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THE EFFECT OF ENVIRONMENTAL FACTORS ON POPULATION DYNAMICS OF *DREPANOPUS BISPINOSUS* (CALANOIDA: COPEPODA) IN BURTON LAKE, ANTARCTICA

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Abstract: The population dynamics of *Drepanopus bispinosus* (Calanoida: Copepoda) was studied throughout the year from December 1983–January 1985 in Burton Lake, a littoral saline lake in the Vestfold Hills, Antarctica. Also the environmental factors of the lake were observed simultaneously. *D. bispinosus* is univoltine The population life cycle could be in 20–21 months. Their reproductive activities spread from winter to early summer. The adults (male and female) and nauplii mainly constitute the winter population. Adult females and copepodites are absolutely components of the summer population. From late summer through autumn, the population consists mainly of copepodites in stages II–V. The densities of population components have presented considerable variations throughout their life time Most of nauplii occurring in winter might not develop and transform into further stages because of restrictive conditions such as low oxygen content and food scarcity. Earlier stage copepodites of new generation appear largely in summer, when the lake is rich in oxygen and phytoplankton The adult females decrease markedly after their reproductive activities when the strong salinity was diluted in early summer. Such variations of densities of population compositions are closely related to changing of environmental factors in the lake The material obtained from another saline lake in the same hills supported the above.

1. Introduction

Drepanopus (Calanoida: Copepoda) occurs very abundantly in coastal Sub-Antarctic and Antarctic waters. Some of them are general even dominant species in planktonic communities in those regions (BAYLY, 1982; TUCKER and BURTON, 1987). *D. bispinosus* also occurs in considerable abundance in the onshore waters of Antarctica. Collections from some saline lakes and fjords in Vestfold Hills, consisted almost entirely of this species in 1984. The ecology of *D. bispinosus* in Burton Lake has been described by BAYLY (1986) based on the extensive fieldwork and the material obtained separately for 1979–1982.

Burton Lake, unlike other meromictic lagoons, has limited water exchange with the connected bay. There is conspicuous seasonal variations in the lake with main physical and chemical factors, such as light, temperature and salinity, which play the important role of controlling nutrient recycle and primary producers (WRIGHT and BURTON, 1981), and directly affect consumers of those primary producers. FRANZ-

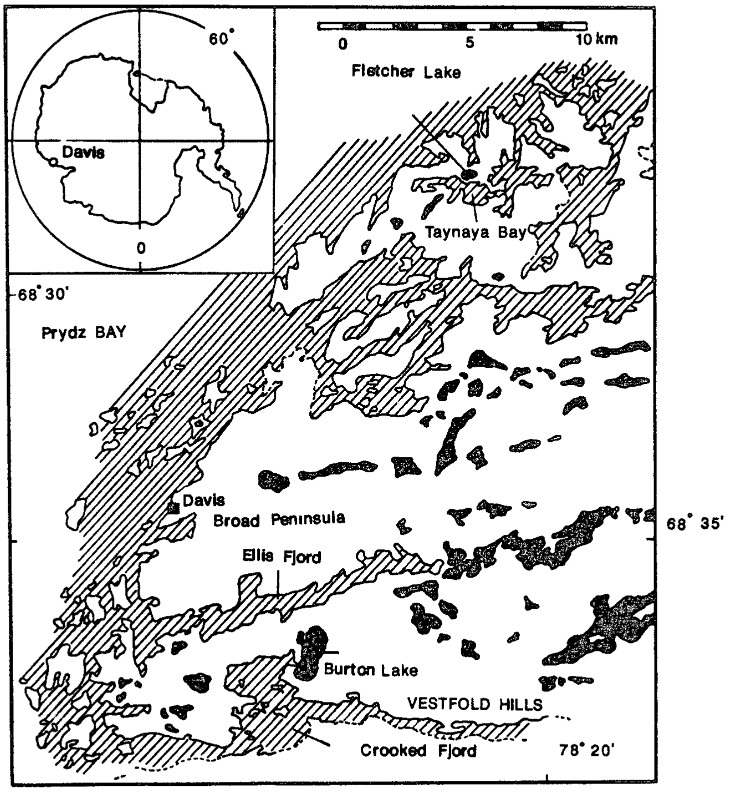

Fig 1 Location map of Burton Lake in the Vestfold Hills, Antarctica.

MANN *et al.* (1988) reported that dissolved sulfide occurs in the bottom water of Burton Lake and limits the distribution of copepods to the epilimnion. These, as above, must affect *D. bispinosus* 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 ambient circumstances.

This paper is based on the overwinter fieldwork throughout the year in 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 influenced by variant lake conditions in different seasons.

2. Materials and Methods

Samples were collceted from the centre of the northern part of the lake (depth 16 m). The collapsible plankton net (mesh size 210 μm for zooplankton collection and 100 μm for eggs, nauplii, phytoplankton concentration) described by BAYLY (1986) and KIRKWOOD and BURTON (1987) was used for animal samples. A series of five replicate vertical hauls at each sampling date was made through the entire width of measured oxylimnion The contents of the net were preserved in a 5% formaldehyde/seawater solution. The preserved samples were examined on return to the laboratory and the presence or absence of species recorded

Main environmental factors of the lake, such as ice thickness, temperature,

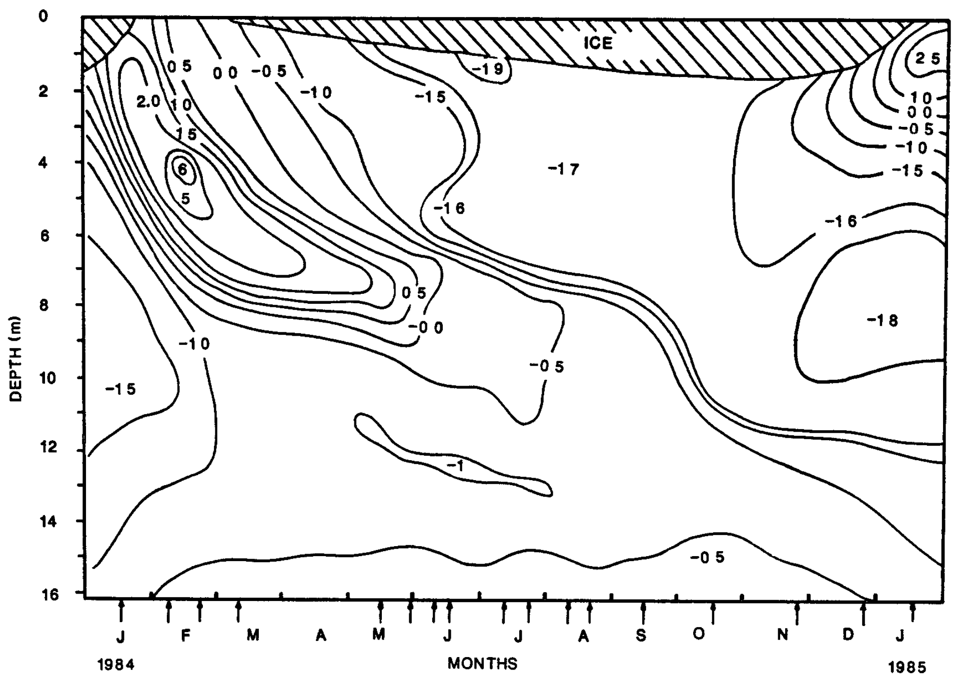

Fig 2. Isotherms (°C) in Burton Lake during 1984 Arrows indicate sampling dates.

salinity, dissolved oxygen and pH, were measured *in situ*. Salinity measurements were calculated from chlorinity measurements made with a DIONEX-10 liquid chromatograph. Temperatures were measured using the QT Digital Display Thermometer. Dissolved oxygen was fixed *in situ*, and measurements were made using WINKLER method in laboratory.

3. Results

3.1. Environmental condition of the lake

Burton Lake is a semi-enclosed body of water, and meromictic with an upper oxylimnion sharply separated from a lower anoxylimnion. The natural environment of the lake has been described by Bayly (1986) and Wang *et al.* (1989). The properties of the lake water obtained in 1984 are given below.

3.1.1. Temperature

Temperature–depth profiles for the period January 1984–January 1985 are shown in Fig. 2. It is important to note that the temperature of the entire oxylimnion throughout the year shows remarkable seasonal changes The variations occurred mainly in the period from summer to autumn (before June 1984 and December 1984–January 1985) (Fig. 2). The absolute difference of the temperatures appeared in the study period was 8.1°C. Temperature of entire oxylimnion after midwinter to the end of spring was remarkable stable within the range of −1.5°C to −1.7°C.

3.1.2. Salinity

Salinity–depth isopleths for the period January 1984–January 1985 are shown in Fig. 3. The salinity increased as ice thickened in cold season and decreased as

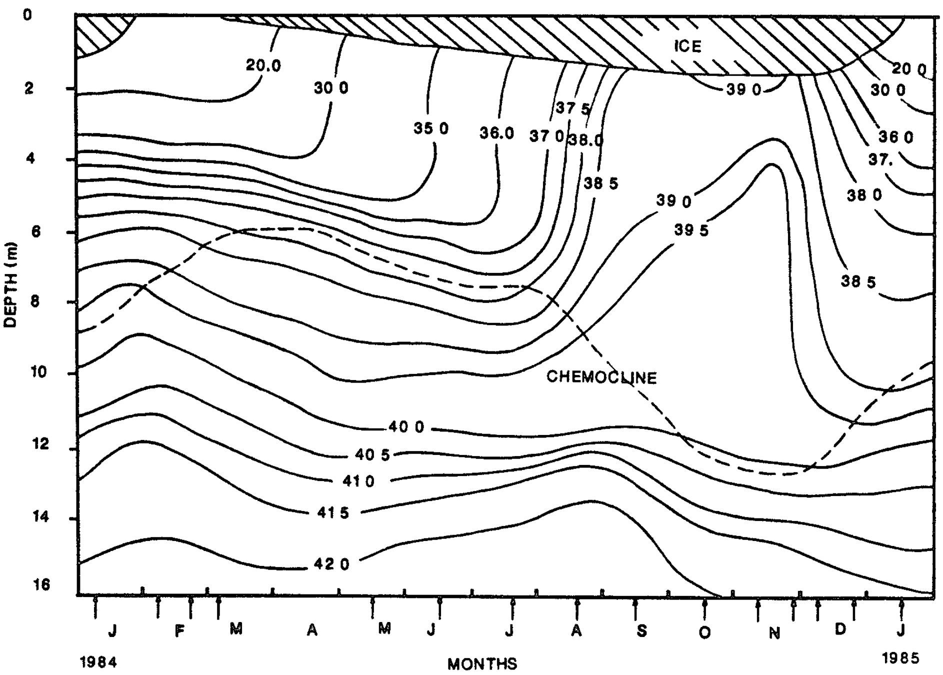

Fig 3 Isohaline (‰) map of Burton Lake during 1984 Arrows indicate sampling dates

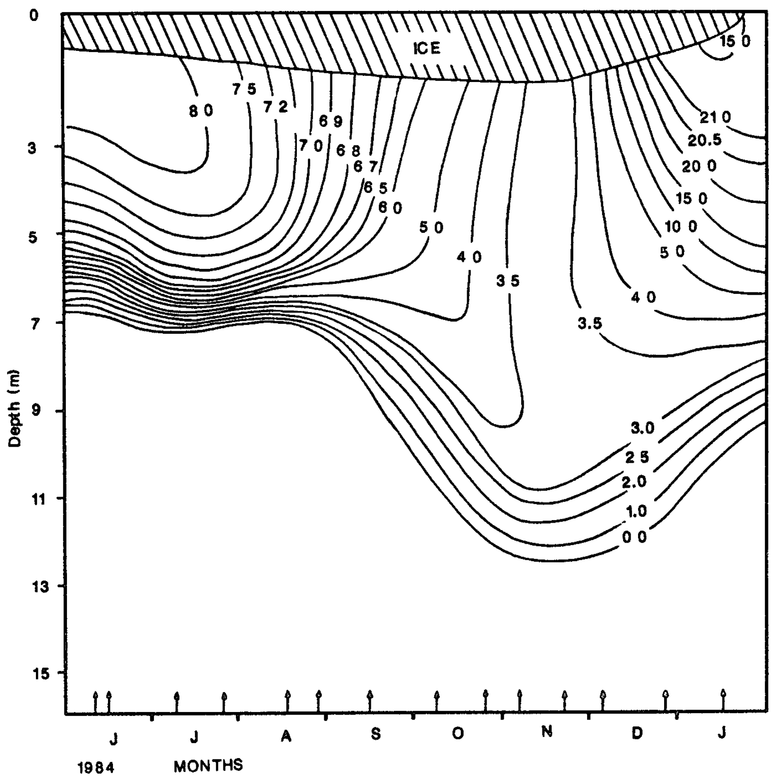

Fig 4 Profiles of oxygen content (ml/L) in Burton Lake during 1984 Arrows indicate sampling dates

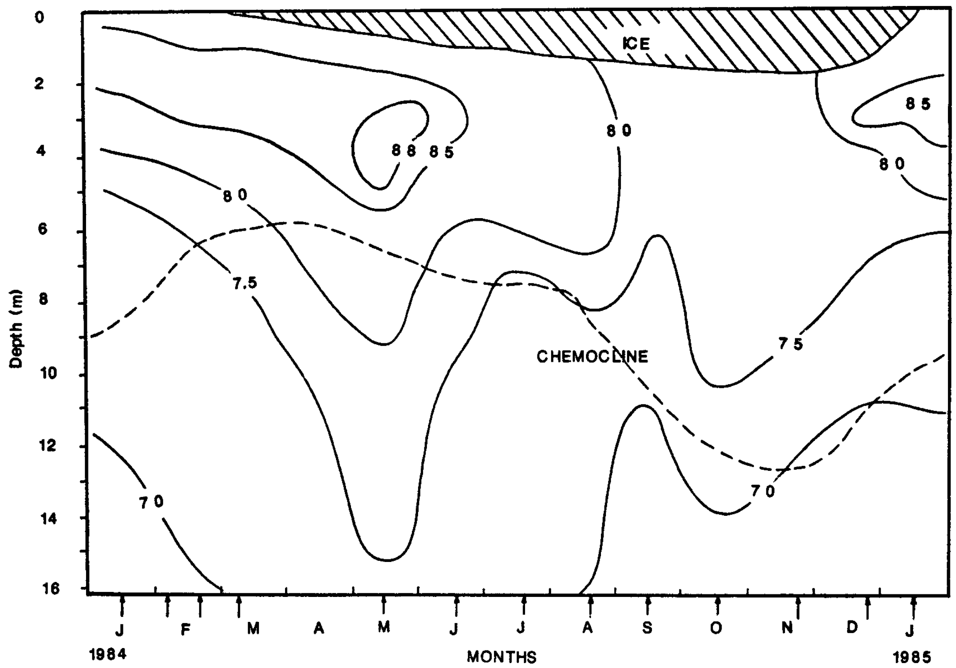

Fig. 5. Profiles of pH in Burton Lake during 1984. Arrows indicate sampling dates.

ice melted in warm season. Snow and ice melting diluted salinity from the surface to deep water mainly for depth less than 5 m, and the salinity varied within the range about 5–37‰. Salinity in the surface water within depth less than 1 m, measured in Fabruary 1984, was less than 5.

3.1.3. Dissolved oxygen

The vertical distribution of dissolved oxygen in the lake presented a decreasing tendency from surface under the ice to deep water. The chemocline position had seasonal variations; it oscillated between 7–12 m from June to November in 1984. The content of dissolved oxygen decreased smoothly as climate got cold, and increased repidly from December to January (Fig. 4). The highest value obtained on 16 January 1985 was 21.0601 ml/L at depth 3 m, but it was 3.2837 ml/L on 5 November 1984 at the same depth.

3.1.4. pH

The range of pH variation measured in 1984 was 6.8–8.9. Figure 5 shows the pH–depth profile for the period January 1984–January 1985. The pH value in oxylimnion was higher than under the chemoline There is a gradual reduction of pH from 8.5 (depth less than 5 m) in May to 7.5 in November (Fig. 5), and return steeply to 8.0 in January.

3.2. Characteristics of population dynamics and life cycle

Figure 6 shows the monthly changes of population densities and composition for the period from December 1983 to January 1985. In this study, the mature males were found at the end of April. They reached a peak in number in June, and disappeared after August. This is in agreement with the suggestion of BAYLY (1986). Some

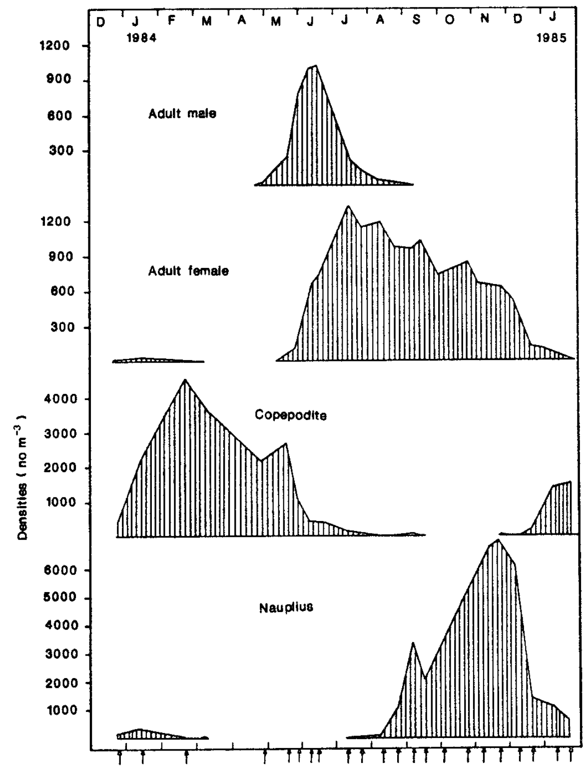

Fig. 6. Monthly variations of population densities of D. bispinosus *in Burton Lake (Dec. 1983–Jan. 1985) Arrows indicate sampling dates*

gravid females and spermatophore carriers were found in the collection of 15 June. The first ovigerous females were observed on 13 July Their number reached the first peak on 9 August with density 562.5/m^3 and the second peak on 5 November with density 292.2/m^3 (Fig. 7). Abundant eggs occurred in the period between these two peaks with the highest density 12847 5/m^3 on 1 October (Fig. 7). The nauplii of stage I were found in the same collection It is likely that the new generation nauplii occur at least in early July, which is two months earlier than that reported by BALAY (1986) The nauplii occurred from July to next February, and their number reached a peak in mid-November with density 7138 1/m^3. Prior to this, a small peak with density 3468 8/m^3 was recorded on 6 September (Fig. 6) The copepodites of stages I–V were present mainly from December to next July. The copepodites of stage I appeared on 17 August 1984 for the first time, they were not found on 26 October and 5 November 1984, but appeared again in late November and their number reached a peak on 22 January 1985 with density 1531 7/m^3 A few copepodites of stage V existed in the period from August to early November. Not many copepodites (nauplii as well) were collected on 24, 27 and 31 December 1983 However, they were abundant 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 of stages II–V (Fig 6).

MARSHALL and ORR (1972) suggested that some marine calanoida copepods have 2–3 generations for one year in low latitude waters. EVANS and GRAIGER (1980)

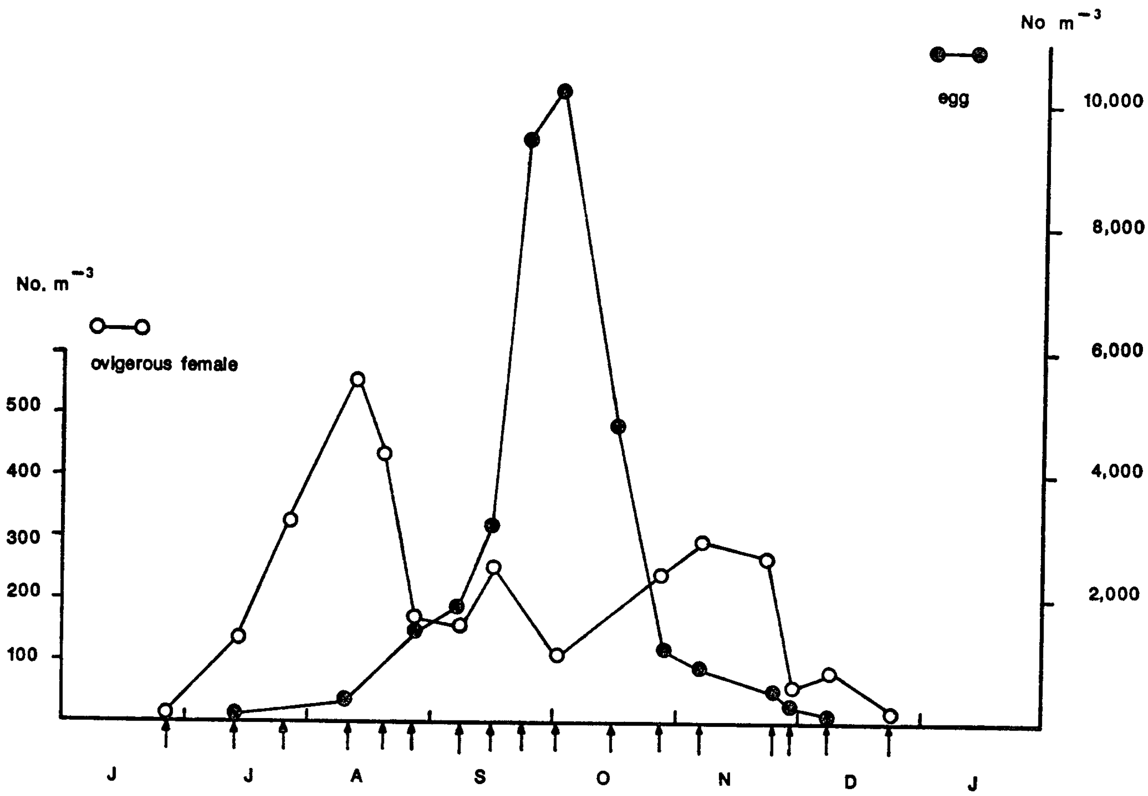

Fig 7. Monthly variations of density of ovigerous female and egg of D. bispinous *in Burton Lake in 1984. Arrows indicate sampling dates.*

reported that *Drepanopus bungei* (Sars) found in Arctic cold estuary water has one generation for one years. BAYLY (1986) suggested that *D. bispinosus* is univoltine. The result of this study is basically in agreement with BAYLY's.

3.3. Phytoplankton density

Figure 8 shows the seasonal variations of phytoplankton density in Burton Lake in 1984. Diatoms are important food resource for the copepods, and are the dominant group of phytoplankton in the lake. Their density was 22.8 cells$\times 10^3$ per liter of water (12 July 1984). The density of diatom resting spores was 7.4 cells$\times 10^3$ per liter (on the same date). The densities of Chlorophyceae and other species of phytoplankton, including phytosynthetic bacteria, were very low in the winter and early spring in this study.

4. Discussion

4.1. Population dynamics related to environmental factors in the lake

Some previous studies have stated that the egg development needs stable conditions of temperature and salinity. *Calanus* species do not necessarily lay eggs as their eggs mature but they retain the mature eggs until the water condition turns favourable. Food and dissolved oxygen could be inducing factors to egg laying and egg development, and would be controlling larvae development as well (MARSHALL and ORR,

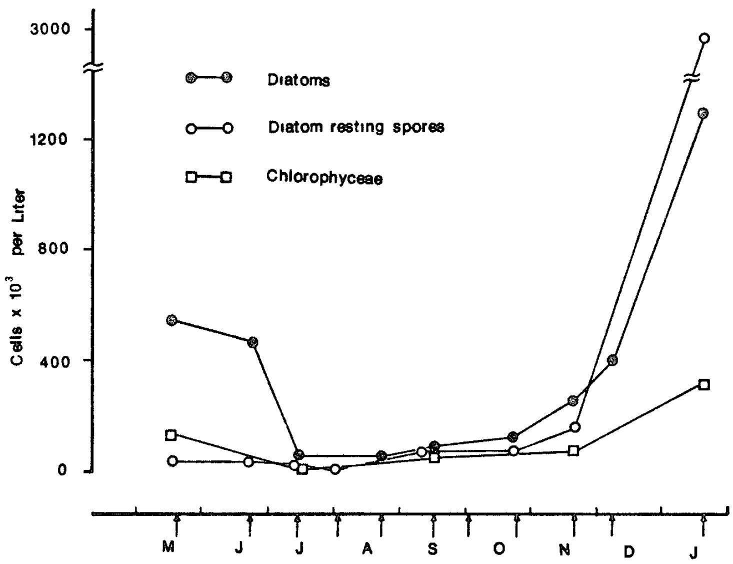

Fig. 8 *Seasonal variations of some phytoplankton densities in Burton Lake (May 1984–Jan. 1985) Arrows indicate sampling dates.*

1972; MCLAREN, 1963).

In Burton Lake, the egg production of *D. bispinosus* occurred mainly in July to November. In this period, the temperatures of the entire oxylimnion were within the range −1.7°C to −1.5°C, and the salinity variations were mainly 37–39.5‰. Thus stable water conditions would be beneficial to reproduction, particularly to larvae development.

Thick ice and dark night in the cold season resulted in a severe decrease of light penetration in the lake. The light penetration was almost zero during the winter (BURKE and BURTON, 1988). There was the lowest phytoplanktonic biomass in the lake in winter (Fig. 8; BURTON, 1981; BURCH, 1988). So the food was scarce in the winter as described in HAND and BURTON (1981), WRIGHT and BURTON (1981), HEATH (1988), BURCH (1988) and BURKE and BURTON (1988). Although the food scarcity in the winter might not influence the survival of the earlier stage nauplii, it would influence their development into copepodite stages. Abundant food in the summer (Fig. 8) would be favorable to larvae development.

The results of oxygen content measurement show that the oxygen in the lake presented a tendency to decrease in winter. Despite of the increasing phytoplankton in spring as light penetration getting better, the oxygen content in the lake kept going down until December (Fig. 4). It is evident that the oxygen producted by the phytoplankton in spring would partly compensate for the oxygen consumption only, which was caused 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 development of larvae, particularly to higher stages, which need more oxygen uptake than earlier stage larvae (MARSHALL and ORR, 1972).

RIPPINGALE and HODGKIN (1977) reported that the growth rate is depressed when the nauplii of *Sulcanus confilictus* are in high salinities, because their energy is diverted from growth to osmoregulation. Similar situation would happen to *D. bispinosus* in Burton Lake. Although the stable salinities in winter–spring could be advantageous to adults egg laying, the higher salinities were inimical to the larvae growth and development. In the field, it was found that higher densities of larvae occurred mainly at depth less than 4 m, salinity ≤33‰ (12 January 1985), and the adults were mostly distributed at depth under 5 m within oxylimnion, salinity ≥37‰. This might indicate that the adult females are more tolerant of high salinities, and the copepodites had higher tolerance for lower salinities (WANG *et al.*, 1990). It is possible that the high salinities within the range 38.5–39.5‰ in September–November prevented nauplii from developing to further stages.

The determinations of reduced sulfur gases and sulfate reduction in Burton Lake show that the chemical change would not much affect the pH of the water (DEPREZ *et al.*, 1986; FRANZMANN *et al.*, 1988). SHABICA *et al.* (1975) described that the pH does have positive relationships with primary production and dissolved oxygen. In this study, a higher value area (pH 8 5) occurred from December would be related to the increase of the phytoplankton, while a higher area occurred in May could be mostly related to the increase of large numbers of copepod adults and their exuberant metabolic activities.

4.2. Decline of adults and its ecological significance

BAYLY (1986) suggested that the mating of *D. bispinosus* occurs mainly in early winter, when significant numbers of mature females first appear. In my study, it occurred exactly in June (Fig. 6).

The ovigerious females, eggs and nauplii appeared in all the samples collected from July to January. This indicates that *D. bispinosus* had carried out reproductive activities uninterruptedly for those months. BAYLY (1986) reported the sex ratio of *D. bispinosus* adults (female: male) was 0.28 in June and 41 in August. In my study also, adult males appeared earlier than adult females (Fig. 6). The sex ratio was 0.68 in June and 51 07 in August. The early death of males 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 diverted to the production of eggs (BAYLY, 1986). The density of adult females has been further sustained, as it reached a peak with 1348.3/m^3 in mid July. There were two conspicuous declines with decreasing rate of 27.32% from 15 September to 1 October and 77.31% from 6 to 20 December (Fig. 6). These correspond to two reproductive peaks in August and November. It is reasonable to consider that the death of most adult females might occur after their reproductive activities.

Of course, the senescence could be one of the important causes of the death of adult females. The main physiological features for senescence may exhibit a great failure in adaptation abilities on environmental stress such as temperature and salinity, and a marked decline in metabolic rate. The determinations of physiological features show that the adult females of *D. bispinosus* might not be very senescent (WANG, 1989; WANG *et al.*, 1990).

Except the above, predation would be regarded as the factor to reduce adult densities. *Rathkea medusae* was the most important consumer of this copepod in

Burton Lake (BAYLY, 1986), but it was *Cydippida ctenophore* in 1984 (WANG, 1988).

4.3. Comparison with Fletcher Lake

Fletcher Lake, another coastal saline lake, is located 20 km north of Burton Lake. Some physical and chemical factors are different between the two lakes (Table 1). The salinity of Fletcher Lake in oxylimnion was about 50‰ and 56‰ in September and December, respectively. The temperature was −2 4°C (13 September), lower than that in Burton, and the oxygen content in the former was much higher than in the latter *D. bispinosus* was found to overwinter in Fletcher Lake. The differences in physiological and ecological features between two populations in the two lakes were determined (WANG, 1989). Table 1 shows the comparison of population densities in the two lakes in 1981. The density of adult females in Fletcher Lake was much smaller than in Burton Lake. It is likely that the strong salinity, which is close to the upper limit of their salinity tolerance, would restrain the survival and fecundity of females in Fletcher Lake.

VERNBERG and VERNBERG (1972) stated that increase in oxygen content would help some animals to enhance their tolerance on high salinities and fluctuating temperature. The dissolved oxygen at the depth less than 5 m was within the range of 8.54–8.87 ml/L (13 September) in Fletcher Lake, and 6.64–6.74 ml/L (15 September) in Burton Lake. It was 11.73–12.68 ml/L (6 December) in the former and 8 66–11.51

Table 1. Comparison of some physical and chemical factors between Burton Lake and Fletcher Lake (21 Dec 1984)

	Burton Lake	Fletcher Lake
Depth (m)	16	11
Oxylimnion line (m)	11	6
Salinity (‰)	38 5	56 2
Temperature (°C)	−1 6	−1 3
Dissolved oxygen (5 m, ml/L)	4 91	13 4
pH	7 5	8 2

Data from WANG (1989)

Table 2 Comparison of population densities of D bispinosus *in Burton Lake and Fletcher Lake (1984)*

Sampling date	Fletcher Lake		Burton Lake	
	13 Sept	6 Dec	15 Sept	6 Dec
Total density* (m^{-3})	205	128	1049	512 9
Adult females (m^{-3})	156	121	1048	510 4
Adult males (m^{-3})	38	0	1	0
Copepodites (m^{-3})	11	7	1	2 5
Ovigerous (%)	49 1	57 4	46 1	56 1
Dev. eggs** (%)	3 8	8 6	7 5	15 2

* Density of adult males, females and copepodites.
** % of adult females carrying nearly developed eggs.
Fletcher Lake data are in WANG, 1989.

ml/L (22 December) in the latter. It might be that the higher oxygen content was in favour of copepods' survival in such harsh salinity, particulary of larvae development in Fletcher Lake. It is possibly explained that more nauplii could develop and moult to first copepodites in September in this lake under the conditions of higher oxygen, and probably abundant food as well. In contrast, they would not develop until December, when the oxygen and food increased in Burton Lake. Despite these, the high salinity had mainly restrainted the population growth and individual development (WANG, 1989).

5. Conclusion

The eggs and nauplii occurred in early winter. With regard to the life cycle of population, this could be considered as a star. 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 winter–spring period, when temperature and salinity have changed less. A large number of nauplii exist in the period of spring–summer, and they could develop to further stages in summer when the ambient conditions turn to be advantageous.

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

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