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## Ecobiological assessment of a freshwater lake at Schirmacher Oasis, East Antarctica, with reference to human activities

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The scale and magnitude of probable impact of human activities over a decade (1983–1994) on the freshwater lake Priyadarshini, at Schirmacher Oasis, East Antarctica, was assessed through an ecological study conducted over an annual cycle during January 1993 to January 1994. Air temperature ranged from  $-34.5^{\circ}\text{C}$  to  $+8.2^{\circ}\text{C}$ , water temperature (below frozen layer) from  $-1.5^{\circ}$  to  $+4.7^{\circ}\text{C}$ , and pH from 8.10 to 8.77. Dissolved oxygen varied from 8.4 to  $12.1\text{ mg l}^{-1}$  with higher values during winter months (June–July). The biological parameters – phytoplankton, chlorophyll-*a* and microbenthos – showed a bi-modal pattern of fluctuations with one maxima in austral summer and another in spring (late winter). Fluctuations in the hydrobiological parameters were closely related to meteorological conditions over the area. Biological productivity of the lake was dependent on the availability of ice-free water and increase in atmospheric temperature. An in-depth analysis and comparison of certain lake environmental aspects over a decadal period indicate that the lake environment is in a healthy condition. However, intensive human activities in the catchment area may deteriorate the ecosystem and hence regular monitoring and stringent regulations are needed to maintain its quality.

THE Priyadarshini lake earlier referred as 'ZUB' lake on the geographical maps, is the second largest water body of Schirmacher Oasis, Queen Maud Land, East Antarctica (Figure 1). Limnological investigations of the water

bodies at Schirmacher Oasis go back to 1964 (ref. 1). Since then, the lake environment has been the subject of scientific investigations by the Russian, German and Indian researchers<sup>2–9</sup>. However, except for the study of Loopmann<sup>4</sup> and Kaup<sup>5</sup> all others were based on seasonal observations restricted only to austral summer.

Aquatic environment in and around Priyadarshini has been studied extensively earlier during the austral summer of 1984–1985 (ref. 3), when the lake environment was not exposed to human activities. The Indian summer research station Maitri was established in the vicinity of this freshwater lake during February, 1985 (ref. 10); it was developed into a full-fledged permanent research station in 1988–1989. However, ever since the inception of the Indian Antarctic programme, this fragile and sensitive lake environment is under continuous ecological monitoring.

Due to the proximity of the Indian research station to Priyadarshini, it was possible to study the lake environment very closely around the year. The movement of vehicles and human beings has increased 5-fold in the last 15 years (i.e. since the landing of the first Indian expedition at Schirmacher Oasis in January 1982). The area was visited by both the authors during austral summer of 1984–1985, 1986–1987 and again in 1993–1994 and one of us (VKD) had an opportunity to spend 18 months at Maitri, when the present ecological data were recorded.

It has been recognized that dry-valley lakes are useful indicators of climate change in Antarctica<sup>11</sup>. Hence, it is necessary to gather biological data that documents the present condition of the Oasis lakes. This investigation was planned in this context, and was aimed at comparing the present ecological conditions with the earlier available data. Variations in biological parameters which occurred over a decade are discussed in relation to anthropogenic perturbations. The information and the arguments presented here may help in improved handling of the environmental effects.



Figure 1. Schirmacher Oasis with Priyadarshini lake in background.

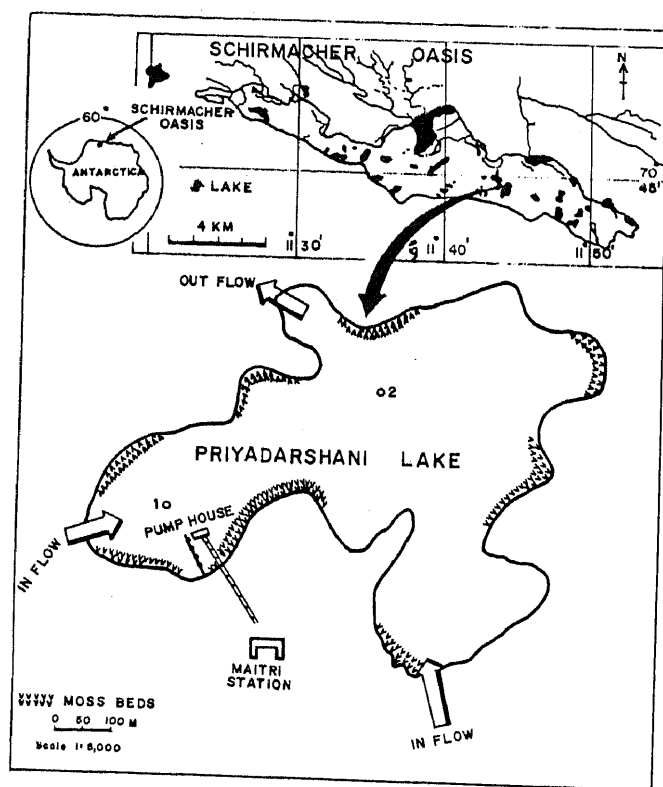


Figure 2. Locations of the sampling stations in Priyadarshini lake.

Although the study site is described in detail by Ingole and Parulekar<sup>12</sup>, general physical and geographic conditions are given here. The Schirmacher Oasis is a group of low lying-hills, essentially snow- and ice-free high-polar rock deserts in the eastern Dronning Maud Land, East Antarctica. It is about 100 km away from the Antarctic shore (the Lazarev ice shelf). The orientation is approximately east-west. It covers an area of about 34 km<sup>2</sup>. The climate is relatively mild due to the low altitude, with air temperature over the glacier ice

Table 1. Meteorological data recorded at Maitri Station (Antarctica) during January–December, 1993 (Source: ref. 16)

Month	Air temperature (°C)			Wind speed (knots)	Blizzards (days)	Snowfall (days)
	Max.	Min.	Mean			
January	8.2	-5.5	0.7	48	0	7
February	5.4	-13.8	-3.5	57	0	8
March	-0.1	-19.7	-7.5	63	0	4
April	-0.3	-24.5	-12.6	62	1	3
May	-2.3	-26.6	-13.3	58	3	9
June	-3.3	-30.0	-15.2	70	2	8
July	-7.1	-33.5	-19.8	52	6	13
August	-5.0	-34.5	-16.9	92	6	9
September	-6.1	-24.8	-14.3	80	4	12
October	-2.8	-21.0	-10.4	86	5	13
November	3.8	-15.8	-5.5	72	1	3
December	5.6	-8.7	-0.4	67	0	11

between  $-7.7$  and  $+8.2^{\circ}\text{C}$  during mid-summer (December–January) when meltwater is abundant. Freshwater lakes, ponds and pools cover approximately 3.4 km<sup>2</sup> oasis area. The altitudes lie between the local zero level and 228 m with an average of 100 m. Its surface is hummocky and undulated. January is the warmest month (monthly mean air temperature  $0.7^{\circ}\text{C}$ , maximum  $8.2^{\circ}\text{C}$ ), and August the coldest (monthly mean air temperature,  $16.3^{\circ}\text{C}$ , minimum  $-34.5^{\circ}\text{C}$ , Table 1). The average wind velocity over many years is around 9.7 m/s.

As shown in Figure 2, two stations were fixed in the lake. Water samples (surface and bottom) were collected with the help of Kahlisco bore hole water sampler (1 l capacity) with a thermometer installed in it. Since the Priyadarshini lake remains frozen almost for eight to nine months every year (from March to November<sup>6</sup>), sampling for present study was done through drill hole using a Jeffy ice drill. Sediment samples, for the analysis of microfauna, sediment texture and organic carbon were collected with the help of a modified van Veen grab. Microfaunal samples were preserved in 70% ethyl alcohol. In the laboratory, the samples were washed through 63 and 20  $\mu\text{m}$  mesh sieve in filtered freshwater. All the animals were sorted, counted and identified to the possible taxon level. Particle size analysis of the sediment was carried out according to Folk<sup>13</sup> and organic content was estimated by the wet oxidation method of El Wakeel and Riley<sup>14</sup>.

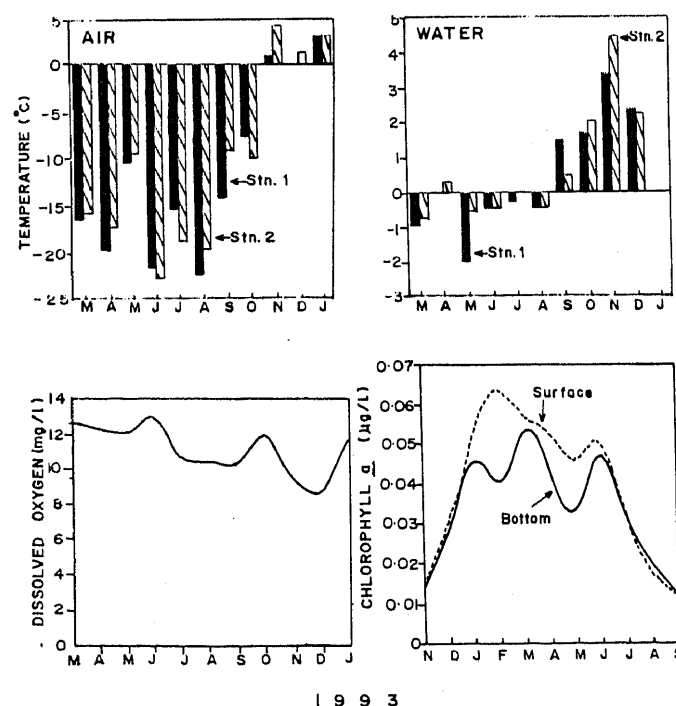
Analyses of chlorophyll *a*, dissolved oxygen and pH were carried out following the standard methods outlined by Grasshoff<sup>15</sup>. Surface water temperature was measured immediately with the help of deep freezer tester ('Bravo', accuracy  $\pm 0.2^{\circ}\text{C}$ , range,  $-40.0$  to  $+90.0^{\circ}\text{C}$ ).

The winds at Schirmacher Oasis are normally easterly-south easterly during summer. Mean monthly wind speed varied from 11 to 22 knots (maximum 92 knots) during August 1993. September and October were the windiest months. Extreme air temperature recorded at

the Maitri station was  $-34.5^{\circ}\text{C}$  and  $+8.2^{\circ}\text{C}$  (ref. 16). Melting of the snow began in October and continued up to February with the peak melting occurring during December–January. Data on the physico-chemical characteristics of the lake are presented in Table 2 and Figure 3. Surface water temperature was much higher as

**Table 2.** Environmental parameters, sediment texture and biological parameters of Priyadarshini lake studied during four antarctic summers

Parameter	Austral summers			
	1985	1987	1992	1994
Air temperature ( $^{\circ}\text{C}$ )	-1.6	5.0	1.4	3.8
Water temperature (surface)	3.0	7.9	4.0	4.2
Sediment temperature	4.7	9.6	5.3	4.8
pH (bottom water)	8.1	8.77	8.25	5.6
DO $\text{mg l}^{-1}$ (bottom water)	10.5	12.07	8.5	8.4
Salinity ( $\times 10^{-3}$ ) (bottom water)	0.09	0.09	0.15	0.15
<b>Sediment characteristics</b>				
Sand (%)	92.33	91.07	90.02	91.14
Silt and clay (%)	7.66	9.93	9.98	8.86
Organic carbon (%)	1.07	1.73	1.95	2.05
<b>Microflora and fauna</b>				
Chlorophyll <i>a</i> $\text{mg m}^{-3}$	0.15	3.31	0.28	0.012
Primary productivity ( $\text{mg C m}^{-3}\text{h}^{-1}$ )	2.6	0.65	7.0	3.95
Faunal density (no. $10\text{ cm}^{-2}$ )	1639	2930	3569	3489
Faunal biomass ( $\mu\text{g}$ $10\text{ cm}^{-2}$ )	737.55	1318.5	1826	1985



**Figure 3.** Air and surface water temperature, dissolved oxygen and chlorophyll *a* in the surface water of Priyadarshini lake studied during March 1993 to January 1994.

compared to the air temperature recorded at the same time. This was mainly due to the absorption of radiant solar energy by water and rock surface around the lake. Penetration of solar radiation into water bodies serves not only as a source of energy for photosynthesis but also determines the thermal regime of the lakes<sup>5,17</sup>.

Comparison of physico-chemical and biological parameters investigated during four summers is presented in Tables 1 and 2. Surface water temperature of the lake remained above freezing during the summer months and ranged from  $1.0$  to  $7.9^{\circ}\text{C}$ . As compared to the surface water temperature, sediment temperature (upper  $5.0\text{ cm}$  layer) was much higher ranging from  $4.7$  to  $9.6^{\circ}\text{C}$ . pH of the surface waters ranged from  $7.55$  to  $8.75$  and bottom water pH ranged from  $8.1$  to  $8.77$ . As shown in Table 2, the lake waters were quite fresh with the salinity values ranging from  $0.01$  to  $0.15 \times 10^{-3}$ . Dissolved oxygen (DO) in the surface waters ranged from  $8.4$  to  $12.07\text{ mg l}^{-1}$ . During winter months (April–November), when the lake surface was frozen the surface water (below the frozen layer) temperature ranged from  $-0.3^{\circ}\text{C}$  to  $3.15^{\circ}\text{C}$ . Temperature of the bottom water ranged from  $-0.2^{\circ}\text{C}$  to  $4.40^{\circ}\text{C}$  (Figure 4). Dissolved oxygen varied from  $8.71$  to  $12.92\text{ mg l}^{-1}$  and did not show significant variation during summer and winter, suggesting that lake waters remained well aerated, even during winter, when the top layer was frozen.

Freezing of the surface water layer of Priyadarshini lake commenced on 23 February 1993 and the lake remained completely frozen till 14 October 1993. Annual cycle of ice thickness is shown in Figure 4. The thickness of ice layer varied between  $38.5\text{ cm}$  and  $191\text{ cm}$  (mean =  $131.4 \pm 51.6$ ;  $n = 9$ ). The maximum ice thickness of  $191\text{ cm}$  was recorded on 25 September 1993. With an increase in air temperature, melting of ice was witnessed on 10 October 1993, resulting in reduction in the thickness of ice cover. Accumulated ice from the nearby area melts and flows into Priyadarshini lake through two small feeding streams. The generation of melt water from inland ice as well as snow and firm ice fields is remarkable and it helps in regulating the quantity of lake water. There is a substantial annual variation in thickness of ice cover, principally related to the winter temperature regime.

Chlorophyll *a* (Chl-*a*) concentration varied from  $0.011$  to  $0.06\text{ mg m}^{-3}$  during March–December 1993. Surface and bottom waters did not show much difference except for summer months when Chl-*a* concentrations were higher corresponding to high photosynthesis rate due to continuous illumination. Data on the biological components studied during four austral summers are presented in Table 2. Chl-*a* concentration in the surface water ranged from  $0.012$  to  $3.31\text{ mg m}^{-3}$  during 1984 and 1994. The highest Chl-*a* value observed in 1987 was mainly due to the filamentous algal mat at the lake periphery from where the water sample was collected<sup>6</sup>. The

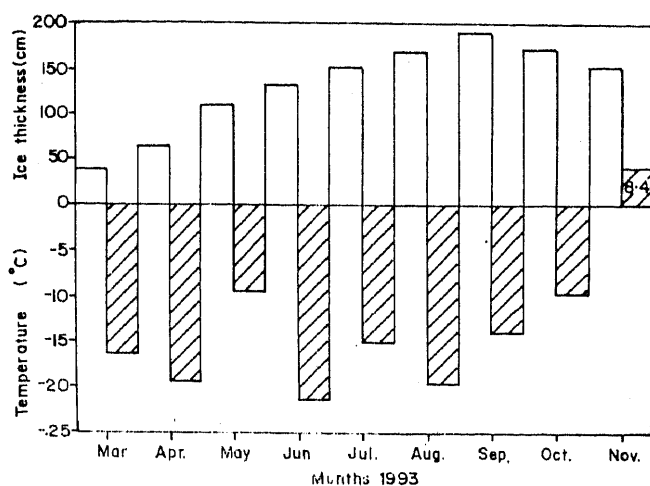


Figure 4. Seasonal cycle of ice cover in Priyadarshini lake as observed during March to November, 1993.

primary productivity in the surface water ranged from  $0.65$  to  $7.0 \text{ mg C m}^{-3} \text{ h}^{-1}$  and the values were much higher during the summer months than the other months which were due to the longer sunlight duration. With long photoperiod and increased temperature, maximum primary production takes place during the austral summer. However, the critical period for release of most essential nutrients from various sources is when the snow melts (i.e. onset of the austral summer).

Table 2 summarizes selected environmental and biological data collected during 1984–1994. This indicates a remarkable increase in sediment silt-clay fraction in bottom sediment over a period of 10 years. Organic content of the sediments increased from 1.07 to 2.05%. Seven taxonomic groups consisting of 15 genera and four species of microfauna have been identified from the catchment of Priyadarshini lake<sup>3,6,8,12</sup>. Population density of micro-invertebrates ranged from 1639 to 3569 individuals  $10 \text{ cm}^{-2}$  and showed increasing trends during the period of observations (Table 2). Increase in population of microorganisms was due to increased sedimentation, organic enrichment and silt deposition from an inflow of streams<sup>12</sup>. The substantial increase in sediment silt-clay is attributed to the mineral soil that is eroded and gets deposited in the lake. Secondly, the increase in human activities such as movements of heavy vehicles in and around the station buildings may result in grinding of the soft rocks and formation of flux of the suspended particles and debris which eventually will settle down in to the lake floor.

While discussing the limnology of Schirmacher Oasis, Ingole and Parulekar<sup>6,12</sup> demonstrated the presence of rich and diverse population of micro-invertebrates in this lake. In addition to this, nine species of bacteria and yeasts<sup>7</sup>, seven species of mosses and blue green algae<sup>9</sup>, and twelve species of lichens<sup>18</sup>, occur in the Schir-

macher Oasis. Among birds, a few pairs of Antarctic Skua, Tern, Petrel and Addeli Penguin spend some time in this dry valley, suggesting the suitability of the environment for biological diversity. The increased anthropogenic activities, especially the movement of heavy vehicles and personnel around the water bodies where moss flora usually develop, could destroy the well-developed moss and lichen beds that will take a long time to recover. As demonstrated by Ingole and Parulekar<sup>12</sup>, Davis<sup>19</sup>, Everitt<sup>20</sup>, McInnes and Ellis-Evans<sup>21</sup>, maximum density of the micro-invertebrates was associated with the silty sediment, having bacterio-algal layer and moss. The algae and moss mat not only provide food to the metazoan fauna but also refuge and insulation from freezing.

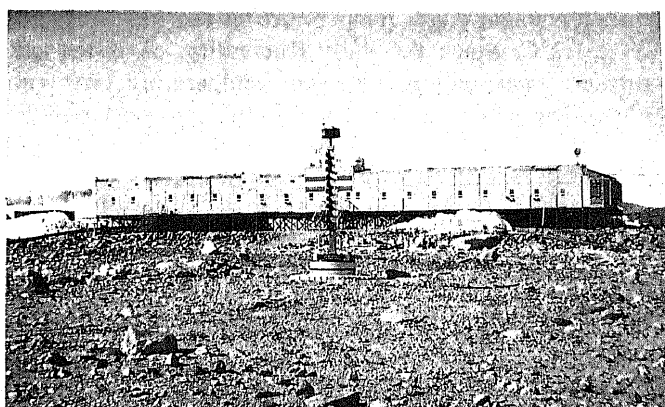
Atmospheric temperature, surface water temperature and temperature of surface sediment from the Priyadarshini lake showed large variations between the sampling seasons. However, the variations were not significant (variance of mean = 4.041,  $p < 0.128$ ) and the fluctuations were within the expected range for Antarctic oasis environment. Values for dissolved oxygen (DO) in lake water were lower in 1992 and 1994 than in 1987, indicating depletion in DO. Significant increase in primary productivity and population density of micro-invertebrates was observed in 1992 which was attributed to the increased silt-clay fraction and organic carbon content in the sediment. Microfaunal density and biomass showed interannual variability ( $p < 0.03$ ) and very strong correlation with organic carbon content ( $r = 0.99$ ,  $p = 0.001$ ) and silt clay fractions of the sediment (Table 3). The flux of suspended particles and debris through melt water contributes to increase in the silt-clay fraction. Secondly, the movement of heavy vehicles in the close proximity of the lake may enhance lake sedimentation<sup>12</sup>. As expected, chlorophyll *a* showed strong relationship with surface water temperature ( $r = 0.97$ ,  $p = 0.03$ ). Since the biological activity in Antarctic lakes is significantly correlated to the amount and duration of ice-free water available to propagate the flora and fauna<sup>12,19–21</sup>, duration of ice cover could be an important factor in determining the degree of fluctuations in biological productivity.

Since 1982–1983, India's Antarctic programme has seen steady increases in scientific and logistics activities. Its budget increased from Rs 27.50 million (1982–1983) to Rs 140.00 million (1993–1994), a spurt in growth that will have an immediate impact in a host of new facilities. The research station Maitri, situated on the hilly range of Schirmacher Oasis (Figure 5) is 100 km from the Lazarev ice shelf. It covers a carpet area of  $\approx 253 \text{ m}^2$ . Construction of the station building has greatly altered the local habitat: (i) generation of electricity results in the emission of gases, waste and dust; (ii) possible oil spill from the storage and repair of vehicles and also from the moving vehicles could get

**Table 3.** Correlation matrix between the various environmental and biological parameters (1, 2 and 3 = temperature (air, water and sediment), 4 = pH, 5 = DO, 6 = sand, 7 = silt and clay, 8 = Organic carbon, 9 = Chlorophyll *a*, 10 = Primary productivity, 11 = Faunal density, 12 = Faunal biomass, *n* = 4)

	1	2	3	4	5	6	7	8	9	10	11	12
1	—											
2	0.81	—										
3	0.67	0.98*	—									
4	-0.19	0.37	0.54	—								
5	-0.87	0.68	0.79	0.66	—							
6	-0.46	-0.24	-0.15	-0.05	0.43	—						
7	0.70	0.65	0.59	0.28	0.01	-0.89	—					
8	0.74	0.29	0.11	-0.44	-0.51	-0.83	0.74	—				
9	0.63	0.97*	0.99*	0.57	0.84	-0.08	0.53	0.53	—			
10	-0.28	-0.59	-0.64	-0.21	-0.87	-0.63	0.23	0.22	-0.69	—		
11	0.68	0.20	0.09	-0.35	-0.53	-0.89	0.78	0.99*	0.02	0.51	—	
12	0.59	0.07	0.12	-0.56	-0.69	-0.79	0.61	0.97*	-0.18	0.57	0.97*	—

\*0.1% significance.



**Figure 5.** Indian research station Maitri in Schirmacher Oasis, Antarctica.

accumulated in the lake, and (iii) storing of food, domestic and human waste in and around the station, though not intentional, may possibly result in the accumulation of unwanted material into the lake.

The biological parameters showed a bi-modal pattern of fluctuations with one maxima of standing stock occurring in austral summer and the second in spring (i.e. late winter). The biological productivity of the lake depends on the availability of ice-free water and increase in atmospheric temperature during austral summer and is evident from the increased dissolved organic carbon in the sediment. The values of the DO in the water column were higher during the winter months (May–June and October), possibly due to the higher contribution of bottom algae in production of DO. However, when compared with the earlier (1984–1985) data, it indicates that the ecology of the Priyadarshini lake is healthy and there has not been much influence of anthropogenic changes on the biota in general.

It can be concluded that the impact of human activities on the freshwater environment in general was local and connected with physical changes in terrain, and

freeze–thaw cycle. These may have little influence on the distribution and dispersion of microfauna. Relatively few pairs of Skua and Petrel nest in the area, and there may be less inter-annual variation in number and location of territories and chicks fledged (personal observations). However, while studying the avian fauna of Queen Maud Land area, Chattopadhyay<sup>22</sup> reported that 'Schirmacher Oasis has lost its avian densities'. This report certainly needs further confirmation with detailed investigation on the abundance and distribution of avian fauna over Schirmacher Oasis. Chattopadhyay's remarks are alarming and therefore require stringent measures to preserve the biodiversity of this sensitive ecosystem.

The intensity of human activity is increasing every year in this dry valley which may inflict irreversible damage to the fragile lake ecosystem. Therefore, regular monitoring of the lake environment is essential for understanding better the impact of increasing human activity. Hence the sustainable management and conservation of the oasis ecosystem should be the first and immediate aim of any scientific investigation in the Antarctic dry valley.

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### Influence of group density and sex ratio on the immune response in the tilapia *Oreochromis mossambicus* (Peters)

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We report here the modulatory influence of overcrowding and sex ratio on humoral response to bovine serum albumin in the fish *Oreochromis mossambicus*. Significant enhancement was found in overcrowded groups compared to the control group and the enhancement was directly proportional to the degree of overcrowding. When the sex ratio and the group density were investigated, it was observed that there were differences in antibody titres among the different sex ratio groups. Except equal sex ratio group, all the groups showed enhancement of immune response as a function of overcrowding compared to the control. No immunomodulation due to overcrowding was observed in the case of equal sex ratio group. These results indicate a possible psychoneuroimmunological basis for the immunomodulation related to sex ratio and group density.

THE immune system is a delicate one, whose response is found to change quantitatively on exposure to modulatory factors such as overcrowding, environmental pollutants, etc. Generally, overcrowding is considered as a stressor having suppressing effects on the immune response<sup>1</sup>. In the present study we investigated the effect of overcrowding and the sex ratio on the immune response in *O. mossambicus*.

For the experimental animal, the tilapia *O. mossambicus* (Peters), a common fresh and brackish water cichlid fish was used. Fish weighing 25–30 g were used. Uncon-

trolled ambient water temperature of the fish tanks was  $28 \pm 1.2^\circ\text{C}$ . Since the daily fluctuation of water temperature was negligible, the temperature was not controlled. Water was renewed daily to avoid possible stress due to excretory ammonia.

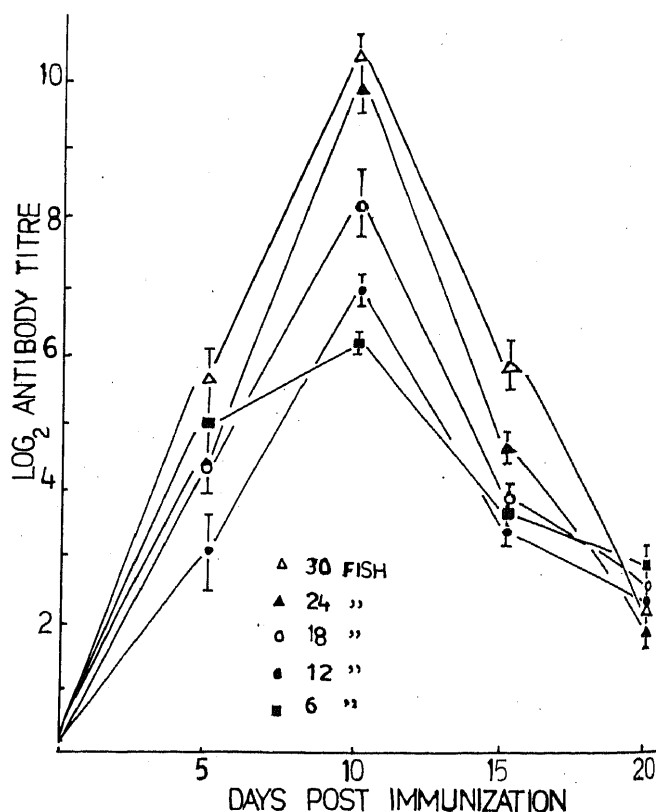


Figure 1. Effect of group density on humoral immune response to S-BSA. Fish were maintained in different group densities of 6, 12, 18, 24 and 30 and immunized with 5 mg of S-BSA. Antibody titres were quantified by passive haemagglutination assay. Each point represents mean  $\pm$  S.E. of 6–8 fish.