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The community structure and seasonal dynamics of plankton in Bange Lake, northern Tibet, China*

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Abstract The seasonal variations in biomass, abundance, and species composition of plankton in relation to hydrography were studied in the saline Bange Lake, northern Tibet, China. Sampling was carried out between one to three times per month from May 2001 to July 2002. Salinity ranged from 14 to 146. The air and water temperature exhibited a clear seasonal pattern, and mean annual temperatures were approximately 4.8°C and 7.3°C, respectively. The lowest water temperature occurred in winter from December to March at -2°C and the highest in June and July at 17.7°C. Forty-one phytoplankton taxa, 21 zooplankton, and 5 benthic or facultative zooplankton were identified. The predominant phytoplankton species were *Gloeothece linearis*, *Oscillatoria tenuis*, *Gloeocapsa punctata*, *Ctenocladus circinnatus*, *Dunaliella salina*, and *Spirulina major*. The predominant zooplankton species included *Holophrya actra*, *Brachionus plicatilis*, *Daphniopsis tibetana*, *Cletocamptus dertersi*, and *Arctodiaptomus salinus*. The mean annual total phytoplankton density and biomass for the entire lake were 4.52×10^7 cells/L and 1.60 mg/L, respectively. The annual mean zooplankton abundance was 52, 162, 322, and 57, 144 ind./L, in the three sublakes. The annual mean total zooplankton biomass in Lakes 1–3 was 1.23, 9.98, and 2.13 mg/L, respectively. The annual mean tychoplankton abundances in Bg1, 2, and 3 were 47, 67, and 654 ind./L. The annual mean tychoplankton biomass was 2.36, 0.16, and 2.03 mg/L, respectively. The zooplankton biomass (including tychoplankton) in the lake was 9.11 mg/L. The total number of plankton species in the salt lake was significantly negatively correlated with salinity.

Keyword: community structure; spatio-temporal pattern; plankton; Bange Lake; northern Tibetan saline lakes

1 INTRODUCTION

Saline lakes in North Tibet are very important for resource exploitation, biodiversity protection, and monitoring global temperature changes in the northern Tibet. Saline lakes contain important raw materials for industry, agriculture, and medicine, e.g., halite, mirabilite, lithium, magnesium, boron, gypsum calcium chloride, tungsten, cesium, rubidium, strontium, hydromagnesite, and zeolite (Zheng et al., 1989). Considerable quantities of biological resources, such as halophilic organisms, e.g., *Spirulina* sp., *Dunaliella* sp., *Brachionus plicatilis*, *Moina mongolica*, and *Artemia* sp., which have economic and scientific value, occur in saline lakes (Zheng et al., 1989; Zhao et al., 2005, 2010b). Several limnological studies on Tibetan saline lakes have been carried out, but most have focused on physical and hydrochemical features (Yu and Tang, 1981), chemical exploitation (Chen, 1981; Zheng et al., 1989; Zheng, 1995), and either geographical or geological features. Very little is known of the biological resources in Tibetan saline lakes and no

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information is available on the seasonal variations in plankton communities in the saline lakes of north Tibet.

Previous reports have mentioned halosaline and freshwater halophilic species in surveys on invertebrates in the Tibetan Plateau (Wang et al., 1975; Gong, 1983; Jiang et al., 1983; Shen, 1983). Unfortunately, data on salinity, alkalinity, pH, and ionic composition were not provided. There are reports in the literature on the aquatic organisms of Qinghai Lake (14) (Wang et al., 1975) and Dali Lake (5.5) (He et al., 1981). Williams (1991) discussed the fauna of Chinese saline lakes in a review on Chinese and Mongolian saline lakes; however, many northern Chinese saline waters were not included, notably, information on zooplankton (He et al., 1984, 1989, 1993, 1994, 1996, 2001; Zhao and He, 1993, 1995, 1999; Zhao, 1992a, b; Zhao et al., 1993, 1996, 2010a; Ma, 1995; Ren et al., 1996). With the development of aquaculture, several plankton species, e.g., *Artemia*, *Brachionus plicatilis*, and *Moina mongolica*, have been used as food, leading to studies on their biology and ecology (An and He, 1991; Ren et al., 1996).

Zheng et al. (1989) reported on the sedimentology of Bange Lake; however, community structure and spatio-temporal dynamics were not discussed. The aim of this study is to elucidate seasonal variations in plankton species composition, biomass, and abundance in three Bange Lake sublakes in the margin of an unpopulated zone in northern Tibet, and the relationships between community structure, diversity index, and environmental factors, e.g., salinity, pH, and temperature.

2 MATERIAL AND METHOD

2.1 Sampling location

Bange Lake (or Bange Co in Tibetan, or Brang Khog Mtsho in Wylie Transliteration; Drangkhok Tso in THL standard) is located in northwestern Bange County, northern Tibet, China (Fig.1). The geographical location is 89°29′E, 31°43′N, and 4 522 m altitude. The lake is in a cold, arid region at high altitude. It includes three sublakes, Bange Lakes 1, 2, and 3 (hereafter Bg1, 2, and 3). Bg1 is a small shallow aquatic ecosystem, less than 1 km^2 in area and average depth is 2.2 m. Bg2 is 39 km^2 and 1.0 m average depth. Bg3 is 75 km^2 and 1.0 m. They contain water all year round. The climate was very cold and dry. According to local weather data, winds occur frequently, generally in the afternoon and cease at

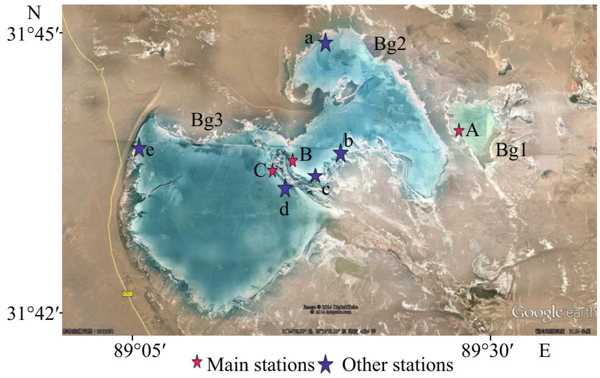

Fig.1 Map of Bange Lake

dusk. Rainfall is concentrated between June and mid-September. The annual air temperature ranges from a minimum of -37°C in January to a maximum of 22.9°C in July. Annual precipitation is low ~308 mm, but annual evaporation is >2 239 mm.

2.2 Sampling

Sampling was undertaken one to three times (twice in most months) per month at main stations in Bg1 (Station A only), Bg2 (one main Station B and three supplementary Stations a–c), and Bg3 (one main Station C and two supplementary Stations e and d) (Fig.1) from June 2001 to July 2002. Air and water temperature, salinity, and pH were measured. Water temperature was measured with a mercury thermometer. Water chemistry, including pH, HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}, Ca^{2+}, and Mg^{2+} were determined by routine methods (He et al., 1989). K^+ and Na^+ were measured by flame atomic absorption spectrophotometry (Huang et al., 1999). Salinity was measured with a saltmeter (ATAGO S-10). Transparency was measured by Secchi disc. Total nitrogen was measured by the Kjeldahl method. Total phosphorus was measured with the phosphorus molybdenum blue spectrophotometer method.

In total, 102 plankton samples were collected, including eight qualitative samples collected on the lakeshore. Generally, only surface water samples were obtained because of the shallow water (2.2 m in depth). Phytoplankton was studied by the precipitation concentration method by preserving samples in 1.5% Lugol's solution. Macro-zooplankton were obtained by filtering 20 L of water through a plankton net (64-µm mesh size) and preserved in 5% formaldehyde. Micro-zooplankton species (e.g., protists and rotifers) were obtained from phytoplankton samples after further concentration. The phytoplankton and zooplankton biomass (mg/L) were calculated

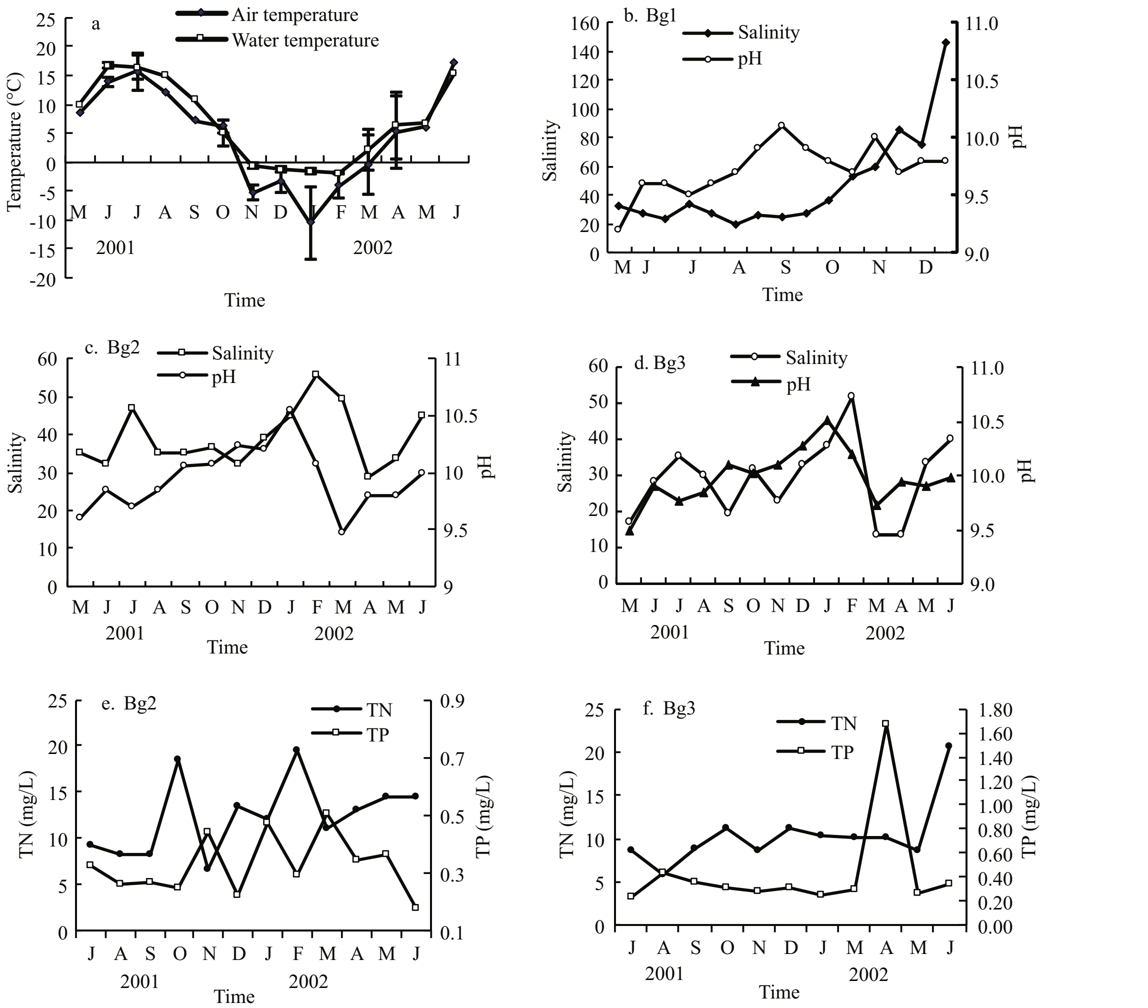

Fig.2 Seasonal changes in temperature, salinity, pH, and the concentrations of total nitrogen and total phosphorus in Bange Lake

volumetrically. Shannon-Wiener and Pielou's diversity indices (*H'* and *J*) were calculated (He et al., 1989). Statistical analysis was performed based on SPSS 20.0.

Species were identified according to the literature (Fott, 1971; Wang, 1977; Koste, 1978; Jiang and Du, 1979; Shen, 1979; Hu and Wei, 1981; Jiang et al., 1983; Ehrlich and Dor, 1985; Li et al., 1992; Zhu and Chen, 2000). Most were identified to the species level, and a few to higher taxonomic levels.

3 RESULT

3.1 Environmental conditions

The lake water was cold and highly saline. The contribution of snow water in this region is highly variable every year (Zheng, 1989). The mean temperature of the lake in the top 0.5 m exhibited a clear seasonal pattern (Fig.2a). The lowest temperatures were recorded from November to March (-2 to -3°C). The air temperature was lower than the water temperature for the entire year.

The water temperature began to increase in March/April reaching its maximum in late June (mean water temperature was 17.7°C, 22°C in late July 2001 in Bg1) and decreased thereafter. The mean annual air and water temperatures were approximately 4.8°C and 7.3°C in the lake. The salinity and pH variations in the lake are shown in Fig.2b–d. The salinity rose from 14 to 146 in Bange Lake. The mean annual salinity and the range (in bracket) of Lakes 1, 2, and 3 were 46.5 (20–146), 39.2 (28–55.5), and 29.4 (14–52.25), respectively. Mean annual pH values were 9.7 (9.2–10.1), 9.9 (9.47–10.54), and 10.0 (9.5–10.5), respectively (Table 1). The three sublakes were similar in salinity with seasonal variation: high salinity in summer and winter, and lower in mid-spring and autumn. The mean annual salinity and pH value of the entire lake water were approximately 38 and 9.9, respectively. Total lake transparency ranged from 0.2 to 0.8 m.

Seasonal variation in total nitrogen and total phosphorus based on monthly measurements at the surface at the main stations in Lakes 2 and 3 are shown in Fig.2e and f. The total nitrogen content was high during all sampling periods. The mean annual range was approximately 12.43 mg/L, it was lowest in August (<5 mg/L) and highest in February (10.0 mg/L). In Bg2, the total phosphorus concentration was 0.328 mg/L, it was lowest in December (<5 mg/L) and increasing gradually to the maximum in March (0.591 mg/L). In Bg3, the mean annual total nitrogen content was approximately 10.37 mg/L, it was lowest in August (5.9 mg/L) and highest in April (20.53 mg/L); the total phosphorus concentration was 0.437 mg/L, it was lowest in July (0.240 mg/L) and increased gradually to the maximum in April (1.68 mg/L).

In general, the dominant cation was sodium, followed by magnesium; carbon was the dominant anion (Table 1). The water type was classified as $NaCO_3SO_4$ according to Hammer (1986).

3.2 Phytoplankton

There were 41 phytoplankton taxa in Bange Lake, belonging to six phyla (Table 2). Cyanobacteria (18 species), diatoms (nine taxa), and green algae (eight taxa) were the most diverse. Other taxa included four species of Cryptophyta, one species of Euglenophyta, and one species of Chrysophyta.

The dominant species were *Gloeothece linearis*, *Oscillatoria tenuis*, *Gloeocapsa punctata*, *Phormidium tenue*, *Navicula* sp., *Ctenocladus circinnatus*, and *Dunaliella salina*. Most of the algae recorded are common in other saline lakes, but some are rather rare, particularly *Ctenocladus circinnatus*.

The seasonal variation in total phytoplankton biomass varied from 0.31 mg/L in July 2001 to

Table 1 Hydrochemical features and main ion composition of Bange Lake, China

Lakes	Major irons (mg/L)							Salinity	pH	TN (mg/L)	TP (mg/L)
	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	Ca^{2+}	Mg^{2+}	K^++Na^+				
Bange 1								46.5	9.7		
Bange 2	7 701. 7	15 086.7	1 464.2	-	-	70.7	12 133	39.2	9.9	12.43	0.328
Bange 3	4 940.9	9 012.7	851.8	-	-	57.6	7 595.4	29.4	10.0	10.37	0.437

Table 2 Phytoplankton species composition, distribution, mean density, occurrence frequency, and biomass in Bange Lake, China

Taxa	Distribution			The mean of whole lake		
	Bg1	Bg2	Bg3	Density (10^4/L)	Occurrence rate (%)	Biomass (mg/L)
Cyanophyta						
Anabaena osicellariordes Bory	+	+	+	2.47	39.80	0.005
Chroococcus minor (Kutz) Nag	+	+	+	0.95	11.06	0.001
Chamaesiphon curvatus Nordst		+	+	0.58	20.95	0.002
Dactylococcopsis rhaphidioides Hansg	+		+	0.94	8.42	0.000
Gloeothece linearis Nag	+	+	+	985	97.37	0.288
Gloeocapsa punctata Nag	+	+	+	3222	99.12	0.161
Gomphosphaeria lacustris Chod.		+	+	2.08	2.60	0.001
Lyngbya sp.	+	+	+	6.27	19.87	0.019
Nostoc sp.		+	+	0.00	11.81	0.000
Nodularia spumigena Mert	+	+		0.47	6.20	0.001
Oscillatoria tenuis Ag	+	+	+	17.97	81.84	0.180

Occurrence rate is calculated by the percentage of samples number of some species occurred accounting for the total number of samples.

To be continued

Table 2 Continued

Taxa	Distribution			The mean of whole lake		
	Bg1	Bg2	Bg3	Density (10^4/L)	Occurrence rate (%)	Biomass (mg/L)
Cyanophyta						
Oscillatoria agardhii Gom	+	+		1.88	13.35	0.019
Oscillatoria formosa Bory	+	+		9.37	32.33	0.094
Phormidium tenue (Menegh.) Gom	+	+	+	81.95	40.41	0.164
Rhoabdoderma Schmd		+	+	48.95	7.79	0.013
Synechococcus sp.	+		+	1.28	8.42	0.000
Spirulina major Kütz	+	+	+	3.10	51.38	0.006
Spirulina platensis (Nordst) Geitl		+		0.00	2.63	0.000
Bacillariophyta						
Cuclotella Kütz		+	+	0.29	6.51	0.001
Cymbella pusilla Ag		+	+	1.54	6.48	0.002
Navicula sp.	+	+	+	33.77	41.46	0.433
Navicula halophila	+	+	+	0.74	13.58	0.009
Nitzschia sp.	+	+	+	2.85	11.99	0.026
Fragilaria sp.			+	0.00	5.13	0.000
Gyrosigma acuminatum (Kutz.) Rabenh		+	+	0.34	5.23	0.004
Rhopalodia gibba Müll		+		4.50	21.05	0.005
Synedra sp.			+	0.00	2.56	0.000
Cryptophyta						
Chroomonas acuta Uterm		+		15.58	26.32	0.016
Cryptomonas erosa Ehr		+	+	2.22	10.39	0.022
Cryptomonas ovata Ehr		+		1.39	7.89	0.014
Cyanomonas coerulea		+		0.00	5.26	0.000
Chrysophyta						
Chromullina pascheri Haf		+		0.00	5.26	0.000
Euglenophyta						
Euglena viridis Ehr		+	+	1.03	16.77	0.062
Chlorophyta						
Chlororcoccum sp.		+	+	0.00	3.91	0.000
Cladophora sp.		+	+	0.00	2.60	0.000
Chlorella vulgaris Beij	+	+	+	51.15	36.47	0.026
Ctennocladus circinnatus Borzi	+	+	+	0.47	49.91	0.002
Dunaliella salina Teodor	+	+	+	18.44	44.63	0.025
Oocystis sp.			+	0.00	7.89	0.000
Spirogyra sp.			+	0.00	7.69	0.000
Ulothrix sp.	+	+	+	0.11	16.98	0.001
Total	20	35	32	4 519.25		1.60

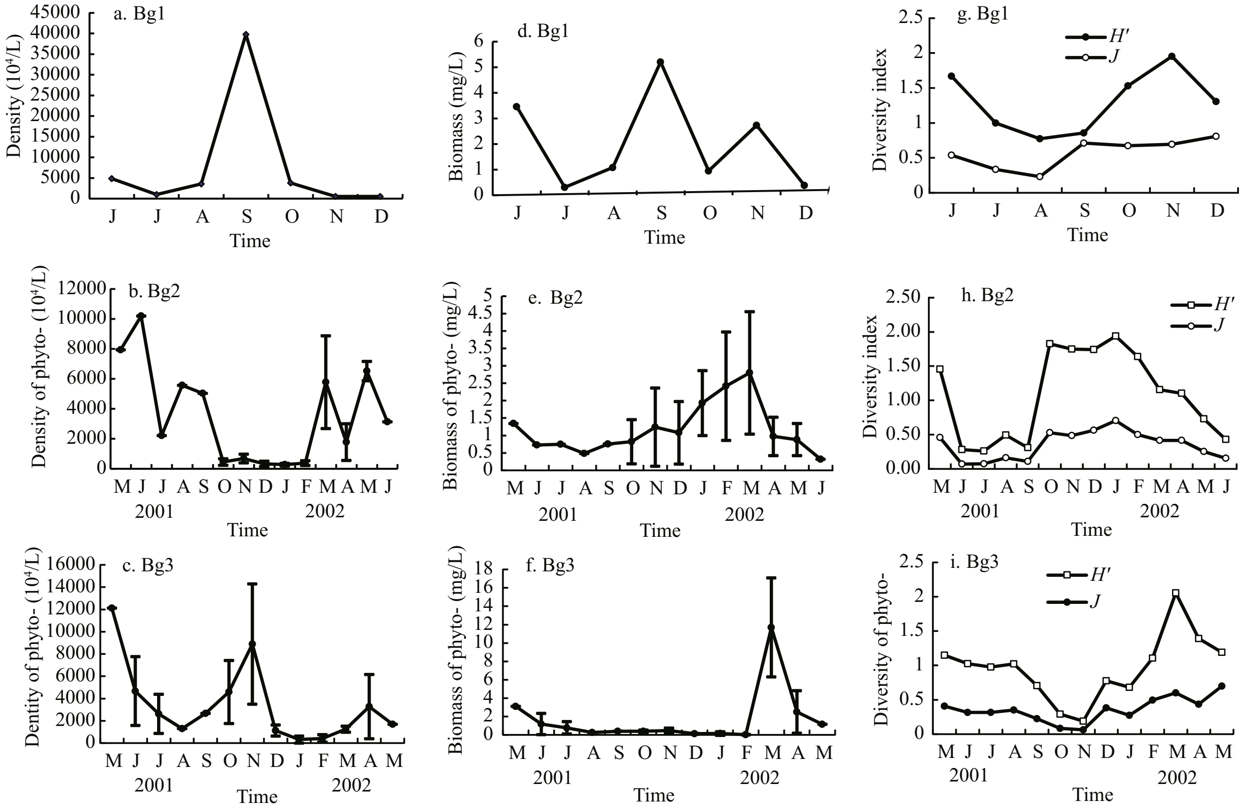

Fig.3 Dynamics of the density (a–c), biomass (d–f), and diversity index (g–i) of total phytoplankton in Bange Lakes 1, 2, and 3 from May 2001 to June 2002

5.21 mg/L in September 2001 in Bg1 (Fig.3d); from 0.32 mg/L in summer to 2.80 mg/L in late spring in Bg2 (Fig.3e); and from 0.04 mg/L in winter to 11.69 mg/L in late spring in Bg3 (Fig.3f). The total phytoplankton biomass remained low, the annual mean phytoplankton biomass in Lakes 1, 2, and 3 were 2.02, 1.28, and 1.21 mg/L, respectively. The mean annual total phytoplankton biomass in the lake was 1.60 mg/L.

The seasonal cycle of phytoplankton abundance showed no difference from that of biomass but the patterns differed among the three sublakes. The seasonal variation in total phytoplankton density ranged from 5.20×10^6 cells/L in December 2001 to 3.98×10^8 cells/L in September 2001 in Bg1 (Fig.3a); from 2.76×10^6 cells/L in winter to 1.02×10^8 cells/L in late spring and summer in Bg2 (Fig.3b); and from 3.16×10^6 cells/L in winter to 1.21×10^8 cells/L in late spring and to late autumn 0.89×10^8 cells/L in Bg3 (Fig.3c). The total phytoplankton density remained high, the annual mean phytoplankton abundance of Lakes 1, 2, 3 were 7.74×10^7, 2.89×10^7, and 2.81×10^7 cells/L, respectively. The mean annual total phytoplankton density in the lake was 4.52×10^7 cells/L.

Seasonal variation in the phytoplankton diversity index was characterized by the lowest value in summer and highest in winter and spring (Fig.3g–i). The annual mean phytoplankton diversity indices H' and J (in bracket) of the three sublakes were 1.299 (0.571), 1.080 (0.350), and 0.966 (0.358), respectively. The annual means of phytoplankton H' and J were 1.112 and 0.426, respectively.

3.3 Taxonomic composition of phytoplankton

The seasonal changes in relative abundance of the major taxonomic groups are presented in Table 2. Cyanobacteria abundance was dominated by phytoplankton all year. The cyanobacteria *Gloeothece linearis* (70.3%) and *Gloeocapsa punctata* (21.8%) dominated the total phytoplankton density (92.1%). In Bg1, the cyanobacteria biomass dominated the phytoplankton all year (Fig.4). In Bg2, diatoms made up a large proportion of the total phytoplankton biomass in winter and spring, and cyanobacteria in other seasons. In Bg3, cyanobacteria were the major contributor to the total phytoplankton biomass in summer and autumn, while diatoms were in winter and spring. The percentage of cyanobacteria in the three sublakes for the year was 88.3%, 39.6%, and 50.1%; and that of diatoms was 8.62%, 45.4%, and

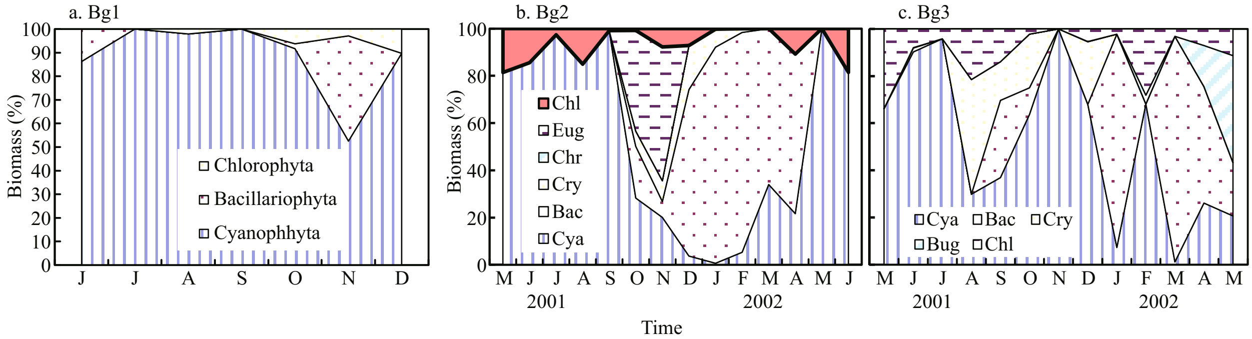

Fig.4 Relative biomass frequency of the most numerous phytoplankton taxa in Bange Lake from May 2001 to July 2002

The values are means of the lakes sampled.

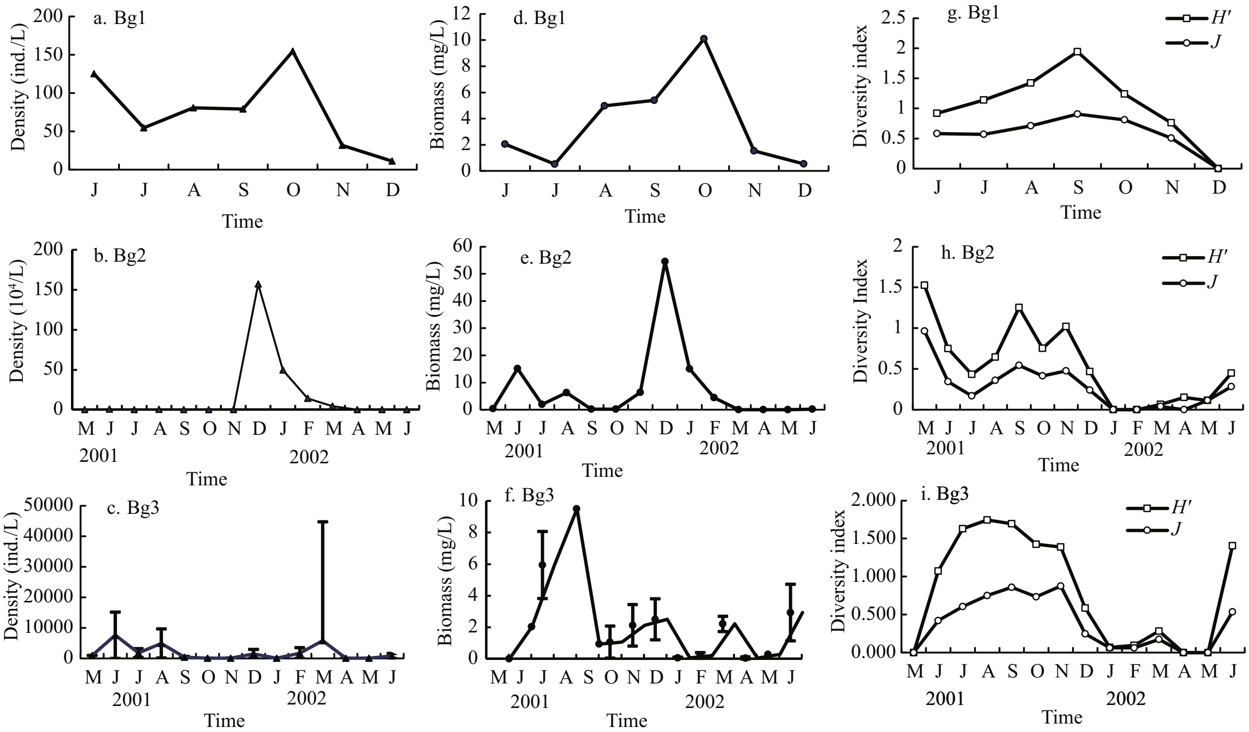

Fig.5 Dynamics of the density (a–c), biomass (d–f), and diversity index (g–i) of total zooplankton in Bange Lakes 1, 2, and 3 from May 2001 to June 2002

32.6%, respectively. As far as the entire lake is concerned, the biomass percentages of Cyanophyta, Bacillariophyta, Chlorophyta, Euglenophyta, and Cryptophyta for the year were 59.3%, 28.9%, 6.57%, 3.58%, and 1.69%, respectively. Five algae species, including *Navicula* sp. (27.1%), *G. linearis* (18%), *O. tenuis* (11.3%), *G. punctata* (10.1%), and *P. tenue* (6.5) were the main contributors to the total phytoplankton biomass (72.9%).

3.4 Zooplankton

In Bg1, the seasonal variation in total zooplankton biomass featured a low winter value (0 mg/L) and a maximum (3.45 mg/L) in the mid-autumn (Fig.5d). In Bg2, it was low in winter and late autumn (0–0.20 mg/L) and peaked (54.6 mg/L) in winter (Fig.5e). In Bg3, it was low in late winter and spring (0–0.10 mg/L) and reached a maximum (9.49 mg/L) in the autumn (Fig.5f). The annual mean total zooplankton biomass in Lakes 1–3 was 1.23, 9.98, and 2.13 mg/L, respectively, with a total-lake average of 4.45 mg/L.

The seasonal succession of zooplankton abundance in Bg1 was similar to that of biomass: low winter values and a peak value in the early summer, reaching a minimum of ~0 ind./L in December and a maximum of 116 ind./L in June (Fig.5a). In Bg2, zooplankton abundance values peaked in winter (1.57×10^6 ind./L) and were lowest in spring (0–200 ind./L) (Fig.5b). In

Bg3, values were low in autumn and winter (0–50 ind./L) and high in spring (3.89×10^5 ind./L) (Fig.5c). The annual mean zooplankton abundance was 52,162, 322, and 57, 144 ind./L, in the three sublakes, respectively.

The seasonal succession of zooplankton diversity index generally reflected the variations in zooplankton abundance in the three sublakes, with a similar pattern of a winter/spring low and autumn/summer high (Fig.5g–i). The annual mean zooplankton diversity indices H' and J (in bracket) of Lakes 1, 2, and 3 were 1.060 (0.583), 0.544 (0.281), and 0.814 (0.381), respectively. The annual mean zooplankton H' and J were 0.662 and 0.415, respectively for the entire lake combined.

3.5 Taxonomic composition of zooplankton and benthic tychoplankton

The zooplankton species/taxa composition and distribution are given in Table 3. A total of 21 species and taxonomic groups were identified, including 11 Protista, 4 Copepoda, 3 Rotifera, 2 Cladocerans, and 1 Anostraca. In the frequency of occurrence, biomass, and density, the major species were *Holophrya actra* [Protista]; *Brachionus plicatilis* [Rotifera]; *Artemia* sp. [Anostraca]; *Daphniopsis tibetana* and *Alona quadrangularis* [Cladocera]; and *Cletocamptus dertersi* and *Arctodiaptomus salinus* [Copepoda]. The number of animal species ranged 1–12, and tended to decrease with increasing salinity. Most of the animals recorded are common in other Tibetan saline lakes. The most abundant groups are discussed in more detail below.

Four benthic tychoplankton (macroinvertebrates) taxa are listed in Table 3. They were represented by *Cypris* sp. [Ostracoda], chironomids *Tendipus group salinarius* [Diptera], Nematoda, and *Ephedra* sp. Moreover, mosquito eggs were dominant in the lakes. The annual mean tychoplankton abundances in Lakes 1, 2, and 3 were 47, 67, and 654 ind./L, respectively. The annual mean tychoplankton biomass was 2.36, 0.16, and 2.03 mg/L, respectively.

The seasonal changes in the relative abundance and biomass of the major taxonomic groups are illustrated in Fig.6. Tychoplankton dominated all year in Bg1, accounting for 47% zooplankton abundance and 65.8% biomass (including Tychoplankton). Rotifera (57.2%) dominated zooplankton abundance and Branchiopoda (58.6%), such as *D. tibetana*, dominated the biomass (not including Tychoplankton) in Bg1 (Fig.6a, b). In Bg2, the Protista dominated zooplankton abundance and biomass in winter and spring from November 2001 to April 2002, and Rotifera dominated in summer and autumn (Fig.6c, d). The Branchiopoda dominated in June and November 2001 (Fig.6d). Protista dominated the zooplankton, accounting for 99.4% zooplankton abundance and 68.54% biomass for the entire year. Moreover, Rotifera was the second most dominant taxonomic group (0.58% abundance and 18.8% biomass). The pattern of abundance and biomass in Bg3 was similar to that in Bg2 (Fig.6e, f). Protista dominated zooplankton abundance (85.8%) all year (Fig.6e). Tychoplankton dominated zooplankton biomass with 48.8% (Fig.6f).

3.6 Dominant zooplankton community succession

The dynamics of dominant zooplankton and tychoplankton species in Bange Lake are presented in Fig.7. Some of the dominant species in the sublakes exhibited similar patterns of variation in seasonal abundance. The numbers of *Brachionus plicatilis* remained low during the winter and spring months and peaked once during the summer from June to August at 100, 8 622, and 2 712 ind./L in Lakes 1–3, respectively (Fig.7a, f, h). *Daphniopsis tibetana* densities remained low in the spring and summer months and peaked once during the autumn and early winter at 18, 62, and 17.4 ind./L in Lakes 1–3, respectively, and *Artemia* sp. numbers remained high during the summer at 2.2, 37, and 8.7 ind./L, respectively (Fig.7b, d, j). *Holophrya actra* abundance peaked once (1.31×10^8 ind./L) in late winter in Bg2 and twice in July 2001 (6 375 ind./L) and March 2002 (5 791 ind./L) in Bg3. *Cletocamptus dertersi* peaked in August at 94 and 326 ind./L in Lakes 2 and 3, respectively. *Arctodiaptomus stewartianus* also peaked in August in Lakes 1–3, at 30.4, 15.6, and 41.5 ind./L, respectively. Nematoda was dominant species of benthic macroinvertebrate, with one peak in October 2001 (99 ind./L, in Bg1) and one in May 2002 (783 ind./L in Bg2).

3.7 The effects of ecological factors on plankton

The phytoplankton taxa numbers, abundance, and biomass were significantly negatively correlated with salinity (R_{89}=-0.175 to 0.225, P<0.05). The phytoplankton diversity index tended to increase with increasing salinity but decreased with increasing water temperature (Table 4).

The zooplankton taxa numbers, abundance, and biomass decreased with increasing salinity, but taxa numbers were significantly positively correlated with

Table 3 Zooplankton species composition, distribution, mean density, occurrence frequency, and biomass in Bange Lake, China

Taxa	Bg1	Bg2	Bg3	Mean of whole lake		
				Density (ind./L)	Occurrence (%)	Biomass (mg/L)
Protista						
Arcella vulgaris	+		+	0.96	8.42	0.000 3
Accineta tuberosa		+	+	2.30	2.44	0.002 4
Chilodonella cucullulus		+	+	1.22	3.78	0.000 1
Difflugia sp.	+	+	+	8546	7.30	0.427 3
Epistylis daphniae			+	5.50	15.38	0.000 3
Euplotes		+		3463	2.44	0.174 0
Holophrya actra Srec.		+	+	114 817	43.81	3.490 3
Litonotus fasciola Ehrenberg			+	0.00	2.56	0.000 0
Paramecium caudatum Ehr			+	87.50	15.38	0.140 0
Rhabdostylasp sp.		+		0.22	4.88	0.000 0
Vorticella campanula Ehrenberg	+		+	1.48	3.57	0.000 1
Rotifera						
Brachionus plicatilis O.F. Muuller	+	+	+	322	44.16	0.507 3
Brachionus quadridentatus	+			0.00	7.14	0.000 0
Notholca acuminata cincta			+	0.34	2.56	0.000 2
Brachiopoda						
Alona quadrangularis O.F. Muller		+		5.04	39.02	0.730 1
Artemia sp.	+	+	+	0.64	19.75	0.313 6
Nauplius of *Artemia*	+	+	+	0.75	7.24	0.030 6
Daphniopsis tibetana Sars	+	+	+	3.94	52.00	0.594 1
Copepoda						
Arctodiaptomus salinus Daday	+	+	+	3.30	15.97	0.141 0
Arctodiaptomus stewartianus (Brehm)		+		0.00	2.44	0.000 0
Cletocamptus dertersi (Richard)	+	+	+	12.23	14.99	0.148 0
Cyclops vicinus Uijanin	+			0.99	7.14	0.020 4
Nauplius	+		+	5.61	7.42	0.019 1
Nauplius of *C. dertersi*			+	0.08	0.00	0.000 2
Copepodid		+	+	2.75	7.57	0.033 5
Tychoplankton						
Nematoda	+	+	+	41.9	53.20	0.954 6
Cypris sp.			+	0.00	2.56	0.000 0
Tendipes gr. salinarius	+	+	+	3.32	16.11	0.303 1
Eggs of mosquito	+	+	+	45.6	24.07	1.077 5
Ephrdra sp.			+	0.00	0.00	0.000 0
Total	15	18	23	127 373.67		9.11

water temperature (R_{103}=0.512, P<0.01). The zooplankton diversity index was significantly negatively correlated with salinity and pH (R_{103}= -0.200, P<0.05 salinity and R_{103}=-0.303, P<0.01 pH), but positively correlated with water temperature (R_{103}=0.507 and R_{103}=0.512, P<0.01) (Table 5).

4 DISCUSSION

The annual mean salinity in the Bange Lake sublakes was 46.5, 39.2, and 29.4. The salinity reached its maximum value in late December 2001 in Bg1 and its minimum in early April 2002 in Bg2

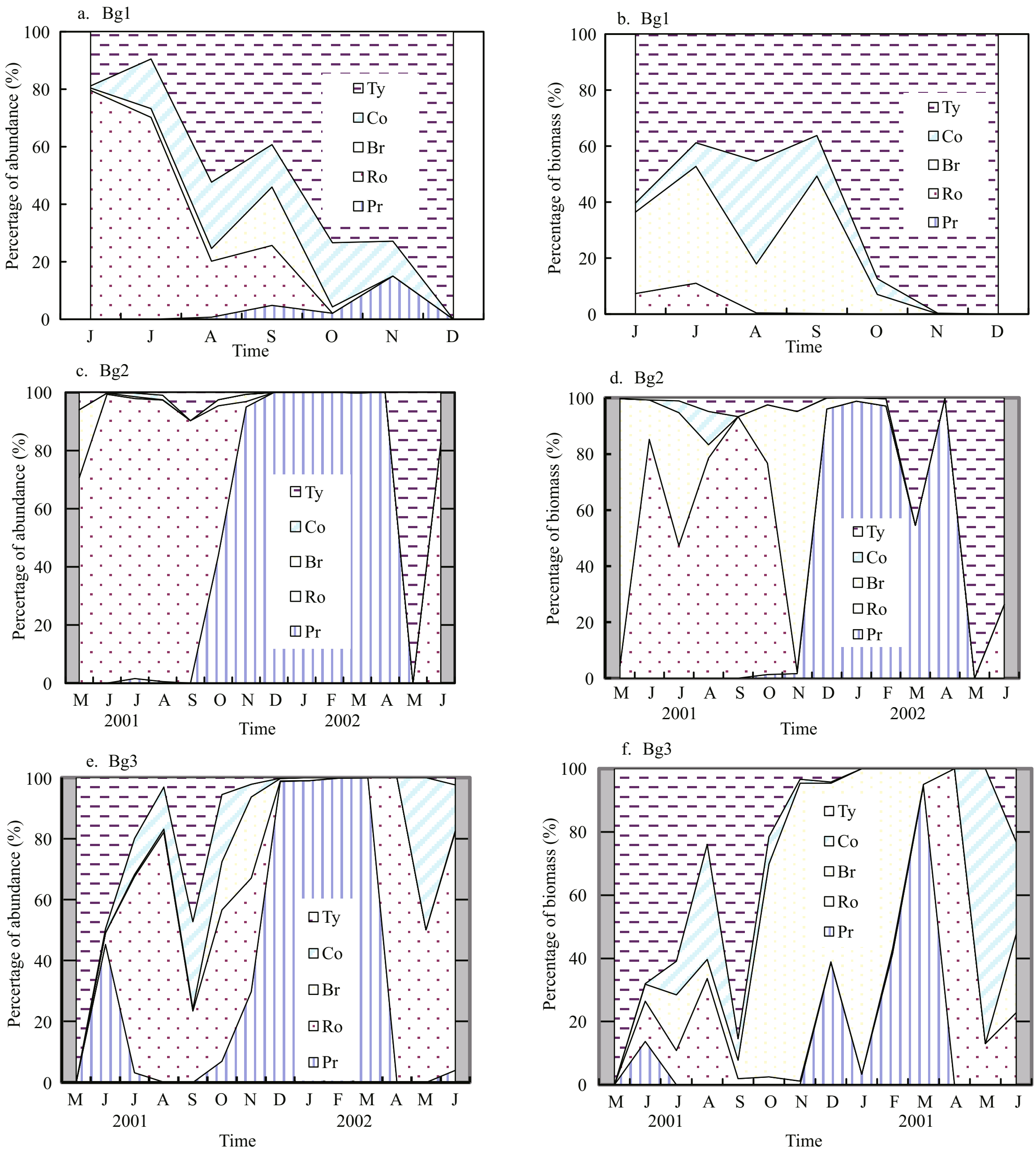

Fig.6 Relative frequency of zooplankton taxa density (a, c, e) and biomass (b, d, f) in Bange Lakes 1, 2, and 3, from May 2001 to July 2002

(Fig.2) ranging from 4 to 146. The water type was $NaCO_3SO_4$ according to the Hammer (1986) scheme. Salinity was significantly negatively correlation with water temperature (R_{106}=-0.325, P<0.01). Thus, in late spring, the relative quantity of snow water melt from jokul was highest, while during spring salinity decreased as a result of the mixing of the jokul water. The mean phytoplankton biomass in Bange Lake was 1.60 mg/L, and was dominated by Cyanophytes, diatoms, and green algae. The mean zooplankton biomass was 4.45 mg/L. The ratio of zooplankton biomass to that of phytoplankton was 2.8. The predominant zooplankton members included *Daphniopsis tibetana*, *Cletocamptus dertersi*, and *Arctodiaptomus stewartianus*.

In general, biological composition in inland saline waters is very simple. Long-time investigations on plankton flora and fauna in Tibetan saline lakes are scarce. Wang et al. (1975) reported 53 algal genera and 26 zooplankton species in Qinghai Lake (12.5 salinity, 4 456 km^2 in area); and the sampling lasted 4 years. Ma (1995) reported 23 algal species in some

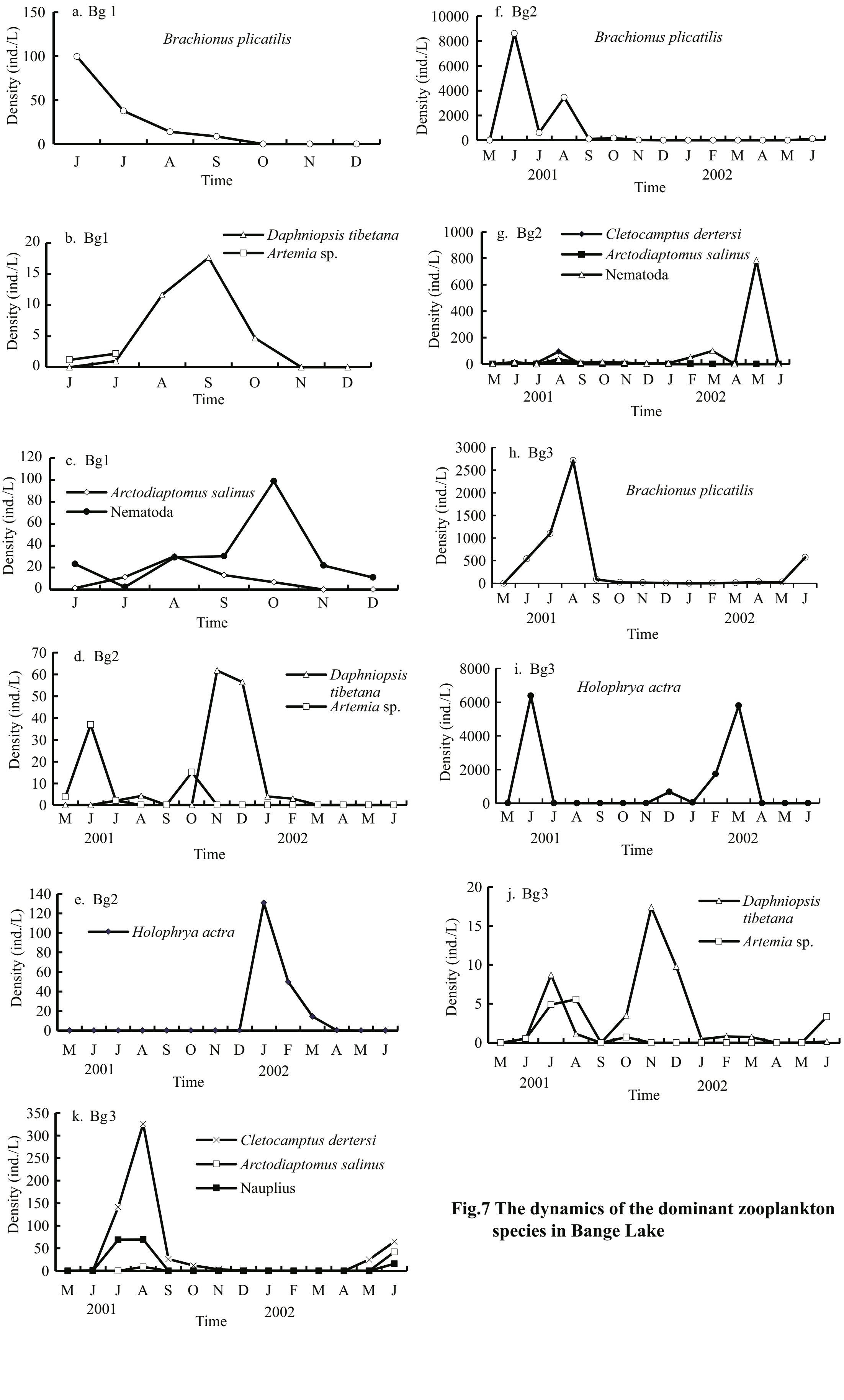

Fig.7 The dynamics of the dominant zooplankton species in Bange Lake

northern Chinese saltpans and lakes ranging in salinity from 61.0 to 320.0. Zhao and He (1999) reported 91 algal species in saline waters and lakes in Zhangjiakou, northern Hebei Province, ranging in salinity from 0.98 to 175.2. Ren et al. (1996) reported 92 species (or genera) of algae in 23 inland saline lakes (12.4–394.5) in NW China. He et al. (1981) reported 52 genera algae and 35 species zooplankton in Da-Li Lake located in eastern Inner Mongolia, China (5.5, 238 km^2 in area, sampling 4 times in a year). He et al. (1994) identified 42 algal genera and 62 zooplankton species in Xiaochi Lake (10.3–78.3, 15 km^2 in area, five samples in 4 years). Xu et al (2002) reported 46 algae taxa and 12 zooplankton species in Gahai Lake (119, 37.4 km^2 in area, sampling in summer 1997). Zhao et al. (2005) reported 95 algae taxa and 42 zooplankton taxa in Ali-Tibetan saline lakes in Ali, northern Tibet, China, where salinity ranged from 1 to 390.

In the present investigation, 41 phytoplankton and 21 zooplankton taxa were identified in Bange Lake during the year in bi-monthly sampling. Compared to those of other studies, the plankton species and taxa in Bange Lake were very few. In particular, there were fewer zooplankton species in Bange Lake than in Qinghai, Dalai, and Xiaochi lakes. We believe that this situation can be attributed to the salinity, ion composition, and other adverse conditions in the environment. In terms of fish fauna, there are two species of *Gymnocypris przewalskii*, four *Nemacheilus* species, crucian carp (*Carassius auratus* L.), and *Leuciscus walekii* (Dyb.) in Dalai Lake. There is only one fish species (*Oryzias latipes*) in Xiaochi Lake (16.3). No fish were found in Bange Lake.

Among the 41 phytoplanktonic algae taxa recorded, *Dunaliella salina*, *Ctenocladus circinnatus*, *Spirulina major*, *Diatoma elongatum*, and some others were either typical hyposaline or halobiont species, and most of them were either salt-tolerant freshwater species, euryhaline species or halophile species that are adapted to a wide range of salinities. These results are in accordance with those from other regions (Fott, 1971; Geddes et al., 1981; He et al., 1981, 1989, 1993, 1994; Hammer et al., 1983; Hammer, 1986; Ehrlich and Dor, 1985; Colbur, 1988; Wood and Tailing, 1988; Jakher, et al., 1990; Servant-Vildary and Roux, 1990; Zhao, 1992b; Zhao et al., 1993; Ma, 1995; Ren et al., 1996; Zhao and He, 1999).

Of the 21 zooplankton species recorded, *Brachionus plicatilis*, *Artemia* sp., and *Daphniopsis tibetana* are regarded as halobiont species as per Beadle (1981), Gong (1983), Williams (1983), Hammer (1986), He et al. (1989), Alonso (1990), Zhao (1992a), Zhao and He (1993), Zhao et al. (1996, 2010b), and Ren et al. (1996). Information on protistans in inland saline waters around the world is rare (Shen, 1983; Hammer, 1986; Stephens, 1990; Zhao and He, 1995). Freshwater species were predominant in Bange Lake phytoplankton and zooplankton, but many were halobiont species. The proportion of halobiont species in both total species and taxa was 10%.

Our previous study (Zhao and He, 1995) and this one have shown that protozoans, especially ciliates, play an important role in inland saline waters, and ciliates density and biomass are usually higher in hypersaline waters where they might dominate particular communities in some seasons, they were abundant in Bg2 in January 2002. Nevertheless, as noted by other researchers, most protistan species in inland saline waters are of freshwater derivation, indicating that the Protista are very salt tolerant (Wang, 1977; Shen, 1983; Zhao and He, 1995).

D. tibetana is a halobiont Cladoceran, which lives in plateau lakes at altitudes of >4 000 m and occurs widely in hyposaline lakes in the northern Tibet, Qinghai, and Xinjiang, China (Zhao et al., 2002). Additionally, *D. tibetana* often occurs in Russia and India. In China, the species is endemic to the Tibet region as cited by Jiang et al. (1983); however, it was also found in Sayram Lake, Xinjiang, where temperatures ranged from -2°C to 20°C, salinity from 9 to 35 and pH from 9.0 to 10.4 (Zhao et al., 2002). In this investigation, *D. tibetana* was dominant above all other species at a density of 83 ind./L. This Cladoceran is a potential live food for marine fish and other economic animals in marine water acclimation.

In the northern Tibet, *Ctenocladus circinnatus* is widespread where there are no filamentous green algae. It can survive salinities as high as 200 (e.g., Gangtang Lake). In this investigation, *Ctenocladus circinnatus* occurred in Rabang Lake (73–75) and Kahu Lake (300–310). Some green algal taxa are endemic to salt lakes in this region, for example, as Hu and Wei (1981) mentioned in particular, *Didymonema tibeticum*. Moreover, *Cladophora globulina* and *Ulothrix implexa* are two other green algal genera found in the northern Tibetan saline waters, although they are less important than *C. circinnatus*. A form of *Dunaliella salina* particularly tolerant to cold was reported from Zabuye Lake (Zheng et al., 1989). Cyanophyta in Tibetan salt lakes, according to Li (1981), are the most common taxa that can inhabit in both fresh and saline waters.

High and often variable salinity in salt lakes often reduces biodiversity. The higher the salinity, the fewer plankton species occur, resulting in smaller a diversity index and total species number, which was confirmed by our results. High alkalinities could also decrease diversity and species number (Beadle, 1981; Zhao and He, 1999). Williams et al. (1990), in a study on the macroinvertebrate fauna of 79 Australian salt lakes, suggested that although salinity per se is relatively unimportant in determining what species occur in a particular lake, species richness and composition nevertheless strongly correlate with salinity over the total salinity range. This relationship, however, becomes insignificant above an intermediate salinity range, which has been also reported by other authors (Colburn, 1988; Wood and Talling, 1988; He et al., 1989; Hammer et al., 1990; Zhao, 1992a). The implication is that many factors other than salinity may determine the distribution of aquatic organisms in salt lakes. In the present study, the saline lakes investigated have high alkalinity and pH. Again, this suggests that salinity itself is not the only important factor determining the species composition of plankton. Local climate, ionic composition, alkalinity, pH, and some biological factors are also influential (Lei et al., 1985). In this study, in terms of the number of taxa, the zooplankton diversity index was significantly negatively correlated with pH in Lakes 2 and 3. However, community structure and diversity are also strongly determined by resource interactions (Paine, 1980; Leibold et al., 1997; Vargas et al., 2006).

The mean phytoplankton biomass in Bange Lake was 1.60 mg/L, and was dominated by cyanobacteria and diatoms. The mean zooplankton biomass (including tychoplankton) was 9.11 mg/L (Table 3). The ratio of total zooplankton biomass to that of phytoplankton was 5.7:1, which was lower than the 14.8:1 reported in Namuka Lake (Zhao et al., 2010a), near Bange Lake. The zooplankton biomass (ZB) in freshwater lakes is generally much lower than the phytoplankton biomass (PB). For example, the PB/ZB ratio was 0.9:1 in Xiaochi Lake in the southern Shanxi Province, 1.2:1 in Dali Lake in Inner Mongolia; PB/ZB ratio in Namuka Lake was close to that of 10.4 in Lake Bolshoy Sanntroy in pre-Soviet Union, where the ratio of phytoplankton: bacterioplankton: zooplankton biomass was 1:2.5:10.4 (Hammer, 1986).

The zooplankton biomass in Bange Lake may be higher, equal to the level of high-production fishponds (10–20 mg/L), indicating that a higher biomass of bacteria and detrital phytoplankton maintained zooplankton food resources. Moreover, higher zooplankton biomass may be the result of there being no fish feeding in the lake. Therefore, the zooplankton biomass was at the top position of communities in this aquatic ecosystem.

In Bange Lake, total nitrogen and phosphorus concentrations were very high. The nutrient characteristics were that of a typical eutrophic lake. Furthermore, the dominant phytoplankton groups were cyanobacteria, diatoms, and chlorophytes; phytoplankton density and biomass were also very high in some months, similar to other subtropical and eutrophic lakes in China (Zhao et al., 2010b). The zooplankton and phytoplankton biomass exhibited obvious seasonal variations. The maximum phytoplankton biomass in Bg2 and Bg3 occurred in March 2002, which coincided with lower TP concentrations. Meanwhile, the ratio of TN to TP was 37.9:1 for Bg2, and 23.7:1 for Bg3, which differs from the optimum TN:TP ratio (10:1–17:1) for phytoplankton growth proposed by Wetzel (1983). In winter (December), lower phytoplankton biomass likely resulted from cooler water and light deficiency, while higher phytoplankton biomass in spring (March) likely resulted from higher TP concentrations.

Some species of *Arctodiaptomus*, e.g., *A. salinus*, *A. rectispinosus*, and *A. stewartianus*, are geographically widespread in inland saline waters in the northern hemisphere; they were also a common feature of the Bange Lake fauna.

Artemia is the best-known and most economically useful salt lake species. In the present investigation, *Artemia* sp. occurred in Bange Lake from April to July 2002. However, the density was very low because of the low salinity of <60. Therefore, it could not compete with other zooplankton such as *B. plicatilis* and *D. tibetana*, which reproduce and grow faster than *Artemia* sp.

This investigation did not look at planktonic bacteria. Future research into the genetic biodiversity and resource development and utilization of saline lake organisms would be useful.

5 CONCLUSION

This study clarifies the seasonal variations in plankton species composition, abundance, and biomass in relation to hydrography in the saline Bange Lake. Forty-one phytoplankton, 21 zooplankton, and 5 benthic/facultative zooplankton taxa were identified over 1 year. The major phytoplankton species were *Gloeothece linearis*, *Oscillatoria tenuis*, *Gloeocapsa punctata*, *Ctenocladus circinnatus*, *Dunaliella salina*, *Spirulina major*. The major zooplankton species included *Holophrya actra*, *Brachionus plicatilis*, *Daphniopsis tibetana*, *Cletocamptus dertersi*, and *Arctodiaptomus salinus*. The total number of plankton species was significantly negatively correlated with salinity.

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