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Seasonal and spatial distribution of some benthic Protozoa in an eutrophic freshwater lake of Central Himalaya

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Abstract. The species composition, population density and diversity of benthic Protozoa in the littoral zone of Lake Naini Tal during 1993 -1994 are described both seasonally and spatially. Ciliates were dominant protozoans in terms of abundance. Most common were *Branchioecetes* sp. Penard, *Bursaridium* sp. Lauterborn, *Paramecium multimicronucleatum* Power and Mitchell, *P. aurelia* Ehrenberg, *P. caudatum* Ehrenberg, *Spirostomum minus* Raux and *S. teres* Claparede & Lachmann.

Protozoans were the most abundant in winter and summer. Both the peaks were preceded by phytoplanktonic peaks in the lake. Spatially, the maximum concentration of Protozoa was found at a site, influenced by pollution.

Key words: Lake Naini Tal, littoral zone, ciliates.

Introduction

Protozoa play a significant role in the functioning of aquatic ecosystems. They consume bacteria and thus reduce their numbers in environments rich in organic matter. They also feed voraciously on phytoplankton (Finlay *et al.* 1988; Pratt and Cairns 1985) and in turn are eaten by many species of metazoans (Berk *et al.* 1977; Porter, Pace and Battey 1979). Being highly efficient in releasing phosphorus (Buechler and Dillon 1974; Porter, Pace and Battey 1979), bacterivorous Protozoa are instrumental in relieving nitrate limitation of the primary producers by releasing the nitrate from the bacterial biomass (Caron, Joel and Mark 1988).

When we compare the scientific research efforts on freshwater protozoans with that of other biotic components (e.g. zooplankton, phytoplankton, etc.) of ecosystems, it becomes obvious that works on protozoan ecology are few. This is perhaps, mainly due to the methodological difficulties involved in this type of study. However, important contributions in the related field have been made by Goulder (1971, 1974, 1980), Bick (1973), Finlay (1978, 1980, 1981, 1982), Beaver and Crisman (1982), Horthorn and Ellis-Evans (1984), Finlay and Fenchel (1986), Finlay *et al.* (1987, 1988), Barbieri and Orlandi (1989), Dragesco and Kerneis (1991), Leakey, Burkill and Sleigh (1992), Amblard *et al.* (1993), Gasol (1993), Carrias, Amblard and Bourdier (1994), etc.

The present investigation was undertaken with the objectives of describing the diversity, abundance and seasonal and spatial distribution of benthic Protozoa in the littoral zone of a freshwater eutrophic subtropical lake situated in the high altitude of the Himalayan mountain. This report is a part of series of limnological investigations on Lake Naini Tal. Previous limnological studies were mainly concerned with physico-chemical properties (Pant, Sharma and Sharma 1980; Pant *et al.* 1981, 1985; Gupta and Pant 1983a; Pande and Das 1980), phytoplankton (Sharma 1980), zooplankton (Sharma and Pant 1984; 1985) and macrozoobenthos (Gupta and Pant 1983b, 1986, 1990, 1991). A comprehensive study on the protozoan community of this lake is lacking.

Lake description

Lake Naini Tal (29°24' N lat. and 79°28' E long.), situated 1,937 m a s l in the north-east border of the Indian sub-continent (Fig. 1) is a natural freshwater body. The lake is warm monomictic, having an area of 0.48 km^2, a mean depth of 16.2 m and a maximum depth of 27.3 m. The annual gross primary production of the lake is 719 g C cm^{-2} while net primary production is 136 g C cm^{-2} (Sharma 1980). The chief macrophytes in the littoral zone consist of *Potamogeton pectinatus, P. crispus, Hydrilla vorticellata* and *Polygonum glabrum*. Of these, the first one consists almost a monospecific community at several places. The average temperature

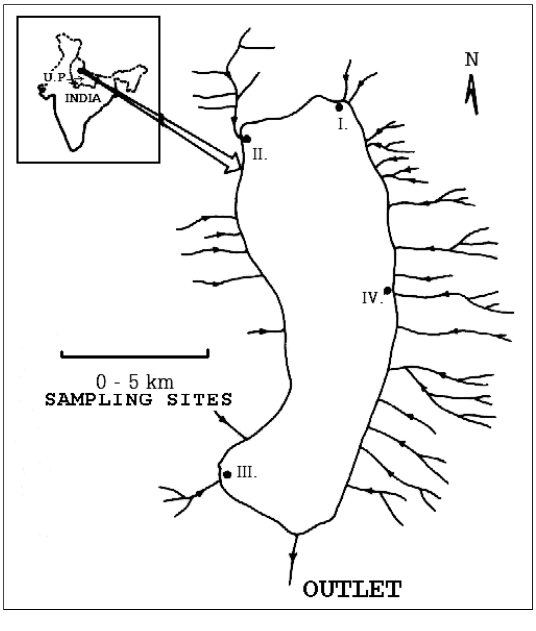

Fig. 1. Sketch map of Lake Naini Tal showing position of sampling sites and drains around the lake.

Protozoan taxa	Mean size	Food preference
Rhizopoda		
Amoeba megastoma Ehrenberg	450	B
Arcella discoides Ehrenberg	130	B
Arcella megastoma Penard	280	B
Arcella mitrata Leidy	130	B
Astramoeba sp. Vejdovsky	90	A/B
Chaos diffluens Muller	540	B
Difflugia lobostoma Leidy	140	B
Plagiopyxis callida Penard	110	-
Pleomyxa palustris Greeff	2500	B
Pyxidicula cymbalum Penard	70	-
Pyxidicula scutella Playfair	20	-
Flagellata		
Ancyromonas sp. Lemmermann	9	B/A
Bodo sp. Dujardin	8	B/A
Euglena sp. Ehrenberg	8	B/A
Monas sp. Ehrenberg	19	B/A
Peranema sp. Ehrenberg	13	B/A
Ciliata		
Acineria sp. Dujardin	110	B/A
Amphileptus sp. Stein	135	B/A
Branchioecetes sp. Penard	122	B/A
Bursaria sp. O.F. Muller	680	B/A
Bursaridium sp. Lauterborn	220	B/A
Carchecium sp. Linnaeus	95	B
Climacostomum sp. Ehrenberg	260	B/A
Colpoda sp. O.F. Muller	88	B
Compenella umbellaria Linnaeus	160	B
Cothurnia imberbis Ehrenberg	75	B
Diceras bicornis Kahl	190	B
Didinium balbiani Fabre-Domergue	70	C
Didinium nasutum O.F. Muller	85	C
Didinium sp.	80	C
Epistylis sp. Ehrenberg	140	B
Euplotes sp. O.F. Muller	115	B/A
Glossatella sp. Kent	30	B
Intrastylum invaginatum Stokes	30	B
Lionotus sp. Ehrenberg	130	C
Loxodes magnus Stokes	490	B/A
Loxodes striatus Stokes	580	B/A
Metopus sp. O.F. Muller	120	B
Opercularia sp.Claparede & Lachmann	30	B/A
Ophridium sp. Ehrenberg	270	B
Ophryoglena sp. Lieberkuhn	270	B
Paramecium aurelia Ehrenberg	160	B
Paramecium caudatum Ehrenberg	200	B
P. multimicronucl. Power & Mitchell	270	B
Paravorticella sp. Kent	80	B
Pseudoblepharisma sp. Kahl	200	B/A
Spirostomum minus Raux	890	B/A
S. teres Claparede & Lachmann	530	B/A
Stentor sp. Ehrenberg	510	B/A
Strombidinopsis sp. Ehrenberg	60	B/A
Stylonychia sp. Ehrenberg	135	B/A
Urceolaria sp. Siebold	110	B/A
Urocentrum turbo Schewiakoff	21	B/A
Vaginicola sp. O.F. Muller	48	B
Vorticella sp. Ehrenberg	90	B
Zoothamnium sp. Ehrenberg	30	B/A
Unidentified ciliate		-
Unidentified flagellate		-

Table 1. List, size (mm) and food of benthic Protozoa identified in Lake Naini Tal (A = Algae, B = Bacteria, C = carnivorous).

in the surface water of the lake varies from 9 °C to 28 °C, pH from 7.1 to 8.9 and dissolved oxygen concentration from 2 to 13.1 mg per l. The climate of Nainital is subtropical. The rainfall is rather seasonal, most of the precipitation (80-90%) occurring during monsoon months (mid June - mid September). The average rainfall is 2,153 mm. Further details about the lake can be found in Pant, Sharma and Sharma (1980) and Pant *et al.* (1981, 1985).

Sampling and identification

Four sampling sites in the littoral zone around the lake (Fig. 1) were selected. Samplings were done fortnightly for nine months from November, 1993 to July, 1994 at each of the four sites.

Sediment samples (app. 30 cm water depth) were collected in small plastic boxes by dipping the hand in water to the sediment. The plastic boxes were closed immediately while under the water to avoid the mixing of sediments with water. All living samples were brought to the laboratory within 1 hour of collection.

Protozoans were examined live either with a light microscope (150X) or projection microscope. They were identified according to the work of Edmondson (1959). Kudo (1977), Pennak (1978), Curds (1982), Fitter and Munuel (1986) and others, Three subsamples of sediment, diluted ten folds in the sterilised lake water (water filtered through a millipore filter, pore size 0.22 (mm), were counted in a Sedgwick - Rafter chamber with microscope.

In order to examine seasonal changes in the abundance, the average monthly data of four sites were treated as four replicates. The arithmetic means were calculated from these replicates. Similarly, to examine variations in space, arithmetic means were calculated from the monthly data from nine months at each of the four sites.

Food preferences of various species are defined (Table 1) according to Kudo (1977), Pratt and Cairns (1985) and Finlay (1988).

General features of ecology of Protozoa in the Lake Naini Tal

The identified species or genera are listed in Table 1. On annual mean basis (across months and sites), the total number of Protozoa was 592 ind cm^{-2}. The ciliates were most abundant (83%) followed by flagellates (9%) and rhizopods (8%).

The average monthly density of total Protozoa varied from 193 to 1,216 ind cm^{-2} being minimum in February and maximum in December (Fig. 2). The seasonality in the numbers was characterised by two peaks during the study period. Both peaks (December and April) were more or less of the same magnitude.

Interestingly, December (winter) peak showed preponderance of *Paramecium multimicronucleatum, Bursaridium* sp., *P. caudatum* and *Spirostomum teres* which contributed 18%, 16%, 10% and 10% respectively, to the total protozoan number during that period; *Branchioecetes* sp. was the largest contributor to the April (summer) peak and shared as much as 25% of the total Protozoa at that time.

The protozoan species (excluding two unidentified) found in the present study are divided into two arbitrary groups: (a) fairly abundant species which contributed =>2% to the total protozoan number and (b) a number

Protozoan taxa			1993				1994		
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.
Amoeba megastoma Ehrenberg	4	5	5	-	-	-	-	10	1
Arcella megastoma Penard	1	3	-	-	-	-	-	-	-
Arcella mitrata Leidy	18	8	3	10	11	10	9	13	13
Chaos diffluens Muller	-	11	8	-	-	-	-	-	-
Difflugia lobostoma Leidy	-	-	-	-	-	1	1	3	3
Pyxidicula cymbalum Penard	3	18	-	-	1	13	3	3	3
Pyxidicula scutella Playfair	-	-	1	-	1	-	-	-	-
Compenella umbellaria Linnaeus	-	-	-	-	1	3	1	-	-
Cothurnia imberbis Ehrenberg	-	6	-	-	-	-	-	-	-
Diceras bicornis Kahl	-	-	-	-	-	4	2	-	-
Didinium balbiani Fabre-Domergue	17	13	4	4	1	18	4	-	4
Didinium nasutum O.F. Muller	5	14	4	-	3	17	8	9	5
Intrastylum invaginatum Stokes	-	-	25	-	-	-	-	-	-
Loxodes magnus Stokes	13	7	4	1	5	23	13	7	12
Loxodes striatus Stokes	9	13	14	5	11	33	8	8	9
Urocentrum turbo Schewiakoff	1	-	6	1	-	4	1	-	5

Table 2. Seasonal variation in the number of individuals per cm^2 of species contributing < 2% to the total protozoan number.

of others which occurred more or less regularly but contributed <= 2% to the total number (those determined at the level of species are presented in Table 2).

Dominant species and genera

Paramecium multimicronucleatum: Numerically, it was the most significant species which contributed 14.2% to the total Protozoa (annual mean across months and sites). The population density of the species ranged between 30 and 220 ind/cm^2 during the study period. There occurred a single peak in seasonal density with 220 ind/cm^2 in December.

Bursaridium sp.: The genus contributed 7.3% to the total Protozoa. The monthly mean density varied from 1 to 191 ind/cm^2. In general, it showed high abundance during winter and low during rest of the months.

Branchioecetes sp.: On mean annual basis it accounted for 6.8% of the total annual number of Protozoa. The seasonal oscillations in the genus density was represented by a single peak (277 ind/cm^2) in the month of April. The density was low during rest of the months.

Paramecium aurelia: It contributed 6.8% to the total protozoan number. The density varied from 10 (Jan. and July) to 93 (April) ind/cm^2 with a single pronounced peak in April. A minor spurt in density with 65 ind/cm^2 was also noticed in December (Fig. 3).

Spirostomum teres: This species contributed by 6.2%. The density, increased sharply in December culminating into a pronounced peak (122 ind/cm^2) in this month. The density, thereafter declined and attained a minimum value of 2 ind/cm^2 in February. Thus, the species showed a bimodal pattern in density (Fig. 3) when the second increase was in April, 58 ind/cm^2.

Paramecium caudatum: 5.7% of the total Protozoa. Single peak in seasonal density was in December (127 ind/cm^2, Fig. 3).

Spirostomum minus: 4.5% of the total Protozoa. Bimodal pattern of seasonal density (Fig. 4).

Monas sp.: 3.8% of the total Protozoa. The density oscillated from 7 to 40 ind/cm^2. In general, the density was lower during winter and higher during summer months (Fig. 4).

Arcella discoides: 2.8% of the total number of

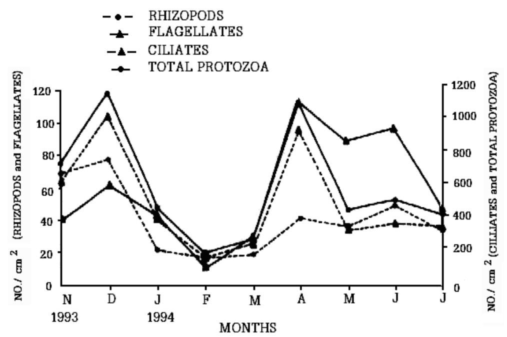

Fig. 2. Seasonal variation in the total protozoan number, total ciliates, flagellates and rhizopods.

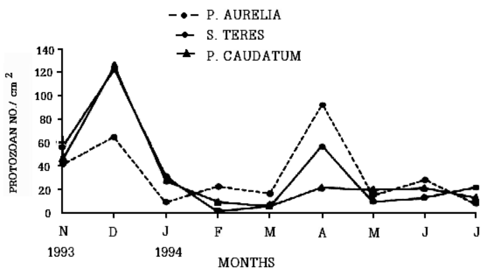

Fig. 3. Seasonal variation in the population density of *Paramecium aurelia, P. caudatum* and *Spirostomum teres.*

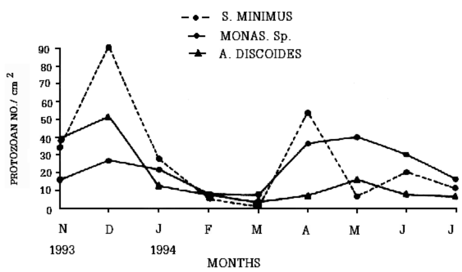

Fig. 4. Seasonal variation in the density of *Spirostomum minus, Arcella discoides* and genus *Monas.*

Protozoa. The density varied between 3 (March) and 51 ind/cm^2 (December). Single peak in December (Fig. 4).

Peranema sp.: 2.5% of annual number of Protozoa. The density oscillated from 2 (November and February) to 32 (April) ind/cm^2. Two pronounced

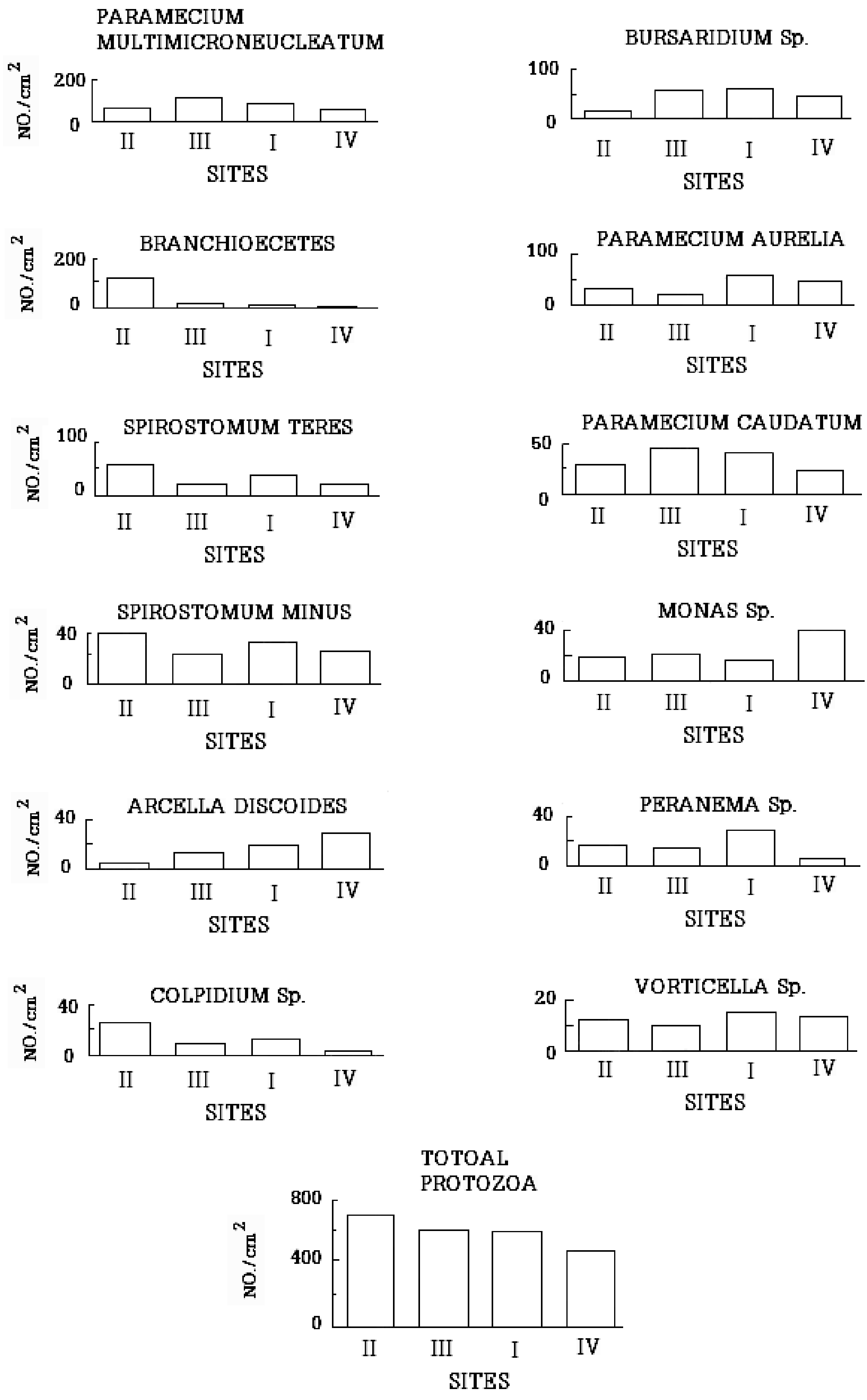

Fig. 5. Histograms showing spatial changes in the group size of numerically dominant species and genera, and of total Protozoa at four sampling sites in Lake Naini Tal. (The sites are arranged in order of decreasing total protozoan number).

peaks were noticed. The first one occurring in December was smaller than that occurring in April.

Colpoda sp.: This genus accounted for 2% of the total protozoan number. The maximum density was found in November (45 ind/cm^2). The density, thereafter, declined sharply until minimum value of 16 ind/cm^2 (February). The genus was not found from March to July.

Vorticella sp.: 2% of the total protozoan number. The density varied from 3 to 23 ind/cm^2 being minimal in January and maximal in March. In general, the density was lower during winter and higher during summer months. The species was not found in November.

Spatial variation

The average group size of 12 numerically important species or genera and total protozoan number at four sampling sites are presented in Fig. 5. The highest concentration of Protozoa was at site II and the lowest at IV. The majority of Protozoa found in the present study (Table 1) were also reported in other lakes (Goulder 1974; Finlay, Bannister and Stewart 1979; Madoni 1989; Hawthorn and Ellis-Evans 1984) and many of the species probably posses the cosmopolitan nature of distribution.

The number of species of Protozoa occurring in different water bodies varies widely. Ruggiu (1965, 1969) studied the profundal zones of Lakes Maggiore and Orta and found only 20 and 17 ciliate species, respectively. Grabacka (1965, 1971 a, b) has reported a mean number of 72 species of ciliates in 15 Polish fish ponds studied. Finlay, Bannister and Stewart (1979) isolated as much as 91 species of ciliated Protozoa from the eutrophic Airthrey Loch. Hawthorn and Ellis-Evans (1984) reported 41 species in Sombre lake, 37 in Heywood lake and 33 in Knob lake. A total of 56 species of ciliates have been found in lake Suviana by Madoni (1989). In the present study, the number of ciliate species or genera isolated was 41 which corresponds with Lake Sombre but deviates from the other water-bodies discussed above. The variation in the number of species in different water bodies may be attributed to the differences in the lake area, number of sampling occasions, analytical procedures, climatic regions in which the lake is situated and also to the time of sampling and techniques employed.

The spatial distribution pattern indicated a marked variation in the density of individual species as well as total protozoan number at 4 sampling sites of the lake. The greatest concentration of Protozoa at site II could be related to high degree of pollution at this site. It is important to note here that the site II is fed by a permanent drain which carries a large amount of organic matter and other organic pollutants (domestic wastes). Gupta and Pant (1986) mentioned that different locations (sites) in the inshore area of Lake Naini Tal differ widely in sediment texture, amount of organic matter present and in magnitude of pollution, which could affect the bacterial activity and hence the protozoan number.

Seasonal variation

The seasonality in the total number of Protozoa was represented by two peaks: one during winter (December) and the other during summer (April). The double peaks of Protozoa occurrence in the Lake Naini Tal is similar to the double peak occurrence of these organisms reported by Hawthorn and Ellis-Evans (1984) but do not correspond to the single summer peak found in other studies (Fenchel 1967; Goulder 1974; Finlay 1980). In Naini Tal lake, it has been reported that high densities of phytoplankton occur during autumn and spring (Sharma 1980). It seems that with the death of these organisms, there is greater deposition of dead plankton and as a result, a larger number of bacteria and amount of detritus available to the Protozoa, which in turn increase in density. Thus, the benthic protozoan peaks in Lake Naini Tal are preceded by phytoplanktonic peaks in the lake. Similar observation relating to a large abundance of Protozoa after the death of the phytoplankton and simultaneous bacterial growth has been made in Lake Dalnee (Russia; Sorokin and Paveljeva 1972), and in Lobo Reservoir (Brazil; Barbieri and Godinho-Orlandi 1989).

In the Lake Naini Tal, the ciliates predominated having about 83% of total protozoan number. The domination of ciliates over other groups has also been observed by Finlay *et al.* (1979) in Airthrey Loch, by Semtacek (1981) in the Bay of Keil (Germany), by Hunt and Chein (1983) in Cayuga Lake (New York, U.S.A.) by Barbieri and Godinho-Orlandi (1989) in a tropical reservoir and several others. Since protozoan community is dominated by ciliates, which basically feed on bacteria (Kudo, 1977), it could be argued that Protozoa in Lake Naini Tal are acting as nutrient releaser from bacterial biomass.

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References

Amblard, C., Sime-NGando, Rachiq, S. and Bourdier, G. 1993: Importance of ciliated Protozoa in relation to the bacterial and phytoplanktonic biomass in an oligo-mesotrophic lake, during the spring diatoms bloom. *Aquat. Sci.*, **55**:1-9.

Barbieri, S.M. and Godinho-Orlandi, M.J.L. 1989: Plank tonic Protozoa in a tropical reservoir: Temporal varia tions in abundance and composition. *Rev. Hydrobiol. Trop.*, **22**:275-285.

Beaver, J.R. and Crisman, T.L. 1982: The trophic response of ciliated protozoans in freshwater lakes. *Limnol. Oceanogr.*, **27**:246-253.

Berk, S.G., Brownlee, D.C., Heinle, D.R., Kling, H. J. and Colwell, R.R. 1977: Ciliates as a food source for marine planktonic copepods. *Micro. Ecol.*, **4**:27-40.

Bick, H. 1973: Population dynamics of Protozoa associated with the decay of organic material in freshwaters. *American Zoologist*, **13**:149-160.

Buechler, D.G. and Dillon, R.D. 1974: Phosphorus regenera tion in freshwater Paramecia. *J. Protozool.*, **21**:393-343.

Caron, D.A., Joel, C.G. and Mark, R.D. 1988: Experimental demonstration of the roles of bacteria and bacterivorous Protozoa in plankton nutrient cycles. *Hydrobiol.*, **159**:27-40.

Carrias, J.F., Amblard, C. and Bourdier, G. 1994: Vertical and temporal heterogeneity of planktonic ciliated Pro tozoa in a humic lake. *J. Plankt. Res.*, **16**:471- 485.

Curds, C.R. 1982: British freshwater ciliated Protozoa, Part I: Ciliophora: Kinetofragminophora . Cambridge Uni versity Press .

Dragesco, J. and Kerneis, A.D. 1991: Free living ciliates from the coastal area of lake Tanganyika (Africa) . *Europ. J. Protistol.*, ***26***:216-235.

Edmondson, W.T. 1959: Freshwater Biology, Ward and Whipple 2nd ed., John Wiley and Sons: New York .

Fenchel, T. 1967: The ecology of marine microbenthos I . *Ophelia*, **4**:121-137.

Finlay, B.J. 1978: Community production and respiration by ciliated Protozoa in the benthos of a small eutrophic loch. *Freshwater. Biol* ., **8**:327-341.

Finlay, B.J., Bannister, P. and Stewart, J. 1979: Temporal variation in benthic ciliates and the application of association analysis. *Freshwat. Biol.*, **9**:45-53.

Finlay, B. J. 1980: Temporal and vertical distribution of ciliophoran communities in the benthos of a small eutrophic loch with particular reference to redox profile. *Freshwat. Biol.*, **10**:17-34.

Finlay, B.J. 1982: Effect of seasonal anoxia on the commu nity of benthic ciliated Protozoa in a productive lake. *Arch Protistenk* ., **125**:215-222.

Finlay, B.J. and Uhlig, G. 1981: Calorific and carbon values of marine and freshwater Protozoa . *Helgolander Meeresunters*, **34**:401-412.

Finlay, B. J. and Fenchel, T. 1986: Physiological ecology of the ciliated protozoan Loxodes. *Rep. Freshwat. Biol. Ass.*, **54**:73-86.

Finlay, B.J., Clarkes, K.J., Andrew, J.C., Hindle, R.M. and Andrew, R. 1988: On the abundance and distribution of protozoan and their food in a productive freshwater pond. *Europ. J. Protistol* ., **23**:205-217.

Finlay, B.J., Curds, C.R., Bamforth, S.S. and Befort, J.M. 1987: Ciliated Protozoa and other micro-organisms from two African soda lakes (L. Nakuru and L. Simbi, Kenya) . *Arch. Protistenk.*, **133**:81-91.

Fitter, R. and Manual, R. 1986: Field guide to the freshwa ter life of Britain and North West Europe. William Collins Sons & Co. Ltd. London, Glasgow, Sydney, Toronto.

Gasol, J.M. 1993: Benthic flagellates and ciliates in fine freshwater sediments: calibration of live counting procedure and estimation of their abundances. *Microb. Ecol* ., **25**:247-262.

Goulder, R. 1971: Vertical distribution of some ciliated protozoan in two freshwater sediments. *Oikos*, **22**:199-203.

Goulder, R. 1974: The seasonal and spatial distribution of some benthic ciliated Protozoa in Esthwaite water. *Freshwat. Biol.*, **4**:127-147.

Goulder, R. 1980: The ecology of two species of primitive ciliated Protozoa commonly found in standing water, Loxodes magnus Stokes and L. striatus Penard. *Hydrobiol.*, **72**:131-158.

Grabacka, E. 1965: Microfauna of the bottom of fish pond in Golysz. *Acta. Hydrobiol . (Krakow)*, **7**:317-328.

Grabacka, E. 1971a: Ciliata of the bottom of rearing fishpond in the Golysz Complex. *Acta Hydrobiol. (Krakow)*, **13**:5-28.

Grabacka, E. 1971b: Ciliata in the bottom sediments of fingerlings ponds. *Pol. Arch. Hydrobiol.*, **18**:225-233.

Gupta, P.K. and Pant, M.C. 1983a: Chemical composition of surface sediments in a eutrophic lake (Lake Naini Tal, U.P., India). *Env. Pollut. (B)*, **6**:95-107.

Gupta, P.K. and Pant, M.C. 1983b: Macrobenthos of Lake Naini Tal, U.P. (India) with particular reference to pollution. *Water, Air and Soil Pollution*, **19**:393-405.

Gupta, P.K. and Pant, M.C. 1986: Analysis of the inshore macrozoobenthic community in Lake Naini Tal, U.P., India. *Int. Revue. ges. Hydrobiol.*, **71**:115-125.

Gupta, P.K. and Pant, M.C. 1990: Distribution and sea sonal abundance of benthic macro-invertebrates in Lake Naini Tal (U.P.), India. *Int. Revue. ges Hydrobiol.*, **75**:493-506.

Gupta, P.K. and Pant, M.C. 1991: Macrobenthic community of two Kumaun Lakes (U.P.), India. In: *Ecology of the mountain waters* (eds. S.D. Bhatt and R.K. Pande), pp. 266-275. Asish Publisher New Delhi, India.

Hawthorn, G.R., Ellis-Evans, J.C. 1984: Benthic Protozoa from maritime Antarctic freshwater lakes and pools. *Br. Antarct. Surv. Bull.*, **62**:67-81.

Hunt, C.W. and Chein, S.M. 1983: Seasonal distribution, composition and abundance of the planktonic ciliata and testacea of Cayuga lake. *Hydrobiol.*, **98**:257-266.

Kudo, R.R. 1977: Protozoology, 5th edn ., Charloes, C. Thomas, Illinois.

Leakey, R.J.G., Burkill, P.H. and Sleigh, M.A. 1992: Plank tonic ciliates in Southampton Water: abundance, biomass, production and role in pelagic carbon flow. *Marine Biology*, **114**:67-83.

Madoni, P. 1984: Estimation of the size of freshwater ciliates population by a sub-sampling technique. *Hydrobiol.*, **111**:201-206.

Madoni, P. 1989: Community structure of microzoobenthos in Lake Suviana (Tusco-Emilean Apennines). *Boll. Zoo.*, **56**:159-165.

Pande, J. and Das, S.M. 1980: Metallic contents in water and sediments of Lake Naini Tal, India. *Water, Air and Soil Pollution*, **13**:3-7.

Pant, M.C., Sharma, A.P. and Sharma, P.C., Pande, J. and Sharma, A.P. 1981: Aspects of water pollution in Lake Naini Tal (U.P.), India. *Environ. Conserv.*, **81**:113-117.

Pant, M.C., Sharma, P.C., Sharma, A.P. and Gupta, P.K. 1985: Lake Naini Tal: An ecological perspective. In: *Environmental Regeneration in the Himalaya: Concepts and Strategies* (ed. J.S. Singh), pp.339-348. Gyanodaya Prakashan, Naini Tal, India.

Pennak, R.W. 1978: Fresh water invertebrates of United States. 2nd. edn., John Wiley and Sons, Inc., New York.

Porter, K.G., Pace, M.L. and Battey, I.F. 1979: Ciliate protozoans as link in fresh water planktonic food chains. *Nature*, **227**:563-65.

Pratt, J.R. and Cairns, J.Jr. 1985: Functional groups in the Protozoa: Roles in differing ecosystems. *J. Protozool.*, **32**:415-423.

Ruggiu, D. 1965: Ciliati de grande profondita nel lago Maggiore. *Bull. Zool.,* **32**:325-329.

Ruggiu, D. 1969: Benthic ciliates in the profundal of Lake Orta (Northern Italy). *Verh. Int. Ver. Limnol.,* **17**:255-258.

Sharma, A.P. 1980: Phytoplankton primary production and nutrient relations in Naini Tal Lake. Ph.D. thesis, Kumaun University, Naini Tal, India.

Sharma, P.C. and Pant, M.C. 1984: Abundance and community structure of limnetic zooplankton in Kumaun lakes. *Int. Revue ges. Hydrobiol.*, **69**:91-109.

Sharma, P.C. and Pant, M.C. 1985: Species composition of zooplankton in two Kumaun Himalayan lakes, U.P., India. *Arch. Hydrobiol.*, **102**:387-403.

Smetacek, V. 1981: The annual cycle of protozooplankton in the Kiel Bight. *Mar. biol.,* **63**:1-11.

Sorokin, Y.I. and Paveljeva, E.B. 1972: On the quantitative characteristics of the pelagic ecosystem of Dalnee lake (Kamchatka). *Hydrobiol.*, **40**:519-552.

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