

# Historical variability of subfossil chironomids (Diptera: Chironomidae) in three lakes impacted by natural and anthropogenic disturbances

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**Abstract** In the eastern boreal forest of Quebec, Canada, harvesting strategies try to mimic the effects of fire on forest ecosystems, assuming that both disturbances have similar impacts. However impacts of both types of perturbations on lacustrine ecosystems, especially on chironomids (non-biting midges), are still poorly understood. The objectives of this study were to determine if logging and fire resulted in chironomid assemblages significantly different than pre-disturbance states and to see if the harvesting strategy (careful logging around advanced growth (CLAAG) and buffer zones) protect lakes from logging effects in the boreal forest. Three statistical tests were used to study the difference between pre- and post-disturbance assemblages: a principal

component analysis (PCA), analysis of similarity (ANOSIM) and a non-metric multi-dimensional scaling (MDS) ordination. All statistical analyses suggested that fire did not have any effects on chironomid assemblages. The PCA analysis showed that two logging events in Lac aux Huards created chironomid assemblages slightly outside the pre-disturbance variability. However, ANOSIM showed that these differences were not significant at the 0.5% level of significance. These results suggest that the presence of a buffer zone probably limited the impacts of logging on lakes in this area.

**Keywords** Fire · Careful logging around advanced growth (CLAAG) · Chironomids · Boreal forest · Canada

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## Introduction

In the Canadian boreal zone, strategies in forest management are based on the assumption that fire and logging have similar impacts on ecosystems; forest exploitation patterns emulating fires should thus sustain forest dynamics and biodiversity (Hunter 1993). However, this assumption remains unverified for aquatic ecosystems and on a longer time perspective. In fact, wildfire and forestry are both characterised by temporary local deforestation but have different mechanisms and may exhibit important

differences in spatial extent and frequency of occurrence and in their impact on water quality (Carignan and Steedman 2000). The existing long-term studies have looked at the effect of fire (Philibert et al. 2003a, b) or logging (Laird and Cumming 2001) separately with few exceptions (Francis 2001). To be able to determine if both type of disturbances exhibit similar impacts on lake ecosystems, changes through time should be studied in lakes where both perturbations have occurred.

Following impact studies, logging practices in Quebec have changed from total harvesting by clear cut to less severe strategies such as careful logging around advanced growth (CLAAG) where stems of diameters smaller than 10 cm are left in place (Bérard and Côté 1996) and buffer strips of about 20 m are left untouched. These buffer zones have been effective to reduce but not completely eliminate the short-term impacts of logging (Miller et al. 1997; Moore et al. 2005). However, most of the studies have not looked at variability prior to the perturbations or, if they did, they used two sets of lakes, a control lake and a perturbed lake (Rask et al. 1998). The present study examines differences between pre- and post-perturbation states in single-lake systems to avoid spatial confounding factors (Underwood 1992).

While modern and paleoecological studies on disturbance effects on diatom, plankton, zooplankton and fish communities in the boreal forest have been conducted, only one study, to our knowledge (Francis 2001), looked at the impact of deforestation and fires on lake-dwelling chironomid communities. Here, we examine the variation of pre- and post-disturbance chironomid assemblages in three lakes of Quebec that have been impacted by fire and forest harvesting. Our goals are to determine: (1) if fire and logging have similar impacts on chironomid assemblages and (2) if the buffer zones left after logging are effective in limiting the impact of perturbation on chironomid assemblages.

#### Site description

The study area is located in the boreal forest of Quebec, on the Boreal Shield near Lac Mistassini (Fig. 1). This region is part of the temperate biozone, with temperatures varying between  $-44.5^{\circ}\text{C}$  in winter and  $23.0^{\circ}\text{C}$  in summer (Environment Canada 2007). The forest in this region is dominated by

virgin black spruce (*Picea mariana* (Miller) BSP). The humic layer covering the bedrock is thin and the lakes in this area are oligotrophic (Carignan et al. 2000). The catchment topography and geology locally influence water chemistry (D'Arcy and Carignan 1997). Most lakes in this region were formed as a result of the action of the Laurentide ice sheet (Dyke and Prest 1987).

Three lakes were chosen for the high number and the good preservation of their chironomid remains in sediments and their recent history of clear-cutting events that varied in size (Tables 1 and 2). Lac Chantale ( $50^{\circ}26''\text{N}$ ,  $72^{\circ}48''\text{W}$ ) has an area of  $0.42\text{ km}^2$ , a maximum water depth of 14.7 m (Table 1) and a drainage ratio (catchment area/surface area) of 16.59. Lac Maurice ( $50^{\circ}33''\text{N}$ ,  $72^{\circ}33''\text{W}$ ) has an area of  $0.71\text{ km}^2$ , a maximum water depth of 9.7 m and a drainage ratio of 6.89. Lac aux Huards ( $49^{\circ}40''\text{N}$ ,  $72^{\circ}38''\text{W}$ ) has an area of  $2.56\text{ km}^2$ , a maximum water depth of 20.0 m and a drainage ratio of 8.41. Five summer cottages were built at the northern side of Lac aux Huards in the early 1990s. Major fish species in Lac Maurice are *Perca flavescens*, *Esox lucius*, *Couesius plumbeus*, *Lota lota*, *Cottus* sp., *Stizostedion vitreum* and *Catostomus commersoni*. No record of fish populations was available for Lac Chantale and Lac aux Huards. However, fishless lakes are rare in this area (P. Couture, pers. commun.) and we assume that these lakes are inhabited by fish.

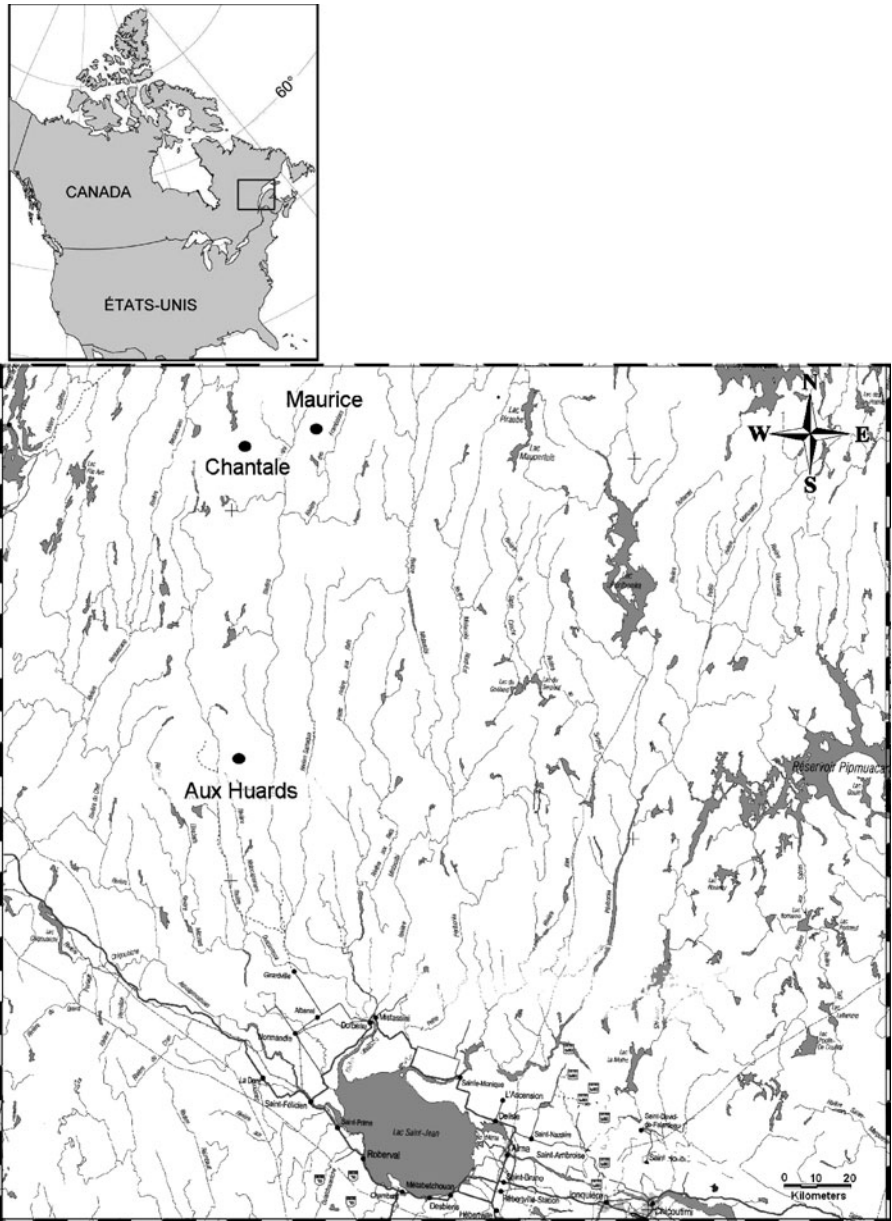
#### Forest harvesting

In the Lac-St-Jean area, forest harvesting is made by careful logging around advanced growth (CLAAG) which removes at least 75% of the stands (Bergeron 2003) but leaves forested borders of 20 m around lakes (Winkler et al. 2009). Lac Chantale was influenced by forest harvesting in 2000–2001 and 21.0% of its catchment was cut. At Lac Maurice, 57.9% of the catchment was logged in 2002–2003, and the catchment of Lac aux Huards was logged between 1990 and 1994 and again in 2000 when 42.6% of its forest was affected (Table 2).

#### Fire history

The boreal forest of the Lac-St-Jean area is dominated by spruce and mosses. The typical fire that

**Fig. 1** Location map of the three study lakes: Lac Maurice (50°33'N, 72°48'E), Lac Chantale (50°26'N, 72°33'E) and Lac aux Huards (49°40', 72°38'E) in the Saguenay-Lac-St-Jean region of eastern Quebec, Canada



**Table 1** Characteristics of the studied lakes

Lake	Latitude	Longitude	Altitude (m)	Depth (m)	Lake area (LA) (km <sup>2</sup> )	Volume area (km <sup>2</sup> )	Catchment area (CA) (km <sup>2</sup> )	Drainage ratio (CA/LA)	Catchment slope
Lac Chantale	50°26''	72°48''	478	14.7	0.42	2.77	6.97	16.59	11.7
Lac Maurice	50°33''	72°33''	492	9.7	0.71	1.84	4.92	6.89	6.59
Lac aux Huards	49°40''	72°38''	383	20	2.56	ND	21.53	8.41	8.26

**Table 2** History of harvesting and fire in the catchment area of the three studied lakes

Lake	Harvesting			Historical fires Years
	Years	Km <sup>2</sup>	% of catchment	
Lac Chantale	2000–2001	1.375	21	1991 (RN)
Lac Maurice	2002–2003	2.434	57.9	1810 (D) 1996 (RN)
Lac aux Huards	2000 1990–1994	8.075	42.6	1810 (D) 1984 (RN)

D based on dendrochronology; RN based on maps from *Ressources Naturelles du Canada*

occurs in this forest type is crown fire of high intensity (Bergeron and Dansereau 1993) that ranges in size from 950 to 2000 ha (Bergeron 2003).

## Methods

Short sediment cores were retrieved from the deepest part of each lake in September 2004 using a Renberg corer (Renberg 1991). The complete sediment cores were passed under a Cat-Scan at the “Laboratoire multidisciplinaire de scanographie du Québec” located at the Institut National de Recherche Scientifique, centre Eau, Terre et Environnement (INRS-ETE). No laminae were visible after the scan. The cores were then sub-sampled at 0.25-cm increments and kept frozen until analyzed.

### Chironomid analysis

Samples of freeze-dried sediment (0.3–0.6 g) were de-flocculated overnight in 10% KOH, and then sieved on a 100- $\mu$ m mesh. Analyses were first done at 1-cm intervals. Additional samples were analysed when noticeable changes in the chironomid assemblages were observed. Each residue was placed in an ultrasonic bath for 2–5 s to remove residual organic matter in the head capsules (Lang et al. 2003). This technique does not damage head capsules in this type of sediment (Rolland and Larocque 2007). Chironomids from Lac aux Huards and Lac Maurice were extracted via a floatation technique, using ethanol and kerosene (Rolland and Larocque 2007). For Lac Chantale, chironomids were picked individually following the method described in Larocque et al. (2001). Head capsules from each lake were placed in a Bogorov chamber and examined with a stereo-zoom

microscope at 35–40 $\times$  magnification. In accordance to Heiri and Lotter (2001), Larocque (2001) and Quinlan and Smol (2001), at least 50 head capsules were recovered and mounted on a microscope slide using Hydro-Matrix. Larval head capsules were identified under a light microscope at  $\times$ 400 magnification with reference to Oliver and Roussel (1983), Wiederholm (1983) and Epler (1992). Members of the tribe Tanytarsini were divided into taxonomic types based on Brooks et al. (2007). In the absence of mandibles, the Tanytarsini were separated by the presence (Tanytarsini with spur) or absence (Tanytarsini without spur) of a spur on their antennal pedicel. Tanytopodinae groups were separated using the position of setae following Rieradevall and Brooks (2001).

We used the known ecology of taxa to group chironomid observations into autecological categories that included profundal, littoral, semi-terrestrial, oligotrophic or meso/eutrophic categories (Table 3). We used mainly the ecological description of taxa in Brooks et al. (2007), Oliver and Roussel (1983) and Wiederholm (1983), as well as descriptions in papers enumerated in Table 3. Only taxa indicative of distinct ecological states were considered in this list (e.g. we did not consider any taxon that can be found in either mesotrophic or oligotrophic lakes, or in littoral and/or profundal zones.)

### Carbon and nitrogen (C/N) analysis

We performed C/N analysis to determine the concentration of total carbon, organic carbon and nitrogen. For each core, freeze-dried sediment samples were analysed at 1-cm intervals. The analysis of carbon and nitrogen was made on a LECO CHNS-932.

**Table 3** Classification of chironomid taxa

Category	Associated taxon	Reference
Oligotrophic	<i>Micropsectra insignilobus</i> -type	Brooks et al. (2007)
	<i>Micropsectra radialis</i> -type	Brooks et al. (2007)
	<i>Heterotrissocladius grimshawi</i> -group	Brooks et al. (2007)
	<i>Heterotrissocladius maeri</i> -group	Brooks et al. (2007)
	<i>Heterotrissocladius marcidus</i> -group	Brooks et al. (2007)
	<i>Heterotrissocladius subpilosus</i> -group	Brooks et al. (2007)
	<i>Paracladopelma</i>	Hoffman (1984)
	<i>Paratanytarsus</i>	Brooks et al. (2007)
Mesotrophic/eutrophic	<i>Chironomus anthracinus</i> -group	Brooks et al. (2007)
	<i>Chironomus plumosus</i> -group	Brooks et al. (2007)
	<i>Chironomus</i> sp.	Brooks et al. (2007)
	<i>Dicrotendipes</i>	Brooks et al. (2007)
	<i>Einfeldia</i>	Langdon et al. (2006)
	<i>Glyptotendipes</i>	Brooks et al. (2001)
	<i>Polypedilum</i>	Klink (2002)
Semi terrestrial	<i>Eukiefferiella</i>	Brooks et al. (2007)
	<i>Parametriocnemus</i>	Moog (1995)
Littoral	<i>Corynoneura</i>	Brooks et al. (2007)
	<i>Dicrotendipes</i>	Pinder and Reiss (1983)
	<i>Einfeldia</i>	Brooks et al. (2007)
	<i>Glyptotendipes</i>	Walker and MacDonald (1995)
	<i>Polypedilum</i>	Hoffman (1984)
	<i>Tanytarsus chinyensis</i> -type	Brooks et al. (2007)
Profundal	<i>Tanytarsus</i> sp. C	Brooks et al. (2007)
	<i>Heterotrissocladius grimshawi</i> -group	Brooks et al. (2007)
	<i>Heterotrissocladius maeri</i> -group	Brooks et al. (2007)
	<i>Heterotrissocladius marcidus</i> -group	Brooks et al. (2007)
	<i>Heterotrissocladius subpilosus</i> -group	Brooks et al. (2007)
	<i>Procladius</i>	Saether (1979)
	<i>Protanypus</i>	Oliver (1983)

## Fire history

Two methods were used to determine the fire history at each site. First, dendrochronology was performed on wood samples obtained from four quadrats around each lake. In each quadrat, 10 tree disks of different species (black spruce (*Picea mariana* (Miller) BSP), balsam fir (*Abies balsamea* (Linné) Miller) and silver birch (*Betula papyrifera* Marshall) were sampled at chest height, for a total of 40 trees at each lake. The disks were sanded then analysed under a binocular microscope. The age of the cohorts were established by counting the number of rings in each tree disk. The last fire was established by determining the age of the

oldest tree or, by dating fire scars, if present (Table 2). Secondly, we consulted maps created by the *Ministère des Ressources naturelles et de la Faune—Direction de la protection des forêts* (2006). According to these maps, the most recent fire at Lac Chantale occurred in 1991 and affected most of the watershed. At Lac Maurice, the last fires occurred in 1996, and at Lac aux Huards, the last fire occurred in 1984.

## Dating

Freeze-dried sediment samples (12 for Lac Maurice and 13 for Lac Chantale and Lac aux Huards) were analyzed for  $^{210}\text{Pb}$  by direct gamma assay at MyCore

Scientific Inc, Ontario, Canada. Radiometric dates were calculated following Appleby et al. (1986). Dry weight of each samples was used to correct for compaction in the core and to date the core using the CRS model. Radioisotopic activity was corrected for organic matter content in the samples.

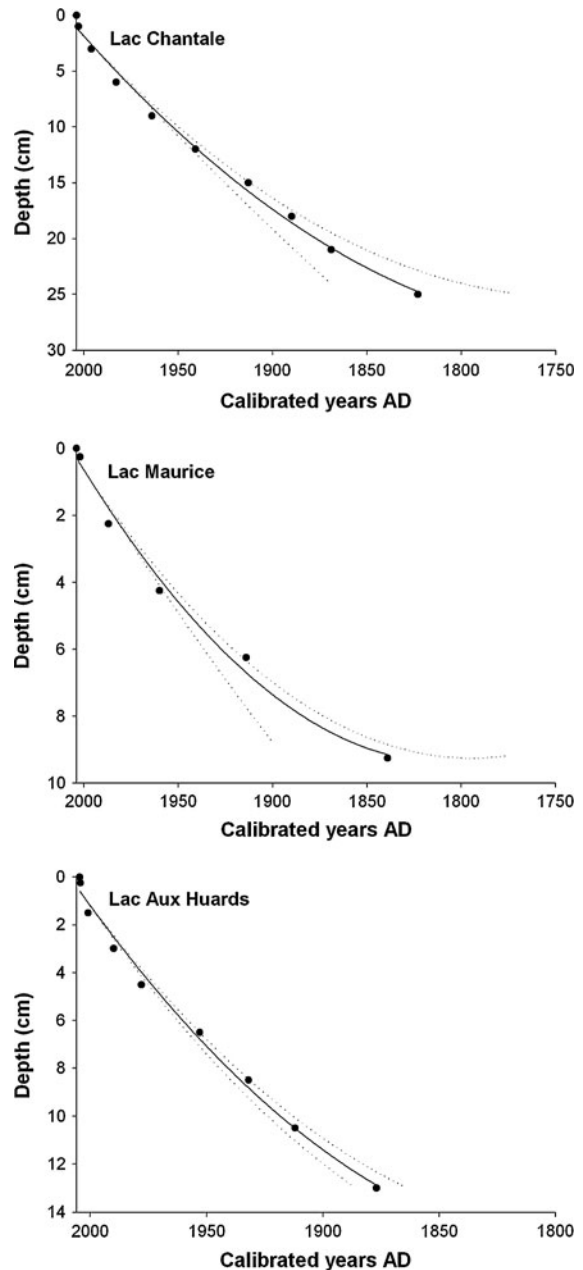
### Numerical analyses

Only taxa with a relative abundance of at least 1% in two samples per core were used for statistical analyses. Stratigraphic diagrams were produced using C2 v1.4.2 (Juggins 2003). The linearity or unimodality of the chironomid assemblages were assessed using a detrended correspondence analysis (DCA). Because the lengths of gradients were shorter than 2 (i.e. for Lac Chantale lengths = 1.33, 1.75, 1.42, 0.881; for Lac Maurice 1.51, 1.24, 1.06, 0.98; for Lac aux Huards 1.81, 1.22, 1.11, 1.24), linear analysis was used (Lepš and Šmilauer 2003). To determine the similarity between samples, three analyses were used: a principal component analysis (PCA), an analysis of similarity (ANOSIM) and a non-metric multi-dimensional scaling (MDS) ordination where samples were divided in two groups (pre- and post-disturbance samples). The ANOSIM and the MDS were based on a Bray-Curtis dissimilarity matrix built in the statistical package PRIMER (version 5.2.2). The closer the R-Statistic in the ANOSIM was to 0 value, the lower was the similarity between the groups.

## Results

### Temporal resolution

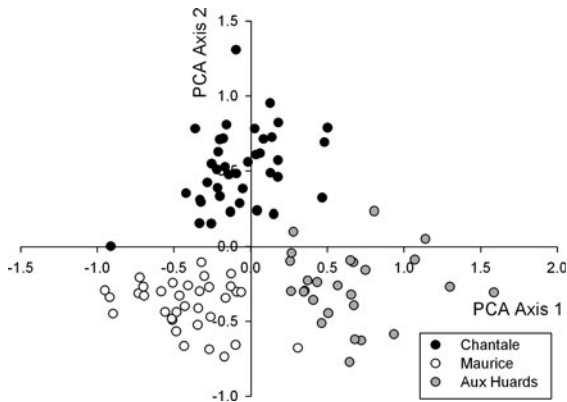
The  $^{210}\text{Pb}$  detection limit was reached at 27.5 cm in Lac Chantale, at 9.75 cm in Lac Maurice, and at 13.75 cm in Lac aux Huards. Polynomic relationships between depth and dates were used to develop age-depth curves (Fig. 2). In Lac Chantale, the sediment accumulation rates were around  $0.2 \text{ g cm}^{-2} \text{ year}^{-1}$  between 3.25 cm and the top of the core and  $0.15 \text{ g cm}^{-2} \text{ year}^{-1}$  from 3.5 to 25 cm. In Lac Maurice, the sediment accumulation rates varied between 0.09 and  $0.15 \text{ g cm}^{-2} \text{ year}^{-1}$  from 9.25 cm to the top of the core. In Lac aux Huards, the sediment accumulation rates were constant and around  $0.1 \text{ g cm}^{-2} \text{ year}^{-1}$  from the top to 13.75 cm.



**Fig. 2** Age-depth relationship in the sediment of the three study lakes. The dotted lines are based on the estimated errors

### Chironomid assemblages

The location of the chironomid assemblages in different quadrants of the PCA graph (Fig. 3) suggests that the chironomid communities were specific to each lake. Profundal taxa percentages were higher in Lac aux Huards than in Lac Chantale



**Fig. 3** Principal component analysis (PCA) of the three study lakes. *Black circles* are samples from Lac Chantale, *empty circles* are samples from Lac Maurice and *gray circles* are samples from Lac Aux Huards

and Lac Maurice (Figs. 4, 5, and 6) as a result of the greater lake depth of Lac aux Huards (Table 2).

Eighty-two taxa were identified in the sediment samples of Lac Chantale. Only the taxa with more than 2% in at least four samples were presented in the stratigraphic diagram (Fig. 4). *Tanytarsus* sp. C, *Tanytarsus* with spur, *Tanytarsus* sp., *Sergentia*, *Tanytarsus* without spur, *Procladius*, *Heterotrissocladius marcidus*-group and *Micropsectra radialis*-type dominated the assemblages (up to 20%) in Lac Chantale (Fig. 4). *Pseudorthocladius*, *Microtendipes*, *Chironomini*, *Tanytarsus* sp. C and *Tanytarsus* with spur were recorded only after ca. 1870 AD while *Psectrocladius septentrionalis*-group, *Eukiefferiella* and *Glyptotendipes* were not recorded after ca. 1925 AD.

In Lac Maurice, 53 taxa were identified. *Procladius* and *Tanytarsus* without spur were the dominant taxa (up to 40%) in this core with *Tanytarsus* with spur, *Pentaneurini* and *Heterotrissocladius marcidus*-group as co-dominant (up to 20%; Fig. 5). *Tanytarsus* sp. B, *Heterotrissocladius subpilosus*-group, *Tanytarsus chinyensis*-type, *Pagastiella* and *Lauterborniella* were recorded only in samples before ca. 1900 AD.

In Lac aux Huards, 46 taxa were identified. *Procladius*, *Heterotrissocladius marcidus*-group, *Sergentia*, *Micropsectra radialis*-type and *Tanytarsus* without spur dominated the assemblages (Fig. 6). *Paratanytarsus*, *Heterotrissocladius subpilosus*-group, *Parakiefferiella* and *Heterotrissocladius grimshawi*-group were more abundant in samples after ca.

1940 AD. *Paracladopelma* was recorded, in low abundances, only before ca. 1870 AD.

#### Changes in chironomid assemblages with time

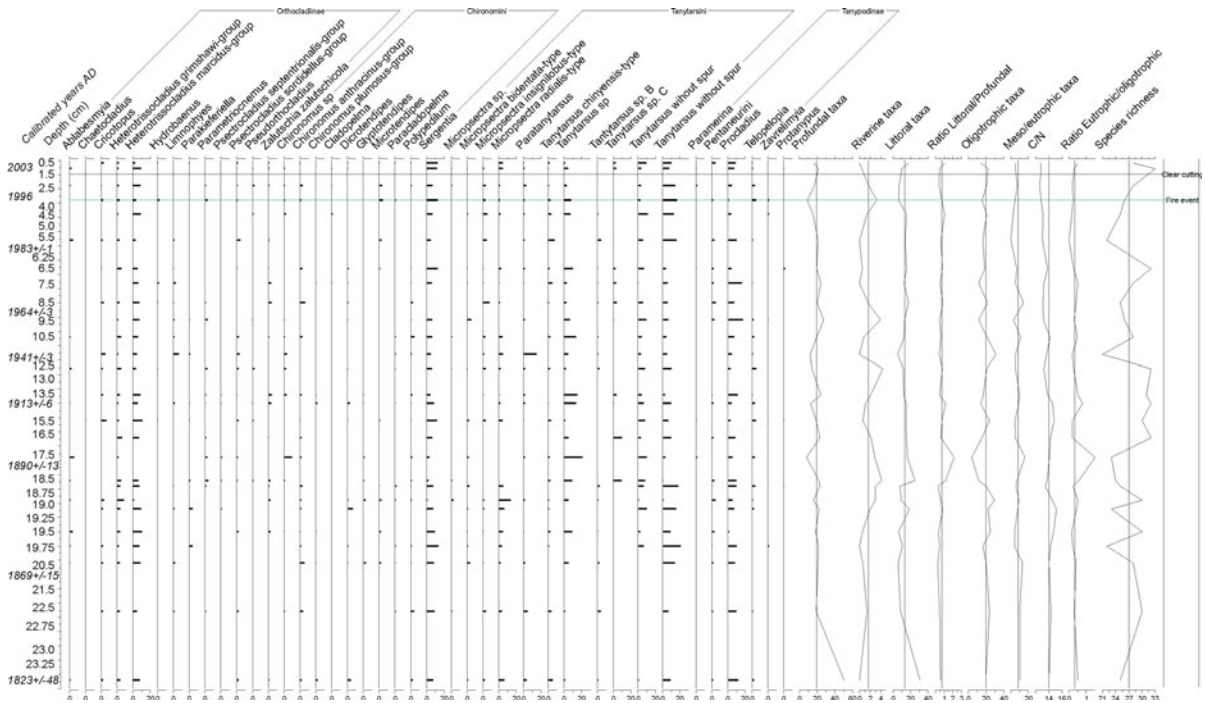
The pre-disturbance chironomid assemblages in the three lakes changed through time, but there was no obvious directional change in any of the three lakes (Fig. 7). In ca. 1823 AD, the chironomid assemblage in Lac Chantale was dominated by *Procladius*, *Sergentia*, *H. marcidus*-group and *M. radialis*-type while various *Tanytarsus* increased in the more recent samples (Fig. 4). Profundal, littoral and meso/eutrophic taxa had few variations (<10%) during the approximate 170 years of the record. The littoral/profundal ratio changed between ca. 1885 AD and 1905 AD in association with oligotrophic taxa. Species richness oscillated around  $27 \pm 6$  and demonstrated little variation in chironomid assemblages through time. C/N ratios showed minor variation (from 12 to 14).

In Lac Maurice, the samples at the bottom of the core were dominated by *Tanytarsus* without spur and *Heterotrissocladius marcidus*-group. In more recent samples, *Procladius* dominated the assemblages (Fig. 5). Variations of profundal, littoral, oligotrophic and meso/eutrophic taxa did not exceed 10%. Species richness was more or less constant with  $20 \pm 5$  taxa. C/N ratios showed little variation (12–14) over time.

In Lac aux Huards, chironomid assemblages changed from samples dominated by *Procladius*, *H. marcidus*-group and *M. radialis*-type to more diverse communities including other types of *Micropsectra* and *Tanytarsus* with *Cricotopus* and other Orthoclaadiinae (Fig. 6). Between ca. 1930 and 1955 AD, the percentages of profundal were approximately 20% above average (Fig. 6). The ratios of littoral/profundal taxa were always below 1 suggesting that the lake remained deep through time. Species richness varied more than in the two other lakes with  $18 \pm 10$  taxa. The C/N ratios showed little variation over time (from 12 to 14).

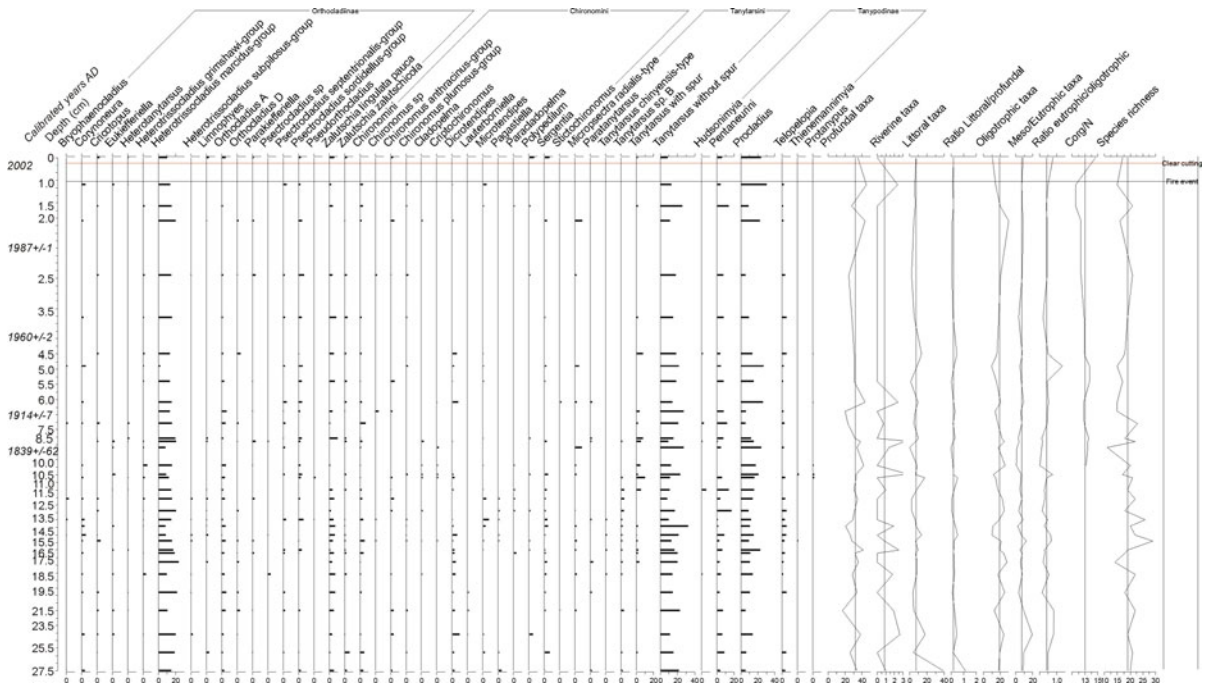
#### Changes in chironomid assemblages with disturbances

In Lac Chantale, the pre- and post-disturbance samples were similar. In the PCA analysis (Fig. 7), the post-disturbance samples were located in the same quadrants as pre-disturbance samples. In the



**Fig. 4** Chironomid stratigraphy (in percentages) at Lac Chantale. Fire events are identified by “Fire” and logging events are identified by “Clear cutting”. The vertical lines in

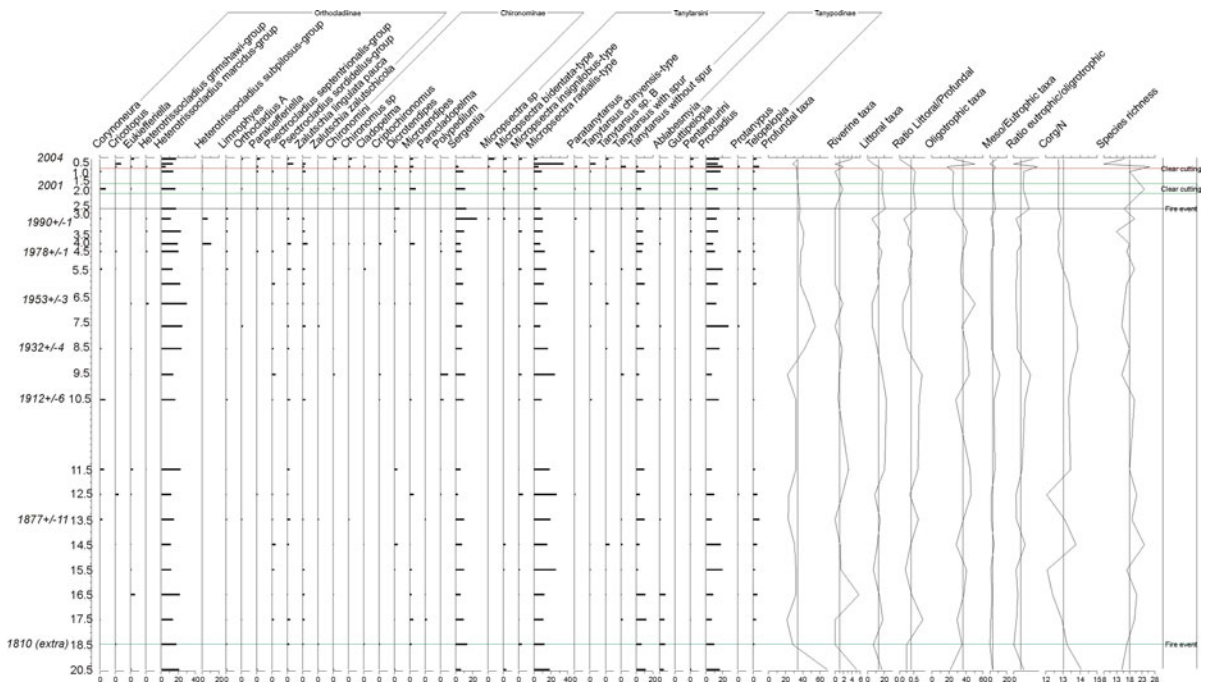
C/N, profundal, stream/terrestrial, littoral, ratios, oligotrophic, mesotrophic and eutrophic taxa are the average



**Fig. 5** Chironomid stratigraphy (in percentages) at Lac Maurice. Fire events are identified by “Fire” and logging events are identified by “Clear cutting”. The vertical lines in

C/N, profundal, stream/terrestrial, littoral, ratios, oligotrophic, mesotrophic and eutrophic taxa are the average





**Fig. 6** Chironomid stratigraphy (in percentages) at Lac Aux Huards. Fire events are identified by “Fire” and logging events are identified by “Clear cutting”. The vertical lines in C/N,

profundal, stream/terrestrial, littoral, ratios, oligotrophic, mesotrophic and eutrophic taxa are the average

MDS representation, all post-disturbance samples had short distances from pre-disturbance samples (Fig. 8). Since the ANOSIM analysis had a  $R = 0.22$ , the samples failed to show differences at the  $\alpha = 0.05$  level of significance. Samples following fire and logging were located in the same quadrant, indicating that logging and fire in Lac Chantale had similar impacts on the chironomid assemblages.

In Lac Maurice, all post-disturbance samples were located close to pre-disturbance samples in the PCA (Fig. 7), the chironomid assemblages following the fire event are slightly outside the range delimited by the pre-disturbance samples. Both samples associated with post-disturbance were located in the same quadrant, suggesting similar impacts of fire and cutting on chironomid assemblages. Interestingly, the MDS representation showed a larger distance between the pre-disturbance samples and the cutting event (Fig. 8). However, the ANOSIM analysis had an  $R = 0.37$  and failed to show differences at the  $\alpha = 0.05$  level of significance, suggesting similarity between pre- and post-disturbance samples.

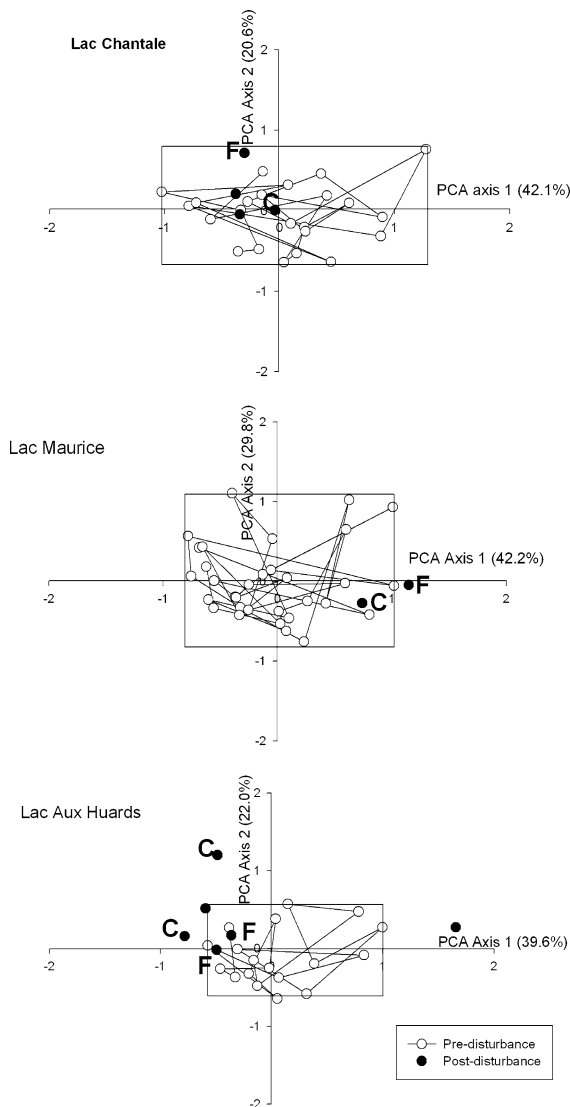
In Lac aux Huards, the post-disturbance samples associated with loggings were located outside the

range delimited by the pre-disturbance samples (Fig. 7). The MDS representation of samples indicated that the distance between the sample following the logging of 2000 AD and the other samples was large (Fig. 8). However, the ANOSIM analysis had an  $R = 0.33$  and failed to show differences at the  $\alpha = 0.05$  level of significance, which indicated similarity between pre- and post-disturbance samples. The post-disturbance samples were located in the same quadrant, suggesting similar impacts of both perturbations on chironomid assemblages. The sample approximately 2 years after the logging of 2000 AD also was located outside the range of pre-disturbance variability while the sample approximately. Four years after the clear cut was within the pre-disturbance variability.

### Discussion

#### Variability of chironomid assemblages through time

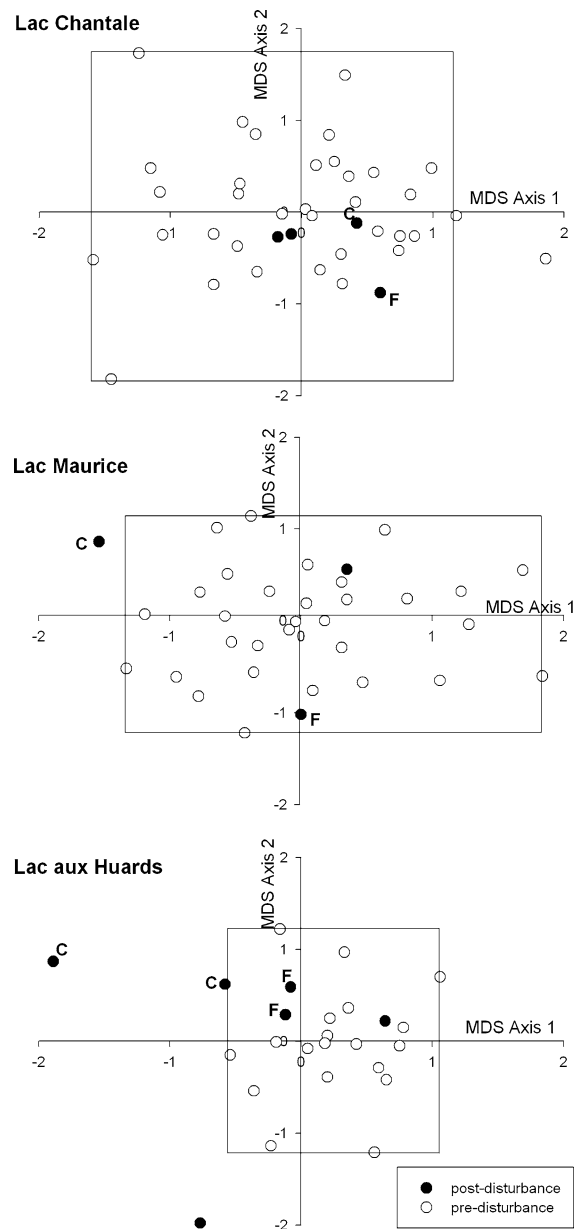
Chironomid assemblages were specific to each lake, indicating site specific differences in lakes



**Fig. 7** PCA analysis in the three study lakes. The *empty dots* are the samples pre-disturbance and the *black dots* represent the samples post-disturbance. **F** identified the sample which  $^{210}\text{Pb}$  date follows a fire event and **C** identified the samples which  $^{210}\text{Pb}$  date follows a logging event. The *box* represents the area delimited by the samples before perturbation, defined as the “pre-disturbance variability”

characteristics. For example, profundal taxa were more abundant in the deeper Lac aux Huards. This specificity in chironomid composition between sites illustrates the importance of studying impacts of perturbations within single lakes to limit confounding factors (Underwood 1992).

Specific changes in the chironomid assemblages of the three lakes occurred through time and these variations were not always linked to disturbances (i.e.



**Fig. 8** MDS representation of the samples separated into two groups: pre- and post disturbance. The *empty dots* are the samples pre-disturbance and the *black dots* represent the samples post-disturbance. The **F** identified the sample which  $^{210}\text{Pb}$  date followed a fire event and **C** identified the samples which  $^{210}\text{Pb}$  date followed a logging event. The *box* represents the area delimited by the samples before perturbation, defined as the “pre-disturbance variability”

logging and fire events). Chironomids have been shown to be influenced by various factors such as changes in sedimentary organic content (Larocque et al. 2001), lake depth (Korhola et al. 2000),

nutrients including total *P* (Lotter et al. 1998; Brooks et al. 2001; Larocque et al. 2009), limnetic chlorophyll-*a* (Brodersen and Lindegaard 1999), climate (Walker et al. 1997; Larocque et al. 2006) and macrophyte composition (Langdon et al. 2010). The stable ratios of eutrophic/oligotrophic taxa and C/N suggest that the lakes remained mostly oligotrophic and that terrestrial inputs did not vary through time. In Lac Chantale and Lac Maurice, taxa associated with macrophytes (*Corynoneura*, *Limnophyes*, *Zalutschia*, *Paratanytarsus*, *Cricotopus*, *Polypedilum*, *Chaetocladius*, *Dicrotendipes*, *Glyptotendipes*, *Lauterborniella*) (Brooks et al. 2007; Langdon et al. 2010) did not substantially change through time. With few changes recorded in the studied lakes, we can only conclude that the variations represent normal environmental variability over time and were not due to perturbations.

#### Disturbances and variability

In each of the three studied lakes, the chironomid assemblages following fire events were similar to those before perturbation, as shown both in the PCA and the ANOSIM analyses. Two logging events in Lac aux Huards had assemblages outside the pre-disturbance variability, as shown in the PCA analysis. However, ANOSIM showed that these samples were not significantly different from pre-disturbance samples. The distances between pre- and post-disturbance samples were relatively short in both PCA (axes ranging from  $-1.5$  to  $+1.5$ ) and MDS representations ( $-2.0$  to  $+2.0$ ) suggesting slight differences in taxa. The stratigraphic diagrams indicate that changes occurred mainly in abundances of taxa, not in assemblage composition.

Other studies have demonstrated non-responsiveness of organisms to fire and logging perturbation on long and short temporal scales. For example, Winkler et al. (2009) showed that 1 year after perturbation, pelagic phytoplankton biomass and zooplankton community structure were unaffected in lakes within our study area. In lakes located in the Cascade Range (Oregon, USA), no significant differences in density of phytoplankton, zooplankton nor amphibians were found 1 year after fire (Gresswell et al. 2003). Pinel-Alloul et al. (1998) and Patoine et al. (2002a, b) showed that fire and logging failed to have effect on zooplankton diversity, size spectra and assemblages

in lakes of eastern Quebec. Jalal et al. (2005) showed that zooplankton communities were very stable 3 years following wildfires and clear-cutting. In Finland, Rasanen et al. (2007) demonstrated only minor differences in diatom assemblages between lakes impacted and not impacted by logging. Laird and Cumming (2001) and Laird et al. (2001) showed that on a decadal scale, diatom assemblages in lakes of western Canada were unaffected by logging. In eastern Quebec, diatom assemblages showed little change following fires (Paterson et al. 2002; Philibert et al. 2003a, b) showed that changes lasted less than 5 years after fire occurrence.

To our knowledge, only Francis (2001) has looked at the effect of fire and logging on chironomid communities, and in that study, both perturbations demonstrated significant changes in the chironomid fauna. Substantial changes occurred in the watershed of that study, however, because the surrounding forest was clear-cut for agriculture purposes, and at least nine major fires occurred during the clear-cutting period between 1880 and 1923. In contrast, fire frequency was comparatively low in the watersheds of our study lakes, with an average of 1–2 fires for the last 200 years. Fire frequency, therefore, might explain some of the differences observed between our study and that of Francis (2001). Logging history in the watersheds of our lakes also is comparatively recent (1–2 periods of cutting in the 1990s–2000). Careful logging around advanced growth (CLAAG) is mainly used in this part of Quebec, leaving stems with diameters smaller than 10 cm and a buffer zone. Consequently, our study suggests that this logging approach and buffer zones seem to effectively protect lake ecosystems.

#### Conclusions

Our results differ from those of (Francis 2001), in which intensive fire and logging demonstrated observable impacts on chironomid assemblages. Our study failed to demonstrate significant differences between pre- and post-disturbance chironomid assemblages, indicating that fire and logging did not impact chironomid assemblages in our study lakes. This lack of impact on chironomid assemblages might be due to buffer zones and the selective nature of logging practices in the watersheds of our study.

Low fire frequency also might have limited long-term effects on the lake and watershed ecosystems, and thus on chironomid assemblages. We conclude, therefore, that the effects of fire and logging on lakes apparently are moderated by buffer zones, selective logging practices, and the frequency of fire over time.

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