CHIRONOMIDAE (DIPTERA) IN ALPINE LAKES: A STUDY OF SUBFOSSIL ASSEMBLAGES IN LAKE SURFACE SEDIMENTS

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With 3 Figures and 1 Table

ABSTRACT: Subfossil chironomid assemblages in surface sediments from Swiss mountain lakes show a strong, statistically significant relationship with lake depth and with parameters related to altitude, such as July temperature, dissolved organic carbon concentration, or organic matter content of the sediments. Unexpectedly, water chemistry variables such as total phosphorus concentration and pH were not identified as relevant parameters.

RESUMO: As comunidades dos sub-fósseis quironomídeos existentes nos sedimentos de superfície presentes nos lagos montanhosos da Suiça, mostraram uma associação estatisticamente significativa com uma série de parâmetros ambientais. São de destacar a profundidade do lago, mas também parâmetros relacionados com a altitude, tal como a temperatura do mês de Julho, concentração de carbono orgânico dissolvido e conteúdo de matéria orgânica dos sedimentos. Todavia e, apesar de esperado, as variáveis relacionadas com a química da água, tal como concentração de fósforo e pH, não foram consideradas como variáveis estatisticamente relevantes.

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INTRODUCTION

Our knowledge of the chironomid fauna of mountain lakes is still fragmentary, probably mainly due to logistic problems associated with sampling benthic organisms in high altitude lakes. In the European Alps, the chironomid fauna of only a few selected high altitude lakes has been studied intensively with monthly visits and a detailed analysis of larval assemblages (e.g. BRETSCHKO 1974). Other surveys have analyzed the chironomid communities in a number of alpine lakes (e.g. BOGGERO *et al*. 2006) but were usually restricted to a single visit per lake during which chironomid larvae were obtained from the littoral of these using kick sampling, with no samples from deep-water environments analyzed.

Chironomid remains, especially the strongly sclerotized larval head capsules, are well preserved in lake sediments. Recent advances in fossil chironomid taxonomy, allow fossil chironomid head capsules to be identified to the generic level and in many cases to an even higher taxonomic resolution. The top 1-2 cm of sediment in the lake centre typically encompasses remains of larvae inhabiting the lake in the past years to a few decades at most. These surface sediment subfossil assemblages can be analyzed to assess the contemporary chironomid fauna of lakes (e.g. LOTTER *et al.* 1997). The method has a number of advantages. First, chironomid remains from several years are usually incorporated into the top 1-2 cm of lake sediment; thus a single sample will include chironomids living in the lake at different times of the year and provide a robust estimate of the chironomid assemblage composition. Second, sediment particles tend to move towards the deepest part of a lake basin. Therefore, a single sample taken in the deepest part of a lake will incorporate not only remains of chironomid larvae inhabiting the centre of the lake basin but also remains transported from the littoral region. Due to the processes mentioned above, a single sediment sample can provide an integrated estimate of chironomid diversity and abundance in a lake over time (i.e. over several years) and space (i.e. in the entire lake basin). As a consequence, the analysis of lake surface sediments is a very effective method for monitoring chironomid assemblages in relation to their environment.

This study examine the chironomid faunal communities from 45 high-altitude lakes in the Swiss Alps by analyzing subfossil chironomid assemblages in surface sediments. The survey intends to document the dominant chironomid taxa in these lakes, relate chironomid assemblage composition to major physical and chemical parameters and, demonstrate the usefulness of chironomid remains in lake surface sediments for studying the chironomid fauna in remote mountain lakes.

METHODS

Lake surface sediment samples were obtained from the deepest part of the lake basins using a gravity corer. From each core the top 1-2 cm of sediment was analyzed for fossil chironomids using standard methods. Further details on fieldwork and the measurement of environmental variables are presented in LOTTER *et al.* (1997), HEIRI (2001) and BIGLER *et al.* (2006). Of the 115 chironomid assemblages presented in these publications only those from 45 mountain lakes situated higher than 1800 m a.s.l. are discussed here (Fig. 1). For direct gradient analyses we used the program CANOCO version 4.5 (TER BRAAK & ŠMILAUER 1998).

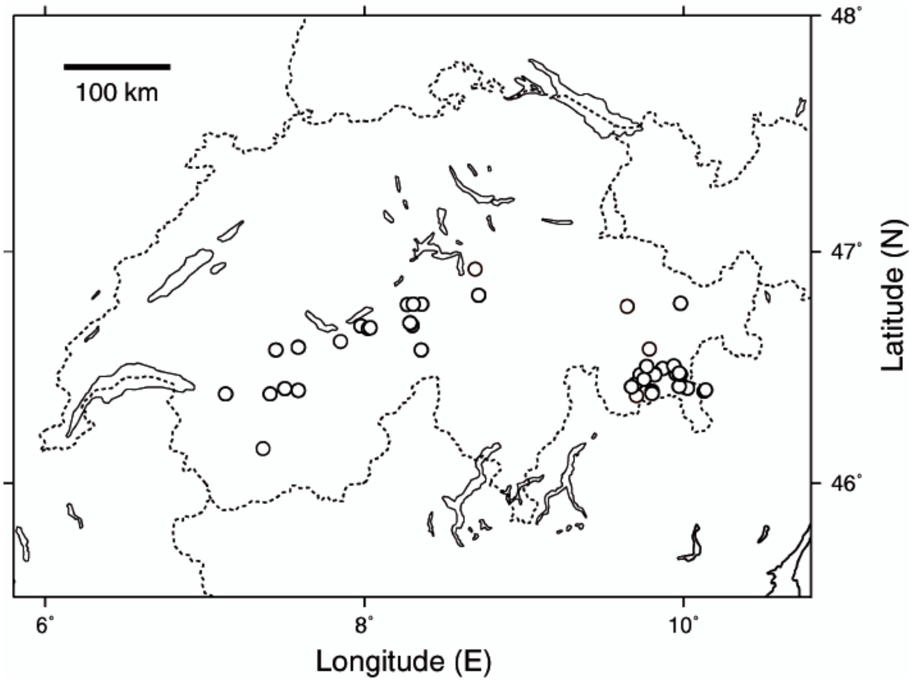

Figure 1. Outline map of Switzerland. The circles indicate the different study sites.

RESULTS AND DISCUSSION

The distribution of most chironomid taxa showed a strong relationship with altitude (Fig. 2). Lakes higher than 2400 m a.s.l. were dominated by taxa such as *Pseudodiamesa*, *Micropsectra radialis*-type and *Paracladius*. Between ca. 2400 and 2000 m a.s.l. taxa such as *M. radialis*-type, *Psectrocladius sordidellus*-type, and *Tanytarsus lugens*-type showed high abundances and chironomid remains belonging to, e.g., *Paratanytarsus austriacus*-type, *Heterotrissocladius marcidus*-type, *Zavrelimyia* type A and *Micropsectra insignilobus/contracta*-type reached moderately high abundances. In lakes between 1800 and 2000 m a.s.l. taxa such as *T. lugens*-type, *H. marcidus*-type, *Chironomus anthracinus*-type and *Stictochironomus* were found at high abundances. Furthermore, a range of taxa which are absent or only occur at low abundances at higher altitudes occur regularly in these lakes, e.g. *Dicrotendipes nervosus*-type, *Heterotrissocladius grimshawi/scutellatus*-type, or *Microtendipes*.

We used direct gradient analysis (Table 1) to assess how well the measured environmental variables can explain the distribution of chironomid remains in the study lakes. Variables strongly correlated with altitude all explained statistically significant amounts of variance in the chironomid assemblages. Similar to findings by BIGLER *et al.* (2006), dissolved organic carbon of the lake water (DOC) and the organic content of the sediments explained more variance than July air temperature. Dissolved or total organic carbon concentration of lake water and the organic matter content of the sediments were also identified as important explanatory variables for chironomid assemblages in subarctic and arctic regions. It therefore seems that at the cold end of the temperature gradient the relationship between chironomid assemblages and summer temperature that has been reported by numerous studies may be influenced by the effects of organic carbon content of lake water and sediments on the larvae. In addition to parameters correlated with altitude, maximum water depth was also identified as a significant explanatory variable (Table 1). Again, this is not surprising, since the depth of a lake basin will have a distinct influence on factors of importance for the survival of chironomid larvae, e.g., water temperature at the sediment-water interface, light and food availability, and habitat structure (e.g. composition of the substrate, presence or absence of aquatic macrophytes).

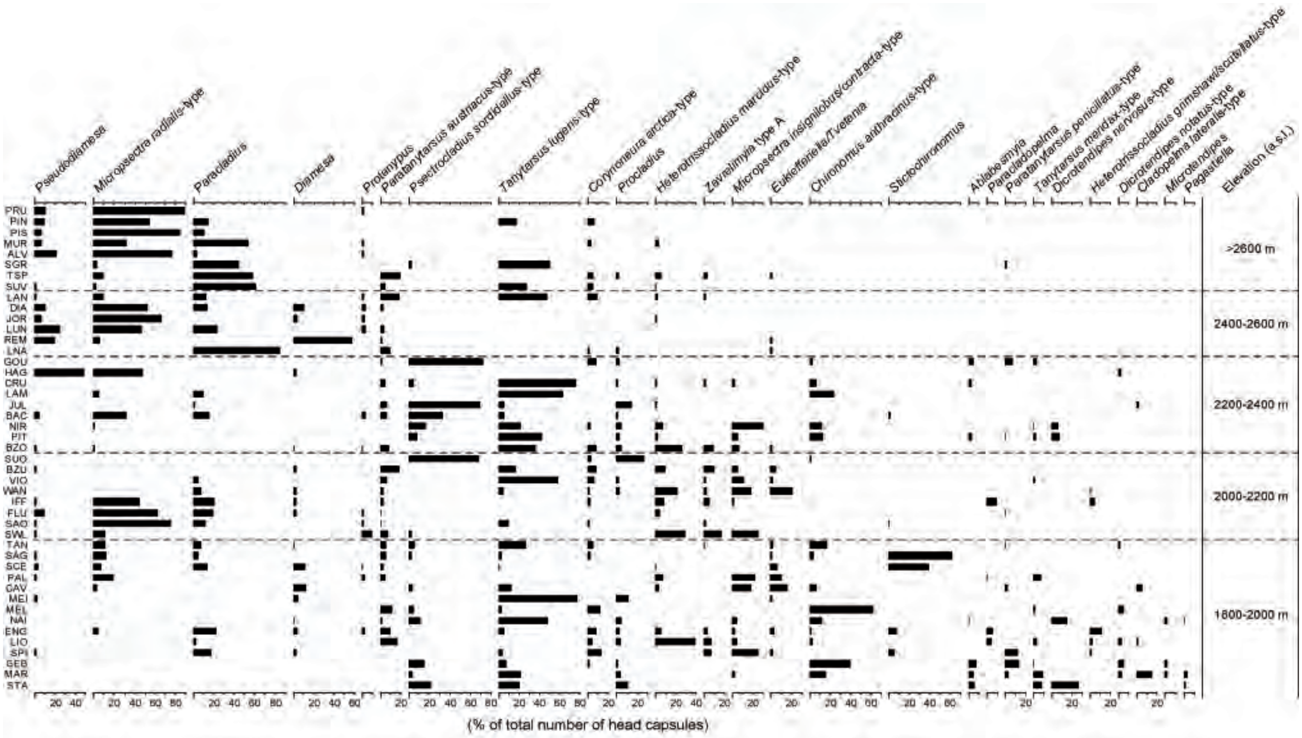

Fig. 2: Subfossil chironomid assemblages analyzed in the surface sediments of 45 mountain lakes in Switzerland. The sites are arranged according to altitude and only the most abundant taxa are shown.

Of the measured environmental variables, lake water alkalinity, pH, and total phosphorus content (TP) explained only low proportions of variance in the chironomid data and these relationships were not significant as assessed by a Monte Carlo permutation test (Table 1). Phosphorus is a key element limiting algal growth and productivity in lakes and TP has been identified as an important explanatory variable for the distribution of chironomid assemblages in a data set containing Central European lakes from the lowlands to the alpine zone (LOTTER *et al.* 1998). The weak relationship between chironomid assemblages and TP in mountain lakes is therefore an unexpected result. Lake water pH has also been repeatedly reported as being a significant variable affecting chironomid larvae (e.g. BROOKS *et al.* 2007, and references therein). However, in our survey pH does not explain a significant proportion of the variance in the chironomid assemblages, possibly due to the fact that no strongly acidified lakes were included in our survey, although the sampled sites included lakes over more than 2 pH units.

TABLE 1: Direct gradient analysis of subfossil chironomid assemblages in 45 surficial lake sediments and measured environmental parameters, and the correlation of these parameters with elevation. %Var indicates the explanatory power of axis 1 of a Canonical Correspondence Analysis (CCA) with the tested environmental parameter as sole constraining variable, n indicates the number of sites at which the different parameters were measured and r is Pearson's correlation coefficient calculated between the tested variable and altitude. Relationships statistically significant at the P=0.01 level as assessed by a Monte Carlo permutation test (999 permutations) are marked with an asterisk (*).

Environmental parameter	**Range**	**n**	**r**	**% Var**
Altitude (m a.s.l.)	1809-2815	45	1.00	8.5*
Mean July air temperature (°C)	5-11	45	-0.95	9.2*
Max. water depth (m)	2.1-49.0	45	-0.14	5.9*
Dissolved organic carbon (DOC) concentration (mg/l)	0.4-4.6	37	-0.55	13.0*
Alkalinity (mmol/l)	0.1-2.8	43	-0.59	3.6
pH	6.4-8.7	42	-0.30	3.2
Total phosphorus (TP) concentration (µg/l)	4-28	43	0.04	3.5
Sedimentary organic matter (% DW)	3-45	35	-0.29	10.9*

The combined effect of the different environmental variables on the chironomid assemblages is perhaps best illustrated in the distribution of selected chironomid taxa. For example, *C. anthracinus*-type, *H. grimshawi/scutellatus*-type, *Paracladopelma*, *P. sordidellus*-type, and *Stictochironomus* are all restricted to the warmer end of the summer temperature gradient included in our survey. However, the secondary environmental parameters influencing their distribution differ among these taxa (Fig. 3). *C. anthracinus*-type and *P. sordidellus*-type tend to have high abundances in lakes with comparatively high DOC values and are largely absent from lakes with low DOC. *H. grimshawi/ scutellatus*-type and *Paracladopelma*, on the other hand, are largely restricted to deep lakes and are absent from the shallower ones. *Stictochironomus* is found only in lakes with low sedimentary organic matter content. *T. lugens*-type, finally, is present over the entire summer temperature gradient covered in our study. However, in contrast to lowland lakes, where larvae of the *T. lugens*-type (e.g. *Tanytarsus bathophilus*, *T. lugens*) are typically encountered in the hypolimnion of deep and stratified lakes (REISS & FITTKAU 1971), the taxon shows a marked preference for shallower lake ecosystems in our study.

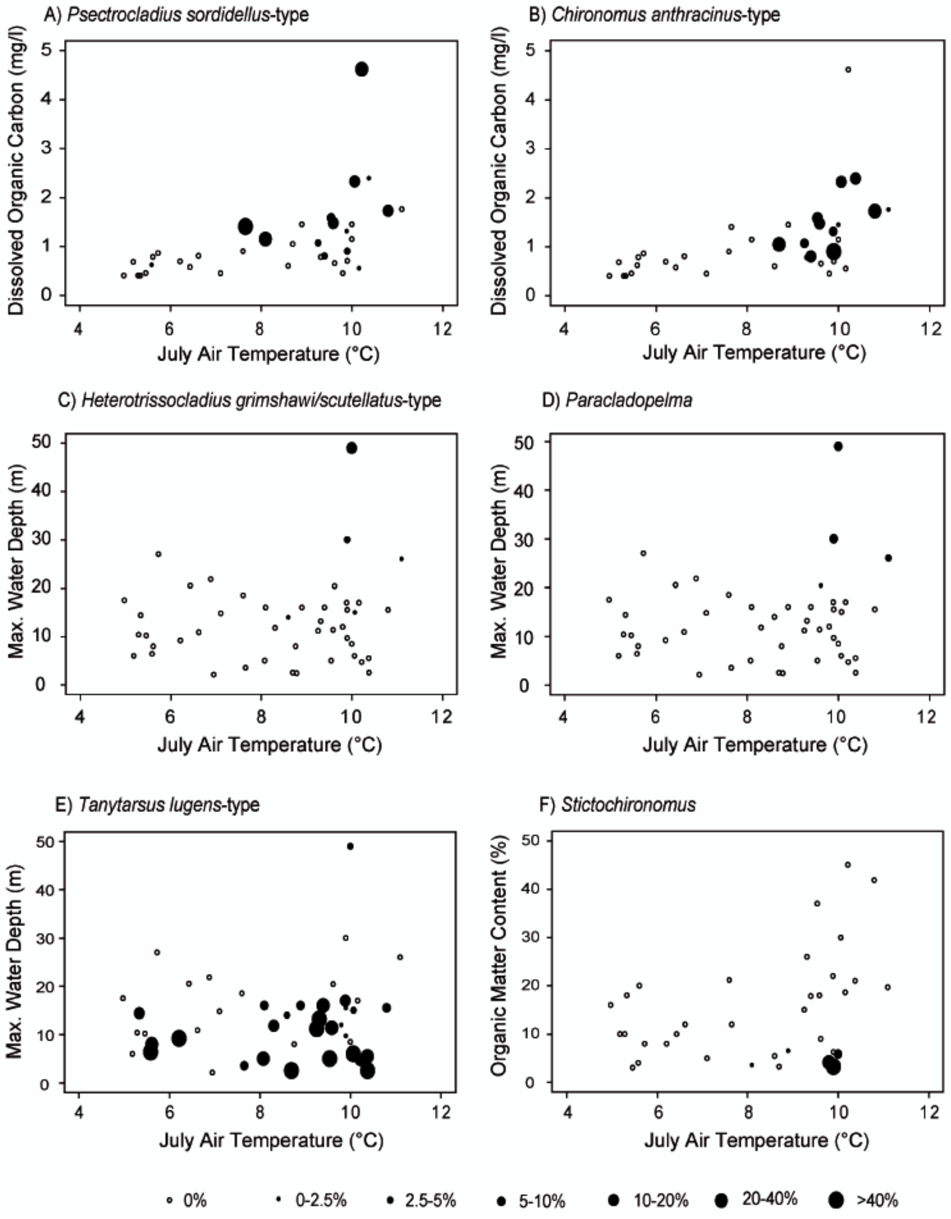

Fig. 3. Distribution of selected chironomid taxa in the 45 study lakes with respect to summer temperature and DOC concentrations (A-B), maximum water depth (C-E), and the organic content of the sediment (F). The symbol size in the different scatter plots indicates the percent abundance of the chironomid taxa in the lakes.

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