

Ecobiological Studies of the Freshwater Lakes at Schirmacher Oasis, Antarctica

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Abstract

Ecological studies of the freshwater lakes at the Schirmacher Oasis have been reported. Physical variables such as atmospheric temperature, solar radiation, winds, etc. showed that the environment at Schirmacher Oasis is less extreme than near the coast. Lakes showed similarities in structure and were classified as proglacial lakes in the rock basins. NO_3 and PO_4 in lake waters were low ranging from 0 to $3.08 \mu\text{M}$ and 0.06 to $0.4 \mu\text{M}$ (except for one value of 1.07) respectively. These values were comparable to other freshwater lakes in Antarctica. SiO_3 concentration showed large fluctuations between lakes. Urea, ammonia, total nitrogen (TN) and dissolved organic phosphorus (DOP) attained maximum values of 1.39, 1.79, 16 and $0.52 \mu\text{M}$ in surface waters and contributed as an important N and P substitute to the algal growth. While chlorophyll *a* was low, surface values $< 0.7 \text{ mg m}^{-3}$, the primary productivity was variable. Thick moss beds and benthic algal mats were dominant in some lakes. Based on these characteristics the lakes were grouped as oligotrophic in nature.

Organic carbon content of sediment was low, ranging from 0.05 to 1.8% and consequently the faunal density was also low. Protozoans, Nematodes, Turbellaria, Tardigrades and Rotifers were dominant faunal groups. Bacteria and yeasts were predominant in soils and lake sediments. Detritus and associated bacteria form an important source of food for the opportunistic feeders such as metazoans. Long term studies of the lake environment from 1981 to 1994 have shown fluctuation in nutrients and chlorophyll without any signs of eutrophication. POC, sediment bacterial counts and microfaunal density showed an increasing trend. Survival of *Phoromidium* sp. for several years in lake waters was noted as a remarkable feature which supported the view that the reproductive cycle in these lakes maintains a steady state, in spite of harsh changes in the environmental conditions.

Introduction

Antarctica contains a number of lakes in ice free areas. Some of the lakes harbour important flora and fauna of the Antarctic continent. A continuous cycle of freezing and melting in winter and summer brings a large amount of

changes in physico-chemical and biological properties of the waters and bottom sediments. There are instances where the lakes are even subjected to drying in course of time as a result of negative water balance. The influence of environmental and physical changes provide unique conditions for the development of biotic communities in and around the lakes.

The relative importance of light, temperature and nutrients on primary productivity and species composition of plankton communities of Lake Vanda in the southern Victoria Land and Deep Lake (Vestfold Hills) have been indicated by Vincent and Vincent (1982), Parker *et al.* (1982) and Campbell (1978). Suren (1990) and Cathey *et al.* (1981) concluded that the environmental parameters and conductivity influenced the macrofaunal colonisation on algal mats and on artificial substrates in dry lakes in northern Victoria Land.

Schirmacher Oasis lakes have received relatively less attention. Early reports were those of the German Expedition of 1938-39, which described these lakes as series of ponds known as Schirmacher ponds, formed in the depressions between the hills. Komarek and Ruzika (1966) working on the ice covered lakes of Schirmacher found that these lakes were highly productive of blue green algae *Phormidium* even at low temperature of 0 to -5°C . The biology of these lakes was investigated by the first Indian Expedition to Antarctica in 1982. The lake waters were found to contain high bacterial population with low nitrate and phosphate (Matondkar and Gomes, 1983; Sengupta and Qasim, 1983).

In order to investigate the influence of different physical and chemical factors on ecobiology of this freshwater environment, detailed investigations were carried out on the nutrients, primary productivity, microfloral and macrofaunal characteristics of 10 different lakes during Antarctic summer 1984-85. Data collected from 1982 to 1994 for Zub (Priyadarshini) lake has been used to predict long term responses of environmental stresses on biological productivity.

Description of the Study Area

Schirmacher hill is a typical desert oasis of Antarctica situated 70 km away from Prince Astrid coast. It is a low lying range tending with the maximum width of 2.7 km in the central part between latitude $70^{\circ}44'33''\text{S}$ to $70^{\circ}46'30''\text{S}$ and longitude $11^{\circ}22'40''\text{E}$ to $11^{\circ}54'00''\text{E}$. Unlike the main mountain range, Schirmacher forms a group of low lying hills of about 50 to 200 m high interspersed with a few glacial lakes ranging in size from 0.02 to 0.75 km^2 (Fig. 1a).

Extreme air temperature recorded at Schirmacher vary from a minimum of -40°C in winter to a maximum of $+6^{\circ}\text{C}$ in summer (Fig. 2). Precipitation in

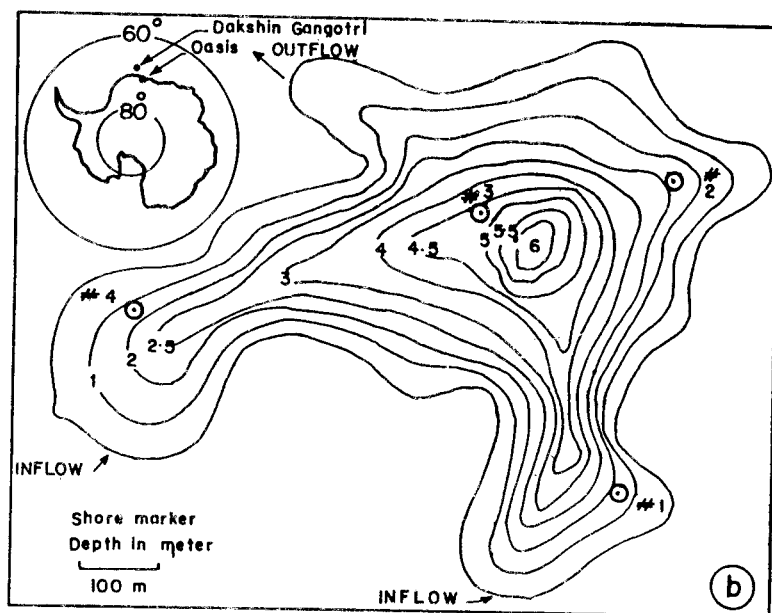
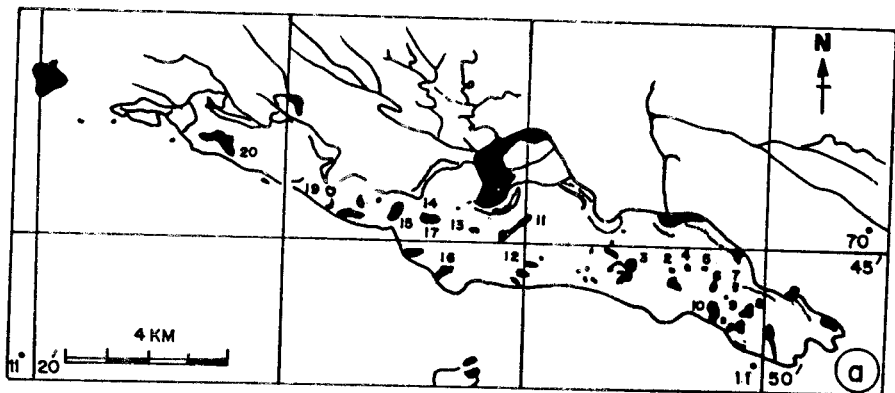


Fig. 1a. Map of Schirmacher Oasis, Antarctica showing different lakes, numbers 1 to 10 represent the lakes sampled during austral summer 1985

Fig. 1b. Bathymetric map of Zub lake with depth contours in metres (not referred to seawater; source: Ingole and Parulekar, 1990). Symbol shows station positions occupied

the form of snowfall is quite heavy but most of it is blown by strong katabatic winds from easterly direction. Monthly average of daily global solar radiation values ranged from 0 to $33.92 \text{ MJ m}^{-2} \text{ d}^{-1}$ for the years 1984 to 1986 (Fig. 3). Summer melting of glaciers and snow banks replenishes the water losses in these lakes due to evaporation.

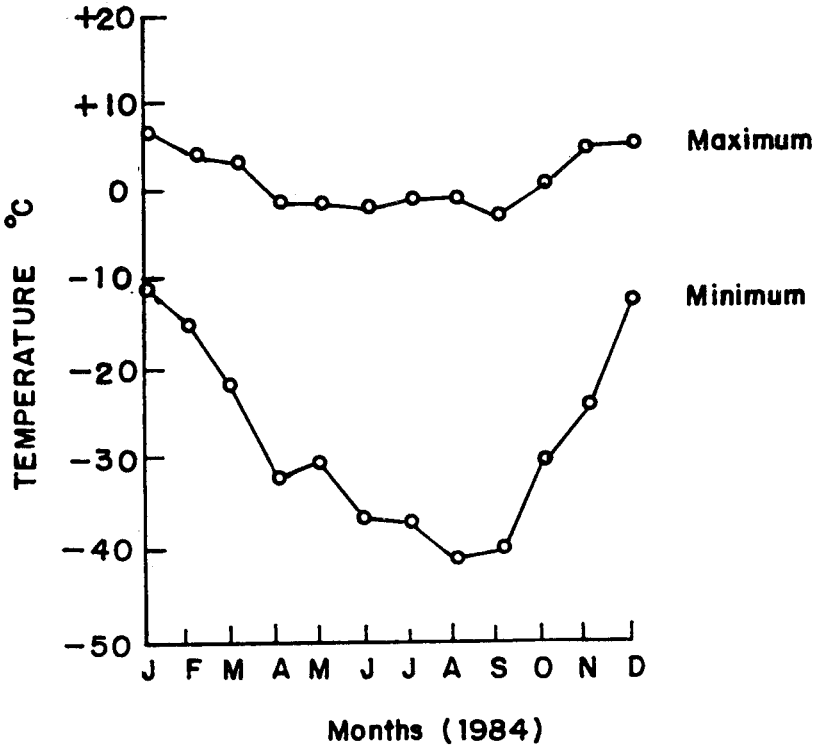


Fig.2. Monthly average of atmospheric temperature at Schirmacher Oasis in 1984

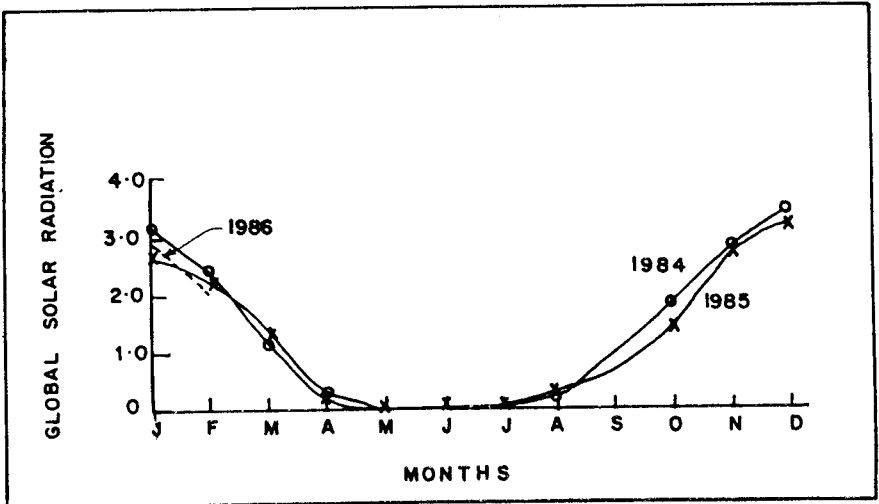


Fig.3. Daily global solar radiation for years 1984-85 at Schirmacher, $MJ m^{-2} d^{-1}$

Many of these lakes are thickly covered with permanent moss carpets. Zub lake which is broad and shallow at the periphery, with an area of about 0.75 km^2 , invited special attention because of the location of Maitri station on its banks. Details regarding the bathymetry and water inflow in this lake are shown in Fig. 1b.

Material and Methods

Four stations were fixed in the Zub lake, two at the centre and two at the peripheral lobes (Fig. 1b). Nine other lakes in the Schirmacher range were also sampled for water and sediments from bottom and peripheral regions (Fig. 1a). Surface water samples were collected from a boat with a clean plastic bucket during austral summer period from 18 to 24 January, 1985. Depth of the lakes varied from 3 to 8 metres. The bottom water was sampled using 5 l capacity Van Dorn bottle.

Bottom sediments were collected using a Van Veen grab. Water temperature was measured immediately after sample collection with the help of thermometer. For nutrient analysis the water samples were frozen and transferred to the laboratory on board the ship. Urea, ammonia, nitrate, nitrite, phosphate, silicate, total dissolved organic phosphorus, salinity and dissolved oxygen were analysed using procedures outlined by Grasshoff (1976). *In situ* primary productivity was studied using the method of Strickland and Parsons (1972). A pyrex reagent bottle (125 ml) was filled with water sample and inoculated with $5 \mu\text{Ci}$ of ^{14}C in the form of $\text{NaH}^{14}\text{CO}_3$. These samples were suspended for 24 hour incubation at the depths sampled. After incubation the contents in the bottles were immediately filtered through Millipore membrane filters of 0.45μ pore size filters. The ^{14}C on the filters was determined by liquid scintillation counting. Chlorophyll *a* and phaeophytin were measured fluorometrically using Turner Designs fluorometer (Strickland and Parsons, 1972).

Zooplankton samples were obtained by horizontal hauls from 5 stations using $300 \mu\text{m}$ mesh rectangular plankton net. Duplicate hauls (each of 5 minutes) were taken at each station. The samples were preserved in 5% formaldehyde and identified and counted. Microfauna samples were collected from periphery of all the lakes using a hand held plastic corer (10 cm length, 4.5 cm inner diameter). Duplicate samples up to 6 cm sediment depth were fixed in 4% formaldehyde solution to which 1% of rose bengal solution was added. A portion of the sediment sample was used for determination of the organic carbon content and particulate size analysis. Sediment organic carbon was analysed using wet oxidation method of El-Wakeel and Riley (1959). A

systronic digital pH meter was used to measure hydrogen ion concentration of the samples.

Faunal samples were washed through 0.5 mm and 0.063 mm sieves, in filtered fresh water on board and the contents of the 0.063 mm sieve were then preserved in 4% formaldehyde solution. All organisms were sorted, counted and identified to the possible taxa using a Projectina microscope. Particulate size analysis of the sediments was carried out following the method of Holme and McIntyre (1971).

Results and Discussion

Physical and Chemical Environment

Surface Winds: Winds at Schirmacher range normally varied from ENE to SE. They remained strong from 0600 to 1100 hrs, with a maximum around 1000 hrs. Southerly component of the wind showed an increase around 2100 hrs, which became normal by early morning. The winds are normally easterly-south easterly, 10 to 15 knots. The surface winds increase in speed due to low pressure system as shown in Table 1. At times, without any difference in barometric pressure the winds reached up to 30 knots at night. Further due to terrain, the gustiness of winds is much more than the ice shelf station, Dakshin Gangotri or at the coast on board the ship.

Weather at Schirmacher normally remained better than at the coast. Snow-fall/snowstorm/overcast sky indicated some changes in the weather parameters. However, the incidence of low clouds and fog near Schirmacher was much less than near the sea coast. In general, the clouding is much more near the sea coast than at Schirmacher.

Solar Radiation and Temperature: Mean global radiation value for January 1985 recorded at the Schirmacher was $27.99 \text{ MJ m}^{-2} \text{ d}^{-1}$ (Apte and Upadyai, 1990; Fig. 3). Air temperature during sampling period 18 to 24 January 1985 varied from -3 to 1°C . Compared to air, the surface water temperature of the lake was found to be much higher varying from 1.5 to 7°C (Fig. 4). The bottom temperature remained lower than the surface water, ranging from 1.5 to 5°C at lakes 1 to 3. This showed that the lake waters are stratified. The maximum difference between surface and bottom waters was 3°C . The sediment temperature at these two lakes ranged from 4 to 8.1°C . The higher temperature of the sediment is due to absorption of solar radiation penetrating the water column (Goldman *et al.*, 1972).

Based on the values of the incident solar radiation and the temperature of air and ice, the net radiation input to the snow cover could be calculated. The

Table 1: Low pressure systems : Latitudinal position and weather (Gauri Shankar, IAF – personal communication)

Sr. No.	System Movement	System Strength	Effect on DG Weather
1.	North of 55°S	Weak	No effect
		Well marked	Increase in low clouds in northern horizon, no effect on DG
2.	North of 60°S	Weak	No much effect.
		Well marked	Increase in clouding for one to two days with increase in surface winds.
3.	South of 60°S	Weak	Increase in clouding (becoming mainly overcast/overcast) accompanied by gusty strong surface winds and low clouds and at times with snowfall.
		Well marked	Increase in clouding and strong surface winds exceeding 30 knots and snowfall weather for 36-48 hrs.
4.	South of 60°S	Well marked	Increase in clouding and persistent strong winds exceeding 40 knots, blizzards and snowfall. Bad weather existing more than 72 hrs depending on ridge.

horizontal conduction of this adsorbed solar radiation is an important mechanism in initiating and accelerating the melting of ice cover, as shown in Table 2. The summer melting begins in October and continues up to February reaching a peak in December-January. Several lake waters are replenished annually by melting of the adjoining glaciers and snow banks.

Salinity, Dissolved Oxygen and pH: The lake waters were almost non-saline, salinity ranging from 0.09 to 1.93×10^{-3} units (Fig 4). The values did not show any change in the bottom waters. Dissolved Oxygen (DO) in the surface waters ranged from 4.3 to 5.9 ml l⁻¹ showing that the lake waters were well aerated. DO in the bottom waters remained higher than in the surface waters ranging from 5.86 to 6.02 ml l⁻¹ (Fig. 4). Parker *et al.* (1982) reported that lake Vanda and some of the ice covered deep lakes in the southern Victoria Land (Ross ice shelf) were supersaturated with DO 15 mg l⁻¹. The water column of most of these lakes was stratified. Under this condition the shallowest water represented the most recent influx of water into lakes from adjacent glaciers in the catchment basins. At Schirmacher lakes, while the input from melt water observed visually was large, the recent influx of water could not be distinguished due to weak density stratification.

Table 2: Net energy (Q) in MJ m⁻²d⁻¹ available to snow surface and snowmelt cm d⁻¹ at Dakshin Gangotri station in summer (Source: Apte and Upadhyai, 1990)

Month/Year	Q	Snow Temp °C	Snow Melt
Oct. 84	0.66	-15.2	0.01
Nov. 84	0.06	-8.4	0.14
Dec. 84	5.74	-2.0	0.86
Jan. 85	3.57	-1.3	0.82
Feb. 85	2.33	-5.3	0.13
Oct. 85	0.38	-14.3	0.01
Nov. 85	4.91	-9.5	0.15
Dec. 85	5.33	-3.5	0.45
Jan. 86	3.64	-2.0	0.54
Feb. 86	1.63	-3.5	0.14

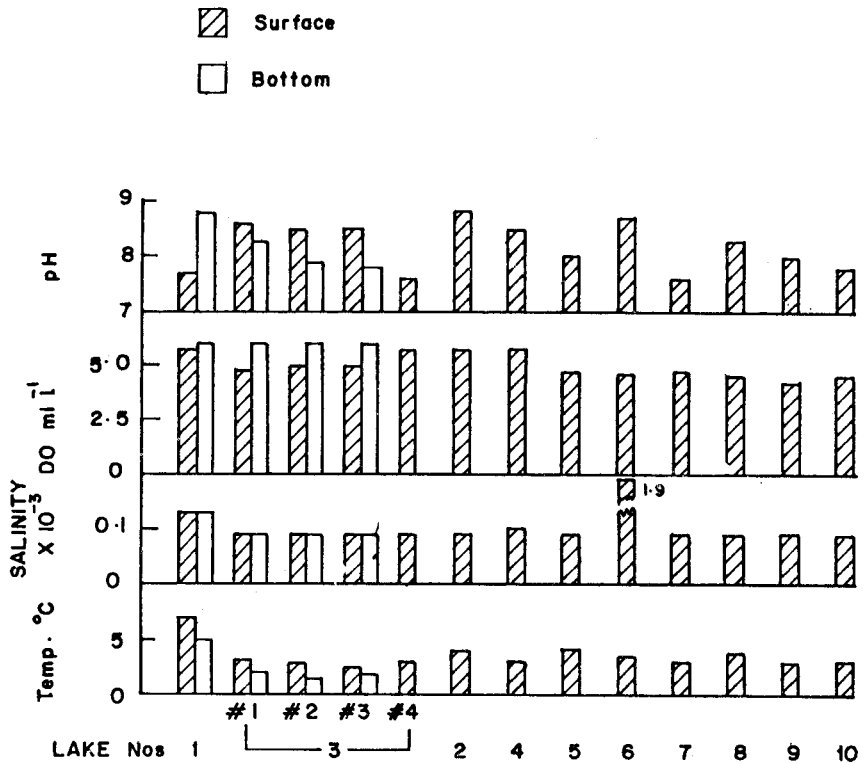


Fig. 4. Temperature, salinity, dissolved oxygen (DO) and pH in 10 lakes at Schirmacher Oasis in January 1985

pH in the surface waters ranged from 7.55 to 8.75 showing alkaline nature of the lakes (Fig 4). In lake 1 the pH in the bottom water was high while the reverse was observed in lake 3. Such changes may reflect the chemical composition of the bed rock sediments of each of the lakes. Ca and Mg content of lake 3 was reported to be 107 and 67 mg l⁻¹ respectively (Sengupta and Qasim, 1983). The high content of Ca, Mg and photosynthetic benthic algae may partly be responsible for the increased pH in this lake. However, the pH values reported at these lakes are comparable to those of south Victoria Land and Signy island (Cathey *et al.*, 1981; Priddle and Heywood, 1980).

Nutrients: Silicate concentration in the surface waters showed large variation from one lake to the other with values ranging between 0.9 to 67.7 µM (Fig. 5). In the bottom waters Si remained slightly higher than the surface waters. The highest concentration of Si was found in lake 1 and station 4 in lake 3. While the former location was embanked by rocks and silt the later received melt water passing through the glacial moraine. These may serve as Si sources for the lakes. The maximum PO₄ and NO₃ values recorded in the surface waters were 0.4 µM (except for one value of 1.1) and 3.1 µM respectively. There is no regular trend of increase or decrease of these nutrients in the bottom waters. However, the NO₂ was uniformly low (< 0.1 µM) in all lakes.

Urea and ammonia varied from 0 to 1.39 and 0.28 to 1.72 µM respectively in different lake waters (Fig. 5). The concentration was almost similar in the bottom waters. Total nitrogen (TN) content of lake waters ranged from 0.8 to 18 µM except for one high value of 74.6 µM. In the bottom waters TN in the lakes 1 and 3 ranged from 0.8 to 7.5 µM with a maximum difference of 1.61 µM between surface and bottom waters. Dissolved organic phosphorus (DOP) in the surface waters ranged from 0.13 to 0.46 µM. The concentration of DOP was higher in the bottom waters with a maximum value of 0.57 µM. Nutrient concentrations observed at Schirmacher lakes were similar to those reported from freshwater Tarn lake in Vestfold Hills [Si: 2.86 to 88.2 µM, NO₃: 0.06 to 30.6 µM, ammonia: 0.1 to 16 µM, PO₄: 0.1 to 0.48 µM; (Everitt, 1981)]. However, the values were lower than most of the lakes in Vestfold Hills (Hand and Burton, 1981). The DOP values at Schirmacher lakes were within the range as observed by Ellis-Evans (1982) for some of the salt water lakes at Ross Island (*i.e.*, 0.09 to 0.22 µM), while TN values in these lakes were also slightly higher (22.4 to 41 µM) than the Schirmacher lakes. Concentration ratio of NO₃ : PO₄ ranged from 0.8 to 27.6. The fall in NO₃ : PO₄ ratio to < 4 in lakes 1, 2 and 3 was mainly due to low nitrate values which indicated that these lakes are oligotrophic. But urea, ammonia and TN available in these waters probably act as nitrate substrate for the algal growth.

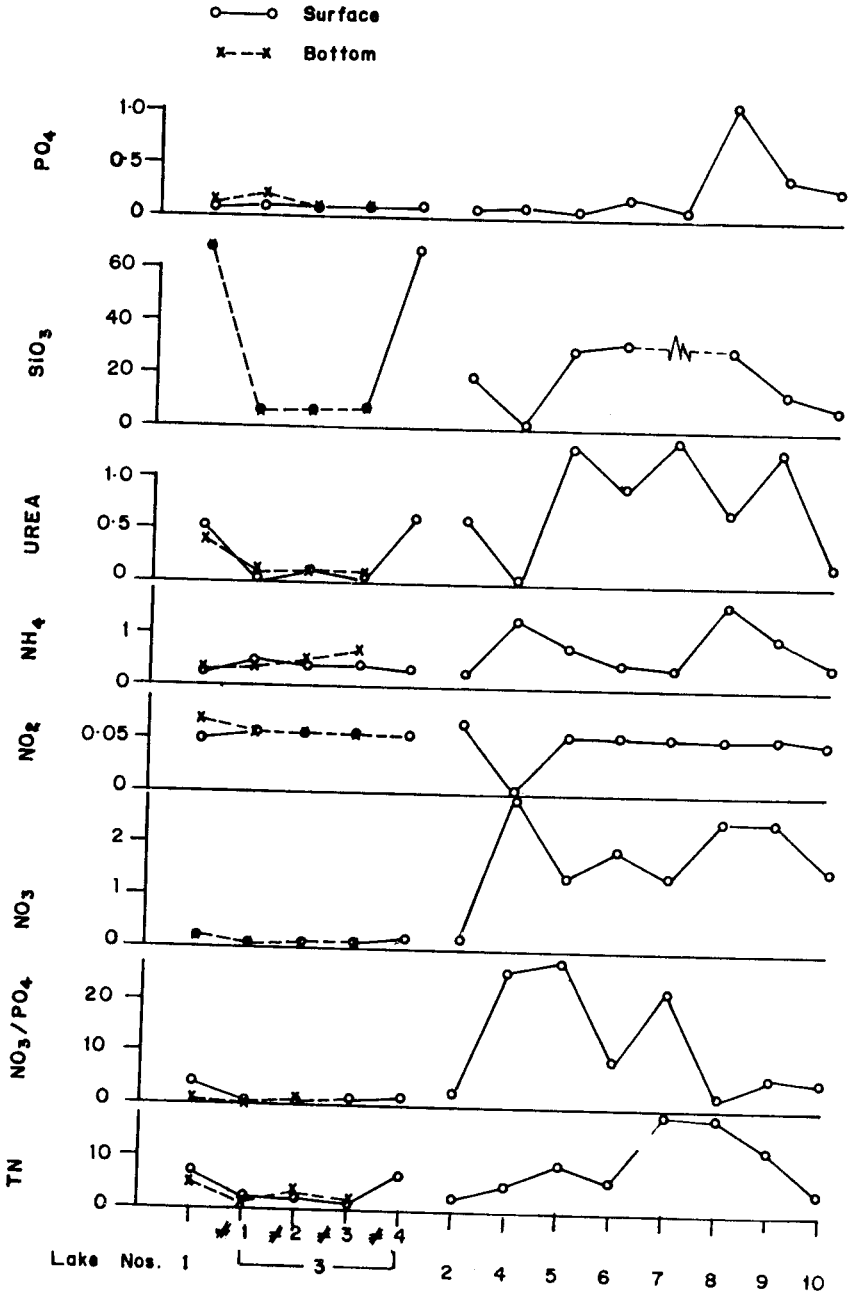


Fig. 5. Total nitrogen (TN), NO₃, NO₂, Urea, NH₄, SiO₃ and PO₄ in μM and NO₃/PO₄ observed at Schlmacher lakes in January 1985

Biological Production

Chlorophyll : Concentration of chlorophyll *a* (chl. *a*) in the surface waters in all lakes remained below 0.7 mg m^{-3} (Fig. 6). The bottom water values were higher than the surface water. The maximum value in the bottom waters was 1.18 mg m^{-3} at station 2 of lake 3. The layer of filamentous algal mat in the bottom waters (Kashyap, 1990) could contribute to high chl *a* observed at some occasions.

Primary Productivity: Surface waters showed a maximum of $4 \text{ mgC m}^{-3}\text{hr}^{-1}$ of primary productivity (PP) values. PP in the bottom waters was less than the surface except in case of station 2 where the value of $5.6 \text{ mgC m}^{-3} \text{ hr}^{-1}$ was recorded. At the Bratina island of McMurdo ice shelf chl *a* values at 8 ponds in January 1988 were reported to range from 1.4 to 15.7 mg m^{-3} , the freshwater lakes showing minimum value of 1.4 mg m^{-3} (Suren, 1990). This value is slightly higher than chl *a* values observed at Schirmacher lakes. However, in the freshwater Moss lake chl *a* ranged from 0.5 to 8 mg m^{-3} (Ellis-Evans, 1981). Similarly, in the oligotrophic lakes of Signy island, chl *a* was reported to vary from 1.6 to 3.7 mg m^{-3} (Heywood *et al.*, 1979, 1980). Chl *a* and PP values at 8 perennially ice covered saline and freshwater lakes of south Victoria Land and Ross ice shelf during 1977-78 was reported to range from 1 to 13.2 mg m^{-3} and 0 to $8.2 \text{ mgC m}^{-3}\text{day}^{-1}$ respectively (Cathey *et al.*, 1981). Campbell (1978) has shown that in the freshwater Watts lake near Vestfold Hills PP ranged from 0.2 to $0.94 \text{ mgC m}^{-3} \text{ hr}^{-1}$ while in the salt water lakes in the same region the PP values were still lower $0.15 \text{ mgC m}^{-3}\text{hr}^{-1}$. If the effective period of solar radiation is considered as 20 hours in January then the minimum and maximum surface PP values per day at Schirmacher lakes should vary from 2.2 to $7.9 \text{ mgC m}^{-3} \text{ d}^{-1}$. This is in accordance with the values reported by Cathey *et al.* (1981) and Campbell (1978). However, it can be pointed out that chl and PP values in different lakes are highly fluctuating and may depend on the availability of nutrients, favourable temperature and sufficient solar radiations.

PP/chl *a* ratio in the surface waters which is known as assimilation number (AN) ranged from 1.4 to $39.5 \text{ mgC (mg chl)}^{-1} \text{ hr}^{-1}$. This ratio showed low values in the bottom waters. While describing the oligotrophic and eutrophic lakes, Priddle and Heywood (1980), suggested that oligotrophic lakes were poor in nutrients. In such lakes the increased deposition of the sediment at the bottom allows better development and more varied benthic vegetation. Abundance of aquatic mosses are characteristics of oligotrophic lakes in which phytoplankton communities are poorly developed. Heywood *et al.* (1979, 1980) noted that the plankton productivity in the Signy island in summer was low. Similarly, in Norsel point lake ^{14}C uptake of the water column was

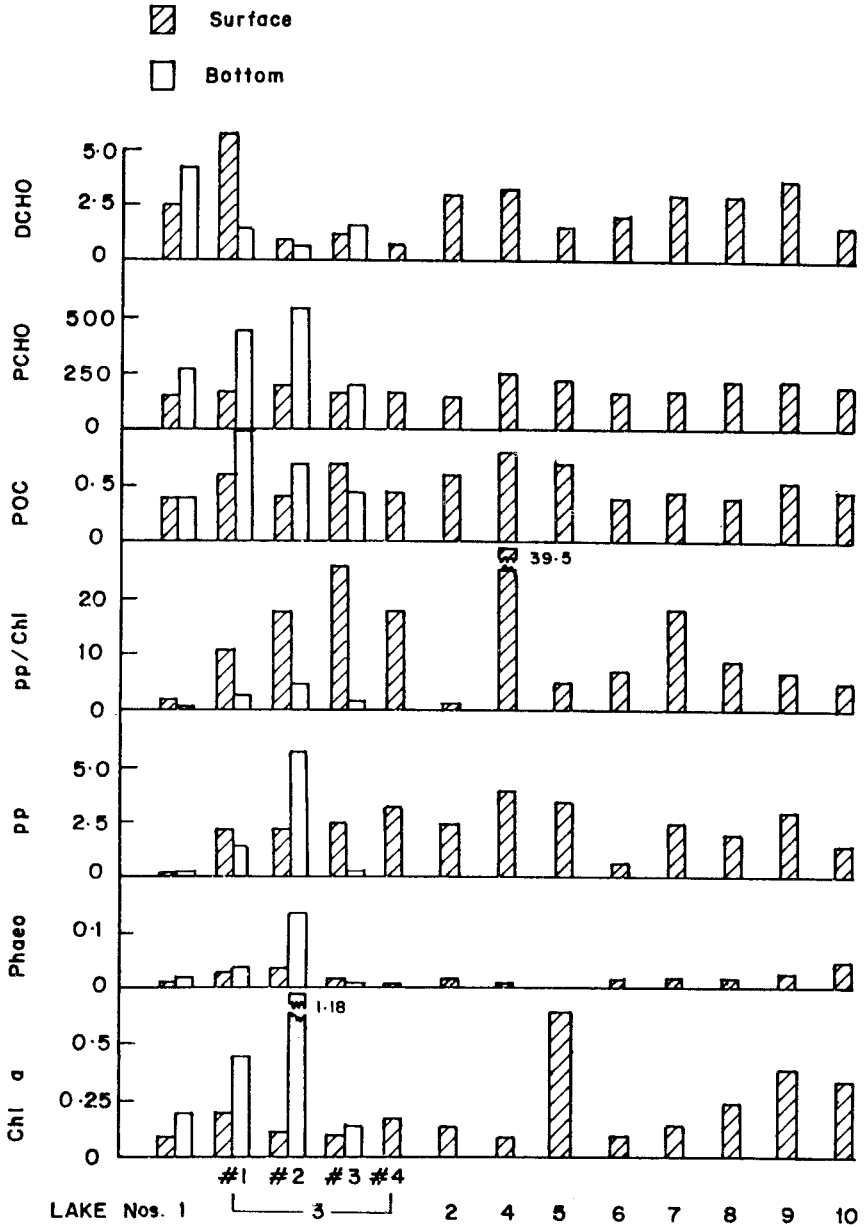


Fig. 6. Chlorophyll *a* (*chl*) mg m⁻³, Primary productivity (*PP*) mgC m⁻³ hr⁻¹, *PP/chl* mgC mg chl⁻¹ hr⁻¹, Particulate organic carbon (*POC*) mg l⁻¹, Particulate carbohydrates (*PCHO*) µg l⁻¹ and Dissolved carbohydrates (*DCHO*) mg l⁻¹ in waters of different lakes at Schirmacher

0.28 mgC m⁻³ hr⁻¹ and in the O-Ike and Kamome lakes PP was 15 and 18 mgC m⁻³ hr⁻¹ respectively (Parker *et al.*, 1972 and Tominaga, 1977).

In the euphotic lakes the natural enrichment help to keep N and P content high. Chlorophyll content remain higher than 10 mg m⁻³ and the phytoplankton are highly productive. PP for eutrophic lakes in Humble island and Skua lake was recorded to be 147 and 993 mgC m⁻³ d⁻¹ respectively (Samsel and Parker, 1972; Goldman *et al.*, 1972). Moreover, high AN ratio of 10 mgC (mg chl)⁻¹ hr⁻¹ was calculated from Heywood lake during summer 1978 (Ellis- Evans, 1981). Based on the physical and morphological features, the Schirmacher lakes can be classified as proglacial lakes in rock basins (Priddle and Heywood, 1980). However, other characteristics such as low nutrients, low chlorophyll in water column and rich proliferation of benthic flora and fauna lead us to the conclusion that these lakes are oligotrophic in nature. Nevertheless, the high PP/chl ratio seen in some of these lakes appears to be misleading. But laboratory experiments in which the bottom waters were exposed to 100% irradiance gave high PP/chl ratio (Table 3). Also experiment on photosynthesis as a function of light indicated that the highest ¹⁴C assimilation of surface water takes place at 60% irradiance (Table 4). These suggest that it is the nutrient enrichment associated with light and favourable climate, during the short summer that increases the activity of chlorophyll in lake waters (Uhlman, 1978).

Table 3: PP/Chl ratio of surface and bottom water exposed to 100% light intensity; January, 1985

Location	Water depth	Surface water	Bottom water	
			with 100%	<i>in situ</i>
Irradiance				
Lake 1	4	2.43	1.2	0.6
Lake 3	#1	3	11.5	7.1
	#2	5	17.7	7.1
	#3	8	26.0	27.1

Table 4: Photosynthesis as a function of light, January 1985 (surface water exposed to varying light intensities)

Location	Chl mg m ⁻³	PP mgC m ⁻³ hr ⁻¹			
		100%	60%	30%	16%
Lake 2	0.16	3.24	2.65	1.2	0.8
Lake 3	0.18	3.3	4.4	2.3	1.82
Lake 4	0.1	3.95	4.18	1.31	0.31

Dissolved (DCHO) and particulate carbohydrates (PCHO) in the surface waters of Schirmacher lakes varied from 1.6 to 3.6 mg l⁻¹ and 147 to 241 µg l⁻¹ respectively (Fig. 5). DCHO concentration in the bottom waters varied from 0.6 to 4 mg l⁻¹ while PCHO values showed clear increase at the bottom in relation to the surface waters with a maximum value of 551 µg l⁻¹ at station 2 of lake 3. Particulate oxidised carbon (POC) in the surface waters ranged from 0.38 to 0.79 mg l⁻¹ and in the bottom waters from 0.41 to 1.04 mg l⁻¹. Table 5 gives the correlation matrix of chl and other related parameters for the surface waters of these lakes. PP showed statistically significant relation with POC and PCHO. The relation of chlorophyll with these two parameters is low but positive. But DCHO showed highly insignificant relation with PP and chlorophyll. This suggested that PCHO and POC are derived from the photosynthetic materials in the lakes while DCHO was affected by the external inputs.

Algal flora: Besides the pelagic microalgal communities in water column the aquatic freshwater flora at Schirmacher lakes occupied 3 distinct levels of habitats. They were identified by Kasyap (1990) as algae growing : (a) in association with moss, (b) on soils and (c) on quartz rocks in the water pools and lake bottoms (Table 6). Moss (*Bryum* species) was associated with five species of the unicellular algae, two *Nostoc* species and *Stigonema* species. Wide range of blue green algae and *Nostoc commune* were encountered on the soil surface. Observations during diving have shown that the lake bottoms contain fine sediments with overlying felt of blue green algae and diatoms. Similarly, the quartz rocks favoured growth of green algae and diatoms. Algae of *Cosmarium* species which are of common occurrence was found in small pools (receiving melt water), as a mucilagenous ball (0.5 to 2 cm size). In these, the filaments of *Calothrix* species was embedded. Majority of algae recorded at the Schirmacher range possess tough and coloured mucilage. These properties of algae may help in two possible ways (a) light filtration and (b) increasing water retention capacity. Komarek and Ruzicka (1966), while working on the ice covered lakes of Schirmacher oasis found that the lakes were highly productive of algae. The main component was reported to be the green *Phormidium* species which in large fan shaped colonies supersaturated the water with oxygen. The *Phormidium* species was present even during the recent observations of January 1988 (Kasyap, 1990). This reflects the steady reproductive capacity of the later species to withstand harsh environments of repeated freezing and thawing seasons. Data on nitrogen fixation by Kasyap (1990) using acetylene reduction technique showed that 60% of the blue green algae were nitrogen fixers. Davey (1983) has also reported the existence of nitrogen fixing communities of *Nostoc commune* and *Calothrix* species in Vestfold Hills. The occurrence of nitrogen fixing algae at Schirmacher are in

Table 5: Correlation matrix for some parameters in surface lake water, n = 13

	Chl	PP	POC	PCHO	DCHO
Chl	1				
PP	0.369	1			
POC	0.171	0.664	1		
PCHO	0.465	0.600	0.254	1	
DCHO	-0.019	0.027	0.216	0.142	1

Table 6: Distributional algal species among different habitats in Schirmacher Oasis, Antarctica (Source: Kasyap, 1990)

Algal class	Habitat, algae and species number		
	In moss association	On soil	In association of quartz rocks
A. Cyanophyceae	<i>Gloeocapsa</i> (3)	<i>Gloeocapsa</i> (2)	<i>Gloeocapsa</i> (1)
	<i>Aphanothece</i> (1)	<i>Chroococcus</i> (1)	<i>Oscillatoria</i> (2)
	<i>Aphanocapsa</i> (1)	<i>Oscillatoria</i> (1)	<i>Lyngbya</i> (1)
	<i>Nostoc</i> (1)	<i>Phormidium</i> (1)	
	<i>Stigonema</i> (1)	<i>Schizothrix</i> (2)	
	-	<i>Nostoc</i> (2)	
	-	<i>Calothrix</i> (1)	
B. Chlorophyceae	-	-	<i>Chlorococcus</i> (1)
	-	-	<i>Pinnularia</i> (1)
	-	-	<i>Hantzschia</i> (1)

confirmation with those reported by Davey (1983), however, the rate of nitrogen fixation may differ depending on the locality and seasons.

As regards the distribution of different algal species, Everitt (1981) reported that the algal mat samples of freshwater lake Tarn in the Vestfold Hills consists of variety of filamentous and unicellular algae and diatoms such as species of *Navicula*, *Pinnularia*, *Surirella*, *Stauroners* and *Hantzchia*. In the Heywood lake at Signy island, Light *et al.* (1980) observed that the community of the mainly small Chlorophytes and Crysophytes produced a spring peak under ice and this succeeds the highly productive Cryptomonad dominated community growing under high irradiance region of open water summer conditions. Nevertheless, the dominant vegetation of these lakes was phytoplankton formed of micro and nano-algae. According to Whitman (1976), the

algal mats release extracellular products which serve as a major source of nutrients. Analysis of Schirmacher lake water showed the presence of *Oscillatoria*, *Chocous*, *Synechocystis* and some diatom species.

Zooplankton: Observations on zooplankton samples showed lack of true planktonic herbivores. The fauna was largely made of rotifers (47 individuals/haul), Ciliates (39), Turbellaria (4) and microvertebrate eggs (150). In general, the fauna was poor with low community diversity (Ingole and Paruleker, 1990). While reporting the plankton population in south Victoria land lakes Parker *et al.* (1982), have observed ciliate *Strombidium*, which are essentially herbivores, but euplanktonic metazoans have been reported in the east Antarctic regions and sub-Antarctic lakes (Heywood, 1977).

Sediments: Sediment characteristics of each lake at Schirmacher along with the microfaunal biomass are shown in Table 7. Organic content of the sediments ranged from 0.05 to 1.8%. The sediment covered with the vegetation (moss or algae) showed high organic carbon content compared to those without vegetation. These values are low in comparison to the sediments of lakes in Orkney island which ranged from 2.4 to 12% (Ellis-Evans, 1982). Thus, the Schirmacher lake sediments are poor in organic matter. Faunal density in the upper 6 cm layer varied from 45 to 1920 numbers m^{-2} . Seven microfaunal groups were identified consisting of 10 genera and 4 species both from peripheral and littoral zones (Table 8). Protozoa (Ciliata, Mastigophora and Sarcodina) were most dominant (23%) and Rotifera (2%). Dormant eggs of invertebrates (Rotifera, Turbellaria and Tardigrada) were abundant (39% at littoral stations). Table 8 shows that Nematodes *Teratocephalus tilbrooki* and *Aphelenchoides* species were recorded in all peripheral stations. Whereas, only *T. tilbrooki* was found in littoral stations. Three genera of Tardigrades were recorded in peripheral sediments in the watermass interface. *Macrobiotus* species and *Echinocoides* species dominated the algal sediments. In Signy island Tardigrades were reported to be most abundant (1032 individuals m^{-2}) in terrestrial habitats (Jennings, 1979). The microfaunal density at Schirmacher was found to be high in moss associated sediments. This could be related to the availability of rich organic matter in the moss beds (Davis, 1980).

Everitt (1981) has shown the benthic mat community of lake Tarn to consist of Cyanophytes, Chlorophytes, Chrysophytes, Pyrrophyte, Rotifers, Tardigrades, Nematodes, Protozoans and bacteria. Cathey *et al.* (1981) also noted four major faunal groups, namely Protozoa (25 genera), Rotifers (5 genera), Tardigrade (1 genus) and Nematodes in 8 lakes in southern Victoria land. The freshwater lakes had higher number of genera and the majority of species being associated in area with organic enrichment. McInnes and Evans (1987) have described enhanced invertebrate production in parallel with algal mat develop-

Table 7: Sediment characteristics and faunal standing crop of 10 freshwater habitats

Stn. No.	Sand (%)	Silt & clay (%)	Texture	Organic Standing Crop	
				carbon (%)	density nos./m ²
Lake 1	82.80	17.20	Silty sand covered with moss turf	0.85	1460
Lake 2	96.05	03.94	Coarse sand with pebbles	0.08	860
Lake 3	84.57	15.43	Silty sand covered with moss turf & algae	1.73	900
Lake 4	93.01	06.99	Coarse sand covered with moss turf	1.15	1610
Lake 5	87.83	12.17	Silty sand covered with moss turf	1.80	1920
Lake 6	97.58	02.42	Coarse sand with pebbles	0.01	510
Lake 7	91.67	08.33	Coarse sand with pebbles covered with moss carpet	0.01	450
Lake 8	96.18	03.82	Coarse sand with pebbles	0.05	490
Lake 9	86.53	13.47	Silty sand covered with moss carpet	0.85	1200
Lake 10	96.37	3.62	Coarse sand with moss carpet	0.05	450

Table 8: Most common species of the freshwater fauna of Zub lake, during 1987
(Source: Ingole and Parulekar, 1990)

Taxon	Species	Density numbers m ⁻²	
		Peripheral	littoral
Ciliata	<i>Oxytricha fallx</i>	580	40
Rotifera	<i>Philodina gregaria</i>	95	38
Nematoda	<i>Teratocephalus tilbrooki</i>	1594	79
	<i>Aphelenchoides</i> sp.	510	-
Tardigrada	<i>Hypsibius</i> sp.	356	24
	<i>Echinoscoides</i> sp.	286	83
	<i>Macrobiotus</i> sp.	390	-
Turbellaria	<i>Neorhabdocoel</i> sp.	896	66
	<i>Kalyptorhynchia</i> sp.	352	33
Insecta	<i>Cryptopygus sverdrupi</i>	86	-

ment in Signy island lakes, thereby suggesting that the fauna responds positively to the increased food availability. Suren (1990) reported that this relation was true for the freshwater lakes at Bratina island, South Victoria island but the same was not true in case of salt water lakes. Heywood (1979) has also shown that many invertebrates are plant feeders. It may be stated, therefore, that the species reported in 10 lakes of Schirmacher are those that are distributed widely in Antarctic continental lakes with similar behavioural pattern, that is thriving well in sediments rich in microflora and organic matter (Wynn-Williams, 1983).

Bacteria and yeasts: Microbiological studies in water, sediment and soil samples clearly indicated that bacteria and yeasts are predominantly present in the lake environment (Matondkar and Gomes, 1983; Matondkar, 1986; Shivaji, 1987). Matondkar (1986) has reported bacterial counts in peripheral lake sediments in January 1985 to range from 21×10^5 numbers g⁻¹ of dry sediment. In loam and moss soil, their concentration varied from 12×10^2 to 2.5×10^3 and 10×10^2 to 1.2×10^3 per g dry weight respectively. Moss algae and moist soil were rich in bacterial counts as compared to dry sand. Ellis-Evans (1982) have reported bacterial counts to vary from (1 to 25) 10^6 per g dry weight in some

of the Antarctic lake sediments. The dominant species present at Schirmacher were the gram positive rods identified as *Pseudomonas fluoresceus*, *P. putida* and *P. syringae* (Shivaji *et al.*, 1989a) and gram positive cocci as *Micrococcus roseus* and *Planococcus* species and 13 gram positive strains belonging to genus *Arthrobacter*. In soil of dry valley of Victoria Land, in addition to the above genera *Brevibacterium*, *Corynebacterium* and *Deinococcus* were also reported (Sieburt and Hirsch, 1988; Miller and Leschine, 1984; Johnson and Bellinoff, 1981; Johnson *et al.*, 1981; Madden *et al.*, 1979). Similarly, in the soil samples at Schirmacher 8 strains of yeasts have been identified (Ray *et al.*, 1989). Three of these were the red yeasts *Rhodotorula rubra*, one *Bullera alba*, one diamorphic *Candida humicola* and one *C. famata* and the remaining two tentatively identified as *C. ingeniosa* and *C. auricularia*. In the dry valleys elsewhere in Antarctica various yeast strains such as *Cryptococcus*, *Candida*, *Rhodotorula* and others have been reported (Vishniac and Baharaeen, 1982; Vishniac and Hempfling 1979; Allas *et al.*, 1978).

Birds: Three major bird communities such as albatross, Antarctic skua and snow petrel visit the lakes in summer. The shores of the lakes were found infested with the feathers, skeletons and excreta of the birds. Eggs and chicks of these birds were sometimes found in the burrows on the sides of the lakes. This indicated that the Schirmacher lakes were used by the birds as habitats during winter also. Analysis of the faecal pallets and ingested food by Antarctic skua showed the presence of insect skeleton and frustules of micro-organisms. This suggested that littoral microfauna of lake sediment can serve as a food to Antarctic bird communities.

Variability of Physical and Biotic Environments

Seasonal changes in temperature, dissolved oxygen and pH and their influence on phytoplankton biomass from March, 1993 to January, 1994 are shown in Table 9. While temperature in the water column ranged from -1.5 to 4.4°C , the annual changes in chl *a* were low ranging from 0.011 to 0.06 mg m^{-3} and did not show much relation with the temperature variations. Dissolved oxygen and pH which varied from 6.1 to 9.05 ml l^{-1} and 5.35 to 6.49 respectively showed that the waters were well aerated and maintained stable H ion concentration.

Long term interannual variability of the environmental and biotic features of Schirmacher lakes were examined by analysing the data available from Zub lake from 1982 to 1994 for the summer season (Table 10).

Atmospheric temperature of Antarctic summer varied from -3.2 to 5°C from 1982 to 1994. The maximum water temperature recorded in the lakes was

Table 9: Mean variation in temperature (Temp.) dissolved oxygen (DO), pH and Chlorophyll (chl) *a* in surface (S) and bottom (B) waters of Zub lake near Maitri station from March 1993 to January 1994

Months		Temp. (°C)	DO (ml.l ⁻¹)	pH	Chl <i>a</i> (mg.m ⁻³)
March '93	S	-0.750	8.80	6.08	0.015
	B	-1.000	8.70	6.49	0.014
April	S	-0.150	8.61	5.99	0.030
	B	-0.015	8.35	6.29	0.024
May	S	-0.035	8.42	6.06	0.051
	B	-1.500	8.21	6.23	0.049
June	S	-0.500	9.05	5.90	0.031
	B	-0.450	8.31	5.73	0.042
July	S	-0.250	7.40	5.53	0.037
	B	-0.120	8.40	5.51	0.060
Aug.	S	-0.400	7.27	5.96	0.042
	B	-0.500	7.30	6.42	0.055
Sept.	S	-0.030	7.20	5.47	0.041
	B	2	7.13	5.35	0.041
Oct.	S.	0.85	8.30	6.07	0.058
	B	2.75	8.30	6.18	0.059
Nov.	S	3.15	6.50	5.76	0.024
	B	4.40	6.25	5.70	0.027
Dec.	S	0.85	6.10	5.89	0.019
	B	3.80	6.70	6.02	0.017
Jan. '94	S	3.70	8.20	5.64	0.013
	B	4.10	8.00	5.51	0.011

7.9°C. NO₃ and PO₄ showed wide fluctuations attaining the highest value of 2.4 and 2.89 µM respectively for the year 1987 and a low of 0.3 and 0.14 µM respectively for 1989. Silicates were high during 1982 and 1985 and decreased to a low of 1.0 during 1989. In comparison to the earlier values Ca and Mg dropped by a factor of 5 and 10 respectively in 1987. The chlorophyll was seen increasing to almost to 9 fold in 1987. PP during all these years did not show any consistency with the chlorophyll content. POC in water and sediment organic carbon was seen increasing from 1982 onwards. Bacterial counts in sediments showed an increasing trend over the years. Similarly, the mean microfaunal density recorded in 1989 was much higher than the earlier values.

Table 10: Changes in the environmental features and biological characters of Zub lake at Schirmacher Oasis in January, 1982, 1985, 1987, 1989, 1992 and 1994

S.No.		1982	1985	1987	1989	1992	1994
1	Air °C	3	-1.6	5	-3.2	1.4	-
2	Surface Water °C	1	3.0	7.9	2.8	4	3.7
3	Sediment °C of Lake bottom	-	4.7	9.6	-	5.3	-
4	Dissolved Oxygen ml l ⁻¹	-	5.1	8.45	8.2	-	8.4
5	pH	-	8.3	8.15	7.4	-	5.6
6	SiO ₃ -Si µM	26.97	21.1	-	0.95	0	-
7	PO ₄ -P µM	0.64	0.1	2.89	0.14	0.49	-
8	Urea -N µM	-	0.35	-	-	-	-
9	NH ₄ -N µM	-	0.41	-	-	-	-
10	NO ₂ -N µM	0.56	0.06	1.17	0.22	-	-
11	NO ₃ -N µM	2.04	0.12	2.4	0.3	1.75	-
12	Ca mg l ⁻¹	107	-	10	-	-	-
13	Mg mg l ⁻¹	67.1	-	12	-	-	-
14	Chlorides µg l ⁻¹	0.013	0.048	0.049	ND	-	-
15	Chlorophyll mg m ⁻³	0.37	0.15	3.31	-	0.28	0.012
16	Primary productivity mgC m ⁻³ hr ⁻¹	0.68	2.6	0.65	-	7.0	-
17	POC µg l ⁻¹	81.5	555	-	-	-	-
18	ATP	0.17	-	-	-	-	-
19	Sediment Bacterial counts Nos gm ⁻¹ dry weight	5.4×10 ⁴	5.6×10 ⁴	-	-	-	4.4×10 ⁵
20	Sediment Composition %						
	Coarse Sand	-	92.33	91.07	-	-	-
	Silt and Clay	-	7.66	8.93	-	-	-
21	Organic Carbon %	-	1.07	1.73	-	-	-
22	Sediment Organism density individuals m ⁻²	-	1639	2930	251000	-	-

Large variations in the environmental parameters such as atmospheric and water temperature could be expected as the data was based on a single spot observation (not the mean of 24 hours record). This can be affected by incoming solar radiations, cloudiness, wind speed, etc. However, the temperature values at Schirmacher do not differ much than the other regions in Antarctic landmass (Goldman *et al.*, 1972). DO, pH, salinity, Ca and Mg content indicated that the lakes were well aerated and could be a source of freshwater supply to Antarctic oasis zone.

Nutrients did not indicate any signs of eutrophication but the occasional rise in NO_3 and PO_4 could signify their release through *in situ* remineralisation or addition from external sources such as glacial melt water or human interferences. Although chlorophyll showed elevated values in 1987, the concentrations did not reach the alarmingly high level. Moreover, the inconsistency in the chlorophyll values and PP suggest that the increased rate of production could occur only under favourable light, temperature and availability of nutrients (Vincent and Vincent, 1982).

Higher percentage of silt-clay fraction and organic carbon in lake sediment in 1987 suggest that the organic matter is on increase. While most of the parameters varied in a limited range the sharp boost in density of the benthic fauna in 1989 appears to be absurd. Such discrepancies could occur due to personal bias of different individuals involved in collection, preservation and analysis of the samples. The preservation of the samples was done using 5% formalin and common procedure was followed while counting. However, the first two samples were collected by the single individual and reported for upper 6 cm sediment core while those in 1989 were collected by another participant and reported for the upper 2 cm sediment core only. Suren (1990) has observed that in the ponds having the algal mats, the upper layers contained many more animals than the underlying sediments. And since the availability of food and oxygen is more in upper sediments it could harbour more animals. This could explain the reason why the faunal density was more in 1989 as compared to the earlier reports. Nevertheless, the increase in the microfaunal biomass, consequent to the increase in the organic matter content of lake sediments at Schirmacher over the years cannot also be disregarded (Suren, 1990). Moreover, the bacterial biomass of sediments in the lake periphery also showed an increasing trend. Sufficiently low levels of nutrients and absence of vibro group of organisms in lake waters and peripheral sediments (Ramaiah-personal communication) suggest that the effect of the faecal contamination or human interference is still low at this Maitri station lake.

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