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Primary Research Paper

Biological and ecological features of saline lakes in northern Tibet, China

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Abstract

In May and July 2001, the biological and ecological features of 22 salt lakes in northern Tibet , China, were investigated.Their salinity ranged from 1 to 390 g l^{-1}. One hundred and thirty two samples were collected. Ninty five taxa of phytoplankton and 42 taxa of zooplankton were recorded. The dominant cation was sodium, with magnesium generally sub-dominant; CO_3^{2-} was the dominant anion in low salinity, chloride was the dominant anion with increasing salinity. Major species were *Gloeothece linearis*, *Oscillatoria tenuis*, *Chroococcus minutus* (blue-green algae); *Navicula* spp, *Cymbella pusilla*, *Diatoma elongatum* (diatoms); *Dunaliella salina*, *Chlorella vulgaris* and *Ulothrix tenerrima* (green algae). Major zooplankton included: *Vorticella campanula*, *Epistylis daphniae* (Protista); *Keratella quadrata*, *Brachionus plicatilis* (Rotifera); *Artemia* spp. (Anostraca); *Daphniopsis tibetana* (Cladocera); *Cletocamptus dertersi* and *Cyclops vicinus* (Copepoda). Ten species were recorded in hypersaline waters; apart from those metioned above, they included *Cyclidium* spp., *Litonotus fasciola*, *Euplotes terricola*, *Strombilidium viride*, *Brachionus variabilis*, *Colurella adriatica, Keratella cochlearis*, *Colurella adriatica*, and *Cyclops* sp. Seven taxa of benthic macroinvertebrates are recorded, represented by *Cypris* sp. (Ostracoda), *Gammarus* sp. (Amphipoda), *Radix* sp. and *Hippeutis* sp. (Mollusca); chiroonomids *Tendipus group salinarius* (Diptera), Nematoda, Trochophora and *Ephrdra* sp. At present, there are fishes only in Bangong Co., and no fishes recorded in other salt lakes. The total number of plankton species has a significantly negative correlation with the salinity, and decreased with increasing altitude, but not significant.

Introduction

Inland saline lakes or athalassic saline waters are an important type of lake. Generally the lower limit of salinity for saline lakes is defined as 3 g l^{-1} (Williams, 1964, 1996; Hammer, 1986). Many saline lakes occur widely in arid and semi-arid areas of China, and more than half of the total lake area of China is contributed by saline lakes (Wang, 1977). Almost all of inland saline waters lie in western and northern China Tibet, Xinjiang, Qinghai and Inner Mongolia. Other adjacent provinces or regions also have saline waters, e.g. Shanxi, Jilin, Hebei, Ningxia, Shanxi and Gansu.

Saline lakes can 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 zealite. Considerable quantities of biological resources, such as halophilic organisms, e.g. *Spirulina*, *Dunaliella*, *Brachionus plicatilis*, *Moina mongolica* and *Artemia*, which have economic and scientific value, occur in saline lakes. Several limnological studies of Chinese saline lakes have been made, but most of them are related to physical and hydrochemical features (Yu, 1984), chemical exploitation (Chen, 1981; Zheng, et al., 1989; Zheng, 1995) as well as geographical or geological features. However, the biological resources of inland saline waters were little known. Studies on the fauna of saline waters through the world have been made by many authors (e.g. Remane & Schlieper, 1971; Bayly, 1972; Beadle, 1981; He et al., 1981, 1989; Williams, 1981, 1991b, 1990; Timms, 1983; Hammer, 1986; Colburn, 1988; Wood & Talling , 1988; Alonso, 1990), but the studies on the plankton of salt lakes in China are limited. Shen et al. (1979) and Jiang & Du (1979) recorded some species of Copepoda, Cladocera and other freshwater crustaceans that can occur in some saline water bodies. Wang (1977), Shen(1983), Jiang et al. (1983) and Gong (1983) have also mentioned some species of halosaline and freshwater halophilic species in a survey of invertebrate animals in the Tibetan Plateau. Unfortunately, data on salinity, alkalinity, pH and ionic composition are not provided. Aquatic organisms of Lake Qinghai (~14 g l^{-1} S, Wang, 1977; Academia Sinica, 1979) and Lake Dali (5.5 g l^{-1} S , He et al., 1981) have been reported. Williams (1991a) has discussed the fauna of Chinese saline lakes in his review on Chinese and Mongolian saline lakes, but many northern Chinese saline waters are not included, particularly, recent information on the zooplankton of Chinese saline waters (Hetl et al., 1984, 1989, 1987, 1993, 1994, 1996; Zhao & He, 1993, 1995, 1999; Zhao et al., 1993, 1996; Zhao, 1991, 1992a, 1992b; Ren et al., 1996; Ma, 1995). With the development of aquaculture, several species of plankton are used as aquaculture foodstuff such as *Artemia*, *B. plicatilis* and *M. mongolica*. provoking studies of their biological and ecological features (An & He, 1991; Ren et al., 1996).

The purposes of our paper are to elucidate species composition, population density, biomass of aquatic organisms in saline lakes in northern Tibet, China and the relationship between community structure, diversity index and environmental factors e.g. salinity, pH and temperatures.

Description of the study area

Almost all saline lakes in the present paper are located at high altitudes in high arid or cold regions in northern Tibet, China (Fig. 1). The average altitude above sea level is 4500–5000 m. The position, altitude, area, mean depth and salinity of 22 saline lakes with a salinity 1–390 g l^{-1} are given in Table 1.

High winds occur frequently, and rainfall is concentrated between July and August. Annual air temperatures range from −10 °C in January (minimum −40 °C) to −3–18 °C in July (maximum 24 °C), with a mean of −10 °C. Annual precipitation is low, general about 30–50 mm, but annual evaporations > 2000 mm. The distribution, origin and major physical features of these salt lakes have been detailed by Williams (1991a) and Zheng et al. (1989).

Material and methods

Investigations were carried out during May and July 2001. Water temperature, salinity and pH were measured. Water temperature was measured with a mercury thermometer. Determinations of water chemistry, including of pH, HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}, $Ca^{2+}$and Mg^{2+} followed routine methods (He et al., 1989). K^+ and Na^+ were measured with flame atomic absorption spectrophotometry (Huang et al., 1999). The major ions were measured on only one sample for each saline lakes. Salinity was measured by a salt meter (ATAGO S-10). Transparency were measured by Secchi plate.

One hundred and thirty two plankton samples were collected, including 66 quantitative samples. The number of samples per lakes was 2–5, and were collected at the shore, middle or representative site in most of lakes. Generally, only surface water samples could be obtained because the water-bodies were shallow. Phytoplankton was studied from water after precipitation and preserved in 1.5% of Lugol's solution. The macro-zooplanktons were obtained from water filtered using a plankton net (64 μm mesh size) and preserved in 5% of formaldehyde, the water volume sampled was 20 l. The micro-zooplanktons (e.g. Protista and Rotifera) was obtained from phytoplankton samples after further concentration. The biomass (mg l^{-1}) of phytoplankton and zooplankton were calcu-lated volumetrically. Diversity index (H′) was calculated according to Shanon-Weaner(He et al., 1989). Statistical analyses were performed based on Du (1985).

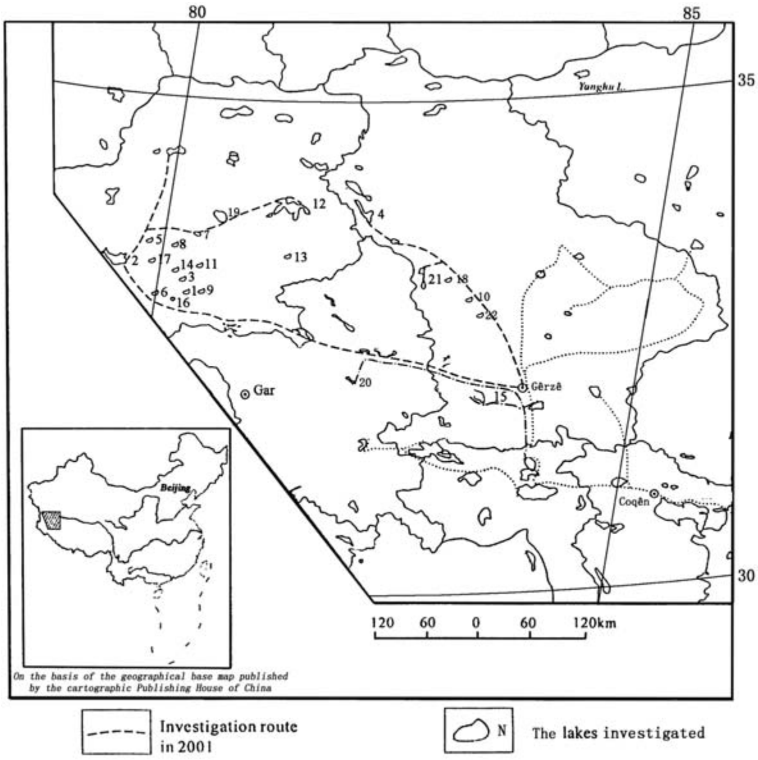

Figure 1. Distribution of saline lakes (1–22) investigated in northern Tibet in 2001. 1.Lubu Co; 2. Bangong Co; 3. Ayongbu Co; 4. Aru Co; 5. Angla Co; 6. Zuoyong Co; 7. Lula Co; 8. Tai Co; 9.Kunzhong Co; 10. Gaohong Co; 11.Changmu Co; 12. Lumajiangdong Co; 13. Bala Co; 14. Nitan Lake; 15. Lakor Co; 16. Rabang Co; 17. Kayi Co; 18.Tielukong Co; 19. Gêrzê Caka; 20. Nieer Co; 21. Kahu Co; 22. Chamu Co.

The species identification in this investigation is based on the literatures (e.g. Fott , 1971; Wang, 1977; Kost, 1978; Jiang and Du, 1979; Shen et al., 1979; Hu and Wei, 1981; Jiang et al., 1983; Ehrlich & Dor, 1985; Wu et al., 1989; Zhu & Chen, 2000).

Results

Chemical features

Salinity ranged from 1 g l^{-1} to 390 g l^{-1}. Field pH values ranged from 7.5 to 11.1, most of which exceed 9.0 (Table 1). The dominant cation was sodium, with magnesium generally sub-dominant; carbonate was the dominant anion in low salinity, chloride was the dominant anion with increasing salinity (Table 2).

Phytoplankton

The species composition and distribution of phytoplankton are listed in Table 3. Ninety five taxa of planktonic algae are recorded: 35 species of Bacillariophyta, 33 species of Chlorophyta, 17 species of Cyanophyta, 4 species of Euglenophyta, 3 species of Pyrrophyta, 2 species of Cryptophyta, and 1 species of Chrysophyta.

Based on their frequency of occurrence as well as the relative abundance (biomass and density), major phytoplankton species were *G. linearis*, *O. tenuis*, *C. minutus* (blue-green algae); *Navicula* spp., *C. pusilla*, *D. elongatum* (diatoms); *D. salina*, *C. vulgaris* and *U. tenerrima* (green algae). The occurrence rate was the percentage number of lakes with the species.

Thirty-eight taxa of algae are recorded in hypersaline waters (>40 g l^{-1}); in addition to those listed above, they include *Dactylococcopsis*

Table 1. Natural status of saline lakes in the Ali region, Tibet, China (2001)

No.	Lakes	Position		Date	Area (km^2)	Water depth (m)	Altitude (m)	Salinity ($g\ l^{-1}$)	pH	Alkalinity ($mmol\ l^{-1}$)	Water T (°C)	Water type	Transparency (m)
		W	N										
[1]	Lubu Co	80°16′	33°06′	23 June	8.4		4342	1	10.0	11.36		$NaMgCO_3Cl$	
[2]	Bangong Co	79°50′	33°30′	6 June	565.6		4241	1	8.70	5.92		$MgNaCO_3Cl$	
[3]	Ayongbu Co	80°29′	33°25′	17 June	5.0	2	4290	10	10.2	57.35		$MgNaCO_3Cl$	0.2
[4]	Aru Co	83°00′	33°15′	1 June	36	9.0–30.0	4950	12	9.5	63.11	6	$MgNaCO_3Cl$	1.7–3.0
[5]	Angla Co	79°58′	33°33′	19 June	1.5	0.8	4239	12	10	75.44	20	$MgNaCO_3SO_4$	1.001
[6]	Zuoyong Co	80°11′	33°05′	19 June	7.0		4300	12	10.6	92.62	16	$NaCO_3$	
[7]	Lula Co	82°40′	33°42′	28 May	26		4805	15	7.5	6.82	4	$NaMgClSO_4$	
[8]	Tai Co	80°43′	33°43′	14 June	8	1.2–2.3	4504	20	8.9	34.24	16	NaCl	0.35–1.5
[9]	Kunzhong Co	80°24′	33°06′	22 June	14	1.5	4338	20	11.1	24.45	18	Na Cl CO_3	0.6
[10]	Gaohong Co	83°01′	33°20′	29 May	0.36	2–5.5	4787	25	9.0	97.49	8	$NaClCO_3$	
[11]	Changmu Co	80°17′	33°30′	18 June	6	1.2–2	4300	31	10	46.95	15	NaCl	0.9–1.3
[12]	Lumajiangdong Co	81°35′	34°00′	11 June	322	3.5–21.9	4810	35	10.3	160.00	7	Na Cl CO_3	3.0–4.5
[13]	Bala Co	82°59′	33°25′	29 May	1.59	2.5–5.0	4760	36	9.6	90.77	2	$NaClCO_3$	
[14]	Nitan Lake	80°12′	33°31′	19 June	0.05		4280	36	10	31.16		$NaClSO_4$	
[15]	Lakor Co	84°05′	32°02′	27 May	92		4610	52.6	9.3	35.14		NaCl	
[16]	Rabang Co	80°34′	33°02′	22 June	32.65	0.6–5.5	4324	75	10	41.92	18	$NaSO_4Cl$	0.2–2.3
[17]	Kayi Co	80°05′	33°32′	19 June	3.00		4280	130	9.2	10.36		$NaClSO_4$	
[18]	Tielukong Co	82°59′	33°20′	2 June	1.5		4794	150		22.63		NaCl	
[19]	Gêrzê Caka	80°53′	33°58′	16 June	104	1.5–10.4	4554	160	9.7	111.40		NaCl	1.2–1.4
[20]	Nieer Co	82°12′	32°12′	28 June	24	0.15–0.5	4400	190	10.1	9.35	14	$NaSO_4Cl$	
[21]	Kahu Co	82°59′	33°23′	29 May	24.13	0.6–2	4763	300	8.7	109.75	10	NaCl	
[22]	Chamu Co	83°07′	33°15′	2 June	0.7		4798	390		19.59		NaCl	

Table 2. Major Hydrochemical features of saline lakes in northern Tibet, China

	Lakes	Major ions (mmol l^{-1})							
		Cl^{-1}	SO_4^{2-}	CO_3^{2-}	HCO^{3-}	Ca^{2+}	Mg^{2+}	K^+	Na^+
[1]	Lubu Co	6.49	4.56	6.66	8.03	2.02	10.04	0.95	12.61
[2]	Bangong Co	6.39	4.76	2.00	4.92	2.50	10.52	0.80	7.35
[3]	Ayongbu Co	55.39	31.40	1.60	56.56	0.96	135	10.23	59.57
[4]	Aru Co	60.05	30.84	8.23	58.98	0.26	142	10.46	59.74
[5]	Angla Co	53.39	47.86	0.40	75.24	4.24	152	0.20	74.78
[6]	Zuoyong Co	28.73	36.50	0.00	92.62	1.28	28.14	0.13	138
[7]	Lula Co	149	153	2.82	5.41	1.60	142	3.24	166
[8]	Tai Co	300	26.02	42.10	13.19	0.16	21.92	2.42	332
[9]	Kunzhong Co	257	94.50	24.00	12.45	0.24	5.26	3.32	325
[10]	Gaohong Co	255	81.72	90.64	52.17	0.14	46.60	11.76	358
[11]	Changmu Co	409	108	60.32	16.80	0.28	38.24	14.96	475
[12]	Lumajiangdong Co	298	194	215	52.64	0.10	52.90	23.09	514
[13]	Bala Co	381	177	131	25.13	0.04	6.46	19.55	498
[14]	Nitan Lake	415	341	22.66	19.83	3.02	605	20.20	333
[15]	Lakor Co	628	90.26	48.98	10.65	1.58	159	74.30	949
[16]	Rabang Co	457	1103	59.32	12.26	0.58	59.92	54.00	1071
[17]	Kayi Co	1271	1634	4.00	8.36	18.96	623	44.37	1770
[18]	Tielukong Co	2327	207	21.32	11.96	0.50	21.38	89.97	2361
[19]	Gêrzê Caka	2285	342	176	23.60	0.06	37.42	161	2525
[20]	Nieer Co	1454	3041	3.90	7.40	45.02	1534	200	2162
[21]	Kahu Co	4480	712	165	27.04	0.04	5.30	111	4965
[22]	Chamu Co	6133	1019	37.66	0.76	25.50	4013	102	4959

rhaphidioides, *Gloeocapsa punctata* , *Nodularia spumigena*, *Phormidium tenuis*, *Spirulina major*, *Rhabdoderma lineare*, *Merismopedia tenuissima* *Synedra* sp., *Synedra acus*, *Nitzschia* sp., *Navicula halophila*, *Pinnularia* sp., *Amphora ovalis,* S*urirellia spiralis*, *Nitzschia lorenziana*, *Epithemia zebra*, *Cocconeis* sp. *Chroomonas acuta*, *Euglena viridis*, *Strombomonas* sp., *Chlororcoccum* sp., *Kirchneriella contorta*. *Chlamydomonas* sp., *Spirogyra* sp., *Ctenocladus circinatus*, *Closterium venus*.

Species numbers, biomass, density and dominant species were listed in Table 4. As the table indicates, the numbers of species (or genera) tend to decrease with increasing salinity. Biomass ranged from 0 to 28 mg l^{-1}, and density from 0 to 1.03×10^8 cell l^{-1}. *Dunaliella salina*, *Navicula* spp and *G. linearis* were dominant, especially, *D. salina*. The diversity index of phytoplankton was 0–3.64.

Zooplankton

The zooplankton species composition and distribution are given in Table 5. Forty two taxa were recorded, including 16 species of Protista, 12 species of Rotifera, 1 species of Anostraca, 5 species of Cladoceran, and 8 species of Copepoda. Based on the frequency of occurrence, biomass and density, the major species were *Vorticella campanula*, *Epistylis daphniae* (Protista); *Keratella quadrata*, *Brachionus plicatilis* (Rotifera); *Artemia* spp. (Anostraca); *Daphniopsis tibetana* (Cladocera); *Cletocamptus dertersi* and *Cyclops vicinus* (Copepoda). Ten species were found in hypersaline waters; apart from those metioned above, they included *Cyclidium* spp., *Litonotus fasciola*, *Euplotes terricola*, *Strombilidium viride*, *Brachionus variabilis*, *Keratella cochlearis*, *Colurella adriatica*, and *Cyclops* sp.

Table 3. Species composition, distribution, occurrence and highest tolerance salinity of phytoplankton in northern Tibet salt lakes

Taxon	Salt lake in which phytoplankton occurr	Occurrence (%)	Highest salinity g l^{-1}
Cyanophyta			
Aphanothece sp.	[5]	4.6	12
Calothrix sp.	[1]	4.6	1
C. minutus (Kutz)Nag.	[5] [6]	9.1	12
C. minor (Kutz)Nag.	[1] [2] [3] [4] [5] [8] [9] [10] [13] [15] [16] [18] [20]	59.1	200
D. rhaphidioides Hansg	[1] [3] [6] [8] [9] [10] [13] [16] [17] [19] [20] [21]	54.6	310
G. linearis Nag	[1] [2] [3] [4] [5] [6] [7] [8] [9] [11] [13] [14] [15] [16] [17] [18] [19] [20] [21]	86.4	310
G. punctata Nag	[1] [4] [6] [8] [19] [20]	27.3	200
Lyngbya sp.	[13]	4.6	36
M. tenuissima Lemn	[1] [3] [6] [9] [14]	22.7	79
N. spumigena Mert	[4] [7] [21]	13.6	310
O. tenuis Ag.	[4] [8] [10] [11] [12] [13] [14] [15] [16] [20] [21]	50	310
O. amphibia Ag.	[14] [16]	9.1	79
P. tenus (Menegh) Gom.	[1] [10] [14] [16] [21]	22.7	310
R. curvata Fritsh.	[5]	4.6	12
R. lineare Schm.	[4] [7] [8] [11] [13] [16] [18] [20]	36.4	200
S. major Kutz	[3] [9] [12] [15]	18.2	35
S. sp.	[6]	4.6	12
Pyrrophyta			
C. hirundinella	[2]	4.6	
Glenodinium sp.	[4] [5] [9]	13.6	20
Peridinium sp.	[6]	4.6	12
Chrysophyta			
C. parscheri Haf.	[7]	4.6	22
Bacillariophyta			
Amphora ovalis	[7] [20]	9.1	200
Amphora ovalis	[1][5] [6]	13.6	12
Caloneis schumanniana	[3]	4.6	10
Campylodiscus noricus	[1]	4.6	1
Cocconeis sp.	[2] [4] [6] [17]	18.2	79
Cyclotella stelligera	[4] [5] [6]	13.6	12
Cyclotella sp.	[7] [12] [15]	13.6	35
C. gracilis (Rabenh.)Cl.	[10]	4.6	25
C. pusilla Grun.	[3] [6] [8] [9] [13] [14] [16] [17][20]	40.9	200
C. lanceolata	[5] [9]	9.1	20
C. tumida	[1] [9]	9.1	20
Cymatopleura solea (Breb.) W. Smith	[2] [5]	9.1	12
D. elongatum Ag.	[3] [8] [9] [10] [14] [16] [1] [18] [20]	40.9	200
Eunotia sudetica (mull.) Hust.	[4] [14]	9.1	79
Epithemia zebra	[1] [6] [9] [14]	18.3	79
Fragilaria sp.	[1] [7] [10]	13.6	25
Gomphonema spp.	[3] [4] [5] [6]	18.2	12
Gyrosigma acuminatum (Kutz.) Rabenh.	[5]	4.6	12

Table 3. (Continued)

Taxon	Salt lake in which phytoplankton occurr	Occurrence (%)	Highest salinity g l^{-1}
Melosira sp.	[7]	4.6	22
Nitzschia sp.	[6] [13] [17] [20]	18.2	200
Nitzschia spp.	[7] [15]	9.1	22
N. lorenziana Grun.	[5] [7] [14] [21]	18.2	310
Navicula spp.	[1] [2] [4] [5] [6] [7] [9] [10] [13] [14] [15] [16] [17] [20] [21]	63.6	310
N. halophila (Grun.) Cl.	[6] [7] [10] [13] [20]	22.7	200
N. rhynchocephala Kutz	[10]	4.6	25
N. cryptocephala	[2]	4.6	1
Pinnularia sp.	[1] [5] [7] [10] [13] [15] [21]	31.8	310
Schroederia setigera Lemm.	[5]	4.6	12
Staturoneis anceps (Eur.)	[1] [10]	9.1	25
Surirella ovata Kutz	[4] [7] [10] [21]	18.2	310
S. ovalis var.salina	[4]	4.6	16
S. ovalis var.brightwellii	[4]	4.6	16
S. spiralis Kutz	[21]	4.6	310
Synedra sp.	[1] [5] [6] [7] [14] [20]	27.3	200
S. acus Kutz	[3] [6] [14]	13.6	79
Cryptophyta			
Chroomonas acuta Uterm.	[4] [6] [7] [9] [12] [14]	31.8	75
Cryptomulina parscheri Haf.	[7]	4.6	22
Euglenophyta			
Euglena viridis Ehr	[1][9][10][13][16]	22.7	75
E. intermidia	[9]	4.6	20
Strombomonas sp.	[20]	4.6	200
Trachelomonas volvocina Ehr	[7] [14] [20]	13.6	200
Chlorophyta			
Ankistrodesmusconvolutus Cord.	[1]	4.6	1
Attheya sp.	[14] [16]	9.1	36
Chlamydomonas sp.	[4] [6] [7] [13] [20]	22.7	200
Chodatella	[9]	4.6	20
C. wratislaviensis(Schr.) Ley	[9]	4.6	20
C. vulgaris Beij	[4] [7] [8] [9] [11] [12] [13] [14] [16] [18] [20] [21]	54.6	310
C. ellipsoidea Gren	[2]	4.6	1
C. circinatus Borzi	[14] [21]	9.1	310
Cosmarium meneghinii Breb.	[1] [2]	9.1	1
Crucigenia apiculata (Lemm.) Schm	[9]	4.6	20
C. venus Kutz.	[1] [2] [7] [20]	18.2	200
Chlororcoccum sp.	[2] [4] [5][9] [14] [16] [20]	31.8	200
Dictyosphaerium sp.	[9]	4.6	20
D. salina Teodor	[7] [10] [11] [13] [16] [17] [18] [20] [21]	40.9	310
Fmannceia ovalis (France.) Lemm	[9]	4.6	20
K. contorta (Schm.) Bohl	[5] [8] [13] [16] [20]	22.7	200
K. obesa (Schm.) Bohl	[9]	4.6	20

Table 3. (Continued)

Taxon	Salt lake in which phytoplankton occurr	Occurrence (%)	Highest salinity g l^{-1}
K. lunaris (Kirch.) Bohl	[2] [9]	9.1	20
Oocystis sp.	[3] [5] [6] 9]	18.2	20
Platymonas cordiformis (Carter) Dill	[5] [7]	9.1	12
Pandorina movum (Muell.) Bory	[6]	4.6	12
Pediastrum duplex Mey.	[9]	4.6	20
P. boryanum (Turp.) Men	[1] [9]	9.1	20
Quadrigula chodatii (Tan-Ful.) G.M. Smith	[2]	4.6	1
Scenedesmus bijuga (Turp.) Lag	[5]	4.6	12
S. quadricauda (Turp.) Bre'b	[1] [9]	9.1	20
S. acuminatus (Lag.) Chod	[1]	4.6	1
Selenastrum bibraianum Reinsch	[1] [2] [6]	13.6	12
Spirogyra longata (Vauch.) Kutz	[1] [4] [5] [9] [14] [16]	27.3	79
Spirogyra sp.	[1]	4.6	1
Tetraedron tumidulum (Rensch)	[1] [5] [10]	13.6	20
U. tenerrima (Kutz.) Kutz.	[2] [4] [7] [13] [16] [17] [20] [21]	31.8	310

* The occurrence was referred to the percentage number of lakes with the species.

The number of species and the biomass, density and dominant species of zooplankton are listed in Table 4. The number of species ranged from 0 to 18, and tend to decreased with increasing salinity. Biomass ranged from 0 to 22.7 mg l^{-1}; and total density from 0 to 64, 943 ind l^{-1}. The diversity index of zooplankton was 0–3.17. Total biomass and density was not correlated with salinity.

The effects of ecological factors, e.g. salinity, altitude on plankton

Figure 2 indicated the relationship between the total species number and salinity. The total number of species has a significant negative correlation with the salinity ($r_{22} = -0.6887$, $p < 0.001$). The diversity of phytoplankton and zooplankton has no correlation with the salinity. The total number of species of plankton decreased with altitude increasing, but not significantly ($r_{22} = -0.3600$).

Benthic macroinvertebrates

Seven taxa of benthic macroinvertebrates are listed in Table 5. They are represented by *Cypris* sp. (Ostracoda), *Gammarus* sp. (Amphipoda), *Radix* sp. and *Hippeutis* sp. (Mollusca); chiroonomids *Tendipus group salinarius* (Diptera), Nematoda, Trochophora and *Ephrdra* sp.

Fishes

At present, there are fishes only in Bangong Co. The fishes which natural distribution were *Racoma labiata* McClelland, *Diptychus maculates* Steindachner and *Schizopygopsis stolicikae* Steindachner. No fishis were recorded in other salt lakes.

Discussion

The saline lakes investigated cover a wide range of salinity. Unlike most other north-western Chinese saline lakes (Yu & Tang, 1981; Williams 1991a; Ren et al., 1996; Zhao & He, 1999), the patterns of major ionic dominance in nothern Tibetan salt lakes are almost always $Na^{+} > Mg^{2+} > K^{+} > Ca^{2+}$ and $HCO_3^{-} + CO_3^{2-} > CI > SO_4^{2-}$. A general chemical feature of salt lakes in northern Tibet is that the dominant cation was sodium, with magnesium generally sub-dominant. Carbonate is the dominant anion in low salinity; chloride was the dominant anion with increasing salinity.

The number of algae in Tibetan salt lakes decreased at the highest salinities. Amongst the 95

Table 4. Species numbers, density, biomass, diversity index and dominant species in northern Tibet salt lakes

Lakes	Phytoplankton					Zooplankton				
	Species number	Biomass (mg l^{-1})	Density (10^6 l^{-1})	H′	Dominant species	Species number	Biomass (mg l^{-1})	Density (ind l^{-1})	H′	Dominant species
Lubu Co	23	0.79	18.46	1.74	*S. acuminatus*, *S. quadricauda*	16	3.69	345	2.93	*K. quadrata*, *Polyarthra trigla*
Bangong Co	14	0.08	0.19	1.76	*Chlororcoccum* sp., *S. bibraianum*	5	1.01	994	1.27	*K. cochlearis* trochophora
Ayongbu Co	10	7.55	16.97	1.46	*S. major*	7		1375	0.44	*Epistylis daphniae* *Alona rectangula*
Aru Co	21	0.10	0.61	2.87	*Chlamydomonas* sp., *Chlororcoccum* sp.	4	2.07	7	0.99	*D. pamirensis*, *A. stewartianus*
Angla Co	23	1.37	3.09	2.12	*Navicula* spp., *Chlororcoccum* sp.	12	5.00	64943	0.35	*V. campanula*
Zuoyong Co	24	3.02	3.07	2.62	*Synedra* sp., *Chroomonas acuta*	–	–	–	–	–
Lula Co	25	0.12	0.37	2.80	*Nitzschia* spp., *D. salina*	4	2.28	17292	1.00	*Cyclidium* sp., *Lagynophrya* sp.
Tai Co	9	0.05	1.84	2.01	*R. lineare*, *G. linearis*	18	2.04	434	3.17	*D. tibetana*, *C. dertersi*
Kunzhong Co	28	18.75	102.7	2.92	*Dictyosphaerium* sp, *C. lanceolata*	7	0.39	1103	0.53	*K. quadrata*, *Cyclops vicinus*
Gaohong Co	16	0.19	9.55	0.00	*Euglena viridis*, *G. linearis*	6	16.91	0	1.91	*D. tibetana*, *C. dertersi*
Changmu Co	5	0.52	19.32	1.36	*D. salina*, *G. linearis*	9	0.20	48	2.28	*C. dertersi*, *B. plicatilis*
Lumajiangdong Co	6	0.00	0.06	0.07	*C. vulgaris*	6	3.77	5	1.72	*D. tibetana*
Bala Co	20	1.31	1.13	3.64	*D. salina*, *Chlororcoccum* sp.	3	22.68	12	1.37	*Artemia* spp.
Nitan Lake	16	0.05	0.45	0.82	*Navicula* spp., *G. linearis*	2	1.10	6		*C. adriatica*, *Artemia* sp.
Lakor Co	9	–	–	–	*S. major*, *D. salina*	3	–	–	–	*Artemia* spp.
Rabang Co	20	1.05	29.56	1.08	*Navicula* spp., *G. linearis*	5	2.13	31	1.93	*Artemia* spp.
Kayi Co	18	28.00	12.30	2.72	D. salina, *Amphora ovalis*	2	0.59	11	0.96	*Artemia* spp.
Tielukong Co	6	0.01	0.13	2.13	*D. elongatum*, *D. salina*	0	0.23	0		

Table 4. (Continued)

Lakes	Phytoplankton					Zooplankton				
	Species number	Biomass (mg l^{-1})	Density (10^6 l^{-1})	H′	Dominant species	Species number	Biomass (mg l^{-1})	Density (ind l^{-1})	H′	Dominant species
Gêrzê Caka	3	0.00	0.17	1.06	*D. rhaphidioides*	2	2.13	11	0.96	*Artemia* spp.
Nieer Co	22	0.32	0.85	2.93	*K. contorta*, *D. elongatum*	6	0.09	18	1.97	*Artemia* spp.
Kahu Co	13	0.08	0.47	1.74	*D. salina*, *Navicula* spp.	6	2.04	7	0.99	*B. plicatilis*
Chamu Co	0	0.00	0.00	0	–	0	0.00	0	0.00	–

Table 5. Species composition, distribution, occurrence and highest tolerance salinity of zooplankton and benthic macroinvertebrates in northern Tibet salt lakes

Taxon	Locality	Occurrence* %	Highest salinity g l^{-1}
Protista			
Acineta sp.	[8]	4.6	23
Arcella vulgaris Ehrenberg	[1] [5]	9.1	12
Cothurnia annulata	[12]	4.6	35
Cyclidium sp.	[5] [16]	9.1	75
C. citrullus Cohn	[7]	4.6	22
Difflugia oblonga Ehrenberg	[5]	4.6	12
Epistylis daphniae	[1] [3] [5] [8] [16]	22.7	75
E. terricola Penard	[20]	4.6	200
Litonotus fasciola Ehrenberg	[16] [20]	9.1	200
Lagynophrya sp.	[7]	4.6	22
Paramecium caudatum Her	[1]	4.6	1
Rhabdostylasp sp.	[10]	4.6	25
Trichodina sp.	[7] [10]	9.1	25
Vorticella campanula Ehrenberg	[1] [2] [10] [13] [15]	22.7	35
V. kahli	[8] [9] [11]	13.6	32
Rotifer			
Brachionus quadridentatus	[1] [3]	9.1	10
B. variabilis Hempel	[20]	4.6	200
B. plicatilis O.F.Muller	[8] [11] [21]	13.6	310
B. urceus Linnaeus	[1]	4.6	1
C. adriatica Ehrenberg	[1] [9] [14]	13.6	79
Conchiloides unicornis Rous	[11]	4.6	32
K. cochlearis Gosse	[2] [5]	9.1	12
K. quadrata Muller	[1] [3] [8] [9] [11] [20]	27.3	200
Lepadella patella (Muller)	[1] [5]	13.6	12
Lecane nana	[12]	4.6	35
Notholca squamula (O. P. Muller)	[1]	4.6	1
Polyarthra trigla Ehrenberg	[1]	4.6	1
Philodina sp.	[8]	4.6	23
Branchiopoda			
Artemia spp.	[3] [13] [16] [17] [19] [20] [21]	31.8	310
Nauplius of *Artemia*	[13] [14] [16] [17] [19] [20]	27.3	200
Alona rectangula Sars	[3] [5]	9.1	12
Chydorus sphaericus O.F. Muller	[1]		
Daphniopsis tibetana Sars	[8] [10] [11] [12]	18.2	35
Daphnia carinata King	[1]	4.6	1
D. pamirensis Lylov	[4]	4.6	16
Copepoda			
Arctodiaptomus sp.	[11]	4.6	32
A. stewartianus (Daday)	[4]	4.6	16
A. salinus (Daday)	[8]	4.6	23
C. strenuus Fischer	[7]	4.6	12
C. vicinus Uijanin	[2] [8] [9]	13.6	20

Table 5. (Continued)

Taxon	Locality	Occurrence* %	Highest salinity g l^{-1}
Cletocamptus dertersi (Richard)	[3] [8] [9] [10] [11]	22.7	32
Cyclops sp.	[21]	4.6	310
Eucyclops serrulatus (Fischer)	[1]	4.6	1
Copepodid	[3] [8]	9.1	23
Nauplius	[1] [3][4] [5] [8] [9][11] [12]	36.4	35
Benthic macroinvertebrates			
T.g. salinarius	[1]	4.6	1
Gammarus sp.	[8]	4.6	23
Ostracoda	[1] [3] [5] [7] [8] [9] [10] [11] [21]	40.9	310
Cypris sp.	[10]	4.6	25
Nemotoda	[4] [7] [13]	13.6	36
Trochophora	[2]	4.6	1
Ephrdra sp.	[21]	4.6	310
Radix auricularia	[8]	4.6	23
Hippeutis sp.	[5] [17]	9.1	1

* The occurrence was referred to the percentage number of lakes with the species.

species of phytoplanktonic algae recorded, *Dunaliella salina*, *Oscillatoria tenuis*, *Ctenocladus circinatus*, *Spirulina major*, *Diatoma elongatum* and some others are typical hyposaline or halobiont species, most of other algae were salt-tolerant freshwater species, euryhaline species or halophile species with a broad adaptation to salinity. These results accord with those of other regions (Fott, 1971; Geddes et al., 1981; He et al., 1981, 1989, 1993, 1994; Hammer et al., 1983; Ehrlich & Dor, 1985; Hammer, 1986; Colbur, 1988; Wood & Tailing, 1988; Jakher et al., 1990; Servant-Vildary & Roux, 1990; Zhao, 1992; Zhao et al., 1993; Ma, 1995; Ren et al., 1996; Zhao & He, 1999). Blue-green algae, green algae and diatoms are common in Tibetan salt

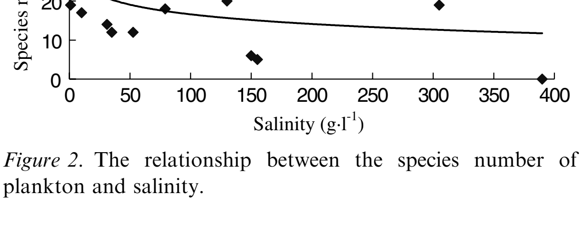

Figure 2. The relationship between the species number of plankton and salinity.

lakes, especially blue-green algae, which thrive at higher alkalinity and pH, with some able to grow in 300 g l^{-1} (Ehrlich & Dor, 1985; Zhao, 1992). Some algae, e.g. *Gloeothece linearis*, *Oscillatoria tenuis*, *Dunaliella salina*, *Chlorella vulgaris*, *Navicula* and *Diatoma elongatum* are the most important or dominant algae in hypersaline waters. Hammer et al. (1983) reported 91 genera and 212 species of algae from 41 Canadian saline lakes where salinity ranges from 3.2 to 428.0 g l^{-1}, of which, 13 species of algae occur in the lakes with a salinity more than 50.0 g l^{-1}; Zhao (1992) reported 100 genera and 132 species algae in 28 northern Chinese inland saline waters with salinity ranging from 0.57 to 214.0 g l^{-1}, which 55 species occur at salinity > 50.0 g l^{-1}; Ma (1995) reported 23 algal species in some northern Chinese salt pans and lakes with a salinity ranging from 61.0 to 320.0 g l^{-1}. Ren et al. (1996) reported 92 species (or genera) of algae occurring in 23 inland saline lakes of north-western China where the salinity ranges from 12.4 to 394.5 g l^{-1}. Zhao & He (1999) reported 91 algal species in China saline water and lakes in Zhangjiakou, northern Hebei Province, where salinity ranges from 0.98 to 175.2 g l^{-1}. In the present paper, 38 species are recorded at a salinity > 50.0 g l^{-1}. So far as the species number, biomass and density are concerned, they show no correlation with pH ($p > 0.5$).

D. tibetana is a halobiont species of Cladocera, which lives in plateau lakes at altitude of more than 4000 m and occurs widely in hyposaline lakes in northern Tibet, Qinghai and Xinjiang, China. The temperatures range from −2 to 20°C, salinity varies from 9 to 35, pH ranges from 9.0 to 10.4 (Zhao et al., 2002). In this investigation, *D. tibetana* is recorded at four localities, i.e. Lake Gaohong, Lake Tai Co, Lumajiangdong Co and Changmu Co, and the densities are 1.7, 77, 1 and 9 ind. l^{-1}, respectively.

In northern Tibet *Ctenocladus circinatus*, is a widespread if not cosmopolitan filamentous green algae; It can occur in salinities at least as high as 200 g l^{-1} (Gangtang Lake). In this investigation, *C. circinatus* occurs in Rabang Co (salinity 73–75) and Kahu Co (salinity 300–310), Some green algal taxa are endemic to salt lakes in this region. Hu & Wei (1981) mentioned, in particular, *Didymonema tibeticum*, *Cladophora globulina* and *Ulothrix implexa* are two other green algal genera found in northern Tibetan saline waters, though they are less important than *C. circinatus*. A form of *D. salina* particularly tolerant to cold has been reported from Zabuye Lake (Zheng et al., 1989). The Cyanophyta of Tibetan salt lakes, according to Li (1981), largely conmprise taxa able to live in both fresh and saline waters.

Of the 42 species in the zooplankton recorded, *Brachionus plicatilis*, *Brachionus variabilis*, *Colurella adriatica*, *Keratella quadrata*, *Artemia* spp. and *Daphniopsis tibetana* can be regarded as halobionta species according to Goulden (1968), Gong (1983), Williams (1983), Beadle (1981), Hammer (1986), He et al., (1989), Alonso (1990), Zhao (1991), Zhao & He (1993) , Zhao et al. (1996) and Ren et al. (1996). With regard to the protistians, information on them in inland saline waters worldwide is rare (Shen, 1983, Hammer, 1986, Stephens, 1990, Zhao & He, 1995). Our previous work (Zhao & He, 1995) and present work show that protistians, and especially the ciliates, play an important role in inland saline waters, and that the density and biomass of ciliates are usually higher in hypersaline waters, where they may dominate particular communities in some localities. Nevertheless, as noted by Wang (1977), Shen et al. (1983) and Zhao & He (1995), most protistians species in inland saline waters are of freshwater origin indicating that protist have a high salinity tolerance, i.e. *Euplotes terricola and Litonotus fasciola* can occur in localities with a salinity of 200 g l^{-1}.

Many species of plankton such as *Ctenocladus circinatus*, *Daphniopsis tibetana* and *Daphnia pamirensis* are endemic species in northern Tibetan salt lakes. Many authors thought *Daphnipopsis* and *Daphnia* are of freshwater origin, not marine. In fact most organisms in inland salt lakes are derived from freshwater ancestors (Hammer, 1986; Williams, 1981; Williams et al., 1990). On the other hand, the major composition of the zooplankton is similar to salt lakes elsewhere in the northern hemisphere (Beadle, 1981; He et al., 1989), and their zooplankton is freshwater salt-tolerant species or halophilic species of generally wide distribution in freshwaters.

The high and often variable salinity of salt lakes is reflected by a decreased biodiversity; the higher the salinity, the fewer the species of plankton, with both the diversity index and total species number declining. Certainly, our own results confirm this. High alkalinities also cause the diversity and species number to decrease (Beadle, 1981; Zhao & He, 1999). Williams et al. (1990), in a study of the macroinvertebrate fauna of 79 Australian salt lakes, suggested that although salinity *per se* is relatively unimportant in determining what species occurs in a particular lake, species richness and composition nevertheless strongly correlate with salinity over the total range of salinity. This relationship, however, become insignificant over intermediate range of salinity. Other authors (e.g. Colburn, 1988; Hammer, et al. 1990; Wood & Talling, 1988; He et al., 1989; Zhao, 1991) have also noted this. The implication is that the factors other than salinity may determine the distribution of aquatic organisms in salt lakes. In the present paper, most of the waterbodies investigated have high alkalinity and pH. Again, this suggests that salinity itself is not the only important factor determining the species composition of the plankton. The ionic composition, alkalinity, pH and some biological factors are also influential.

Some species of genus *Arctodiaptomus*, e.g. *A. salinus*, *A. rectispinosus* and *A. stewartianus* had been known as geographically widespread forms of inland saline waters in the northern hemisphere.

Which appears to be one of the common features of faunas of inland saline waters in Tibet, China.

Artemia is the best-known and economically most useful species found in salt lakes. *Artemia* occurs widely in inland saline lakes and coastal salt pans (Jiang, 1983, Guo, 1988, Cai, 1988). *Artemia* occuring in salt lakes of northern China seems not belong to a single species of *Artemia* (*i.e. A. salina*). Cai (1989) names *Artemia* occuring in Lake Yanchi (Xiechi), Shanxi Province, as a new species, *A. sinica*, which may be a synonym of *A. urmiana*. Almost certainly the *Artemia* distributed in northern Tibet is not *A. salina*, which has been shown to have a rather limited distribution in North Africa, Europe, and Middle East and may be extinct (Belk & Brtek, 1997). Abatzopoulos et al. (1998) names *Artemia* collected from a lake on the high plateau of Tibet, China, almost 4.5 km above sea level, as a new species, *A. tibetiana*, but they not provides the place that the pattern sample was preserved. *Artemia* can occur in highly saline waters, distributed mainly in water bodies with a salinity ranging from 60 to 200 g l^{-1}. The upper value of salinity tolerance is 340 g l^{-1}. In the localities with a salinity less than 60 g l^{-1}, there are no or few species, which is not because of the limits of non-biotic surroundings, and it can not compete with other zooplankton such as *Moina mongolica*, *B. plicatilis*, *Apocyclops royi*, whose reproduction and growth are more quickly than it.

Moina rectirostris, *M. brachiata*, *M. macrocopa* and *Daphniopsis tibetana* are true halophiles, and they occur normally in moderate saline waters. *D. tibetana* usually occurs in the former Soviet Union and India. In China, the species is endemic to the Tibetan region as cited by Jiang (1983); however, it is also found in Lake Sayram, Xinjiang.

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