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Research Article

Seasonal Pattern of Planktonic Ciliates in a Subtropical Shallow Urban Lake

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Abstract: In order to realize the ecological specialty of man-made lake located in urban area in South China, species composition, dominant species dynamics and other parameters of ciliate community were investigated with the qualitative and quantitative observations from April of 2009 to March of 2010, in Dongshan Lake, a subtropical shallow urban lake in South China. The relationship between the parameters of ciliate community and aquatic environment was analyzed by using statistics method. The highest abundance of ciliates was 164.7×10^3 ind/L and the largest biomass of ciliates was 11.23 mg/L. Among the 111 species of ciliates, *Urotricha* spp. (*U. agilis*, *U. armata*, *U. farcta*, *U. furcata*, *U. globosa*, *U. ovata* and *U. saprophila*), *Halteria grandinella*, *Cinetochilium margaritaceum*, *Strobilidium caudatum* and *Cyclidium* spp (*C. citrullus*, *C. elongatum*, *C. glaucoma* and *C. simulans*) contributed more to total ciliate abundance, meanwhile *Holophrya discolor*, *Didinium nasutum*, *H. grandinella*, *R. caudatum, Coleps hirtus* and *Monodinium balbianii* made more contributions on biomass. Shannon-Wiener biodiversity index of the ciliate communities was from 2.1 to 3.2 during the investigation. The patterns of abundance temporal distribution on major planktonic ciliates could be divided into 3 groups. The first one presented typical monomodal composed by *Coleps hirtus* and *Cinetochilium margaritaceum*; the second was trimodal type, including *Halteria grandinella*, *Urotricha* spp. and *Cyclidium* spp.; the last type had no significant peaks during the investigation. Based upon the data from ciliate abundance and biomass and take the hydrochemical parameters into consideration the lake were hypereutrophic. The results from both parametric and non-parametric analysis showed that there was no relationship between the abundance and other biotic or abiotic factors and biomass of ciliate was no relevant with. other biotic or abiotic factors as well.

Keywords: Biodiversity index, ciliated protozoa, dynamics, plankton, shallow lake, subtropical

INTRODUCTION

As an important part of plankton, ciliated protozoans not only have higher diversities, but also play a significant role in energy flow and material cycles in water ecosystems (Fenchel, 1987; Laybourn-Parry, 1992; Arndt and Berninger, 1995). Within the last two decades, ciliate protozoan abundance, biomass and species composition in marine and freshwater have been investigated at various locations, as reviewed by Beaver and Crisman (1982), Fenchel (1987), Porter *et al*. (1985) and Laybourn-Parry (1992). The species compositions and population dynamics of ciliate communities in inland temperate freshwater lakes and ponds with various trophic status have been reported by some authors (Cruz-Pizarro *et al*., 1994; Esteban *et al*., 1995; Finlay *et al*., 1991; Guhl *et al*., 1996; James *et al*., 1995; Laybourn-Parry *et al*., 1990a, b; 1994; Madoni, 1990; Müller, 1989; Rublee and Bettez, 1995; Petersen, 1990; Salbrechter and Arndt, 1994; Schlott-Idl,1984; Schönborn, 1981). Although some reports on the time and spatial patterns of pelagic ciliates have been made (Bark, 1981; Laybourn-Parry *et al*., 1990b; Carrias *et al*., 1994; Obolkina, 2006; Yasindi *et al*., 2006; Agasild *et al*., 2007; Conty *et al*., 2007; Zingel *et al*., 2002, 2007), the knowledge of the distribution patterns of subtropical shallow lakes ciliated zooplankton was limited.

The aim of this work was to study the temporal distribution of ciliated protozoan community in a eutrophic shallow subtropical lake, Dongshan Lake located in urban area of Guangzhou City, South China. On the other hand, this study was expected to provide more detailed information about zooplanktonic especially micro zooplanktonic communities in subtropical shallow lake since there were only a few publications on ciliate ecology in Chinese freshwater lakes (Shen and Gu, 1964; Xu *et al*., 1991).

Description of the lake: Dongshan Lake is situated in Dongshan Park of Guangzhou City (Fig. 1). Its surface area is about 0.318 km^2 with a mean depth of 1.30 m and a maximum depth of 2.60 m. It is a shallow urban lake with insignificant inflow and outflow to Pearl

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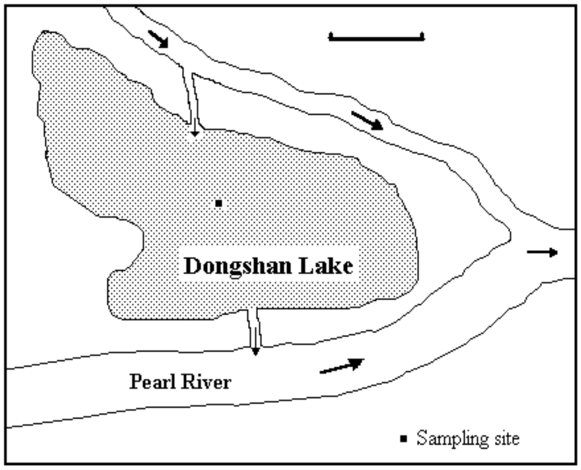

Fig. 1: The schematic map of the lake and sampling site. Bar: 200 m

River which is the third largest river in China. In this area of Pearl River, many lakes in most cities are man-made lake, but the Dongshan Lake is a natural one. So it could be considered as an independent freshwater system in the region. The information of planktonic ciliate ecology in Dongshan Lake could be used to explain the characteristics of the freshwater planktonic ciliate communities in this region.

MATERIALS AND METHODS

Sampling: Water samples were taken monthly from April 2009 to March 2010. Each sample was 1 L lake water taken from mixed waster, which was 2.5 L water taken from surface and near bottom in the lake with the water sampler respectively and mixed in a large vat in site. The water sample was fixed with fresh Bouin's liquid. Meanwhile, water temperature, pH, Total Nitrogen (TN), Total Phosphorus (TP), O_2 and O_2% were measured with the method provided by American Public Health Association (1985). The primary production of the lake was measured with the method given by Vollenweider (1969). Additionally, the living protozoans were collected with planktonic net (mesh size is about 40 μ). Water samples were concentrated to 30 mL with sedimental method.

Qualitative and quantitative observation: The identification of ciliated protozoan was processed with living animals and protargol stained specimens was prepared as the method of Foissner (1991). Quantitative examination was done according to the method of Quantitative Protargol Staining (QPS) given by Montagnes and Lynn (1987). Taxonomy of ciliates was based on the descriptions of De Puytorac (1994), Dragesco and Dragesco-Kerneis (1986), Foissner *et al*. (1991, 1992, 1994, 1995, 1999) and Shen *et al*. (1990).

It should be pointed out that, due to the sizes of species from Genus *Urotricha* were very small, the identification of the species were very difficult even by using the QPS. The abundance and biomass of *Urotricha* were no longer distinguished among the different species in this genus.

Biomass and biodiversity index calculations: The biomass for each ciliate species was calculated by using the method from Foissner *et al*. (1995) and Shannon-Wiener biodiversity index of planktonic ciliate community was calculated by a formula as follows:

$$H = -\sum_{i=1}^{s} P_i \log_2 P_i$$

(P*i* = N*i*/N; *S* = total species number; N = Total abundance; N*i* = Abundance of species *i*.)

Statistical analyses: The statistical analyses were done with SPSS 11.5 software.

RESULTS

Limnological features: Seasonal changes of water temperature, TN, TP and primary productivity were showed in Fig. 2 and 3.

Water temperature changed from 15 to 31°C, the lowest temperature appeared in Dec. 2009 and the highest temperature was recorded in Sept. 2010. The pH values of water were between 6.0-6.5.

Figure 3 shows that TP kept a high concentration, but TN showed a higher peak only in August. The annual average of TP, TN concentrations and primary productivity were 0.049 mg/L, 4.291 mg/L and 6.7 gC/m^2, respectively.

Ciliate species composition: During the investigation period, 111 ciliate species, belonging to 62 genera were found (Table 1). Most of them were from Prostomatida, Peritrichida, Hymenstomata and Oligotrichida. Common genera were *Halteria*, *Urotricha*, *Rimostrombidium*, *Cyclidium*, *Holophrya*, *Tintinnidium*, *Monodinium*, *Epistylis*, *Coleps* and *Didinium*. Based upon Foissner *et al*. (1991, 1992, 1993, 1994, 1995), among of these 111 ciliate species, 60 species were pelagic, 41 species were explicitly benthic and 10 species were epibiontic or periphytic.

Seasonal changes of ciliate species numbers and biodiversities: Seasonal changes of ciliate species number and biodiversity index were shown in Fig. 4. The species number curve was peaked in May (41 species), September (37 species) 2009, February (34 species) 2010 and the biodiversity index curve had same trend but peaked in later.

Seasonal changes of ciliate abundance and biomass: Seasonal changes of ciliate abundance had two peaks (Fig. 5), the first (149.5×10^3 ind/L) was found in July

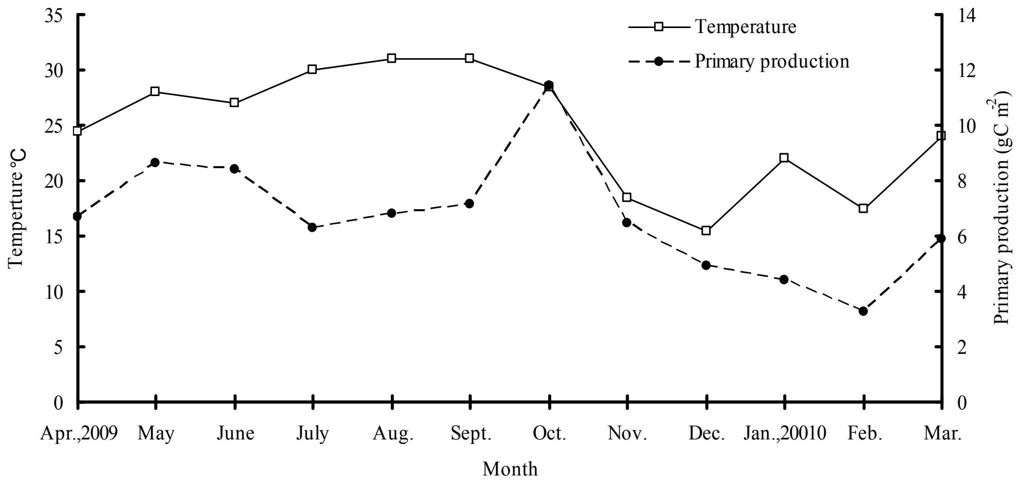

Fig. 2: Seasonal changes of water temperature and primary production in Dongshan Lake

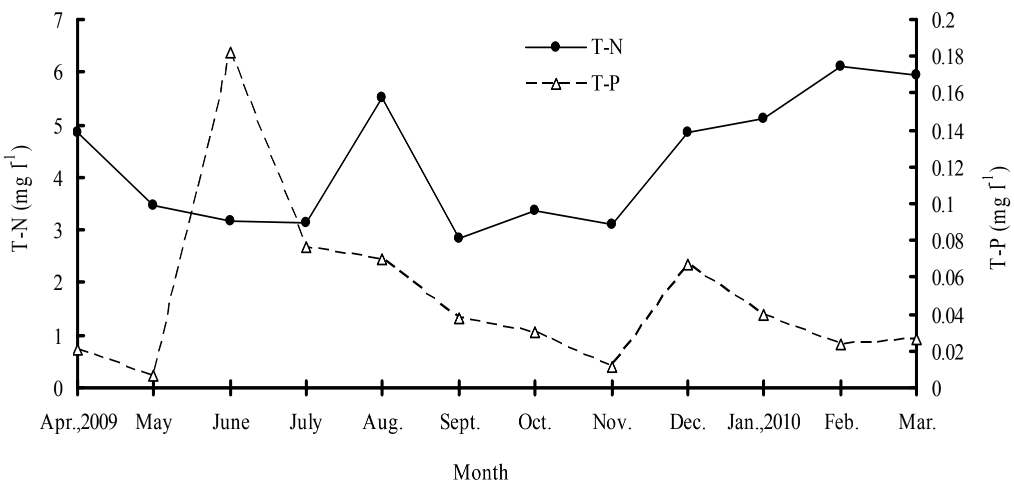

Fig. 3: Seasonal changes of TN and TP in water of Dongshan Lake

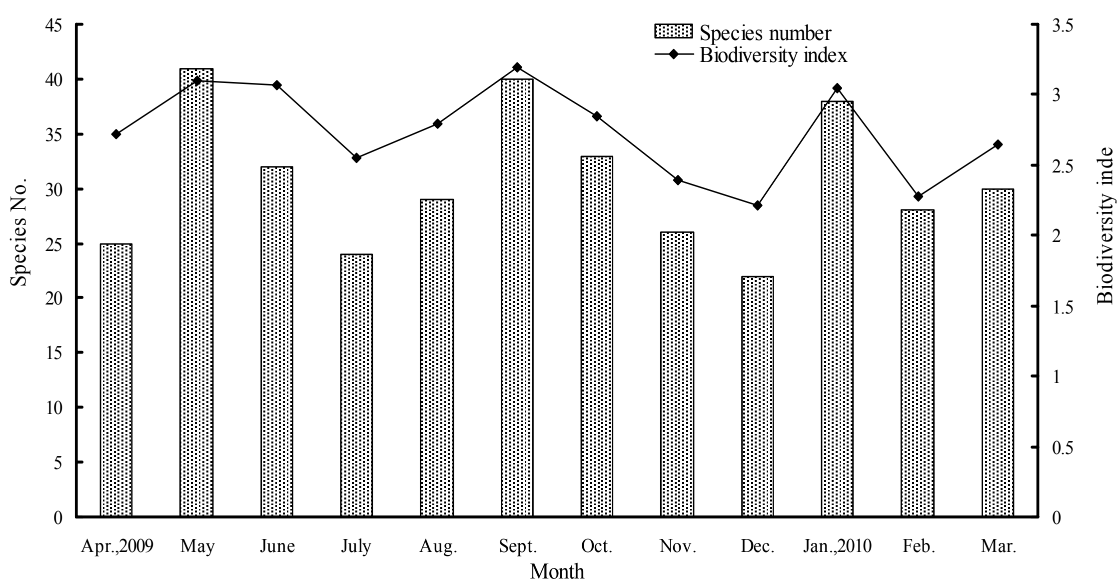

Fig. 4: Seasonal changes of ciliate species number and biodiversity index in Dongshan Lake

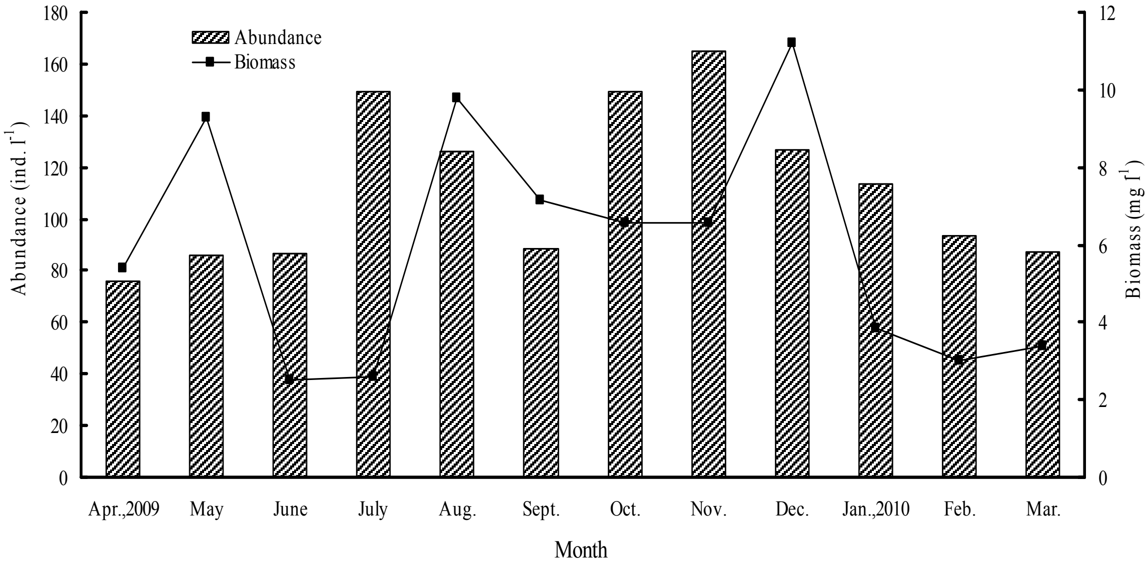

Fig. 5: Seasonal changes of total planktonic ciliate abundance and biomass in Dongshan Lake

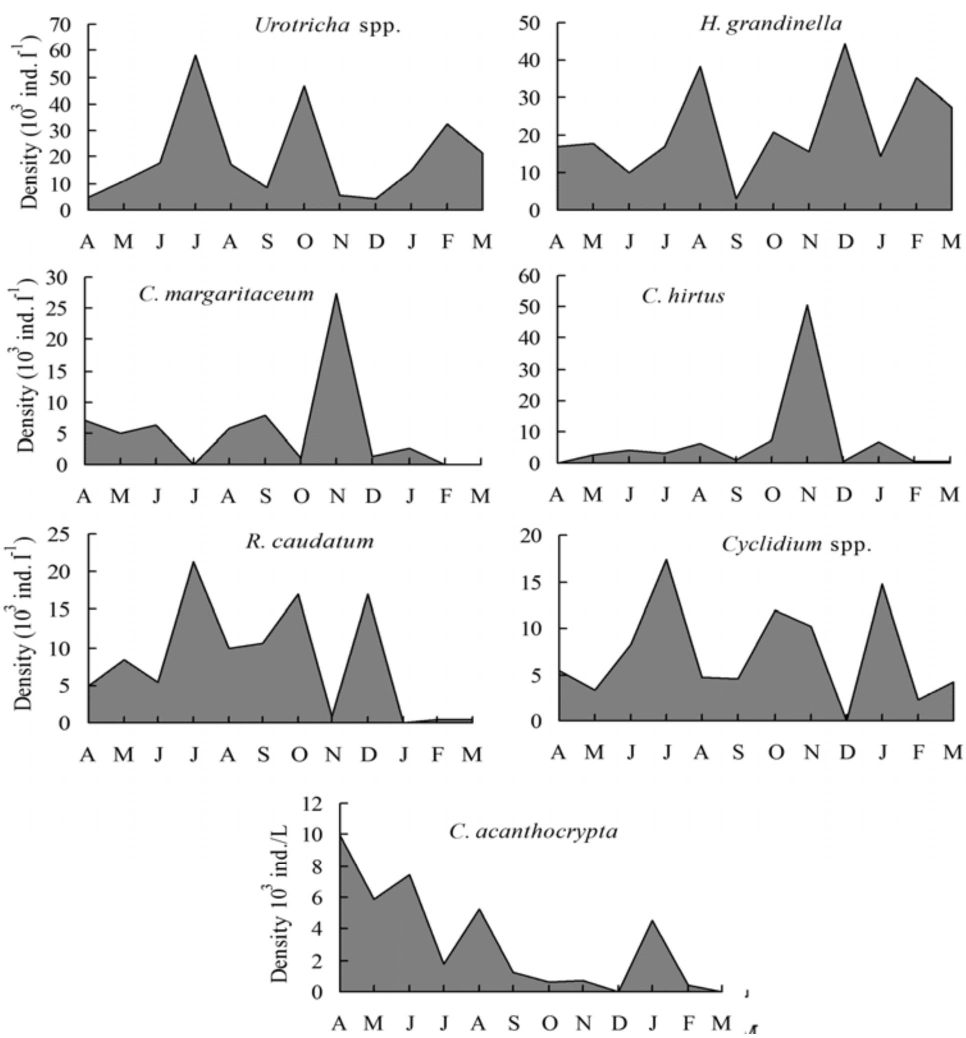

Fig. 6: Abundance seasonal changes of dominant ciliate species in Dongshan Lake from 2009 to 2010

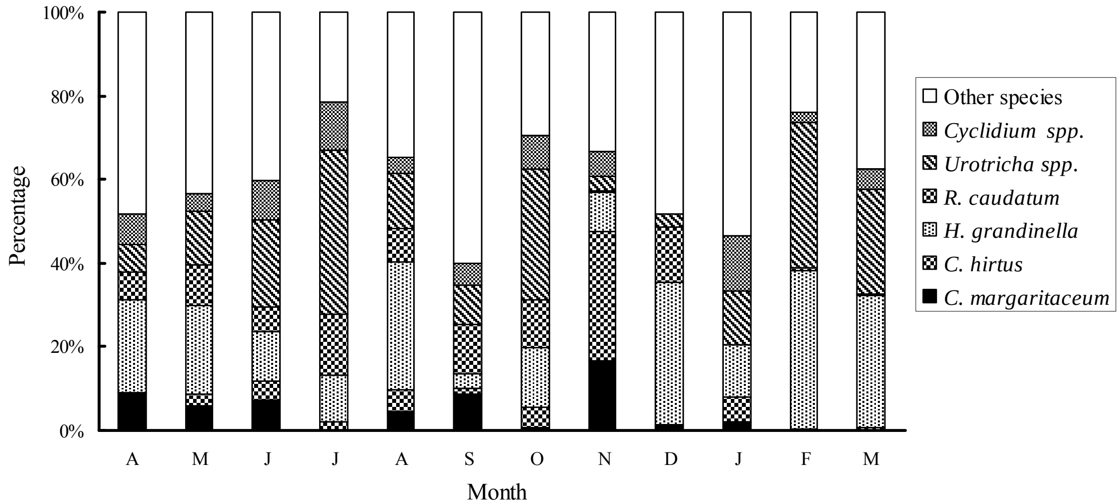

Fig. 7: Percentage in abundance of dominant ciliate species within the different months from 2009 to 2010

Table 1: A species list of planktonic ciliates found in Dongshan Lake

Askenasia volvox	*Euplotes affinis*	*Spathidium spathula*
Aspidisca costata	*Frontonia acuminata*	*Sphaerophrya soliformis*
Balanion planctonicum	*Gastrostyla mystacea*	*Spirostomum teres*
Blepharisma lateritium	*Halteria chlorelligera*	*Stentor roeseli*
Blepharisma steini	*Halteria grandinella*	*Stichotricha aculeata*
Calyptotricha lanuginosa	*Hastatella radians*	*Strombidium acuminatum*
Cinetochilum margaritaceum	*Holophrya collaris*	*Strombidium crassulum*
Codonella cratera	*Holophrya discolor*	*Strombidiumsulcatum*
Coleps bicuspis	*Holophrya ovum*	*Strombidiumviride*
Coleps hirtus	*Holophrya viridis*	*Strombidium wulffi*
Coleps spetai	*Holosticha pullaster*	*Strombidium* sp.
Colpoda cucullus	*Holosticha* sp.	*Strongylidium crassum*
Colpoda magna	*Hypotrichidium conium*	*Strongylidium lanceolatum*
Colpoda steini	*Kerona pediculus*	*Stylonychia mytilus*
Condylostoma caudatum	*Lacrymaria olor*	*Stylony chia* sp.
Condylostoma luteum	*Lacrymaria vermicularis*	*Tachysoma pellionella*
Condylostoma vorticella	*Lagynophrya acuminata*	*Tintinnidium fluviatile*
Ctedoctema acanthocrypta	*Lagynophrya conifera*	*Tintinnidium pusillum*
Cyclidium citrullus	*Lembadion lucens*	*Trachelophyllum chilense*
Cyclidium elongatum	*Loxodes rostrum*	*Uroleptus musculus*
Cyclidium glaucoma	*Loxodes striatus*	*Uronema nigricans*
Cyclidium simulans	*Monodinium balbianii*	*Urostyla grandis*
Cyrtolophosis bursaria	*Nassula* sp.	*Urosoma cienkowskii*
Cyrtolophosis mucicola	*Oxytricha haematoplasma*	*Urotricha agilis*
Dexiotrichides centralis	*Oxytricha saprobia*	*Urotricha armata*
Didinium nasutum	*Paramecium caudatum*	*Urotricha farcta*
Dileptus cygnus	*Paradileptus elephantinus*	*Urotricha furcata*
Enchelydium labeo	*Paraurostyla viridis*	*Urotricha globosa*
Enchelyodon elegans	*Paruroleptus musculus*	*Urotricha ovata*
Enchelys gasterosteus	*Phascolodon vorticella*	*Urotricha saprophila*
Enchelys mutans	*Placusluciae*	*Vorticella aequilata*
Enchelys pupa	*Platyophrya lata*	*Vorticella cupifera*
Enchelys variabilis	*Rimostrombidium caudatum*	*Vorticella convallaria*
Epistylisentzii	*Rimostrombidium gyrans*	*Vorticella mayeri*
Epistylisplicatilis	*Rimostrombidium humile*	*Vorticella microstoma*
Epistylis rotans	*Rimostrombidium velox*	*Vorticella natans*
Epistylis lacustris	*Sathrophilus muscorum*	*Vorticella vernalis*

2009 and the second peak (the highest peak 164.7×10^3 ind/L) appeared in November 2009 and lowest ciliate density (75.6×10^3 ind/L) was observed in the spring of 2010 (April). The seasonal change of ciliate biomass trended with three peaks and the largest biomass (11.195 mg/L) was found in December 2009.

Major species contributions to abundance and biomass: Figure 6 and 7 presented the abundance seasonal changes of 6 major species or groups of planktonic ciliates in Dongshan Lake and their contributions to the total abundance. In most months, these 6 ciliate groups gave out over 50% of total abundance. If abundance is considered only, it was not surprising that *Urotricha* spp. composed by *U. agilis*, *U. armata*, *U. farcta*, *U. furcata*, *U. globosa*, *U. ovata* and *U. saprophila* and *Coleps hirtus* were very important in the lake. In July, the first peak of the ciliate density, *Urotricha* spp. had more contribution to the total abundance than other genera. In November, the blooms of *Coleps hirtus* and *Cinetochilum magaritaceum* made nearly 50% of total ciliate abundance. It should be noticed that when the highest densities of ciliates occurred, the higher abundance of these 6 species ciliates kept.

DISCUSSION

There were some papers regarding ciliate species composition in tropic and subtropic lakes (Finlay *et al*., 1987; Xu and Nauwerck, 1996) but very limited information had been contributed about planktonic ciliate ecology in these lakes. There were detailed information from Tanganyika Lake (Hecky and Kling, 1981), Valencia Lake and Lanao Lake (Lewis, 1985). Until now there were only a few reports on the temporal pattern of planktonic ciliates in temperate, but subtropical freshwater lakes (Shen and Gu, 1965; Gong, 1986) in China. Unlike in other parts of the world, most freshwater lakes in China are shallow lakes. Most species found in this study were reported in many freshwater bodies, even in the rice-fields (Madoni, 1996). In terms of the species composition, there were 51 species benthic and epiphytic ciliates presented in pelagic zone in the lake (Table 1). In fact, many benthic and epiphytic species could periodically leave their original habitats and present planktonic in their life cycles, because of the roles of wind waves and currents or other biotic and abiotic factors. Therefore, the benthic or epiphytic ciliate species found in pelagic water samples from lakes and reservoirs in all parts of the world were very common (Shen and Gu, 1965; Gong, 1986; Madoni, 1991; Mori *et al*., 1998; Zingel and Ott, 2000; Yasindi and Taylor, 2003; Gaedke and Wickham, 2004; Zingel *et al*., 2002, 2007; Mieczan, 2007; Azary *et al*., 2005).

It had been confirmed that many ecological factors such as water temperature, food and predators can affect planktonic ciliate existence, reproduction and distribution by many studies. Generally, though ciliates can live in wide ranges of ecological factors in many temperate freshwater lakes, the slower rates of ciliate reproduction in winter resulted in lower ciliate density due to lower temperature. On the other hand, ciliate density is decreased in summer because of higher temperature inhibit to the ciliate reproduction (Laybourn-Parry, 1992; Shen and Gu, 1965; Xu and Nauwerck, 1997).

In the spring or autumn, the water temperatures were almost the optimum for ciliate existence, which promote ciliate reproduction. In subtropical zone, air temperature changes between seasons are not as clear as that in temperate zone and there is no an ice cover period in natural waters. So a sharp decrease of ciliates density is not appeared in the winter (Fig. 5). Additionally, due to influence of monsoons from South China Sea, the air temperature of Guangzhou in summer is not as high as that in the center of China, where the air temperatures could be over 39 °C during the summer. Therefore, the obvious density decrease of ciliates in the lake in summer (from July to September) was not found in this study. Considering annual abundant changes of planktonic ciliates and compared with data from other temperate lakes, ciliate density temporal pattern of Dongshan Lake was similar to that of Francis Lake in U. S. A. (Beaver and Crisman, 1989) and Holden Pond (Laybourn-Parry, 1992), but it was different to that of Lunzer Untersee in Austria (Schlott-Idl, 1984), Esthwaite Lake of British (Laybourn-Parry, 1990), Annie and Wauberg Lakes in U. S. A. (Beaver and Crisman, 1989), Norris and Eaton Lakes (Laybourn-Parry, 1992).

Another factor that would influence ciliate distributions is the trophic status of the lake. Normally, the higher is the trophic status, the higher are the ciliate densities (Table 2).

Although the trend of ciliate biomass changes in Dongshan Lake was not synchronous with that of abundant change (Fig. 5), the biomass peaks were recorded in summer and winter respectively, due to the

Table 2: Comparison of the most ciliate abundance in the lakes with different trophic status

Lakes	Trophic status	Ciliate abundance (10^3/L)	Sources
LunzerUnterzee Lake	Oligotrophic	1.8	Schlott-Idl (1984)
Tohopekaliga Lake	Mesotrophic	86.1	BeaverandCrisman (1990)
Esthwaite Lake	Eutrophic	9.2	Laybourn-Parry *et al*. (1990a)
Oglethorpe Lake	Eutrophic	100-200	PaceandOrcutt (1981)
Scott lakes Lake	Hypereutrophic	355.5	BeaverandCrisman (1990)
Dongshan Lake	Hypereutrophic	164.7	This study

Table 3: Comparison of the maximum ciliate biomass in the lakes with different trophic status

Lakes	Trophic status	Max. Biomass (mg /L)	Sources
Norris Lake	Oligotrophic	0.08	Laybourn-Parry (1992)
Holden Pond	Oligotrophic	0.33	Laybourn-Parry (1992)
Tohopekaliga Lake	Mesotrophic	0.4068	BeaverandCrisman (1990)
Scott Lake	Hypertrophic	4.4136	BeaverandCrisman (1990)
Dongshan Lake	Hypertrophic	11.230	This study

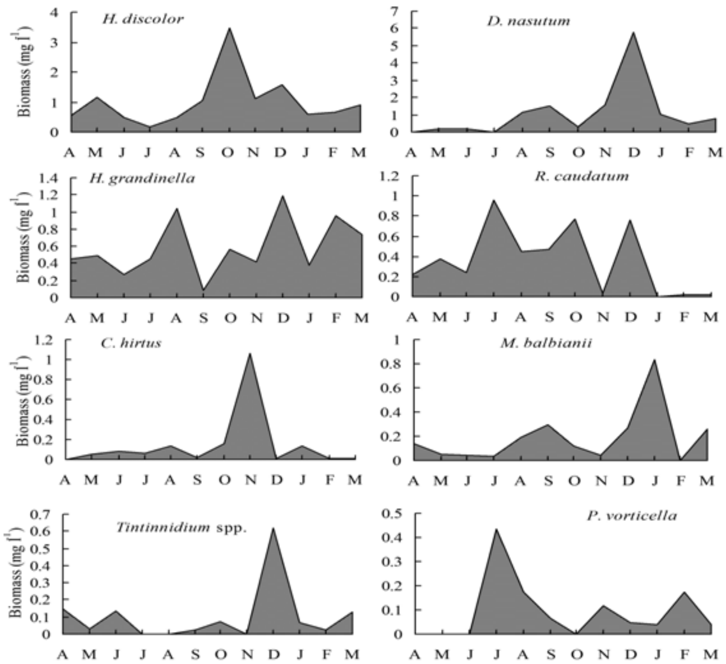

Fig. 8: Biomass patterns of the dominant ciliates in Dongshan Lake from 2009 to 2010

contribution of larger size species to the biomass. Meanwhile, smaller species like *H. grandinella* and *Urotricha* spp. had higher percentage in abundance (Fig. 7).

Similar to abundance, the relationship between biomass of planktonic ciliates and the trophic status was listed in Table 3.

Temporal patterns of major species in the lake: Taking all species of planktonic ciliates into account, *H. grandinella*, *Urotricha* spp., *Rimostrombidium caudatum*, *C. hirtus*, *S. humile*, *Cyclidium* spp. (including *C. citrullus*, *C. elongatum*, *C. glaucoma* and *C. simulans*), *H. discolor*, *M. balbianii*, *Epistylis* sp. and *D. nasutum* could be considered as common species in the community. *H. grandinella*, *Urotricha* spp., *Rimostrombidium caudatum* and *C. hirtus* had densities over 20×10^3 ind/L (Fig. 6). According to the ciliate density changes shown in Fig. 6, the planktonic ciliate abundance patterns in Dongshan Lake can be divided into three types in abundance patterns. *Coleps hirtus* and *Cinetochilium margaritaceum* belonged to Type I, their abundance patterns were typical monomodal. As the first dominant ciliate in the Lake, *Halteria grandinella* appeared throughout the year. The highest density was recorded in December 2009 (about 44×10^3 ind/L) and the densities in August and February were closed to the maximum value (35 to 38×10^3 ind/L). Its lowest density was 3.0×10^3 ind/L presented in September 2009. Based on the density changes, the abundance pattern of *H. grandinella* was trimodal. If all genera were considered, *Urotricha*, most members of which had small sizes, should be a very important genus in abundance contribution in the lake. In the midsummer, the density of the genus had reached its maximum value (58×10^3 ind/L) and there were two smaller peaks appeared in mid-autumn and winter, respectively. The change trend of *Urotricha* spp. was very similar to *H. grandinella*. So, the seasonal density changes of *H. grandinella* and *Urotricha* spp., as well as *Cyclidium* spp., were thought to be the Type II, trimodal. Compared with the abundance patterns of the species mentioned above, the abundance pattern of *Ctedoctema acanthocrypta* was belonged to other type, Type III, there was no significant peaks in the annual change. If considering the contributions of abundance only, the order of dominant species succession was as follow: from *Ctedoctema acanthocrypta* to *Rimostrombidium caudatum* and *Urotricha* spp. and *Cyclidium* spp.; then to *Halteria grandinella*; to *Cinetochilum margaritaceum* and *Coleps hirtus*, to *H. grandinella* and *Rimostrombidium caudatum*; and finally to *H. grandinella*, *Urotricha* spp. and *Cyclidium* spp. (Fig. 6).

If the contribution to biomass from each ciliate species was considered, the dominant species might change. Figure 8 displays the patterns of the dominant ciliate species regarding biomass during the investigation.

Similar to abundance, the biomass of *H. grandinella, Rimostrombidium caudatum* and *Urotricha* spp. showed trimodal patterns. The biomass of *H. discolor*, *D. nasutum, C. hirtus, Tintinnidium* spp. (*T. fluviatile* and *T. pusillum*) and *M. balbianii* had monomodal patterns. If regarding to biomass, the most important ciliate species should be *Holophrya discolor* and *Didinium nasutum* due to their larger sizes.

The results of abundance and biomass of planktonic ciliates in the lake validated a viewpoint given by Laybourn-Parry (1992), which was the ciliate species with smaller sizes could have more contributions in abundance but not in biomass in a eutrophic lake.

With the parametric analysis, or non-parametric analysis, such as linear regression and *Spearman's* rank correlation analysis, there is no relevant between ciliate abundance and other biotic or abiotic factors ($p \geq 0.05$) and no relevant between ciliate biomass and other biotic or abiotic factors ($p \geq 0.05$) either. This result is not similar with that of Zingel and Ott (2000).

CONCLUSION

Most of the species of planktonic ciliates from Dongshan Lake were common species in China and even in other parts of the world. The dominant species of planktonic ciliates include *Urotricha* spp., *Halteria grandinella*, *Cinetochilium margaritaceum, Rimostrombidium caudatum* and *Cyclidium* spp., meanwhile, *Holophrya discolor, Didinium nautum, H. grandinella, Strob. caudatum*, *C. hirtus* and *Monodinium balbianii* made more contributions to ciliate biomass in the lake. The ciliate abundance and biomass implied the trophic status of the lake being hypertrophic. It is coincident to hydrochemical parameters of the lake. The abundance and biomass temporal patterns of dominant ciliate species have three types. During the investigation, if considering the contributions on abundance, the dominant species succession was as follow sequences: from *Ctedoctema acanthocrypta* to *Rimostrombidium caudatum* and *Urotricha* spp. and *Cyclidium* spp.; then to *Halteria grandinella*; to *Cinetochilum margaritaceum* and *Coleps hirtus*, to *H. grandinella* and *Rimostrombidium caudatum*; and finally to *H. grandinella*, *Urotricha* spp. and *Cyclidium* spp.. If considering the contribution on biomass.

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