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Study on ecological structures of coastal lakes in Antarctic continent

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Abstract Coastal region on the Antarctic continent, where it is under the influences both of ocean and ice sheet, as well as frequent human activities, could be considered as a fragile zone in Antarctic ecological environment. There are many lakes in coastal region, showing much differences from each other in physical-chemical features because of individual evolutionary history in their geographical environments, and suffering from different outside factors, such as climate changes and precipitation. Thus, it results in respective biological distribution and ecological structure in lakes. The present paper reports the results from the studies of chemical components, species distributions and community structures, which mainly consisted of planktons in lakes in the Vestfold Hills (68°38′S, 78°06′E), and the Larsemann Hills (69°30′S, 76°20′E), East Antarctica. It also treats the biological diversities and nutrient relationships of these different types of lakes. So as to provide more scientific basis for monitoring of climate changes and environmental protection in Antarctica.

Key words ecological structure, lakes, Antarctic continent.

1 Introduction

There are lot of lakes in the coastal zone on the Antarctic continent. Processes of evolution and formation of these lakes were much related to the global climate change, ice sheet retreat and subsequent flooding of areas by sea-water and isostatic uplift raising (Burton 1981; Zhang 1985; Peterson *et al*. 1988). Distinct experiences of the lakes in regional natural evolution in geological ages resulted in considerable differences from each other in both of geographical environmental features and physical-chemical characteristics. They can be generally differentiated into saltwater lakes and freshwater lakes. In the Vestfold Hills (68°38′S, 78°06′E), for example, there are more than 700 lakes and catchments there. After several times of ice sheet retreat, isostatic uplift and sea level movement (8000 - 6000 a B. P., Adamson and Pickard 1986; Zwartz *et al*. 1997), some ends and arms of paleooceanic bays became lakes. Some lakes near the ice sheet edge were more diluted by snow and ice melted water and became freshwater lakes, while the others, which are close to beach, are still brackish water (Zhang 1985; Wang and Deprez 1998). The Larsemann Hills (69°30′S, 76°20′E), a small part of the Cristensen Coast of the Princess Elizabeth Land, appeared as land, followed after ice sheet retreat and isostatic uplift as earlier as 10000 – 12000 a B. P.. More than 150 lakes and catchments in there mostly are freshwater by feeding of snow and ice melting, except for a few of them, which are near the beach (Gillieson *et al*. 1990; Burgess *et al*. 1997).

Coastal zones are being influenced by both of marine and land, particularly by human activities, it can be regarded as a more fragile link of regional ecological chain called as ECOTONE (Niu 1990). The Antarctic coastal zones are directly affected by both of marine and ice sheet, which could be moving because of global climate change and the Greenhouse Effect. Furthermore. these areas are housed as the expedition bases by many countries. Environmental pollution, such as the exploiting activities of man and harmful material transported from the world even by water current or atmospheric circulation, have influenced greatly over coastal areas (Dunbar 1977; Zhao *et al*. 1998). Therefore, Antarctic coastal zones could be regarded as ECOTONE of Antarctic environment and ecosystems. The lakes in Antarctic coastal zones are under certain stress of environmental dynamics because of water freezing and melting, leaking and evaporation in the lakes, and unbalanced precipitation in Antarctic regions as well. Meanwhile, because of a lot of garbage, contamination and excretory material, brought from surroundings into lakes by melted water and wind blow, the lake water changes both qualitatively and quantitatively. Thus, it can be said that water system of Antarctic lakes should be regarded as most fragile link of the Antarctic ECOTONE. Variant physical-chemical characteristics of lake waters as well as unstable environmental situation must affect habitants strongly in species compositions and community structures in lakes, even in same region. Any slight changes in biological species distribution or ecological structures could be reflection related to changes both in water quality and environment of the lakes, even local climate change. Thus, systematic study on ecological structures in Antarctic coastal lakes, should be very significant to clarifying global climate change and making stratagem measures for protection of Antarctic environment and ecosystems.

So far, numbers of studies on ecology of Antarctic lakes have been done. The earlier materials were mostly taken from the areas of Antarctic Peninsula or some sub-Antarctic islands (Heywood 1977; Parker *et al*. 1977). Studies on Antarctic continent lakes were mostly carried out in 1980's (Bayly 1978, 1986; Hand and Burton 1981; Burton 1981; Parker *et al*. 1982; Franzmann *et al*. 1987, 1988; Burck and Burton 1988a, b; Heath 1988; Volkmann *et al*. 1988), and many documents on biological species or biochemical studies in single-lake were published. But it seems to be lack of systematic study on those lakes. However, Wright and Burton (1981) discussed on ecology of lakes in Victoria Land. Wang and Eslake (1997) reported community succession in some marine derived saline lakes in Vestfold Hills. Microbial planktons of lakes in the Vestfold Hills and Victoria Land were reported in recent ten years (Laybourn-Parry and Marchant 1992; Laybourn-Parry *et al*. 1995, 1997; Lizotte *et al*. 1998). The present paper provides the results of studies on ecological structures of fresh and salty lakes in the Vestfold and Larsemann Hills.

2 Materials and methods

During the years 1983 – 1990, field investigations were carried out several times including winters in 1984 (Wang and Deprez) and 1986 (by Eslake), 1987 (Yang) in the Vestfold Hills (VH), winter in 1989 (Wang) and 1997/1998 summer team in Larsemann Hills (LH). Biological and chemical samples were taken from 5 lakes in the LH and from 9 lakes and nearly bays in the VH. The methods and equipment for biological sampling and analysis were used as done by Bayly (1986) and Wang (1991, 1992). However, some microbial samples were obtained from water sampler. Physical-chemical sampling and analysis methods were used as done by Deprez and Frazmann (1985) and Wang (1995). Chemical samples collected in December 1989 to January 1990, from lakes in the LH were measured at laboratory in Davis Station in 72 h after collecting. Data for biological diversity of different type of water environment were based on species statistics numbers from each lake. The formula after Margalef (1951) was used for biological diversity calculation: $d = \frac{S-1}{\log N}$

3 Results and discussion

3.1 *Biological species composition*

There are considerable differences in biological species composition and ecological structure between fresh and saline lakes because of their much differences of chemical components and nutrients concentration in waters. Ecological structure in Antarctic lakes is generally simple with confined species structures of microorganisms up to crustacean zoo-plankton. Heywood (1977) reported that 4 fish species have been found in Antarctic Peninsula saline lake, such as in Ablation Lake, but there was no record in any continental saline lake.

The distributions of biological species in freshwater lakes in the VH and LH are shown in Table 1. So far, the study on microorganisms in Antarctic lakes, is still limited. The phytoplankton is dominated by Pyrrophyta flagellates *Chlamydomonas* and *Ochromonas* in lakes from both of the Hills. Some more species have been documented, such as dino-flagellate *Peridinium* and two Chlorococcales species of *Chlorella* and *Gloeotilla* and a diatom species *Fragilaria* (Laybourn-Parry *et al*. 1991) in Croocked lake, one of the largest freshwater lakes on the surface of Antarctic continent, located in the southeast of the VH and just nearby ice sheet. Also a few heterotrophic flagellate species, such as *Paraphysomonas vestita* (Laybourn-Parry *et al*. 1991) and some other protozooplankton, Amoebina and Heliozoea *Actinosphaerium*, *Clathrulina* (*C. elegans var. Planktonicum*, Laybourn-Parry *et al*. 1991), and several ciliated species of *Strombidium viride*, *Halteria grandinella*, *Tintinnidium fluviatile* as well have been found in this lake. At least 5 species of algae, which belong to Bacillariophyta, Chlorophyta and Cryptophyte respectively, were recorded in Watts Lake. A cladoceran crustacean *Daphniopsis studeri* as highest animal was found in most of those freshwater lakes both in the VH and LH, but a copepod crustacean *Acanthocylops mirni* was found at least in Watts Lake. In comparison with freshwater, much more biological species exist in brackish lakes. Table 2 shows that microbial planktons, including at least 11 species of cyanobacteria within 5 families and 9 genera, were dominated by *Chlorobium vibrioforme*, which was distributed mostly in waters containing sulphide or in most of

Table 1. Distribution of plankton in some freshwater lakes in the East Antarctica

	Mochou	Heart	Big	High	Progr	Watts	Croocked*
Cyanobacteria	?	?					+
Bacillariophyta							
Oedogonium sp.	c	+				+	
Vaucheria sp.			+			c	
Mougeotia sp.						+	+
Fragilaria spp.	+	+	+				+
Navicula glaciei	c	c					
N. mutica	+	+					
Chlorophyta							
Chlamydomonas spp.	+	c	+	+	+		c
Peridinium sp.	c	+	+				+
Chlorella sp.							+
Gloeotila sp.							+
Paraphysomonas vestita							+
Cosmarium spp.	+	+	+			c	
Cryptophyte							
Ochromonas spp.	+	+					+
Rhodomonas sp.						c	
Sarcodina							
Amoebina spp.							+
Actinosphaerium sp.	+	+				+	+
Clathrulina sp.							+
Ciliata							
Strombidium viride	+	+				+	+
Halteria grandinella							+
Vorticella campanula	+						+
Askenasia sp.	+						+
Tintinnidium fluviatile							+
Stokesia vernalis							+
Cladocera							
Daphniopsis studeri	a	a	+	c	+	+	c
Copepoda							
Acanthocyclops mirnyi						+	+

+ : present; a: abundant; c: common; * : data after Laybourn-Parry *et al*. 1991.

marine derived lakes in the VH (Burke and Burton 1988a, Volkman *et al*. 1988). Another common species *Rhodopseudomonas palustris* appears around the oxylimnion (Burke and Burton 1988b). The phytoplanktons totalling 12 families, 15 genera and 19 species (Heath 1988, Volkman *et al*. 1988), include Diatoms, Dinoflagellates, Chlorophyceae and Chrysophyte. Common and wider-spread species were *Acanthoecopsis unguiculata* and *Pyramimonas gelidicola* (Burke and Burton 1988b). Some zooplankton (see Table 3) with medusa (Coelenterata, *Rathkea lizzioides*) and 1 ctenophore (Cydippida), and 8 species of copepod, dominated by *Drepanopus bispinosus* and *Pralabidocera antarctica* were found in high distribution densities in lakes (Burton 1981, Bayly 1986, Wang and Eslake 1997). Zooplankton can survive mostly in suitable conditions, because their distributions in lakes are restricted mainly by salinity and dissolved oxygen contents. In Southern Victoria Land (VL), blue algae, Oscillatoriaceae, Oscillatoria for example, were most common species accounting for 70% of total phytoplanktons and including more than 16 species in brackish lakes, such as Lake Bonney and Vanda, secondly were Chlorophyceae and Bacillariophyceae. Beside

Table 2. Distribution of microbial plankton in marine derived lakes and some near bays in East Antarctica

	Fel	Ace	Abr	Shl	Org	Deep	Bur	CroF	Tay	Ell	Bon	Van
Cyanobacteria												
Rhodopseudomonas												
R. palustris	+		+	+			c	+	+	c		
Chlorobium vibrioforme	c	c	c				a	+	c	c		
C. limicola	+	c	c				a	+		+		
C. spp.		+					c			c		
Anaeroplasma sp.		+										
Asteroleolasma sp.		+										
Chromatium sp.		+	+				+	+		+		+
Bacillus megaterium											+	+
Micrococcus sp.											c	+
Pseudomonas sp.											+	+
Mycobacterium sp.											+	
Thiocapsa roseopersicina		+	+				+					
Desulfotomaculum spp.		+								+		
Desulfovibrio spp.										+		
Halomonas meridiana	+				c		+					
H. subglacicscola	+				+		+			+		
H. spp.						+						
Flavobacterium												
Gondwanense	+				+							
F. salegens	+				+							
Bacillariophyta												
Navicula sp.	c	c			+		c			c	c	
N. spp.						+						
Thalassiosira sp.							+					
Fragilaria spp.									+			
Nitzschia curta	c		c				c	+	+	+		
N. fragilis									+	c		
Chaetoceros sp.	+				+		+		+	a		
C. compressus							a			+		
Pinnularia sp.	+	c	+					+		a		
Chlorophyta												
Gymnodinium sp.		+										
G. spp.	+			+			+	+	+	+		
Gyrodinium lachryma		+										
Chlamydomonas sp.						+					+	
Acanthoecopsis unguiculata					+							
Cladophara subsimale							+			+		
C austrogcorgiae	+						+	+		+		
Pyramimonas gelidicola	+	a	+				+	+		+		
P. sp.					+							
Chlamydomonas subcaudata											+	+
C. spp.						+						
Dunaliella sp.					c	+						
Chlorella sp.											c	
Chrysophyta												
Desmarelia menziesii	+		+				+					
Phyllophora antarctica								+				
Ochromonas sp.											+	
Cryptophyte												
Cryptomonas sp.		c	+									
Rhodomonas sp.								c				
Chroomonas lacustris											c	

Fle: Fletcher; Shl: Shleid; Org: Organic; Abr: Abraxas; Bur: Burtun; Wat: Watts; Tay: Taynaya; Ell: Ellis; CroF: Croocked Fjord; + : present; a: abundant; c: common. Data from this study and after Parker *et al*. 1977, 1982; Heywood 1977; Bayly 1978; Hand and Burton 1981; Wright and Burton 1981; Burke and Burton 1988 a, b; Volkman *et al*. 1988; Heath 1988; Burch 1988; Franzmann and Rohde 1992; James *et al*. 1994; Lizotte *et al*. 1996; Perriss and Laybourn-Parry 1997.

ciliates, there were several zooplankton species, such as Rotifera *Philodium* sp., Tardigrada, Nematoda and Gastrotricha, as well as copepods (see Table 3) (Dougherty and Harris 1963, Heywood 1977).

Table 3. Distribution of zoo-plankton in some marine derived lakes and the near bays in the Vestfold Hills, East Antarctica.

	Fle	Ace	Abr	Shl	Org	Deep	Bur	CroF	Tay	Ell	Bon	Van
Ciliata												
Mesodinium rubrum	+	+		+					+	+		
Rotifera												
Philodina gregaria											c	
P. sp.												c
Tardigrada											+	+
Gastrotricha												+
Anthomedusae												
Rathkea lizzioides							c	+	+	+		
Ctenophora												
Cydippida sp.	+						a		+	c		
Copepoda												
Drepanopus bispinosus	c						a		c	+		
Paralabidocera antarctica	+	c	c				+	+	+	+		
Acartia sp.		+										
Amphiascoides sp.			c						+			
Harpacticus furcatus	+								+			
Idomene sp.								+				
Oithona similis								+	+	+		
Oncaea curvata								+	+	+		
Amphipoda												
Paramoera walkeri						+	+	c	+			

Fle: Fletcher; Shl: Shleid; Org: Organic; Abr: Abraxasl; Bur: Burtun; Wat: Watts; Tay: Taynaya; Ell: Ellis; Cro: Croock; + : present; a: abundant; c: common. Data from this study and after Parker *et al.* 1977, 1982; Bayly 1978; Hand and Burton 1981; Wright and Burton 1981; Volkman *et al.* 1988; Heath 1988; Burch 1988; Wang and Eslake 1997.

3.2 *The environment of lakes and biological diversity*

Chemical components from some lakes in Antarctic continental coast are shown in Table 4. It is clear that ionic concentration in those fresh lakes was considerably lower than that in brackish lakes, particularly the concentrations of Na^+ and Cl^- in freshwater were 0.48% – 0.58% and 0.27% – 0.31% of those in brackish lakes respectively, and the concentrations of SO_4^{2-} and PO_4^{2-} were 5% – 7% and 0.5% – 3% of those in brackish lakes respectively. Most of freshwater lakes in the LH are lakes of ice eroded and/or fed by snow melted water (Li 1994), therefore, it is much poor with nutrients which biological organisms need. However, some lakes are comparatively not lack of nutrient sources from the sea because of their locations. Mochou and Heart Lakes for example, two of the 5 lakes in the LH listed in Table 4, have lower elevation and are much closer to the beach at north top of the Mirror Peninsula. Where mostly as habitants or colonies, sea birds like penguins and skuas lived (Wang 1991; Wang *et al.* 1996). That is more reasonable to make high concentration of PO_4^{2-} and TN in those lakes. Birds activities also could bring some intertidal algae species into lakes, such as *Navicula glaciei*, a dominant species existing in nearest Zhongshan Bay (Zhu *et al.* 1995). Further, in Mochou Lake, chemical contents as well as biological species and biomass are higher than the others, this is probably due to human activities and even environmental contamination. In contrast with this, High Lake is located at a higher inland and, Progress Lake is just on the edge of the ice sheet. Chemical concentration and biological distribution in these two lakes are remarkably lower. However, higher value of total nitrogen in the High Lake should be relative to the excrement from a skua nest at the top of a rock near the lake (Wang *et al*. 1996), and to the excretion of zooplankton in the lake as well.

Table 4. Comparison of chemical components ($\times 10^{-6}$) in different Antarctic lakes

Lakes	Depth /m	Oxyl. /m	Temp /℃	Sal /‰	pH	Na^{+}	K^{+}	Mg^{2+}	Ca^{2+}	Cl^{-}	SO_4^{2-}	PO_4^{2-}	TN
LH													
Mochou	3.8		+6.3	1.2	6.6	185	6.4	12.1	10.4	344	75.5	0.03	0.19
Heart	4.1		+6.8	3.5	7.4	240	5.0	17.3	19.1	353	55.6	0.04	0.12
Big	3.8		+6.6	2.7	7.3	390	7.3	13.1	12.5	452	57.3	0.03	0.09
High	4.1		+4.5	0.5	7.2	66	3.2	2.4	4.1	97	10.1	0.02	0.20
Progress	34		+4.9	0.5	6.7	34	1.5	2.6	2.2	62	10.5	0.01	0.03
VH													
Watts	35		+4.8	2.2	6.9	670	35	31	29	510	55	0.02	0.01
Croocked			+2.1	6.7	0.1	375	14	19	17	442	38.5	0.02	0.02
Deep	36	19	+8.5	222	7.4	67900	4210	12580	2400	165000	2550	0.57	0.65
Fletcher	11	6	−1.2	55	8.1	14550	4640	1950	620	30100	2150	0.21	–
Burton	16	8	+0.5	38.5	7.5	9800	280	1220	450	18300	2080	0.24	0.45
Organic	7	4	+6.1	105	7.0	25300	1007	3648	940	90680	2730	–	1.10
Ace	24	10	+6.0	29.5	7.6	7350	300	960	140	13400	410	0.15	0.34
VL				(Cond)									
Bonney	32	14	+7	40845	6.8	16900	1200	13000	1110	70300	2230	0.34	0.59
Vanda	64	40	+8.5	2700	7.1	377	35	70	264	827	36	0.32	0.50

Depth: measured depth; Oxyl: Oxylimnion; Temp: Temperature; TN: Total nitrogen; Cond: Conductivity. Data from this study and after Heywood 1977; Parker *et al*. 1977; Peter 1978; Gillieson *et al*. 1990; wang 1992; Wang and Deprez 1998.

According to Zhang´s study (1985), there were two transgressions in the Vestfold Hills after the late Pleistocene. The first one took place during the ice melting of last glacial period (about 50000 – 25000 a B. P.). And the second was larger than the first in scale and took place in the climatic optimum of the past glacial period at 7500 – 3200 a B. P.. At that period sea level rose about 25 m high, and the coastline retreated back to inland for about 75 km. As the time when the ice sheet retreated, the isostatic uplift took place. The coastline was translocated forward to sea again. Thus. part of coast appeared as land, and some arms of sea became trapped and formed as saline lakes. It is reasonable to hypothesize that biological species should originate from the sea, despite of many lakes fed by ice and snow melted water afterwards (Wang and Eslake 1997).

Comparison with VH and LH, the lakes in Victoria Land are considered to be very older, probably thousands upon thousands of years. The desert oasis has been ice free for up to 5 million years (Laybourn-Parry *et al*. 1997). Chemical components and biological species also should originate from the sea (Burton 1981). In Table 4, there are not so much differences in chemical components in saline lakes between these two ice free areas. However, remarked differences in species composition from those two oasis, mean that there are two unique biological structures, which probably presente biogeographic features. Referring to the saline lakes in same area, the differences in chemical components and biological structures of the lakes may be due to the regional geographical condition, the variant processes of local climate and the geomorphological changes. Here, property of environmental geomorphology of lake, like size and depth, particularly water level and the distance from lake to sea directly has an effect on water exchange between lake and sea. For example, Deep Lake (water level 50.4 m lower than sea level) and

Abraxas Lake (10 m higher than the sea), are completely cut off from the sea, there is no any water exchange between lakes and the sea. While Burton Lake keeps same water level with the sea and, there is seasonal water exchange from the near bay. We believe that these should be main reasons to cause very differences of physical-chemical conditions in respective lakes. Temperature, salinity and dissolved oxygen are three most important factors for aquatic organism survival. Salinity should be first factor of controlling conditions particularly to low forms of aquatic life, because the limitation of organism resisting outer osmotic pressure is depended on ionic concentration in surroundings (Vernberg and Vernberg 1972). Furthermore, the salinity could affect the content of dissolved oxygen, which is also stronger to limit the livings in lakes. We divide Antarctic lakes into several types based on salinity:

* Freshwater lakes:

  Salinity< 3‰, Higher oxygen content ($5.0< O_2< 10.0$), lower nutrients;

  (a) Ice eroded lake, such as High, Progress and Croocked Lakes.

  (b) Marine derived lake, such as Watts and Heart Lakes.

* Brackish Lake:

  (a) High salinity (> 100‰), evident seasonal differences in temperature (> 17℃), lower oxygen content ($O_2< 3.0$), more nutrients, such as Deep , Organic and Shield Lakes.

  (b) Suitable salinity (20‰ – 55‰), smaller seasonal differences in temperature (> 5℃), suitable oxygen content ($3.0< O_2< 8.0$), rich nutrients, such as Lake Abraxas, Ace, Fletcher and Burton Lakes.

The comparison of biological diversities from different types of Antarctic lakes is made as shown in Table 5. Ice eroded lakes in the LH have rare biological species because of their poor nutrient contents. Average index number of biological diversity is as low as 0.62. We did not analyse bacteria species in those lakes, and actual number should be higher than this. In Croocked and Watts Lakes in the VH, ionic concentration and nutrient contents are higher than those in the LH, and the biological species are comparatively more than the latter. Many remains of tubeworm can be found on the beach of Watts Lake. As a typical lake which turned from salt to fresh, the lake was much diluted by ice melted water and became freshwater lake in the period of about 4000 – 3000 a B.P. (Pickard *et al*. 1986; Wang and Deprez 1998). At that time, Croocked Lake was covered entirely by ice sheet. So far, there is no any transgression evidence to be found in the lake. The freshwater zoo-plankton species Cladocera, which immigrated into this lake, must be much later.

After-long term processes of the evolution with water loss, some brackish lakes in the VH became high salinity lakes, with large seasonal temperature difference and low oxygen content. In the processes most of marine organisms, particularly the high forms of life, are hard to survive. Only some low forms of organism like a few species of bacteria and single algae could be found in those lakes, such as in Deep Lake. So far, more microbial species have been found from fresh lakes, but in such extreme environments as high salinity lakes. The average index of biological diversity (EIBD) of freshwater is 1.91 (should be higher in fact) and higher than that in the latter (1.41) (see Table 4). Most of brackish lake is comparatively rich in biological species in the VH, because the salinity in those lakes is moderate and/or close to sea water, which is suitable for marine organisms to survive. 32 species have been recorded and the EIBD is as high as 2.84, and higher than that in Booney and Vanda Lakes (2.70) in Victoria Land. In geographical viewpoint, many lakes in the VH are completely cut off from the sea, and it is impossible that any marine organism could immigrate from the sea into lakes, so that the structures of community are quite stable.

Table 5. Comparison of biological diversity and community in different Antarctic lakes

Type	Salinity / ‰	Species	d*	Community structure	Dominant species
Freshwater					
LH	< 3	15	1.91	bacteria	?
				+ diatoms	*Oedogonium* sp.
				+ Chlorophyta	*Chlamydomonas spp.*
				+ Cladocera	*Duphniopsis studeri*
VH	< 3	24	2.19	bacteria	?
				+ diatom	*Mougeotia* sp.
				+ Chlorophyta	*Chlamydomonas spp.*
				+ Cladocera	*Duphniopsis studeri*
				+ Copepoda	*Acanthocyclopsmirnyi*
Brackish water					
VH	> 100	11	1.41	bacteria	*Halomonas* sp.
				+ diatoms	*Navicula* sp.
				+ Chlorophyta	*Dunaliella* sp.
VH	20 – 55	33	2.84	bacteria	*Chlorobium vibrioforme*
				+ diatoms	*Navicula* sp.
				+ Chlorophyta	*Pyramimonasgelidicola*
				+ Copepoda	*Drepanopus bispinosus*
				+ Ctenophera	*Cydippida* sp.
VL		30	2.70	bacteria	*Microccus* sp.
				+ Cyanophyta	*Oscillatoria breuis*
				+ Rotifera	*Philodina* sp.

d*: Biological diversity index.

However, water exchange between lakes and the sea did take place in some cases, and it resulted in occurring of biological community succession. Taking Fletcher Lake for example, the collection in 1978 contains no any zooplankton species in the lake, when salinity as high as 66‰. It has been known that water budget in this lake increased by stronger tide from Taynaya Bay at least in last 10 a. As salinity was diluted in a larger range, some marine plankton species immigrated into the lake followed by tide flood. Only few individuals of calanoida copepod *Drepanopus bispinosus* were discovered in 1982. Afterwards, we found over-winter population and reproductive activities of this species for the first time at salinity of about 50 in 1984. Then, 6 marine zooplankton species, such as copepods *D. bispinosus*, *Paralabidocera antarctica*, *Oncaea curvata*, two harpacticoids *Harpacticus furcatus* and *Idomene* sp., and one Ctenophora *Cydippida* sp. appeared at salinity of 45 in this lake (Wang and Eslake 1997). Such analogous phenomena as water exchange and community succession did we never see in any freshwater lakes in Antarctica.

3.3 Biological trophic structures in Antarctic lakes

The water columns of coastal lakes in Antarctic continent for most time of the year are covered by thick ice, and can be regarded as closed or semi-closed meromictic water bodies compared with open sea water (Bayly 1986, Wang and Deprez 1998). Therefore, in general, there is a comparative independent small ecosystem in each lake. The growth and/or decline in biological species and communities depend on evolution of lake condition and environment. The biological food web of the lake is comparatively independent.

Biological trophic structure of Antarctic lakes was preliminarly described by Bayly (1986) and Vincent (1988). However, numbers of literatures on the ecology of Antarctic freshwater and brackish lakes have been published since then. Copepod crustacean animals, as highest forms of life, are most dominant grazers in most of saline lakes in the VH (see Fig. 1). Those species should be of marine origin, such as *Drepanopus bispinosus*, *Paralabidocera antarctica* and *Harpacticus furcatus*, and can be found in near coastal waters. Calonoida copepod *P. antarctica* as a host habitant exists in many marine derived lakes like Ace and Abraxas Lakes, which are completely cut off from near bays. Ctenophora and Hydromedusa, as consumers of copepods, come into the lakes only in the time when the lake water has seasonal exchange with sea water. However, the ctenophora in Burton Lake should be one of host habitant specie for quite a long period (Wang and Eslake 1997).

It has been understood that nano and pico phytoplanktons including cellule organisms and cyanobacteria, as primary producers to contribute as much as 50% ‑ 60%

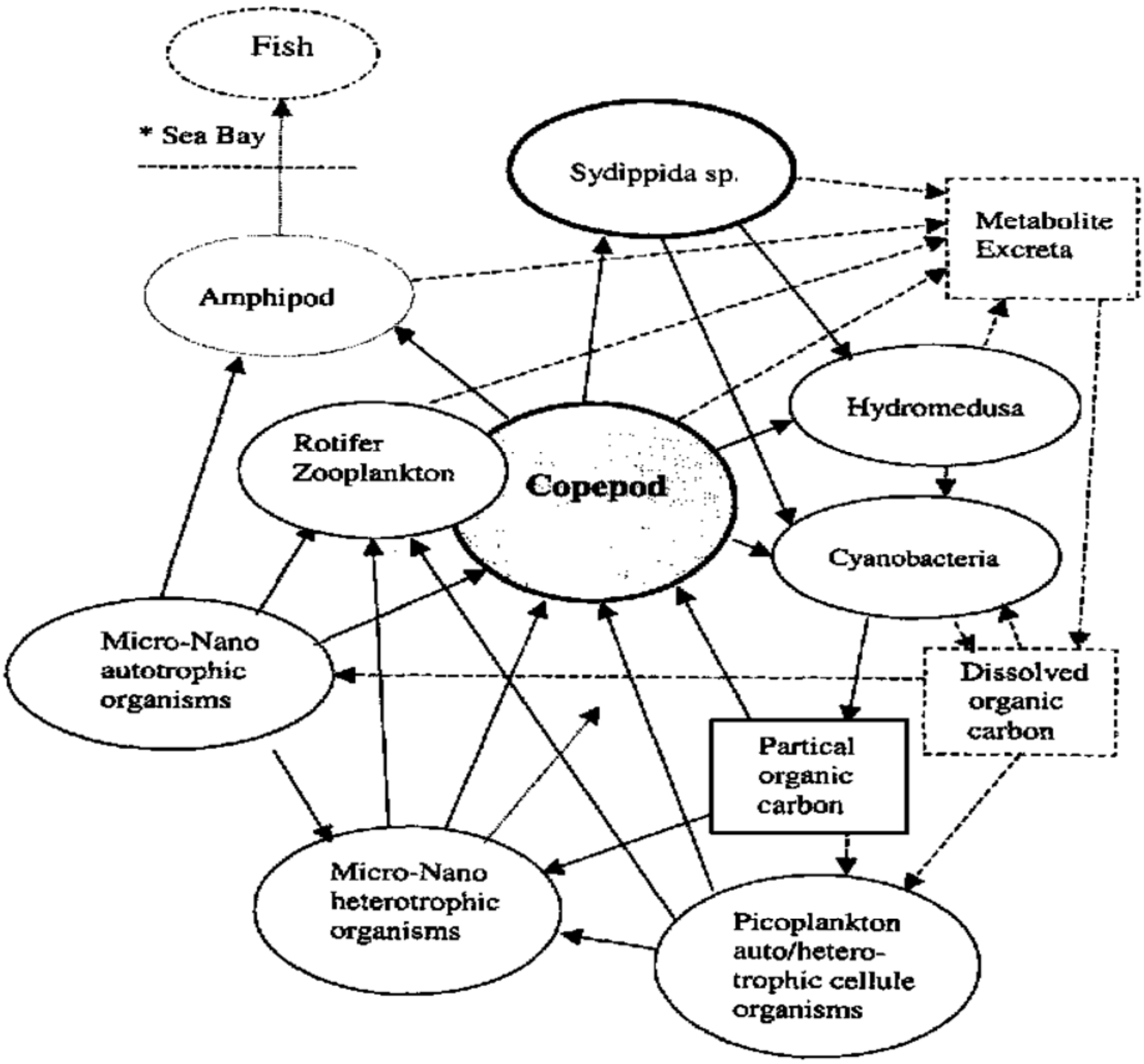

Fig. 1. Illustration of biological trophic relationship in Antarctic marine derived saline lakes. * : with water exchanging between the lake and the sea water only.

of primary production in the ocean, play an important role in Antarctic marine ecosystems. In Antarctic coastal water, heterotrophic and/or some autotrophic flagellates over the size range of 0.063 μm to 1.0 μm, ingest large quantity of sub-micrometer particles and dissolved organic material and clear about 7% of the water column per day (Marchant and Scott 1993). Those microorganisms are basis to support the simple food web in continental water ecosystems.

In comparison with the above, freshwater lake systems in Antarctic continent provide extremely oligotrophic environment for plankton communities. Low microbial biota also much limits their consumer species in low abundance. Laybourn-Parry *et al*. (1995) reported that bacterial and heterotrophic flagellate abundances were less than 4.46×10^3/L and 50.9×10^3/L respectively. Both groups exhibit low productivity, phytoplankton activities essentially control ecological dynamics of the lake (Bayliss *et al*. 1997). Cladocera crustacean animals as highest grazer dominate in most freshwater lakes in VH and LH (see Fig. 2). Copepod *Acanthocyclops* was found only in freshwater lakes in VH. Ciliated protozoa with three to four species were also common grazers in freshwater lakes. In general, the grazing pressure in freshwater lakes is low because of the environmental constraints on the physiological function of the grazers (Laybourn-Parry *et al*. 1995). Grazing on bacteria and micrometer particles would vary indifferent lakes with different plankton community structures (Vaque and Pace 1992). We would like to hypothesize that it might be related mainly with the size of microorganisms and sub-micrometer particles.

4 Conclusion

We would like to make the conclusion and suggestion as follows:

(1) Composition and distribution of biological species in continental Antarctic lake

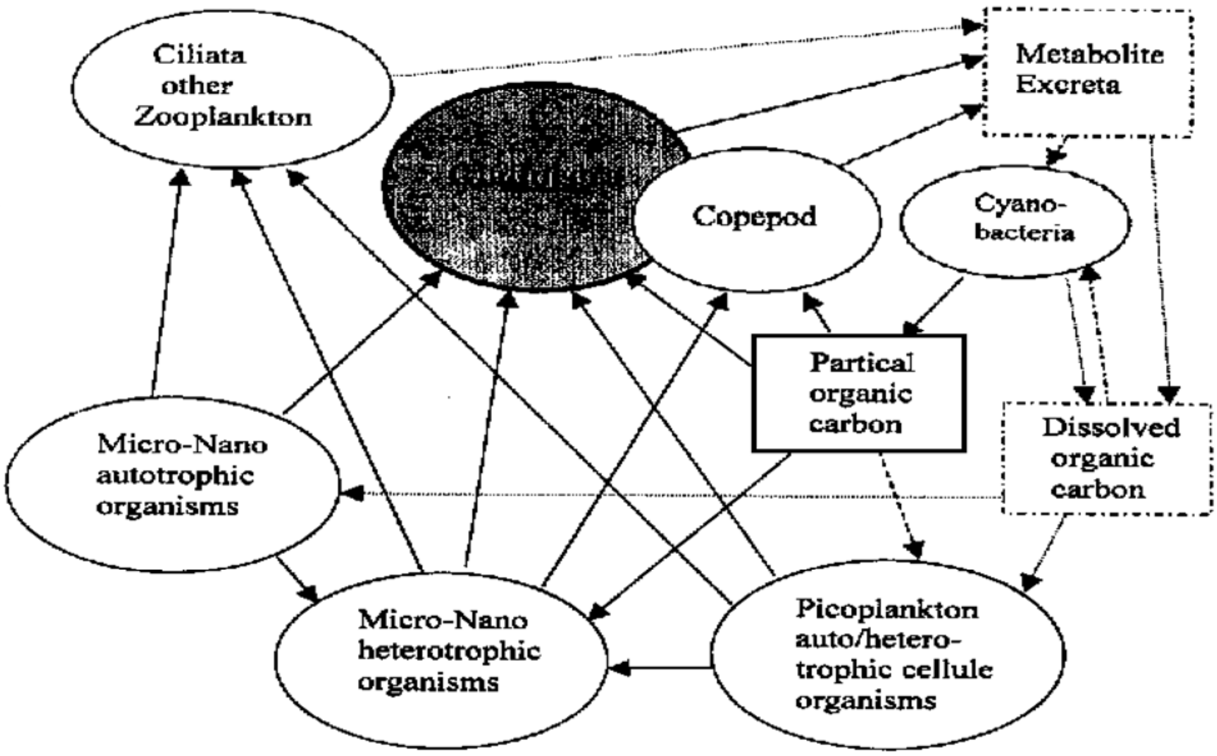

Fig. 2. Illustration of biological trophic relationship in Antarctic freshwater lakes.

systems are considerable unharmonious. It has simple community structures with low biological diversities in freshwater lakes, while it has more structures with comparatively higher biological diversities in marine derived saline lakes. Such unbalanced status was ascribed to the processes of development and evolution history of different lakes.

(2) Chemical components and biological structures are two basic properties of the water in continental Antarctic coastal lakes. This is the most concentrated record reflecting the history and processes of environmental evolution and climate change in Antarctic regions.

(3) Because of closed and/or semi-closed and limited water column, continental Antarctic lakes systems have low cushioning effect to the pressure by human activities and environmental contamination. There is a much necessity to emphasize in study and protection of those lake ecosystems.

(4) The Vestfold and Larsemann Hills are two important ice free areas, which are much valuable places for monitoring and assessing of global climate change and the impact of human activities on Antarctic environment. It could be necessary to select suitable lakes in both of the lands as basic standard unit of environmental monitory. Also it should be the time to set up a database of chemical-physical and biological factors, including a few species as indicators from the lakes.

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