Late Quaternary Climate Dynamics Inferred from the Stable Oxygen Isotope Composition of Aquatic Insects (Chironomidae: Diptera) from Idavain Lake, Southwest Alaska

Research proposal to the Alaska Quaternary Center David and Rachel Hopkins Fellowship Competition – 2006

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I am applying for the Alaska Quaternary Center 2006 David and Rachel Hopkins Fellowship to support stable oxygen isotope analyses of aquatic insect (Chironomidae: Diptera) chitin preserved in the lake downcore sediments (ca. 14,000 yr. B.P. to present) from Idavain Lake from southwest Alaska, eastern Beringia. My proposed research will contribute to an enhanced understanding of paleoenvironmental changes in southwest Alaska using a newly developed proxy--stable oxygen isotope analysis on chironomid (Wooller et al., 2004) in concert with other existing paleoenvironmental proxy data, such as pollen, stable nitrogen and carbon isotope analyses of sediments and opal concentration etc. (Finney et al., pers. comm..) from Idavain Lake.

Relevance to the research focus area: Beringia experienced remarkable spatial and temporal variability in both vegetation and climate change throughout the late Quaternary (Anderson et al., 2004; Bigelow & Edwards, 2001; Brubaker et al., 2001; Finney et al., 2004). In spite of the increase in paleoecological research in Beringia over the last two decades, the responses of effective moistures and temperature variability to its regional climate controlling mechanisms and process are still poorly understood (Brubaker et al., 2001; Finney et al., 2004). In order to obtain a coherent picture of climate change for Beringia during the late Quaternary, three focal research areas remain high priorities for current paleoclimate research in the region: (1) acquiring better chronological controls to conduct more accurate regional climate comparisons; (2) developing new paleo-climate proxies and other techniques for multi-proxy paleoenvironmental reconstruction; (3) further understanding the processes and mechanisms controlling observed/ reconstructed climate patterns in comparison with climate model simulations (e.g. Edwards et al., 2001; Finney et al., 2004). My research aims to further develop and apply a new proxy (Wooller et al., 2004), which can potentially extend the record of temperature changes in high latitudes beyond the instrumental record using the stable oxygen isotope analyses of chironomid headcapusles preserved in lake sediments. This new approach can add significantly to the relatively small database of quantitative temperature reconstructions from terrestrial sites in Beringia.

The stable oxygen isotope composition ($\delta^{18}O$) of precipitation is highly correlated with the Mean Annual Temperature (MAT) at high latitudes due to the precipitation Raleigh distillation effect (Dansgaard, 1964), a relationship used to obtain temperature records from the Greenland and Antarctica ice cores (Cuffey & Vimeux, 2001; Vimeux et al., 2002; White et al., 1997). In a limniologically suitable lake (catchment area/surface area ratio >20) (Sauer et al., 2001), Mean Annual lake-water $\delta^{18}O$ would equal Mean Annual precipitation $\delta^{18}O$, which is tightly linked to the MAT (Gonfiantini, 1986; Sauer et al., 2001). Since the $\delta^{18}O$ of a lake's water controls the $\delta^{18}O$ of chironomid larvae that live in that lake (because aquatic invertebrates build their bodies using lake water--Schimmelmann et al., 1987; Wooller et al., 2004) the preserved part of these aquatic invertebrates present in lake sediment (i.e. chitinous larval headcapsules) can be used as an indicator of past lake water (and therein precipitation) stable oxygen isotopes, and by proxy, the MAT.

This approach is similar to applications of using $\delta^{18}O$ measurement on the carbonates such as *Chara* sp. calcites (Anderson et al., 2001) and ostracod shell (Hu et al., 2003), or the $\delta^{18}O$ of aquatic cellulose (Anderson et al., 2001) to reconstruct the paleo-temperature or effective moisture from lake sediment archives. The use of $\delta^{18}O$ of the calcite carbonate is limited due to lack of calcite carbonate in most high latitude lakes. Meanwhile, failing to separate aquatic celluloses from terrestrial celluloses can be problematic and can complicate the reconstruction of past lake water /precipitation $\delta^{18}O$. On the contrary, family Chironmidae is widely distributed and frequently the most abundant group of insects in subarctic/arctic freshwater environments (Gullan & Cranston, 2000; Oliver, 1971). In addition, the chitinous chironomid headcapsules preserve well in lake sediments, retaining the stable oxygen isotope signature of the lake in which they lived when their remains settle to the lake bottom and are entrained in sediments. Therefore, the $\delta^{18}O$ of chironomid headcapsule chitin, compared to cellulose and biogenic calcite carbonate, can have wider applications at high latitudes and allow comparison from various regional settings. Paleoecologists in the last two decades have widely used the taxonomic affiliation of chitinous remains of Chironomidae in lake sediments to infer past aquatic environments (including past lake temperatures) in arctic regions using transfer functions (Battarbee, 2000; Lotter et al., 2000; Smol, 2002; Walker, 1995; Walker & Pellatt, 2003). Temperature reconstruction using chironomid taxonomy is fairly time consuming and regional temperature reconstruction transfer functions based on taxonomy have prevented temperature comparisons between regions. The recent development of High Temperature Conversion Elemental Analyzer (TC/EA) in stable isotope mass spectrometry allows the determination of stable hydrogen isotope compositions (δD) and $\delta^{18}O$ in rapidly, and precisely (Koziet, 1997; Sharp et al., 2001). This on-line method has dramatically reduced sample size by an order of magnitude (Sharp et al., 2001; Werner, 2003; Werner et al., 1996) and made it possible to conduct measurement of the stable isotope composition on chironomid chitin.

Even though the $\delta^{18}O$ of chironomid chitin can be used to reconstruct the paleo-lake water/ paleo precipitation $\delta^{18}O$ and by proxy MAT, the significance of reconstructing the MAT downcore must be considered in the light of lake hydrology and the influence of the local climate regime (Anderson et al., 2001; Sauer et al., 2001). The $\delta^{18}O$ of lake water may not necessarily equal that of the precipitation. The discrepancy of the $\delta^{18}O$ of precipitation and lake water can be attributed to the combined isotopic composition of other input waters (snowmelt, soil pore water, and glacial water input) from catchment runoff, groundwater flow, and seasonality of precipitation. Also evaporative enrichment can be caused by preferential evaporation of the lighter ^{16}O isotope by the "Kinetic effect" in water molecules due to higher diffusion and evaporation rate. However, if a lake size is bigger than $10^6 m^3$ (Sauer et al., 2001) with a catchment area/lake surface area ratio greater than 20 (Gonfiantini, 1986), the hydrological influences to lake water $\delta^{18}O$ is negligible and it will allow the data to be interpreted more confidently as marking changes in temperature (Sauer et al., 2001). Thus, reconstruction of the paleotemperature using chironomid chitin $\delta^{18}O$ can be achieved by selecting sites that only receive a single source of precipitation, negligible other isotopic composition of input waters, and small seasonal isotopic variability.

Study site-regional importance: Boundaries between climate zones, where the vegetation is very sensitive to changes in air mass transportation, precipitation and evaporation, are ideal places to examine short-term climate changes. Southwest Alaska extending from central Alaska to coasts of Bristol Bay and southern Beringia straits (Fig. 1) is located at the edge of the Aleutian low-pressure cell in winter and the North Pacific subtropical high pressure cell in summer. Southwest Alaska is characterized by a transitional climate condition between maritime and continental climate zones (Bowling, 1979). The regional vegetation gradients of this region range from conifer and/or hardwood boreal forest in north and *Betula* shrub tundra with extensive *Alnus* shrub down the south (Fig. 2) (Brubaker et al., 2001). However, compared to central and northern Alaska, few paleoclimate studies have been conducted in southwest Alaska despite the importance of its location (Brubaker et al., 2001; Hu et al., 1995, 1996). A pollen record from Idavain Lake (58°46´N, 155°57´W, 223m asl) located at the south foothill of the Alaska Range and at the northwest of Katmai mountain, southwest Alaska shows three marked vegetation shifts in the region, including herb-dominated tundra (ca. 14,000 to 12,000 yr. B.P.), mixed herb/*Betula* shrub tundra (ca. 12,000 to 8, 000 yr. B.P), and *Alnus*/*Betula* shrub tundra (ca. 8,000 yr. B.P. to present) (Brubaker et al., 2001). A distinct Younger Dryas cold period (ca. 11,000 to 10,000 yr. B.P.) was also recognized from the pollen zone in the region (Brubaker et al., 2001). Vegetation patterns revealed from other lake sites in southwest Alaska show different timing and vegetation type successions (Brubaker et al., 2001). The complex of vegetation history suggests a heterogenous climatic response as a result of variations in atmospheric circulation (Mock et al., 1998) and changes in different components in climate system within Beringia during the late Quaternary (Finney et al., 2004). However, pollen records alone are insufficient to determine the specific mechanisms controlling late-Quateranry climate change in southwest Alaska (Brubaker et al., 2001). Multiple paleolimniological proxies including lake nutrients changes, organic content and opal concentrations (Finney et al., personal communication) in concert with stable isotope techniques are, therefore, essential to provide a better understanding of the regional effective moisture and temperature change since deglaciation in southwest Alaska (Brubaker et al., 2001). Extending back to ca.14,000 yr. B.P., the high resolution multi-proxy paleoclimate reconstruction from the Idavain lake core can also further test whether extinction of large mammals in East Beringia was the result of drastic vegetation change during Pleistocene-Holocene transition (ca. 13,000-11,000 yr. B.P.) driven by climate change rather than human colonization (ca.12,000 yr. B.P) (Guthrie, 2006).

Idavain Lake is also an ideal site for accessing the regional moisture availability and temperature change using stable isotopic analyses of chironomid headcapsule chitin preserved in the core. Located at the southeastern margin of Nushagak Lowland and bordered by the Alaska Range on the north and Aklund Mountain on the west, Idavain Lake has mostly likely received a single source of precipitation during the Holocene and has less continental effect compared to interior Alaska. Moreover, even though Idavain Lake was glaciated during the last glaciation and the glacial deposits can be found at the bottom of the lake core (Finney et al., person communication), the lake is not fed by glacial melt. The limnological characteristics (catchment/surface ratio ~20 and lake water depth is 8-20m) of Idavain are also ideal for reconstructing the precipitation $\delta^{18}O$ from lake water. In addition, it is encouraging to note that the measured $\delta^{18}O$ of the lake water of Idavain (-11.1‰) (Finney et al., pers. comm..) also closely resembles the predicted $\delta^{18}O$ (-12.9‰) of mean annual precipitation at the site (http://www.waterisotopes.org/).

Approach and method: A 16 meter sediment core (ca. 14,000 yr. B.P. to present) was collected by Finney et al. (pers. Comm..) and this core is stratigraphically comparable with Brubaker et al's core (2001) using correlation of the magnetic susceptibility. Sixty sediment subsamples (1-3cc) spreading out the core will be taken from the core. Sediments will be sieved through a 100-µm sieve. Chironomid remains will be isolated following a series of pretreatments, including defloccation in warm 5% KOH for 1 hour, with distilled water rinses using a 100-µm sieve (Walker, 2001). Headcapsules remaining in the sieve will be hand picked from a Bogorov counting tray (Walker, 2001) under 50x microscope to a 5x3.5mm silver capsule. Minimum of 120 headcapsule (0.05mg) per sediment sample will be required for the $\delta^{18}O$ measurements. The headcapsules in the silver capsule will be freeze-dried and folded into a ball. The samples will be then placed in an autosampler attached to a ThermoFinnigan TC/EA-IRMS at the Alaska Stable Isotope Facility (ASIF), which will analyze the stable isotope composition of the samples. Duplicates of chironomid headcapsules will be also selected from several horizons to check the sample precision. Also the oxygen stable isotope analysis of two species of chironomid headcapsule as well as combination of all species from one sediment sample at five random horizons will allow between species variability to be checked. My anticipation is that there will be no significant variability between species. In addition, the precipitation samples all year around (one weighted precipitation sample from all the rain events each month) from a nearby town King Salmon will be collected. The precipitation samples will also be analyzed using TC/EA at the ASIF and the results will be compared with Idavain lake water $\delta^{18}O$.

Significance of this project: I anticipate that the $\delta^{18}O$ of the chironomid headcapsules chitin will have marked changes in concert with major vegetation successions and opal concentration changes in Idavain Lake region. I aim to link the vegetation and other proxies to reconstruct a coherent picture of climate change for southwest Alaska. This project will indeed make a novel contribution to a better understanding of the climatic mechanism controlling the regional climate variability since deglaciation.

Figures

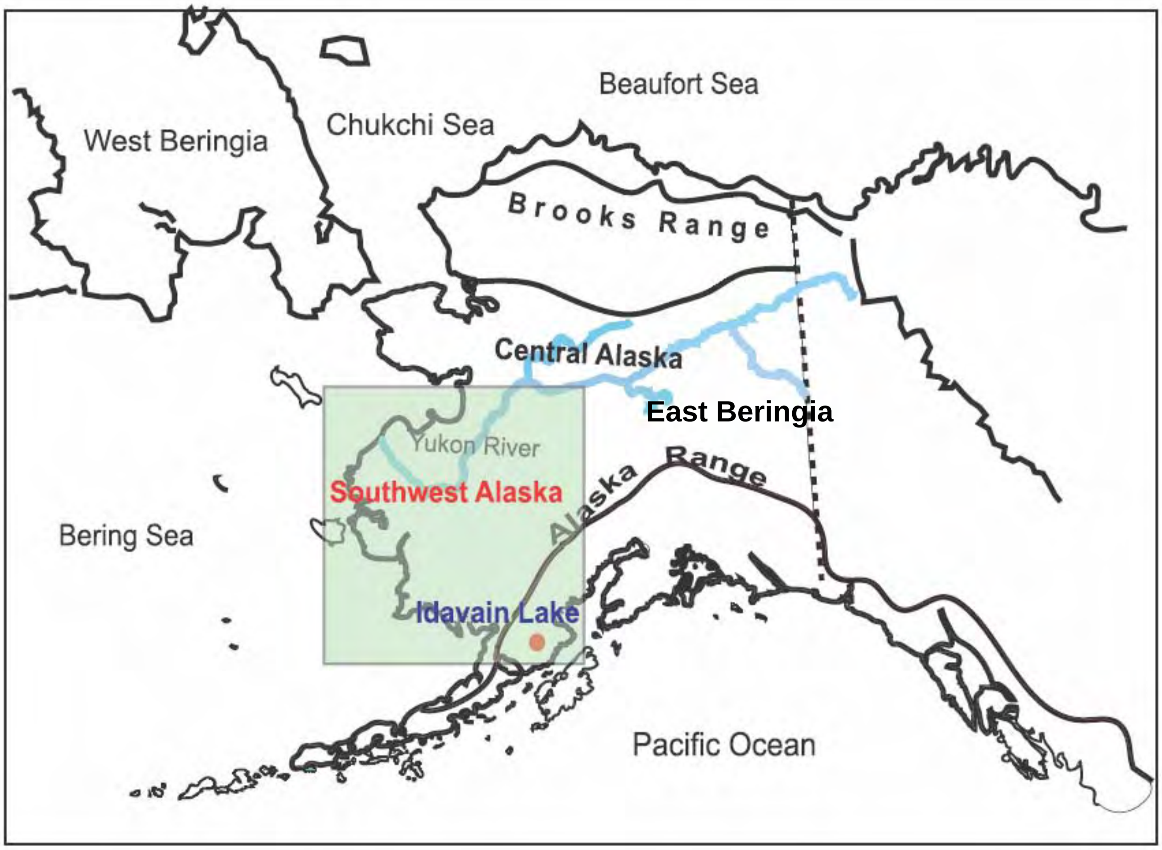

Figure 1. Location of southwest Alaska and the study site Idavain Lake.

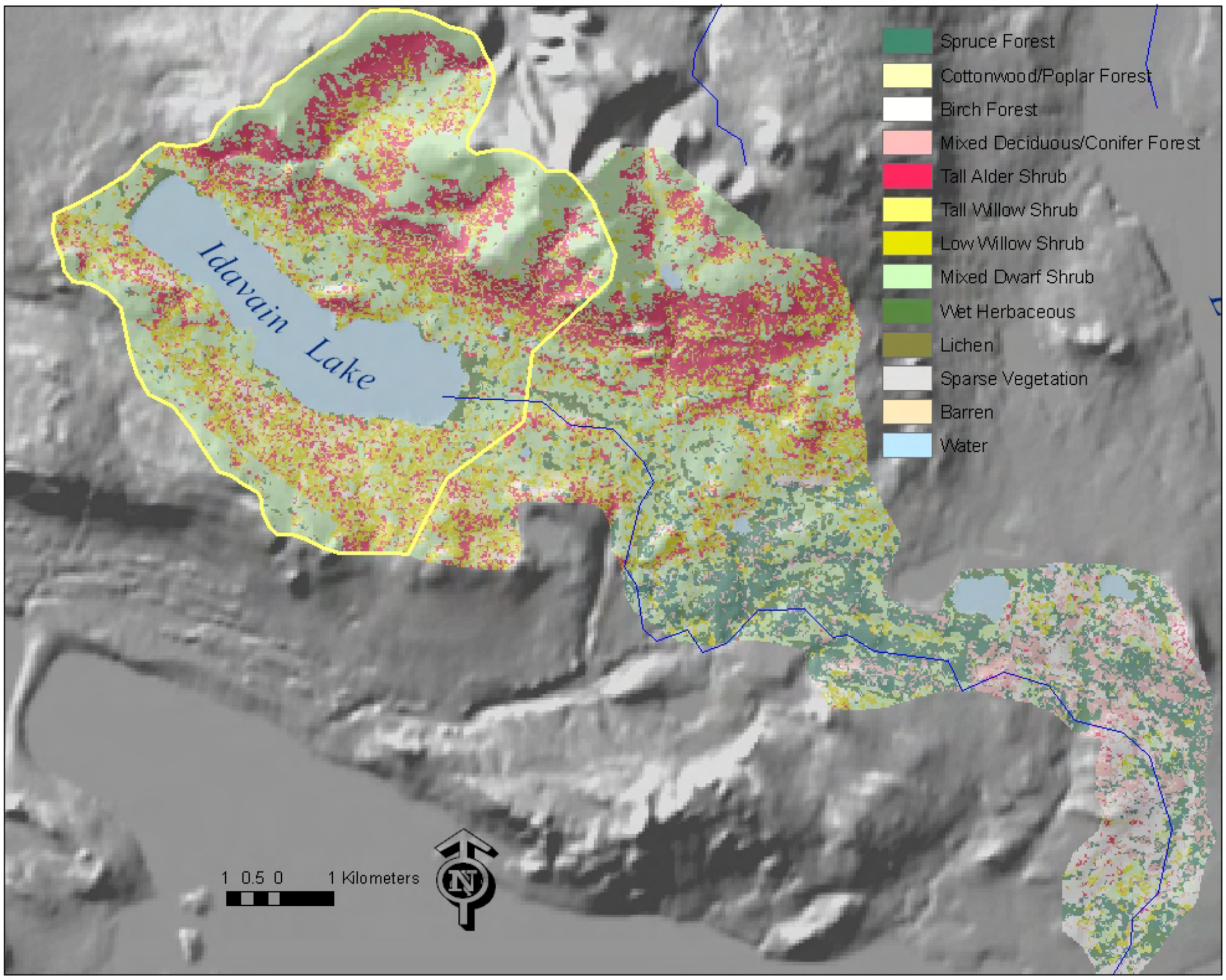

Figure 2. Regional vegetation around Idavain Lake composes of *Betula* shrub tundra and extensive *Alnus* thickets on the hill slopes (Cohn et al., pers.comm..).

Itemized Budget

Title of category	**Price per unit**	**Sample numbers**	**Total amount budgeted**
The $\delta^{18}O$ analysis on chironomid Headcapsule chitin	$15	75	$ 1125
The $\delta^{18}O$ analysis on precipitation	$22	12	$264
Reserved for Sample rerun			$111
Total			$1500

Budget justification

This proposal to Alaska Quaternary Center David and Rachel Hopkins Fellowship is to apply for the analysis of the stable oxygen isotope composition of modern chironomids headcapsules from a lake sediment core from Idavain Lake, southwest Alaska at the Alaska Stable Isotope Facility (ASIF). The isotope analysis on O and H cost $15 per sample if samples are prepared by the investigator. I will weigh out the sample myself in the laboratory. Sixty sediment subsamples will yield at least 60 chitin sample for the $\delta^{18}O$ analysis. I would also like to do some analysis on duplicate samples from at least five horizons downcore to check the sample precision of the measurements within the core. Also the oxygen stable isotope analysis on two specific species of chironomid headcapsule as well as combination of all species from one sediment sample at five random horizons will allow between species variability to be checked. Sample duplicates and specific species analysis will add another 15 samples to the budget. Therefore total 75 chironomid headcapsule samples will be analyzed for the $\delta^{18}O$.

Meanwhile precipitation samples all year around (one for each month) from southwest Alaska will also be analyzed to asses the seasonal $\delta^{18}O$ variability of precipitation. Water sample cost $22 per sample at the ASIF.

Other funding sources

I currently do not have any other funds to support this research.

References

Anderson, L., Abbott, M.B., & Finney, B.P. (2001) Holocene climate inferred from oxygen isotope ratios in lake sediments, central Brooks Range, Alaska. Quaternary Research, 55, 313-321.

Anderson, P.M., Edwards, M.E., & Brubaker, L.B. (2004) Results and paleoclimate implications of 35 years of paleoecological research in Alaska. In Developments in Quaternary Science, Vol. 1, pp. 427-440. Elsevier, B.V.

Battarbee, R.W. (2000) Palaeolimnological approaches to climate change, with special regard to the biological record. Quaternary Science Reviews, 19, 107-124.

Bigelow, N.H. & Edwards, M.E. (2001) A 14,000 yr paleoenvironmental record from Windmill Lake, Central Alaska: Lateglacial and Holocene vegetation in the Alaska range. Quaternary Science Reviews, 20, 203-215.

Bowling, S.A. (1979). Alaska's weather and climate. In Alaska's weather and Climate (ed G. Weller), pp. 1-24. Geophysical institute, University of Alaska Fairbanks, Fairbaniks, AK.

Brubaker, L.B., Anderson, P.M., & Hu, F.S. (2001) Vegetation ecotone dynamics in Southwest Alaska during the Late Quaternary. Quaternary Science Reviews, 20, 175-188.

Cuffey, K.M. & Vimeux, F. (2001) Covariation of carbon dioxide and temperature from the Vostok ice core after deuterium-excess correction. Nature, 412, 523-527.

Dansgaard, W. (1964) Stable isotopes in precipitation. Tellus, XVI, 436-468.

Edwards, M.E., Mock, C.J., Finney, B.P., Barber, V.A., & Bartlein, P.J. (2001) Potential analogues for paleoclimatic variations in eastern interior Alaska during the past 14,000 yr: atmospheric-circulation controls of regional temperature and moisture responses. Quaternary Science Reviews, 20, 189-202.

Finney, B.P., Ruhland, K., Smol, J.P., & Fallu, M. (2004). Paleolimnology of the North American Subarctic. In Long-Term Environmental Change in Arctic and Antarctic Lakes (eds R. Pienitz, M.S.V. Gouglas & J.P. Smol), pp. 269-318. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Gonfiantini, R. (1986). Environmental isotopes in lake studies. In Handbook of Environmental Isotope Geochemistry: V.2: The Terrestrial Environment B. (eds P. Fritz & J.C. Fontes), pp. 113-168. Elsevier Press, New York.

Gullan, P.J. & Cranston, P.S. (2000). Aquatic insects. In The Insects An outline of Entomology. Blackwell Science.

Guthrie, R.D. (2006) New carbon dates link climatic change with human colonization and Pleistocene extinctions. Nature, 441, 207-209.

Hu, F.S., Brubaker, L.B., & Anderson, P.M. (1995) Postglacial Vegetation and Climate-Change in the Northern Bristol Bay-Region, Southwestern Alaska. Quaternary Research, 43, 382-392.

Hu, F.S., Brubaker, L.B., & Anderson, P.M. (1996) Boreal ecosystem development in the northwestern Alaska range since 11,000 yr BP. Quaternary Research, 45, 188-201.

Hu, F.S., Kaufman, D., Yoneji, S., Nelson, D., Shemesh, A., Huang, Y., Tian, J., Bond, G., Clegg, B., & Brown, T. (2003) Cyclic variation and solar forcing of Holocene climate in the Alaskan subarctic. Science, 301, 1890-1893.

Koziet, J. (1997) Isotope ratio mass spectrometric method for the on-line determination of oxygen-18 in organic matter. Journal of Mass Spectrometry, 32, 103-108.

Lotter, A.F., Birks, H.J.B., Eicher, U., Hofmann, W., Schwander, J., & Wick, L. (2000) Younger Dryas and Allerod summer temperatures at Gerzensee (Switzerland) inferred from fossil pollen and cladoceran assemblages. Palaeogeography Palaeoclimatology Palaeoecology, 159, 349-361.

Mock, C.J., Bartlein, P.J., & Anderson, P.M. (1998) Atmospheric circulation patterns and spatial climatic variations in Beringia. International Journal of Climatology, 18, 1085-1104.

Oliver, D.R. (1971) Life history of the Chironomidae. Annual Review of Entomology, 211-230.

Sauer, P.E., Miller, G.H., & Overpeck, J.T. (2001) Oxygen isotope ratios of organic matter in arctic lakes as a paleoclimate proxy: field and laboratory investigations. Journal of Paleolimnology, 25, 43-64.

Schimmelmann, A., Lavens, P., & and Sorgeloos, P. (1987). Carbon, nitrogen, oxygen and hydrogen-stable isotope ratios in Artemia from different geographical origin. In Artemia Research and its Applications (ed J. E.), Vol. 1, pp. 380. Universal Press, Wettern, Belgium,.

Sharp, Z.D., Atudorei, V., & Durakiewicz, T. (2001) A rapid method for determination of hydrogen and oxygen isotope ratios from water and hydrous minerals. Chemical Geology, 178, 197-210.

Smol, J.P. (2002). The paleolimnologist's Rosetta Stone: calibrating indicators to environmental variables using surface-sediment training sets. In Pollution of lakes and Rivers, a Paleoenvironmental Perspective, pp. 67-78. Oxford University Press, New York.

Vimeux, F., Cuffey, K.M., & Jouzel, J. (2002) New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction. Earth and Planetary Science Letters, 203, 829-843.

Walker, I. (1995). Chironomids as indicators of past environmental change. In The Chironomidae: The biology and ecology of non-biting midges (eds P.D. Armitage, P.S. Cranston & L.C.V. Pinder), pp. 403-422. Chapman & Hall, London.

Walker, I.R. & Pellatt, M.G. (2003) Climate Change in Coastal British Columbia -- A Paleoenvironmental Perspective. Canadian Water Resources Journal, 28, 531-566.

Werner, R.A. (2003) The online O-18/O-16 analysis: Development and application. Isotopes in Environmental and Health Studies, 39, 85-104.

Werner, R.A., Kornexl, B.E., Rossmann, A., & Schmidt, H.L. (1996) On-line determination of delta O-18 values of organic substances. Analytica Chimica Acta, 319, 159-164.

White, J.W.C., Barlow, L.K., Fisher, D., Grootes, P., Jouzel, J., Johnsen, S.J., Stuiver, M., & Clausen, H. (1997) The climate signal in the stable isotopes of snow from Summit, Greenland: Results of comparisons with modern climate observations. Journal of Geophysical Research-Oceans, 102, 26425-26439.

Wooller, M.J., Francis, D., Fogel, M.L., Miller, G.H., Walker, I.R., & Wolfe, A.P. (2004) Quantitative paleotemperature estimates from delta O-18 of chironomid head capsules preserved in arctic lake sediments. Journal of Paleolimnology, 31, 267-274.