    265.0
  12    267.0
  13    269.0
  14    271.5
  15    273.0
  16    275.0
  17    277.0
  18    279.0
  19    281.0
  20    283.0
  21    285.0
  22    287.0
  23    289.0

                                        -- --
  24    291.0

                                        -- --
  25    293.0
  26    295.0
  27    297.0
  28    299.0
  29    301.0
  30    303.0
  31    305.0

                      -- -- -- -- -- -- -- -- --
  32    307.0
  33    309.0
  34    311.0
  35    313.0
  36    315.0
  37    317.0
  38    319.0
  39    321.0
  40    323.0
```

IV

```
41      325.0
42      327.0
43      329.0
44      331.0
45      333.0
46      334.0
47      335.0
48      337.0


                            -- -- -- -- -- -- --
49      343.5
50      344.5
51      354.0


                            -- -- -- -- --
52      366.5
53      378.0
54      388.5


                            -- -- -- -- --
55      402.5
56      404.0
57      415.5
58      517.0
59      527.0
60      577.5
```

Output from BSTICK:

```
26 variables with total variance       62446.00

    k    % tot var       variance

    1       14.825      9257.427
    2       10.979      6855.657
    3        9.055      5654.773
    4        7.773      4854.183
    5        6.812      4253.741
    6        6.043      3773.387
    7        5.402      3373.092
    8        4.852      3029.982
    9        4.371      2729.761
   10        3.944      2462.898
   11        3.559      2222.721
   12        3.210      2004.378
   13        2.889      1804.231
   14        2.593      1619.479
   15        2.319      1447.924
   16        2.062      1287.806
   17        1.822      1137.696
   18        1.596       996.415
   19        1.382       862.984
   20        1.180       736.575
   21         .987       616.486
   22         .804       502.116
   23         .629       392.945
   24         .462       288.520
   25         .302       188.447
   26         .148        92.376
```

V

Part 3: Output from Canoco

Table 3- 1: N2 values of samples score based on species data .

No.	Levels	N2
1	0.5	4.08
2	2.5	6.73
3	4	6.75
4	6	5.56
5	9.5	6.27
6	10.5	6.13
7	11.5	7.8
8	14.5	8.14
9	14.8	6.99
10	17.5	5.03
11	20	4.4
12	22	3.07
13	24	4.81
14	26.5	5.6
15	28	6.94
16	30	10.21
17	32	6.6
18	34	6.08
19	36	6.16
20	38	4.51
21	40	5.09
22	42	4.67
23	44	6.45
24	46	4.69
25	48	5.51
26	50	7.65
27	52	5.54
28	54	6.42
29	56	5.43
30	58	6.83
31	60	7.13
32	62	7.26
33	64	6.3
34	66	6.05
35	68	6.13
36	70	6.95
37	72	7.47
38	74	7.74
39	76	7.16
40	78	7.11
41	80	7.18
42	82	5.32
43	84	3.77
44	86	5.91
45	88	5.61
46	89	5.36
47	90	7.07

48	92	6.52
49	98.5	4.5
50	99.5	6.19
51	109	4.98
52	121.5	4.31
53	133	3.3
54	143.5	5.87
55	157.5	6.23
56	159	4.73
57	170.5	5.51
58	272	4.84
59	282	5.44
60	332.5	4.71

Table 3- 2: PCA and N2 values of species score from species data.

NAME	AX-1	
EIG	0.4449	N2 fra DCA
Procladius	-0.1916	1
Diameza zernyi/cinerella-type	0.348	37.04
Diameza aberrata-type	0.1345	5.63
Birilia	0.2521	2.91
Chaetocladius	0.0271	25.63
Eukiefferiella	0.1012	1.85
Hydrobaenus conformis-type	0.2434	16.46
Hydrobaenus johanseni-type	0.4435	10.14
Hydrobaenus lugubris-type	0.5356	52.35
Limnophyes	0.0478	5.43
Metriocnemus fuscipes-type	-0.1121	1
Orthocladius type 1	-0.0016	4.6
Orthocladius oliveri-type	0.011	1
Orthocladius trigonolabis-type	-0.0039	32.92
Paracladius	-0.191	16.86
Thiemaniella	-0.2144	2.97
Orthocladiinae sp.	0.5864	30.01
Corynoneura	-0.3413	6.11
Micropsectra insgnilobus-type	-0.9282	46.28
Micropsectra radialis-type	-0.7759	52.15
Paratanytarsus austriacus-type	0.192	2.97
Paratanytarsus penicillatus-type	-0.2454	9.04
Paratanytarsus sp.	0.4063	4.75
Tanytarsini sp.	0.0402	33.44
Oliveridia tricornis	0.9298	52.94
Metriocnemus eurynotus-type	0.0099	2.73