Journal of Animal and Veterinary Advances 11 (3): 304-313, 2012
ISSN: 1680-5593

The Diversity and Distribution of Chironomidae from Shallow, Trophic Lake Chaohu, Southeast of China

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Abstract: The chironomid compositions and spatial configuration were first assessed through the analysis of 41 surface sediment samples from Lake Chaohu. Chironomid assemblages were mainly dominated by *Microchironomus tabarui*, *Chironomus plumosus*, Microchironomus and Harnischia, denoting totally eutrophicated conditions throughout the whole lake. Hierarchical cluster analysis and MDS (non-metric multi-dimensional scaling) ordination analysis categorized all sampling sites into three groups. The difference of fauna diversity and evenness index (i.e., H, d and J) among the three clusters were not statistically significant. Common taxa in individual samples showed high similarities (72.5-93.3%) with total chironomid fossils in the basin. The resuspension and redistribution of sediments might not enough to bring about the fully homogenization of chironomid remains. Effective explanation for the even distribution of chironomid was the totally eutrophication in the whole lake. The rapid and accurate response of organism communities to environment changes in habitats confirmed the importance of biological monitoring. The researchers should pay more attention to evaluation results just based on chemical proxy which may not reflect the real situation of aquatic systems. Comprehensive counter measures should be carried out for improving water quality in Lake Chaohu.

Key words: Chironomid, configuration, diversity, eutrophication, Lake Chaohu, China

INTRODUCTION

Chironimidae is one of the most abundant and ubiquitous groups of insects that are found in freshwater habitats (Cranston, 1995; Armitage *et al.*, 1995; Brooks *et al.*, 2007). The chironomid larva colonizes sediment, rocks and submerged wood as consumers. It provides necessary food for other organisms and acts as a competitor in lake ecosystems. As other invertebrates, chironomid plays a significant role in material cycle and energy flow in freshwater ecosystems (Lindegaard, 1994; Heiri, 2004; Landgon *et al.*, 2010). Among environmental variables controlling fauna communities, trophic status (usually presents the productivity of lake and oxygen conditions in bottom water) of a lake is considered to be a primary parameter for chironomids abundance and distribution (Brodersen and Quinlan, 2006). In the context of eco-environment change and increasingly aroused eutrophication in aquatic systems, studies about the chironomid compositions, configuration and diversity seems highly necessary no matter in modern bio-monitoring or in palaeolimnology researches.

Lake Chaohu, one of the five largest freshwater lakes in China, located in the center of Anhui province (117°16'-117°51'E, 31°25'-31°43'N) with a mean depth of approximately 3.0 m and an area of 770 km^2. The population within the Lake Chaohu catchment (13,350 km^2) had exceeded 9 million until 2007 (Huang *et al.*, 2010). The lake plays a critical role on sustainable development of economy, society and environment in the catchment. Lake Chaohu is not only important for local fisheries but also as a source of water for drinking and irrigation purposes. In the last few decades, the area has been affected by pollutants from industry, agriculture and residential sources which increased manifolds. The accumulation of nutrients such as nitrogen and phosphorous has led to increased lake productivity and eutrophication. After the establishment

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of Chaohu Dam in 1962, it became an artificial-controlled, semi-enclosed lake and the natural connection with Yangtze river was cut off. The inherent water-exchange capacity of the lake was almost lost and the lake ecosystem experienced tremendous changes since then and the prolonged retention time foreshadowed the increased eutrophication (Tu *et al*., 1990). Since 1999, blue algae dominant in the lake led to algae bloom in large area, mainly in the Northwest of the Lake Chao. The average concentration of Total Phosphrous (TP) and Total Nitrogen (TN) in water column was 256 and 2850 μg L^{-1} during 1984-2006 and the concentration of chlorophyll a range from 20-40 μg L^{-1} (Xie, 2009). It can be categorized as one of the typical eutrophic lakes in the middle and lower reaches of Yangtze river (Renxian, 1988; Tu *et al*., 1990; Yin and Zhang, 2003). Compared with lots of reports on spatial variation of geochemical indicators (Zhang *et al*., 2006a, b, 2008; Xu *et al*., 2003; Shang and Shang, 2006), few researches focused on the biotic distribution (Gao *et al*., 2011; Deng *et al*., 2005; Hu *et al*., 2007) in Chaohu Lake, the present study might be the first attempt to provide the information about the spatial configuration of this valuable bio-indicator of water quality in this typical eutrophic lake. The researchers tried to evaluate the actual water state from the fauna aspect and evident the importance of biological monitoring in the assessment of water quality.

MATERIALS AND METHODS

Sampling: Surface-sediment samples (n = 41) were collected during June 2009 to January 2010 with a Kajar gravity corer (Fig. 1). The uppermost 1 cm of the sediment was taken and refrigerated at 4°C in field until further analysis.

Laboratory analysis of fossil chironomids: Sediment samples for chironomid analysis were conducted by standard techniques (Brooks *et al*., 2007). Wet sediment samples were deflocculated in 10% KOH in water bath at 75°C for 15 min and then rinsed on 212 and 90 μm sieves. The residue was transferred to a grooved perpex sorting tray and examined under a stereo-zoom microscope at ×25 with fine forceps manually. A minimum of 50 identifiable whole head capsules should be contained in each sample to be representative. The head capsules were permanently mounted on slides using Hydromatrix®, ventral side uppermost and subsequently identified under ×100-400 biological microscope followed by Brooks *et al*. (2007) with reference to Wiederholm (1983), Oliver and Roussel (1983) and Rieradevall and Brooks (2001).

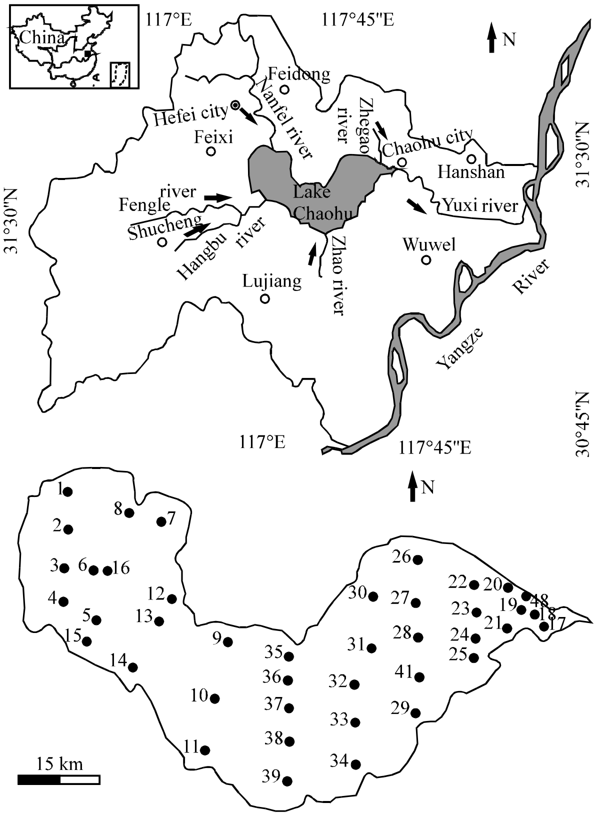

Fig. 1: Map of the catchment of Lake Chaohu and the locations of the sampled surface-sediments

Taxon richness estimation: Taxa recovered from all the samples were classified into three units; common, uncommon and rare. A specific taxon with <3 occurrences was distinguished as rare. With the occurrences exceeded 3, the species were indentified as common or uncommon when their mean frequency exceed or remained below one specimen per sample (Eggermont *et al*., 2007).

The percentage of each taxon extracted from sediments was calculated. Then a similarity matrix was used to get a similarity index to conduct a cluster analysis based on Bray-Curtis to assess the changes of the taxonomic composition and group all these samples (Schmah, 1993). SIMPER (similarity percentages) was used to find out the species which contributed the most to the similarities/dissimilarities within/between groups. The significance or not of differences among these groups based on cluster analysis were testes by ANOSIM (one-way Analysis of Similarities). Moreover, non-metric Multidimensional Scaling (MDS) ordination, based on the former similarity matrix was constructed to configure the sampling sites according to chironomid assemblages. All these statistic analyses were performed in PRIMER Version 5.0 (Clarke, 1993; Zhou and Zhang, 2003).

The PRIMER software package allows a series of diversity index were available. Shannon-Wiener index (Shannon and Weaver, 1963), Margalef's species richness (Margalef, 1958) and Pielou's evenness index (Pielou, 1975) were calculated to assess the chironomid diversity though the whole lake. Additionally as the reciprocal of Simpson's index, the Hill's N2 (Hill, 1973) was sensitive to changes in the more abundant species (Greenstreet and Hall, 1996) and also was selected for the present analysis. They were calculated as follows:

$$H' = -\Sigma\ (n_i/N)\ \ln\ (n_i/N) \quad (1)$$

$$d = (S-1)\ /\ln N \quad (2)$$

$$J' = H'/\ln S \quad (3)$$

$$N2 = 1/\lambda;\ \lambda = \Sigma\ n_i\ (n_i-1)\ /n\ (n-1) \quad (4)$$

Where:

n_i = The number of individuals in each species
N = The total number of individuals in all species
S = The total number of species

The similarity of chironomid taxa in individual sample sites with the entire chironomid assemblages of a whole lake in measured by the proportion of the total number of taxa recovered from a lake that is present in a single sample from a specific location (Heiri, 2004). Here the researchers assessed the representation of individual sample both for common taxa only and for all fauna just excluded the rare taxa.

RESULTS AND DISCUSSION

Chironomid composition: A total of 2411 chironomid head capsules were recovered from 41 surface-sediment samples (Fig. 2). The fossil fauna consisted of 4 sub-families, 25 genera and 32 species. The 10 of the taxa were categorized as common which together dominated 89.8% of the fauna with individual abundances between 1.7-29.6%. The most abundant taxa >5% were *Microchironomus tabarui* (29.6%), *Chironomus plumosus* (23.0%), Microchironomus (non-tabarui; 9.9%) and Harnischia (6.8%). The uncommon consisted of 14 taxa with the individual frequency <1, about 9.5% of all fauna were accounted by the group. The remaining 9 taxa were classified as rare fauna and their emergency and distribution in samples is probably controlled by chance occurrence (Fig. 3).

Community configuration: The results of hierarchical clustering based on group-average linking on percentage abundance of chironomid for all 41 sampling sites are shown in Fig. 4. In dendrogram based on the Bray-Curtis similarity index, the horizontal line was used to connect the two samples or clusters of samples with high similarity. Figure 4 shows that three major cluster groups of sampling sites were formed at a 61% similarity level. The similarity value seems so high which may indicate unconspicuous variation among samples. Sampling sites in the most western lake area split into two groups, almost all of them were classified as group A while three

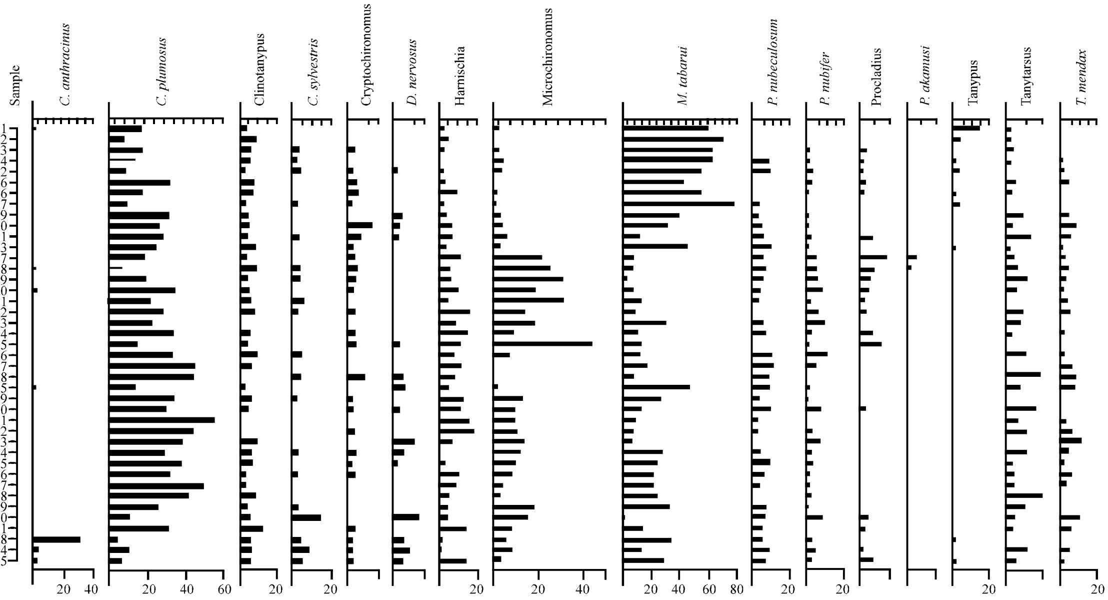

Fig. 2: Main chironomid taxa for 40 surface-sediment samples from Lake Chaohu

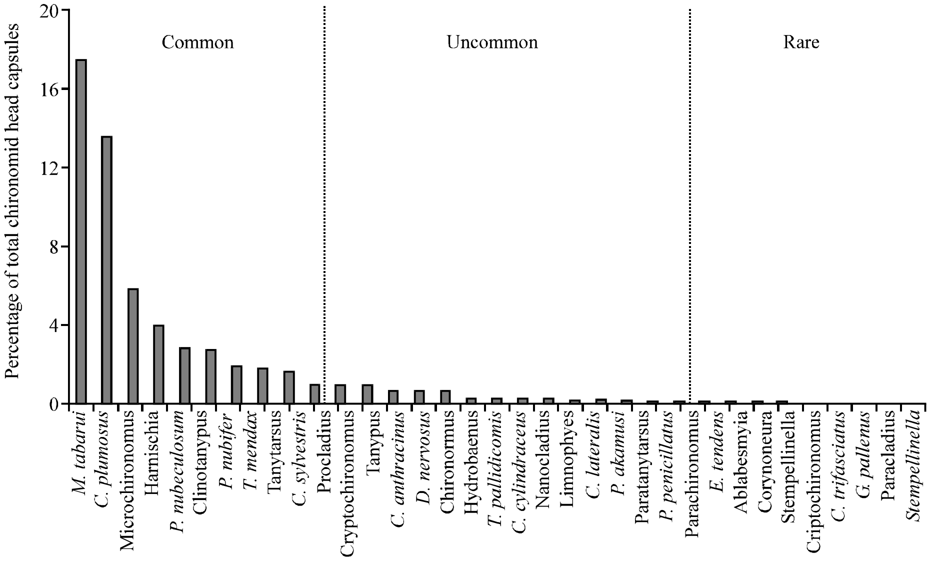

Fig. 3: Species-frequency for the total chironomid species assemblages in Lake Chaohu

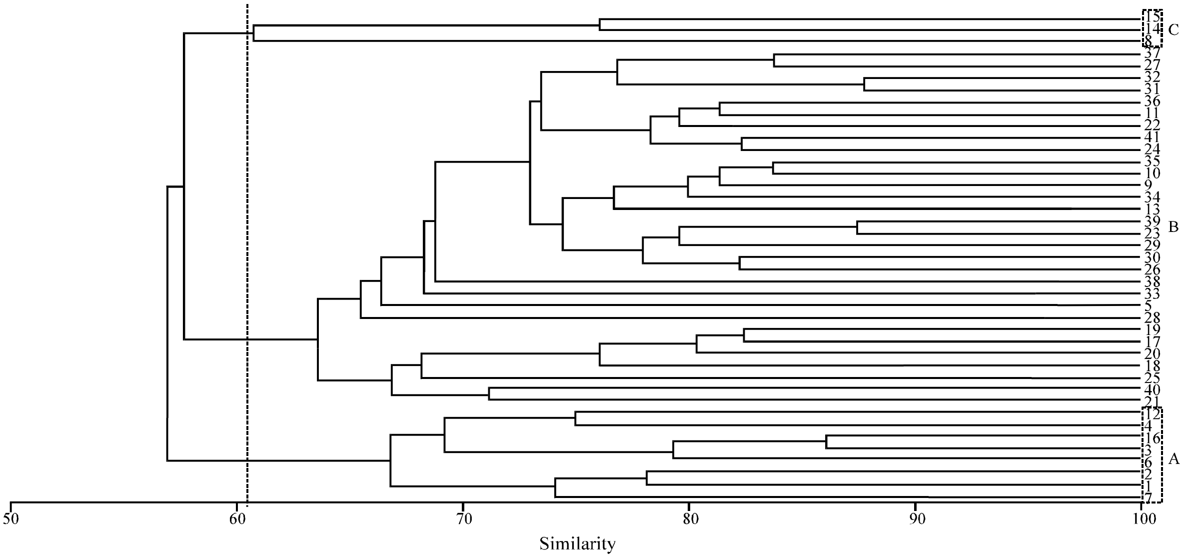

Fig. 4: Hierarchical clustering based on group-average linking on percentage abundance of chironomid for 41 surface sediments

sites (8, 14 and 15) situated around estuarine regions were regarded as group C. The remaining sites in cluding those located in the middle and eastern regions were all labeled as group B because of their high similarity values between each other.

Basing on root-transformed abundance data of chironomids, SIMPER analysis figured out the species which contributed the most to each assemblage group (Table 1). The average Bray-Curtis similarity in cluster A, B and C was 70.14, 68.95 and 65.87, respectively. In group A, five species with contribution exceeded 5% accounted up 81.78% of the total contributions, such as *M. tabarui* (42.44%), *C. plumosus* (18.72%), Clinotanypus (9.98), Harnischia (5.60%), Tanypus (5.04). Nine dominant species contributed 93.83% of the total Bray-Curtis similarity in group B with the individual contribution ranged from 23.29-5.36% while 76.08% contributions were made up by nine species in group C with the respective values scattered among 16.81-5.93% as showed in Table 1. Similarly, the results of SIMPER analysis also indicated the potential species contributed the most to the inter group dissimilarity (Table 2). The average

Table 1: Main species in each assemblage group showed by SIMPER analysis (the species with contribution >5% displayed here only)

Species	Average abundance	Average similarities	Similarity/SD	Contribution (%)	Cumulative contribution (%)
Group A					
M. tabarui	60.68	29.77	7.53	42.44	42.44
C. plumosus	15.02	13.13	6.07	18.72	61.16
Clinotanypus	4.98	7.00	2.77	9.98	71.13
Harnischia	2.83	3.93	1.48	5.60	76.73
Tanypus	4.02	3.54	0.95	5.04	81.78
Average similarity	70.14				
Group B					
C. plumosus	29.75	16.06	3.71	23.29	23.29
M. tabarui	18.36	11.11	2.83	16.11	39.41
Harnischia	8.58	7.80	2.63	11.31	50.71
Microchironomus	12.47	7.78	1.92	11.28	61.99
P. rubeculosum	5.37	5.29	1.59	7.67	69.66
Clinotanypus	4.73	4.82	1.56	6.99	76.65
P. rubifer	3.87	4.22	1.73	6.12	82.77
T. mendax	4.23	3.94	1.21	5.71	88.48
Tanytarsus	3.42	3.69	1.33	5.36	93.83
Average similarity	68.95				
Group C					
M. tabarui	25.13	11.07	3.84	16.81	16.81
P. rubeculosum	6.83	6.09	33.86	9.25	26.05
Clinotanypus	4.93	5.51	9.68	8.37	34.42
C. plumosus	6.27	5.14	11.94	7.80	42.22
C. sylvestris	5.32	4.88	634.34	7.42	49.64
Microchironomus	5.38	4.87	4.78	7.39	57.03
P. rubifer	3.91	4.50	9.68	6.83	63.86
D. nervosus	3.91	4.50	9.68	6.83	70.69
C. anthracinus	11.63	3.55	3.96	5.39	76.08
Average similarity	65.87	-	-	-	-

Table 2: Main species and their contribution to inter-group dissimilarity showed by SIMPER analysis (the species with contribution >5% displayed here only)

Species	Av. Abund	Av. Abund	Av. Diss	Diss/SD	Contrib (%)	Cum. contrib (%)
Group A, C	**Group A**	**Group C**				
C. anthracinus	0.15	11.63	4.52	1.18	9.87	9.87
M. tabarui	60.68	25.13	4.42	2.66	9.66	19.53
P. rubeculosum	1.85	6.83	2.96	1.85	6.46	25.99
D. nervosus	0.15	3.91	2.89	3.70	6.31	32.30
C. sylvestris	0.98	5.32	2.51	1.89	5.49	37.79
Average dissimilarity	45.78					
Group B, C	**Group B**	**Group C**				
C. plumosus	29.75	6.27	4.41	2.07	10.42	10.42
C. anthracinus	0.21	11.63	4.20	1.21	9.93	20.35
C. sylvestris	1.49	5.32	2.44	1.90	5.77	26.12
M. tabarui	18.36	25.13	2.26	1.43	5.34	31.46
Harnischia	8.58	5.83	2.17	1.75	5.13	36.59
Microchironomus	12.47	5.38	2.14	1.33	5.05	41.65
D. nervosus	1.22	3.91	2.11	1.91	5.00	46.65
Average dissimilarity	42.29					
Group A, B	**Group A**	**Group B**				
M. tabarui	60.68	18.36	6.78	2.44	15.89	15.89
Microchironomus	1.86	12.47	4.10	1.57	9.59	25.48
C.plumosus	15.02	19.75	3.38	1.56	7.93	33.41
P. rubeculosum	1,85	5.37	3.02	1.51	7.08	40.49
Tanypus	4.02	0.05	2.96	1.29	6.94	47.42
Harnischia	2.83	8.58	2.79	1.58	6.53	53.95
T.mendax	1.14	4.23	2.70	1.43	6.32	60.26
Average dissimilarity	42.71					

Av. Abund: Average Abundance; Av. Diss: Average Dissimilarity; Diss/SD: Dissimilarity/Standard Deviation; Contrib (%): Contribution (%); Cum. contrib (%): Cumulative contribution (%)

dissimilarity coefficients between group A and C, group B and C, group A and B were 45.78, 42.29 and 42.71, respectively.

One-way ANOSIM test based on pairwise test validated the results of the hierarchical clustering (Table 3). It is showed that group A and C were well separated with the R Statistic value was 0.847 (>0.75; p<0.006) while group A and B, group B and C were just obviously different with somewhat overlapping (R>0.5 but <0.75). The results of MDS ordination analysis also confirmed the three groups clustering (Fig. 5).

Chironomid richness and diversity: Shannon-Wiener diversity index (H'), Margalef's species richness index (d) and Pielou's evenness index (J') showed no significant difference among the three groups (Fig. 6) (p>0.05, one-way ANOVA).

Especially, the almost horizontal line of the J' values indicated that there were no obvious discrepancy though the whole lake in the distribution of chironomid despite of the clustering groups. Hill's N2 which was sensitive to changes in the more abundant species, showed some differences here among these groups.

Conspicuously, the N2 values in group A were much lower than that in group B and C. It may be attributed to the slightly higher average abundance of *M. tabarui* in group A while the percentage of this species was relatively lower in other two groups (Table 1).

Representativeness of individual samples for total chironomid composition: Here the researchers evaluated the representativeness of total chironomid assemblage in individual samples for the whole lake through two aspects: calculated the representativeness for the common taxa only and for the common and uncommon taxa (Fig. 7). Considering the occurrence of rare taxa with a strong chance, the researchers excluded them in this assessment. Single samples in group A contained 5-9 common taxa (50-90% of the total 10 common taxa in all samples) and 7-16 taxa with >3 occurrences (29.2-66.7% of the total 24 common and uncommon taxa in all samples). The average representativeness of common taxa and all taxa in group A were 72.5 and 43.2%, respectively. About 6-10 common taxa and 7-17 common and uncommon taxa were recovered in individual samples in group B with the average representativeness were 85.7 and 46.7% correspondingly. As the minimum clustering (only three sites), group C included 8-10 common taxa and 13-21 total taxa with the average values were 93.3 and 72.2%. The corresponding values were shown in Table 4.

Table 3: Results of one-way ANOSIM with pairwise tests among group (Global R = 0.668; p<0.001; No. of permutations: 999; No. of permuted statistics greater than or equal to Global R: 0)

Groups	R statistic	Sig. level (p-value)	Possible permutations	Actual permutations	No. of permutated Rγ observed R
A, B	0.637	0.001	48903492	999	0
A, C	0.847	0.006	165	165	1
B, C	0.713	0.001	5456	999	0

where R>0.75: clusters well separated; R>0.5: clusters distinct but overlapping somewhat; R>0.25: groups can not be separated at all

Sediment winnowing and focusing in shallow and wind driven lakes has an important impact on the taphonomy of sediment particles and organisms (Davis *et al*., 1984; Schmah, 1993; Heiri, 2004). The process more or less winnows, the finest sediment particles from nearshore and redeposit upon the sediments offshore (Likens and Davis, 1975). A number of studies (Wiederholm, 1979; Frey, 1988; Brodersen and Lindegaard, 1999) denied the conclusion that the subfossil chironomid head capsules were consisted with the extant chironomid fauna. The chironomid remains were not always deposited around the place where they live.

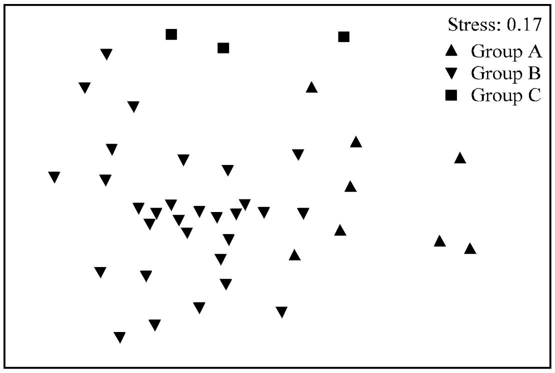

Fig. 5: Plots of non-Metric Dimensional Scaling (MDS) ordination analysis based on chironomid abundance data for 41 samples

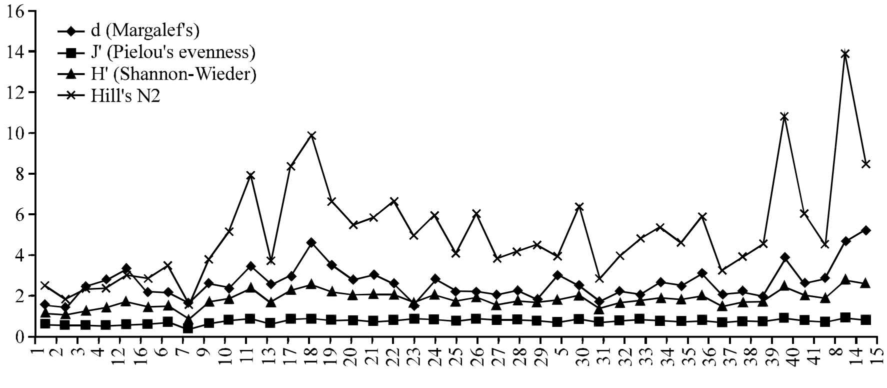

Fig. 6: Results of chironomid diversity and evenness index for Lake Chaohu

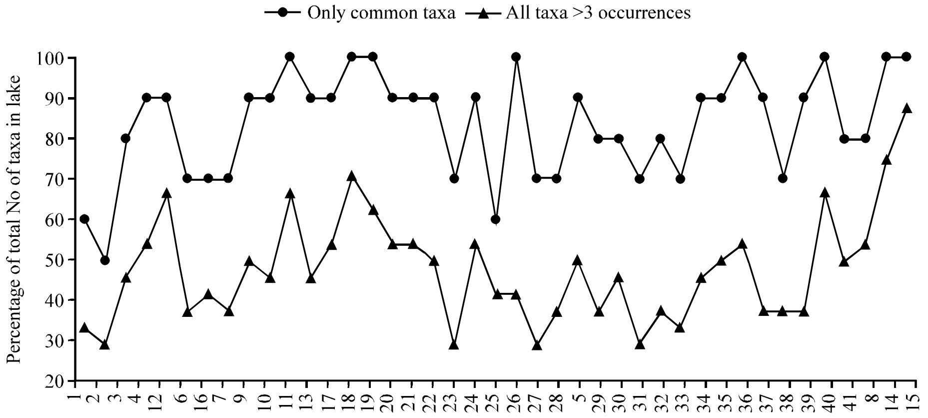

Fig. 7: The similarity of total chironomid assemblages in individual samples for the whole lake

Table 4: Values of representativeness of common taxa and all taxa (>3 occurrences) in three clusters

Groups	No. of common taxa	Tot. of common taxa	Percent of com. taxa	Av. repre. (%)	No. of all taxa	Tot. of all taxa	Percent of all taxa	Av. repre. (%)
A	5-9	10	50-90	72.5	7-16	24	29.2-66.7	43.2
B	6-10	10	60-100	85.7	7-17	24	29.2-70.8	46.7
C	8-10	10	80-100	93.3	13-21	24	54.2-87.5	72.2

Common/all taxa: Total common/all taxa; Av. repre. (%): Average representativeness (%)

Schmah (1993) and Kansanen (1986) both reported that most chironomid remains in deeper zones were transported from nearshore or the slope and the samples from the profundal tend to be more representative of the whole lake. However, through the studies about a shallow fluctuating tropical lake in Kenya, Eggermont *et al.* (2007) concluded that the sediments transport was not enough to create complete spatial integration of chironomid subfossil in a sufficient large lake. The nearshore samples were better representative than offshore samples for the total chironomid assemblages of a whole lake. In present study, Fig. 6 and Table 4 shown that there were a very high similarity among the single samples from different lake zones and total chironomid remains when just measured with the common taxa only (72.5-93.3%). But if taking all taxa with more than three occurrences into consideration, the representativeness sharply reduced to 43.2-72.2%. As a shallow and large sufficient (780 km^2) water body, Lake Chaohu suffers from permanent wind driven and the vertical water column is completely mixed frequently (Tu *et al.*, 1990). It is a so large lake however, the resuspension and redistribution of sediments might not enough to bring about the fully homogenization of chironomid remains (Eggermont *et al.*, 2007). Except the redeposition of sediments, another feasible explanation of the high similarity between individual samples and total subfossil head capsules for common taxa might be the overall appearance of eutrophication in this large water system.

In the recent two decades, the issue of pollution in Lake Chaohu has become increasingly serious. Especially after 2003, the concentration of nutrient materials showed a rising tendency, the water quality further deteriorated and hyper-trophication or eutrophication appears in every lake region (Hu *et al.*, 2007). Throughout the whole lake of Chaohu, the chironomid communities were mainly dominated by *Microchironomus tabarui*, *Chironomus plumosus*, Microchironomus, Harnischia (Fig. 2 and 3). Table 1 also shows that there were high average abundance values of these taxa in all three groups. These taxa mentioned above exhibit a wide range of tolerance to trophic status and the most abundant taxa were totally good indicators of eutrophication (e.g., *M. tabarui*, *C. plumosus*) (McGarrigle, 1980; Little and Smol, 2000; Broderson *et al.*, 2001; Zhang *et al.*, 2006a, b, 2010). It is more notably that they presented in large portions of all fauna in almost all sampling sites. The frequent presence of common taxa in single samples, combined with their trophic-tolerant characteristics was considered to confirm that the nutrition level in Lake Chaohu has exceeded the ecological thresholds of oligotrophic species and was no more suitable for their survival. Meanwhile, the species with high nutrition optimum values colonized the favorable habitat and dominated the chironomid communities. The barely changes of species diversity and even distribution of chironomid might attributed to this highly trophicated water state in Lake Chaohu.

Several existent researches denoted that there were spatial variations of nutrition enrichment no matter in water or in sediments of Lake Chaohu (Xu *et al.*, 2003; Shang and Shang, 2006; Xie *et al.*, 2010; Zan *et al.*, 2011). Owing to discharges of the industrial and domestic sewage from Hefei city, the eutrophication state in the Western part is more serious than that of the Eastern part. Shang and Shang (2006) denoted that the average concentration of TP and TN was 255 and 2920 μg L^{-1}

between 1984 and 2004 and the highest concentration of COD_{Mn} was 8130 μg L^{-1} which all exceeded the standard (GB3828-2002) values several times. Comparing with the Western part, the average concentration of TP, TN and CON_{Mn} in eastern part lake was 117, 1530 and 4180 μg L^{-1}, respectively from 2001-2005 (Liu, 2008). Organism communities in aquatic systems could be heavily influenced by their surrounding habitat. Particularly in shallow and trophic lakes in the middle and lower reaches of Yangtze river in China, the nutritional gradient were always considered as the most principal factors controlling the composition and distribution of organisms (Zhang *et al.*, 2006a, b; Dong *et al.*, 2006). Chironomid assemblages also made an accurate respondence to this trophic variation in different lake areas. As a result, all the sampling sites were clustered into different groups according to their fauna compositions and were dominated by diverse taxa. Although, these dominant species were all trophic-resisted, their subtle difference in options of the optimum nutrition allowed that there exist no paradox between the clustering groups and the general even distribution of the total taxa appeared in the basin. The emergence of Tanypus in the western part (including the sites of group A and C), an indicator of hypeutrophication, seems to be an excellent evidence to confirm that the configuration of organisms demonstrated the state of water quality more accurately.

CONCLUSION

In this study, values of traditional chemical proxy proved strongly the variation of trophic state between the two lake parts; the Western with more serious eutrophication problem than the eastern part. The analysis about chironomid communities illustrated this point through the discrepancy of dominant species in clusters. When taking the general homogeneous distribution of fauna into consideration, however we concluded that there were critical problem through the whole lake in water quality and the water state in eastern part might be not so satisfying as we expected. The real structure of aquatic ecosystem might not be reflected appropriately just depend on the chemical monitoring. The configuration of organisms should be considered as the real mirror of a lake healthy or not. The biological monitering might act as an indispensable process in assessment of water quality. As a shallow and thoroughly mixed lake, the system could respond directly to the reduced pollutants concentration after nutrients control (Shang and Shang, 2006). The variation of nutrient concentration observed appears exciting after the implement of a series of control regulations and we have to find out whether it is just a pseudomorph or not. It is an issue should be paied more attention when evaluate the alternative of water state in aquatic ecosystems and comprehensive counter measures not just focused on external control should be carried out for improving water quality in Lake Chaohu.

ACKNOWLEDGEMENTS

The researchers would like to thank Dr. Enfeng Liu for his assistance in the field sampling. This study was funded by the National Major Projects on Control and Rectification of Water Body Pollution (2008ZX07103-003), the Knowledge Innovation Program of the Chinese Academy of Sciences (kzcx2-yw-319) and the National Natural Science Fund of China (41072267).

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