Effects of seasonal succession and water pollution on the protozoan community structure in an eutrophic lake

Jian-Guo Jiang a,*, Sheng-Gui Wu b, Yun-Fen Shen c

a College of Food and Bioengineering, South China University of Technology, Guangzhou 510640, China
b Institute of Reservoir Fisheries, Chinese Ministry of Water Resources and Chinese Academy of Sciences, Wuhan 430079, China
c Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China

Received 6 March 2006; received in revised form 17 May 2006; accepted 21 May 2006
Available online 5 July 2006

Abstract

The purpose of the research is to study the seasonal succession of protozoa community and the effect of water quality on the protozoa community to characterize biochemical processes occurring at a eutrophic Lake Donghu, a large shallow lake in Wuhan City, China. Samples of protozoa communities were obtained monthly at three stations by PFU (polyurethane foam unit) method over a year. Synchronously, water samples also were taken from the stations for the water chemical quality analysis. Six major variables were examined in a principal component analysis (PCA), which indicate the fast changes of water quality in this station I and less within-year variation and a comparatively stable water quality in stations II and III. The community data were analyzed using multivariate techniques, and we show that clusters are rather mixed and poorly separated, suggesting that the community structure is changing gradually, giving a slight merging of clusters form the summer to the autumn and the autumn to the winter. Canonical correspondence analysis (CCA) was used to infer the relationship between water quality variables and phytoplankton community structure, which changed substantially over the survey period. From the analysis of cluster and CCA, coupled by community pollution value (CPV), it is concluded that the key factors driving the change in protozoa community composition in Lake Donghu was water qualities rather than seasons.

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Keywords: Protozoa community; Eutrophic lake; Multivariate analysis; Water quality; Lake Donghu

1. Introduction

Protozoa communities are integrally linked to aquatic habitats and their abundance and community structure are related to both chemical and physical in lake conditions, making them useful biological indicators (Jiang and Shen, 2003b). PFU microbial communities have been shown to form complex species assemblages, which exhibit many of the characteristics of structural communities (Xu et al., 2005). Various structural and functional characteristics of PFU microbial communities have been tested to be correlated with the degree of the lake’s eutrophication (Cairns and McCormick, 1993). As a main group in PFU microorganisms, protozoa communities are directly influenced by water quality such as changing nutrient concentrations, heavy metal, and organic poisons such as HgCl₂ (Weitere and Arndt, 2003). Unlike water quality measurements, which only provide an instantaneous assessment of stream conditions, protozoa assemblages can be used to identify past disturbances and toxic effects that are not readily detected by chemical means.

In the development of meaningful measures of environmental health, first efforts were usually chemically based and parameter specific (e.g., dissolved oxygen, pH, turbidity). Next were attempts to find a single reductionist metric (e.g., evenness or $H'$) or graph (e.g., abundance biomass curves) to describe abundance and diversity of organisms within an ecosystem (Washington, 1984) and this research is still applied in a wide range (Gomes and Godinho, 2003; Lohrenza et al., 2003; Jiang et al., 2004; Froneman, 2004).
Following that came statistical treatments of data collected in nearfield/farfield situations (McKenna, 2003; Peterson and Keister, 2003; Huttig and Oehme, 2005). The most powerful of these methods, involving multivariate methods, such as PCA (principal components analysis) and MDS (myelodysplastic syndromes) have proven to be more sensitive to detecting pollution than univariate methods (Etaon, 2001; Gotz and Lauer, 2003; Mouser et al., 2005).

Seasonal variability and water environment are the two most important factors that affect aquatic biological community structures. Significant amounts of research have been conducted on the effects of season and water quality on aquatic community (Arashkevich et al., 2002; Keith-Roach et al., 2002; Martin-Cereceda et al., 2002; Jeae et al., 2003; Reiss and Kroncke, 2004; Bode et al., 2005). But the two aspects are often considered separately. The characterisation of a protozoa community over time and the changes within it, mapped to changes in the chemistry of the system, may therefore provide information, which could help in understanding these often-complex processes.

The aims of this study were to investigate: (1) the seasonal variability in PFU (polyurethane foam unit) protozoa communities and environmental parameters from different areas of Lake Donghu, in order to determine (2) whether spatial differences in temporal variability in environmental factors are related to protozoa community variability; and (3) to get an insight into which one of water quality and seasonal changes is the main factor of changing the protozoa communities in the eutrophic Lake Donghu.

2. Material and methods

Chemical and biological variables including protozoa community structure were investigated monthly at three stations in Lake Donghu for a period of one year. Stations were located in the sites representing different pollution degrees (Jiang and Shen, 2003b).

2.1. Study site

Lake Donghu (30°33’N, 114°23’E) is located at the eastern end of the Wuhan city, the capital of Hubei province, China. At an elevation of 20.5 m above sea level, the lake has a surface area of 33.66 km². The average depth of the lake basins is 2.21 m and the maximum is 4.75 m. The lake is composed of several basins separated by artificial dykes. Hydrobiological studies and water quality monitoring of the lake were started in the 1950s, and have been followed up intermittently since then. Primary production of phytoplankton in the water column of the lake area concerned has been rated as 6.3 mg O₂ m⁻² day⁻¹ over the years. The urban expansion and industrial development around the lake began in the 1950s. Since then, a large amount of wastewater has been released into the lake from the residential district by many small outlets along the bank especially the southwest bank of the lake (Jiang and Shen, 2003b). This lake has been segmented into several parts by causeways across the lake proper and the bay region (still allowing the passage of water between adjacent parts through a watercourse). These sublakes considerably differ in trophic status and biota.

2.2. Water chemistry

The water samples for the analysis were taken monthly at the middle of each month at stations I, II, III (Fig. 1). Station I is located in the middle of the Shuiguo Hu Bay, near the western end of the lake. Station II is in the central part of the Guozheng Hu area, Station III is in the central of Tanglin Hu.

Water samples were collected monthly from mid-August to mid-July next year, a total of 12 sampling events. For analysis with protozoa communities, water was sampled immediately following the PFU communities’ collection for each site. Chemical oxygen demand (COD, mg/l), total phosphorus (TP, mg/l), ammonia–nitrogen (mg/l as NH₃–N), nitrate–nitrogen (mg/l as NO₃–N), nitrite–nitrogen (mg/l as NO₂–N) and dissolved oxygen (DO, mg/l) were analyzed according to the ‘Standard Methods for the Examination of Water and Wastewater (APHA, 1993).

2.3. Protozoa communities sampling

The protozoans were collected by PFU (polyurethane foam unit) method (Jiang and Shen, 2003a). PFU may host most protozoans including planktonic, periphytic and benthic protozoan assemblages. The PFU block was about 6.5 × 6.5 × 7.5 cm in size and blocks were soaked in distilled water for 24 h and squeezed before use. The PFU blocks were tied with thin ropes and placed at the depth of 1 m below the water surface. Every month on days 15, several PFU blocks were collected each time for analysis and the blank PFU blocks were placed in for the next sampling.
Samples were examined in the laboratory within five hours after collection. Sampling was carried out in the morning and living protozoans were identified and enumerated immediately after squeezing the PFU into a beaker. All samples were completed for microscopic examination within 5 h.

2.4. Statistical analysis

Multivariate statistical analysis is a way of looking at all variables simultaneously and is used to group samples in clusters of the most similar samples on the basis of all components. Multivariate statistics, such as ordination and clustering, establish a visual picture of samples groups within a data set. Both techniques should be employed together because clustering and ordinations are subject to different sources of distortion. Clustering preserves small-scale similarities at the expense of large-scale distortion. Conversely, ordinations retain large-scale patterns at the cost of small-scale distortion (Kalin et al., 2001). We selected the unweighted pair group method (UPGMA) for clustering because it minimizes the amount of distortion in the dendrogram relative to the original similarity or difference matrix. Euclidean dissimilarity distances for samples were used here.

To best explore the available data, we conducted two types of analyses, involving binary data and quantitative data, respectively. PCA was applied to the binary data, which can be expected to give a basic, but complete, picture on protozoa community changes in relation to major water quality variables. The PCA was appropriate for analyzing data containing many variables including several protozoa taxon and various operational parameters because it creates several groups that have observed relationships. In addition, correlation coefficients were performed to further enhance understanding of the relationships between protozoa community and chemical parameters. The quantitative data was analyzed using canonical correspondence analysis (CCA), which relates the quantitative changes in protozoa community directly. CCA examines variations in the community composition by constraining ordination axes to be linear combinations of environmental variables (Hansel-Welch et al., 2003). In the ordination diagram, environmental variables are represented by arrows pointing in the direction of maximum change and the arrow length indicates the importance of the environmental variable. Weighted intra-set correlation coefficients were used to identify ecological explanations of the ordination axes derived from the biological data (Hansel-Welch et al., 2003). Both PCA and CCA were implemented using MVSP software, Kovach Computing Services, Wales, and UK.

2.5. Community pollution value (CPV)

Community pollution value was a biotic index based on community structure (Jiang and Shen, 2003a, 2005). Each protozoa species was given a species pollution value (SPV) and CPV was calculated from the SPV:

$$\text{CPV} = \frac{\sum_{i=1}^{n} \text{SPV}_i}{n},$$

where SPV is the species pollution value of species $i$, $n$ is the number of species in a community. CPV is used to evaluate the pollution status of sampling site and compare the pollution degrees between sampling sites. The higher the CPV, the heavier the pollution is.

3. Result and discussion

3.1. Water quality

The concentration ranges and the temporal variation of six water quality variables during the year in the three stations are shown in Fig. 2. The temporal variability of these parameters are obvious. For example, at station I, NH$_3$ peaked in January and April, but in other months at lower levels. NO$_3$ peaked in November and was higher from February to April (Fig. 2(A)). The variability of NO$_3$ in stations II and III were similar to station I (Fig. 2(B) and (C)). NH$_3$ in station II had an obvious peak in April. DO in station III had a peak in January (Fig. 2(C)), etc. As a whole, the variable ranges of NO$_2$ in each were the minimum.

Among these six variables, only TP with NH$_3$ ($r = 0.59$, $n = 36$, $P < 0.01$), TP with NO$_2$ ($r = 0.51$, $n = 36$, $P < 0.01$), TP with DO ($r = -0.48$, $n = 36$, $P < 0.01$), and NO$_2$ with DO ($r = -0.46$, $n = 36$, $P < 0.01$) showed correlation respectively during the year. Other variables did not show significant correlations with one another. This is why we can see in Fig. 2 that annual peaks in TP, NH$_3$ and NO$_3$ were not coincident, which may indicate differences in the source of wastewater during different period. But among the three stations, any single parameter showed significant correlation between any two stations ($r = 0.62–0.98$, $n = 12$, $P < 0.01$) during the year, indicating that these elements had a common variable pattern among the three stations.

The comprehensive chemical index (PB) is a method of converting various chemical parameters into a standard value, which is used to evaluate the pollution status of sampling site (Jiang and Shen, 2003b). The annual average PB for stations I, II, and III were 5.24, 3.89 and 3.02, respectively. According to the evaluating standard PB (Jiang and Shen, 2003b), the pollution statuses of stations I, II, III were severely polluted, heavily polluted, and moderately to heavily polluted water, respectively.

The PCA ordination of the 36 water samples showed an apparent temporal trend (Fig. 3). In the plot, the length of arrow indicates the magnitude of the change in the corresponding variable, which increases along the arrow. The vertical casting of a sample position on each variable-arrow indicates the relative level of the variable in the sample. Given that $x$ measures the correlation coefficient between
the variable and the axis (Kalin et al., 2001). The first PCA axis explains a large proportion of the total variance (43.731%) (Table 1). Variables such as TP (0.51), NO$_2$ (0.48), NH$_3$ (0.45) weigh most heavily on the first axis (scores > 0.4), followed by COD (0.37), DO (−0.35) and NO$_3$ (0.22), which also contributed markedly to this axis. The first axis was explained negatively by DO and this axis is significantly negatively related to the NO$_2$ ($r = 0.80$, $n = 36$, $P < 0.001$), which had a minimum fluctuation, confirming that it represents the variables of water quality. The second axis is better negatively correlated with NO$_2$ ($r = 0.68$) and DO ($r = 0.61$), both of which had a large fluctuation during the year. Therefore, the axis seems representative of a second variable of water quality.

In the first two-dimensional space, station I samples were widely dispersed, indicating the fast changes of water quality in this station. The samples of stations II and III were rather compressed and overlapped more or less, suggesting less within-year variation and a comparatively stable water quality. Further more, samples between stations II and III were more overlapped, while station I is noticeably apart, indicating station I and station II having similar water qualities and being dissimilar with that of station I. As we analyze above, PB values of the three stations give us the same conclusion.

3.2. Protozoa community composition in relation to season succession

A total of 232 protozoan species were recorded from the three stations during the year. Among those species, 63 were Phytomastigophorans, 49 were Zoomastigophorans, 29 were Sarcodines and 91 were Ciliates. Table 2 lists the taxa composition and total number of protozoan species
collected from PFUs at the three sampling stations. Water quality of station I was poorest among the three stations, but the station had the most species number (115). Percentage of Phytomastigophorans in stations I, II, III were 24.35%, 29.41% and 31.43%, respectively, which reflected the autotrophic component in communities increased along the water quality gradient and coincided well with the improved water conditions.

Table 1
Results from the principal components analysis of the chemical data

<table>
<thead>
<tr>
<th>Variables</th>
<th>Eigenvalues</th>
<th>Variance (%)</th>
<th>Sum variables</th>
<th>Factor loadings</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Axis 1</td>
</tr>
<tr>
<td>COD</td>
<td>2.624</td>
<td>43.731</td>
<td>43.731</td>
<td>0.374</td>
</tr>
<tr>
<td>TP</td>
<td>1.387</td>
<td>23.123</td>
<td>66.854</td>
<td>0.514</td>
</tr>
<tr>
<td>NH₃</td>
<td>0.838</td>
<td>19.723</td>
<td>80.825</td>
<td>0.447</td>
</tr>
<tr>
<td>NO₂⁻</td>
<td>0.643</td>
<td>10.711</td>
<td>91.536</td>
<td>0.476</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>0.321</td>
<td>5.353</td>
<td>96.889</td>
<td>0.223</td>
</tr>
<tr>
<td>DO</td>
<td>0.187</td>
<td>3.111</td>
<td>100</td>
<td>-0.346</td>
</tr>
</tbody>
</table>

Table 2
Taxonomic composition and species number collected at the three stations over the year

<table>
<thead>
<tr>
<th>Taxa</th>
<th>Stations</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phytomastigophorans</td>
<td></td>
<td>28</td>
<td>25</td>
<td>33</td>
<td>63</td>
</tr>
<tr>
<td>Zoomastigophorans</td>
<td></td>
<td>21</td>
<td>21</td>
<td>19</td>
<td>49</td>
</tr>
<tr>
<td>Sarcodines</td>
<td></td>
<td>11</td>
<td>11</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>Ciliates</td>
<td></td>
<td>55</td>
<td>28</td>
<td>38</td>
<td>91</td>
</tr>
<tr>
<td>Total species</td>
<td></td>
<td>115</td>
<td>85</td>
<td>108</td>
<td>232</td>
</tr>
</tbody>
</table>

Fig. 4 shows the species numbers of the three stations at each month of the year. The species number in winter was apparently less than that in summer and the species number was greater in spring as well. There was a great variation in species number at each station. The species number between stations II and III was significant correlated (r = 0.69, n = 12, P < 0.01), but the species number between stations I and II, stations I and III did not showed close relationships. This incongruous variable of station I with stations II and III was probably due to its location. Station I is located in the Shuiguo Hu Bay, near the western end of Lake Donghu. Around the Shuiguo Hu Bay, there are several wastewater outlets, the ruleless pollution discharge from these outlets made the pollution status of station I fluctuate drastically, which caused the station having a large number of species and made the species vary quickly. Station II is in the central part of the Guozheng Hu area and station III is in the central of Tanglin Hu.
where the wastewater had diluted more or less by the self-purification of the lake. The species number of the two stations was less affected by wastewater than station I.

For the binary data analysis, all protozoa data was converted to simple presence–absence data. In the statistical analysis, samples are labeled with the month in which they were collected. Fig. 5 illustrates the dendrograms of the three stations for 12 samples of year, respectively, based on 115 species (station I, Fig. 5(A)), 85 species (station II, Fig. 5(B)), and 108 species (station III, Fig. 5(C)).

The dendrogram shows the formation of 4 clusters of like samples, based on the 12 samples from station I of the year (Fig. 5(A)). Each generally contains samples which are from an adjacent month, with the exceptions of sample of August, which solely form a cluster with the most dissimilar with other three clusters. Samples in November and December, September and October, respectively, form a cluster. Samples from January to July form another cluster, which contains three subclusters: May, February–June–July, and January–April. Fig. 5(B) shows the dendrogram for station II of the year. Three major clusters were formed based on the samples of each month. Samples from September to May form a larger cluster which contains several subclusters. June and July form another cluster. Similar to station I, sample of August form a cluster itself. The dendrogram of station III (Fig. 5(C)) shows that samples of August, September and October form a cluster, respectively. Samples from November to July next year form another larger cluster in which there are not obviously segregated smaller clusters. The groupings here are rather mixed and poorly separated, this suggests that the community structure is changing gradually, giving a slight merging of clusters from the summer to the autumn and the autumn to the winter. The analysis gives a useful overview of the shifts in the community and indicates another factor, water quality as discussed later, must be causing the clustering in this way.

The samples of August all had the farthest distance with others within their each station. But the chemical data do not show that the water qualities of August in the three stations were any special. The possible reason for their clustering in this way is due to the sampling differences. Sampling was initial in August, PFUs exposed in water only ten days for the first sampling. It is about 30 days for other month samples. Generally the PFU protozoa community needs more than 25 days to develop to mature and reach equilibrium. This makes the August samples lack of comparability with other samples.

There are no major clusters formed according to season, e.g., cluster representing the winter and summer months. All the clusters are apparently formed in time order. At this level of analysis there is no information about why they cluster in this way, we suppose water quality is the main driving forces behind the clustering. For a eutrophic lake like Lake Donghu, the pollution discharge is irregular, the lack of seasonally groups is just interrupted by random pollution discharge, especially certain single element. Most of smaller clusters form between two continuous months, and the water quality between any two consecutive months is possibly close. In station I, only one small cluster forms between two inconsecutive months, January and April (Fig. 5(A)). January and April both character with the highest concentration of NH₃ (30.48 and 22.15 mg/l, respectively), which is much higher than that of other months during the year. In station III, September and

![Fig. 5. Dendrogram for samples from the three stations over the year in Lake Donghu. (A) Station I, (B) station II, (C) station III.](image-url)
October each form a cluster with the most distance between them and with other clusters. Comparing the chemical parameters of the two months, we find that, except NH₃, other chemical parameters were close between the two months. But NH₃ of October was 2.70 mg/l, the highest of the year; in Sep the concentration was 0.068 mg/l, the lowest of the year. It seems that NH₃ is the main factor of making the cluster in this way.

3.3. Protozoa community composition in relation to water quality

Canonical correspondence analysis (CCA) was used in order to find relationships between the protozoa community and the chemical variables. CCA biplot of protozoa samples collected at the three stations and over the year is shown in Fig. 6. Eigenvalues (indicating strength of the model) for the first two multivariate axes were 0.367 (CCA1) and 0.297 (CCA2). The sum of all canonical eigenvalues was 0.72. The first two CCA axes account for 45% of the total variance with the first axis alone explaining 25%, indicating a strong gradient in the data set. When water quality variables were imposed on the PCA plot, each water quality variable is represented by an arrow, which determines an axis. In the final CCA model (Table 3), the first two axes were significant and together explained 70% of the variance in species-environmental relationship, therefore results for these two axes are plotted (Fig. 6). CCA axes are interpreted using intraset correlations and canonical coefficients (Reiss and Kroncke, 2005). Canonical coefficients are the best weights for the environmental variables that make up each biplot axis. Intraset correlations indicate how well these weights correlate with each environmental variable. Intraset correlations are illustrated in the biplot by vectors representing each significant environmental variable (Duggan et al., 1998). Canonical coefficients indicate that axis one is a gradient of increasing all chemical variables, whereas axis two is a gradient of
decreasing COD, NH$_3$, NO$_2$ and increasing TP, NO$_3^-$. DO (Table 3). Species-environment correlations are high and are significant, 0.972 and 0.966 for the first and second axis, respectively, conforming the relationship between community structure and overall level of contamination (Table 3).

Correlations between all six environmental variables and the first two canonical axes were statistically significant ($P < 0.001$). NO$_3^-$ (0.818) and COD (0.781) had highest correlated with the first axis (axis one explained 58.2% of species-environment relation). TP had a highest correlation (0.566) with the second axis (58.5% of species-environment relation). These results suggested that, in the eutrophic lake, N and P (two main factors of eutrophication) controlled the variance of protozoa community.

Community pollution value (CPV) is a biotic index based on the composition of community, more than 700 species of protozoa has been given a species pollution value (SPV) (Jiang, 2006). CPV of any sampled community can be calculated from its species SPV (Jiang and Shen, 2003). CPV is established from PB based on their logarithmic relationship, correlation analysis between CPV and PB could be best described by a logarithmic curve. CPV for mic relationship, correlation analysis between CPV and PB was calculated from SPV, correlation could be best described by a logarithmic curve. CPV for mic relationship, correlation analysis between CPV and PB was calculated from its species SPV (Jiang and Shen, 2003). CPV of any sampled community can be calculated from its species SPV (Jiang, 2006). CPV of any sampled community can be calculated from SPV, correlation analysis between CPV and PB could be best described by a logarithmic curve. CPV for each of the 36 samples is calculated from SPV, correlation analysis indicated that CPV is significantly correlated to COD ($r = 0.37$, $n = 36$, $P < 0.05$), TP ($r = 0.41$, $n = 36$, $P < 0.01$), NH$_3$ ($r = 0.50$, $n = 36$, $P < 0.01$), NO$_2^-$ ($r = 0.38$, $n = 36$, $P < 0.05$), NO$_3^-$ ($r = 0.48$, $n = 36$, $P < 0.01$), and is only not significantly correlated to DO ($r = -0.15$, $n = 36$, $P > 0.05$). The correlation analysis between PB and CPV is: CPV = 0.0964Ln(PB) + 3.4967, $r = 0.67$, $n = 36$, $P < 0.00003$ (Fig. 7). It is clear that the protozoa community was strongly correlated to water quality.

Further, The average CPVs for stations I, II, III were 3.94, 3.82, 3.81, respectively. The gradient of CPV is same to that of PB discussed above. According to the evaluation standard by CPV (Jiang, 2006), the pollution statuses of stations I, II, III were heavily to severely polluted, moderately polluted, and moderately polluted water respectively, which is approximate to the result evaluated by PB.

4. Discussion

Using PCA and CCA techniques, different biological groups, such as phytoplankton community (Kalin et al., 2001), ostracods (Kulkoyluoglu, 2005), rotifer (Castro et al., 2005) and macrophyte community (Hansel-Welch et al., 2003) were employed to research their relationships with physical and chemical changes in lake water quality. These studies showed that environmental variables, such as TP, arsenic and total suspended solid (TSS), etc. were considered to be the key factors driving the change in community composition.

The CCA and PCA ordination clearly showed that the PFU protozoa community had experienced substantial changes. These changes were statistically related to many chemical water quality variables, including COD, NH$_3$, NO$_3^-$, TP, NO$_2^-$ and DO. However, statistical significance does not imply an ecological importance (Kalin et al., 2001). The concentrations of some elements were low and fell within narrow ranges and reflect normal surface water characteristics in each sampling zone. For example, the concentrations over the period of observation ranged from 2.01 to 4.87 mg/l in COD in station III and from 0.074 to 0.192 mg/l in TP in station I. In contrast, several variables showed substantial changes over time. The concentration of NH$_3$ increased from 0.947 mg/l (April) to 30.475 (June) in station I. The highest and lowest values of NH$_3$ were, respectively, 0.145 mg/l and 5.054 mg/l in station II, and 0.068 mg/l and 3.226 mg/l in station III. The highest and lowest values of NO$_2^-$ were respectively 0.031 mg/l to 0.518 mg/l in station I, 0.004 mg/l to 0.651 mg/l in station II, 0.004 mg/l to 0.353 mg/l in station III. DO of the three stations also showed large changes over the year. These water quality variables appear to be mainly related to phytoplankton changes (Fig. 2).

Multivariate techniques were extremely useful for characterizing changes of community following the temporal variation, as well as in illustrating how this community varies along gradients of water quality (Hansel-Welch et al., 2003). Cluster analysis and PCA were most useful in characterizing differences in the protozoa communities and water qualities among months in Lake Donghu, whereas CCA showed how changes in protozoa community composition related to environmental conditions. Our results confirm that the combination of CCA and clustering (using the UPGM) reflects community structure most accurately. Cluster significance testing examines a highly pertinent statistical question, that is, whether or not two clusters of samples were drawn from overlapping or disjunct parent populations. This technique for that reason is more rigorous than conventional significance tests such as the Student’s $t$-test, canonical variates, discriminant analysis, and analysis of variance (ANOVA), which only compare.
the taxonomic means of two or more samples (Bonuso et al., 2002).

Although the cluster and CCA analyses of the protozoa community similarity gave very similar clusters, the CCA analysis gave much more detailed information on the differences between the groups of like samples. Similar, but qualitative, information may be derived by plotting community structure similarity coefficient of each cluster, but quantification gives increased confidence in the conclusions (Keith-Roach et al., 2002). It is difficult to identify the features separating clusters with confidence from Fig. 5, and it is therefore extremely important to have quantitative information on the distinguishing characteristics. Cluster analysis based on community structure showed that there were no distinct clusters separating the data into a summer and winter, and the protozoa community changed gradually in time order, but without explanation. The CCA analysis allows quantification of the important relationship between water samples and protozoa community samples, reducing uncertainty in the interpretation. Nevertheless, the clusters appear to represent months of the year, showing that the analysis is successfully mapping temporal patterns in the protozoa community structure in Lake Donghu.

Some multivariate approaches showed that certain genera of protozoa and some dominant species could be employed as biological indicators because there is a strong positive correlation between the abundance of some protozoa and chemical parameters in freshwater system (Martin-Cereceda et al., 2002; Gomes and Godinho, 2003; Weitere and Arndt, 2003). The present research lacked the data of species abundance, which makes us difficult to use dominant species or the species groups for further multivariate analysis. But these metrics should be among those considered for future evaluation to the restoration effect of the lake and mathematical spreadsheet models could be constructed to estimate chemical parameters removal efficiency.

In conclusion, this study of the seasonal dynamics of the PFU protozoa community at three stations in Lake Donghu demonstrated that PFU protozoa communities do vary over the course of a year in response to changing conditions. Our results clearly indicate that between cluster variation and within cluster variation of the protozoa community is drawn from different parent distributions. Hence, this implies that the community changes gradually throughout months. These communities were significantly different among those at different stations and in different months, but, as for all protozoa samples, there was no significant difference between the structures of the transition community among seasons. In the eutrophic lake, the change of protozoa community structure is mainly determined by the water quality, next by the seasonal succession. In other word, the natural seasonality of protozoa community was more or less interrupted by chemical water quality. The analysis of each sample’s CPV, a biotic index based on community structure, also shows that the variables of the PFU protozoa community structure is closely related to the changes of water chemical quality. PB, PCA and CPV give the same conclusion that stations I and II had similar pollution level, and that of station I was obvious higher.

References


Reiss, H., Kroncke, I., 2005. Seasonal variability of infaunal community structures in three areas of the North Sea under different environmental conditions. Estuarine, Coastal and Shelf Science 65, 253–274.

