Late-Quaternary history of midge communities and climate from a tundra site near the lower Lena River, Northeast Siberia

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Abstract

Analysis of midge remains in late-Quaternary sediment, recovered from a lake situated north of treeline in northeast Siberia, indicates the occurrence of notable climatic fluctuations during the last 12 ka. The onset of late-glacial warming was disrupted by a marked cooling event – possibly correlative with the Younger Dryas – that occurred between 11,000 and 10,000 yrs BP. Increases in the relative abundance of taxa typically found in tundra lakes, such as *Hydrobaenus/Oliveridia* and *Parakiefferiella nigra*, and the concurrent decrease in temperate taxa, such as *Microtendipes* and *Corynocera ambigua*, suggest climatic deterioration occurred during this interval. At approximately 10,000 yrs BP there was a large increase in temperate taxa such as *Microtendipes* and *C. ambigua*, and a decline of essentially all cold-water taxa. This suggests that climate was warmer than present since the modern distribution of both *Microtendipes* and *C. ambigua* is limited to forested sites in this region. This warm interval lasted until approximately 6000 yrs BP when there was a precipitous decline in temperate chironomid taxa and an increase in cold-water chironomid taxa, such as *Paracladius*, *Hydrobaenus/Oliveridia*, *Abiskomyia*, and *Parakiefferiella nigra.* This cooling continued through the late-Holocene and the modern tundra chironomid assemblage developed by approximately 1400 yrs BP.

Introduction

Chironomids are cosmopolitan insects and are frequently the most abundant insect found in freshwater ecosystems (Cranston, 1995). Third and fourth instar chironomid larvae possess a chitinized head capsule that is resistant to decomposition. Consequently, fossilized chironomid head capsules tend to be well preserved in lake sediment and are easily identified (Iovino, 1975; Walker, 1987). Adult midges are mobile and have relatively short life cycles. These two characteristics enable chironomids to respond to climate change very quickly and, as a result, they are likely to have distributions in equilibrium with climate (Walker, 1987; Wilson et al., 1993; Smol et al., 1995; Walker & Mac-

Donald, 1995). The ecology of chironomids and their use in paleoecology is reviewed in Walker (1987) and Armitage et al. (1995).

The effect of climate on the distribution of organisms is especially pronounced at ecotonal boundaries. Circumpolar treeline is an especially sensitive ecotone, typified by sharp northward gradients of decreasing summer temperature and precipitation (Bryson, 1966). Bryson (1966) and Krebs and Barry (1970) recognized that a strong correlation exists between the position of circumpolar treeline and the mean July position of the Arctic Front (AF). Tundra areas to the north of treeline are dominated by cold, dry air masses during the summer, whereas forested regions south of treeline are influenced by warmer, moister air masses. The location

of circumpolar treeline can serve as an indicator of the mean summer position of the AF (Bryson, 1966), and by tracking the past movement of circumpolar treeline paleoecologists may be able to determine how climate has changed (MacDonald et al., 1993). The position of circumpolar treeline and the areal extent of boreal forest will be greatly affected by global warming, and changes in the position of circumpolar treeline may, through biospheric feedback mechanisms, further impact global climate (Rizzo & Wiken, 1992; Foley et al., 1994; Velichko et al., 1997; Kremenetski et al., 1998). Determining the nature of the response of circumpolar treeline to past periods of climate amelioration may improve our ability to predict and detect the effects of future warming.

Radiocarbon dates obtained on *in situ* tree macro-fossils found in lakes currently situated north of treeline in northern Eurasia suggest that, between 9000 and 7000 yrs BP, boreal forest expanded to the Arctic coast and retreated to its current position between 4000 and 3000 yrs BP (MacDonald et al., 2000). In certain sectors of Eurasia, the movement of boreal treeline during this interval represents a migration of 100's of kilometres. It has been suggested that early to mid-Holocene boreal forest expansion resulted from a number of factors: increased summer insolation, reduced sea-ice cover, enhanced continentality due to lower sea level, and an increase in the penetration of warmer, moister air into northern Eurasia (MacDonald et al., 2000).

Recent work has illustrated that significant changes in chironomid assemblages occur across latitudinal treeline in north-central Canada (Walker & MacDonald, 1995), eastern Canada (Walker et al., 1991a), Fennoscandia (Olander et al., 1999) and northeastern Siberia (Porinchu & Cwynar, 2000). Researchers have used chironomids to quantify changes in past surface lake-water temperature in Atlantic Canada and the northeastern United States during the late-glacial (Walker et al., 1991b; Levesque et al., 1993; Wilson et al., 1993; Levesque et al., 1994; Cwynar & Levesque, 1995; Levesque et al., 1997). Brooks and Birks (2000) used changes in chironomid abundances to reconstruct mean July air temperatures in Western Norway during the late-glacial and the early Holocene.

In this paper, we present the results of chironomid analysis of a late-Quaternary sediment core recovered from a lake currently located north of treeline in northeastern Siberia and qualitatively interpret this record in terms of the changing local paleoenvironment.

Study site

The study area is located in northeastern Siberia (Figure 1). Lake sediment was recovered from Dolgoye Ozero (unofficial name; 71°52′41″ N, 127°04′39″ E), a moderately sized lake (3500 by 500 m) with a maximum depth of 4 m. Dolgoye Ozero is currently a dilute (conductivity = 25 μS), circumneutral (pH = 7.4), oligotrophic (total phosphorus = 7 μg/L) lake (Laing et al., 1999). It is located approximately 1000 m west of the main channel of the Lena River and approximately 25 m above it (Pisaric et al., 2001). The lake is a surficially closed basin with drainage occurring on the east side of the lake through a below-ground channel (Pisaric et al., 2001). The Laptev Sea is approximately 150 km to the north, the Verkhoyansk Mountains are found to the east, and the Central Siberian Plateau is situated to the south-west.

The tectonic nature of the lower Lena River basin is complicated in structure (Muratov, 1964; Markov, 1970). Reactivation of tectonic movements occurred during the first half of the Cenozoic. It was during this period that the Kengdeyan graben was formed running sub-parallel to the Lena River valley and constrained by the Verkhoyansk mountain range in the east. Deposits in this area are predominantly colluvium of Quaternary age (Pisaric et al., 2001).

The glacial history of this region is controversial. Grosswald et al. (1992) suggest that the Lena River region was glaciated during the most recent glacial stade. This would limit the basal date of Dolgoye Ozero sediment to the late-glacial interval. However, others argue that the area was not glaciated during the last glacial interval (Velichko, 1995).

Dolgoye Ozero is currently situated in tundra, 10 km north of the forest-tundra transition zone. The vegetation surrounding the site is comprised of shrub species, such as *Alnaster fruticosa* (green alder) and *Betula nana* (dwarf birch), herbs such as *Artemisia* (sage), *Eriophorum* (cotton grass) and Cyperaceae (sedges). An isolated stand of *Larix dahurica* (dahurian larch) is found in a sheltered location approximately 1 km to the south. The forest-tundra ecotone in this region is a mixed assemblage of shrubs, herbs and scattered individuals of *Larix dahurica.* The closed canopy of the boreal forest found further to the south is dominated by *Larix* (Pisaric et al., 2001).

This region is typified by a cold continental climate regime. Mean annual precipitation is ≤ 300 mm with most of the precipitation falling during the summer
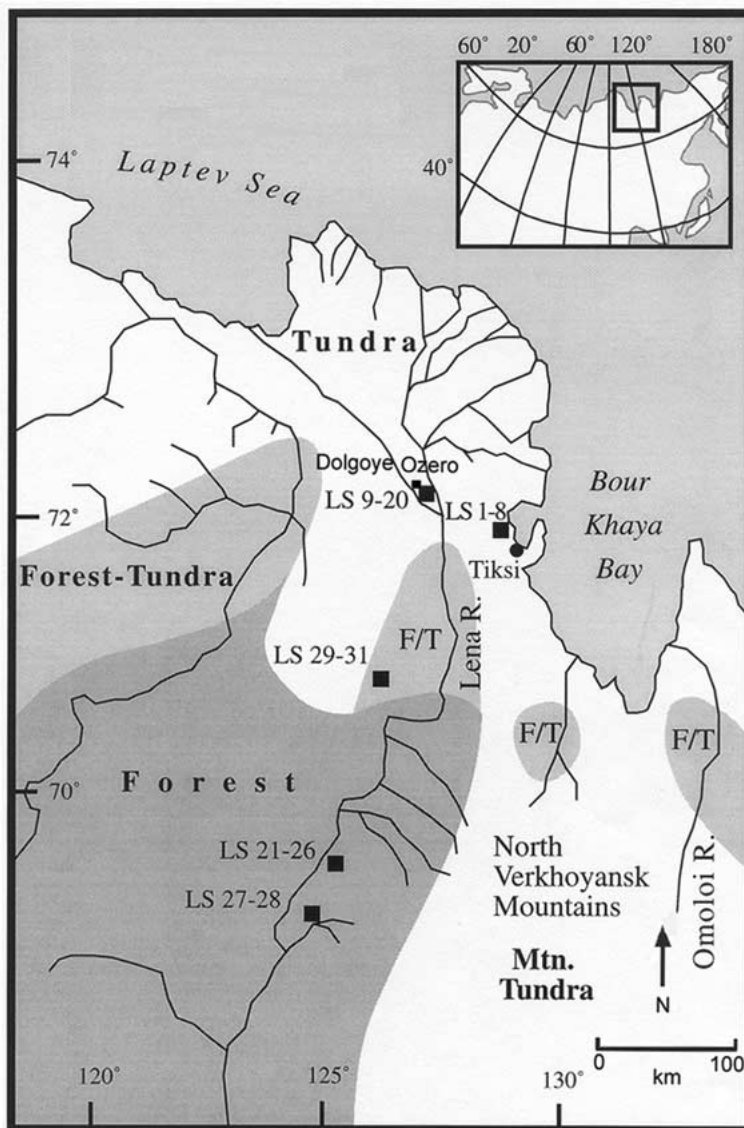
Figure 1. Location of study site, Dolgoye Ozero, and associated vegetation zones (tundra, forest-tundra, and forest) along the lower Lena River, northeastern, Siberia. Also indicated are locations of the lakes incorporated in the modern surface sample data-set. Lakes LS1–LS20 are located in tundra, lakes LS21–LS28 are located in forest, and lakes LS29–LS31 are located in forest-tundra.

months (Pisaric et al., 2001). The mean temperature for January is −34 °C and the mean July temperature is 8 °C (Miachkova, 1983).

Methods

A 368 cm sediment core was recovered from the approximate center of Dolgoye Ozero using a modified Livingstone piston sampler (Wright, 1991). The cores were labelled, wrapped in plastic film and aluminum foil, and transported to the laboratory where they were stored at 4 °C. A plastic tube fitted with a piston was used to sample the upper, flocculent sediment which was sectioned immediately in the field at 1 cm intervals and stored in Whirl-paks®. Co-ordinates were obtained using a Magellan® Global Positioning System (GPS).

Two mL of sediment were sub-sampled at 3.5 cm intervals. Sample preparation followed standard procedures as outlined in Walker (1987). Samples were deflocculated in 5% KOH at 80 °C for 30 min, the sus-

pension was sieved on a 95 µm mesh screen, and the remaining residue was backwashed into a beaker with distilled water. Aliquots of this solution were poured into a Bogorov plankton counting tray and chironomid head capsules were sorted and picked with the use of a dissection microscope. Permanent mounts of the fossilized head capsules were made using Entellan®. The head capsules were identified at 400× using bright-field illumination. Specimens that consisted of half the mentum were enumerated as half a head capsule, specimens consisting of more than half the mentum were enumerated as a whole head capsule, and specimens that consisted of less than half the mentum were not enumerated.

In most cases, identifications were made to genus. However, in certain situations larger taxonomic groupings were required, e.g., *Cricotopus* and *Orthocladius* are grouped together due to low taxonomic resolution. In some instances, taxa were identified to species, e.g., *Corynocera ambigua* and *Corynocera oliveri.* Identifications are based on Oliver and Roussel (1983) Wiederholm (1983), and Walker (1988), and a reference collection of 3800 individually mounted fossil head capsules from the region.

The chironomid percentage diagram was created and zoned using the stratigraphic analysis program TILIA (version 1.12) developed by E. Grimm (Illinois State Museum, Springfield, IL, USA). Excluded from the analysis were chironomid taxa that did not constitute ≥ 2% of the total chironomid sum at 2 or more depths, and samples with less than 100 identifiable head capsules. As a result, the samples excluded from the analysis were at 284, 294.5, and 298 cm, and all the samples between 315.5–326 and 340–365 cm. The zonation, which was stratigraphically restricted, is based on the constrained incremental sum of squares cluster-analysis (CONISS) program available in TILIA. Prior to the cluster analysis, the taxa were subjected to a square-root transformation. The percentage diagram was based on total identifiable chironomid head capsules. The chironomid head capsule influx was also calculated using TILIA.

Correspondence analysis (CA) was used to compare the fossil chironomid assemblages recovered from Dolgoye Ozero to the modern distribution of chironomids in the region. The average abundance of chironomid taxa at 1000 yr intervals (500 yrs for Younger Dryas period) was passively ordinated with data describing the modern distribution of chironomids from a transect of 31 lakes spanning treeline in this region. The first two axes of the ordination were constrained using the modern surface sample data-set (Porinchu &

Cwynar, 2000). Only taxa that were found at ≥ 2% in two or more lakes (surface sample data-set) or 2 or more samples (long core data-set) and that were common to both the late Quaternary sediment and the surface sediment were included in the analysis. The taxa included in the ordination were *Micropsectra*, Tanytarsina, *Cricotopus/Orthocladius, Microtendipes, Corynoneura/Thienemanniella, Hydrobaenus/Oliveridia, Paracladius, Parakiefferiella nigra, Abiskomyia, Heterotrissocladius, Corynocera ambigua, Corynocera oliveri, Chironomus, Dicrotendipes, Stempellinella/Zavrelia, Zalutschia zalutschicola, Psectrocladius* subgenus *Psectrocladius, Psectrocladius* subgenus *Monopsectrocladius, Psectrocladius* subgenera *Allopsectrocladius/Mesopsectrocladius, Stictochironomus, Sergentia, Parakiefferiella* cf. *bathophila, Procladius, Zalutschia* and Pentaneurini. The ordination analysis was carried out using the statistical package CANOCO version 3.12 (ter Braak, 1988–1991).

Results

Chronological control for the record was provided by AMS ^{14}C dating of aquatic moss remains and wood fragments (Table 1; Pisaric et al., 2001). Ten radiocarbon dates were obtained with two dates rejected. The date obtained on the sample at 249 cm was rejected because it produced an order of magnitude less carbon after processing than the other samples. The small amount of datable gas could have easily been contaminated and have led to the inconsistent date. The sample at 61 cm was also rejected. This sample may have

Table 1. Radiocarbon dates of aquatic and terrestrial organic matter from Dolgoye Ozero

Lab number	Depth (cm)	Material	CO^2 (ccSTP)	Age (^{14}C yr BP)
TO-5254	61	aquatic moss	3.7	−2000 ± 50*
TO-5719	71.5	aquatic moss	2.8	1630 ± 60
TO-5245	117	aquatic moss	2.3	3780 ± 70
TO-5255	145	aquatic moss	0.7	5150 ± 70
TO-5720	192–194	aquatic moss and wood	2.8	7250 ± 80
TO-5246	229	aquatic moss	3.1	9830 ± 80
TO-5256	249	aquatic moss	0.3	7300 ± 280*
TO-5721	252.5	aquatic moss	1.1	10240 ± 120
TO-5722	287.5	aquatic moss	1.8	11520 ± 110
TO-5247	298	aquatic moss	4.3	12310 ± 100

Lab – Isotrace Laboratory, University of Toronto, Canada. *rejected dates (see text for explanation).

been contaminated by nuclear testing which occurred in the area, or by contamination in the lab (Pisaric et al., 2001). The eight remaining dates were plotted on an age vs. depth profile and suggest that the sedimentation rate has remained relatively constant during the Holocene (Pisaric et al., 2001).

MacDonald et al. (1987) have demonstrated that radiocarbon dates based on aquatic moss samples may lead to a systematic overestimation of the true sample age. Although the possibility of a hardwater effect does exist, we do not feel that it is an issue at this site (Pisaric et al., 2001). The timing of the movement of treeline into this area, based on this radiocarbon chronology and the pollen and stomate evidence from this site, correlates well with dates obtained on over 100 terrestrial macrofossils recovered from northern Russia and Siberia (Pisaric et al., 2001; MacDonald et al., 2000).

Sediment between 336.5 and 365 cm did not produce any identifiable chironomid head capsules. Seven chironomid zones (DO-1 to DO-7) were identified through the stratigraphically constrained cluster analysis of 80 samples (Figure 2).

DO-1 (336.5–273.5 cm)

This zone, along with the remaining zones, is dominated by taxa belonging to the sub-tribe Tanytarsina (including *Microspectra*). This zone is characterized by considerable variation in the chironomid assemblages. The most common taxa are *Micropsectra*, Tanytarsina, *Cricotopus/Orthocladius*, *Microtendipes*, and *Corynoneura/Thienemanniella*. Temperate taxa, such as *Microtendipes*, are found at high levels reaching 25% at the top of the zone. *Corynocera ambigua*, which is found only in forested landscapes in this region (Porinchu & Cwynar, 2000), is absent in the middle of this zone, but is present at high levels (10%) initially and at the top of the zone. Cold-water taxa, such as *Paracladius* and *Hydrobaenus/Oliveridia*, are found consistently at low values (5%). No chironomid head capsules were recovered between 315.5 and 326.0 cm. The influx of cool-water taxa varies between 40–300 head capsules/cm^2/yr, while the influx of temperate chironomid head capsules ranges between 25–100 head capsules/cm^2/yr.

DO-2 (273.5–239.5 cm; ≈ 11,000–10,000 yrs BP)

This zone is characterized by declines in *C. ambigua* and *Microtendipes*. These taxa are replaced by cooler-water taxa, such as *Hydrobaenus/Oliveridia*, *Parak-*

iefferiella nigra and *Abiskomyia*. *Abiskomyia* is found for the first time near the top of the zone. *C. oliveri* appears in this zone, albeit at low values, and *Paracladius* persists from DO-1. Approximately 20% of the total identifiable head capsules consist of *Micropsectra*. There is also a large increase of *Cricotopus/Orthocladius*. Midway through this zone the influx of temperate chironomid head capsules declines from approximately 50 to 5 head capsules/cm^2/yr.

DO-3 (239.5–208.0 cm; ≈ 10,000–8300 yrs BP)

This zone is dominated by warm-water taxa, such as *Microtendipes* (30%), *Chironomus* (8%), and to a lesser extent *Dicrotendipes* (5%) as well as *C. ambigua* (20%), which is currently found only at forested sites in this region. *Stempellinella/Zavrelia* reaches maximum values in this zone. DO-3 is also characterized by a decrease in the relative abundance of cold-water taxa. *Hydrobaenus/Oliveridia*, *Paracladius*, and *Micropsectra* reach minima, and other cold-water taxa, such as, *Parakiefferiella nigra* and *Abiskomyia*, disappear completely. Also of note is the absence of *Heterotrissocladius*. This zone is characterized by a large increase in the deposition of temperate chironomid head capsules, while the influx of cool-water taxa reaches a core minimum (approximately 25 head capsules/cm^2/yr).

DO-4 (208.0–173.0 cm; ≈ 8300–6400 yrs BP)

This zone is distinguished by the appearance of *Zalutschia zalutschicola*. DO-4 is characterized by fluctuations in the relative abundance of temperate chironomid fauna, e.g., *Microtendipes*. This zone is also characterized by fluctuations in *C. ambigua*. However, both of these taxa are still present at high levels at the top of the zone. Initially, there is a large increase in *Psectrocladius* subgenus *Psectrocladius* (25%), which subsequently decreases to a relatively constant level for the remainder of the core. Cold-water taxa such as *Heterotrissocladius* and *Micropsectra* reappear in this zone, although cold stenotherms are not present. The deposition of temperate chironomid reaches its highest values in the record in this zone (approximately 300 head capsules/cm^2/yr). The influx of cool-water types also increases.

DO-5 (173.0–113.5 cm; ≈ 6400–3600 yrs BP)

Cold-water midges such as *Paracladius* and *Hydrobaenus/Oliveridia* are found more consistently and at higher relative abundances in this zone. *Abiskomyia*

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Figure 2. Chironomid percentage diagram from Dolgoye Ozero, northeast Siberia. Influx of cool-water taxa and temperate taxa in head capsules/cm²/yr also indicated. *Psectrocladius* is split into three groups: *Psectrocladius* subgenera *Allopsectrocladius/Mesopsectrocladius*, *Psectrocladius* subgenus *Monopsectrocladius* and *Psectrocladius* subgenus *Psectrocladius*, which are identified in the diagram as *Psectrocladius* subg. *Allo./Meso.*, *Psectrocladius* subgenus *Mono.* and *Psectrocladius* subgenus *Psectro.* respectively. Values for sub-tribe Tanytarsina do not include *Micropsectra*, *Corynocera ambigua* or *C. oliveri*.

and *Parakiefferiella nigra*, cold-water taxa, reappear in DO-5. *Sergentia* reaches its maximum values, and the relative abundance of *Parachironomus* and *Cricotopus/Orthocladius* increases, while *Microtendipes* and *C. ambigua* decline rapidly to very low levels. The presence of *Zalutschia zalutschicola* is limited to this zone and the one below (DO-4). The upper boundary is marked by a sharp decrease in *Parakiefferiella* cf. *bathophila* and *Chironomus.* The influx of cool-water taxa stabilizes at approximately 110 head capsules/cm^2/yr and remains near this value for the remainder of the core.

DO-6 (113.5–61 cm; ≈ 3600–1400 yrs BP)

This zone is characterized by the decline of most temperate midge taxa and increased abundances of cold-water taxa, such as *Heterotrissocladius*, *Micropsectra*, *Sergentia* and *Abiskomyia*. *Micropsectra* increases from 15% in the previous zone to approximately 30%. The relative abundance of the tribe Pentaneurini (other) increases at the beginning of this zone and remains at 5% throughout this zone and the next. *Zalutschia* increases throughout this zone and reaches approximately 15% at the top. *Heterotrissocladius* also increases from approximately 8% in DO-5 to about 20%. There is a gradual decrease in *Sergentia* and a sharp decrease in *Cricotopus/Orthocladius.* The influx of temperate chironomid head capsules decreases to approximately 10 head capsules/cm^2/yr and remains at this level for the remainder of the core.

DO-7 (61.0–0.0 cm; ≈ 1400 yrs BP–present)

Within this zone, *Paracladius* disappears from the record and *Heterotrissocladius* decreases gradually. *Abiskomyia*, *Zalutschia*, and *Sergentia* remain relatively constant. The sub-tribe Tanytarsina (excluding *Microspectra* and *Corynocera)* increases throughout the zone, reaching a core maximum of 45% near the top. There is also an increase in *Chironomus* towards the top of the core (≈ 4%).

Time trend analysis

The ordination diagram (Figure 3) produced by correspondence analysis (CA) indicates that between 12,000 and 10,000 yrs BP the chironomid community in Dolgoye Ozero changed rapidly. By 9,000 yrs BP the chironomid assemblage present in Dolgoye Ozero was similar to the chironomid communities that are cur-

rently found in lakes surrounded by boreal forest. However, the movement of the long-core chironomid assemblage towards the assemblages that are typical of modern forest lakes was not monotonic. There was a reversion between 11,000 and 10,000 yrs BP when the long-core chironomid assemblages moved through ordination space towards assemblages that are more typically associated with modern tundra lakes. The chironomid community at 10,500 yrs BP is positioned within the envelope describing the chironomid communities that are currently present in lakes north of treeline. Between 9000 and 7000 yrs BP, taxa which are currently associated with warmer, forested sites, e.g., *Corynocera ambigua* and *Microtendipes*, were present at high levels. After 6000 yrs BP the chironomid community present in Dolgoye Ozero became increasingly similar to the chironomid communities that characterize modern tundra lakes.

Earlier analysis of the surface samples identified taxa such as *Corynocera ambigua, Zalutschia zalutschicola* and *Microtendipes* as being important constituents of the chironomid community present in forest lakes (Porinchu & Cwynar, 2000). Taxa that are found more commonly in tundra lakes include *Abiskomyia*, *Heterotrissocladius*, *Parakiefferiella nigra* and *Paracladius.* The chironomid community present in Dolgoye Ozero between 10,000 and 7500 yrs BP contains a relatively high proportion of taxa associated with forested environments; these taxa begin decreasing in importance by approximately 7000 yrs BP. Following 6,000 yrs BP the chironomid community present in Dolgoye Ozero becomes increasingly dominated by Orthocladiinae such as *Abiskomyia* and *Heterotrissocladius*.

Discussion

The origin of Dolgoye Ozero is uncertain, although it has been suggested that it was formed due to the scouring activity of the Lena River during periods of high flow of alpine glacial meltwater during the late Pleistocene (Pisaric et al., 2001). The elongated shape of the lake and its proximity to the Lena River support this suggestion. The bedrock in this area is comprised primarily of sandstone, and preferential erosion may have led to the formation of a depression which filled with water and remained when the level of the Lena River decreased (Pisaric et al., 2001). The basal lake sediment, which is comprised of sand and some pebbles, also supports this suggestion.
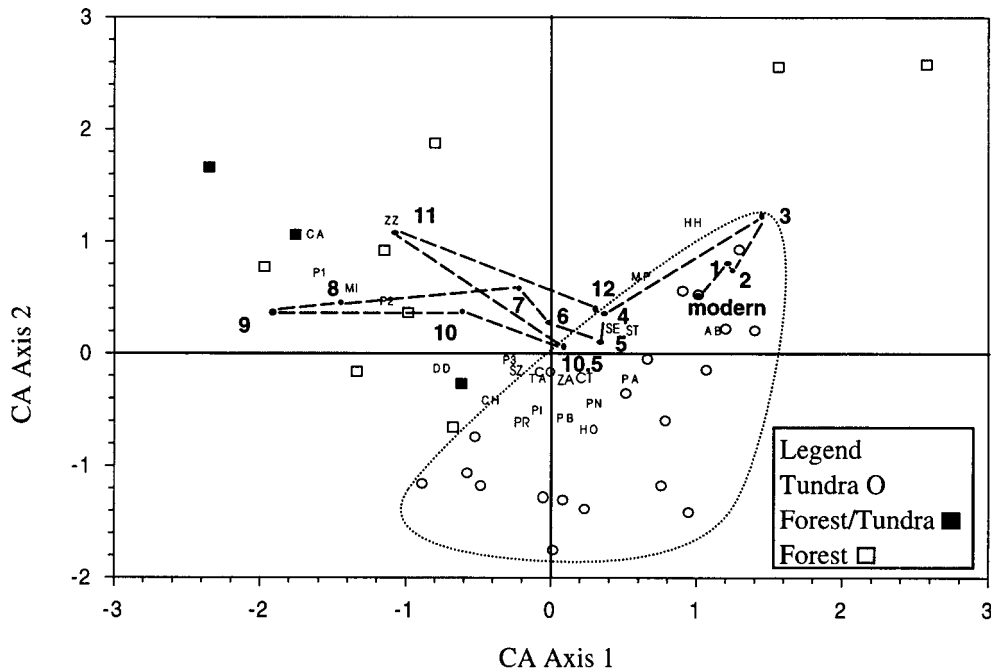
Figure 3. Time-trend CA joint plot comparing the fossil chironomid assemblages from Dolgoye Ozero with the modern samples of chironomids from lakes in lower Lena River region. Lakes in the surface sample data set are represented by symbols, with tundra lakes encircled. Numeric values represent the fossil chironomid assemblages at 1000 yr intervals ($\times 10^3$). Selected taxa are represented by two letter codes; AB – *Abiskomyia*; CH – *Chironomus*; CA – *Corynocera ambigua*; CI – *Corynocera oliveri*; CT – *Corynoneura/Thienemanniella*; CO – *Cricotopus/ Orthocladius;* DD – *Dicrotendipes*; HH – *Heterotrissocladius*; HO – *Hydrobaenus/Oliveridia*; MP – *Micropsectra*; MI – *Microtendipes*; PA – Paracladius; PB – *Parakiefferiella* cf. *bathophila*; PN – *Parakiefferiella nigra*; PI – Pentanneurini (Other); PR – *Procladius;* P1 – *Psectrocladius* subgenera *Allopsectrocladius/Mesopsectrocladius*; P2 – *Psectrocladius* subgenus *Monopsectrocladius*; P3 – *Psectrocladius* subgenus *Psectrocladius*; SE – *Sergentia*; SZ – *Stempellinella/Zavrelia*; ST – *Stictochironomus*; TN – Tanytarsina; ZZ – *Zalutschia zalutschicola*.

DO-1 spans the period between lake formation and 11,000 yrs BP. The chironomid record in this zone is difficult to interpret due to the lack of a basal date and the hiatus in the chironomid record between 315.5 and 326 cm. Fossilized remains of chironomids, diatoms, and chrysophytes were not recovered from the sediment between 315.5 and 326 cm and pollen deposition was considerably depressed during this period. The lack of any fossils of aquatic organisms during this period suggests the possibility that Dolgoye Ozero had temporarily desiccated. The presence of taxa currently associated with forested sites in this region, e.g. *Microtendipes* and *C. ambigua*, together with a large number of cold-water midges, e.g., *Paracladius*, *Hydrobaenus/Oliveridia*, and *Parakiefferiella nigra*, at relatively high values makes the interpretation of these incongruous assemblages difficult.

Time-trend analysis suggests that DO-1 was characterized by rapid changes in the chironomid community in Dolgoye Ozero. At 12,000 yrs BP the fossil chironomid assemblage is similar to the assemblages found in modern tundra lakes, however, by 11,000 yrs BP the composition of the chironomid community is typified by the communities found in modern forested environments. This rapid change may be attributable to postglacial warming.

DO-2 is characterized by a pronounced change in the chironomid fauna with a precipitous drop in warmwater midges, e.g., *C. ambigua* and *Microtendipes*, and an increase in cold-water taxa, such as, *Hydrobaenus/ Oliveridia*, *Abiskomyia* and *Parakiefferiella nigra.* The interpolated dates for the upper and lower boundaries of this zone are approximately 10,000 and 11,000 yrs BP respectively. The appearance of cold-water taxa such as *Abiskomyia* and *Parakiefferiella nigra* suggest a pronounced cooling of summer surface water temperatures during this period. *Parakiefferiella nigra* and *Abiskomyia* are restricted to cold, well-oxygenated water and are commonly found in arctic and alpine lakes (Walker & Mathewes, 1989a; Walker et al., 1992, 1993). The modern distribution of these two taxa is restricted to lakes north of treeline in this region

(Porinchu & Cwynar, 2000). These changes in the chironomid community suggest a cooler climate and they correspond with pollen data from this core used to infer the presence of the Younger Dryas (Pisaric et al., 2001). A very close chronological correlation exists between the chironomid and pollen zones, indicating that the vegetation response to the implied decline in temperature was rapid. The time-trend analysis also indicates a pause in late-glacial climate amelioration; during this interval the chironomid fossil assemblages show a distinct move in ordination space towards tundra lake assemblages. The chironomid record is consistent with the pollen evidence for the presence of the Younger Dryas in northeastern Siberia.

At approximately 10,000 yrs BP (*DO-3*), there is an abrupt increase in the relative abundance of temperate chironomids, such as *Microtendipes*, *C. ambigua* and *Chironomus*, and a precipitous decline in cold-water taxa. The high relative abundances and the increase in the influx of these temperate taxa suggest a climate warmer than modern. The increases in *C. ambigua* and *Microtendipes* during this period are particularly interesting because the modern distributions of these two taxa are restricted to sites south of treeline in this region (Porinchu & Cwynar, 2000). *Microtendipes* has been identified as a thermophilous, littoral genus commonly found in shallow and low elevation lakes (Walker & Mathewes, 1989a; Walker & MacDonald, 1995). Treeline clearly demarcates the modern distribution of *C. ambigua* in this region; it is present only in sites south of treeline (Porinchu & Cwynar, 2000). Lakes in forested catchments are generally characterized by higher water temperatures. Based on the modern distribution of *C. ambigua* in this region, we have inferred that the presence of *C. ambigua* in DO-3 is suggestive of warmer conditions. Brodersen & Lindegaard (1999) review what is known about the distribution of *C. ambigua*. They note that, although it is commonly thought of as an arctic or subarctic taxa, it has been found in temperate lakes. The presence of *C. ambigua* raises the possibility that temperature may have been sufficiently warm to support the migration of trees into the area from the south during this period. The ordination diagram indicates that large and rapid changes in the chironomid community occurred between 10,000 and 7000 yrs BP. The fossil assemblages present in Dolgoye Ozero during this interval are strongly representative of assemblages that are currently found in forested environments, further substantiating the inference of climatic amelioration. An increase in the relative abundance of the shrub *Alnaster fruticosa* during

this period (Pisaric et al., 2001) is consistent with the chironomid evidence for warming. The increase in temperate midges and the increase in *Alnaster* pollen occur approximately 1800 years before coniferous trees colonized the area (Pisaric et al., 2001). This suggests that a lag may have existed between when summer temperatures became sufficiently warm to support trees and when trees actually arrived in the area.

Zalutschia zalutschicola is characteristic of humic lakes (Sæther, 1979) and is present only in zones *DO-4* and *DO-5*. Its modern distribution in this area is restricted to forested regions and its appearance suggests warmer-than-present summer surface lake water temperatures (Porinchu & Cwynar, 2000). The increase in *Psectrocladius* subgenus *Psectrocladius* may suggest increasing humic acid inputs during this period, since *Psectrocladius* is commonly found in acidic lakes (Walker & Mathewes, 1989a).

A decrease in temperate taxa, such as *Microtendipes* and *C. ambigua,* between 6400 and 3600 yrs BP, and an increase in cold-water midges, e.g., *Paracladius* and *Hydrobaenus/Oliveridia*, suggest that by this time summer temperatures were decreasing. Pollen and stomate evidence record the presence of trees in the area between 8500 and 3500 yrs BP (Pisaric et al., 2001). Furthermore, fossil wood, in the form of stumps and branches found on the landscape, dating between 8000 and 3500 yrs BP, strongly supports the movement of treeline into the area during this period (MacDonald et al., 2000).

The reappearance of cold taxa, e.g., *Abiskomyia* and *Parakiefferiella nigra*, at approximately 6400 yrs BP when trees (*Larix* and *Picea)* were still abundant (Pisaric et al., 2001), suggests that the magnitude of the cooling was not sufficient to pass the survival threshold of these trees. The deposition of temperate chironomid head capsules decreases precipitously at 6400 yrs BP, while the deposition of cool-water types increases dramatically at approximately 8300 yrs BP. This suggests that climatic deterioration may have begun as early as 8300 yrs BP. Between 6000 and 3000 yr BP, time trend analysis indicates that the chironomid community in Dolgoye Ozero was increasingly dominated by cold-water chironomids such as *Heterotrissocladius*, *Paracladius* and *Parakiefferiella nigra,* suggesting that the environment surrounding the lake was becoming increasingly tundra-like.

The increase in cold taxa, such as *Abiskomyia* and *Micropsectra*, at approximately 3600 yr BP suggests that climate deterioration continued through this zone since both taxa are most abundant today in tundra lakes

(Porinchu & Cwynar, 2000). The increase in *Hetero-trissocladius*, a taxon common to cold well-oxygenated lakes, further supports the suggestion of cooling after 3600 yrs BP (Walker & Mathewes, 1989b). The chironomid assemblage present during this period indicates the establishment of a climate similar to modern conditions. The implied decrease in temperature was severe enough to lead to the southward retreat of treeline in this region, as indicated by the pollen and stomate record (Pisaric et al., 2001).

The modern chironomid assemblage was established by approximately 1400 yrs BP, with the decline of *Paracladius* and all temperate taxa. The taxa present are common to tundra lakes in this region (Porinchu & Cwynar, 2000) and indicative of cold temperatures. The vegetation present during this period, which was dominated by shrub species of birch and alder, supports the interpretation of a reversion to a cooler climate (Pisaric et al., 2001).

Conclusion

The use of Chironomidae as a proxy for paleoclimate has provided investigators with an independent means of assessing the rate and magnitude of past climate change. The results of this study reveal that a cooling occurred between 11,000 and 10,000 yrs BP, correlative to the Younger Dryas. This is the first evidence, independent of the palynological record, of the possible presence of the Younger Dryas in northeastern Siberia. The early Holocene is marked by a large change in the relative abundances of warm and cold-water chironomids. The increases in temperate chironomids, specifically *Microtendipes* and *C. ambigua*, suggest that a climate warmer than modern was present between 10,000 and 6400 yrs BP. However, the dramatic increase in the influx of cool-water types at approximately 8,000 yrs BP suggests that changes in the paleoenvironment, possibly related to climatic deterioration, may have occurred even earlier. It is clear from the time-trend analysis that significant changes in the chironomid community occurred between 8,000 and 7,000 yrs BP. Climate amelioration was certainly terminated with the initiation of the first stage of a two-stage cooling process at approximately 6400 yrs BP. The second stage, which began at approximately 3600 yrs BP, led to the establishment of the modern chironomid assemblage and is indicative of an environment similar to the modern.

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