

**NOUVELLE FONCTION DE TRANSFERT  
POUR RECONSTRUIRE LA  
TEMPÉRATURE À L'AIDE DES  
CHIRONOMIDES PRÉSERVÉS DANS LES  
SÉDIMENTS LACUSTRES**

**ISABELLE LAROCQUE**

*Rapport de recherche No R1032*

*Décembre 2008*

**Table des matières**

<b>1. Abstract</b>	5
<b>2. Introduction</b>	6
<b>3. Sampling sites</b>	9
<b>4. Methods</b>	10
4.1 Chironomid analysis	10
4.2 Statistics	11
<b>5. Results</b>	12
5.1 Distribution of chironomids in the training set lakes	12
5.2 Identification of lakes based on their chironomid composition	14
5.3 Unimodal distribution	15
5.4 Development of the transfer function	15
5.5 Temperature optima	17
5.6 Comparison of reconstruction	18
<b>6. Discussion</b>	21
6.1 Chironomids and temperature	21
6.1.1 <i>Cold indicators</i>	21
6.1.2 <i>Warm indicators</i>	23
6.1.3 <i>Temperature optima</i>	23
6.2 Transfer function	24
6.3 Temperature reconstructions	25
<b>7. Conclusion</b>	26
<b>8. Acknowledgements</b>	27
<b>9. References</b>	28

## Liste des Figures

Fig. 1. Life cycle chironomids.....	5
Fig. 2. Establishment of a training set and transfer function.....	6
Fig. 3. Example of the improvement in taxonomy from Walker et al. (1997) to Larocque et al. (2006).....	7
Fig. 4. Location map of the studied sites. The numbers are the 60 lakes from Larocque et al. (2006) and the white circle indicate the location of the thirteen new lakes.....	8
Fig. 5. Method for extracting the chironomid head capsules from lake sediment.....	9
Fig. 6. <i>Corynocera oliveri</i> : the identification is based on the large tooth on the Mandible.....	10
Fig. 7. Distribution of chironomid taxa in the 73 lakes of the training set.....	12
Fig. 8. Canonical analysis (CA) of the lakes categorized by their mean August air temperature .....	13
Fig. 9. Characteristics of the transfer function.....	15
Fig. 10. Comparison of temperature reconstructions in two lakes of Southampton Island. The arrow indicates the present mean August air temperature.....	18
Fig. 11. Reconstruction at Lac du Sommet, Québec. The arrow indicates today's temperature.....	19

**Liste des tableaux**

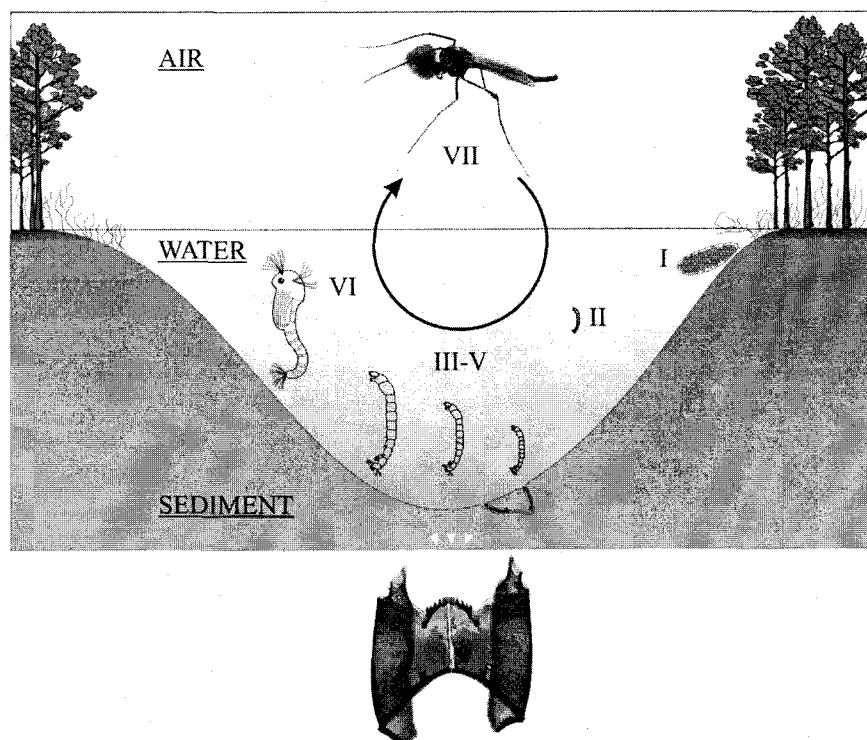
Table 1. Statistics of the transfer functions.....	15
Table 2. Comparison between temperature optima from both transfer functions.....	17
Table 3. Comparison of temperature optima with other transfer functions.....	23
Table 4. Comparison of Canadian transfer functions: statistics and characteristics.....	24

## 1. Abstract

The distribution of chironomid larvae was studied in 73 lakes from Québec to Ellesmere Island, covering a temperature gradient of 24.5°C. Cold lakes (i.e. mean August air temperature <10°C) had chironomid assemblages significantly different than lakes with warm (i.e. mean August air temperature >15°C) temperatures. Taxa restricted to cold lakes were *Eukiefferiella*, *Corynocera ambigua*, *Paracladius*, *Pseudodiamesa* and *Abiskomyia*. Taxa only found in warm lakes were *Sergentia longiventris*, *Lauterborniella*, *Corynoneura* type 2, *Pseudorthocladius* and *Polypedilum*. Most of the taxa (62%) had a unimodal distribution and those with linear distribution were either taxa composed of undifferentiated specimens (*Cricotopus*, *Tanytarsus* without spur, *Procladius*) or found in very low abundances. A weighted-average-partial-least square model with two components was developed for quantitatively reconstruct mean August air temperature. This model yielded a coefficient of correlation of 0.87, a root-mean-square error (RMSEP) of prediction of 1.67°C and a maximum bias of 2.33°C. The temperature optima obtained were comparable to those obtained from various transfer functions worldwide, except for *Microtendipes*, *Cladotanytarsus* and *Psectrocladius septentrionalis*-group. The divergence might be due to variation in the taxonomy used. When this transfer function was applied to three lakes, the inference at the surface of each lake compared well (by 0.2-0.3°C) with instrumental data, suggesting that, although the RMSEP is high, the error of the estimates is well below the RMSEP calculated by the model. Although this model performs well, other lakes should be added to get a better distribution of some of the taxa in the training sets, obtain better temperature optima for each taxon and possibly obtain a transfer function even more powerful.

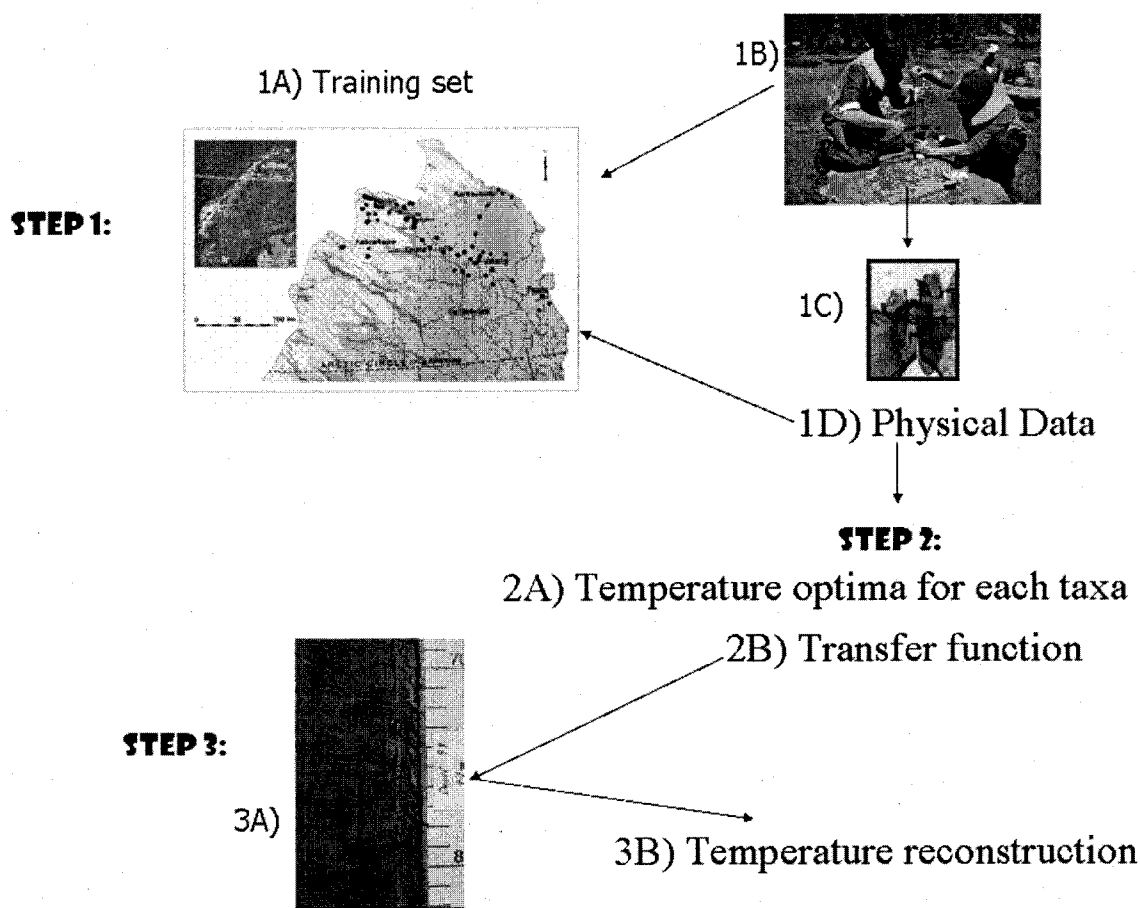
## 2. Introduction

Determining the effect of climate change on natural resources is a major concern for scientists, politicians and the general public. Although the concept of a global changing climate is starting to be widely accepted, the changes at local or regional scales are still poorly understood in many regions of the world by lack of data, or by data which does not extend beyond the so-called anthropogenic period. Paleodata are thus needed to better understand the natural variability of climate, superimposed on the climate change induced by human activities. One major source of paleodata can be extracted from lake sediments by analyzing biological remains. The larvae of chironomids (non-biting midges), living in aquatic environments such as lakes, ponds and rivers have a head capsule made of chitine, a substance which preserves for thousands of years in the sediment. While most stages of the larvae development are influenced by temperature, either water or air (Fig. 1), it was suggested in the late 1980's that chironomids could be used to reconstruct water temperature (Walker and Mathewes, 1989b).



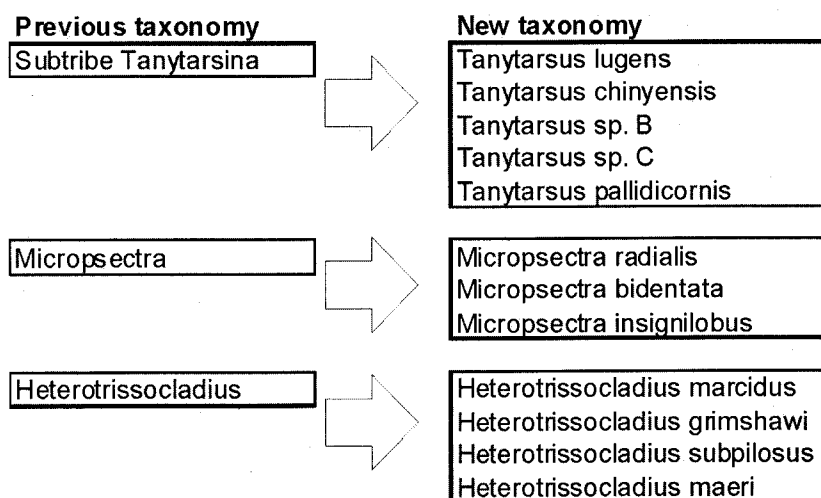
**Fig. 1.** *Life cycle chironomids*

This idea brought heated discussion on factors affecting the chironomid assemblages (Warwick, 1989; Walker and Mathewes, 1989b). Since then training sets established in various countries demonstrated that temperature (air and/or water) is an important factor affecting the distribution of chironomids (e.g. in Sweden (Larocque et al., 2001), Fennoscandia (Olander et al., 1999), Norway (Brooks and Birks, 2000), Switzerland (Heiri et al., 2003), Canada (Walker et al., 1997, Larocque et al., 2006, Rolland et al., in press) and the United States (Porinchi et al., 2007)) and mathematical models (i.e. transfer functions) have been made to use chironomid head capsules preserved in lake sediments to quantitatively reconstruct temperature.



**Fig. 2.** Establishment of a training set and transfer function

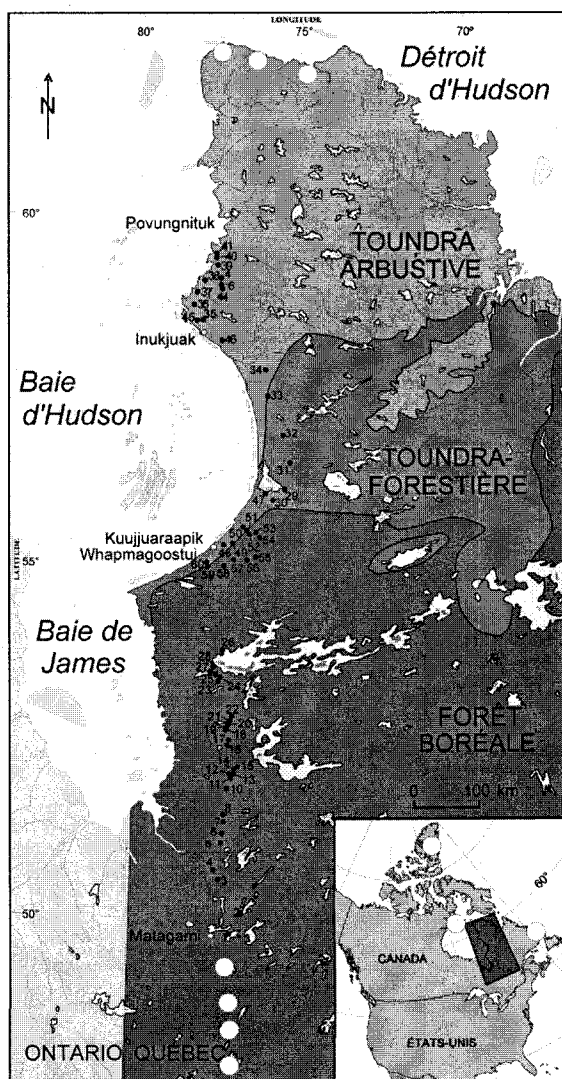
Various training sets have been developed in western Canada (Barley et al., 2006), in eastern Canada (Walker et al., 1997), and the Arctic (Francis et al., 2006; Porinchi et al., in press). In 2006, a training set was developed in Québec (Larocque et al. 2006). This training set was developed to reconstruct climate in lakes in Québec, lakes which are less influenced by an oceanic climate than the lakes sampled in the training set of eastern Canada (Walker et al., 1997). Furthermore, the eastern Canada training set was based on a taxonomy which was less developed than it is presently (Fig. 3). The Québec training set included 60 lakes from 49°48'N to 59°32'N, the coefficient of correlation ( $r^2$ ) was 0.67 and the root-mean-square error of prediction was 1.17°C. A detrended canonical correspondence analysis detected linearity in the chironomid assemblages, thus redundancy analysis was used to identify the variables affecting the chironomid communities. The best models developed for quantitative reconstruction are those where most of the taxa have a unimodal distribution in the lakes of the training set. Since most taxa showed a linear distribution in the Quebec training set, more lakes were sampled south and north of the pre-existing transect in the hope of obtaining a unimodal distribution of taxa, and thus a model with better predictive statistics.



**Fig. 3.** Example of the improvement in taxonomy from Walker et al. (1997) to Larocque et al. (2006)

### 3. Sampling sites

Sixty lakes between  $49^{\circ}48'N$  to  $59^{\circ}32'N$  and  $75^{\circ}43'W$  to  $78^{\circ}78'W$  were sampled for the previously published transfer function (Larocque et al., 2006). Twenty-eight physical, limnological and climatic parameters were measured in these lakes. Mean August air temperature was one of the best parameters explaining the distribution of chironomids. In the hope of obtaining a unimodal distribution of chironomid taxa, eight lakes were sampled south of the previous transect in August 2006, and the surface sediment of thirteen lakes from northern Québec (Saulnier-Talbot et al., 2007; Fallu et al., 2005), Southampton Island (Rolland et al., 2008; Rolland et al., in press) and Ellesmere Island (Fig. 4). The new transect covers lakes from  $42^{\circ}32'$  to  $81.36^{\circ}N$ , and a temperature gradient of  $24.5^{\circ}C$ . This is the higher temperature gradient of all the Canadian training sets.

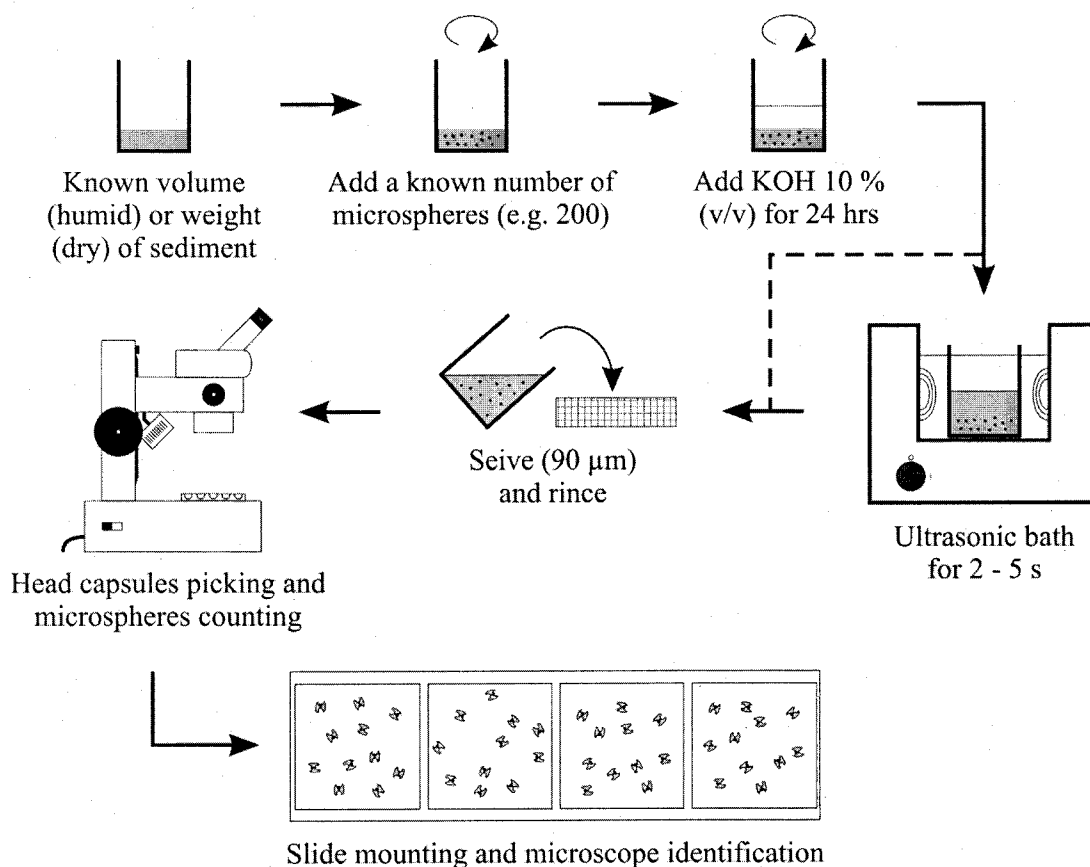


**Fig. 4.** Location map of the studied sites. The numbers are the 60 lakes from Larocque et al. (2006) and the white circle indicate the location of the thirteen new lakes.

## 4. Methods

### 4.1 Chironomid analysis

KOH 10% was added overnight to the surface sample of the studied lakes. The samples were then sieved in a 100- $\mu\text{m}$  mesh, the residue was placed in a Bogorov counting tray and observed under a stereomicroscope at 20-40X. Each head capsule was individually picked and mounted on a microscope slide in a solution of Hydromatrix (Fig. 5).



**Fig. 5.** Method for extracting the chironomid head capsules from lake sediment

Identification was made with a microscope at a magnification of 400X. The taxonomy followed mainly Wiederholm (1983), Oliver and Roussel (1983) and a taxonomic guide developed for the Quebec taxonomy (Larocque and Rolland, 2006). The Tanytarsini are identified if a mandible is present (Fig. 6). In the absence of mandible and a spur on the pedicel of the antenna, the Tanytarsini were grouped under “Tanytarsisni without spur” and if a spur was present it was grouped under “Tanytarsisni with spur”. In the previous training set, *Heterotrissocladius maeri*-group was called *Heterotrissocladius brundini*-group. The name has been changed following the nomenclature in Brooks et al. (2007). The name *Polypedilum* IIC is based on the picture in Wiederholm (1983). *Corynoneura* type 2 does not have reticulation on the head capsule. At least 50 head capsules were used for temperature reconstruction following Larocque, 2001.



**Fig. 6.** *Corynocera oliveri*: the identification is based on the large tooth on the mandible

#### 4.2 Statistics

A correspondence analysis (CA) was used to study the variation in the chironomid assemblages in the surface sediment of the 73 lakes of the training set. A canonical correspondence analysis (CCA) was used to determine the type of distribution of each taxon. If the gradient length of the CCA analysis was larger than 3 SD, the chironomids had a unimodal distribution and weighted averaging could be used for the transfer function (Leps and Smilauer, 2004). The program C2 (Juggins, 2003) was used to illustrate the abundances of each taxon. Only the taxa with at least 2% in 2 lakes were used for statistical analysis and climate reconstruction. The transfer function was created using C2.

## 5. Results

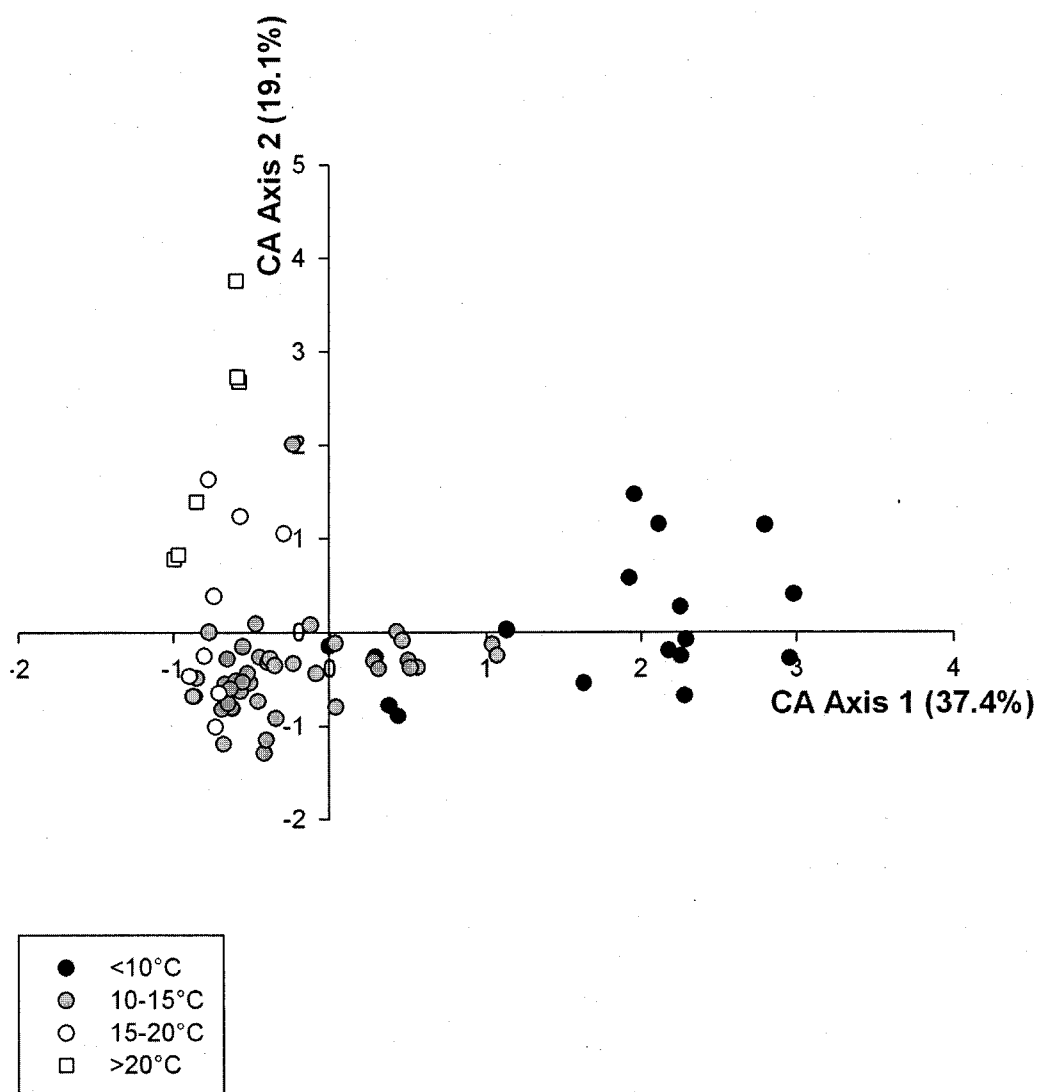
### 5.1 Distribution of chironomids in the training set lakes

Eighty taxa were found in the 73 lakes of the training set. Selected taxa are presented in figure 7. *Eukiefferiella*, *Corynocera ambigua*, *Paracladius*, *Pseudodiamea*, *Stictochironomus*, *Abiskomyia* and *Thiennemanimyia* were restricted to lakes with mean August air temperature colder than 10°C. *Heterotrissocladius subpilosus*-group, *Heterotrissocladius maeri*-group, *Sergentia coracina*-type, *Paracricotopus*, *Corynoneura* and *Corynocera oliveri* were found only in lakes colder than 15°C. *Heterotrissocladius marcidus*-group and *Heterotrissocladius grimshawi*-type were found in low numbers in lakes warmer than 12°C. *Zavreliomyia* was found in low numbers only in lakes with mean August temperature between 10 and 15°C. *Microtendipes* was found in lakes warmer than 12°C. *Psectrocladius septentrionalis*-group was restricted to lakes with mean August air temperature between 10 and 15.5°C. *Polypedilum* IIIIC was found in lakes with temperatures in August between 12 and 18°C. *Constempellina*, *Endochironomus* and *Zalutschia zalutschicola* were restricted to lakes warmer than 10°C. *Dicrotendipes* and *Tanytarsus chinyensis*-type were present in low numbers in only one lake colder than 10°C. Four taxa (*Sergentia longiventris*-type, *Lauterborniella*, *Corynoneura* type 2, *Pseudorthocladius* and *Paraphaenocladius*) were found only in lakes warmer than 15°C. Group of taxa (i.e. *Cricotopus*, *Procladius*) or *Tanytarsus* without spur (comprising taxa of the Subtribe *Tanytarsina* which did not have mandibles for identification) were found in most of the lakes.



## 5.2 Identification of lakes based on their chironomid composition

A canonical analysis (CA) (Fig. 8) indicates that the first axis explained 37.4% of the variance and the second axis explained 19.1% of the variance in the chironomid composition of the 73 lakes in the training set. All the lakes with mean August air temperature colder than 10°C were separated from lakes with mean August air temperature higher than 15°C, suggesting that their chironomid composition is significantly different.



**Fig. 8.** Canonical analysis (CA) of the lakes categorized by their mean August air temperature

### 5.3 Unimodal versus linear distribution

The canonical correspondence analysis (CCA) had gradient length of the four first axis of 3.2, 3.1, 2.9, 2.7 suggesting that most taxa had unimodal distributions and that weighted averaging could be used to develop the transfer function. Forty-five taxa had unimodal distribution, two had a bi-modal distribution and thirty had a linear distribution. Apart from *Cricotopus*, *Tanytarsus* without spur and *Procladius* the other taxa with linear distributions had very low abundances in the surface samples. *Heterotrissocladius subpilosus*-group and *Micropsectra radialis*-type, their distribution is skewed-unimodal and their highest abundances is in the coldest lake of the gradient. If we extended the transect to include colder lakes, their distribution might become unimodal and a better temperature optimum could be estimated. Similarly, *Sergentia longiventris*, *Lauterborniella* and *Polypedilum* were found in the lakes at the warmer end of the gradient. Their optima could be better estimated if warmer lakes would be included in the training set.

### 5.4 Development of the transfer function

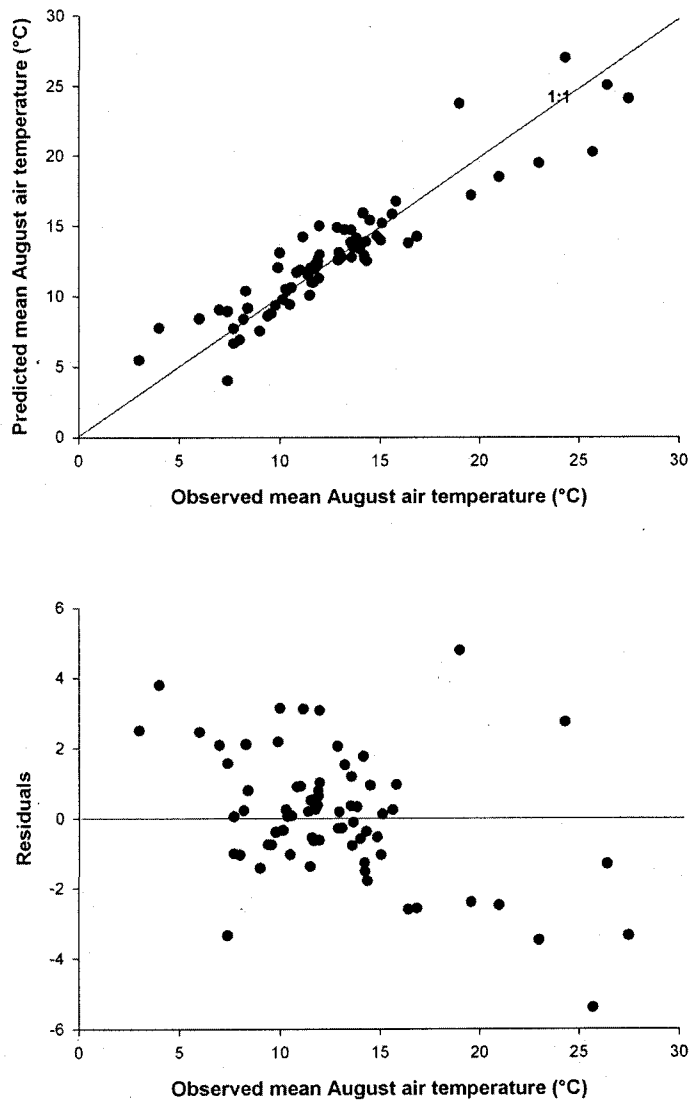
Since unimodal distributions were obtained for most taxa considered, a weighted-average partial-least-square (WAPLS) model was used. This model yielded a jackknifed correlation coefficient ( $_{\text{jack}}r^2$ ) of 0.87, a root-mean-square error of prediction (RMSEP) of 1.67°C and a maximum bias of 2.3°C. While the correlation coefficient improved compared to the previous model with 52 lakes, the RMSEP increased (Table 1).

**Table 1.** Statistics of the transfer functions

	Old*	New
<b>Number lakes</b>	52	73
<b>Number of taxa</b>	79	80
<b>Model</b>	PLS	WAPLS
$_{\text{jack}}r^2$	0.67	0.87
<b>RMSEP</b>	1.2°C	1.7°C
<b>Max Bias</b>	3.5°C	2.3°C

\* Larocque et al. 2006

The model characteristics (Fig. 9) indicate that temperatures warmer than 20°C will have a tendency to be over or underestimated as the residuals of the model are bigger at the end of the temperature gradient. Temperatures lower than 5°C will have a tendency to be overestimated.



**Fig. 9.** *Characteristics of the transfer function*

## 5.5 Temperature optima

Table 2 shows a comparison between the temperature optima obtained with the new transfer function and the ones obtained with the previous transfer function. Thirteen of the 79 taxa presented have temperature optima which differ greatly (i.e. warm/cold versus cold/warm optima).

Table 2. Comparison between temperature optima from both transfer functions

Taxa	New	Old*	Taxa	New	Old*
<i>Corynocera ambigua</i>	-7.91	-4.10	<i>Chironomus plumosus</i> -group	<b>16.48</b>	<b>9.62</b>
<i>Parakiefferiella</i>	-1.43	9.12	<i>Stempellinella</i>	16.92	18.06
<i>Paracricotopus</i>	-0.76	4.33	<i>Chaetocladius</i>	17.22	9.70
<b>Paracladius</b>	<b>-0.61</b>	<b>11.29</b>	<i>Procladius</i>	17.41	15.00
<i>Heterotrissocladius subpilosus</i> -group	-0.54	4.70	<i>Heterotanytarsus</i>	17.60	18.58
<i>Sergentia</i>	0.89	0.58	<i>Criptochironomus</i>	18.19	21.17
<i>Cladotanytarsus</i>	1.60	7.06	<i>Pentaneuini</i>	18.57	18.40
<b><i>Corynoneura</i> sp</b>	<b>1.87</b>	<b>13.96</b>	<i>Micropsectra insignilobus</i> -type	<b>18.82</b>	<b>10.75</b>
<i>Micropsectra radialis</i> -type	2.16	6.06	<i>Zalutschia zalutschicola</i>	18.92	18.21
<i>Corynocera oliveri</i>	3.89	6.20	<i>Endochironomus impar</i> -type	19.92	31.74
<i>Zavrelymia</i>	4.37	10.82	<i>Glyptotendipes</i> type 2	20.22	39.74
<i>Stictochironomus</i>	4.57	0.00	<i>Thiennemanimyia</i>	20.46	0.00
<i>Abiskomyia</i>	5.46	0.00	<i>Endochironomus tendens</i> -type	20.57	17.33
<i>Oliverdia</i>	5.90	6.88	<b><i>Omisus</i></b>	<b>20.67</b>	<b>2.40</b>
<b><i>Einfeldia</i></b>	<b>6.95</b>	<b>15.20</b>	<i>Abiabesmyia</i>	21.14	11.36
<i>Eukiefferiella</i>	7.57	0.00	<i>Hydrobaenus</i>	21.42	29.97
<i>Psectrocladius septentrionalis</i> -group	7.66	13.49	<b><i>Tanytarsus</i> with spur</b>	<b>22.12</b>	<b>12.24</b>
<b><i>Mesocricotopus</i></b>	<b>7.72</b>	<b>22.45</b>	<i>Micropsectra bidentata</i> -type	22.52	13.60
<b><i>Smittia</i></b>	<b>7.81</b>	<b>21.90</b>	<i>Cryptotendipes</i>	22.95	24.65
<i>Polypedilum</i> III C	7.94	15.21	<i>Allopsectrocladius</i>	23.87	14.46
<i>Psectrocladius sordidellus</i> -group	8.41	8.35	<i>Tanytarsus</i> sp. C	24.21	18.61
<i>Cricotopus</i>	8.67	12.00	<i>Tanytarsus chinyensis</i>	29.18	22.44
<i>Zalutschia lingulata</i> pauca	9.30	14.21	<b><i>Parasmittia</i></b>	<b>30.02</b>	<b>-3.72</b>
<i>Heterotrissocladius maeri</i> -group	9.32	12.08	<b><i>Limnophyes</i></b>	<b>32.03</b>	<b>9.60</b>
<i>Tanytarsus</i> without spur	9.52	12.57	<b><i>Phaenopsectra</i></b>	<b>38.42</b>	<b>-2.25</b>
<i>Protanypus</i>	9.72	12.95	<i>Polypedilum</i>	38.71	15.03
<i>Pseudodiamesa</i>	9.74	0.00	<i>Paraphaenocladius</i>	51.16	24.80
<i>Microtendipes</i>	9.84	12.22	<i>Lauterborniella</i>	58.23	
<i>Paralimnophyes</i>	10.10	5.19	<i>Pseudoorthocladius</i>	63.63	22.55
<i>Parachironomus</i>	10.20	3.96	<i>Corynoneura</i> 2	66.46	
<b><i>Polypedilum</i> type II</b>	<b>10.34</b>	<b>23.41</b>	<b><i>Microtendipes</i> II</b>	<b>67.01</b>	<b>10.40</b>
<i>Cladopelma</i>	10.92	7.99	<i>Sergentia</i> 2	77.49	
<i>Tanytarsus pallidicornis</i>	11.33	8.19			
<i>Heterotrissocladius grimshawi</i> -group	11.77	11.05			
<i>Brillia</i>	11.79	22.75			
<i>Tanytarsus lugens</i>	12.71	7.25			
<i>Heterotrissocladius marcidus</i> -group	12.73	13.73			
<i>Nanocladius</i>	13.32	13.37			
<i>Chironomus anthracinus</i> -group	13.87	8.53			
<i>Tanytarsus</i> sp. B	14.22	11.32			
<i>Orthocladius</i>	14.28	10.12			
<i>Paracladopelma</i>	14.47	16.52			
<i>Glyptotendipes</i>	14.99	16.99			
<i>Paratanytarsus</i>	15.29	11.46			
<i>Endochironomus</i>	15.38	12.10			
<i>Pagastiella</i>	15.48	18.26			
<i>Telopelopia</i>	15.50	10.92			
<i>Dicrotendipes</i>	15.95	15.68			
<i>Constempellina</i>	16.18	14.89			

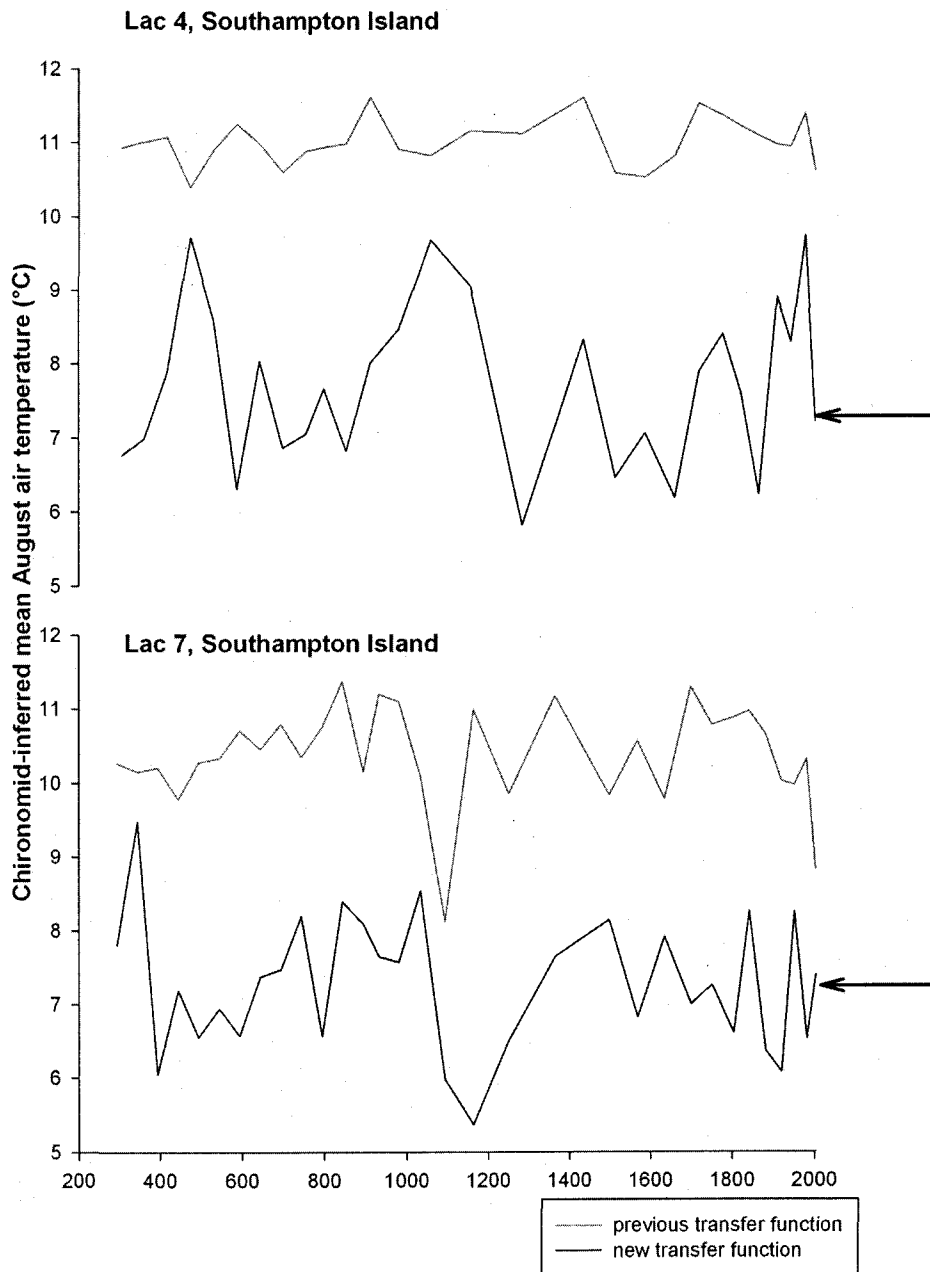
\* Larocque et al. 2006

*Paracladius* is, in the new transfer function, established as a cold taxon. It was found in some of the coldest lakes in Scandinavia and is usually found during cold episodes (Brooks et al., 2007). The optimum estimated here is thus more plausible than the warmer optimum obtained in the previous transfer function. The differences in optima are probably due to a better identification of this taxon in the new transfer function since this taxon was separated in two types. *Einfeldia* was found in cool conditions and during the Lateglacial in Switzerland (Brooks, 2000; Heiri, 2001). This relates better with the colder optimum estimated by the new transfer function. *Mesocricotopus* is an indicator of cold conditions (Brooks et al., 2007), thus his present estimated optimum is more plausible. *Smittia* has been described as rare in Europe and restricted to the material from the Swiss Alps where it had a cold temperature optimum (Brooks et al., 2007). *Chironomus* is abundant in warm, eutrophic lakes, although it can occur in arctic lakes. Its warmer optimum in the new transfer function suggests that its distribution was better studied when including warmer lakes in the training sets. *Micropsectra insignilobus*-type is considered as a cold stenotherm (Brooks et al., 2007) and its optimum in the new training set might be biased. One reason for this difference might be due to the identification of *M. insignilobus*-type. It is possible that what we called *M. insignilobus*-type is another type of *Micropsectra*. The chironomid assemblages of the training set should be re-counted for *Micropsectra*, following the descriptions in Brooks et al., 2007. *Omisus* was found in the Norwegian training set at the warmer end of the gradient (Brooks, unpublished), which corresponds better to the new optimum obtained here.

## 5.6 Comparison of reconstruction

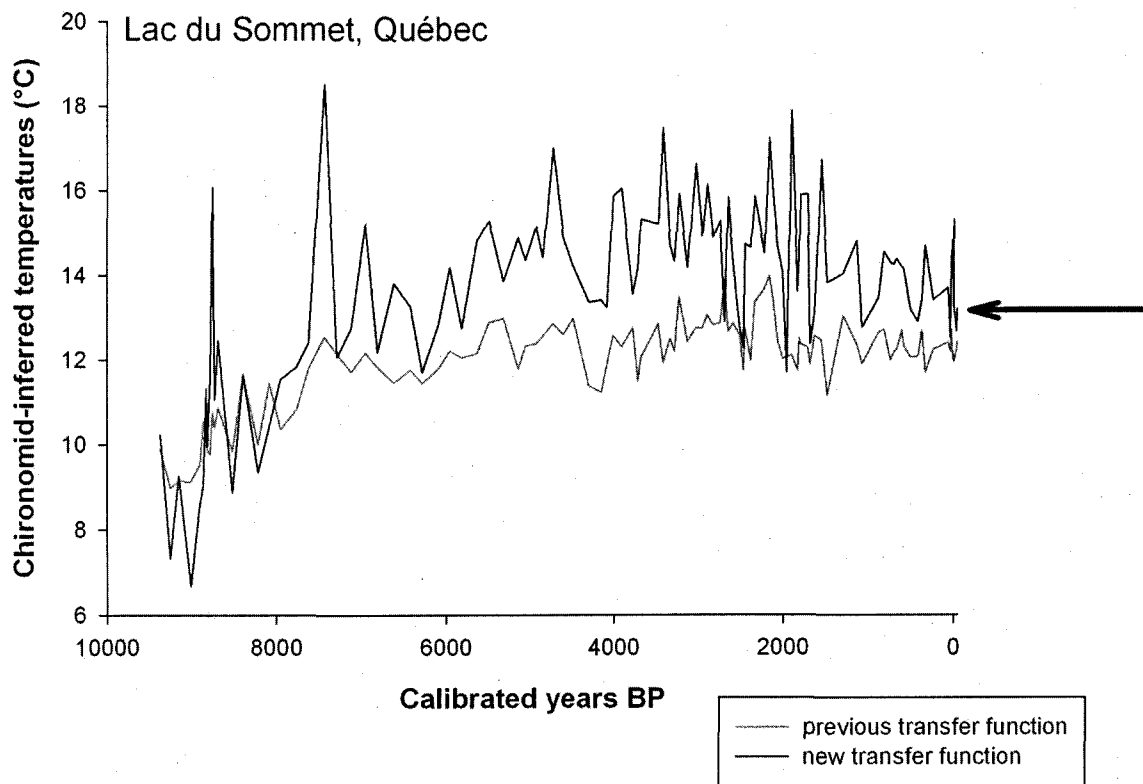
The two transfer functions were used to reconstruct the climate on Southampton Island (Fig. 10). The pattern of temperature changes was quite different through time. With the new transfer function, today's temperature was estimated at  $-0.2^{\circ}\text{C}$  while the previous transfer function overestimated today's temperature by  $3^{\circ}\text{C}$ . This is not surprising since the previous training set did not include lakes with temperatures as cold as those on Southampton Island. The temperature decrease of about  $1^{\circ}\text{C}$  at ca. 1200 cal. years

correspond well to the so-called "Little Ice Age", but the previous model failed to reconstruct it at Lake 4.



**Fig. 10.** Comparison of temperature reconstructions in two lakes of Southampton island. The arrow indicates the present mean August air temperature

The same comparison (Fig. 11) was made at Lac du Sommet located in Québec, at the warmer end of the transect. Again the new transfer function estimated today's temperature with a small variation ( $0.3^{\circ}\text{C}$ ) while the temperatures obtained with the previous transfer function were mainly  $2^{\circ}\text{C}$  colder. However, the general pattern of temperature change recorded by both models is similar, but the amplitude of change is greater with the new model.



**Fig. 11.** Reconstruction at Lac du Sommet, Québec. The arrow indicates today's temperature

## 6. Discussion

### 6.1 Chironomids and temperature

#### 6.1.1 Cold indicators

Most of the 80 taxa considered here had a distribution influenced by mean August air temperature. Cold taxa (i.e. only found in lakes with mean August air temperature  $<10^{\circ}\text{C}$ ) were *Eukiefferiella*, *Corynocera ambigua*, *Paracladius*, *Pseudodiamesa*, *Stictochironomus* and *Abiskomyia*. Apart from *Eukiefferiella* the other taxa were described as cold stenotherm. *C. ambigua* was found in cold oligotrophic lakes in Norway and in early Holocene sediments from Scotland, Scandinavia and central Europe (Brooks et al., 2007). In Canada, it was found in the Arctic (Gajewski et al., 2005) in lakes colder than  $14^{\circ}\text{C}$  (Barley et al., 2006) and had a temperature optimum of about  $9^{\circ}\text{C}$  (Porinchu et al., in press). *Paracladius* is a useful indicator of cold, oligotrophic conditions (Walker et al., 1991). *Pseudodiamesa* is a cold stenotherm (Walker et al., 1991). *Stictochironomus* is cold (Brundin, 1956) and acidophilic (Raddum and Saether, 1981). *Abiskomyia* occurs in the coldest arctic and subarctic lakes (Cranston et al., 1983). *Heterotrissocladius subpilosus*-group, *Heterotrissocladius maeri*-group, *Sergentia coracina*-type, *Paracricotopus* and *Corynocera oliveri*-type occurred in lakes with mean August air temperature  $<15^{\circ}\text{C}$ . In western Canada, *C. oliveri*-type has its highest abundance in lakes between  $14\text{-}15^{\circ}\text{C}$  in July. In the arctic, its abundance is higher on Victoria Island than in sites at lower latitude (Porinchu et al., in press). In Canada, *Sergentia* was found in many lakes along the temperature gradient, however *Sergentia coracina* (cold indicator) was not distinguished from *Sergentia longiventris* (warmer indicator). *Paracricotopus* is relatively uncommon in lake sediments, thus its temperature preference is not well defined. *Heterotrissocladius* are cold stenotherms but *H. subpilosus* occurs in the coldest lakes (Brooks et al., 2007), as they do in the studied lakes of this training set. *H. maeri* was described as being found in warmer lakes than *H. grimshawi* in Europe (Brooks et al., 2007) but this is not the case here. These groups

were not separated in the other training sets from Canada thus we cannot compare their specific distribution.

### 6.1.2 Warm indicators

Six taxa were found mainly in lakes warmer than 20°C. *Sergentia longiventris*-type has been described in Europe as thermophilic (Brooks et al., 2007). However few studies have separated *S.coracina* from *S. longiventris*. *Lauterborniella* is found in relatively warm lakes (Brooks et al., 2005). *Pseudorthocladius* and *Corynoneura* seem to be eurythermic in Europe. Since they probably comprise many species, it is difficult to determine their ecology. Intermediate taxa (ie. with higher abundances in lakes with mean August air temperature between 10-15°C) were *Cladopelma*, *Microtendipes*, *Dicotendipes*, *Zalustchia lingulata pauca*, *Polypedilum* IIC, *Constempellina*, *Endochironomus impar*-type and *Polypedilum*. *Cladopelma* was described as a warm stenotherm (Walker et al., 1991). *Microtendipes* is an indicator of intermediate temperatures in northern Europe (Brooks and Birks, 2001). *Polypedilum* is an indicator of temperate climatic conditions (Brooks et al., 2007). *Zalustchia* tends to occur in lakes in the warmer end of the temperature gradient in the boreal zone (Walker et al., 1991).

### 6.1.3 Temperature optima

The temperature optima obtained for each taxon were compared to temperature optima obtained in other transfer functions worldwide (Table 3). The comparison of temperature optima can be tricky since a) the method of calculating these optima vary from one transfer function to the other since the model used diverge, b) the temperature optima will be dependant on the temperature gradient of the training sets, which differ from one study to the other, c) the temperature optima are dependant on taxonomy and d) the tolerance for one taxon can be high and thus the optimum might not represent the reality. However, the temperature optima compared reasonably well with the temperature optima obtained in other studies worldwide.

Table 3. Comparison of temperature optima with other transfer functions

Temperature optima	Porinchu	Barley	Larocque	Heiri	Walker*	Lotter	Porinchu 2	Francis
<b>Cold (optima &lt;10°C)</b>								
<i>Corynocera ambigua</i>	yes	warmer	yes				warmer	
<i>Parakiefferiella</i>	yes	yes	warmer	yes				yes
<i>Paracladius</i>	yes	yes		yes				yes
<i>Heterotrissocladius subpilosus</i> -group			yes					
<i>Sergentia</i>	yes	yes						yes
<i>Cladotanytarsus</i>	warmer	warmer	warmer	warmer				
<i>Corynoneura</i> sp	yes		yes	warmer				yes
<i>Micropsectra radialis</i> -type			yes	yes			warmer	
<i>Corynocera oliveri</i>	yes	warmer	yes				warmer	
<i>Zavrelmia</i>				yes				
<i>Stictochironomus</i>	yes	warmer		yes				yes
<i>Abiskomyia</i>	yes	yes	yes					yes
<i>Oliverdia</i>			warmer					yes
<i>Einfeldia</i>		warmer	yes	warmer				
<i>Eukiefferiella</i>	warmer			yes				yes
<i>Psectrocladius septentrionalis</i> -group	warmer	warmer	warmer					
<i>Mesocricotopus</i>	yes	warmer						yes
<i>Smittia</i>				yes				yes
<i>Psectrocladius sordidellus</i> -group	yes		warmer	yes				
<i>Cricotopus</i>	yes		warmer					yes
<i>Zalutschia lingulata pauca</i>	yes		yes					warmer
<i>Heterotrissocladius maeri</i> -group			warmer					
<i>Protanypus</i>	warmer	yes	yes	yes	warmer	warmer		yes
<i>Pseudodiamesa</i>	yes	yes	yes	yes				yes
<i>Microtendipes</i>	warmer	warmer	warmer	warmer	warmer	warmer	warmer	warmer
<b>Intermediate/cold (optima 10-15°C)</b>								
<i>Parachironomus</i>		yes						warmer
<i>Polypedilum</i> type II		yes	yes		yes	yes	yes	
<i>Cladopelma</i>	yes	yes	yes	warmer				
<i>Tanytarsus pallidicornis</i>	warmer		yes	yes	yes	yes		warmer
<i>Heterotrissocladius grimshawi</i> -group			yes	yes				
<i>Brillia</i>				yes				
<i>Tanytarsus lugens</i>	colder		yes	colder				
<i>Heterotrissocladius marcidus</i> -group			yes	colder				
<i>Nanocladius</i>		yes	yes	warmer				
<i>Chironomus anthracinus</i> -group	colder		warmer	colder				
<i>Tanytarsus</i> sp. B			yes	warmer				
<i>Orthocladius</i>	yes	yes	yes	yes				
<i>Paracladopelma</i>				yes	warmer	warmer		
<i>Glyptotendipes</i>	warmer	yes		warmer				
<b>Warm (optima &gt;15°C)</b>								
<i>Paratanytarsus</i>	yes		colder	colder			yes	
<i>Endochironomus</i>		colder		yes				yes
<i>Pagastiella</i>	yes	yes	colder					yes
<i>Dicrotendipes</i>	yes	colder	colder	yes	yes	yes	yes	yes
<i>Constempellina</i>			yes					
<i>Chironomus plumosus</i> -group	yes		yes	yes				
<i>Stempellinella</i>	yes	colder		yes				yes
<i>Chaetocladius</i>				colder				
<i>Procladius</i>	colder	colder	colder	yes	colder	yes	yes	colder
<i>Heterotanytarsus</i>	yes	yes	colder					yes
<i>Cryptochironomus</i>		colder		yes				yes
<i>Pentaneurini</i>	yes	colder	colder					colder
<i>Micropsectra insignilobus</i> -type			colder	colder			yes	
<i>Zalutschia zalutschicola</i>	yes	colder	colder					yes
<i>Endochironomus tendens</i> -type				yes				
<i>Abiabetesmyia</i>			yes					
<i>Tanytarsus</i> sp. C			colder	yes				
<i>Limnophyes</i>				colder				colder
<i>Phaenopsectra</i>		colder		yes				
<i>Polypedilum</i>				yes				yes
<i>Lauterborniella</i>				yes	colder	colder		yes
<i>Sergentia longiventris</i>				yes				

Porinchu et al., in press, Barley et al., 2006, Larocque et al., 2001, Heiri et al., 2003, Walker+Lotter in Lotter et al. 1999, Porinchu et al., 2002  
Francis et al., 2006

Only three taxa (*Cladotanytarsus*, *Psectrocladius septentrionalis*.group and *Microtendipes*) had temperature optima which did not agree with at least one of the

temperature optimum obtained from other transfer functions. These divergences can be due to problems in identification. *Cladotanytarsus* might have been here confused with *Pseudochironomus* and samples containing these taxa will need to be re-counted. *Psectrocladius septentrionalis*-group differs from *Psectrocladius sordidellus*-group by the length of the ventromental plates. These could be recounted to be sure of our identification, although we are pretty confident that identification of this taxon was properly made. *Microtendipes* was divided here into two types, which was not done in any of the other training sets considered. In our training set, *Microtendipes* has a distribution at both ends of the gradient and if *Microtendipes* and *Microtendipes* II are merged, the temperature optimum increased substantially and compare well with the optima obtained in the other transfer functions. The divergence is due to the separation of *Microtendipes* into two sub-groups.

Since the new transfer function covers the largest gradient of temperature, it is likely that the distribution of chironomids is better represented and that the temperature optima for most taxa are better estimated here than in the other Canadian transfer functions.

## 6.2 Transfer function

The coefficient of correlation improved in the new transfer function but the RMSEP is higher compared to the previous transfer function (Larocque et al., 2006). Comparing with other Canadian transfer functions (Table 4), the new transfer function has the highest number of taxa and the largest temperature gradient.

**Table 4.** Comparison of Canadian transfer functions: statistics and characteristics

	<b>Our</b>	<b>Larocque</b>	<b>Porinchu</b>	<b>Barley</b>	<b>Francis</b>
<b>Nb lakes</b>	73	52	88	147	68
<b>Nb Taxa</b>	80	79	41	62	44
<b>Temperature Gradient</b>	air August 3-27.5°C	air August 9.4-16.8°C	air July 6.7-15.1°C	air July 3.9-16.5°C	air July 5.0-19.0°C
<b>Model</b>	WAPLS	PLS	WAPLS	WAPLS	WA
<b>r<sup>2</sup></b>	0.87	0.67	0.77	0.82	0.88
<b>RMSEP</b>	1.67°C	1.20°C	1.03°C	1.46°C	1.53°C
<b>Max Bias</b>	2.33°C	3.5°C	1.37°C	2.47°C	1.47°C

The coefficient of correlation of the new transfer function is the second highest however, the RMSEP is also the highest. Brooks and Birks (2001) have shown that the RMSEP has a tendency to increase when more taxa are considered in a model. Although the RMSEP is high, the comparison between today's temperature and the inferences obtained by chironomids in the two lakes of Southampton Island and Lac du Sommet indicate a small difference of 0.2-0.3°C. The error of prediction was also evaluated when inferences were compared to instrumental data at Lake Silvaplana, Switzerland (Larocque et al., 2008) and in four lakes in northern Sweden (Larocque and Hall, 2003) . The average errors were in the range of 0.5°C. Although the RMSEP is an indication of the possible error of estimates, the comparison with instrumental data suggest that the models generally performed much better than estimated.

### **6.3 Temperature reconstructions**

It is not surprising that the new model performs better when reconstructing the climate in the two lakes on Southampton Island since the previous transfer function did not comprise lakes with such cold temperatures. However, the good correspondence between the instrumental data and the chironomid-inferred temperature in the surface sample indicate that the model performs well. Rolland et al. (2008) and Rolland et al. (in press) used an alternative model (i.e. the transfer function included the lakes on Southampton Island but not the coldest and warmer lakes) and reconstructed appropriately the climate of the last ca. 4000 years. The same general patterns are reconstructed here, suggesting that the new model provides good estimates of climate change.

At Lac du Sommet, the chironomids reconstruct today's temperature with good accuracy (by 0.3°C). The general pattern of temperature changes throughout the last 10,000 years BP is also comparable to changes reconstructed by other proxies in Quebec (Hausmann et al. in prep). It seems that the model developed here has a good performance.

## 7. Conclusions

The transfer function presented here included 73 lakes covering a temperature gradient of 3 to 27.5°C and included 80 taxa. This is the existing Canadian training set covering the largest gradient of temperature and the highest number of taxa to date. This model has a high coefficient of correlation (0.88) but the highest RMSEP of the Canadian transfer functions. This high RMSEP can be due to the higher number of taxa included in the model. However the transfer function provides estimates of today's temperature with a difference of only 0.2-0.3°C, suggesting that the RMSEP is overestimated. Although this new transfer function was based on unimodal distribution of most of the taxa, new lakes should be sampled on the northern and southern sites of the gradient to pin-point the optima of a number of taxa such as *Heterotrissocladius subpilosus*-group, *Micropsectra radialis*-type, *Sergentia longiventris*-type and *Lauterborniella* which had their highest abundances in the coldest or warmest lakes. The taxonomy should also be revised for two taxa: *Cladotanytarsus* and *Psectrocladius septentrionalis*-group which had a distribution contrasting with other training sets worldwide.

## **8. Acknowledgements**

I would like to thank Pierre Francus for sampling lakes on Ellesmere Island, Emilie Saulnier-Talbot and Marie-André Fallu for the use of their slides for the lakes in northern Québec/Labrador and Nicolas Rolland for the use of his data. This research was possible with funding from NSERC.

## 9. References

Barley, E.M., Walker, I.R., Kurek, J., Cwynar L.C., Mathewes, R.,W., Gajweski, K., Finney, B.P. 2006. A northwest North American training set: distribution of freshwater midges in relation to air temperature and lake depth. *Journal of Paleolimnology* 36: 295-314

Brooks S.J., Birks, H.J.B. 2000. Chironomid-inferred late-glacial and early-Holocene mean July air temperatures for Kråkenes Lake, western Norway. *Journal of Paleolimnology* 23:77-89

Brooks S.J., Birks, H.J.B. 2001. Chironomid-inferred air temperatures from late-glacial and Holocene sites in north-west Europe: progress and problems. *Quaternary Science Reviews* 20: 1723-1741

Brooks, S.J., Langdon, P.G. and Heiri, O. 2007. The identification and use of Palaeartic Chironomidae larvae in palaeoecology. QRA Technical Guide No. 10, Quaternary Research Association, 276 pp.

Brooks, S.J., Udachin, V., Williamson, B. 2005. Impact of copper smelting on lakes in the southern Ural Mountains, Russia, inferred from chironomids. *Journal of Paleolimnology* 33: 229-241

Brundin, L. 1956. Zur Systematic der Orthoclaadiinae (Dipt. Chironomidae). Report of the Institute of Freshwater Research, Drottningholm 37: 5-185

Cranston, P.S., Oliver, D.R., Saether, O.A. 1983. The larvae of the Orthoclaadiinae (Diptera: Chironomidae) of the Holarctic region. Keys and diagnoses. *Entomologica Scandinavica Supplement* 19: 149.291

Francis, D.R., Wolfe A.P., Walker, I.R., Miller, G.H. 2006. Interglacial and Holocene temperature reconstruction based on midge remains in sediments of two lakes from Baffin Island, Nunavut, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology* 236: 107-124

Fallu, M.-A., Pienitz, R., Walker, I.R., Lavoie, M. 2005. Paleolimnology of a shrub-tundra lake and response of aquatic and terrestrial indicators to climatic change in arctic Que'bec, Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology* 215: 183-203

Gajewski, K., Bouchard, G., Wilson, S.E., Kurek, J., Cwynar, L.C. 2005. Distribution of Chironomidae (Insecta: Diptera) head capsules in recent sediment of Canadian arctic lakes. *Hydrobiologia* 549: 131-143

Heiri, O. 2001. Holocene palaeolimnology of Swiss mountain lakes reconstructed using subfossil chironomid remains: past climate and prehistoric human impact on lake ecosystems. PhD thesis, University of Bern, Bern, Switzerland

Heiri, O., Lotter, A.F., Hausmann, S., Kienast, F. 2003. A chironomid-based Holocene summer air temperature reconstruction from the Swiss Alps. *The Holocene* 13: 477-484

Juggins, S. 2003. C2 data analysis, version 1.5.1. University of Newcastle, Newcastle, UK.

Larocque, I. 2001. How many chironomid head capsules is enough? A statistical approach to determine sample size for paleoclimatic reconstruction. *Palaeogeography, Palaeoclimatology, Palaeoecology* 172 :133-142.

Larocque, I., Rolland, N. 2006. Le guide visuel des chironomids sub-fossiles, du Québec à l'île d'Ellesmere, INRS rapport de Recherche R-900, ISBN 2-89146-430-3

Larocque, I., Hall, R.I., Grahn, E. 2001. Chironomids as indicators of climatic and environmental change: A 100-lake training set from a subarctic region of northern Sweden (Lapland). *Journal of Paleolimnology* 26: 307-322.

Larocque, I., Pienitz, R., Rolland, N. 2006. Factors influencing the distribution of chironomids in lakes distributed along a latitudinal gradient in northwestern Québec, Canada. *Canadian Journal of Fisheries and Aquatic Sciences*. 63: 1286-1297

Larocque, I., Grosjean, M., Heiri, O., Bigler, C., Blass, A. Online. Comparison between chironomid-inferred July temperatures and meteorological data AD 1850–2001 from varved Lake Silvaplana, Switzerland. *Journal of Paleolimnology*

Lepš, J., Šmilauer, P. 2003. Multivariate analysis of ecological data using CANOCO. Cambridge University Press, Cambridge, UK.

Olander, H., Birks, H.J.B., Korhola, A. and Blom, T. 1999. An expanded calibration model for inferring lake water and air temperatures from fossil chironomid assemblages in northern Fennoscandia. *The Holocene* 9: 279-294

Oliver, D.R. , Roussel, M.E. 1983. The insects and arachnids of Canada, part II. The genera of larval midges of Canada. Agriculture Canada, Publication 1746, 263 pp.

Porinchu, D.F, Rolland, N., Moser, K.A. in press. Development of a chironomid-based air temperature inference model for the central Canadian Arctic. *Journal of Paleolimnology*

Porinchu, D.F., MacDonald, G.M., Bloom, A.M., Moser, K.A. 2002. The modern distribution of chironomid sub-fossils (Insecta: Diptera) in the Sierra Nevada, California: Potential for paleoclimatic reconstructions. *Journal of Paleolimnology* 28: 355–375

Porinchu, D. F., Moser, K.A., Munroe, J. 2007. Development of a Midge-based Summer Surface Water Temperature Inference Model for the Great Basin of the Western United States. *Arctic, Antarctic and Alpine Research* 39: 566-577

Raddum, G.G., Saether, O.A. 1981. Chironomid communities in Norwegian lakes with different degrees of acidification. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* 21: 399-405

Rolland N., Larocque I., Francus P., Pienitz R., Laperrière L. in press. Evidence for a warmer period during the 12th and 13th century from chironomid assemblages in Southampton Island, Nunavut, Canada. *Quaternary Research*

Rolland, N., Larocque, I., Francus, P., Pienitz, R. 2008. Holocene climate inferred from biological (Diptera: Chironomidae) analyses in a Southampton Island (Nunavut, Canada) lake. *The Holocene* 18: 229-241

Saulnier-Talbot, E., Leng, M.J., Pienitz, R. 2007. Recent climate and stable isotopes in modern surface waters of northernmost Ungava Peninsula, Canada. *Canadian Journal of Earth Sciences* 44:171-180

Walker, I.R., Mathewes, R.W. 1989a. Chironomidae (Diptera) remains in surficial lake sediments from the Canadian Cordillera: analysis of the fauna across an altitudinal gradient. *Journal of Paleolimnology* 2: 61-80

Walker, I.R., Mathewes, R.W. 1989b. Much ado about dead Diptera. *Journal of Paleolimnology* 2: 19-22.

Walker, I.R., Levesque, A.J., Cwynar, L.C., Lotter, A.F. 1997. An expanded surface-water palaeotemperature inference model for use with fossil midges from eastern Canada. *Journal of Paleolimnology* 18: 165-178

Walker, I.R., Smol, J.P., Engstrom, D.R., Birks, H.J.B. 1991. An assessment of Chironomidae as quantitative indicators of past climatic change. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 975-987

Warwick, W.F. 1989. Chironomids, lake development and climate: a commentary. *Journal of Paleolimnology* 2, 15-18.

Wiederholm, Y. 1983. Chironomidae of the Holartic region. Part 1, Larvae. *Entomologica Scandinavia*, Supplement 19, 457 pp.