Lauterbornia 68: 59-70, D-86424 Dinkelscherben, 2009-12-17

Subfossil chironomids in shallow lakes of northern Germany

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With 4 figures and 3 tables

Keywords: Chironomidae, Diptera, Insecta, Brandenburg, Germany, lake, subfossil, paleolimnology, functional groups
Schlagwörter: Chironomidae, Diptera, Insecta, Brandenburg, Deutschland, See, subfossil, Paläolimnologie, Biozönotik

In this study, the chironomids of five shallow lakes in northern Germany were investigated using a freeze corer technique for sampling. The aim of the study was to analyse the chironomid assemblages to find evidences for the historical status of the various lakes concerning taxonomic composition, lake productivity and habitat (macrophyte coverage). Chironomid head capsules from sediment layers of various time periods (from before 950 A.D. to 1950 A.D.) were identified. Based on the taxonomical and ecological analysis, different lake types are pointed out. Over the time span studied, some lakes were conservative in taxa composition and ecological functions, while others changed between periods. These results suggest that no single pristine lake status can be inferred for shallow lakes, but different ones have to be considered, reflecting the individual history and situation of each lake.

1 Introduction

Recent shallow lakes are frequently eutrophied due to intensive increase of human populations and land use. However, eutrophication from anthropogenic causes is not always the case (Gathorne-Hardy et al. 2007, Woodward and Shulmeister 2005), as high productive conditions in a lake can also be natural. For restoration concepts and similar purposes, knowledge of the pristine lake status is crucial. In northern Germany, most shallow lakes can be classified as eutrophic, polytrophic or hypertrophic. Following the EU Water Framework Directive, the ecological quality of the larger of these lakes should be enhanced, with reference to potential natural conditions. In order to estimate the natural conditions prior to greater impact by man, palaeolimnological studies were performed at five lakes. This paper presents some results on (1) the actual ecological character of the lakes as indicated by chironomids; (2) the possible inference on pristine conditions, e.g. trophy parameters, lake depth and macrophyte coverage; and (3) indication of different states or changes of lake quality and function in different time layers, from low to high impact periods. Only data on chironomids are evaluated here. Results from other organisms (diatoms, macrophytes, cladocera) have been presented in Mischke et al. (2003) following the multi-proxy approach of Jeppesen et al. (2001). A more detailed and extended analysis of the communities and inference on ecological settings will be given by Orendt et al. (in prep.).

2 Study sites

The lakes investigated are situated in the region southeast of Berlin. Having originated from the melting of glaciers at the end of the last ice age (10,000 B.C.), they now lie within the catchment of the River Spree, which flows through Lake Schwieloch and receives tributaries from two more of the studied lakes (Kossenblatter See, Langer See). The lakes are highly productive and classified as highly eutrophic to hypertrophic according the LAWA classification system (LAWA,1999); none of them are stratified. Mean water depths ranged between 1.2 and 3.1 m. Details are given in table 1. All lakes can be considered as plankton-dominated. At present, the lakes are used mainly for recreation (swimming, angling, boating). Land use in the lake catchments includes a greater than 20% share of intensive agriculture. In earlier times, the land was used for settlements and fisheries by Slavs and Germans (Tab. 2). Periods of denser settlement (Middle Ages) alternated with periods of nearly complete depopulation (Baroque period, Thirty Years' War). The layers for chironomid analysis were selected according to distinct periods of changing impact of man in the region (Tab. 2), inferred from pollen analysis (see pollen diagrams by Brande & Schindler in Mischke et al. 2003).

Tab. 1: Lake and sampling data (from Mischke et al. 2003)

Lake name	Acronym	Corer length (cm)	Sampling date	Lake surface (10^6 m^2)	Lake volume (10^6 m^3)	Catchment (m^2)	Mean depth (m)	Max. depth (m)
Großer Kossenblatter See	KS	250	13.09.2001	1.68	3.46	<40	2,00	4.0
Langer See near Dolgenbrodt	LS	280	14.09.2001	1.38	3.27	395	1.40	3.5
Rangsdorfer See	RA	220	08.04.2002	2.45	3.80	41	1.53	2.0
Blankensee	BLA	275	09.04.2002	2.90	3.42	738	1.18	3.9
Schwielochsee	SLS	290	10.04.2002	11.50	35.4	530	3.08	4.0

Tab. 2: Periods of human impact and dates of sampled layers (adapted from Mischke et al. 2003). Dating of periods I/II - V extrapolated from pollen diagram results (see methods); dating of period I extrapolated from core bottom AMS carbon isotope dating, which may have been biased by a hard-water effect (values between brackets), see sextion "Study site"

			Layers dated and analysed				
Period	Dating	Human impact	Langer See	Kossenblatter See	Blankensee	Schwielochsee	Rangsdorfer See
V	2001-1950 A.D.	high	-	-	-	-	-
IV	1950-1750 A.D.	medium to high	-	-	-	-	1920
III	1750-1500 A.D.	low	1750 A.D.	1758 A.D.	1644 A.D.	1656 A.D.	-
II	1500-950 A.D.	medium to high	1450 A.D.	1572 A.D.	800 A.D.	1200 A.D., 1428 A.D.	1236
I	before 950 A.D.	low	(791 B.C.)	(1560 B.C., 798 B.C.)	(400 B.C. 200 A.D.)	(658 A.D.)	-

In general, the historical increase of human impact detected from the large decrease of tree pollen and increase of cereal seeds is the most significant character in core stratification. Except for Rangsdorfer See, the later stages of the Subatlantic period (800 B.C. to 1200 A.D.; period I in table 2) were identified in the lower parts of all cores analysed according to the regional zonation after Brande (1996; *Fagus* and *Carpinus*, based on the regional vegetation history corresponding to period IX in Firbas 1949). In the Berlin-Brandenburg region, the period of intensive colonization started at 1200 A.D. (period II in table 2; refers to the beginning of period X according to Firbas, 1949), which is late compared to other regions. In period III (Tab. 2), the increase of tree pollen and decrease of cereal seeds indicates the so-called Little Ice Age (approximately 1500–1885 A.D.) and a decreased human impact when the local human population crashed to 10 % of previous levels due to the Thirty Years' War from 1618 to 1648. According to Brande (1996), more recent signals are represented by the pollen of *Aesculus*, which was introduced by man from 1750 A.D. on (period IV in table 2), and by the recent increase of seeds caused by intensified agriculture (period V in table 2).

The dating of periods I/II–V is extrapolated from pollen diagrams. The dating of the strata in period I (before 950 A.D.; Tab. 2) is an extrapolation based on the core bottom AMS carbon isotope method. However, it turned out that results of the analysis were disturbed by a strong hard-water effect (see Grootes in Mischke et al. 2003). Therefore, those dates are unreliable concerning the exact number of years before 950 A.D. The figures (Tab. 2) concerned are given in brackets.

3 Material and Methods

Samples were taken in 2001 and 2002 using a freeze corer technique (Varlemann, 2000, Mischke et al. 2003). The cores were frozen with liquid nitrogen and stored at -28 °C. In the laboratory, they were cut in slices of 10 cm with a hot wire. A portion of the sediment was sieved through 400 μm, 200 μm and 100 μm mesh, the fossils were picked out with forceps; another portion was processed for other analyses not presented here (e.g. pigment and pollen analysis: Hoffmann et al. 2002; diatoms: Schönfelder 2002; macrophyte remains: Körner 2002, 2003; heavy metals: Varlemann 2001). For each chironomid taxon, the individuals from all sample fractions were totalled. The latter values were then converted to relative abundance in %.

Core layers for chironomid analysis were selected according to distinct periods of changing human impact in the region (Tab. 2), as inferred from pollen analysis (see pollen diagrams by Brande & Schindler in Mischke et al. 2003). From most lakes three or four layers were evaluated for chironomids, from

Rangsdorfer See only two layers. Larval head capsules were mounted on microscope slides in Euparal, then identified using Wiederholm (1983), Hofmann (1971), and Moller Pillot et al. (1997).

The analysis of ecological function metrics indicated by the traits of the chironomids, as well as the taxonomic composition including dominance, should detect differences between the periods or lakes ecosystem functions. The assignment of dominant or subdominant status (as in table 3, figures 2 and 3) for the community analysis was based on results using multivariate methods (Orendt et al. in prep.). However, the metrics concerning ecological traits (feeding type preference, habitat preference) were calculated with all taxa recorded (Fig. 4) applying ASTERICS software V. 3.01 (University of Duisburg-Essen 2008). Only shares of feeding type and dwellers were used as metrics, because they provided sufficient information for statistical evaluation. More precisely, the relative abundance of the taxa, which indicate habitat preferences or feeding habits, should total >70 % of the total abundance (see ASTERICS 3.01), on average. Out of these, only those metric categories of major importance (e.g. portion of phytal dwellers, etc.) were included in the further evaluation which accounted for >50 % on average. Using this criterion, three dweller types (pelal, psammal and phytal dwellers) and three feeding types (gatherer/collector, miner, active filter feeders) were selected. Further multivariate analyses of taxa and metrics will be presented elsewhere (Orendt et al., in prep.).

4 Results

4.1 Taxa list and dominant taxa

A total of 44 taxa were identified from the layers of the five lakes studied (Tab. 3). None of them is decidedly profundal in habitat preference; instead, all are known to be distributed in the littoral zone. The dominant taxa were *Glyptotendipes* sp., *Chironomus* sp. (which were over three times more abundant than *Microchironomus tener* and *Cladotanytarsus mancus* group), followed by *Procladius* sp., *Polypedilum nubeculosum* group, *Tanytarsus* sp., *Dicrotendipes* sp., and *Cricotopus sylvestris* gr. Within *Glyptotendipes*, four types of larvae were discernible: *G. cauliginellus (*syn. *gripekoveni), paripes, caulicola* and *mancunianus/viridis*. Head capsule photographs of some taxa are given in figure 1.

A cluster analysis based on the relative abundance of the taxa in the layers of all lakes identified two taxa groups and two site groups (grouping in table 3 based on cluster analysis in Orendt et. al., in prep.). In the plot of the relative abundance of dominant and subdominant taxa (groups 1 and 2 in figure 2), the two taxa groups are separated well, suggesting two different types of communities dominated by *Chironomus* sp. and *Glyptotendipes* sp., respectively.

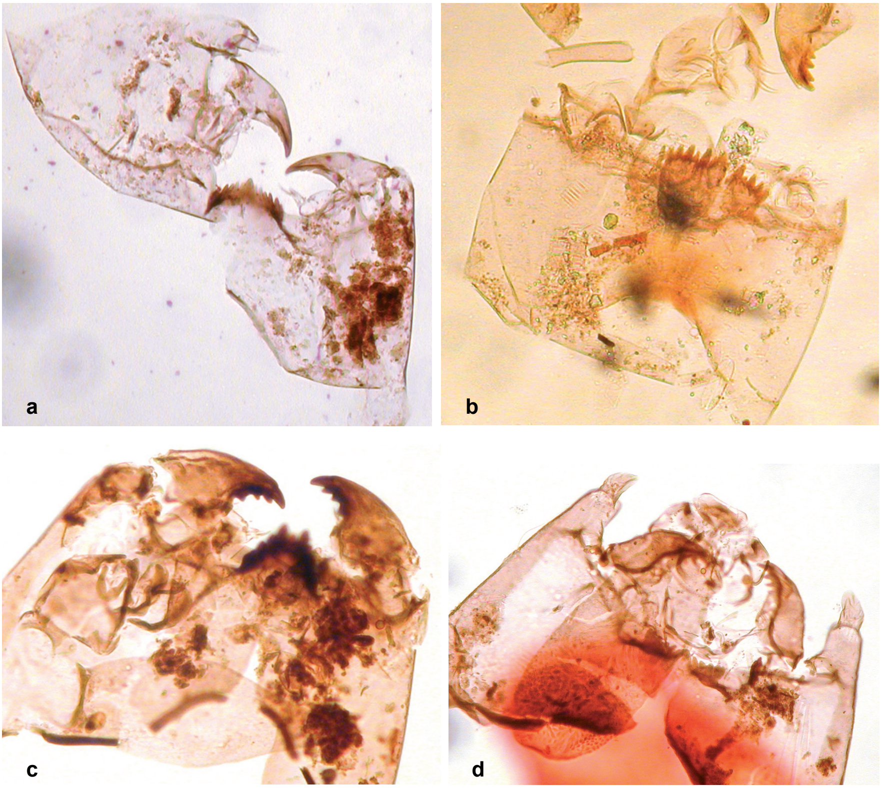

Fig. 1: Head capsules of subfossil chironomids recorded from the shallow lakes in Brandenburg (phot. U. Mischke). a = *Microchironomus tener*; b = *Cladotanytarsus mancus* group; c = *Glyptotendipes* cf. *caulicola*; d = *Thienemanniola ploenensis*

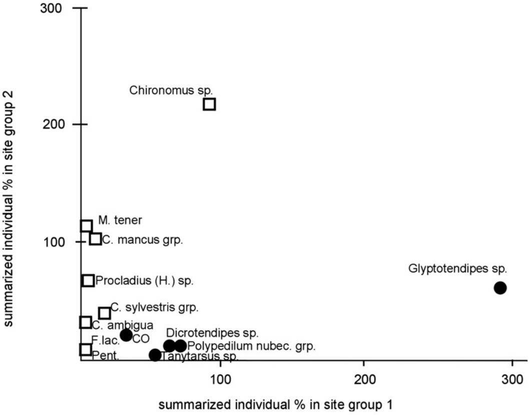

Fig. 2: Plot of summarized individual percentages of significant taxa from the two site and layer groups of the lakes studied

Tab. 3: Taxa recorded in the layers from the shallow lakes in Brandenburg, and their relative abundance (%) in different site and taxa groups after cluster analysis. BLA = Blankensee, KS = Kossenblatter See, LS = Langer See, RA = Rangsdorfer See, SLS = Schwielochsee; numbers indicate years. Bold figures: Abundance of taxa in this group significantly higher than in the other. Separation of groups according to cluster analysis by Orendt et al. (in prep.)

		Site group 1								Site group 2										
		LS 791 B.C.	LS 1450	BLA 400 B.C.	BLA 200	KS 1560 B.C.	KS 798 B.C.	KS 1572	KS 1758	SLS 658	SLS 1656	SLS 1200	SLS 1428	LS 1750	BLA 1644	RA 1236	BLA 800	RA 1920	sum site group 1	sum site group 2
Taxa group 1	Glyptotendipes sp.	**23.5**	**54.6**	**40.9**	**39.3**	**38.3**	**34.0**	**32.7**	**29.1**	1.1	7.8	11.6	2.3	3.1	3.2	7.4	9.5	11.9	**292.2**	57.9
	Dicrotendipes sp.	**0.5**	**4.0**	·	**4.6**	**18.6**	**2.8**	·	**4.6**	3.5	·	0.2	·	3.4	7.0	2.1	0.6	·	**35.1**	16.7
	Cricotopus/Orthocladius	**3.3**	·	·	·	**3.1**	**8.1**	**8.5**	**31.8**	·	·	·	·	·	·	·	·	·	**54.8**	0.0
	Tanytarsus sp.	**44.4**	**5.5**	·	·	**6.2**	**3.3**	·	**4.6**	·	·	1.5	2.3	4.2	·	·	·	·	**64.0**	8.0
	Polypedilum nubeculosum gr.	**9.3**	**22.8**	·	·	**16.5**	**9.4**	**14.1**	·	·	·	·	·	7.1	·	·	·	·	**72.1**	7.1
Taxa group 2	Chironomus sp.	4.1	2.9	21.0	17.1	4.1	10.2	15.7	17.3	**20.1**	**13.0**	**38.2**	**59.8**	**5.7**	**8.1**	**18.6**	**27.2**	**23.0**	92.5	**213.7**
	Microchironomus tener (Kieffer, 1918)	·	0.8	·	·	1.0	·	5.7	·	**19.6**	**26.0**	**10.8**	**18.4**	**8.9**	**1.1**	**12.5**	**7.6**	**5.9**	7.5	**110.8**
	Cladotanytarsus mancus gr.	3.3	1.2	3.1	0.3	2.1	4.9	·	·	**13.9**	·	**3.1**	**6.9**	**38.1**	**10.2**	**16.7**	**7.6**	**3.0**	14.9	**99.4**
	Procladius (Holotanypus) sp.	·	0.7	6.2	2.3	·	·	·	·	**29.8**	**20.8**	**12.9**	·	·	·	**0.6**	·	·	9.2	**64.1**
	Cricotopus sylvestris gr.	·	·	18.5	2.3	·	·	·	·	**10.4**	·	**1.5**	·	·	**2.2**	·	·	**22.7**	20.9	**36.8**
	Corynocera ambigua Zetterstedt, 1838	·	2.0	·	·	·	·	·	·	·	·	·	**2.3**	·	**16.1**	**9.5**	·	·	2.0	**27.9**
	Fleuria lacustris Kieffer, 1924	·	·	·	·	·	·	·	·	·	**5.2**	·	·	·	·	·	**0.6**	·	·	**5.8**
	Pentaneurini gen. sp.	·	0.3	·	·	·	·	·	·	·	·	·	·	**1.7**	**1.1**	·	·	·	0.3	**2.8**
Non-significant taxa	Chironomini gen. sp.	·	2.0	·	4.6	2.1	7.1	2.8	·	·	·	6.2	·	10.6	3.2	0.4	15.9	4.4		
	Cladopelma laccophila gr.	1.0	·	0.4	·	·	1.0	·	·	·	10.4	·	·	0.8	1.1	·	·	·		
	Cladopelma lateralis gr.	·	·	·	·	·	·	·	·	·	·	·	·	·	1.1	·	·	·		
	Cricotopus/Orthocladius/Paratrichocladius	8.7	0.4	·	·	·	·	·	·	·	·	·	·	0.8	·	·	·	·		
	Cricotopus sylvestris gr.	·	·	18.5	2.3	·	·	·	·	10.4	·	1.5	·	·	2.2	·	·	22.7		
	Cryptochironomus sp.	·	·	·	·	1.0	6.2	·	·	·	·	·	1.2	0.8	1.1	·	·	·		
	Dicrotendipes pulsus (Walker, 1856)	0.3	0.2	·	·	1.8	·	·	·	·	·	·	·	·	·	·	·	·		
	Einfeldia/Chironomus	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	3.0		
	Einfeldia/Fleuria	·	0.4	·	2.3	·	·	2.8	·	·	5.2	3.1	4.6	·	·	9.0	11.7	·		
	Einfeldia cf. dissidens (Walker, 1856)	·	·	·	0.3	·	·	·	·	·	·	1.5	·	·	1.1	3.2	14.0	0.7		
	Einfeldia pagana (Meigen, 1838)	·	·	·	·	·	·	·	·	·	·	·	·	·	0.5	·	·	·		
	Endochironomus sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	1.1	2.3	0.6	·		
	"Endochironomus type"	·	·	·	0.6	1.0	1.0	2.8	·	·	5.2	·	·	1.7	6.5	·	0.6	3.0		
	Glyptotendipes caulicola (Kieffer, 1913)	·	0.4	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·		
	Glyptotendipes cf. paripes (Edwards, 1929)	·	·	·	0.3	·	·	·	·	·	·	·	·	·	·	·	·	·		
	Glyptotendipes cauliginellus (Kieffer, 1913)	·	·	·	·	·	·	·	·	1.1	·	0.2	·	·	·	0.2	·	·		
	Glyptotendipes mancunianus/viridis	·	·	·	·	·	·	2.8	·	·	·	1.5	·	·	3.2	·	·	·		
	Macropelopia sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·	0.7		
	Microtendipes chloris gr.	·	0.4	·	·	·	·	2.8	·	·	·	3.1	·	1.7	5.4	4.2	·	·		
	Orthocladiinae gen. sp.	·	·	3.1	9.7	1.0	1.0	·	6.4	·	·	·	2.3	1.7	3.2	2.1	·	·		
	Parachironomus arcuatus gr.	·	·	·	·	·	·	2.8	·	·	·	·	·	·	·	·	·	·		
	Paratanytarsus sp.	·	·	·	·	·	7.8	·	1.8	·	·	·	·	·	1.1	2.1	·	·		
	Polypedilum (Pentapedilum) sp.	·	·	3.1	2.3	·	0.4	·	4.6	·	·	·	·	·	1.1	·	0.6	·		

		Site group 1								Site group 2								
Non-significant taxa	Polypedilum sp.	·	·	3.1	11.6	·	·	·	·	·	·	·	·	·	1.1	2.1	·	·
	Polypedilum type A	·	·	0.4	·	·	·	·	·	0.6	1.3	3.1	·	·	4.8	3.0	0.6	21.7
	Procladius (Psilotanypus) sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	0.5	·	·	·
	Propsilocerus sp.	·	·	·	·	·	·	·	·	·	·	·	·	·	4.8	·	·	·
	Psectrocladius sordidellus gr.	·	·	·	·	·	·	·	·	·	·	·	·	·	1.1	·	·	·
	Stictochironomus sp.	·	0.8	·	·	·	·	3.6	·	·	·	·	·	8.1	·	2.1	·	·
	Tanytarsini gen.sp.	·	0.4	0.4	2.3	3.1	2.9	2.8	·	·	·	1.5	·	1.7	7.5	2.1	2.6	·
	Thienemanniola ploenensis Kieffer, 1921	1.7	0.4	·	·	·	·	·	·	·	5.2	·	·	·	1.6	·	·	·

The grouping (Tab. 3) demonstrates also that the communities in the layers from Kossenblatter See and Schwielochsee did not change remarkably within the periods considered (i.e. all layers from the respective lake fell in the same site group). However, the communities from the strata of the remaining lakes were scattered across the two site groups. This suggests changes in the communities of those lakes between time periods.

This is also illustrated by the plot of summarized abundance-numbers of the site groups (Fig. 3). Using only the significant species (as in figure 2), the changing of the communities of Langer See, Blankensee and Rangsdorfer See can be traced within or between the two main "conservative" community types "Kossenblatter See" and "Schwielochsee".

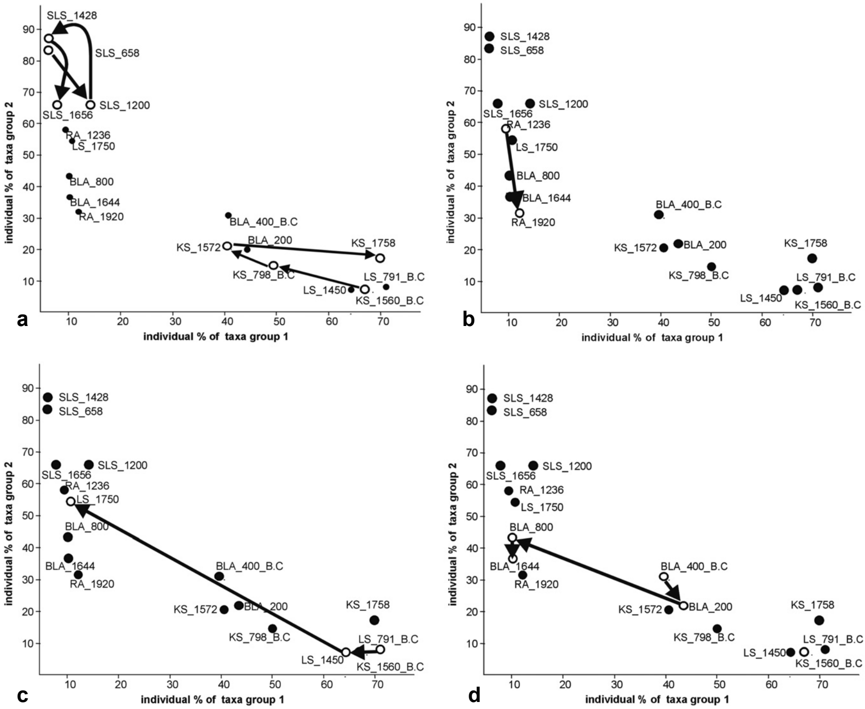

Fig. 3: Plot of summarized individual percentages of the layers of the lakes from the two taxa groups (Spearman rank correlation coefficient r_S 0.933; $p<0.001$); significant species only. Arrows show the direction of temporal succession. BLA = Blankensee, KS = Kossenblatter See, LS = Langer See, RA = Rangsdorfer See, SLS = Schwielochsee; numbers indicate years (A.D. or B.C.). For year dates before 800 A.D. see comment in the text for Tab. 2

4.2 Ecological functions

From the metrics evaluated, a plot of the proportions of collectors/gatherers, active filterers and phytal dwellers distributed in the layers studied (Fig. 4) shows similar results as the evaluation of the taxonomical communities. All layers from Schwielochsee had high shares of gatherers/collectors and low shares of active filterers and phytal dwellers, opposite to Kossenblatter See, which showed low shares of gatherers/collectors and high shares of active filterers and phytal dwellers in all time layers. In the remaining lakes, the ecological functions changed between these two types. While ecological assemblages in Blankensee showed some similarity to those of Kossenblatter See in the antiquity period, they shifted to an assemblage near that of Schwielochsee in later layers. In Langer See, the assemblage startet with a character near that of Schwielochsee, shifted to "Kossenblatter See" conditions in medieval times, and back to the former in the Baroque period.

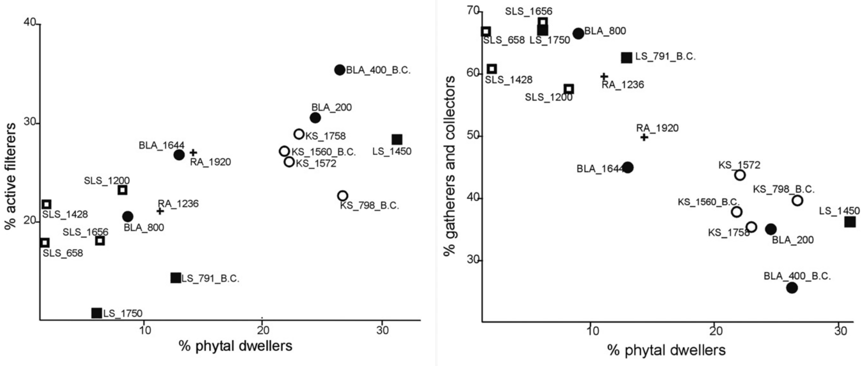

Fig. 4: Plot of summarized guild percentages of the layers of the lakes. a = active filter feeders: Spearman rank correlation coefficient $r_S = 0.761$; $p < 0.001$; b = gatherer/collectors: $r_S = 0.879$; $p < 0.001$;). BLA = Blankensee, KS = Kossenblatter See, LS = Langer See, RA = Rangsdorfer See, SLS = Schwielochsee; numbers indicate years (A.D. or B.C.). For year dates before 800 A.D. see cooment in the text for Tab. 2

5 Discussion and conclusions

Regarding the water depth, only littoral taxa were recorded. *Corynocera ambigua*, which was found in layers from the Middle Ages and the Baroque period, counts as a mesotrophic species and has also been recorded from the littoral and littoral-profundal zone of prealpine lakes (Orendt, 1991, 1993). This indicates that the lakes studied here were shallow lakes in all periods represented by the layers. From the taxa recorded, high productivity can be inferred for all lakes at all times studied, including very early periods. This is confirmed by the inference from total phosphorus concentrations (Orendt et al., in prep.). Both, taxonomical and functional chironomid communities, suggest three ecological types of lakes: (1) "conservative type A" with low macrophyte coverage and presumably high plankton densities not changing between periods (low shares of phytal dwellers and gatherer/collectors, high share of actve filterers), represented by Schwielochsee; (2) "conservative type B" with high macrophyte coverage and presumably low phytoplankton densities not changing between periods (high shares of phytal dwellers and gatherer/collectors, low share of actve filterers), represented by Kossenblatter See; and (3) a "dynamic type", in which communities shifted between types (A) and (B) indicating changes in vegetation (phytoplankton or macrophyte) between the periods. The changes of the chironomid communities do not suggest that macrophyte coverage was a characteristic of the pristine lakes.

From our results, it can be concluded that the lakes of the area studied did not have a uniform, pristine ecological state, but several rather different ones. It can be assumed that there were lakes with no changes in plankton and macrophyte dominance, respectively, while others seem to have changed unidirectionally to another state or alternated between states. For Kossenblatter See and Langer See, the chironomid community indicates an obvious macrophyte coverage in their earlier periods. In the later periods studied, however, they show a chironomid community resembling that of a plankton-dominated lake. The ecological functions indicate a reversible process in Langer See, but the taxonomical community documents a unidirectional development. This is a discrepancy, and it remains an open question whether development from a macrophyte-dominated to a plankton-dominated lake can have been reverted to the pristine state. This may be independent from habitat morphology, as higher shares of *Cladotanytarsus* and *Microchironomus* in later periods indicate increases in sand habitats.

From the individual numbers of the taxa groups (Fig. 3), the macrophyte-dominated Kossenblatter See can be seen as having experienced a community shift to the plankton-dominated lake type represented by Schwielochsee in earlier periods, but then a reversal in a later period (1758 A.D.). More data on this are needed, however, as the number of layers studied so far is low and all shifts concerning this lake remained in the same area of the diagram, giving the appearance of no substantial change.

In this study, only selected sediment layers were considered in order to obtain an overview of greater changes and differences and gain information on the general characters of the lakes as well as general tendencies in a historical context. As the approach was to compare several different lakes, it was not possible to analyse a complete profile in fine stratigraphical resolution, and the number of layers analysed is low compared to other palaeolimnological studies. As a consequence, the community history of each lake may have some gaps.

However, the results from the chironomid community analysis suggest that lake states with and without macrophyte coverage have to be considered for habitat description of reference status of these very shallow Central European lowland lakes. Periodical loss of marcophytes even in periods of low human impact was also recorded by Körner (2003), who used subfossil remainds of macrophytes from all layers of the cores investigated here.

Nevertheless, for any single lake the direct impact of man could not be related to these findings. To elucidate such local impact, further investigations for each lake are needed, including historical data on the particular colonization history by man, which can be assumed to differ between the lakes.

As a conclusion, the chironomid communities have helped to identify temporal tendencies in lake development and status. Therefore, this kind of analysis is a useful tool for the evaluation of lake status and should be considered regularly in palaeo-indication studies, like the study of other indicator groups such as diatoms.

Acknowledgements

The study was supported by the Ministry of Agriculture and Nature Conservation of the State of Brandenburg. Many thanks to Martin Spies, Munich, for the linguistical revision of the manuscript.

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Received: 2009-11-21