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ECOLOGICAL STUDIES ON ZOOPLANKTON OF THE WEST LAKE AND THE INFLOWS

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Abstract:
Zooplankton ecology of the West Lake and the streams that flow into the lake were investigated during January-December 1995. Protozoans were the predominant group among 252 species of zooplankton, accounting for 50.4% of the total number. Due to the seasonal variations in density and biomass of zooplankton, were studied. Changqiao stream recorded the highest density of zooplankton among seven sampling points, with an average of 10,710 inds./L. The lowest density found was Jinsha stream (886 inds./L). Lake Yue recorded the highest biomass of zooplankton in spring (3,737 mg/L) and the lowest biomass occurred in Jinsha stream (0.055 mg/L) in spring. According to the diversity index, Lake Xiaonan and the three streams belong to the β -mesosaprobic level, while other areas belong to the α -mesosaprobic level.

Key words: West Lake, Zooplankton, Seasonal variation, Density and biomass of zooplankton

Introduction

Hangzhou City is the famous for its beautiful West Lake. Due to its small size (5.6 km^2), shallowness (its average depth is 1.6 meter) and the presence of a thick silt on the bottom of 0.2 m - 0.4 m. The West Lake has become eutrophic state with the water being light green in color. There has recently been a large focus on the development of the ecological researches of the West Lake. Recently, most of the water flowing into West Lake comes from Qiantang River and three streams, Chang Qiao, Longhong and Jinsha, which flow into the West Lake.

Ecological studies of zooplankton in the West Lake have been carried out at the several times (Wei *et al.*, 1983, Li *et al.*, 1994), but to date there have been no studies on the zooplankton in the three inflows of the West Lake. The present study attempts to interpret the entire zooplankton ecology and development in these streams and in the West Lake, and to determine the ecological relationship of zooplankton in the two kinds of the water body, so that stream and lake.

Locality and Methods

Seven points for zooplankton sampling were fixed in the West Lake and its tributaries. Four sampling points were within the West Lake, and three points were located along the current water drawing from Qiantang River. These were the Lake Xiaonan (drawing region), Huxin (central region of the lake), and Shaoniangong (Discharge region). The fourth point was located in Yue Lake. The remaining three sampling points were located at the entrance regions of the three streams (Figure 1.). Each point contained two sampling units, one for identifying species and the other for determining the amounts of zooplankton. The sample for determining the amounts took 1 litter of mixed water (i.e. mixed water from upper, middle and lower depths), which were mixed immediately with 2% formalin after collection. Small size crustacea were collected by filtrating 10 litter water through a plankton net with mesh size NXX25.

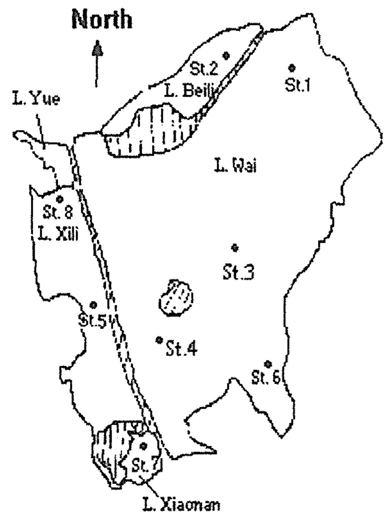


Figure 1. The locations of sampling points in the West Lake and its tributaries

Species of zooplankton were identified by using a microscope with a magnification of 10 to 40 times. Amounts of zooplankton were determined after enriching samples to 20ml in precipitation. 0.1ml and 1.0ml of random selected samples were drown and counted for protozoa and rotifera, respectively. The enriched sample from 10 litter of water for the biomass of protozoa, cladocera and copepoda were calculated according to the methods described by He Zhihui and considered to be exact measurements. The biomass of rotifera was determined by precise measurements using the volume method described by Huang Xiangfei (1981).

2. Result and Discussion

The West Lake and its tributaries contain 252 species of zooplankton, of which 50.4% were protozoa, 33.7% were rotifera, 12.3% were small crustacea and 3.6% were other animals (Table 1).
The amounts of each species of zooplankton in the streams were much greater than those in the West Lake, with the total amount of zooplankton in the streams being 50.4% greater than in the West Lake.

Table 1. Distribution of species of zooplankton in the West Lake and its surrounding streams

	West Lake			Stream			
	L.Xiaonan	Huxin	Shaoniangong	L.Yue	Changqiao	Longhong	Jinsha
Protoroa	25	13	19-56	28	46	56	40-92
Rotifera	32	25	23-46	30	41	43	35-71
Small crustacean	13	11	8-20	13	6	14	4-17
Others	1	1	2-3	2	5	5	8-8
Total	71	50	52-125	73	98	118	87-188

Species common to both waters accounted for 25.0% of the total for species alone. Accordingly, the distinction of the zooplankton habitat in the two waters was clear. Out of the seven sampling points Longhong stream recorded the highest number of species in each group of zooplankton. This could be accounted for as itself and the lake water often reverses its flow back into this stream, such stream that Longhong stream contains species from the lake, and to lesser degree, the other streams.Both the Huxin and Shaoniangong stream a lower amount of species than the West Lake.
A dominant species of protozoan was not apparent in the West Lake. *Tintinnopsis* sp. were, however, commonly found while *Coleps hirtus* was a minor constituent. Several species such as *Stentor*, *Arcella* and so on were found in the streams.
Trichocera pusilla, *Polyarthra trigla*, *Brachionus* sp., *Filinia* sp. and *Anuraeopsis fissa* were dominant species of rotifera in both waters. The large size of *Asplanchna brightwelli* resulted in it being the dominant species with respect to biomass in the West Lake, *Colurella uncinata* and some Bdelloidea were also featured in the streams. *Cyclops*, *Diaphanosoma leuchtenbergianum*, *Moina miura* and *Alona rectangla* were commonly found as the species of small crustacea.
Variations in zooplankton species in the West Lake developed one season later than in the streams (Table 2), with species variations in winter, spring, summer and autumn of the streams coinciding with variations in four seasons of the West Lake, respectively. This was due to the different habitat of the two waters.

Table 2. Seasonal variations in each group of zooplankton species in the West Lake and surrounding streams

	West Lake				Stream			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Protozoa	22	29	6	20	27	30	41	45
Rotifera	32	17	19	21	41	27	29	27
Small Crustacea	6	9	9	9	3	7	9	10
Other	2	0	0	2	2	2	3	7
Total	62	55	34	52	73	66	82	89

Of the four regions sampled in the West Lake, the seasonal changes of species were distinct only in Lake Xiaonan. Of the three streams sampled, the seasonal changes of species were distincted only in Longhong streams. The amount of zooplankton species present peaked in the streams in winter, and was at its lowest in the West Lake in autumn.
There was little difference in the average density of zooplankton in both waters (Table 3). At each sampling point, protozoa dominated the zooplankton composition followed by rotifera. The protozoan average density was higher in the streams than in the lake due to the rapid production of flagellates. This was enabled by a greater amount of sunlight being able to penetrate the clear water of the streams over the murkier lake water. Rotifera had a higher average density in the lake than in the streams due to the higher concentration of nutrients and the more stable habitat in the West Lake. The density of each group of zooplankton in Longhong stream was approximate to the West Lake.This was one of the evidence that Longhong stream was affected by the aquatic organisms of the West Lake.

Table 3. The annual average density of each groups of zooplankton in the West Lake and the streams (inds./L)

	West Lake			Stream			
Sampling Point	L.Xiaonan	Huxin	Shaoniangong	L.Yue	Changqiao	Longhong	Jinsha
Protozoa	2,817	2933	4083	5767	10333	3733	675
Rotifera	290	2310	1833	1680	350	1275	170
Small Crustacea	27	39	41	15	27	6	41
Total	3134	5282	6007	7462	10710	5014	886

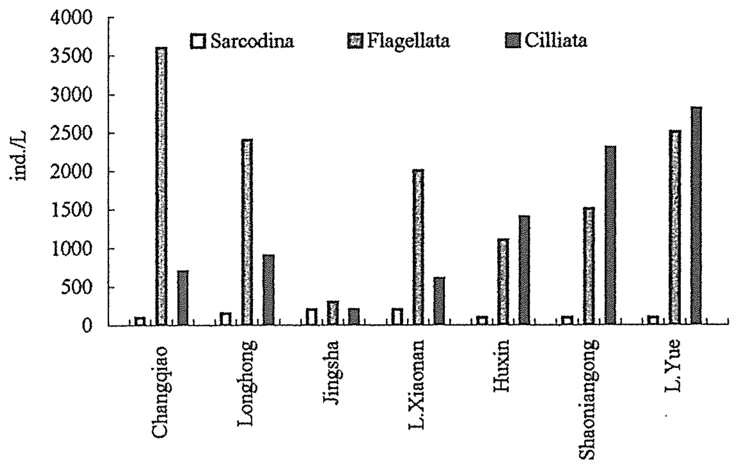


Figure 2. Composition of functional groups of protozoa in the West Lake and adjoining streams

The zooplankton density was inversely proportional to the drawing current in the West Lake. This is, the density increased as the drawing current decreased with the highest density (7,462 inds./L) being found in Lake Yue, in which contained a dead space of drawing current.

According to Table 3, the protozoan density in Lake Xiaonan approximated that of the Huxin region. In connection with the composition of each functional group of protozoa (Figure 2), the density of each functional group of protozoa in Lake Xionan was the intermediate value between those in streams and in the sampling points of the West Lake. The maximum period of protozoan density occurred ealier in the West Lake than in the streams.

Rotifera density in the West Lake was 2.6 times larger than in the streams (Table 3). Compared to the results of studies carried out in 1991 by Gongguo *et al.* (1994), the rotifera density was increased by 53.6%. The Huxin region reached its highest rotifera density in August (6520 inds./L), while Longhong reched its highest density in September (9700 inds./L). The majority of rotifera species were *Trichocera pusilla* which resided and reproduced in lower-middle water depths.

The maximum period of rotifera density occurred early in the West Lake, and was sustained throughout summer to autumn (Figure 3), while the streams only one density peak in autumn.

The density of dominant species of rotifera accounted for 88.5% and 79.7% of the total population density in the West Lake and the streams, respectively. Monthly variations in the total rotifera density were determined by the dominant species (Figure 4).

Additionally, the density of rotifera in the streams were initiated as those in the West Lake were already declining of the seven sampling points in the lake, the most outstanding dominant rotifera was found in the Huxin region. This was *Trichocera pusilla*, and it accounted for 47.9% of the total density of dominant rotifera (Figure5).

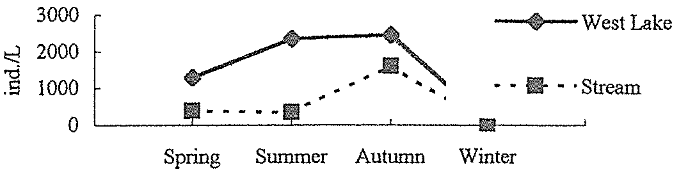


Figure 3. Seasonal variations in the density of rotifera in the West Lake and adjoining streams

The maximum period of density of *Trichocera pusilla* and *Polyarthra trigla* occurred in autumn (Figure 6), and seasonal average density of the former reached 1960 inds./L. The density of dominant rotifera in the streams accounted for only 35.1% of that in the West Lake.

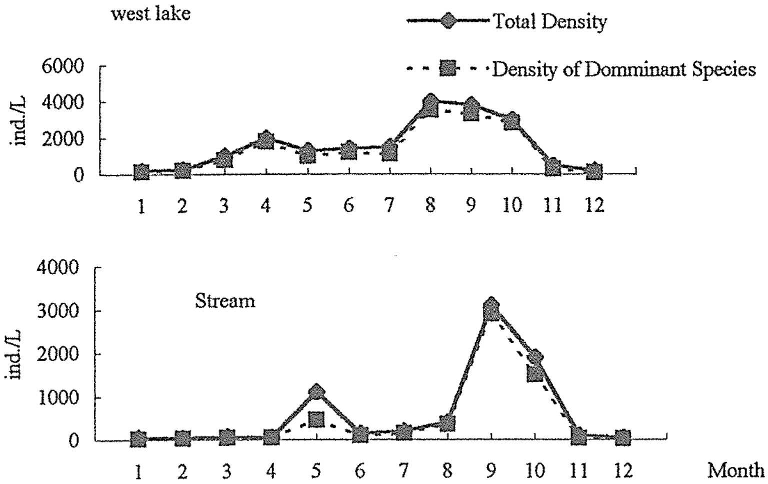


Figure 4. Monthly variations in thetotal density of rotifera and the density of the dominant rotifera species in the West Lake and adjoining streams

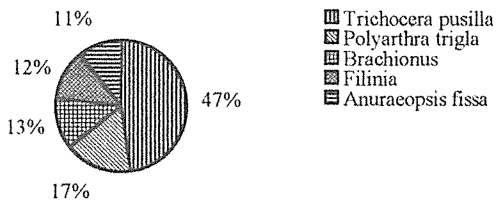


Figure 5. Population densities (%) Of five dominant species of rotifera in the center of the West Lake

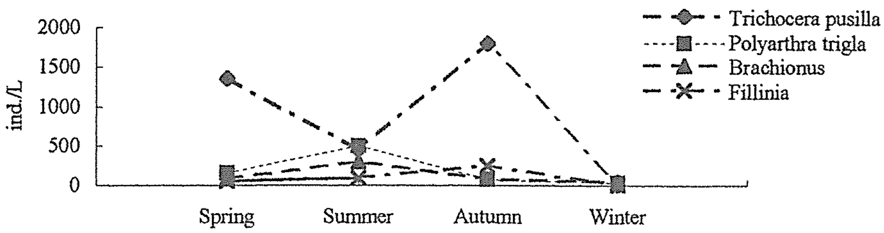


Figure 6. Seasonal variations in the density of dominant species of rotifera in the Huxin region of the West Lake

The highest densities of small crustacea were found in the Shaoniangong and Huxin regions of the West Lake (Table 4). The *Copepoda* nauplieus density in the Jinsha stream peaked to 410 inds./L in August, such that the average density exceeded that of each other sampling spot. The lowest crustacea density occurred in Longhong stream. *Cladocera* only accounted for 4.2% of small crustacea, and its density distribution decreased along drawing current. The average ratio between *Copepoda* nauplieus and adult density was 7.5 in both waters. The overall ratio of in the streams was larger than that in the West Lake, althogh ratios in the West Lake and Longhong stream were the same. *Diaphanosoma leuchtenbergianum* was a common species of small crustacea found, and its density distribution was similar to the total density of *Cladocera*. *Diaphanosoma leuchtenbergianum* density in the West Lake was 9.5 times larger than that in the streams, particularly in summer and autumn. Its density in the West Lake in summer was 3.3 larger than in the streams in autumn.

Table 4. The annual average density of small crustacea in the West Lake and adjoining streams

	West Lake			Stream			
Sampling Point	L.Xiaonan	Huxin	Shaoniangong	L.Yue	Changqiao	Longhong	Jinsha
Cladocera	3.5	1.5	1.3	1.2	0.4	0.3	0.1
Copepoda adult	4.1	3.7	6.3	4.8	1.5	0.9	0.7
Copepoda nauplieus	19.4	34.0	33.1	9.3	25.0	4.6	40.0
Total	27.0	39.2	40.7	15.3	26.9	5.8	40.8

The annual average biomass of zooplankton in the West Lake was 4.0 times greater in the streams, and increased progressively along drawing current (Table 5). Of each zooplankton, rotifera had the largest biomass in the West Lake and Longhong streams, while small crustaceae was the dominant biomass in the Changqiao and Jinsha streams.

Table 5. The annual average biomass of each group of zooplankton in the West Lake and adjoining streams (mg/L)

West Lake			Stream				
Sampling Point	L.Xiaonan	Huxin	Shaoniangong	L.Yue	Changqiao	Longhong	Jinsha
Protozoa	0.085	0.088	0.123	0.173	0.138	0.112	0.020
Rotifera	0.421	1.228	1.239	1.614	0.127	0.286	0.047
Small Crustacea	0.367	0.285	0.314	0.206	0.150	0.047	0.179
Other	0.021	0.008	0.008	0.006	0.017	0.011	0.023
Total	0.894	1.609	1.684	1.999	0.432	0.456	0.269

The rotifera biomass in the West Lake was 7.4 times larger than in the streams (Table 5), and dominated the total biomass and distribution of zooplankton in the West Lake. The peak period of rotifera biomass occurred in summer for both waters (Figure 7). While the rotifera biomass was already larger in spring in the West Lake, it decreased substantially after summer. The streams, however, retained their biomass through autumn. Lake Yue recorded the highest biomass of rotifera, as 9.80 mg/L in May, on account of the reproduction of *Asplanchna brightwelli*, such that the peak period of rotifera biomass occurred in spring.

The dominant species of rotifera biomass in the West Lake and the streams was *Asplanchna brightwelli* and *Polyarthra trigla*, together. These species of rotifera changed in biomass seasonally (Figure 7). The biomasses of five common dominant species of rotifera in the two waters accounted for only small portion of the total rotifera biomass (Table 6). This indicates that the dominant species of rotifera density did not embody the dominant species of biomass

The annual average biomass of small crustacea in the West Lake was 2.3 times larger than that in the streams (Table 5). The cladocera biomass was the main group in the Lake Xiaonan. While the biomass of copepoda adult was the main group in Lake Yue, and nauplieus biomass dominated the remaining sampling points (Table 7).

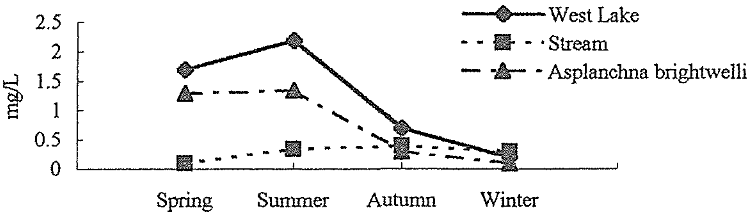


Figure 7. Seasonal variations in the biomass of Rotifera in the West Lake and adjoining streams

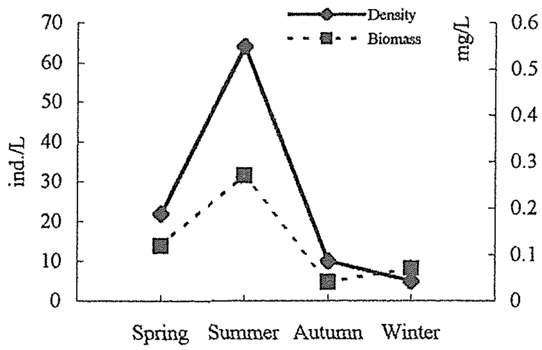
Table 6. The percentages of five dominant species of rotifera in the total rotifera biomass and species in the West Lake and the streams

Dominant species	A dominant species of biomass	5 dominant species of biomass
West Lake	66.2	28.1
Stream	44.5	64.1

The seasonal changes were not distinct between the density and biomass of small crustacea in the West Lake, due to different ratios of *Copepoda* nauplieus and adult (Figure 8).A large difference between density and biomass curves for small crustacea was apparentin the streams, especially in summer. This indicates that *Copepoda* were more numerous in summer.

Table 7. The annual average biomass of each group of small crustacea in the West Lake and adjoining streams (mg/L)

	West Lake			Stream			
Sampling Point	L.Xiaonan	Huxin	Shaoniangong	L.Yue	Changqiao	Longhong	Jinsha
Cladocera	0.175	0.075	0.059	0.065	0.020	0.011	0.005
Copepoda adult	0.114	0.074	0.123	0.104	0.030	0.018	0.014
Copepoda nauplieus	0.078	0.136	0.132	0.037	0.100	0.018	0.160



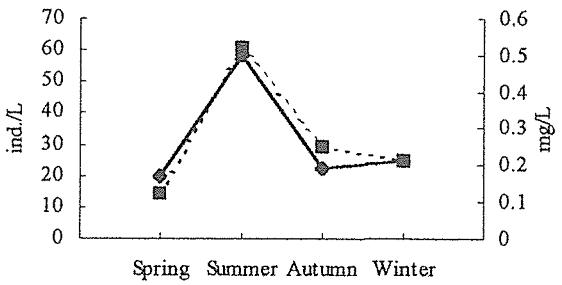


Fig.8 Seasonal variations in density and biomass of small crustacea in the West Lake (upper) and adjoining streams (lower)

Zooplankton biomass had a positive linear relationship with water temperature (Tw), and the chlorophyll-a content, and a negative relationship with transparency by Secchi's disc (SD) (Table 8). Namely, as the water temperature was raised, the biomass in two waters increased. The West Lake recorded its highest biomass of zooplankton in July, as 4.009 mg/L. This was two levels lower than that reported by Yongchang *et al.* (1992) for Lake Dianshan in Shanghai in 1988. Middle to small size protozoa and rotifera has been the main groups of zooplankton reported in the West Lack over last several years by us. Their average weight is light, with heavy small crustacea being less common than

in Lake DianShan. This is reflective feature of the zooplankton biomass in the West Lake.
Streams recorded the highest zooplankton biomass in August, at 1.207 mg/L (Figures 9 and 10). The zooplankton biomass was at its lowest in winter for both waters. The chlorophyll-a content began to peak in May, and declined again in August (Figure 9).

Table 8. Regression analysis of water temperature(Tw), transparency (SD) and Chlorophyll-a content with the biomass of zooplankton in the West Lake

Water body	Term	Regression equation	N	R	Significance test
	Tw(X)()	Y=0.108X-0.431	48	0.514	P<0.01
West Lake	SD(X)(M)	Y=3.996-4.217X	48	0.479	P<0.01
	Chl.a(X)(mg/L)	Y=26X-0.217	48	0.612	P<0.01
Stream	Tw(X)()	Y=0.029X-0.144	36	0.459	P<0.01
	Chl.a(X)(mg/L)	Y* =2X+0.008	10	0.821	P<0.01

* Protozoa biomass

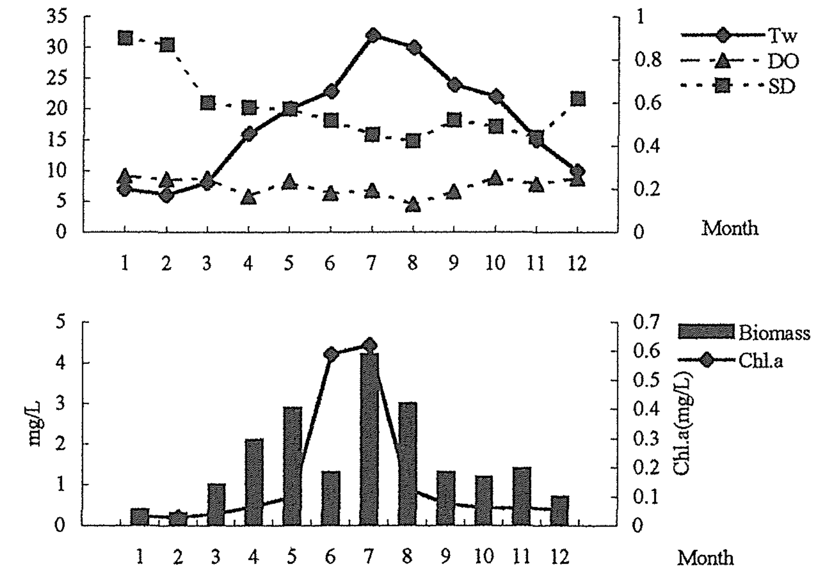


Figure 9. Relationships between the biomass of zooplankton and the water temperature, SD, dissolved oxygen (DO) and Chl.-a content in the West Lake

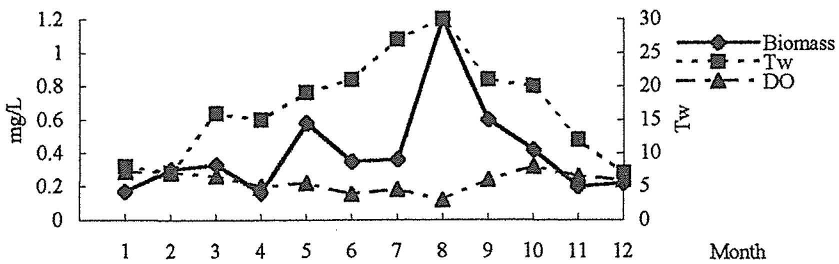


Figure 10. Relationships between the biomass of zooplankton and the water temperature and DO in adjoining streams

The relative degrees of the biomass and chlorophyll-a content were difered in each region of the West Lake with an order of : Xiaonan >Huxin >Lake Yue. Shaoniangong had no obvious relationship between biomass and chlorophyll-a content. The chlorophyll-a content in the streams presented a positive linear relationship with protoaoza biomass only. It was not significant that the changes in the biomass of zooplankton were related to changes in pH, DO, TP and TN, as these parameters could not be immediate limiting factors for zooplankton biomass.
Margalef's diversity index (d) for zooplankton was calculated based on the formula: d=(s-1)/(ln N),

where S is number and N is the density of species. The waters were classified as polysaprobic for d values<1, remained in the mesosaprobic zone for d value of 1-3, and belonging to the oligosaprobic zone for d value 3<. Results placed Lake Xiaonan and three streams in the β-mesosaprobic zone, with d values 2< (Table 9). As Longhong stream and the West Lake are linked with a channel, their ecological features are similar. However, Longhong stream was unique in that it had the most zooplankton species with the greatest diversities.

Table 9. The annual average of Margalef's diversity index (d) for zooplankton in the West Lake and adjoining streams.

sampling point	d
L.Xioanan	2.21
Huxin	1.70
Shaoniangong	1.59
L.Yue	1.92
Changqiao stream	2.13
Longhong stream	2.66
Jinsha stream	2.44

Table 10. Comparison of peak and low period seasons for species, diversity, and biomass of zooplankton in the West Lake and adjoining streams

	species		density		biomass	
	peak	low	peak	low	peak	low
West Lake	spring	autumn	autumn	winter	summer	winter
Streams	winter	summer	spring	spring	summer	spring

Conclusions

1. Mutual relationships of zooplankton between the West Lake and adjoining streams

When drawing from Qiantang River, water of the West Lake flows into the streams, raising the water level. After each heavy rain and flooding in spring, water from the stream also rushes into the West Lake. Thus, zooplankton in the West Lake and its adjoining stream are related to each other, interactively. According to Table 10, zooplankton with higher species abundance underwent peak and low periods one season in earlier in the streams than that in the West Lake. Zooplankton of higher density and biomass underwent peak and low periods either one season earlier in the lake than in the streams, or in the same season. This indicates that species increases or decreases in zooplankton in the West Lake are affected by the numbers of species which swim into it from the streams, while the density and biomass changes of zooplankton in the streams are affected by the spread range of zooplankton from the West Lake. Thus, it can be concluded that the water quality and zooplankton dynamics in the West Lake are continuously improved by the good water quality of the streams from Beigao Peak, Tianzhu, Yuhuang and Jiuyao mountains lying to the southwest of the West Lake.

2. Zooplankton and water environment in the West Lake

The dominant species of zooplankton in the West Lake have once more changed after the drawing current. The variations in dominant species of protozoa and rotifera are, however, not distinct. The dominant species of small crustacea are still changing, and several species which were dominant before the drawing have now become dominant again, for example *Coleps hirtus minor* and *Trichocera pusilla*.

Compared with observation made in 1991, protozoa dynamics in Lake Xiaonan has changed significantly, particularly for the flagellata protozoa, which have decreased quickly (Figure 11). The Huxin region, on the other hand, has undergone little changes in its protozoan dynamics. This indicates that the Lake Wai reads to have a much stabler ecosystem, and Lake Xiaonan is partly influenced by Huxin region.

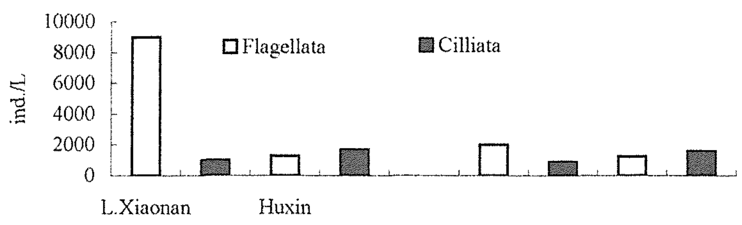


Fig.11 Comparisons between the density of two protozoan groups in Xiaonan Lake and the Huxin region from 1991 to 1995

The density of rotifera has become dominated a widespread and rapidly increased. This is somewhat indicative of the eutrophic process of the lake water (Chen, 1991). The rotifera density in the Huxin region reached 6520 inds./L in August, which is the close to the peak value observed in 1980 before the water drawing. The Margalef's diversity index (d) of the rotifera species in the lake has steadily increased over time from 2.23 in 1978 to 3.05 in 1991, and to 3.10 in 1995. This is evidencs that the aquatic environment of the West Lake has been improved by drawing current from Qiantang River, and will continue to benefit from thus drawing. Its long term effect is not strong, however so further research into this problem is still warranted.

3. Zooplankton nutrition

Chlorophyll-a is an important compornent in algae. Therefore determining the chlorophyll-a content provides an accurate measure of its total algal content in the lakes. As algae and zooplankton are related by a nutrient link, the zooplankton biomass has a positive linear relationship with chlorophyll-a content, on account of the large amounts of algae existing in the West Lake. On the other hand, in spite of the correlation coefficient reached 0.993 between autotrophic flagellate biomass of protozoa and chlorophyll-a content in the streams, there are few algae as zooplankton nutrition. It is therefore clear that the nutrient level for zooplankton in the West Lake is higher than that in the streams.

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