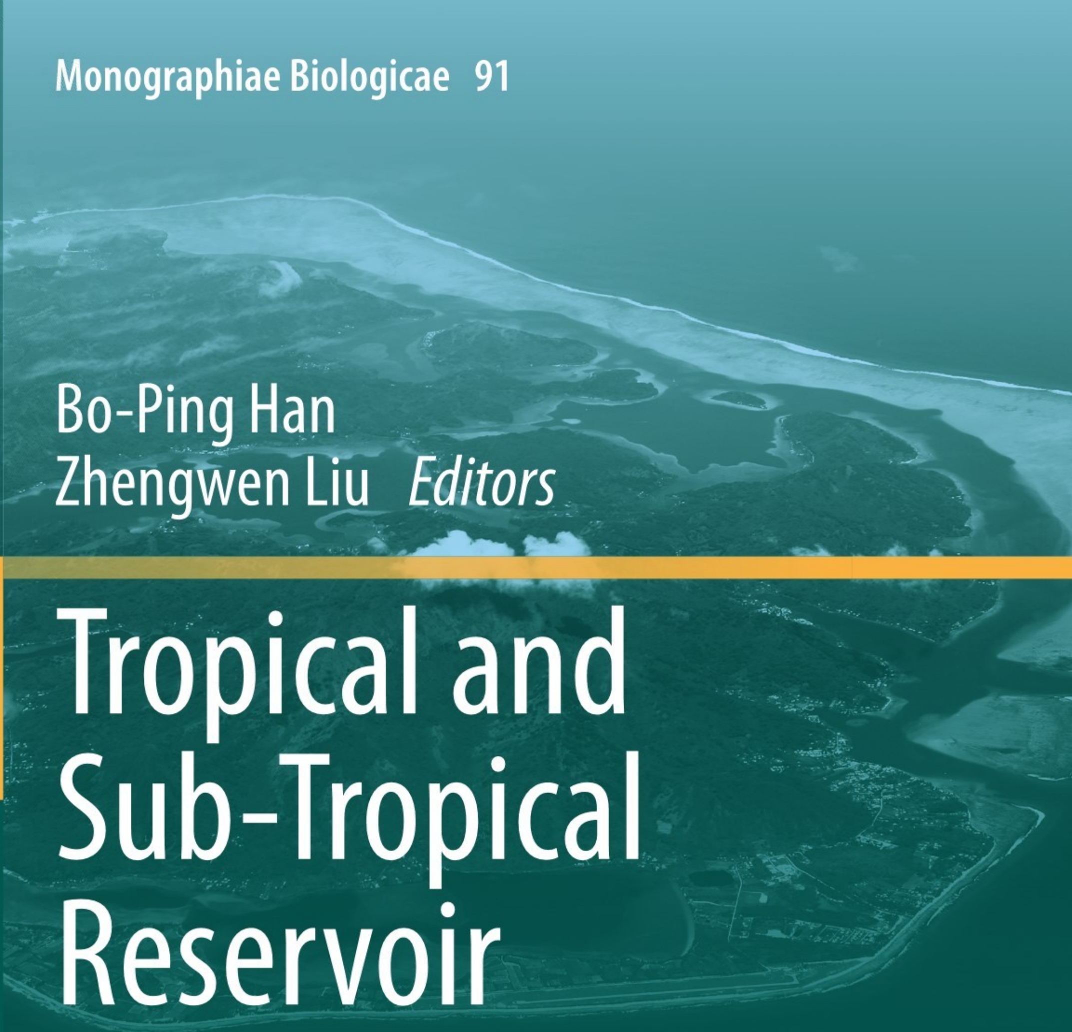

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Bo-Ping Han
Zhengwen Liu *Editors*

Tropical and Sub-Tropical Reservoir Limnology in China

Theory and Practice

Springer

TROPICAL AND SUB-TROPICAL RESERVOIR LIMNOLOGY IN CHINA

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Tropical and Sub-Tropical Reservoir Limnology in China

Theory and Practice

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Preface

Reservoirs are specific aquatic ecosystems with complex behavior, distinct of both natural lakes and rivers. Reservoir limnology and water quality management are associated with functions such as flood control, hydropower generation, irrigation, and fishery. On a global scale, supplying drinking water has become a dominant function of reservoirs. China is endowed with a huge number of reservoirs, and harbors more than 45% of the high dams of the world. In the past 60 years, China built about 86,000 reservoirs for multiple purposes such as agricultural irrigation, power generation, flood control, and water supply. These store a huge amount of water and support economic and social development. But in the last decades, many rivers and lakes have become polluted because of human activities in the catchments and direct discharge of domestic and industrial sewage. Many rivers and lakes have thereby almost lost their function as sources of drinking water. New clean water sources are required, at an affordable cost of water treatment. The reservoirs play an ever-increasing role in this water supply and immediately mitigate water shortage on a regional scale, especially in southern China where there are few natural lakes. However, there is no systematic knowledge of reservoir limnology in China, which is fundamental to water quality management.

Many reservoirs were exploited for fisheries before 2000 and all early limnological data were collected in the context of estimating fish production. Economics of fisheries brought new technology to reservoir fishery but also led to negative effects on water quality and ecosystem health.

Compared to the research on and the protection of lakes, there is a limited public attention to reservoirs in China. This volume aims to offer a first description of reservoir limnology in tropical and subtropical China. It includes 20 articles that come mainly from Guangdong Province and Hainan Island, two regions where only few natural lakes exist. Owing to their monsoonal climate, annual precipitation concentrates in a flooding season (wet season) from the middle of April to the end of September. At that time, much runoff is discharged to the South China Sea. In contrast, many districts suffer from water shortage in the dry season, from October to next April. The construction of reservoirs by damming rivers offered a way to meet water demands in the dry season. Guangdong is one of the more developed provinces, and most of its rivers run across cities and towns; they have become polluted and are no longer suitable as drinking water resources; here, reservoirs became the alternative source of drinking water. Several such water bodies were built specially for water supply to Hong Kong and Macau, which are situated close to Guangdong Province. However, the same situation of water pollution commonly occurs in eastern and northern China as well.

The dam of Liuxihe Reservoir, a large impoundment for the drinking water supply of Guangzhou, the largest city in southern China. Photo taken by Bo-Ping Han.

To mitigate water shortage in northern China, a South-to-North Water Transfer Project was initiated, aimed at reallocating water resources on a national scale. The three channels of this grand project have their beginning at southern reservoir catchments. It is therefore clear that reservoirs begin to play a significant role not only in southern but also northern China.

Besides contributions from southern China, this book contains five invited contributions from Hongfeng Reservoir (Guizhou Province), Danjiangkou Reservoir (Hubei Province), the Three Gorges Reservoir (Chongqing Province), and Xinanjiang Reservoir (Zhejiang Province). In comparison with advances in Europe and North America, the limnological study of reservoirs in China is developing more in pace with the country's social and economic requirements. This means that this work includes information on zooplankton, phytoplankton, zoobenthos, Cyanobacteria, nutrient budgets, sediments, biogeochemical cycling of mercury, and fisheries, but also that its main focus is on eutrophication, because of the current demands on water quality. The publication of this special volume is hoped to encourage the further development of reservoir limnology in China, and it also provides a window on China to all scientists interested in limnology and freshwater ecology. We are grateful to Prof. Henri Dumont from Belgium for his encouragement and suggestions for preparing the volume. We also thank Dr. Ken Chen from Australia for his reading and linguistic correction of the manuscripts. The preparation of the book was supported by a special grant of Project 211 for Hydrobiology and NSF of China (U0733007).

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Part I
Biological Community

Chapter 1
Diversity and Community Structure of Zooplankton in Reservoirs in South China

Qiuqi Lin and Bo-Ping Han

Abstract Zooplankton diversity and its response to eutrophication were investigated in 15 reservoirs of South China from 2000 to 2003. So far, 105 species of Rotifera, 30 species of Cladocera and 24 species of Copepoda have been identified. The majority of rotifer species are monogononts, with bdelloids represented by *Rotaria* sp. only. *Lecane* (with 19 taxa), *Trichocerca* (15) and *Brachionus* (11) are the most speciose genera, with many species cosmopolitan. The most frequently observed genera were *Keratella*, *Brachionus*, *Polyarthra*, *Trichocerca*, *Asplanchna*, *Conochilus*, *Ploesoma*, *Ascomorpha* and *Pompholyx*. Daphniidae (10 species) and Chydoridae (11) were the two rich cladoceran families. *Bosmina tripurae*, *Bosminopsis deitersi*, *Diaphanosoma orghidani*, *D. dubium*, *Moina micrura, Ceriodaphnia cornuta and C. quadrangula* were most frequent in the pelagic zone. In addition, 10 calanoid and 14 cyclopoid species of copepods occurred. Most of the Calanoida are endemic to the tropics and subtropics in China. *Phyllodiaptomus tunguidus*, *Neodiaptomus schmackeri*, *Mesocyclops thermocyclopoides* and *Thermocyclops taihokuensis* were most frequently recorded.

In the year 2000, total abundance of zooplankton varied from 11 to 290 ind./L during the period of June to July. Zooplankton was much more abundant in mesotrophic than in oligotrophic and eutrophic reservoirs. Rotifera numerically predominated in nine reservoirs and Copepoda in six reservoirs. The relative abundance of *Brachionus*, *Trichocerca* and *Asplanchna* increased and the ratio of Calanoida to Cyclopoida decreased with trophic level. Reservoir trophic state and predation were the most direct factors regulating zooplankton abundance and the dynamics of community structure. However, it was also found that hydraulic retention time affected the response of the zooplankton community structure to eutrophication. In reservoirs with long or short retention times, zooplankton

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showed no apparent variation across seasons. In reservoirs with intermediate retention time, in contrast, the zooplankton community changed significantly with trophy.

1.1 Introduction

Zooplankton has been studied intensely and over long periods of time in the North Temperate Zone, but much less so in the tropics. Moreover, most of the current knowledge of tropical zooplankton comes from South America, Africa and Australia (Dussart and Defaye 2001; Korovchinsky 1996, 2006). Much less has become known of the distribution and taxonomic composition of zooplankton in tropical Asia. In South China, natural lakes are scarce, but large numbers of reservoirs were constructed during 1950–1980. Aquaculture of filter-feeding fish like bighead carp (*Hypophthalmichthys nobilis*) was of widespread occurrence in most of these reservoirs. Such filter-feeding fish may play a key role in structuring the zooplankton community, since they consume zooplankton and at the same time compete with it for algal and pelagic sestonic food. Nilssen (1984) argued that heavy predation by juvenile and adult fish may greatly simplify the zooplankton community, with a resulting scarcity of Cladocera, notably the efficient filter feeders of the large genus *Daphnia*. The present contribution is aimed at investigating zooplankton diversity of a number of reservoirs in Guangdong Province, South China, and analyse some characteristics of the zooplankton community under a regime of predation by filter-feeding fish.

1.2 Materials and Methods

The reservoirs studied are located in the subtropical–tropic transition zone of China (20°14′ to 25°31′ N, 109°40′ to 117°20′ E) of which a detailed description can be found in Lin et al. (2003). Characteristics of the reservoirs are described in Table 1.1. Bighead carp (*H. nobilis*) has been extensively aquacultured in all reservoirs. This fish species produces semi-buoyant eggs that require a current to float. There are no appropriate spawning sites with sufficiently long floatation times for the eggs in these reservoirs, so bighead carp cannot reproduce successfully and production must be maintained by periodic introduction of YOY fish. The population is recruited by releasing YOY fish at 10 to 15 cm body length in April to May and/or August to November every year. Usually, Fish $\geq$3 years old are caught by seining from April to October.

Zooplankton of the 15 reservoirs was sampled during June to July (flooding season) in 2000. In addition, three reservoirs, Xinfengjiang, Feilaixia and Gongping, were sampled bimonthly from 2001 to 2003. Quantitative samples were collected with a 5-L water sampler at sites near the dams from the surface to a depth of 10 m at 1-m interval in deep reservoirs, or in shallow reservoirs from surface to bottom.

Table 1.1 Description of the study reservoirs

	Catchment area (km^2)	Normal volume (10^6 m^3)	Average depth (m)	Retention time (days)	Elevation (m)	Max. fish catch (kg/ha)	Year of filling
Xinfengjiang	5,813	10,500	29	644	116	27	1958
Gaozhou	1,022	841.8	21	161	86	–	1960
Gongping	317	163.3	4.5	133	16	–	1962
Liuxihe	539	325	21.3	172	235	21	1958
Chisha	23	1.1	1.5	15	12	–	1960
Chishijin	14	12.4	15	65	128	49	1958
Feilaixia	34,097	432	6.1	6	24	–	1998
Heshui	600	30.4	3	24	134	127	1957
Hexi	41	15.8	8.5	125	53	–	1958
Dashahe	217	153.8	9.4	180	34	299	1959
Dashuiqiao	196	100.1	13.7	343	56	340	1958
Qiyeshi	18	10.2	6.3	236	43	–	1960
Dajingshan	6	10.5	12	120	20	96	1975
Hedi	1,495	795	6.5	123	40	112	1959
Shiyan	44	16.9	6.3	169	36	599	1960

–, No data available

Samples from all depths were filtered through a mesh of 64 μm to form an integrated sample for each reservoir. Qualitative samples were collected at different sites within the littoral, riverine and lacustrine parts of the reservoirs with 64- and 113-μm meshes, respectively. Samples were preserved with 5% formalin. All samples were examined for Rotifera, Cladocera and Copepoda, and identified to species using a variety of sources (Wang 1961; Chiang and Du 1979; Shen 1979; Koste and Shiel 1987; Guo 1999, 2000; Nogrady and Segers 2002; Segers 1995; Shiel and Koste 1992) and counted under a stereomicroscope. Some other, rather unusual groups occasionally found in the pelagic of the reservoirs, are not dealt within this chapter, but information on them can be found in Han et al. (Chapter 16, this volume).

1.3 Results and Discussion

1.3.1 Species Composition

1.3.1.1 Rotifera

So far, of 105 species identified, the vast majority were monogononts (Table 1.2). The richest fractions were the Lecanidae (19 species) > Brachionidae (18) > Trichocercidae (15) > Synchaetidae (10). The most frequently observed species were *Keratella cochlearis*, *K. tropica*, *Brachionus calyciflorus*, *B. forficula*, *B. angularis*, *Polyarthra vulgaris*, *Trichocerca cylindrica*, *T. similis*, *T. elongata*,

Table 1.2 List of zooplankton species in the 15 investigated reservoirs in South China

Rotifera	*P. major* (Burckhardt, 1900)
Philodinidae	*P. remata* (Skorikov, 1896)
Rotaria sp.	*P. vulgaris* (Carlin, 1943)
Dicranoporidae	*Synchaeta oblonga* (Ehrenberg, 1831)
Dicranophorus sp.	*S. pectinata* (Ehrenberg, 1832)
Brachionidae	*S. stylata* (Wierzejski, 1893)
Anuraeopsis fissa (Gosse, 1851)	**Filiniidae**
Brachionus angularis (Gosse, 1851)	*Filinia brachiata* (Rousselet, 1901)
B. budapestinensis (Daday, 1885)	*F. camasecla* (Myers, 1938)
B. calyciflorus (Pallas, 1766)	*F. longiseta* (Ehrenberg, 1834)
B. caudatus (Barrois and Daday, 1894)	*F. terminalis* (Plate, 1886)
B. diversicornis (Daday, 1883)	*F. opoliensis* (Zacharias, 1898)
B. donneri (Brehm, 1951)	**Hexarthridae**
B. falcatus (Zacharias, 1898)	*Hexarthra fennica* (Levander, 1892)
B. forficula (Wierzejski, 1891)	*H. mira* (Hudson, 1871)
B. leydigi (Cohn 1862)	**Testudinellidae**
B. quadridentatus (Hermanns, 1783)	*Pompholyx sulcata* (Hudson, 1885)
B. urceolaris (Muller, 1773)	*Testudinella mucronata* (Gosse, 1886)
Keratella cochlearis (Gosse, 1851)	*T. patina* (Hermann, 1783)
K. tecta (Gosse, 1851)	*T. tridentata* (Smirnov, 1931)
K. tropica (Apstein, 1907)	**Conochilidae**
Notholca labis (Gosse, 1887)	*Conochilus dossuarius* (Hudson, 1875)
Plationus patulus (O.F. Müller, 1786)	*C. hippocrepis* (Schrank, 1830)
Platyias quadricornis (Ehrenberg, 1832)	*C. unicornis* Rousselet, 1892
Epiphanidae	**Collothecidae**
Epiphanes brachionus (Ehrenberg, 1837)	*Collotheca libera* (Zacharias, 1894)
E. senta (O. F. Müller, 1723)	*C. mutabilis* (Hudson, 1885)
Euchlanidae	*C. pelagica* (Rousselet, 1893)
Euchlanis triquetra Ehrenberg, 1838	**Cladocera**
Dipleuchlanis propatula (Gosse, 1886)	***Leptodoridae***
Lepadellidae	*Leptodora richardi* (Korovchinsky, 2009)
Colurella adriatica Ehrenbeng 1831	**Sididae**
Lepadella patella (Müller, 1786)	*Sida crystallina* (O.F. Müller, 1776)
L. ovalis (Müller, 1786)	*Diaphanosoma dubium* (Manuilova, 1964)
Mytilinidae	*D. orghidani transamurensis* (Korovchinsky, 1986)
Mytilina ventralis (Ehrenberg, 1832)	*D. excisum* (Sars, 1885)
Trichotriidae	**Bosminidae**
Macrochaetus collinsii (Gosse, 1867)	*Bosmina fatalis* (Burckhardt, 1924)
Trichotria tetractis (Ehrenberg, 1830)	*B. tripurae* (Kořínek, Saha and Bhattacharya, 1999)
	(Richard, 1895)
Asplanchnidae	*Bosminopsis deitersi* (Richard, 1895)
Asplanchna brightwelli (Gosse, 1850)	**Daphniidae**
A. priodonta (Gosse, 1850)	*Daphnia galeata* (G.O. Sars, 1864)
Asplanchnopus multiceps (Schrank, 1793)	*D. pulex* (Leydig, 1860)
Gastropodidae	*D. lumholtzi* (Sars, 1885)
Ascomorpha ecaudis (Perty, 1850)	*Ceriodaphnia quadrangula* (O. F. Müller, 1785)
	(O. F. Müller, 1785)

(continued)

Table 1.2 (continued)

A. ovalis (Bergendal, 1892)	*C. cornuta* (Sars, 1885)
A. saltans (Bartsch, 1870)	*Moina micrura* (Kurz, 1874)
Gastropus hyptopus (Ehrenberg, 1838)	*M. rectirostris* (Leydig, 1860)
G. minor (Rousselet, 1892)	*M. weismanni* (Ishikawa, 1896)
G. stylifer (Imhof, 1891)	*Simocephalus mixtus* (Sars, 1903)
Notommatidae	*Scapholeberis kingi* (Sars, 1903)
Cephalodella gibba (Ehrenberg, 1832)	**Macrothricidae**
Monommata grandis (Tessin, 1890)	*Macrothrix spinosa* (King, 1853)
Eosphora sp.	**Ilyocryptidae**
Notommata sp.	*Ilyocryptus spinifer* (Herrick, 1884)
Scaridiidae	**Chydoridae**
Scaridium longicaudum (O. F. Müller, 1786)	*Oxyurella singalensis* (Daday, 1898)
Trichocercidae	*O. tenuicaudis* (Sars, 1862)
Trichocerca braziliensis (Murray, 1913)	*Monospilus dispar* (Sars, 1862)
T. bicristata (Gosse, 1887)	*Alona guttata* (Sars, 1862)
T. capucina (Wierzejski and Zacharias, 1893)	*A. affinis* (Leydig, 1860)
T. chattoni (de Beauchamp, 1907)	*Coronatella rectangula* (Sars, 1861)
T. cylindrica (Imhof, 1891)	*Camptocercus rectirostris* (Schoedler, 1862)
T. dixonnuttalli (Jennings, 1903)	*Rhynchotalona falcata* (Sars, 1862)
T. elongata (Gosse, 1886)	*Chydorus sphaericus* (Müller, 1785)
T. gracilis (Tessin, 1886)	*C. ovalis* (Kurz, 1874)
T. insignis (Herrick, 1885)	*Dunhevedia crassa* (King, 1853)
T. longiseta (Schrank, 1802)	**Copepoda**
T. lophoessa (Gosse, 1886)	**Pseudodiaptomidae**
T. rousseleti (Voigt, 1902)	*Schmackeria inopinus* (Burckhardt, 1913)
T. similis (Wierzejski, 1893)	*S. forbesi* (Poppe and Richard, 1890)
T. similis f. *grandis* (de Beauchamp, 1907)	*S. spatulata* (Shen and Tai, 1964)
T. pusilla (Lauterborn, 1898)	**Diaptomidae**
Lecanidae	*Phyllodiaptomus tunguidus* (Shen and Tai, 1964)
Lecane bulla (Gosse, 1851)	*Neodiaptomus schmackeri* (Poppe and Richard, 1892)
L. closterocerca (Schmarda, 1859)	*Mongolodiaptomus birulai* (Rylov, 1923)
L. crepida (Harring, 1914)	*Heliodiaptomus falxus* (Shen and Tai, 1964)
L. curvicornis (Murray, 1913)	*H. serratus* (Shen and Tai, 1962)
L. hastata (Murray, 1913)	*Allodiaptomus specillodactylus* (Shen and Tai, 1964)
L. hornemanni (Ehrenberg, 1834)	**Acartiidae**
L. inermis (Bryce, 1892)	*Acartiella sinensis* (Shen and Lee, 1963)
L. leontina (Turner, 1892)	**Oithonidae**
L. luna (Müller, 1776)	*Limnoithona sinensis* (Burckhardt, 1913)
L. lunaris (Ehrenberg, 1838)	**Cyclopidae**
L. lunaris f. *crenata* (Harring, 1913)	*Eucyclops serrulatus* (Fischer, 1851)
L. ludwigii (Eckstein, 1883)	*Tropocyclops jerseyensis* (kiefer, 1931)
L. papuana (Murray, 1913)	*T. bopingi* (Dumont, 2006)

(continued)

Table 1.2 (continued)

L. quadridentata (Ehrenberg, 1832)	*Paracyclops affinis* (Sars, 1863)
L. signifera (Jennings, 1896)	*Thermocyclops crassus* (Fischer, 1853)
L. stenroosi (Meissner, 1908)	*T. taihokuensis* (Harada, 1931)
L. tenuiseta (Harring, 1910)	*Mesocyclops dissimilis* (Defaye and Kawabata, 1993)
L. ungulata (Gosse, 1887)	*M. pehpeiensis* (Hu, 1943)
L. unguitata (Fadeew, 1925)	*M. ogunnus* (Onabamiro, 1957)
Synchaetidae	*M. thermocyclopoides* (Harada, 1931)
Ploesoma hudsoni (Imhof, 1891)	*M. aspericornis* (Daday, 1906)
P. truncatum (Levander, 1894)	*M. woutersi* (Van de Velde, 1987)
P. lenticulare (Herrick, 1885)	*Microcyclops varicans* (Sars, 1963)
Polyarthra euryptera (Wierzejski, 1893)	

T. capucina, *Asplanchna priodonta*, *Conochilus unicornis*, *C. hippocrepis*, *Ploesoma hudsoni*, *Ascomorpha ovalis* and *Pompholyx sulcata*. Species within these genera of Rotifera differ between the tropics and temperate zone. For example, *Lecane*, *Brachionus* and *Trichocerca* are rich in species in the tropics, while *Keratella*, *Cephalodella*, *Notholca* and *Synchaeta* are richest in the temperate zone (Fernando 1980; Fernando and Zankai 1981; Segers 2001). In South China, *Lecane*, *Brachionus* and *Trichocerca* were the most species-rich genera, accounting for 43% of the observed rotifer species.

Lecane is tropics-centered, with about half of the recognized taxa confined to (sub)tropical regions (Segers 1996). It is known to be dominant in species diversity in tropical acid waters (Fernando 1980), where up to 40 taxa can be found in a single locality. Similarly, *Lecane* was dominant in terms of species in most of the reservoirs investigated in this study, and the maximum species number found in a single water-body was 13 (Liuxihe Reservoir). Of the 19 *Lecane* species recognized, 11 were cosmopolitan, 7 were tropicopolitan and 1 was palaeotropical. Four cosmopolitan species (*Lecane luna*, *L. lunaris*, *L. quadridentata* and *L. bulla*) and three tropicopolitan species (*L. signifera*, *L. curvicornis* and *L. papuana*) were the most widely distributed taxa in our reservoirs. The palaeotropical *L. unguitata* was only found in two reservoirs: Feilaixia and Liuxihe.

Brachionus too is predominantly tropical and subtropical with half of the species restricted to these zones. In South China, 11 species of *Brachionus* were found, and most of them were cosmopolitan. *B. angularis*, *B. calyciflorus*, *B. forficula*, *B. falcatus* and *B. diversicornis* were widely distributed in this area. *B. donneri*, an interesting element in the rotifer fauna of South-east Asia (Dumont 1983), was found in three reservoirs: Liuxihe, Feilaixia and Gaozhou. The maximum number of species (10) was found in two mesotrophic reservoirs (Gongping and Feilaixia). This genus was, therefore, frequently observed in our reservoirs, but was not predominant. This is in concordance with the finding that the dominance of *Brachionus* is decreasing from the equator towards higher latitudes, while other genera and families become more dominant with latitude (Arcifa 1984). Endemism in *Keratella* is concentrated near both poles, with no endemism in the tropics and little in the subtropics. In our study, only three *Keratella* were recognized, and *K. cochlearis* and *K. tropica* distributed widely in all reservoirs.

About 15 species of *Trichocerca* were found, and again most of them were cosmopolitan. Only two cold-water and two warm-water taxa were present. *T. cylindrica*, *T. similis, T. longiseta* and *T. capucina* were the most widely distributed species. *T. similis* f. *grandis* has a morphology similar to that of *T. similis* but with a larger body size. *T. similis* is cosmopolitan and widely distributed in the 15 investigated reservoirs, while *T. similis* f. *grandis* is tropical and only observed in Liuxihe Reservoir, located in the Tropic of Cancer. *T. cylindrica* and *T. chattoni* have a similar morphology too. However, *T. cylindrica* is regarded as a cold-water taxon, while *T. chattoni* may be pantropical. Segers (2003) suggested that tropical records of *T. cylindrica* may refer to *T. chattoni*. He said that he had never found *T. cylindrica* in collections from the (sub)tropics, or *T. chattoni* in temperate regions. However, in subtropical–tropic transition of China, both species simultaneously occurred in Liuxihe and Gaozhou Reservoirs.

In his fauna of the Freshwater Rotifera of China, Wang (1961) records only two *Polyarthra*. However, at least four species have been recognized in our reservoirs. *P. vulgaris* was widely distributed. In China, *P. remata* and *P. vulgaris* have long been misidentified as *P. trigla*, and *P. major* as *P. euryptera*. Of the genera *Asplanchna* and *Ploesoma*, representing the main predators among rotifers, *Asplanchna* is considered cosmopolitan, and was frequently observed in our reservoirs. The other predatory genus, *Ploesoma*, is usually thought to be distributed in the temperate region and not in the tropics (Fernando et al. 1990). Yet, *Ploesoma* was found widely in our reservoirs.

1.3.1.2 Cladocera

A total of 31 species belonging to 20 genera, 7 families and 3 orders have been identified to date (Table 1.2), of which 16 species are pelagic and 15 littoral. Chydoridae was the most diverse family (11 species), followed by Daphniidae (10), Sididae (4), Bosminidae (3); Macrothricidae (1), Leptodoridae (1) and Ilyocryptidae (1). The most species-rich genera were *Diaphanosoma*, *Daphnia* and *Moina*. Most of the limnetic cladoceran species in the tropics are members of nine genera: *Holopedium*, *Diaphanosoma*, *Daphnia*, *Ceriodaphnia*, *Moina*, *Moinodaphnia*, *Scapholeberis*, *Bosmina* and *Bosminopsis* (Kořínek 2002). Similarly, in our reservoirs, limnetic cladoceran species comprised *Diaphanosoma*, *Daphnia*, *Ceriodaphnia*, *Moina*, *Scapholeberis*, *Bosmina* and *Bosminopsis*. The most frequently observed pelagic species were *Bosmina tripurae*, *Bosminopsis deitersi*, *Diaphanosoma orghidani*, *D. dubium* and *Moina micrura*, while *M. rectirostris*, *M. weismanni* and *Daphnia pulex* were rare. Littoral species were primarily Chydoridae (73%), and the widely distributed species were *Coronatella rectangula*, *Alona guttata* and *Chydorus sphaericus*.

Species within individual genera of Cladocera differ between the tropics and the temperate zone. For example, *Diaphanosoma* is rich in species in the tropics. In the temperate zone, only one, rarely two, *Diaphanosoma* co-occur, but there may often be up to four and even more coexisting species in any water body in the tropics (Dumont 1994; Kořínek 2002). Three *Diaphanosoma* species were indentified and *D. orghidani* and *D. dubium* were often found simultaneously in the investigated reservoirs. Lin et al. (2003) reported that the species of *Diaphanosoma* distributed in tropical reservoirs of South China were '*D. brachyurum*' and '*D. leuchtenbergianum*'. However, it is recognized today (Korovchinsky 1992) that the name '*D. brachyurum*' partly includes *D. orghidani* and partly *D. excisum*, while the name '*D. leuchtenbergianum*' applies to *D. dubium*. *Daphnia* is an important and often dominant element of the limnetic cladoceran fauna of the temperate zone. However, in the tropics, *Daphnia* is often absent from most water bodies, probably because of high fish predation augmented by other ecological factors. Though *Daphnia* may occur in few tropical reservoirs, their abundance is usually low, and rarely two species co-occur. *Daphnia* was not widely distributed in the investigated reservoirs, and they only occurred in four reservoirs. *D. galeata* and *D. pulex* co-occurred in Liuxihe and Feilaixia Reservoirs. In all, the limnetic Cladocera were as or slightly less diverse than in temperate regions. For example, only a few species of *Daphnia* (three species), *Ceriodaphnia* (two species) and *Bosmina* (two species) were found. Even in *Diaphanosoma*, a representative genus in the tropics (Fernando 1980), only three species occurred.

Leptodora occurs primarily in the North Temperate Zone (Rivier 1998). It was reported that predatory Cladocera—*Leptodora kindtii*, *Polyphemus pediculus* and *Bythotrephes* spp.—do not occur in tropical freshwaters, and this is considered as a clear-cut difference in predator composition between tropical and southern hemisphere freshwaters on the one hand, and those of the North Temperate Zone on the other hand (Fernando et al. 1990). It is therefore interesting that *Leptodora* was found at least in three reservoirs—Liuxihe, Feilaixia and Qiyeshi—during our investigation. However, the species involved was not the Eurosiberian *L. kindtii* (Focke), but a recently described 'eastern vicariant' to it, *L. richardi* Korovchinsky (Xu et al. 2011).

1.3.1.3 Copepoda

A total of 24 species in 14 genera and 5 families is currently on record (Table 1.2). Among them, 21 species are pelagic and 3 littoral. Cyclopidae was the most diverse family (13 species), followed by Diaptomidae (6), Pseudodiaptomidae (3), Acartiidae (1), and Oithonidae (1). *Mesocyclops* was the most species-rich genus followed by *Schmackeria*, *Heliodiaptomus*, *Thermocyclops* and *Tropocyclops*.

The most frequently observed Calanoida were *Phyllodiaptomus tunguidus*, *N. schmackeri* and *Allodiaptomus specillodactylus*, while *Schmackeria spatulata*, *S. forbesi*, *S. inopinus*, *Heliodiaptomus falxus* and *Acartiella sinensis* were more rarely seen. *P. tunguidus*, *H. falxus*, *A. specillodactylus*, *S. spatulata* and *A. sinensis* are endemic to South China. Among the five endemic species, *P. tunguidus* and *A. specillodactylus* were rather widely distributed in the reservoirs, whereas *H. falxus* and *S. spatulata* occurred in only a single flow-through water body (Feilaixia Reservoir). *A. sinensis* is an estuarine species found in a pumped storage reservoir, Dajingshan Reservoir, which is located near the Pearl River estuary. The conductivity in the reservoir was high (420 μs/cm), due to its pumping up of saline water from the estuary. Compared with São Paulo Reservoirs (Arcifa 1984), Calanoida were relatively more frequent in our reservoirs with ten species found. Calanoida did not occur in only two reservoirs (Qiyeshi and Dashuiqiao) during the investigation. Two to six calanoid species occurred together in ten reservoirs, with the maximum number found in Feilaixia Reservoir. In contrast, in São Paulo Reservoirs, the simultaneous occurrence of more than one Calanoid species was rare (Arcifa 1984).

Of the 14 Cyclopoida recognized, only one species, *Tropocyclops bopingi* is endemic to South China; it was previously known, but appears in the Fauna Sinica under the name *T. parvus* (Dumont 2006). In Cyclopoida, *Mesocyclops*, *Thermocyclops*, *Microcyclops* and *Tropocyclops* are species-rich genera centered in the tropics (Fernando et al. 1990). Six *Mesocyclops* species, two *Thermocyclops* species and two *Tropocyclops* species were found in our reservoirs. The most frequently observed species were *Mesocyclops thermocyclopoides*, *T. bopingi* and *Thermocyclops taihokuensis*, while *Limnoithona sinensis* was rarely observed. Most of the species were non-cosmopolitan, with a range that usually encompassed part or most of the Oriental region.

Predatory Cyclopoida (as important invertebrate predators in the zooplankton) are primarily represented by the genus *Mesocyclops* in the tropics. Tai and Chen (1979) listed only two species, *M. leuckarti* and *M. pehpeiensis* from China. Guo (2000) later found that in reality not less than ten species live here. In the reservoirs of Guangdong Province, six species were identified: *M. thermocyclopoides*, *M. dissimilis*, *M. ogunnus*, *M. pepheiensis*, *M. aspericornis* and *M. woutersi*. Most of these previously appeared under the name of *M. leuckarti*, a Eurosiberian species, in Lin et al. (2003). *M. thermocyclopoides* was the most widely distributed species.

1.3.2 Zooplankton Abundance

Zooplankton abundance varied from 11 to 290 ind./L (Fig. 1.1) with a minimum in Xinfengjiang Reservoir and a maximum in Hexi Reservoir. Analysis of variance showed that zooplankton abundance in small reservoirs was significantly higher than that in medium and large reservoirs ($F = 4.169$, $P = 0.042$, $n = 15$). Nutrients and fish are important for zooplankton community structure and dynamics (Brooks and Dodson 1965; Hurlbert and Mulla 1981; Pinto-Coelho et al. 2005). Increased nutrients and/or decreased fish predation may induce an increase in zooplankton abundance/biomass (Kulikova and Syarki 2004; Brooks and Dodson 1965; Ostojić 2000). Oligotrophic lakes generally display a small biomass

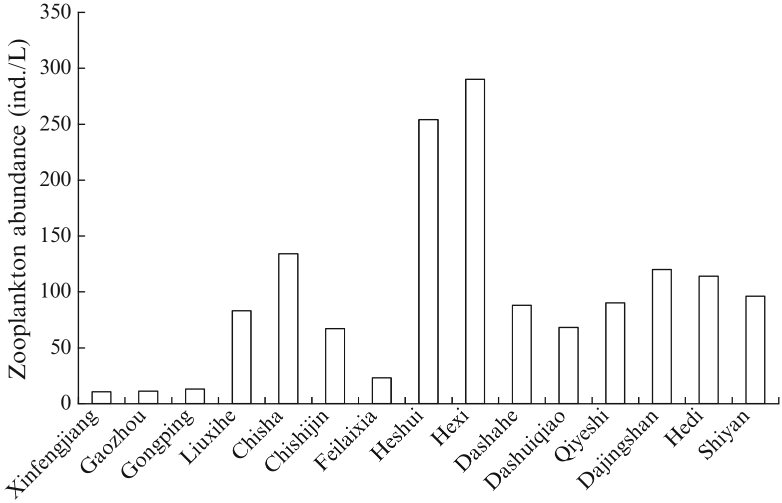

Fig. 1.1 Zooplankton abundance in the fifteen reservoirs

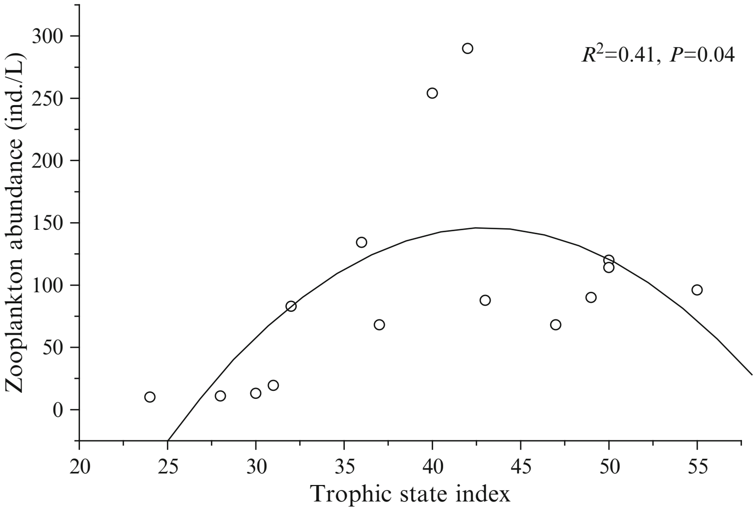

Fig. 1.2 Relationship between zooplankton abundance and trophic state index in the fifteen reservoirs

composed of a great diversity of species, while lakes in 'bloom' condition characteristic of advanced eutrophy exhibit a large biomass but fewer species. Curiously, in the reservoirs of Guangdong Province, zooplankton abundance did not increase with trophic state, and zooplankton abundance was remarkably low as well in oligotrophic as in eutrophic reservoirs (Fig. 1.2). This pattern may be related to the practice of culturing filter-feeding fish in these waters. In reservoirs with fish catch data, fish catch shows a positive relationship with trophic level

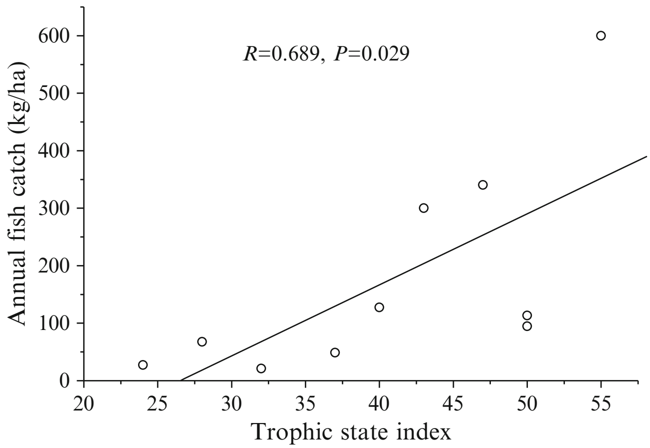

Fig. 1.3 Relationship between maximal annual fish catch and trophic state index

(indicated by TSI) (Fig. 1.3). Severe food limitation resulted in low zooplankton abundance in oligotrophic reservoirs, and increasing food quantity led to relatively higher zooplankton abundance in mesotrophic and eutrophic reservoirs. However, relatively higher predation by filter-feeding fish reduced zooplankton abundance more in eutrophic than in mesotrophic reservoirs.

1.3.3 Zooplankton Community Structure

Relative abundance of rotifers varied from 18.8% to 90.5%, with a minimum in Dashahe Reservoir and a maximum in Chishijin Reservoir (Fig. 1.4). Rotifers numerically dominated in eight reservoirs, reaching a relative abundance of more than 50%. The relative abundance of copepods varied from 1.9% to 69.5%, and was more than 50% in four reservoirs. The maximum relative abundance occurred in Gongping Reservoir, and the minimum in Chishijin Reservoir. Cladocerans were not a dominant zooplankton group in the reservoirs studied, with relative abundance varying from 0.1% to 30.3%. Moreover, the relative abundance of cladocerans was lower in eutrophic and meso-eutrophic than in oligotrophic reservoirs.

Eutrophication can affect not only zooplankton abundance but also species composition. Overlap in resource utilization and competition for similar food is common among the three zooplankton groups. As cladocerans and rotifers mature quickly and typically reproduce parthenogenetically, they show higher intrinsic rates of natural increase than copepods. These exhibit obligate sexual reproduction and must molt through six naupliar and five copepodite instars before reaching sexual maturity. Therefore, cladocerans and rotifers respond more quickly to environmental changes than copepods. Having an advantage of energetic use over the rotifers, cladocerans might have a competitive advantage, and there is indeed

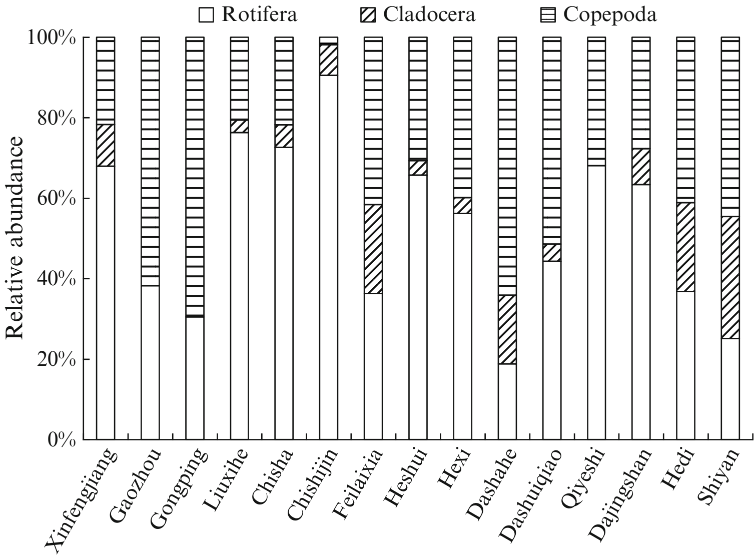

Fig. 1.4 Composition of zooplankton in the fifteen reservoirs

considerable evidence from the field that rotifers are competitively interior to cladocerans. However, rotifers typically become abundant in the plankton of those freshwaters in which the populations of cladocerans are suppressed by planktivorous fish. Predation may therefore reduce the tendency of cladocerans to outcompete rotifers. Heavy predation by juvenile and adult fish may greatly simplify the zooplankton community, and ultimately results in a scarcity of large-sized Cladocera, notably of the efficient filter feeder *Daphnia* in the tropics (Nilssen 1984). When set annual fish catch is used as a control variable, partial correlations analysis shows that there is a positive relationship between relative abundance of cladoceran and chlorophyll *a* ($R = 0.734$, $P = 0.02$) in nine reservoirs with fish catch data, suggesting that the relative abundance of cladocerans might be higher in high than in low trophic state level reservoirs under the same predation pressure. On the whole, it is likely that fish play an important role in shaping zooplankton community structure in Guangdong Reservoirs.

1.3.3.1 Rotifer Community

Trophic state has repeatedly been found to be important in determining the distribution of rotifer communities. Several studies have provided lists of rotifer species indicative of different trophic states (Maemets 1983). For example, *P. hudsoni*, *A. ovalis* and *C. unicornis* are regarded as indicators of oligotrophy, and *Brachionus* spp., *P. sulcata*, *Trichocerca* spp., *K. cochlearis* and *A. priodonta* as indicators of

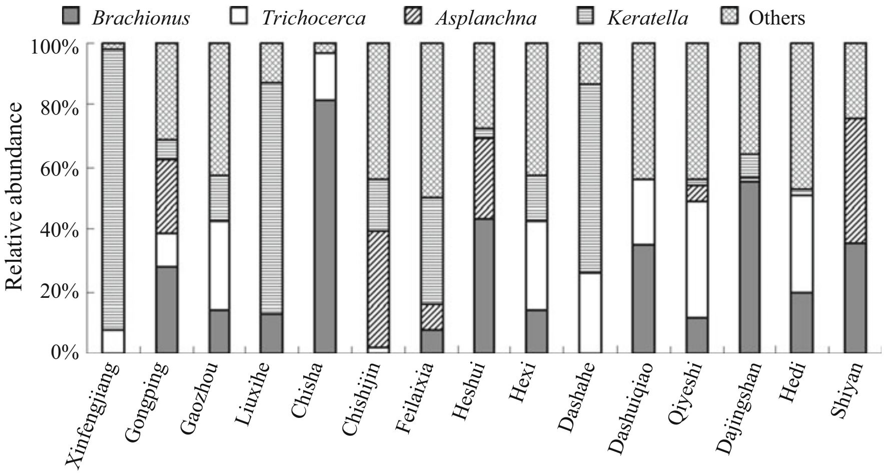

Fig. 1.5 Composition of Rotifera in the fifteen reservoirs

eutrophy. In our study, there were no species characteristics of oligotrophic or eutrophic reservoirs. Most of the above-mentioned species co-occurred in reservoirs with different trophic states. There were seven reservoirs in which *Brachionus* and *Trichocerca* contributed more than 40% of total rotifer abundance, three in which *Brachionus* and *Asplanchna* contributed more than 50% of total rotifer abundance, and three with more than 50% of total rotifer abundance contributed by *K. cochlearis* (Fig. 1.5). *K. cochlearis* is regarded as an indicator of eutrophy in some literature (Maemets 1983; Sládecek 1983). However, *K. cochlearis* was not only widely distributed in our reservoirs, but also the dominant rotifer species in oligotrophic and oligo-mesotrophic reservoirs (e.g. Xinfengjiang and Liuxihe Reservoirs). Therefore, the 'Chinese' *K. cochlearis* appears to be eurytrophic, and cannot be used as an indicator of eutrophy.

Based on physical, chemical and biological data, De Manuel and Armengol (1993) categorized 100 Spanish reservoirs into several groups but found no distinct communities typical of the different reservoir types. Each reservoir type contained a series of rotifer assemblages, with gradual changes in species composition in response to changes in environmental conditions. Similarly, rotifer distribution appears to broadly relate to only trophic state in our study. Gradients in rotifer assemblages occurred in response to changes in trophic state. In oligotrophic reservoirs (Xinfengjiang Reservoir), the rotifer assemblages were primarily dominated by *K. cochlearis*. With the increase of trophic level, the relative abundance of *K. cochlearis* is decreased, while that of *Trichocerca* and/or *Brachionus* increased. In meso-eutrophic and eutrophic reservoirs, rotifer assemblages were predominated by *Brachionus*, *Trichocerca* and *Asplanchna* (Figs. 1.5 and 1.6).

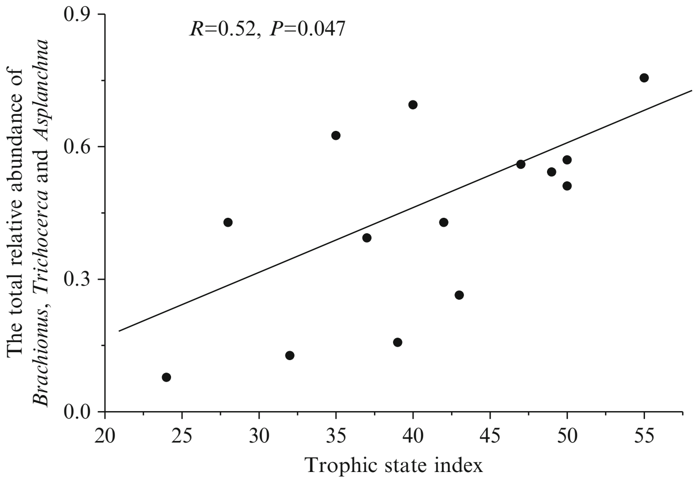

Fig. 1.6 Relationship between total relative abundance of *Brachionus*, *Trichocerca* and *Asplanchna* and trophic state index

1.3.3.2 Cladoceran Community

Most of the limnetic cladoceran species in the reservoirs of Guangdong province are members of five genera: *Diaphanosoma*, *Ceriodaphnia*, *Moina*, *Bosmina* and *Bosminopsis* (Fig. 1.7). The value of cladoceran plankters as eutrophic indicators is limited by regional specificity, probably reflecting a different evolutionary history. For example, *Ceriodaphnia quadrangula* was identified as a eutrophic state indicator in Finland but was not very useful in this regard in Poland (Cannon and Stemberger 1978). Certain bosminid cladocerans have been used as indicators of trophic conditions for many decades. In the reservoirs of Guangdong Province, *B. tripurae* and *D. orghidani* seemed to be eurytrophic, both were widely distributed and dominated the cladocerans in six reservoirs varying from oligotrophic (Xinfengjiang) to eutrophic (Hedi) and three reservoirs varying from mesotrophic (Feilaixia) to eutrophic (Qiyeshi). Both *B. deitersi* and *M. micrura* seemed to be eutrophic indicators, and dominated cladocerans in reservoirs varying from mesotrophic to eutrophic. *B. fatalis* predominated in the oligo-mesotrophic Liuxihe and Gaozhou reservoirs.

1.3.3.3 Copepod Community

The biomass ratio of calanoid copepod to cyclopoid copepod was regarded as a good indicator of the dynamics of copepod community structure. In our study, calanoid/cyclopoid abundance ratio varied from 0 to 0.33, with maximum in Gaozhou Reservoir and minimum in Dashuiqiao, Qiyeshi and Shiyan reservoirs (Fig. 1.8). There were four reservoirs with calanoid/cyclopoid ratio $\geq$0.2. Among them, Xinfengjiang Reservoir had four species of calanoids that co-occurred, while