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Limnology of Freshwater Lakes at Schirmacher Oasis, East Antarctica

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Ten freshwater lakes in the Schirmacher Oasis, Antarctica, with water temperature varying from 1.0 to 7.9° ; dissolved oxygen from 10.4 to 13.8 mg l^{-1} and *p*H from 7.6 to 8.8, were studied biologically during January-February of 1985 and 1987. The nutrient concentrations showed wide fluctuations with some lakes showing very low levels of nitrate and phosphate. The concentrations of dissolved and particulate carbohydrate indicated high organic matter content. Shallow water microfauna included seven taxonomic groups with minimum and maximum faunal density of 43 and 823 individuals 10 cm^{-2} respectively was recorded from covered and uncovered sediments. Faunal density showed a strong correlation wth organic carbon content and the sediment texture.

Key Words: Limnology, Freshwater lakes, Schirmacher oasis, Antarctica

Introduction

The freshwater lakes of the Antarctic continent, representing a biological integration of an entire drainage area, are particularly attractive ecological units for basic study (Priddle & Heywood 1980). The maritime Antarctic freshwater lakes at Signy Island, South Orkney Island and sub-Antarctic Kergulan and Marion Islands have been the subject of recent biological investigations. Available information indicates that major emphasis has been on the terrestrial and microbial ecosystems (McInnes & Ellis-Evans 1987, 1990). Consequently, informations about the faunistic aspects of limnetic and glacial biotopes, are limited (Suren 1990) and insufficient to permit any general interpretation. More recent studies recognised that the majority of the biomass standing crop accumulation in oasis ecosystems is attributable to the benthos (Block 1985) and the benthic vegetation play an important role in maintaining high diversity (McInnes & Ellis-Evans 1990). In addition, these fragile ecosystems are unique in several respects: most of them have a perennial 2-6 m ice cover, variable temperature profile, and abundant microflora and fauna but they lack grazers (Ingole & Parulekar 1990).

Although the Schirmacher Oasis was discovered in 1939 by a German expendition (Die Deutsche Antarctische Expedition 1942), no previous study has been made on lake faunal components and published records of an ecological type are few. The earliest account is of the chemical characteristics (Bardin & Leflat 1965, Wand et al. 1985) which was followed by investigations on the algal production (Komarek & Ruzicka 1966) and on the nutrient concentrations and primary produ-

ctivity in some freshwater lakes (Kaup 1988a, b). The present investigations were carried out during the austral summer of 1984-85 and 1986-87 (during the IV and VI Indian Scientific Expedition to Antarctica). The aim of this study was to describe the microfaunal component of freshwater habitats. The relationships between the distributional pattern of microfauna and certain environmental factors are also discussed as are faunal distribution, relative abundance and standing crop at the lake periphery.

Materials and Methods

Study site: The Schirmacher Oasis, forming a part of Dronning Maud Land, is about 90 km south of Princess Astrid coast of east Antarctica. It is an E-W tending low lying range with the maximum width of 3.5 km in the central part. It has a length of about 20 km and total area of about 35 sq.km (figure 1). The Schirmacher range comprises of a group of low lying hills about 50 to 200 m interspersed with a few glacial lakes ranging in size from 0.02 to 0.70 km^2. The catchment consists of barren moraine material, and patches of macrophytes in wet area. The majority of these lakes are arheic, possessing no outflow (except lakes 1, 2 and 3), and the annual ablation rate is generally balanced by the summer ephemeral inflow of glacial meltstreams. Lakes 4, 5 and 7 are very shallow, small in size and are subjected to periodic drying. The Schirmacher Oasis area was visited twice each year (between 18 Jan.-24 Feb., 1985 and 10 Jan.-10 Feb., 1987) when the material for the present study was collected.

Water collection and analysis: On each sampling occasion, surface water samples were collected by means of a clean polythene bucket during 18 to 24 Jan. 1985 and 10 Jan.-10 Feb. 1987. The water temperature was measured immediately after the sample was collected. For nutrient analysis the water samples were frozen immediately and transferred to the ship and analysed using the procedure outlined by Grassoff (1976). In-situ primary productivity was studied by the method of Strickland & Parsons (1972). The bottles were suspended at water surface. Dissolved oxygn and the salinity of the over-lying water were analysed according to Grasshoff (1976). The *p*H was measured in the ship laboratory using a Systronic digital *p*H meter. Temperature (surface water and sediment surface, under ≈ 5 cm water) and sediment type were also recorded.

Microfauna: Sediment samples were collected by using an acrylic/metallic hand-coring device (4.5 cmϕ)from the periphery (supralittoral) avoiding the inflows and outflows, of all the 10 lakes for the study of microfauna, particle size and organic content. During 1985, triplicate samples (in 1 m^2 area), up to 6

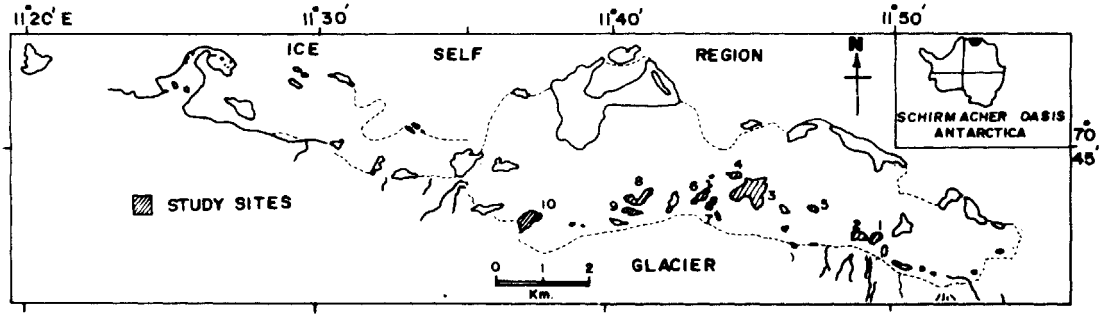

Figure 1 Location of Schirmacher Oasis, Queen maud Land East-antarctica, showing the study sites (Lake-1 to lake-10 in table 1).

cm sediment depth, were fixed in 4% neutralized formaldehyde solution to which 1% Rose-Bengal solution had been previously added. In 1987, faunal samples were preserved in 70% ethyl alcohol. Samples were washed through 63 and 20 μm mesh sieve in filtered freshwater. All animals were sorted, counted and identified to the taxon level. Counts were multiplied by 1.1 to correct for an extraction efficiency of 90% (McLachlan 1978). Particle size analysis of sediments was carried out according to Folk (1968) and organic content was estimated by the wet oxidation method of El Wakeel & Riley (1957).

Results

Environmental charcteristics: Table 1 and figure 2 summarize the data on the physico-chemical characteristics of ten lakes studied during January, 1985 and 1987, using means of three samples. The temperatures recorded during January 1985 in the upper layer of

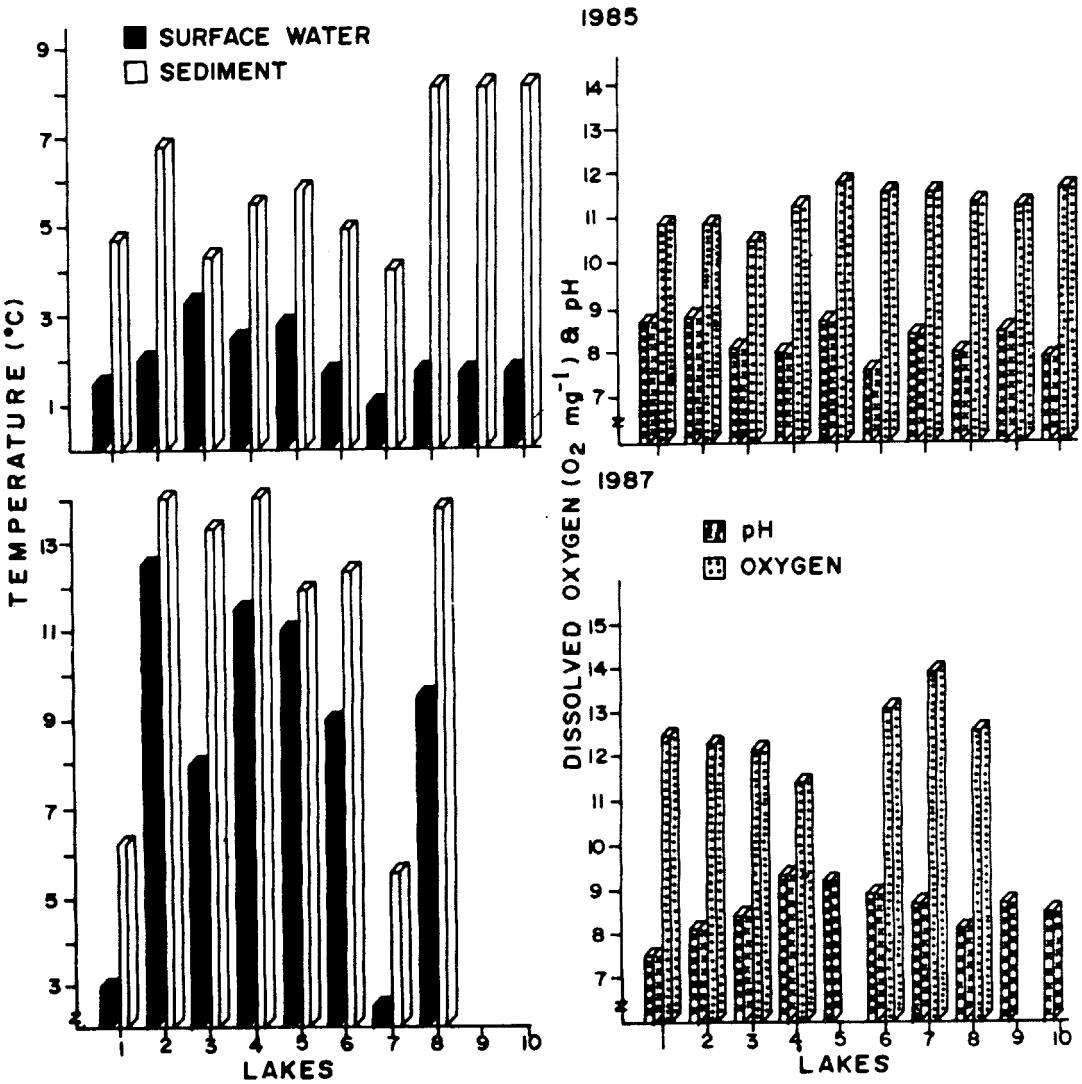

Figure 2 Comparison of environment parameters recorded during two austral summers (1985 & 1987)

Table 1 *Physico-chemical parameters of sediment overlying water of* 10 *freshwater lakes at Schirmacher Oasis, Antarctica (recorded during* 18 *January to* 2 *February* 1985)

	Lake Numbers (as shown in figure 1)										(Mean ± SD)
	1	2	3	4	5	6	7	8	9	10	
Temperature (°C)	7.0	4.0	3.0	3.0	4.0	3.5	3.2	3.7	2.6	2.7	(3.63 ± 1.27)
Salinity (‰)	0.13	0.09	0.09	0.1	0.18	1.9	0.1	0.1	0.1	0.1	(0.28 ± 0.57)
Dissolved oxygen (mg/l)	10.85	10.85	10.5	11.32	11.57	11.57	11.61	10.38	11.32	11.65	(11.16 ± 0.48)
*p*H	7.7	8.8	8.3	8.5	8.0	8.7	7.6	8.3	8.0	7.8	(8.17 ± 0.42)
Chlorophyll *a* (µg/l)	0.07	0.16	0.15	0.1	0.65	0.1	0.14	0.23	0.42	0.35	(0.24 ± 0.18)
PP (mgC/m-3/hr)	0.17	2.24	2.63	3.95	3.5	0.68	2.5	2.1	2.9	1.6	(2.23 ± 1.17)
PP Chl (mgC mg Chl/l/hr)	2.43	1.4	18.4	39.5	5.4	6.8	17.9	9.1	6.8	4.6	(11.23 ± 11.5)
Particulate oxidiable carbon (mg/l)	0.38	0.59	0.56	0.79	0.68	0.43	0.46	0.41	0.53	0.45	(0.53 ± 0.13)
Particulate carbon hydrate (mg/l)	147.3	162.3	179.7	241.3	224.9	186.3	179.5	231.5	223.1	189.3	(196.5 ± 31.73)
Dissolved carbon hydrate (µg/l)	0.8	3.1	5.6	3.2	1.6	1.9	2.9	3.0	3.6	1.6	(2.73 ± 1.35)
Dissolved organic phosphorus (µmol/l)	0.26	0.31	0.24	0.32	0.43	0.25	0.22	0.46	0.15	0.21	(0.29 ± 0.10)
PO_4-P µmol/l	0.06	0.07	0.10	0.12	0.05	0.2	0.06	1.07	0.4	0.3	(0.24 ± 0.31)
SiO_3 µmol/l	67.74	18.8	21.13	0.86	30.39	32.91	—	28.83	14.36	7.8	(22.28 ± 19.8)
Urea Nµmol/l	0.5	0.55	0.35	—	1.36	0.89	1.39	0.75	1.28	0.21	(0.59 ± 0.49)
NH_4-N µmol/l	0.33	0.33	0.41	1.3	0.84	0.53	0.44	1.73	1.01	0.45	(0.74 ± 0.47)
NO_2-N µmol/l	0.05	0.08	0.06	—	0.06	0.06	0.06	0.06	0.06	0.05	(0.05 ± 0.02)
NO_3N µmol/l	0.24	0.21	0.12	3.08	1.38	1.89	1.39	2.41	2.47	1.6	(1.36 ± 1.07)
NO_3/PO_4	4.0	3.0	1.3	25.7	27.6	9.45	22.8	2.25	6.18	5.3	(10.76 ± 10.39)
Total N µmol/l	6.85	2.42	3.04	5.41	9.27	6.05	74.56	17.93	11.89	3.6	(14.10 ± 21.76)

sediment and overlying water ranged from 4.0 to 8.1°C and 1.0 to 7.0°C, respectively. Values for January 1987 were 5.6 to 14°C and 1.0 to 7.9°C. Salinity of the lake water varied from 0.01 to 1.9 ‰ *p*H values were higher in 1987 (7.5-9.4) than in 1985 (7.6-8.8). Dissolved oxygen in overlying water ranged from 10.4 to 13.8 mg l^{-1}. DO values showed considerable increase in January, 1987 (11.5-13.8 mg l^{-1}) over those in January 1985 (10.4 to 11.7 mg l^{-1}).

The values for dissolved nutrient concentration fluctuated highly from one lake to the other, with some lakes showing very low levels of nitrate and phosphate (table 1). The maximum nitrate and phosphate values recorded were 3.1 and 1.1 µmol l^{-1}, respectively. The N:P concentration ratio varied from 0 to 27.6. The concentration of urea and ammonia varied from 0 to 1.4, l^{-1} and 0.3 to 1.7 µmol l^{-1}, respectively and the total nitrogen ranged from 0.8 to 17.9 µmol l^{-1} except for a very high value of 74.6 µmol l^{-1} in lake 7. While nitrate and phosphate values were low, the silicate concentration remained quite high varying between 0 and 67.7 µmol l^{-1} ($\bar{x}$:22.28 ± 19.8 sd). Only lake 4 showed a low Si content of 0.9 µmol l^{-1}.

While chlorophyll *a* was low (0.07 to 0.65 mg m^{-3}), the surface primary productivity (PP) varied between 0.17 and 3.95 mg C $m^{-2}hr^{-1}$. Particulate organic carbon varied between 0.38 and 1.04 mg l^{-1}, dissolved carbohydrate content between 0.8 and 5.6 mg l^{-1} (the higher values were mainly located in the areas containing thick moss beds) and particulate carbohydrate values between 147.3 and 241.3 µg l^{-1}.

Sediments at all the sampling sites were either covered with mosses or filamentous

Table 2 *Sediment characteristics of* 10 *freshwater habitats recorded during two austral summers (January-February,* 1985 *and* 1987)

Lake Nos	Description	1985			1987		
		Sand (%)	Silt & clay (%)	Organic carbon (%)	Sand (%)	Silt & clay (%)	Organic carbon (%)
1	Silty sand covered with moss turf	82.8	17.2	0.9	82.5	17.5	1.5
2	Coarse sand with pebbles	96.1	03.9	0.1	94.9	05.1	0.2
3	Silty sand covered with moss turf and algae	84.6	15.4	1.7	83.9	16.1	2.2
4	Coarse sand covered with turf	93.0	07.0	1.2	92.0	08.0	1.6
5	Silty sand covered with moss turf	87.8	12.2	1.8	87.5	12.5	2.0
6	Coarse sand with pebbles	97.6	02.4	0.0	96.4	03.6	0.2
7	Coarse sand with pebbles covered with moss carpet	91.7	08.3	0.0	90.6	09.4	0.3
8	Coarse sand with pebbles	96.2	03.8	0.1	95.0	05.0	0.4
9	Silty sand covered with moss carpet	86.5	13.5	0.9	86.1	13.9	1.3
10	Coarse sand with moss carpet	96.4	03.6	0.1	95.8	04.2	0.2
	Mean	91.3	08.7	0.7	90.5	09.5	1.0
	±SD	05.5	05.5	0.7	05.2	05.2	0.8

blue-green algae. The average percentage of sand, silt and clay along with the type of substrate recorded during January-February 1985 and 1987 are presented in table 2. Generally the substrate was rich in coarse particle size, poor in crystalline particles and dominated by pebbles. The proportion of coarse sand particles ranged from 82.8 to 97.6% ($\bar{x}$: 90.9 ± 5.2 sd; n = 20). Sediment covered with moss carpet was coarse, being poor in slit--clay fractions as compared to the uncovered sediment. The percentage of silt-clay varied from 2.4 to 17.2% ($\bar{x}$: 9.1 ± 5.2 sd; n = 20).

The organic carbon input from both the vegetation or glacial meltwater in the catchments was very low and ranged from 0.1 to 2.2% ($\bar{x}$: 0.8 ± 0.8 sd; n = 20). In general, the sediment covered with vegetation (the moss *Bryum* sp and green algae) showed a higher carbon content than the uncovered sediment. The minimum and maximum values for organic carbon were recorded at lake-7 during both the sampling years.

Microfauna: Fauna in the upper 6 cm layer of the sediments (including moss turf) comprised of seven taxonomic groups, and the population density (numbers/10 cm²) varied between 43 and 823. The minimum and the maximum mean values of 45 and 304 were recorded during January 1985, in lake 7 and lake 3, respectively (the corresponding values for January 1987 were 43 and 823). The fauna was dominated by Protozoa (Sarcodina, Mastigophora and Ciliata) which comprises 31% of the total microfauna. Dormant eggs of micro-invertebrates were abundant in all the samples and accounted for over 35% of the faunal population. Minimum and maximum density of 6 and 308 egs/10 cm² were recorded in lakes 3 and 2, respectively. Nematodes were next in order of abundance (12.0%) followed by turbellaians (8.8%) and tardigrades (5.1%) (figure 3). Other faunal components were rotifers (3.6%), oligochaetes (1.2%) and acarides (0.8%) which were maximum in the sediment coveed with mosses.

Table 3 *Most dominant species of freshwater fauna from Schirmacher Oasis, Antarctica.*

Taxon	Lakes									
	1	2	3	4	5	6	7	8	9	10
Ciliophora										
Oxytricha falax	+	+	+	+	+	+	−	−	+	+
Turbellaria										
Neorhabdocoel sp.	+	+	+	+	−	−	+	+	+	−
Kalyptorhynchia sp.	+	+	+	−	+	+	−	−	−	−
Rotifera										
Philodina gregaria	+	+	+	+	−	−	−	+	+	+
Nematoda										
Teratocephalus tilbrooki	+	+	+	+	+	+	+	+	+	+
Plectus sp.	+	−	+	+	+	−	−	+	+	+
Tardigrada										
Hypsibius sp.	+	−	+	−	+	−	+	−	+	+
Echinoiscoids sp.	+	−	+	−	−	−	+	+	+	+
Insecta										
Cryptopygus sp.	−	−	+	+	−	−	+	−	+	+

(+, Present; −, Absent).

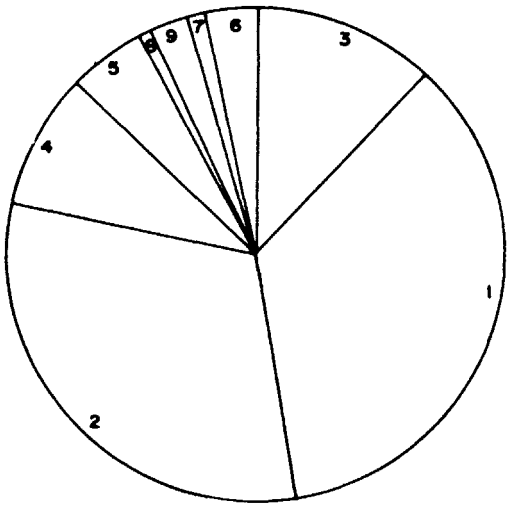

Figure 3 Microfaunal composition (%) in Schirmacher Oasis, Antarctica **1**, Dormant Eggs (35.2%). **2**, Protozoa (30.7%) **3**, Nematoda (12%) **4**, Turbellaria (8.8%) **5**, Tardiarada (5.1%) **6**, Rotifera (3.6%) **7**, Oligochaeta (1.2%) **8**, Acarina (0.8%) **9**, Unidentified forms (2.6%)

Spatial distribution of microfauna was observed and the animals were abundant in the vicinity of plant materials. A list of the

Table 4 *Morisita's Index* (1 δ) *for dispersion in case of dominant groups*

Total fauna	−0.0438
Nematoda	−0.0189
Turbellaria	−0.0193
Tardigrada	−0.0461
Egg capsules	−0.0155
Protozoa	−0.0038

$P < 0.01$

common microfaunal species is presented in table 3. Nematode, *Teratocephalus tilbrooki* was the most encountered species and recorded at all the sampling sites, whereas, *Plectus* sp. was found mainly in the mosses. Ciliate protozoan *Oxytrich falax* was recorded at 8 sampling sites. Tardigrades, and turbellarians, tentatively identified as *Hypsibius, Echiniscus, Macrobiotus, Neorhabdocoel* and *Kalyptorhynchia* spp. were abundant in the lake edge, where benthic algae (*Oscillatoria, Synechococcus, Nostoc, Phormidium, Chroococcus* spp.) and moss (*Bryum* sp.) were luxuriant.

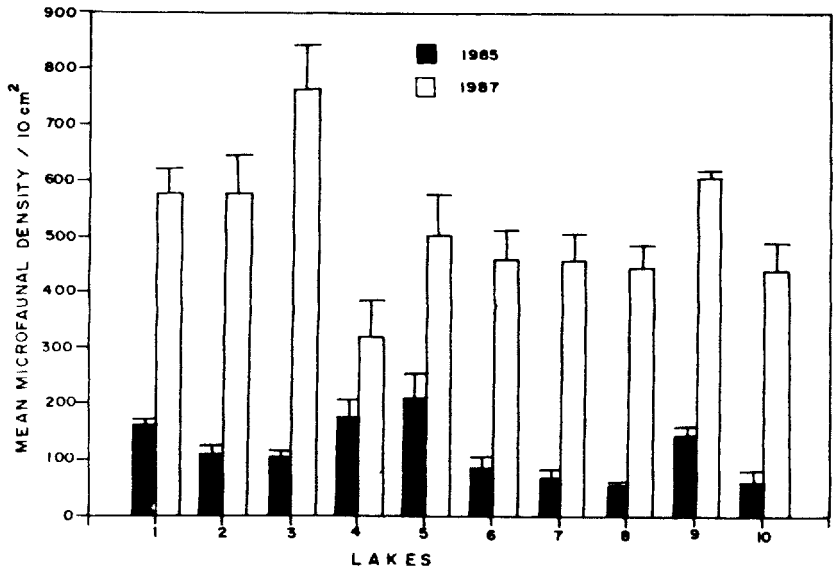

Figure 4 Comparison of microfaunal standing crop (+1 sd) at 10 freshwater lakes in the Schirmacher Oasis, Antarctica in 1985 and 1987.

Total faunal density for both the sampling years was compared against the measured environmental parameters by linear regression and significant results are summarized in table 5. All factors are expected to be relevant to the degree of faunal numbers. The silt-clay fractions of the sediment were positively related to faunal counts, and the sand percentage was inversely related to total faunal density. Microfaunal numbers showed strong correlation with organic carbon content but no signifcant relationships were found between sediment temperature and microfauna or dissolved oxygen tensions and microfauna. Values for all the factors were near to their critical limits suggesting the sensitivity of micro-invertebrates to small environmental changes.

Discussion

The Schirmacher range forms a group of low lying hills which are normally covered with some snow in winter. The snow melts off in summer to provide a free water zone and with the long photoperiod and high temperature, maximum phytoplankton production takes place during summer (Kaup 1988b). Increase in air temperature at Schirmacher Oasis (from −1.6°C in January 1985 to 5.0°C in January 1987), was mainly due to the day-to-day differences in air temperature (Ingole & Parulekar 1990) and was much higher than the values of −7.0° to 0.8°C recorded during November to January 1983-84 (Loopmann & Klokov 1988). The lakes melt completely or partly every year during the increase of air temperature in austral summer (Ingole & Parulekar 1990). The surface water temperature at the lake periphery ranged from 1.0 to 7.0°C during 22 January-23 February, 1985 and from 1.0 to 7.9°C during 10 January-10 February, 1987. Similarly the sediment temperature was found to range from 4 to 8.1°C. Goldman et al. (1972) reported the water temperature of Antarctic lakes to be 9°C above the air temperature in summer. Kelley and Zumberg (1961) observed rock surface temperature as much as 17°C higher than the air temperature. As inferred by Goldman et al. (1972) the large difference between air temperature and that of lake water and sediment indicate the effect of absorption of radiant solar energy in water, and on relatively dark sediment and rock surface.

Table 5 *Significant regression between parameters measured during the year* 1985 *and* 1987 (All have 8 degree of freedom)

1985			1987		
x	*y*	*r*	*x*	*y*	*r*
*p*H	Total numbers	0.65*	*p*H	Total numbers	0.63*
O.C.	Total numbers	0.80***	O.C.	Total numbers	0.66*
Sediment (sand)	Total numbers	−0.63*	Sediment (sand)	Total numbers	−0.68*
Sediment (silt & clay)	Total numbers	0.65*	Sediment (silt & clay)	Total numbers	0.71**
			Total numbers	Nematodes	0.66*
Sediment (silt & clay)	Nematodes	0.67*	Sediments	Nematodes	0.65*

* Microfauna numbers 10 cm^{-2}, **O.C. Organic Carbon, and *** = Significance at 5%, 2% and 1% respectively.

*P*H of all the lakes was found to be alkaline in nature. The values were higher in 1987 than in 1985, and much higher than the values (*p*H 5.88-7.37) reported by Kaup (1988a, b). This could reflect on the chemical composition of bed rock of the lakes or the area from where the input water is received. In lake 3 the *p*H values fluctuated from 7.6 to 8.6. One side of this lake receives water from a snow bank while at the other location it is fed by glacial outfall water passing through moraine consisting of stones and boulders. Sengupta and Qasim (1983) have reported the Ca and Mg content of Schirmacher Oasis lakes to be 107 and 67.1 mg l^{-1}, respectively. The higher content of calcium and magnesium and photosynthesis of bottom and peripheral algae may be responsible for the increased *p*H values observed in 1987.

Considerable increase in DO values in January 1987 (11.5-13.8 mg l^{-1}) over those in January 1985 (10.4-11.8 mg l^{-1}) was probably due to the active photosynthesis by the benthic and planktonic algae. Further, the purity of water resulted in the low consumption of oxygen, and the rising temperature later on contributed to the intensive production of oxygen by the bottom vegetation (Loopman 1988).

The remarkable increase in silt-clay fraction between 1985 and 1987 could be attributed to the mineral soil that thaws and gets deposited during the summer. Secondly, the increased human activities and movements of heavy vehicles, in the close proximity of the lakes may also contribute substantially to lake sedimentation. The flux of suspended particles and debris enter the lakes by melt water and contribute to increase in the silt-clay fraction (Ingole & Parulekar 1990). The values for sediment organic carbon differ significantly among the lakes studied and there was a considerable increase in organic carbon content over a period of two years. The organic substances drained from snow fields and glacial meltwater are concentrated in the residual lake waters by freezing out and the repeated freezing and evaporation of lake water concentrate organic substances in the lake bottom (McInnes & Ellis-Evans 1990). The lichen, mosses and algae, start growing during late spring and flourish well during summer months on the exposed rocky substrate around the lakes. These macrophytes act as a additional source of nutrients (Heywood 1984).

In general, majority of the freshwater animals, which have colonized Antarctic inland waters waters appears to be herbivores or detritirours (Heywood 1984) and accordingly, maximum faunal density was associated with silty sand having bacterio-algal layer and moss carpet. The algae and mosses provide a variety of niches where most of the invertebrates come for refuge and feeding purposes (Davis 1980). The aggregation of free living turbellarians, nematodes and tardigrades in the periphery suggests their preference for the lake vegetation where the organic material was abundant.

In spite of the common faunal communities in all the ten lakes, the values for microfaunal standing crop ranged widely. The chief cause of fluctuations in animal numbers is the instability of the environment and topographical characteristics of the lakes (Heywood 1984). The nature of the catchment and chemistry of water body are known to influence the invertebrate distribution in melt ponds of Ross ice shelf. Secondly, the superlittoral zone of these waterbodies experience rapid change in temperatures as a result of daily variations in air temperature, winds, precipitation and incidental solar radiation (M R Rameshkumar personal communication). In general, the microfauna found in ten lakes of Schirmacher Oasis consisted of invertebrate genera that are common and distributed widely in Antarctic continental lakes (Suren 1990). The faunal pauperism in these lakes could be attributed to cont-

inually low temperature regime, food availability and isolation.

The faunal density was much higher in 1987 and showed positive relationship with sediment silt-clay fraction ($r = 0.71$) and organic carbon ($r = 0.66$; 5% significant level, $df = 9$, table 5). It suggest that the organic enrichment and silt deposition from an inflow stream may influence the primary productivity and distribution of microfauna (Everett 1981, McInne & Ellis-Evans 1988). Secondy, as indicated by Ando (1979) increased air temperature in 1987, must be a factor responsible for the differentiation of faunal standing crop between 1985 and 1987 and may affect the microfauna in combination with other factors such as exposure to wind and degree of snow accumulation.

It may be concluded from present data that the environment in Schirmacher Oasis lakes is mainly controlled by the influx of glacial meltwater, coupled with rise in air and water temperature contribute significantly to the regeneration of dissolved nutrients and oxygen. Microfaunal composition and abundance in the supralittoral zone is related to the sediment texture. The metazoan pauperism in these lakes can be attributed in part to continually low temperature regime and the available low dissolved and particulate organic materials. The dispersal of microfauna depends on the summer flowing streams formed due to the glacial melt water and occasional breaching of lakes. Finally, since no previous study has been made on the microfauna, the present data will serve as basic information for undertaking a long-term ecological research program at Schirmacher Oasis.

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