Summary

*Chironomid seasonality in a high mountain lake ecosystem – case study*

This paper summarizes result of the first complete round-year study of chironomids in the profundal zone of an oligotrophic high mountain Tatra lake – Ladové lake – chosen as the key site in the EMERGE project.

High mountain or arctic lakes are typical by the specific chironomid species composition, low species diversity at all and low abundances as well (Bretschko, 1974, Rieradevall & Prat, 1999, Aagaard, 1986, Brundin, 1956, Steinböck, 1955) Four chironomid taxa identified in the profundal of Ladové lake (after average abundances) – *Micropsectra radialis* (Goetghebuer, 1939), *Pseudodiamesia nivosa* (Goetghebuer, 1928), *Procladius (Holotanypus)* sp. and *Heterotriscladius marcidus* (Walker, 1856) – and the average chironomid density of 1 700 ind m\(^{-2}\) have confirmed this fact. The two most abundant taxa *P. nivosa* and *M. radialis* have demonstrated a univoltine life history with emergences in July and in August, respectively. According to published data, the univoltine life cycle of chironomids is expectable in high mountain or subarctic lakes (Moore, 1979, Wiederholm, 1977, Pechlaner et al., 1972, Laville & Gaini, 1974), even if in some arctic areas chironomids can need more than one year to complete development (Welch, 1976, Lindegaard, 1992). Anyway, the 5–6 month ice free period at Ladové lake ensures long season enough for a chironomid growth.

We could see that the values of chlorophyll-\(a\) and TPV (total volume of particles) in vertical samples did not provide the right answer for the amount of food available for the profundal fauna. As the results from the sedimentation trap in 13 m depth have showed, the short-term December peak of chlorophyll-\(a\) and TPV recorded in the water column have been followed by a long period of very slow sedimentation, and it did not display as a peak of TPV accumulation rate in the deepest trap. As lately as allochtonous sources entering the lake during the ice melting and spring circulation have increase a food supply in the profundal at short time.

The annual variability in chironomid abundances close correlated with an amount of dissolved oxygen above the lake bottom. Even if Ladové lake is the oligotrophic one, the high concentration of December phytoplankton common in mountain lakes (Fott et
al., 1999) could cause observed depletion of dissolved oxygen above the lake bottom during the oncoming period of winter stratification. That probably was the reason for the relocation of oxygen sensitive larvae from the deepest sediment (the abundances of larvae was zero or very low) to the upper part of lake bottom (sublittoral) and migration to the upper layer of water column (as evidenced by the swimming larvae) during this period. Such migrational behaviour is one of many adaptations to low oxygen conditions, but never has been described in a mountain lake before. To confirm the migration hypothesis, a detailed study is necessary with the possibility of taking sublittoral samples, which part of this lake bottom is formed by large boulders.

**Lake Acidification and chironomid responses**

As the first synoptic researches showed, acidification caused a decline of lake water pH and alkalinity as well as an increase concentrations of anions of strong acids and aluminum (Schindler, 1988, Kopáček & Stuchlík, 1994), which have led to the changes in lake water trophy status and consequently to very important changes in the structure of lake water community (Stuchlík et al., 1985, 2002, Fott et al., 1992, 1994, 1999). According to the responses (changes) in both of lake water chemistry and phytoplankton/zooplankton during the peak of acidification from the mid 1980s to early 1990s, lakes above timberline were categorized into three groups: non-acidified lakes, acidified lakes, and strongly acidified lakes (Fott et al., 1994).

The original chironomids species composition in non-acidified lakes did not change during the period of acidification except for the disappearance of the predaceous littoral species *Zavrelimyia* sp. and the appearance of the acido-tolerant *Zalutschia tatrica*. This species occurred in the littoral of seepage lakes affected by the seasonal acidification of surface water layers during snowmelt. Within the period of recovery from acidification, this species disappeared. Chironomid fauna of acidified lakes was also remained unchanged even in the period of strong acidification and along the process of recovery, *C. scutellata* and *Paratanytarsus austriacus* have newly appeared in some lakes of this category, which could point to increasing food availability as these taxa are considered to be more food demanded. Deep stratified lakes have experienced acidification especially in the upper epilimnetic layer and thus the profundal fauna in the deepest part of these lakes remained ensured from a direct effect of low pH (Stuchlik, unpublished...
Also decrease of phytoplankton concentration due to oligotrophication in acidified lake did not have such strong effect on chironomids as did on zooplankton. Input of allochtonous organic matter from catchment probably supported littoral species and profundal species may took advantage of biofilm on sediment-water interface. Nevertheless, the most evident changes have occurred in strongly acidified lake during the period of acidification. From the original chironomid fauna, the sensitive species vanished (*Micropsectra* sp., *T. lugens* and *Zavrelimyia* sp.) and new acid-tolerant appeared (*Tanytarsus gregarius*, *Zalutchia tatrica*, *Chironomus* sp.) persisting to this day. This group of lakes is represented by small and relatively shallow lakes (1.6-4.2 m) and acidified water probably reached to the lake bottom, which directly affected the profundal biota. *Chironomus* sp., species well know from productive dystrophic forest lakes in the High Tatra Mts. indicates an increased concentration of food during acidification. This may support hypotheses about acidification induced eutrophication of strongly acidified lakes.

**Reconstruction of past environmental conditions based on subfossil chironomid stratigraphy in lake sediments.**

The Bohemian forest lake sediments were previously studied by Veselý et al. (1993) and Veselý (1998, 2000) for pollen and metal pollution to evaluate the development of human impact in this remote mountain area over period of last four millennium. Except of contamination by Pb and Cd about 2 000 ago, they also found abrupt changes in the pollen stratigraphy around 3 100 BC and 800 BC which credited with climate shifts. To assess whole lake history, a 543 cm long core covering period of ca. 14.5 cal ka BP was collected from the Plešné Lake. Chironomid remains was analyzes in the upper 280 cm representing 10.4 cal ka BP.

The recent chironomid fauna is formed mainly by Orthocladiinae, and this group also dominated across the whole Holocene sediment. It points out that the trophic status of the lake could have been oligotrophic to mesotrophic, but probably never became eutrophic in its history. At the beginning of the Holocene (ca. 10.4–10.1 cal ka BP), only oligotrophic and cold-adapted taxa (*Diamesa* sp., *Micropsectra insignilobus*-type and *Heterotrissocladius grimshawi*-type) have occurred clearly reflecting a cold climate oscillation during the Preboreal period. The high rate of sedimentation recorded at this
period resulted from a material input from the lake catchment having open tundra vegetation. Following variations in the chironomid fauna after the Preboreal period were reflected mainly by changes in abundances of dominant taxa rather than by changes in species composition. The history of littoral chironomid fauna was closely connected with macrophyte fluctuations (namely quillwort Isoëtes), i.e. lake level fluctuations, resulting from changes of precipitation during the Holocene. At the end of Epiatlantic epoch (6–4.5 cal ka BP), the Plešné lake have probably passed dry climate as abundances of most dominant littoral taxa decreased as well as Isoëtes pollen and semi-terrestrial species (Lymnophyes/Paralymnophyes) became more abundant. Chironomids overall experienced the raise of Chironomini portion during the Middle Holocene, which was partly a result of generally very warm climate and partly of increased afforestation leading to the higher input of organic matter into the lake. The profundal community has not changed dramatically since Boreal for almost 7 000 years, although an evident decrease in the abundance of dominant Heterotrissocladius marcidus was recorded already from ca. 6 cal ka BP. The significant decrease and following extinction of this profundal taxa around ca. 2 ka cal BP, referred to changes in profundal conditions, most likely the increasing of organic matter in the sediment and possible oxygen depletion. The presence of Plantago lanceolata and Rumex acetosella pollen indicating grazing, points to the development of cultural fields and settlements at this time, which could have leaded to the increasing of the lake trophic status (Jankovská, 2006). These mesotrophic conditions persisted to the present, as the presence of Chironomus anthracinus-type in the upper layers confirm. The gradual progression of the chironomid fauna was interrupted by an event in the 1540–1771 interval, when most taxa have entirely vanished. Although, the dating of this event falls into LAI period, the problem of very low sums recorded in this sediment layers makes the fossil record less reliable.

**Chironomid-inferred Holocene summer temperatures**

A number of regional chironomid-inferred temperature models have been development and successfully used for reconstruction of the Lateglacial climate fluctuations (Walker et al., 1991, Lotter et al., 1997, Olander et. al., 1999, Brooks & Birks, 2000, 2001, Larocque et al., 2001, Heiri & Lotter, 2005, Heiri et al., 2007). However, the Holocene
time period records relatively small temperature variability that is often within the prediction errors of the temperature inference models (Broecker, 2001), compared with more pronounced changes occurred during the Lateglacial. Nevertheless, the Holocene temperature reconstruction from Alps (Heiri et al., 2003) demonstrate the ability of chironomid-based temperature inference models to record not only the high magnitude of temperature variations in the Lateglacial, but also a smaller climate signals in the Holocene.

In co-operation with dr. Heiri from the Utrecht University in Netherland, we used the chironomid-July air temperature inference model developed for the Swiss Alps. This transfer function has been calculated by weighted average-partial least squares regression (WA-PLS) (ter Braak, 1995) from a calibration data set relating chironomid distribution from 89 Swiss lakes (Lotter et al., 1997). WA-PLS with two components yielded a chironomid-July air temperature inference model with an $r^2$ of 0.81 and a root mean square error of prediction (RMSEP) of 1.51°C. For more statistical procedure see Heiri et al. (2003). This numerical model was successfully used for the Holocene paleotemperature reconstruction based on subfossil chironomids from three Swiss Alps, as well as for the Lateglacial temperature estimation from Netherlandish lowland lake. It confirms a fact that the chironomid-temperature models can be applied outside of the geographical area they have been developed for.

The inferred July air temperature varied from 10.6 to 14.0°C. The oldest samples coinciding with the period of Preboreal (10.3–9 ka cal BP), produced a temperature range 10.6–12.2°C and showed decreasing trend. During the Boreal interval (9–8 ka cal BP), the largest warming would supposes to take place persisting over next 2,000 years. The temperature inferred for this interval varied between 11.4–12.4°C with a decreasing tendency reversing around 8 ka cal BP. The reconstructed temperature for the followed period of the Late Holocene shows an opposite trend than that is known for European climate history, and exhibits large fluctuations (Fig. 3). Overall, reconstructed temperature demonstrates increasing trend during the Late Holocene with a reverse in period of 3-2 cal ka BP.
The quantitative temperature reconstruction from Plešné lake does not follow the common trend of the maximum temperature recorded in the early Holocene and subsequent cooling, as was documented by chironomid record from other sites throughout much of the northern hemisphere (for reviews see Larocque & Hall., 2004). Although, climate was probably the most important factor affecting not only chironomid fauna in lakes of Europe and North America, during the Holocene, local changes in the hydrology, vegetation history and soil development in the lake catchment could mask the impact of temperature on water biota, including chironomids. Other factors, such as water level fluctuation, nutrient loading, and changes in dissolved oxygen concentrations may have also overridden the effects of temperature on midges during
certain periods of the Holocene (Heinrichs et al., 2005, 2006, Antonsson et al., 2006). These factors are either directly or indirectly related to climate as well.

As was recorded in the chironomid stratigraphy, the abundance of the most dominant taxa has apparently reduced already from ca. 6 cal ka BP and later, the significant decrease (around ca. 2 ka cal BP) and following extinction has occurred (since 1.5 ka cal BP). One of the possible explanations is a depletion of dissolved oxygen content resulting from the increased organic material input from the lake watershed, which made unfavorable conditions for this chironomid taxon. Over the period ca. 6–5 cal ka BP, the greatest afforestation took place in the catchment of Plešné lake, when *Abies*, *Picea* and *Fagus* have formed climax forest that has become a source of organic matter for the lake. Since ca. 2 cal ka BP, the pollen analysis showed a first distinct human impact on the original vegetation: the mixed oak wood retreated and synanthropic herb vegetation began its most intensive expansion. Human activities near the lake have resulted in an increasing of nutrient loading that probably has led to the oxygen deficiency or anoxia (Fig. 3). Also Heiri & Lotter (2003) found in the Swiss Alp lake Sägistalsee that the early human presence in the lake catchment and the lake susceptibility to the anoxia can lead to the incorrect Holocene temperature reconstruction.

The geochemical analysis of Mn/Fe ratio in the lake sediments is commonly used as indicator for paleo-redox conditions (Davison, 1993). In oxygenate waters, Fe and Mn form insoluble precipitates and are transported to deeper areas. Generally, the reduced form of Fe is less stable in the water column than that of Mn and consequently Mn/Fe ratios in the sediment are low when the sediment becomes anoxic (Koining et al., 2003). Decreasing trends of Mn/Fe molar ration in the sediment from Plešné lake (Fig. 3) suggest the oxygen depletion could be the explanatory factor that has overridden the effects of temperature on chironomid community.