

# EFFECT OF ENVIRONMENTAL FACTORS ON POPULATION DYNAMICS OF DREPANOPUS BISPINOSUS IN BURTON LAKE, ANTARCTICA

Wang Zipan

*Second Institute of Oceanography, State Oceanic Administration, Hangzhou 310012, China*

**Abstract** The population dynamics of *Drepanopus bispinosus* (Calanoida: Copepoda) was studied throughout the year of December 1983 -January 1985 in Burton Lake, a littoral saline lake on Vestfold Hills, Antarctica, and the environmental factors of the lake were observed simultaneously. *D. bispinosus* is univoltine. Its population life cycle could be in 20—21 months and reproductive activity stays from winter to early summer. The adults (male and female) and nauplii mainly form the winter population. Adult females are instead of male and, copepodites are instead of nauplii in summer population. Then it consists of copepodites mainly in stages II-V from late summer through autumn. The density of population components considerably varies for their whole life time. Most of nauplii appearing in winter may not develop and transform into further stages under the restrictive conditions, such as low oxygen content and scarce food. Earlier stage copepodites of new generation appear largely in summer, when the lake is rich in oxygen content and phytoplankton. The adult females decrease markedly after their reproductive activities, as the sharp salinity diluting in early summer. This density variation of population compositions is mostly related with the change of environmental factors in the lake. The conception is supported by the data obtained from another saline lake on the Vestfold Hills.

**Key words** population dynamics, *D. bispinosus*, Burton Lake

## Introduction

*Drepanopus* (Calanoida: Calanus) occurs very abundantly in coastal sub-Antarctic and Antarctic waters. Some of this species is general even dominant in planktonic communities in these regions (Bayly, 1982; Turker, *et al.* 1987). *D. bispinosus* also occurs in considerable abundance in the close onshore waters of Antarctica. Collections from some saline lakes on Vestfold Hills and coastal bays consisted almost entirely of this species in 1984.

The ecology of *D. bispinosus* in Burton Lake has been described by Bayly (1986) on the basis of large fieldwork and materials obtained in 1979—1982. It is known clearly that the individual ecology of *D. bispinosus* in different developing stages in Antarctic summer. The population features in winter are partly described as well.

Burton Lake, unlike other meromictic lagoons, has limited water exchange with nearby bay. There is conspicuous seasonal variation of main physical and chemical factors in the lake, such as light, temperature and salinity, which play an important role in controlling nutrient recycle and primary producers (Wright & Burton, 1980), and directly affect consumers of these primary producers. Franzmann and others (1988) reported that dissolved sulfide occurs in the bottom water of Burton Lake, it limits the distribution of copepods to the epilimnion. Thus it quite influences *D. bispinosus* as habitant in its ecological features and population dynamics. Therefore, the complete information of population ecology and simultaneous observation of environmental factors are important and necessary for understanding the relationship between organisms and their ambi-

ent circumstances.

This paper is based on the overwinter fieldwork throughout the year in the Burton Lake (Fig 1.). The population development of *D. bispinosus* has been studied uninterruptedly in that period. It has been explained that the population dynamics in different life stages is much related with different lake conditions in the seasons.

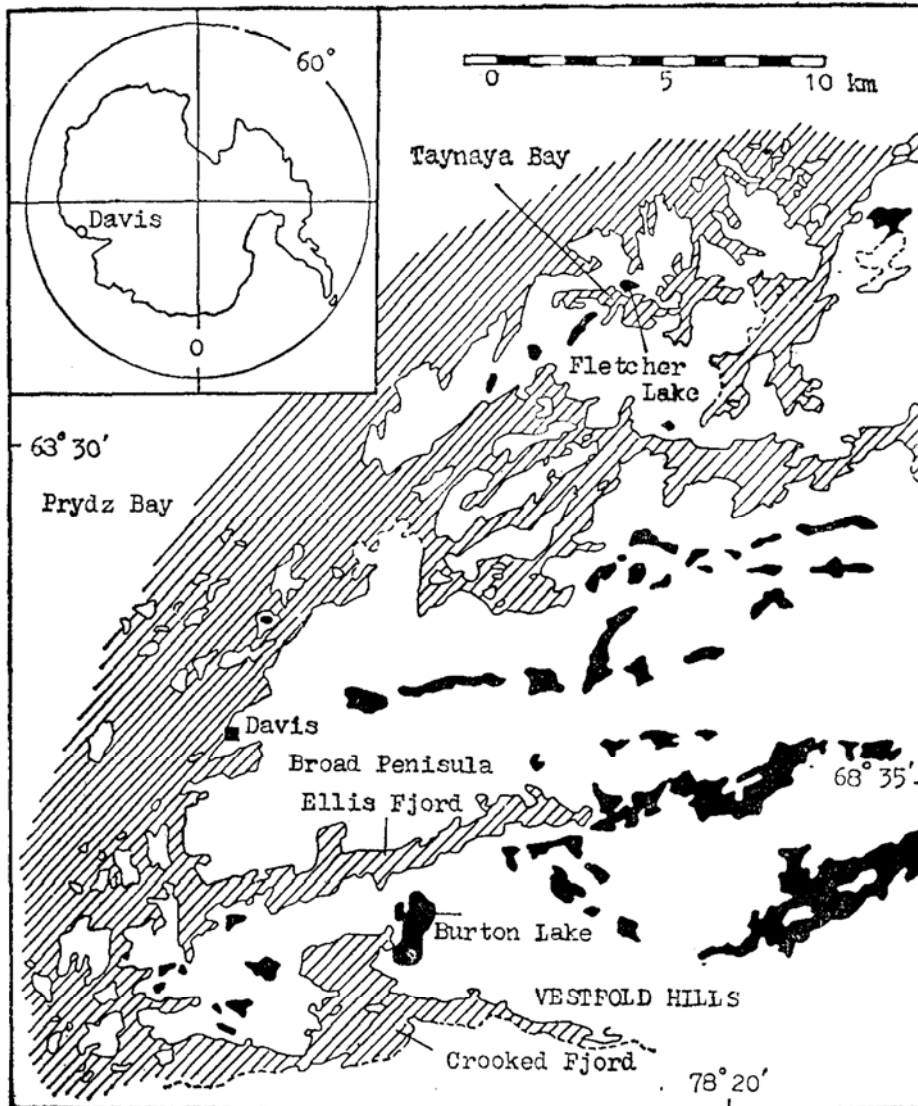


Fig. 1. Showing location of Burton Lake.

### Materials and Methods

Samples were collected from the centre of northern part of the lake (depth 16 m). The collapsible plankton net (mesh size  $210\mu$  for zooplankton collection and  $100\mu$  for eggs and nauplii, brief phytoplankton concentration) described by Bayly (1986) and Kirkwood *et al.* (1987) was used for sampling. A series of five replicate vertical hauls at each sampling date was made through the entire width of the oxylimnion. The contents of the net were preserved in a 5% formaldehyde / seawater solution. The preserved samples were examined in laboratory and the presence or ab-

sence of species recorded.

Main environmental factors of the lake, such as ice thickness, temperature, salinity, dissolved oxygen and pH, were measured *in-situ*. Salinity measurements were calculated from chlorinity measurements with a DIONEX-10 liquid chromatograph. Temperatures were measured using the QT digital display thermometer. Dissolved oxygen was fixed *in-situ*, and measured by using WINKLER method in laboratory.

## Results and Discussion

### 1. Environmental condition of the lake

Burton Lake is a semi-enclosed water body and meromictic, with an upper oxylinnion sharply separated from a lower anoxylinnion. The natural environment of the lake has been described by Bayly (1986) and Wang *et al.* (1989). The data obtained from the lake in 1984 is described as follows.

**a. Temperature** Temperature-depth profiles in the period of Jan. 1984–Jan 1985 are shown in Fig. 2. It is important to note that the temperature of the entire oxylinnion throughout the year has remarkable and seasonal changes. The variation occurred mainly in summer and autumn (before June 1984 and Dec. 1984–Jan. 1985) (Fig 2.). The absolute difference of temperature is  $8.1^{\circ}\text{C}$ .

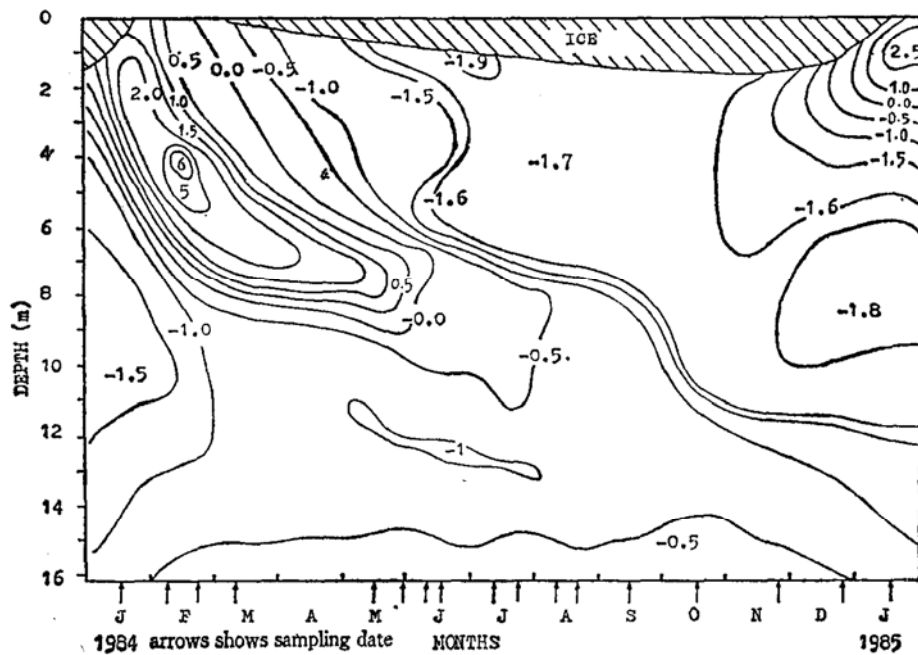


Fig. 2 Isotherms ( $^{\circ}\text{C}$ ) in Burton Lake during 1984.

Temperature of entire oxylinnion after midwinter to the end of spring is remarkably stable within a range from  $-1.5^{\circ}\text{C}$  to  $-1.7^{\circ}\text{C}$ .

**b. Salinity** Salinity-depth isopleths in the period of January 1984–January 1985 are shown in Fig 3. The salinity change throughout the year has a remarkable tendency to increase as ice thickening in cold season and to decrease as ice melting in warm season. Snow and ice melting diluted the salinity from the surface to deep water mainly down to depth less 5m, the salinity variation within the range about 5–37‰. Salinity in surface water within depth less 1m, measured in February 1984,

was less 5‰.

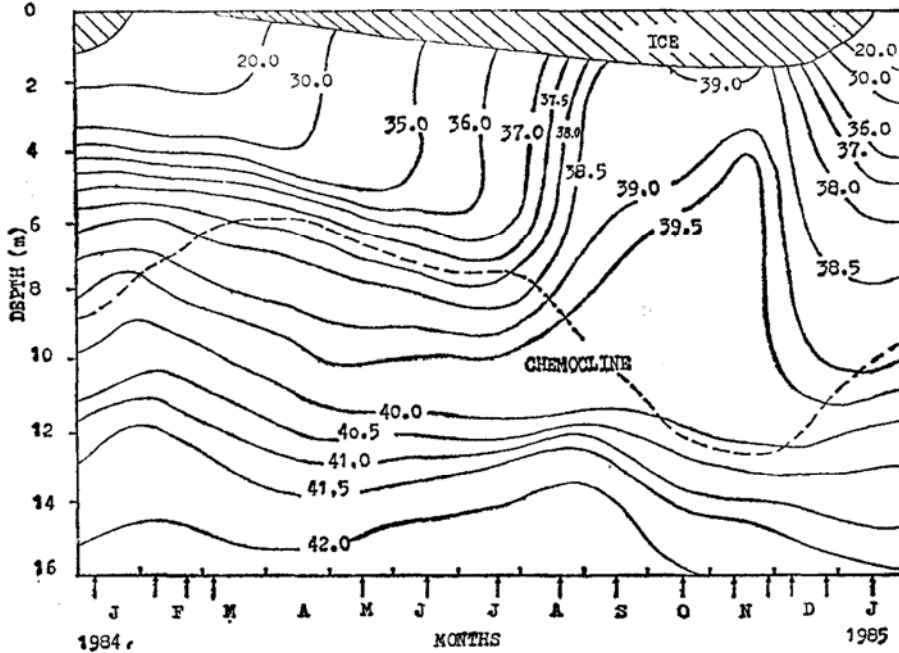


Fig. 3. Isosalinity map of Burton Lake during 1984.

**c. Dissolved oxygen** The vertical dissolved oxygen distribution in the lake shows a decreasing tendency from surface under the ice to deep water. The chemocline position had seasonal variation in a range of 7–12m from June to Nov. of 1984. The content of dissolved oxygen decreases smoothly as climate getting cold, and increases rapidly from Dec. to Jan. (Fig. 4). The highest value obtained on 16 Jan. 1985 was 21.0601 ml / L at depth 3m, but 3.2837 ml / L on 5 Nov. 1984 at the same depth.

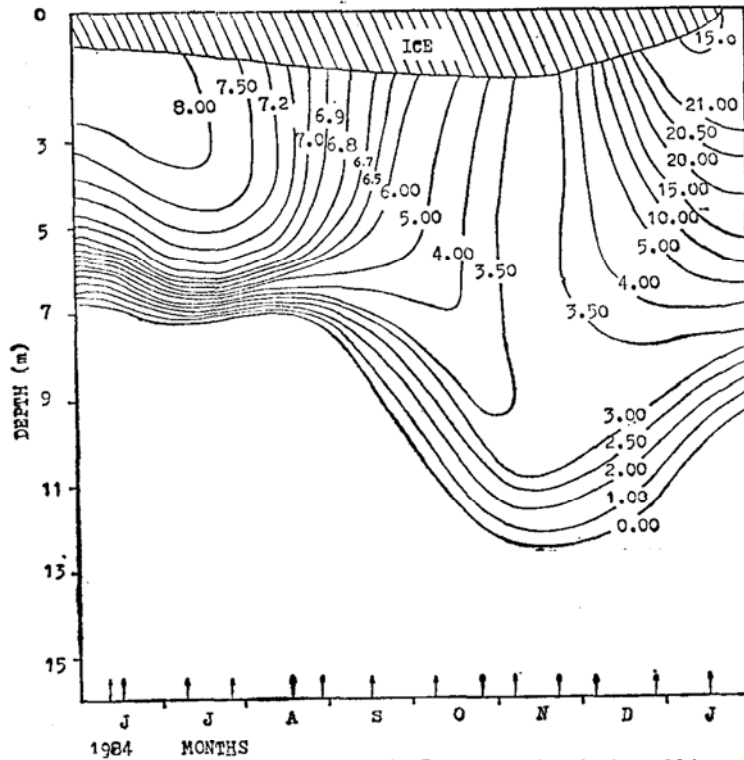


Fig. 4. Profiles of oxygen content in Burton Lake during 1984.

d. pH The range of pH variation measured in 1984 was 6.8–8.9. Fig. 5 shows a pH-depth profile in the period of Jan. 1984–Jan. 1985. The pH value in oxylinnion is higher than that under the chemocline. There is a gradual reduction of pH from 8.5 (depth less 5m) in May to 7.5 in Nov. (Fig. 5), and returns steeply to 8.0 in Jan.

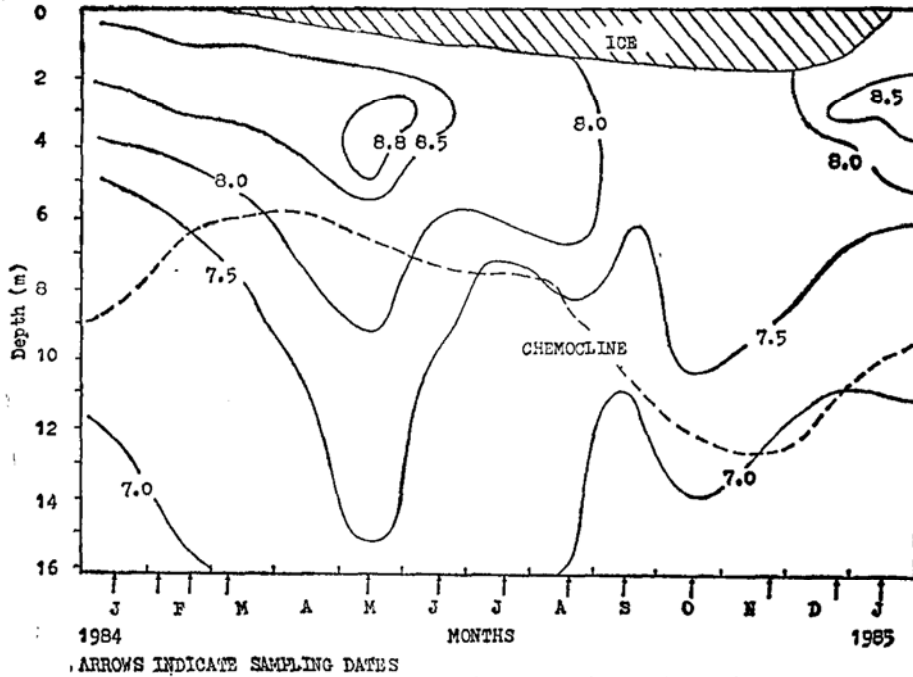


Fig. 5. Profiles of pH in Burton Lake during 1984.

## 2. Characteristics of population dynamics

Marshall & Orr (1972) suggested that some marine calanoid copepods have 2–3 generations in one year in low latitude waters. Evans & Crainger (1980) reported that *Drepanopus bungei* (Sars) found in Arctic cold estuary water has one generation in a year. Based on many fieldworks carried out by Bayly and Burton from 6 December 1981 to 17 January 1982, Burton on 10 February 1979, Heath & Walker on 5 September 1981, and Burck on 23 January, 22 May, 26 June and 26 August 1983, Bayly (1986) suggested that *D. bispinosus* is univoltine. Mature males appear in late autumn and mating occurs mainly in early winter, when significant numbers of mature females first appear. The species overwinter as adult and ovigerous female first appeared in midwinter (27 July 1983). Males lived a short time and were already rare by the end of winter. Stage I nauplii were present in early spring (5 September 1981). Adults and larva would be components of population after winter. Stage I copepodites first appeared on 11 December and reached peak number in mid-January. The last adult females from the previous winter disappeared by late summer (mid-February).

Fig. 6 shows the monthly changes of population density and composition from December 1983 to January 1985. In this study, the mature males were found at the end of April. They reached peak numbers in June, and disappeared after August. This is in agreement with the suggestion of Bayly. The first ovigerous females were observed on 13 July. Then nauplii stage I were found in the same collection. Before this, some gravids and spermatophore carriers were found in the collection of 15 June. It is likely that the new generation nauplii might occur in early July at least, two months earlier than what is reported by Bayly. The nauplii appeared entirely from

July to next February and reached peak numbers with density  $7138.1 / m^3$  in mid-November. Before, there was a small peak with density  $3468.8 / m^3$  on 6 September. The stage I-V copepo-

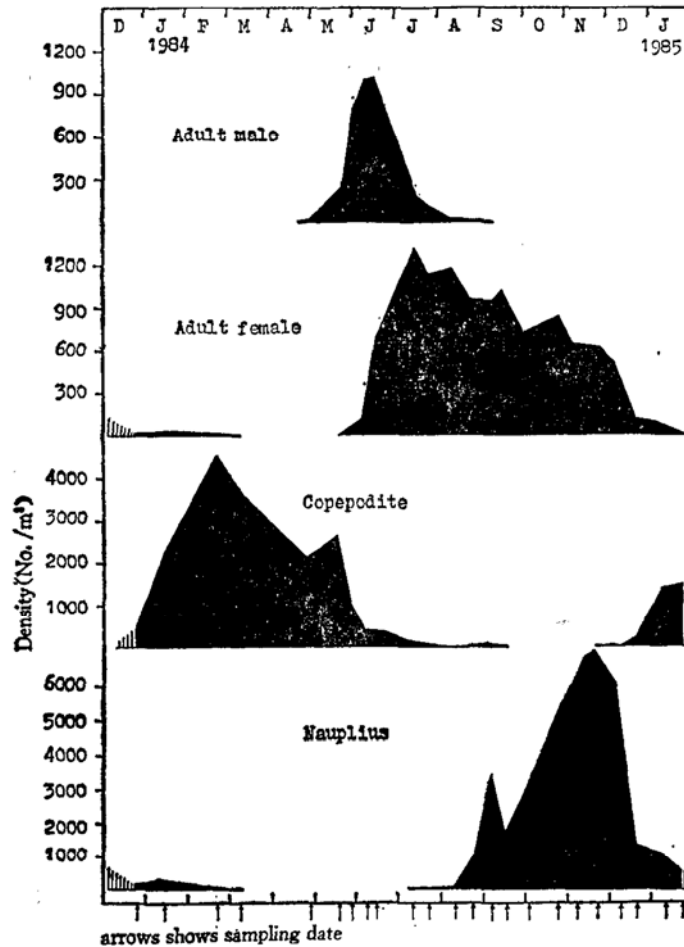


Fig. 6. Monthly variation of population density of *D. bispinosus* in Burton Lake (Dec. 1983~Jan. 1985)

dites appeared mainly from December to next July. It is important to note that the copepodites of stage I first appeared on 17 August, but were not found in the collections from 29 April to 13 July. So it could be new generation copepodites resulted from the nauplii occurred in July. The new copepodites were not found in the collections from 26 October to 5 November. They reappeared in late November and reached peak numbers with density  $1531.7 / m^3$  on 22 January 1985. A few copepodites of stage V existed from August to early November. As yet, it was unknown that why only a few copepodites (nauplii as well) were collected on 24, 27 and 31 December 1983. However, it was large in samples obtained in January. Those previous copepodites reached the peak with density  $4668.4 / m^3$  on 21 February, while most of them were the stage II-V.

The ovigerous, eggs and nauplii appeared in all the samples collected from July to January. This indicates that *D. bispinosus* has reproductive activity uninterruptedly for these months. Fig. 7 shows the proportions of ovigerous, eggs and nauplii in reproductive period. It is clear that the ovigerous exhibited two peaks. It was 47% of ovigerous / adult females on 9 August and 44% on 5 November respectively. The peak number of nauplii / eggs occurred after one month interval, was 64% on September and 95.5% on 21 November respectively. As above indicated that

the egg production throughout the reproductive period is not uniform in some reasons. There is a trough of egg laying in September. Corresponding to this, the brooding rate goes to its trough after about one month.

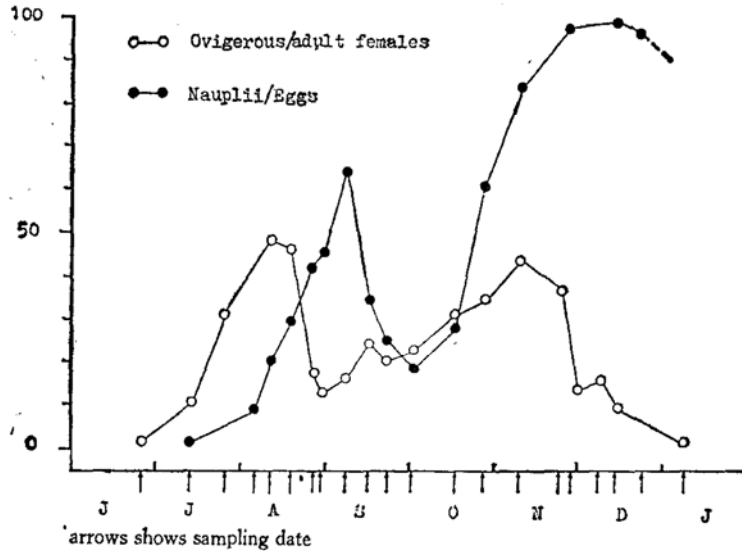


Fig. 7. Monthly variation of ovigerous/adult females and nauplii / eggs of *D. bispinosus* in reproductive period (June 1984—Jan. 1985).

### 3. The exogenous factors in population

A number of studies have explained that temperature, salinity, oxygen content, light, food, etc. would affect the population development and structure, reproduction and individual development of organisms. For example, most of aquatic animals adapt themselves to specific temperature range for their reproduction. This temperature range is mostly narrower than that in their normal life activities (Vernberg, 1972). The egg must be developed under stable conditions of temperature and salinity. The ripe *Calanus* does not necessarily lay its eggs but may hold them up until the condition in the sea are favourable. Food and dissolved oxygen could be inducing factors for egg laying and egg development and would be controlling conditions for larva development as well (Marshall & Orr, 1972; McLaren, 1963).

The adults of *D. bispinosus* in Burton Lake have their ability of adapting to higher salinity and lower temperature in the course of natural acclimatization in such lake environment (Wang, 1990). Their egg production occurred mainly from July to November. In this period, the water condition was more stable in temperature and salinity. The temperature of the entire oxylinion was in a range from  $-1.7$  to  $-1.5^{\circ}\text{C}$ , and the salinity varies mainly in 37—39.5‰. Therefore, it would be benefit to reproduction, particularly to larva development.

Thick ice and dark night in cold season resulted in decreasing light penetration severely in the lake. As shown in Fig. 8, the light penetration was almost zero (Burke, 1988), that means would nothing happen with photosynthesis under 2m depth. There were lowest phytoplanktonic biomass in the lake during this period (Burton, 1981; Burch, 1988). Fig. 9 shows the seasonal variation of phytoplankton density in Burton Lake in 1984. The diatoms, as important food resource for the copepods, also a dominant group of phytoplankton in the lake, its density was 1617 cells /  $1 \times 10^3$  per liter in summer (14 January 1985), and 22.8 cells /  $1 \times 10^8$  per liter in winter (12 July 1984). The diatom

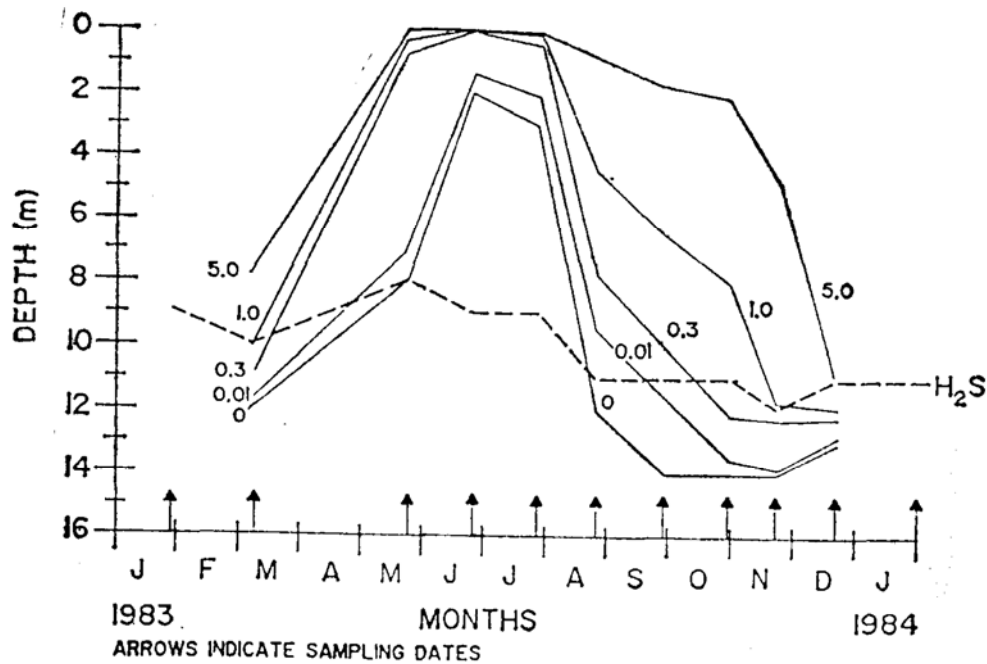


Fig. 8. Light penetration ( $\text{microeinsteins m}^{-2}\text{s}^{-1}$ ) of Burton Lake during 1983 (Burke, 1988).

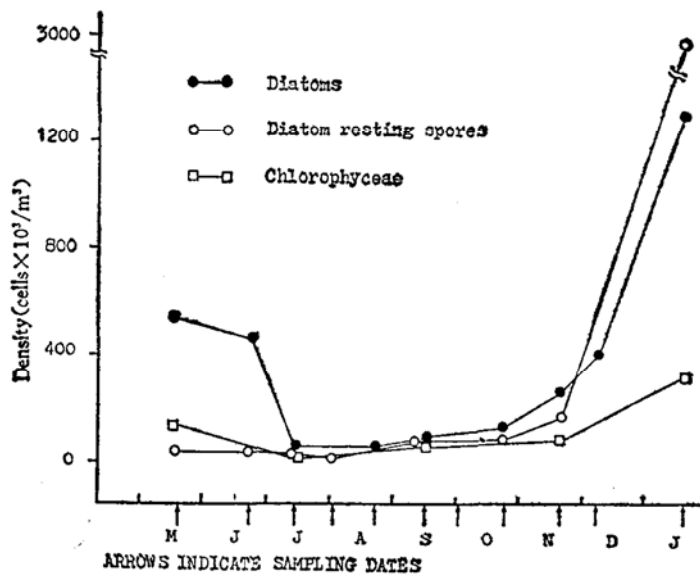


Fig. 9. Seasonal variation of some phytoplankton density in Burton Lake (May 1984—Jan, 1985).

resting spores, its density of cells was 7.4 in winter and 2085 in summer. The densities of Chlorophyceae and other species of phytoplankton, even photosynthetic bacteria were very low in the winter and early spring. However, there is quite food scarcity in this period (Hand & Burton, 1981; Wright & Burton, 1981; Heath, 1988; Burch, 1988; Burke & Burton, 1988). Although it might not much influence the earlier stage nauplii, but at least it would not advantage their developing further into copepodite stages.



The oxygen content measurements show that the oxygen in the lake tends to decrease in winter. Despite the number of phytoplankton increased in spring as light penetration rising up, the oxygen content in the lake tended to decrease until December (Fig. 4). It is evident that the oxygen produced by renewal phytoplankton in spring would partly compensate only for the oxygen consumption by oxidations in water and organisms. Therefore, the oxygen lack does occur for two or three months in spring. This would be much unfavourable to large numbers of larva development, particularly to higher stages. Marshall (1972) has explained that higher stage copepodites need more oxygen uptake than earlier stage larvae already.

Rippingale (1977) reported that the growth rate is depressed, when the nauplii of *Sulcanus conflictus* are in high salinities, because their energy are converted from growth to osmoregulation. Similar situation would be present for *D. bispinosus* in Burton Lake. Although the stable salinity appeared in winter-spring could be advantageous to adults egg laying, the higher salinity is inimical for the larva growth and development. A comparison between the tolerances of female adults and copepodites stage I-II on temperature and salinity indicates that under the same conditions the adults were more tolerant on higher salinities, and the copepodites were more tolerant on lower salinities (Wang, 1990). In the field, it was found that higher density of larvae occurred mainly in depth less 4m, salinity  $\leq 33\%$  (12 January 1985), and the adults were mostly distributed under depth 5m in oxylinion with salinities  $\geq 37\%$ . It is possible that the high salinity in the range 38.5—39.5‰ appeared in September-November, played role in restraining nauplii development to further stages.

The determinations of reduced sulfur gases and sulfate reduction in Burton Lake show that the chemical change would not much affect on the pH of the water (Deprez *et al.*, 1986; Frenzmann *et al.*, 1988). Shabica *et al.* (1975) described that the pH does have positive relation with primary production and dissolved oxygen. In this study, higher value area (pH 8.5) appeared from December would be related with the increasing phytoplankton, while higher area appeared in May could be mostly related with the increasing number of copepod adults and their exuberant metabolic activity.

#### 4. Density variation of adults and its ecological significance

Marshall *et al.* (1972) suggested that in natural conditions there is not much difference in numbers between male and female at least in their early stages. Bayly (1986) reported the sex ratio of *D. bispinosus* adults was 0.28 (in June) and 41 (in August) respectively. In Fig. 10 males are more than females before 15 June, then the adult females outnumber adult males shortly (13 July). The early death of male leaves the adult females free to consume the bulk of the available food during spring and early summer when much of the energy would be converted to the production of eggs (Bayly, 1986). The density of adult females has been more sustained, since it reached peak with 1348.3 / m<sup>3</sup> in mid-July. There were two conspicuous declines with decreasing rate 27.32% from 15 September to 1 October and 77.31% from 6 to 20 December. These are quite corresponding with two reproductive peaks (Fig. 6, 7). It is reasonable to consider that the death of most adult females might be related with their reproductive activity.

Of course, the senescence could be one of the important reasons to cause adult females to die. The main physiological features for senescence may exhibit great failure in adaptation ability to environmental stress, such as temperature and salinity, and remarked decline in metabolic rate. The determinations of physiological features show that the adult females of *D. bispinosus* might not be very much senescent (Wang *et al.*, 1989, 1990)

Except what is mentioned above, the existence of carnivores would be regarded as the factor to reduce adult density. The ctenophores were the most important consumers of this copepod in Burton Lake in 1984.

#### 5. Instance from Fletcher Lake

Fletcher Lake, another coastal saline lake at 20 km north of Burton Lake, In the evolutionary history, both lakes were apart of nearbay, so that they are similar in nature and circumstances, but different in some physical and chemical factors. The salinity of Fletcher Lake in oxylinmion was about 50 and 56 in September and December respectively. The temperature was  $-2.4$  (13 September), lower than that in Burton, and oxygen content in the former was much higher than in the latter. *D. bispinosus* was found as overwintering in Fletcher Lake. It was determined that the two lakes are different in physiological and ecological features of two populations (Wang, 1989). Table 1 shows a comparison of population densities in both lakes in 1984. There were less ovigerous females and less eggs on each ovigerous in Fletcher than that in Burton. It is likely that the high salinity, which is near the uplimit of their tolerance, would restrain the faculty of females in Fletcher Lake.

Table 1. Comparison of population densities of *D. bispinosus* on Burton Lake and Fletcher Lake (1984).

Sampling date	Fletcher Lake		Burton Lake	
	13 Sept.	6 Dec.	15 Sept.	6 Dec.
Total density* (No/m <sup>3</sup> )	205	128	1049	512.9
Female adult (No/m <sup>3</sup> )	156	121	1048	510.4
Male adult (No/m <sup>3</sup> )	38	0	1	0
Copepodite (No/m <sup>3</sup> )	11	7	1	2.5
Gravid female** (%)	49.1	57.4	46.1	56.1
Ovigerous female*** (%)	3.8	8.6	7.5	15.2

\* Including adult and copepodite only.

\*\* Gravid/all female adults.

\*\*\* Ovigerous female/all female adults.

Vernberg (1972) has stated that oxygen content increase would help some animals to enhance their tolerance on high salinity and temperature change. The dissolved oxygen in the depth less 5m was in a range of 8.54—8.87 ml / L (13 September) in the Fletcher Lake, and 6.64—6.74 (15 September) in Burton Lake. It was 11.73—12.68 (6 December) in the former and 8.66—11.51 (22 December) in the latter. It might be that the higher oxygen content was in favour of copepods to survival in such harsh salinity, particularly of larva development in Fletcher Lake. This is possible to explain that more nauplii could develop and moult to first copepodites in September in this lake under the conditions of higher oxygen, probably food as well. In contrast, it must not develop until December, when the oxygen and food have increased in Burton Lake. Despite these, the high salinity has mainly controlled the population growth and individual development (Wang, 1989).

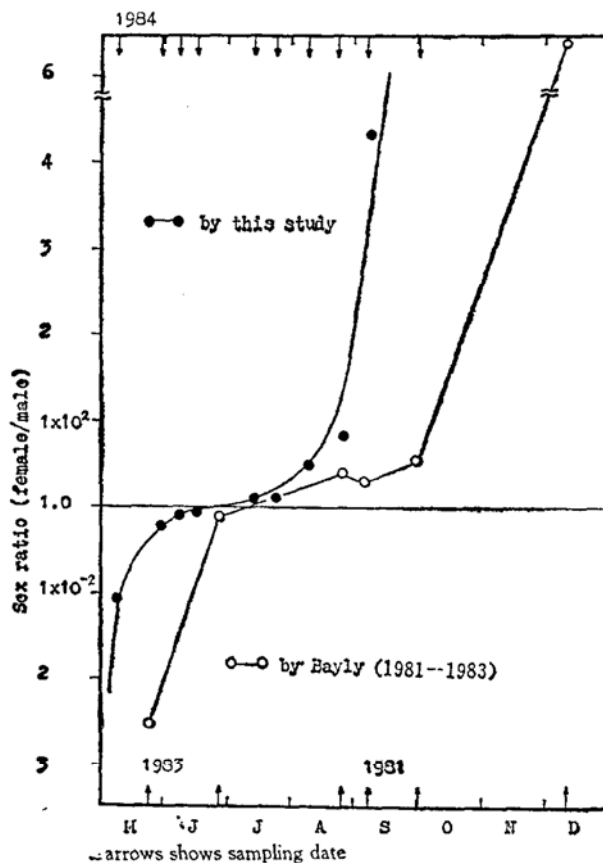


Fig. 10. Sex ratio of *D. bispinosus*.

### Conclusions

The eggs and nauplii occurred in early winter, it marks the beginning of life in new generation. With regard to the life cycle of population, it could be considered as starting. The generation would exist continually throughout the winter, spring and the second year, the life cycle of population (generation length) would last 20–21 months.

*D. bispinosus* lay their eggs mainly in the period of winter-spring, in which temperature and salinity have lesser changes. Large number of nauplii exist in spring-summer, it could develop to further stages in summer, when the ambient conditions turn to advantage.

There are remarkable population fluctuation and variation of population composition in a year. Salinity, oxygen content and food supply would be main external factors in effecting population dynamics in Burton Lake.

**Acknowledgement** This work was performed as part of the 1984 ANARE at Davis Station. I thank members of that expedition for their assistance and in particular H. Burton and D. Eslake for their contribution to some laboratory work.

### References

- Bayly, I. A. E. (1982): The genus *Drepanopus* (Copepoda; Calanoida); a review of species in Antarctic and Sub-Antarctic water, with a description of *D. bispinosus*, sp. nov. *Aust. J. mar. freshwat. Res.* 33: 161–172.
- Bayly, I. A. E. (1986): Ecology of the zooplankton of a meromictic antarctic lagoon with special reference to *Drepanopus bispinosus* (Copepoda: Calanoida), *Hydrobiologia*, 140: 199–231.

- Burton, H. R. (1981): Chemistry, physics and evolution of Antarctic saline lakes, *Hydrobiologia*, 82, 339—362.
- Burch, M. D. (1988): Annual cycle of phytoplankton in Ace Lake, and ice covered, saline meromictic lake, *Hydrobiologia*, 165, 59—75.
- Burke, C. M. & Burton H. R. (1988): The ecology of photosynthetic bacteria in Burton Lake, Vestfold Hills, Antarctica, *Hydrobiologia*, 165, 1—11.
- Deprez, P. P. Frezmann, P. D. & Burton, H. R. (1986): Determination of reduced sulfur gasses in Antarctic lakes and seawater by gas chromatography after solid adsorbent preconcentration, *Journal of Chromatography*, 362, 9—21.
- Evans, M. S. & Graiger, E. H. (1980): Zooplankton in a Canadian Arctic estuary, In V. S. Kennedy (ed.), *Estuarine Perspectives*, Academic Press, N. Y., 199—210.
- Franzmann, P. D., Skyring, G. W. Burton, H. R. & Deprez P. R. (1988): Sulfate reduction rates and some aspects of the limnology of four lakes and a fjord in Vestfold Hills, Antarctica, *Hydrobiologia*, 165, 25—33.
- Hand, R. M. & Burton, H. R. (1981): Microbial ecology of an Antarctic saline meromictic lake, *Hydrobiologia*, 82, 363—374.
- Heath, C. W. (1988): Annual primary productivity of an antarctic continental lake: Phytoplankton and benthic algal mat production strategies, *Hydrobiologia*, 165, 77—87.
- Kirkwood, J. M. & Burton, H. R. (1987): Three new Zooplankton nets designed for under-ice sampling; with preliminary results of collections made from Ellis Fjord, Antarctica during 1985, Mem. natn. Inst. Polar Res., Tokyo (Spec. Issue) (Proc. 9 th Symp. Polar Biol.), 112—122.
- Marshall, S. M. & Orr, A. P. (1972): The biology of a marine copepod, *Calanus finmarchicus* (Gunnerus), Springer-Verlag, Berlin, Heidelberg, New York, 195 pp.
- McLaren, I. A. (1963): Effects of temperature on growth of zooplankton, and the adaptive value of vertical migration, *J. Fish. Res. Bd. Canada*, 20 (3), 685—727.
- Rippingale, R. J. & Hodgkin, E. P. (1977): Food availability and salinity tolerance in a brackish water copepod., *Aust. J. Freshwater Res.*, 28, 1—7.
- Seppelt, R. D. & Broady, P. A. (1988): Antarctic terrestrial ecosystems: The Vestfold Hills in context, *Hydrobiologia*, 165, 177—184.
- Seppelt, R. D., Broady, P. A. Pickard, J. & Adamson, D. A. (1988): plants and landscape in the Vestfold Hills, Antarctica, *Hydrobiologia*, 165, 185—196.
- Shabica, S. V. Hedgpeth, J. W. & Park, P. K. (1975): Dissolved oxygen and pH increases by primary production in the surface water of Aethur Harbor, Antarctica, 1970—1971, In: *Adaptation Within Antarctic Ecosystems*. G. A. Llano (ed), Proceeding of the third SCAR Symposium on Antarctic Biology, Washington. D. C., 83—97.
- Tucker, M. J. & Burton, H. R. (1987): A survey of the marine fauna in shallow coastal water of the Vestfold Hills and Rauer Island, Antarctica, *Anare Res. Notes* No. 55, Antarct. Div., Dept. Sci., Hobart, 24pp.
- Vernberg, W. B. & Vernberg, F. J. (1972): Environmental physiology of marine animals, Springer-Verlag, Berlin Heidelberg, New York, 346 pp.
- Wang Zipan, Eslake, D. S. & Burton, H. R. (1989): Seasonal variance of salinity tolerance of a copepod *Drepanopus bispinosus* in an Antarctic littoral saline lake (Burton Lake), *Acta Oceanologica Sinica*, Vol. 8, No. 1, 137—144.
- Wang Zipan, Lin Bokang & Cao Yunhui, (1990): The study of Adaptability of *Drepanopus bispinosus* to temperature and salinity in the Antarctic Burton Lake, *Science in China* (Series B), Vol. 33, No. 7, 801—809.
- Wang Zipan, (1989): Comparison on ecological and physiological characteristics of *Drepanopus bispinosus* (Copepoda: Calanoida) between two populations in Burton Lake and Fletcher Lake, two Antarctic lagoons, *Acta Oceanologica Sinica*, Vol. 11 No. 6 (Chinese), 753—762.
- Wright, S. W. & Burton, H. R. (1981): The biology of Antarctic saline lakes, *Hydrobiologia*, 82, 319—338.

(received 1991)