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A palaeolimnological study of Tugulnuit Lake, British Columbia, Canada, with special emphasis on river influence as recorded by chironomids in the lake's sediment

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Abstract

Sediments from Tugulnuit Lake in the Okanagan Valley of British Columbia, Canada, were examined for chironomid assemblages. The chironomid stratigraphy obtained encompasses the last 4000 to 5000 years and suggests a warm and fairly stable climate typical for a temperate lake at low- to mid-elevation. This is indicated by the even distribution of warm-water taxa, such as *Cladopelma*, *Dicrotendipes*, *Polypedilum*, Pentaneurini, *Stempellina*, *Stempellinella/Zavrelia* and *Pseudochironomus* throughout the core. Very few cold-water taxa occurred in the sediments. However, stream inputs have had a major impact on Tugulnuit Lake. Sandy sediments and the appearance of Simuliidae and stream-inhabiting chironomid taxa (e.g., *Brillia/Euryhapsis*, *Eukiefferiella/Tvetenia*, *Rheocricotopus*) indicate that a stream intruded into the current lake's basin ca. 3800 yr Before Present (BP). Sediments deposited prior to, and after, the stream's intrusion show a distinctly different chironomid assemblage exhibiting chironomid taxa more typical for lentic habitats. This result indicates that chironomids can serve to detect past stream influences on lake environments. Thus, rheophilic chironomids preserved in lake cores provide a new alternative for reconstructing stream palaeoenvironmental records.

Introduction

The southern interior of British Columbia provides a mosaic of wildlife habitats, including one of Canada's most endangered ecosystems – the hot, dry shrub-grasslands of the southern Okanagan Valley. Although these grasslands constitute less than 0.1% of the province's land mass, this area provides habitat for nearly half the wildlife species at risk in British Columbia (Steeves, 1996). Few palaeoecological studies have been conducted in the region, despite its importance in terms of both provincial and national biodiversity; thus, little information is as yet available concerning the Holocene development of the endangered aquatic and terrestrial communities, nor past changes in climate.

Hebda (1995) reviewed palaeoecological evidence from throughout British Columbia, and concluded that

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southern British Columbia was warmer and drier during the early Holocene. The climate gradually changed as precipitation increased beginning ca. 7000 yr BP, and with the onset of cooler temperatures ca. 4000 yr BP. It is therefore likely that the endangered grassland habitats of the southern Okanagan Valley were formerly much more extensive, but have been greatly reduced by this natural climatic trend.

Palynological studies by Alley (1976) at the Kelowna Bog, by Cawker (1983) in the south Okanagan, and palaeolimnological studies on Mahoney and Kilpoola lakes (Heinrichs, 1995) provide additional insights regarding Holocene environmental changes in the valley, but the palaeoenvironmental record is still very poorly known, and many additional sites from British Columbia's southern interior are needed to strengthen our understanding of the region's pre-history. Furthermore, rapid urban and agricultural development threatens to eliminate much of the remaining shrub-grassland habitat.

In view of the importance of this endangered ecosystem, the Royal British Columbia Museum, in collaboration with other agencies, has begun a series of studies of the region's natural history as one component of its 'Living Landscapes' initiative. Tugulnuit Lake, situated in Oliver, British Columbia, was selected for study since it was likely to contain a long and interesting record of both aquatic and terrestrial environmental changes, in the midst of the formerly more extensive shrub-grassland ecosystem. In this paper we outline the palaeolimnology of Tugulnuit Lake, as revealed by analyses of chironomid remains preserved in the lake's sediments.

Study area

Tugulnuit (= Tuc-el-nuit) Lake (49° 12′N, 119° 32′W) is located in the town of Oliver, British Columbia, at an elevation of 325 m in the southern Okanagan Valley (Figures 1 & 2). Its surface area is 51 ha, the maximum depth is 7.9 m, and the mean depth is 5.7 m. The lake's morphometry is simple; the overall shape of the basin being very much reminiscent of a bathtub (Figure 3). The north and south shores gradually deepen towards the centre of the lake, whereas the east and west shores are much steeper.

The present form of the Okanagan Valley was created in the Pleistocene through intensive glacial erosion (Nasmith, 1962). During oscillating periods of climatic warming and cooling, the ice ages and interglacial periods, Cordilleran glaciers abraded the Thompson Plateau by successive ice advances and retreats (Kelley & Spilsbury, 1949; Clague, 1989). The tremendous ice sheets thus deepened the Okanagan Valley, up to 640 m below sea level in some areas, and also rounded the landscape. At the same time, the deepened valley was infilled with deposits of morainal till and other glacial deposits (Kelowna Geology Committee, 1995).

The 'filled' Okanagan Valley was modified only slightly after that. The system of the Okanagan River, which runs through the valley, has carved itself further into the terrain and has changed the landscape somewhat by depositing sediments. Also, eolian erosion and deposition has taken place to a minor degree.

The soils that occur in the Okanagan Valley today were all formed during the Holocene. The soil parent materials are of glacial and postglacial origin. Gravelly and sandy deposits of glacial meltwater streams or of postglacial river systems formed the soils on the valley bottom in the South Okanagan around the town of Oliver. There, Orthic Dark Brown or Orthic Brown Chernozem soils prevail. The soils on the valley slopes in this area originate from colluvial or morainal deposits, having developed into Orthic Dark Brown or Orthic Black Chernozems (Kelowna Geology Committee, 1995).

The area around Oliver is typical for the warm and dry Bunchgrass – Ponderosa Pine biogeoclimatic zone (Meidinger & Pojar, 1991). Ponderosa Pine can mainly be found on the valley slopes. Large cottonwoods probably dominated natural riparian areas adjacent to the Okanagan River prior to settlement by European immigrants. The natural open Bunchgrass and Sagebrush communities of the valley bottom, however, have been replaced in many areas by lush orchards maintained through irrigation.

Employment opportunities arising from the orchard industry attracted a large influx of people, mainly from the Canadian Prairies, during the drought and depression of the 1930s and also later after World War II (Kelley & Spilsbury, 1949). Thus, the settlement expanded rapidly. The population is still growing rapidly today, as people move to the area attracted by the very comfortable climate. Tugulnuit Lake is directly affected by the dense and growing population in the valley; the lake is closely surrounded by private homes, a campground and beaches. Also, it supplies water for irrigation and domestic use and it is used for recreational purposes. The lakes in the Okanagan Valley are one major reason for the flourishing tourism industry.

Figure 1. Location of study site in British Columbia, Canada.

Tugulnuit Lake receives inflow from underground aquifers and the outflow runs into a gravity fed pipe which leads through a dike into the Okanagan River (Haddrell, pers. comm.). The pipe, which contains a valve to prevent backward flow, also offers flood control for Tugulnuit Lake. Floods naturally occurred quite often in the Okanagan Valley, with the Okanagan River leaving its bed and overflowing into its floodplain. Major floods occurred for example in 1942 and 1948. The latter flood transported large amounts of mud into Tugulnuit Lake. The flood hazard was mitigated through the construction of extensive dikes and river channelization during the 1950s.

Methods

Coring methods & radiocarbon dating

A 14.53-m-long core was taken near the deepest part of the lake in August 1995 using a modified Livingstone piston corer (Wright, 1967). The core was extruded immediately at the lake, photographed and sectioned in 5 cm intervals. All intervals were stored in plastic bags at 4 °C at Okanagan University College.

Sediment subsamples of selected intervals of the Tugulnuit Lake core were screened for organic materials (principally plant remains). Organic material from the 840–845 cm, 955–960 cm and 1165–1170 cm intervals was submitted to Beta Analytic Inc., Miami, Florida for AMS radiocarbon dating.

Laboratory methods

Chironomid head capsules were extracted from the samples using the methods described by Walker (1987). Samples were deflocculated in hot 10% KOH for 20 minutes, then carefully washed with distilled water on a 95 μm mesh. In calcareous sediments, an acid wash with 10% HCl was additionally applied to the samples in order to remove carbonates. The material retained on the sieve was backwashed into a beaker.

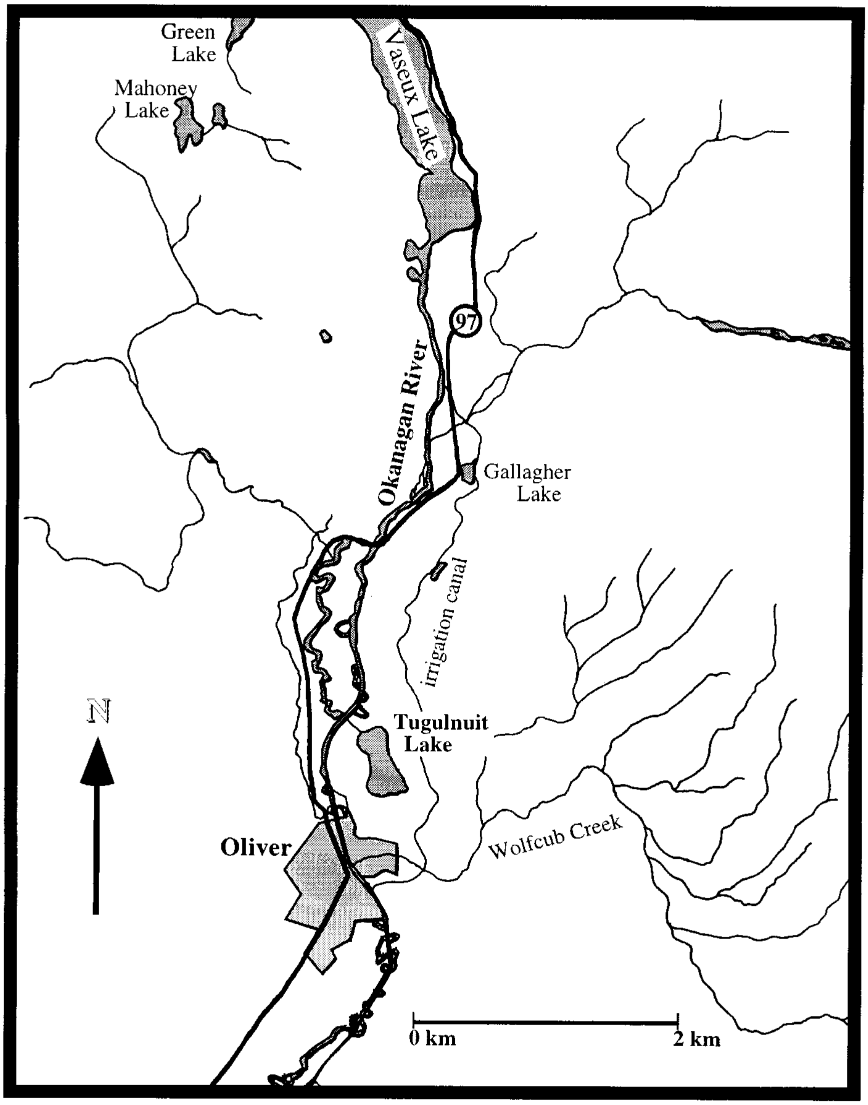

Figure 2. Map showing location of Tugulnuit Lake in the southern Okanagan Valley, British Columbia, Canada.

From the beaker, Bogorov counting trays were filled and chironomid head capsules were picked under an Olympus zoom stereo dissecting microscope at magnifications of 25 to 50 ×. The head capsules were transferred onto 10 mm round coverslips and, when dry, mounted onto slides using Entellan® mounting medium. Simuliid mouthparts, Ephemeroptera mandibles, *Chaoborus* mandibles and ceratopogonid head capsules were picked in addition to the chironomid head capsules. For chironomid identification, an Olympus model BX50 compound microscope was used. Identifications, mostly to the generic level, were done principally with the help of taxonomic keys and descriptions by Walker (1988), Wiederholm (1983) and Oliver & Roussel (1983). As Kowalyk (1985) has shown, well-preserved head capsules of the Pentaneurini can often be identified to the generic level. However, we did not feel that we could make these determinations with sufficient consistency as to be useful in our material.

To ensure that the chironomid percentages were representative of the chironomid assemblage at each interval, a minimum sample size of 50 identifiable head capsules was counted. Thus, the volume of sediment examined at each level varied from 1 ml to 63 ml,

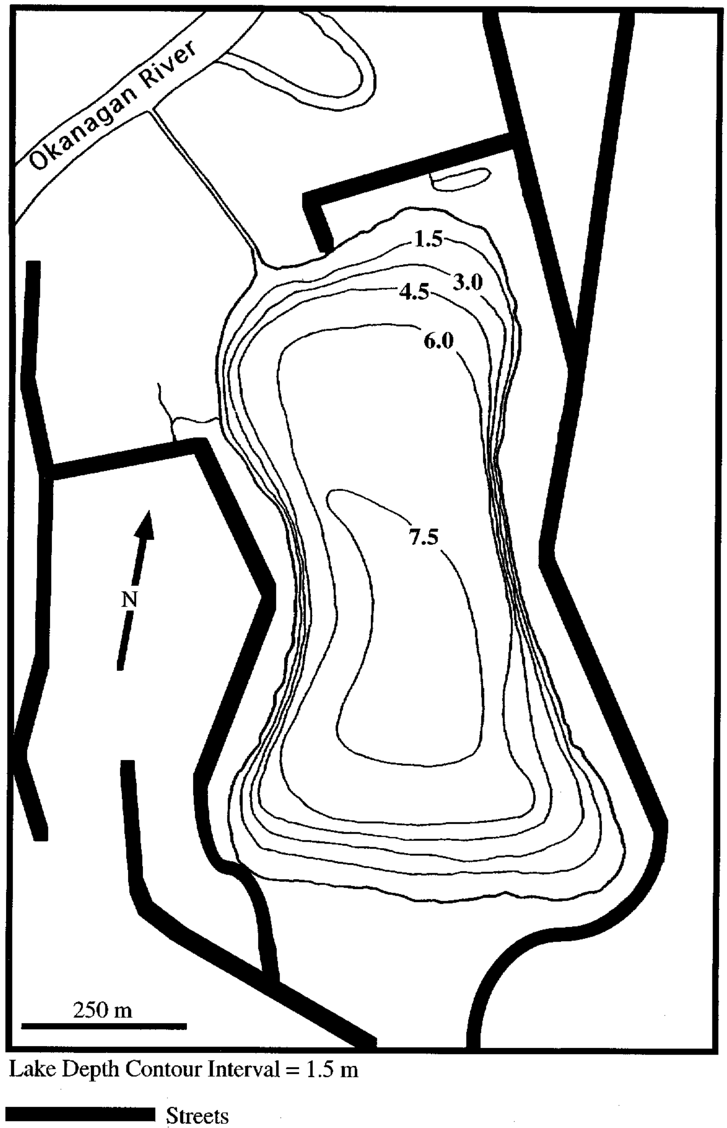

Figure 3. Bathymetric map of Tugulnuit Lake, Oliver, British Columbia. Also shown are adjacent roads and the connection of the lake to the Okanagan River.

depending on the head capsule concentration. To avoid multiple counts of the head capsules, exact halves were counted as halves, fragments bearing more than half of the mentum were counted as one head capsule, and fragments bearing less than a half mentum were not counted.

Data analysis

Chironomid data were processed and analysed using TILIA version 1.12, and chironomid stratigraphy diagrams were created with TILIA-GRAPH version 1.18. In order to detect zones of similar chironomid assemblages within the sediment core, stratigraphically constrained cluster analysis was performed using the program CONISS. The program CA provided means for indirect ordination via Correspondence Analysis (CA) and Detrended Correspondence Analysis (DCA).

All of the computer programs used are available with the TILIA package developed by Dr Eric Grimm.

Table 1. Lithology of Tugulnuit Lake sediments

Depth (cm)	Sediment description	Depth (cm)	Sediment description
10–150	grey to tan calcareous gyttja	890–910	medium to dark grey silt
150–160	reddish discoloration of calcareous gyttja	910–955	medium to dark grey silty sand
160–210	grey to tan calcareous gyttja	955–965	dark grey fine sand
210–310	tan calcareous gyttja with grey mottled zones	965–975	watery sand (contamination?)
310–355	tan calcareous gyttja	975–990	medium dark grey fine sand
355–370	reddish discoloration of calcareous gyttja	990–995	medium grey clay
370–385	contaminated sample	995–1025	medium grey gyttjaish silty clay
385–395	grey clay	1025–1035	medium grey fine sand
395–425	tan calcareous gyttja	1035–1050	grey clay
425–470	grey clayey gyttja	1050–1100	dark grey silty gyttja (contamination?)
470–475	grey clayey gyttja with tan calcareous gyttja mottling	1100–1105	dark grey medium fine sand
475–486	grey clay	1105–1115	dark grey silty gyttja
486–495	tan calcareous gyttja	1115–1125	contaminated sample
495–500	contaminated sample	1125–1130	medium grey silt
500–542	grey to brown mottled clayey gyttja	1130–1155	medium grey silty fine sand
542–580	dense medium brown silty gyttja	1155–1165	grey silty clay
580–604	grey to light brown silty gyttja	1165–1205	medium grey silty fine sand
604–605	blackish silty gyttja	1205–1225	medium grey silt
605–672	tan silty gyttja	1225–1255	medium grey silty sand
672–673	grey clay	1255–1265	medium grey silty clay
673–680	tan silty gyttja	1265–1270	light grey clay
680–714	mottled grey and medium brown clayey gyttja	1270–1280	contaminated sample
714–717	grey clay	1280–1305	light grey clay
717–739	clayey gyttja	1305–1320	tan silt
739–750	grey clay	1320–1330	light brown silt
750–805	grey to brown silty gyttja	1330–1345	light grey silty clay
805–810	grey clayey gyttja with brown mottling	1345–1357	brown silt
810–835	medium grey clay	1357–1370	contaminated sample
835–850	medium grey sand	1370–1375	brown silt
850–863	grey clay	1375–1380	brown silt with thin laminations
863	organic debris	1380–1390	brown silt with grey clay crusts
863–880	grey clayey sand	1390–1405	light grey silt
880–890	grey clay muck (contamination?)	1405–1415	brown silt with possible charcoal
		1415–1452.5	brown silt

Results

Core description

The upper 540 cm of the core (Table 1) consisted mainly of grey to tan calcareous gyttja with two zones of reddish discoloration (150–160 cm and 355–370 cm) and a few layers of grey clay. Brown to grey silty gyttja prevailed from 540 to 680 cm, including one narrow layer of grey clay. Grey to brown clayey and silty gyttja were found from 680 to 835 cm, again including layers of grey clay. The zone from 835 to 1305 cm was dominated by medium to dark grey, fine sand or silty sand; however, medium to light grey clay layers and one layer of organic debris, at 863 cm, were interspersed within these sediments. The lowermost section of the core, from 1305 to 1452.5 cm, was composed of brown to light grey silt, including one layer of grey clay crusts. A more thorough description of the sediments is provided in Table 1.

Although a sub-bottom profile was also obtained, the results did not provide a clear representation of layering within the sediments (Rück, 1996).

Radiocarbon dating

The two intervals of 840–845 cm and 955–960 cm were surprisingly both dated to the same time frame of 3780 ± 50 yrs BP (δ^{13}C corrected dates). The 1165–1170 cm interval was measured to have been deposited 3860 ± 50 yrs BP (δ^{13}C corrected date). This result suggests a very high sediment accumulation rate in the lake at that time. If constant sediment accumulation rates can be assumed for the rest of the core, the bottom-most sediments in the core can be estimated to be about 4000 to 5000 years old. Since the Mazama Ash, a volcanic tephra, was not evident, the bottom-most sediments may not be older than 6800 ^{14}C yr BP.

Chironomid stratigraphy

Three distinct zones in the chironomid stratigraphy were identified by means of stratigraphically constrained cluster analysis (Figure 4).

In zone TUG-I (from 1453 cm to 1295 cm) Chironominae constitute on the average 79%, and Orthocladiinae 15%, of the total identifiable chironomids. This zone is dominated by the subtribe Tanytarsina, *Chironomus* and *Cricotopus/Orthocladius*. Tanytarsina and *Cricotopus/Orthocladius* are very common taxa, incorporating several genera whose representatives occur in lentic habitats, as well as slower reaches of lotic environments (Oliver & Roussel, 1983; Walker, 1988). *Chironomus* species have the same preferences. *Pseudochironomus* and *Dicrotendipes* each constitute, on average, 6% of the total identifiable chironomid fauna. They are both typical of warm littoral areas of standing water, but more rarely they do occur in slower flowing areas of running water (Oliver & Roussel,1983). The same generally applies to *Procladius*, which accounts for about 5% of the total identifiable chironomid fauna.

Zone TUG-II (from 1295 cm to 860 cm) is characterized by a pronounced increase in mostly stream-inhabiting Orthocladiinae, to an average of 52% of the total. The occurrence of Chironominae declines to 39%. The appearance of *Brillia/Euryhapsis*, *Eukiefferiella/Tvetenia*, *Parametriocnemus* and *Rheocricotopus* is striking. *Doithrix/Pseudorthocladius* is also present, and *Corynoneura/Thienemanniella* is abundant. These taxa are often abundant in streams. Their remains are generally rare in lake sediments, except for those lakes that are strongly influenced by inflowing streams (Walker, 1988). Two Chironominae genera, *Paralauterborniella* and *Robackia*, were only present in this zone. *Paralauterborniella* appears to be associated with mineral substrates in lakes of coastal British Columbia (Walker, 1988; Walker & Mathewes, 1989). *Robackia* is associated with sandy substrates in lotic habitats. Tanytarsina-*Micropsectra* type is also associated more with cooler and oligotrophic conditions. At the same time there was a pronounced decline in those taxa that are more typical for lentic habitats; the most important of these are Tanytarsina, *Chironomus*, *Dicrotendipes*, *Einfeldia/Glyptotendipes* and *Pseudochironomus*. This zone is also marked by the appearance of simuliid (black fly) larvae. Simuliidae, with very few exceptions, are confined to lotic habitats (Currie & Walker, 1992).

In zone TUG-III (from 860 cm to 0 cm) the chironomid assemblage returns to a state similar to that evident in zone TUG-I. Chironominae again dominate the fauna, increasing to an average of 81% of the total fauna. The average occurrence of Orthocladiinae drops to 11%. Tanytarsina and *Chironomus* dominate the fauna in this zone, whereas the abundance of *Cricotopus/Orthocladius* declines. The stream-inhabiting Orthocladiinae and the simuliids disappear. The same is true for *Paralauterborniella* and *Robackia*. The closely stream associated *Doithrix/Pseudorthocladius* and *Corynoneura/Thienemanniella* are distinctly less abundant. Tanytarsina-*Micropsectra* type also declines. Chironominae more typical for lentic habitats and slower moving areas of lotic habitats, like *Chironomus*, *Dicrotendipes*, *Endochironomus* and *Einfeldia/Glyptotendipes*, are common in this zone.

Detrended Correspondence Analysis (DCA)

The results of the Detrended Correspondence Analysis (Figures 5 & 6) parallel the results of the cluster analysis.

In the taxon plot (Figure 5), the stream-associated taxa form a distinct group very clearly evident at the higher end of axis 1; the lake-associated taxa occupy the lower end of this axis. Therefore, axis 1 can be interpreted as a variable pertaining to stream influence. The arrangement of taxa along axis 2 does not appear to reflect known differences in chironomid ecological ‘preferences’. Thus, we have been unable to associate axis 2 with a specific environmental variable. The lake taxa show a higher variation in scores on this axis than do the stream taxa.

The DCA sample scores for axis 1 and 2 are presented as depth plots (Figure 6). There is little variation

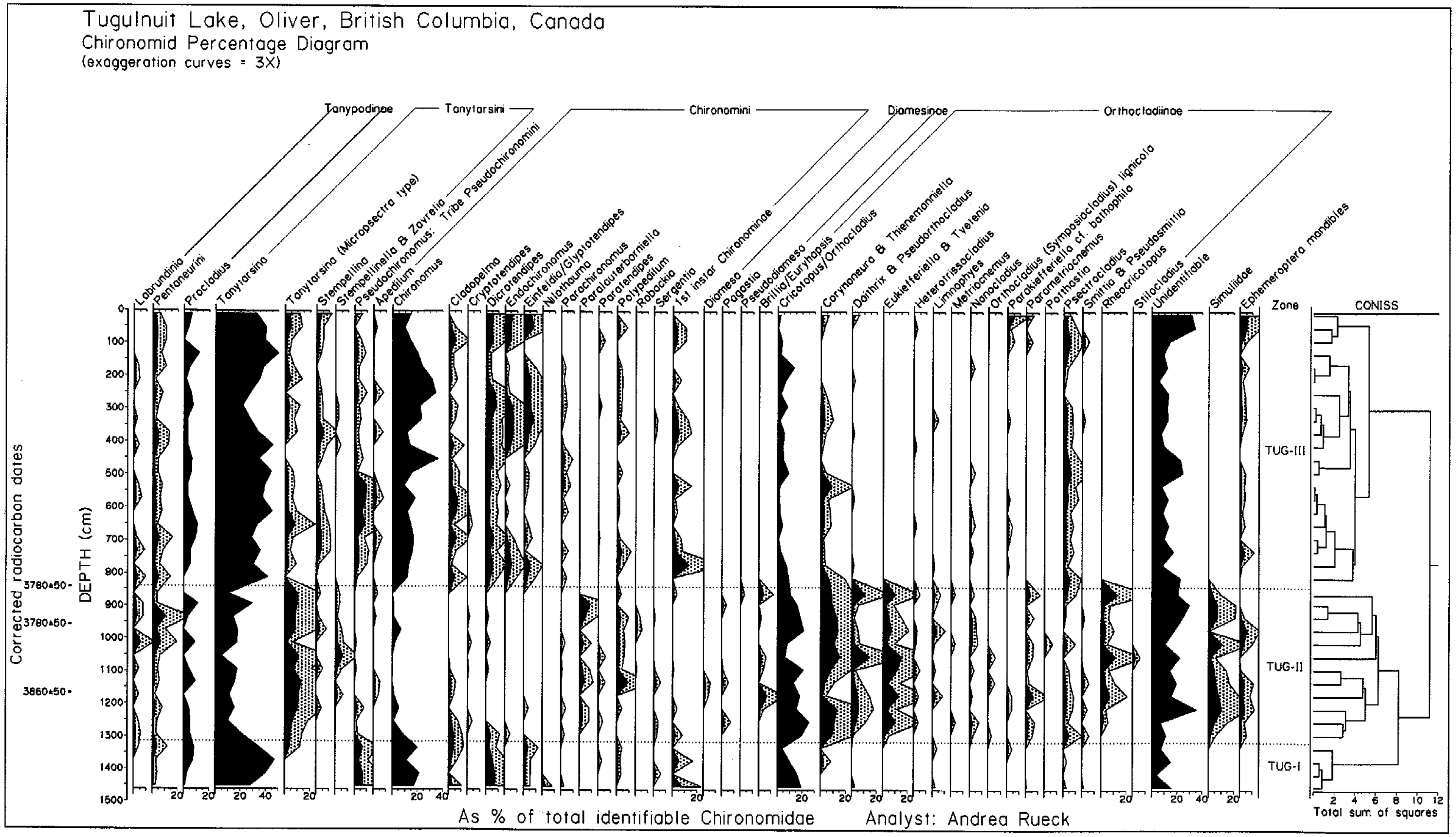

Figure 4. Chironomid stratigraphy, including stratigraphically constrained cluster analysis and radiocarbon dates, for Tugulnuit Lake, British Columbia. Abundances of fossils are expressed as percentages of total identifiable Chironomidae. Rare taxa have been excluded. The complete stratigraphic record (providing data on all taxa) is included in Rück (1996). The raw data has also been archived at the World Data Centre of the US National Oceanographic and Atmospheric Administration's (NOAA) Paleoclimatology Program (http://www.ngdc.noaa.gov/paleo/paleo.html).

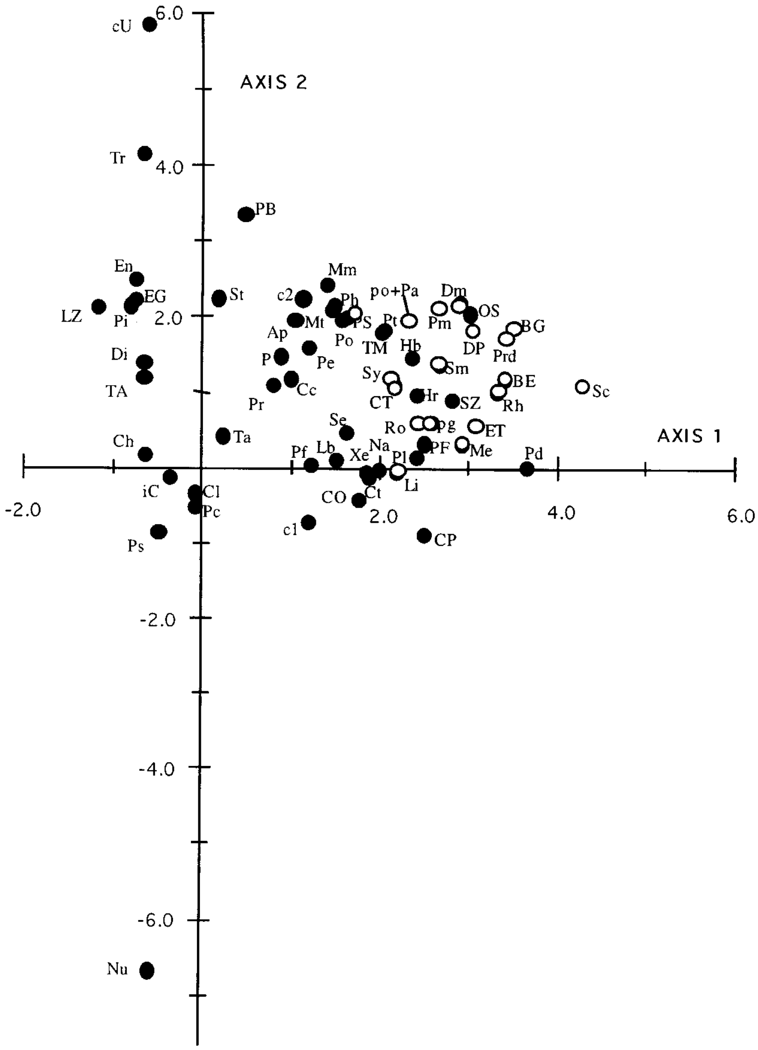

Figure 5. Ordination of midge taxa from detrended correspondence analysis (DCA) of the stratigraphic data. Open circles indicate those taxa that tend to be associated with streams. Abbreviations for taxa: Ap – *Apedilum*; BE – *Brillia/Euryhapsis*; BG – *Bryophaenocladius/Georthocladius* type; Cc – *Cryptochironomus*; Ch – *Chironomus*; Cl – *Cladopelma*; CO – *Cricotopus/Orthocladius*; CP – *Cyphomella/Harnischia/Paracladopelma* type; CT – *Corynoneura/Thienemanniella*; Ct – *Cryptotendipes*; cU – *Chaoborus* (undifferentiated); c1 – Ceratopogonidae (*Bezzia* type); c2 – Ceratopogonidae (*Dasyhelea* type); Di – *Dicrotendipes*; Dm – *Diamesa*; DP – *Doithrix/Pseudorthocladius* type; EG – *Einfeldia/Glyptotendipes* type; En – *Endochironomus*; ET – *Eukiefferiella/Tvetenia*; Hb – *Hydrobaenus*; Hr – *Heterotrissocladius*; iC – 1st instar Chironominae; Lb – *Labrundinia*; Li – *Limnophyes*; LZ – *Lauterborniella/Zavreliella*; Me – *Metriocnemus*; Mm – Ephemeroptera mandibles; Mt – *Microtendipes*; Na – *Nanocladius*; Nu – *Nilothauma*; OS – *Orthocladius* (*Symposiocladius*) *lignicola*; P – *Psectrocladius*; Pa – *Pagastiella*; PB – *Parakiefferiella* cf. *bathophila*; Pc – *Parachironomus*; Pd – *Pseudodiamesa*; Pe – Tribe Pentaneurini; PF – *Phaenopsectra* cf. *flavipes*; Pf – *Polypedilum fallax* group; pg – *Pagastia*; Ph – *Phaenopsectra* (undifferentiated); Pi – *Phaenopsectra* type *dyari*; Pl – *Paralauterborniella*; Pm – *Parametriocnemus*; Po – *Polypedilum*; po – *Potthastia*; Pr – *Procladius*; Prd –*Prodiamesa*; Ps – *Pseudochironomus*; PS – *Smittia/Pseudosmittia* group; Pt – *Paratendipes*; Rh – *Rheocricotopus*; Ro – *Robackia*; Sc – *Stilocladius*; Se – *Sergentia*; Sm – Simuliidae; St – *Stempellina*; Sy – *Synorthocladius*; SZ – *Stempellinella/Zavrelia*; TA – Tanytarsini sp. A; Ta – Tanytarsina; TM – Tanytarsina–*Micropsectra* type; Tr – *Tribelos*; Xe – *Xenochironomus*.

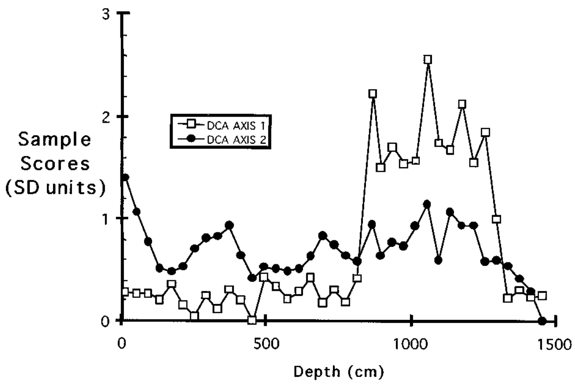

Figure 6. Plot of sample scores on the first two DCA axes versus sediment depth.

in the axis 1 sample scores from the surface of the core down to 852.5 cm and again from 1332.5 to 1452.5 cm. The sample scores in the 852.5 to 1332.5 cm interval are much larger. This result indicates a very strong stream influence at this depth in the core. The sample scores within the zone of stream influence appear to be much more variable than elsewhere in the core.

Axis 2 shows much less variation than axis 1. The chironomid assemblages fluctuate continuously in a narrow range of approximately 0.5 standard deviation units on axis 2. The uppermost samples (from 12.5 to 55.5 cm depth) have the highest sample scores, and the lowermost samples (from 1372.5 to 1452.5 cm depth) have the lowest sample scores. Unfortunately, axis 2 could not be interpreted in terms of a specific environmental variable.

Rare taxa identified in the core

Robackia, a chironomid genus that has never been recorded for any freshwater habitat in British Columbia, was recorded in the core. It occurred in the depth levels of 930–935, 970–975 and 1090–1095 cm, all being part of zone TUG-II. *Robackia* can typically be found in sandy substrates of rivers. As a member of the tribe Chironomini (subfamily Chironominae), *Robackia* has fan-shaped ventromental plates. Their ventromental plates are very coarsely striated and have irregular, drop-like anterior margins; thus they are very distinctive and provide excellent means for identification. The narrow mentum bears one pair of median teeth and five or six pairs of lateral teeth. *Robackia* has been found to occur in Canada only from Alberta and the Yukon Territory, and east to Ontario (Oliver & Roussel, 1983). Its occurrence in British Columbia has not previously been noted.

Apedilum, another representative of the Chironomini, has also not yet been recorded for British Columbia. We have, however, found this taxon recently in lakes of the Cariboo-Chilcotin region of British Columbia.

Paratendipes, *Nilothauma*, *Stempellina* and *Stempellinella/Zavrelia* do not appear as present-day taxa in the 'Catalog of Nearctic Chironomidae' (Oliver & Dillon, 1990) for British Columbia, but have been found in surface sediment samples in this province. Thus, they may be more widespread and are perhaps still common today, but more sampling is needed.

Discussion

As stated in the introduction, the original impetus for this study was to obtain a better understanding of postglacial environmental changes in the Okanagan Valley. Since the sediment core only spans the last 4000 to 5000 years, unfortunately no complete postglacial climatic record could be obtained. The climate, as indicated by the chironomid assemblages, seems typical for a temperate lake at low to mid elevation. Taxa typical for low to mid elevation sites, which are usually absent in colder lakes of higher latitude or elevation, like *Cladopelma*, *Dicrotendipes*, *Polypedilum*, Pentaneurini, *Stempellina*, *Stempellinella/Zavrelia* and *Pseudochironomus* (Walker & Mathewes, 1989), occur throughout the core and indicate relatively warm temperatures. Their even distribution in zone TUG-I and TUG-III suggests a fairly stable climate without major fluctuations. *Chironomus* and *Psectrocladius* do occur in a certain percentage in colder lakes, but are much more common in temperate lakes (Walker & Mathewes, 1989). These taxa are fairly abundant in the lacustrine sediments of Tugulnuit Lake.

In temperate lakes, usually the Chironomini (excluding *Sergentia*, *Stictochironomus* and *Chironomus*), Pentaneurini, *Pseudochironomus*, *Stempellina* and *Stempellinella* together compose about 25 to 30% of the chironomid fauna (Walker & Mathewes, 1989; Walker et al., 1991; Walker et al., 1997). These taxa constitute a temperate littoral element of the fauna, which is rare or entirely absent in arctic or alpine lakes (Walker & Mathewes, 1989; Walker et al., 1991). In zone TUG-I and TUG-III, these taxa make up from 10% to 39% of the fauna, which provides a fairly good indication of a warm climate. In zone TUG-II, they only reach between 6% and 25%, but Tugulnuit Lake seems to have been strongly influenced by a stream at that time.

In the entire sediment core, there are very few cold-water taxa, and they have a scattered distribution throughout the core. *Heterotrissocladius* does occur, however, mostly in zone TUG-II. This again indicates a more highly oxygenated and cooler stream environment. *Pseudodiamesa* appears once in the core, also in zone TUG-II. None of the other late-glacial cold-stenothermous taxa, like *Parakiefferiella nigra*, *Paracladius*, *Protanypus* or *Stictochironomus* (Walker & Mathewes, 1989), could be found. Tanytarsina-*Micropsectra* type, indicating cooler and more highly-oxygenated conditions, also increases in abundance in zone TUG-II. This chironomid evidence, therefore, suggests a warm, stable climate in the area around Oliver since 4000 to 5000 years BP. The water temperatures of Tugulnuit Lake appear to have dropped with the hypothesized stream connection at about 3700 to 4000 BP, but have risen again after lake conditions were re-established.

As indicated in the preceding paragraphs, the results obtained indicate that one major determinant of chironomid distribution within the Tugulnuit Lake core was stream influence. This result was unexpected, but it suggests that chironomids can serve to detect past stream influences on lake environments, such as the occurrence of past floods. Three chironomid zones could be identified in the Tugulnuit Lake core by means of cluster analysis and Detrended Correspondence Analysis. Zone TUG-I and zone TUG-III exhibit similar chironomid assemblages, whereas zone TUG-II shows a distinctly different assemblage, which is shown in the chironomid stratigraphy (Figure 4) and by axis 1 of the DCA depth plot (Figure 6). We interpret zone TUG-II as a zone of pronounced stream influence. This interpretation is strongly supported (1) by the occurrence of Orthocladiinae taxa which are either obligate stream-inhabitants or closely associated with streams, including *Brillia/Euryhapsis*, *Corynoneura/Thienemaniella*, *Doithrix/Pseudorthocladius*, *Eukiefferiella/Tvetenia*, *Parametriocnemus* and *Rheocricotopus*, (2) by the appearance of simuliids, and (3) by the sandy sediment in this zone. The Chironominae taxa *Robackia*, *Paralauterborniella* and *Cryptotendipes* are typical representatives of the fluvially-derived sediment in zone TUG-II. *Robackia*, which only occurs in zone TUG-II in the core, is generally associated with sandy substrates in large rivers (Oliver & Roussel, 1983). *Paralauterborniella* and *Cryptotendipes* are both associated with mineral substrates (Walker, 1988; Walker & Mathewes, 1989). *Paralauterborniella* only appears in zone TUG-II, and *Cryptotendipes* has its main occurrence in zone TUG-II. An additional indicator for lotic environments in zone TUG-II is the increase in Tanytarsina-*Micropsectra* type, indicating cooler and more oxygenated conditions, such as those existing in many stream environments. Preliminary examination of pollen samples from lower levels of TUG-II reveals an abundance of fungal hyphae, corroded and crumpled pollen grains, and occasional moss leaf fragments supporting the interpretation of a stream environment-derived sediment.

Zone TUG-I and zone TUG-III incorporate chironomid taxa more typical for lentic habitats or slower reaches of lotic environments. The taxon plot of the DCA (Figure 5) also separates the chironomid taxa very clearly into the types occurring in zone TUG-II, which are the stream types, and taxa occurring more in zones TUG-I and TUG-III, which are the lake types. The TUG-II types occupy the higher (positive) end of axis 1 in this plot and the TUG-I and TUG-III types occupy the lower (negative) end. This indicates that stream influence is the major environmental variable to have affected chironomid distribution in this core.

All of the AMS-^{14}C dates obtained lie within the chironomid zone TUG-II and span a depth range of 325 cm. These dates however only span an age range of 80 years, suggesting very rapid accumulation of the fluvial sediment in Tugulnuit Lake. Possibly, all of the fluvially-derived sediment entered the lake within only a hundred years.

A connection of Tugulnuit Lake to a nearby river must have existed about 3700 to 4000 years BP. From aerial photographs it can be seen that Tugulnuit Lake today is located near the Okanagan River. Therefore, a change in the river course or a flooding event in the Okanagan River might have been responsible for deposition of the fluvially-derived sediments. Aerial photographs show an abandoned, infilled river channel within approximately 100 metres of the present lake. Another possible explanation is a past connection of Tugulnuit Lake to Wolfcub Creek. Nasmith (1962) suggested that Wolfcub Creek was responsible for creating Tugulnuit Lake by depositing a fan which blocked one channel of the late-glacial Okanagan River. According to Nasmith, Tugulnuit Lake has been occupying this blocked segment of the channel. The Okanagan River was then diverted to its present channel. Though Nasmith's explanation is plausible for late-glacial times, it may be less likely for 4000 years ago, because of the need for a significant amount of sediment to block an active channel and form the lake.

The sediment of zone TUG-II at our coring site is relatively coarse and consists largely of sand. Since sand settles out rapidly in calm water, it is unlikely that this sand and its chironomids could have been transported over a great distance into the deep waters of ancient Tugulnuit Lake. We hypothesize that a stream/riverine environment must have occurred at, or very near the site at the time of deposition of TUG-II. A direct connection with the Okanagan River appears to be the most probable explanation. The question then arises whether this thick, layer of rapidly deposited sediment accumulated directly into a deep water basin during an interval of dramatic flooding, or whether the base level of the Okanagan River was near the elevation of the stream deposit. The second explanation would require an aggradation of the Okanagan River floodplain in the order of 14 to 19 m between 4000 years ago and the present.

The considerable volume of sediment required for either explanation must be derived from sources below Vaseux Lake only a few kilometres to the north. Today Vaseux Lake traps all sediment being transported through the Okanagan Valley north of the study area. Consequently, sediment must have been derived from erosion by the Okanagan River into glacial deposits flanking the valley, or by small tributary streams of which there are few. There is a clear need to understand the geomorphic history of this part of the valley, whatever the explanation. Notably, the 4000 to 3700 B.P. horizon is one of major climatic change in British Columbia, including cooling, and possibly increased precipitation, which both may be associated with glacial re-advances (Hebda, 1995).

Few palaeolimnological studies have considered stream deposits. Usually emphasis is placed on lake sediments, since erosion and redeposition by meandering river activity usually destroys much of the stream sediment record. Walker & Mathewes (1987) discovered rheophilic chironomid taxa in the sediments of Marion Lake, British Columbia. Those taxa, however, occurred throughout the core and were derived from a stream presently feeding the lake; no pronounced shifts in the relative abundance of lake taxa relative to stream taxa occurred, nor were the stream taxa associated with stream sediments.

Klink (1989) initiated palaeoecological river analysis with his study on the Lower Rhine River in the Netherlands. His innovative strategy was to examine sediments of abandoned river channels of the Rhine, dating the time of abandonment by means of historical records, and thus, determining the fauna of the Rhine at the particular time of abandonment of the various river channels. By doing so, he could detect changes in the past river fauna, probably caused by the recent pollution of the Rhine (Klink, 1989). Except for these two studies, not much attention has been paid to rheophilic chironomids for palaeoenvironmental work. Examining river sediments that are embedded in lake sediments therefore offers a new alternative for obtaining stream palaeoenvironmental records.

Human impacts on the lake environment since European settlement, unfortunately, could not be examined at Tugulnuit Lake. The 1452.5-cm-long core was subsampled in fairly large intervals, every 40 cm, to obtain a representative stratigraphy of the complete core. However, 40 cm of sediment represents about 200 years in this core, which is a much too coarse resolution to detect changes in the last approximately 130 years of European settlement.

The appearance of *Robackia* in the Tugulnuit Lake core was surprising as this taxon has never been recorded for British Columbia. No studies exist about its present occurrence in this province. The preferred habitats of *Robackia*, large warm rivers with sandy sediments, are potentially endangered in British Columbia. Only a few large warm rivers exist. Most of the flowing water in British Columbia runs in smaller, rapid streams, and most of the few existing larger bodies of flowing water have been channelized or their free flow is restricted by dams, so that not much natural sandy bottom substrate is preserved. With the destruction of this habitat *Robackia*, and possibly more taxa with similar requirements, could become endangered.

Does *Robackia* still occur in British Columbia at the present time? More studies are needed to clarify this in order to work on preserving the remaining natural large, sandy-bottomed riverine environments as habitats for such species.

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