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Characterisation of tropical reservoirs in Tamil Nadu, India in terms of plankton assemblage using multivariate analysis

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ABSTRACT

The ecological status of reservoirs in Tamil Nadu, India was studied in view of their importance in culture based fisheries. The abundance and distribution pattern of plankton assemblages with respect to important water parameters was selected to characterise the reservoirs. Sampling was carried out seasonally in 22 reservoirs widely ranging in trophic state, during 1993 to 2004. A definite distinction was observed between Western Ghats (WG), rain shadow (RS) and plain land reservoirs (PL) based on plankton communities and environmental factors analysed. Western Ghats reservoirs lying at the head stream of rivers tend to show chemically oligotrophic to mesotrophic status with characteristic dominance of phytoplankters *viz*., chlorophyta, *Selenastrum* spp., *Ankistrodesmus* spp., bacillariophyta, *Navicula* spp., *Nitzshia* spp. and *Synedra* spp. and zooplankton, rotifer, *Brachionus* spp. and copepod, *Diaptomus* spp. Eutrophic to hyper-eutrophic status with dominant presence of cyanophyta, *Microcystis aeruginosa* in all the seasons and lesser presence of *Spirulina* spp. was observed in many plain land reservoirs while others with low anthropogenic pressure were sub-dominant with bacillariophyta, *Nitzshia* spp., *Synedra* spp. and *Navicula* spp. and chlorophyta *Scenedesmus* spp. and *Selenastrum* spp. Blooms of *Microcystis aeruginosa* occurred in shallow plain reservoirs receiving agricultural, industrial and municipal run-off during monsoon. Rain shadow reservoirs depicted early eutrophy stage as estimated through Carlssons Trophic State Index, represented by species of two groups, chlorophyceae and myxophyceae, distribution being influenced mostly by habitat characteristics. Principal component analysis (PCA) suggested that secchi disc transparency and nutrients were important variables determining the ecological status of the reservoirs. The overall division of the reservoirs is explained by species environmental relationship using BIOENV (Primer 6), which described the positive correlation of temperature, specific conductivity and hardness to plankton composition and numerical abundance. Some plain reservoirs move out of their group to assume a solitary position exhibiting different plankton composition with respect to hydrological characteristics.

Keywords: BIOENV, Multivariate analysis, Plankton, Tropical reservoirs, Water parameters

Introduction

A number of small, medium and large river valley projects have come into existence in India during the last four and a half decades with the primary objective of storing river water for power generation, irrigation and a host of other activities. These projects created many manmade lakes, which hold tremendous potential for inland fisheries development and fish yield optimisation from these reservoirs has attracted attention (Sugunan, 2000). An assessment of environment mediated production functions and trophic status of the reservoirs has long been felt by those engaged in fishery management, development, planning and research. Tamil Nadu State, located in the southernmost tip of peninsular India and flanked by Eastern Ghats and Western Ghats along the northern and western boundaries, meeting at Nilgiri Hills, has more than 3 lakh ha under reservoir waterspread area. Western Ghats is a long peninsular mountain range extending over 1500 km with dense forests running parallel to the west coast from the south of Tapti valley (Maharashtra) to Kanyakumari (Tamil Nadu). Tamil Nadu receives rainfall from both south-west monsoon and north-east monsoon. Reservoirs of Tamil Nadu in the Western Ghats and rain shadow region are fed profoundly by south-west monsoon. While the south-west monsoon brings heavier rain fall in the western coastal plains of Kerala (>200 cm) and the Western Ghats (100-200 cm), when it crosses the Western Ghats, it loses much of its moisture and gives very little rainfall (50-100 cm) to the eastern slopes, which lies in the rain-shadow region. The state also receives about 48% of the annual rainfall from the north-east monsoon, filling the reservoirs in the eastern side of the state during this season.

Reservoirs in the tropics with optimum temperature and bright sunshine are normally expected to be conducive for higher biological production (Sreenivasan, 1964; Lewis, 1996; Sugunan, 1997). Reservoirs in the upstream part of a river are largely in mesotrophic state and while those in the downstream part are hyper-eutrophic due to anthropogenic influence. Many authors attribute plankton distribution in reservoirs and lakes to various influencing factors such as basin geology and land use (Sabater and Nolla, 1991; Negro and De Hoyos, 2005), hydric resource use regime (GIG, 2007) as well as geographic location, reservoir type and anthropogenic pressure (Cabecinha *et al.,* 2008a).

Plankton constitutes the major source of energy in the food web of aquatic systems and their population fluctuates depending on the hydrological regime and saprobiotic condition of the water (Murugesan *et al*., 2003a). Phytoplankton productivity and biomass of reservoirs are dependent on several interrelated physical, chemical and biological factors, which in turn are functions of climatic regimes, the size of the watershed, basin morphometry, nature and volume of river inflow and the food web structure (Thornton *et al*., 1990; Harris and Baxter, 1996; Murugesan *et al*., 2003a). Alterations observed in the plankton community on a timescale due to the reservoir formation are believed to have contributed to radical changes in fish stocks. The excessive supply of nutrients causes eutrophication and *Microcystis* blooms during summer, whcih sometimes leads to fish mortalities in reservoirs (Robarts, 1985).

Microcystis aeruginosa is the mainstay of plankton community in many south Indian reservoirs particularly in Tamil Nadu, and these blooms are ubiquitous due to fast turnover of nutrients and availability of sunshine. Fall in diversity and increase in dominance of lentic species, apart from indicating organic enrichment suggests transient eutrophication stage that reservoirs undergo (Sugunan, 1995). Past studies indicate that riverine plankton are mostly chlorophyceae and bacillariophyceae (Sreenivasan, 1964; Franklin, 1969). Post-impoundment, the saprophobes were replaced by saproxenes with substantial reduction in diversity (Abraham, 1980). Zafar (1986) reported that south Indian lakes differ vastly in age, physiography, water flow characteristics, chemistry and trophic state but still maintain a phytoplankton population overwhelmingly dominated (43-93%) by blue green algae.

Biological assemblages are important sentinels of environmental conditions, since they can be more sensitive to the combined effects of stressors than to a single stressor (Karr, 1995; Niemi and Mc Donald, 2004; Cabecinha *et al*., 2008b). Anthropogenic activity and excessive release of pollutants into the aquatic bodies across the world have been altering phytoplankton structure and biomass (Vasconcelos, 2001; Cabecinha *et al*., 2008a). In this backdrop, the present study was undertaken to derive baseline information on reservoirs in Tamil Nadu based on their characteristic plankton assemblages and to observe changes in their trophic status, which would help in monitoring the reservoirs in future and in framing management protocols for fish production enhancement.

Materials and methods

Study area

A total of 22 reservoirs located in different districts of Tamil Nadu were studied during 1993 to 2004 with sampling done at quarterly intervals corresponding to four seasons, summer (March-May), pre-monsoon (June-August), monsoon (September-November) and winter (December-February). Here, monsoon refers to the north-east monsoon. During pre-monsoon, the reservoirs in the rain shadow region receive plenty of water from the south-west monsoon, which is very active in the adjacent state of Kerala.

Twenty two reservoirs located in different river basins namely Chalakudi (3), Cauvery (9) and one each in Vaigai, Vaippar, Tambarabarani, Kodayar, Ponniar, Varahanadhi, Vellar, Bharathapuzha and Noyyal with high climatic heterogeneity were selected for the study (Table 1). The reservoirs selected for the purpose were further classified on the basis of geographical location as reservoirs located in the Western Ghats (WG) ; reservoirs in the rain shadow region (RS - 7 reservoirs), reservoirs located in the plain land (PL 9 reservoirs) and at high altitude (HL - 1lake) (Fig.1).

Parambikulam, Thoonakadavu, Peruvaripallam, Pechiparai and Pilloor, either located in or with their catchment area in the Western Ghats, are perennial, at the upper stretch of the river, receiving high rainfall from the south-west monsoon. These reservoirs were constructed mainly for power generation and irrigation. The reservoirs located in the rain shadow region across the rivers or their tributaries originating from the eastern slopes of the Western Ghats (Manimuthar, Palar Poranthalar, Thirumoorthy, Amaravathi and Vaigai) and eastern slopes of the Eastern Ghats (Gunderipallam and Varattupallam) were constructed for the purpose of flood control, irrigation and drinking. These reservoirs lie in the eastward slope of the mountains and have the advantages of rainfall from both south-west and north-east monsoons, very little anthropogenic influence and receives high detritus load from forest litter. Manimuthar and Pechiparai are also hydel projects with less turbid water, the latter has a catchment covered with rubber plantations.

The reservoirs Krishnagiri, Vembakottai, Wellington, Vidur, Odathurai, Orathupalayam, Uppar, Mettur and

Table 1. Classification of the reservoirs studied

Western Ghats	Rain shadow	Plain	High altitude
Peruvaripallam (PER)	Manimuthar (MAN)	Sulur (SUL)	Sandynulla (SAN)
Thoonakadavu (THO)	Palar-Poranthalar (PAP)	Odathurai (ODA)	
Parambikulam (PAR)	Thirumoorthy (TMT)	Orathupalayam(ORA)	
Pilloor (PIL)	Amaravathy (AMA)	Vidur (VID)	
Pechiparai (PEE)	Gunderipallam (GUN)	Wellington (WEL)	
	Varattupallam (VAR)	Krishnagiri (KRI)	
	Vaigai (VAI)	Vembakottai (VEM)	
		Uppar (UPP)	
		Mettur (MET)	

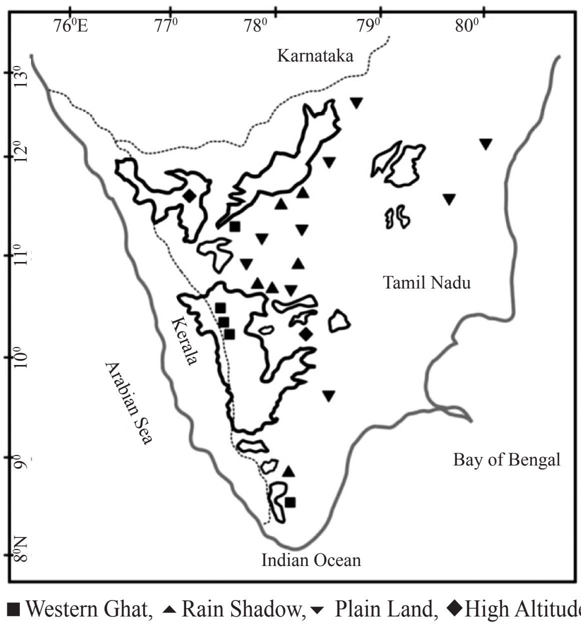

Fig. 1. Map showing location of 22 reservoirs in Tamil Nadu State, selected for the study

Sulur are located in the plain lands across the eastern flowing rivers and are essentially utilised for drinking water and irrigation purposes. Many of these reservoirs are intensively point source polluted and few of them reach hyper-eutrophic state during monsoon due to nutrient enriched rainwater run-off. These are highly seasonal and those in the eastern districts of Virudhunagar and South Arcot districts are associated with algal blooms in monsoon season immediately after receiving sewage mixed rainwater. Orathupalayam Reservoir across Noyyal river was reported to be alarmingly polluted due to effluents generated from hundreds of textile dyeing and bleaching units located in and around Tirupur town (Murugesan *et al*., 2003b). Sandynulla, a high altitude reservoir in Nilgiri hills is a cold water reservoir created for flood control. Mettur is a large reservoir (>5000 ha) whereas, Parambikulam, Vaigai, Pechiparai, Krishnagiri and Wellington are medium reservoirs (1000 to 5000 ha) and the remaining are small reservoirs (<1000 ha). All these reservoirs are situated between latitudes 8° 29' N and 12° 30' N and longitudes 76° 35' E and 79° 41'E at elevation ranging from 38 to 2143 m above MSL. Reservoirs other than Parambikulam, Thoonakadavu and Peruvaripallam located in the Western Ghats forests are intensively used for culture based fisheries. The other important characteristics of the 22 reservoirs are presented in Table 2 a and b.

Analysis of water parameters

Water temperature, pH, dissolved oxygen and conductivity were determined using the portable multiline kit (E Merck). Transparency was determined using secchi disc method. Carbon-dioxide, nitrates, phosphates, silicates, calcium, magnesium and hardness were analysed following standard methods (APHA, 1992). Carlsson's trophic state index based on total phosphorous and secchi depth (Carlsson, 1977) was used for the primary identification of trophic status of the reservoirs.

Plankton analysis

Water samples of 50 l each were collected from surface, 1 m and 2 m depths of the reservoirs using Kemmerer's water sampler and filtered through plankton net made of bolting silk (No. 25) with 79 meshes per cm. The samples collected were transferred to plankton bottles and preserved in Lugol's solution (1% v/v). Plankton assemblages were identified in the laboratory following standard methods (Davis, 1955; Ward and Whipple, 1959; Needham and Needham, 1962; APHA, 1992).

Statistical analysis: A sub data set was prepared by expressing the means of biological and environmental data from a total of 249 samples collected from 22 reservoirs during the four seasons per year for each reservoir. The plankton data was first subjected to overall transformation by square root method in order to obtain the resemblance matrix for further statistical analysis. Cluster analysis was done on the Bray-Curtis similarity matrix between reservoirs followed by non-metric Multidimensional Scaling analysis (n-MDS) to study the measure of relative similarity between reservoirs grouped based on

Table 2a. Important limnological characteristics of the reservoirs

Environmental variables	AMA	VAI	VEM	MANI	PEE	KRIS	VID	WEL	PARA	TH
Water column variables										
Temperature (°C)	27.37 ± 2.3	27.35±1.0	29.15±1.8	26.4±0.9	27.6±1.0	27.25±2.5	30.5±1.75	29.4±1.45	26.65±2.30	25.2±1.9
pH	8±0.4	8.2±0.5	7.8±1.3	7.15±0.15	7.9±0.2	8±0.6	8.2±0.25	8.2±0.30	6.9±0.60	6.97±0.35
DO (mg l^{-1})	8.65±0.8	7.6±0.6	6.6±0.7	7.8±0.2	7.5±0.6	7.7±1.3	7.17±1.1	7.46±0.60	6.1±2.40	7.45±1.0
Conductivity (mS cm^{-1})	47.4±21.5	51.5±16.8	58.2±16.9	40.6±24.0	21.2±8.5	78.6±18.2	38.1±2.2	58.8±3.25	50.15±59.8	38.8±18.7
Total alkalinity (mg l^{-1})	48.2±31.8	117.2±72.6	181±81.6	44.1±8.0	27.7±4.0	147.5±31.5	134±42.6	112±41.0	63.6±76.0	24.5±2.0
TDS (mg l^{-1})	26.6±9.8	24.4±8.2	28±3.6	19.5±12.3	12.12±3.3	38.3±9.9	21.9±7.25	33.2±2.0	23.37±27.1	18.42±8.4
PO_4 (mg l^{-1})	0.062±0.005	0.31±0.15	0.31±0.23	0.34±0.10	0.33±0.14	0.54±0.4	0.4±0.06	0.44±0.06	0.08±0.05	0.05±0.005
NO_3 (mg l^{-1})	0.41±0.3	0.54±0.49	0.613±0.75	1.7±0.2	0.753±0.6	1.18±1.14	0.466±0.12	0.84±0.10	0.63±0.07	0.6±0.07
SIO_3 (mg l^{-1})	7.5±2	15.15±8.9	12.7±1.2	9.52±3.9	6.75±0.9	14.42±4.2	15.9±1.9	18.9±1.50	2.77±0.45	6.8±0.20
Ca (mg l^{-1})	17.1±3.4	16.03±4.1	19.22±1.3	3.2±1.7	2.8±0.7	20.42±5.2	11.85±7.35	20.82±0.80	2.9±0.30	2.8±0.30
Mg (mg l^{-1})	28±3.4	43.15±11.9	45.45±6.4	6±2.3	5.5±2.2	60.95±10.8	74.45±15.8	43.9±10.10	2±0.24	2±0.20
Hardness (mg l^{-1})	55±6.6	88±24	95±9	15±2.9	12±4.0	122±18.0	134±20.0	94±16.0	28±3.30	30±3.6
Regional variables										
Latitude	10°11’	10°37’	9°20’	8°40’	8°29’	12°30’	12°04’	11°54’	10°23’	10°24’
River	Amaravathy	Vaigai	Vaippar	Manimuthar	Kodayar	Ponniar	Varahanadhi	Periyaodai	Parambikulam	Thoona kadavu
Construction period	1953-58	1954-59	1980-85	1951-58	1895-06	1955-58	1958-59	1913-23	1959-67	1963-65
Basin	Cauvery	Vaigai	Vaippar	Tambaraparani	Kodayar	Ponniar	Varahanadhi	Vellar	Chalakudi	Chalakudi
District	Coimbatore	Theni	Vaippar	Tirunelveli	Kanyakumari	Dharmapuri	South Arcot	South Arcot	Coimbatore	Coimbatore
Catchment area (ha)	83900	225330	2691	16161	20179	542843	129800	12950	23050	4335
Gross capacity (M.Cu.m)	114.61	192.57	11.29	156.07	150.26	66.1	16.93	73.4	504.66	15.77
Water area @ FRL(ha)	850	2419	468	940	1515	1248	798	1554	2072	432
Catchment/FRL (C/A)	98.7	93.2	5.8	17.2	13.7	434.9	162.7	8.3	11.1	10
Morpho-edaphic index (MEI)	0.96	3.06	11.26	1.16	1.2	10.1	8.49	10.62	0.43	5.11
Mean depth (m)	13.48	7.96	2.41	16.6	9.9	3.7	2.12	4.17	24.3	3.6
Population	60000	1093950	2539196	2801194	208149	1546700	114700	114700	4271856	4271856
Industries	Sugarmills	Sugarmills	Cotton, paper	Cement	Nil	City sewage	Nil	Nil	Nil	Nil
Trophic state										
Index (SD)	57.9	63.9	69.6	57.9	54.2	66.4	68.2	66.6	46.4	52.8
Index (TP)	63.6	86.87	86.87	88.2	87.77	94.87	90.55	91.92	60.56	60.56

TSI : 40-50 = Mesotrophy; 50-70 = Eutrophy; 70 - >80 = Hypertrophy
AMA- Amaravathy, VAI - Vaigai, VEM - Vembakottai, MANI - Manimuthar, PEE - Peechiparai, KRIS - Krishnagiri, VID - Vidur, WEL - Wellington, PARA – Parambikulam, TH - Thoonakadavu

geographical location. The statistical difference in the four groups of reservoirs (WG, RS, PL, HA) were investigated by performing Analysis of Similarity between groups using ANOSIM (Clarke and Warwick,1994) to observe the significant difference between them. Similarity Percentage Analysis (SIMPER) was performed upon plankton abundance data to understand the relative contribution of the species towards the grouping expressed percentage-wise.

Data on environmental variables were normalised to get a resemblance matrix which was subjected to cluster analysis using Euclidian distance followed by n-MDS for ordination. The PCA was performed for the matrix of environmental data to detect the variables discerning the reservoir groups. The biological and environmental data were subjected to permuted environment and community regression using BIOENV analysis by Spearman rank correlation method and selecting the most appropriate combination using BEST analysis thereby identifying the environmental variables responsible for the distribution pattern of algal flora and zooplankton. Thirteen abiotic parameters were first transformed to validate the use of Euclidean distances. The choice of log transformation was supported by the draftsman plot *i.e.,* the scatter plots of all pair-wise combinations of variables. Data on TDS, specific conductivity and temperature were log transformed to reduce the right skewness. All analyses were done in Primer-E ver.6.0 (Clarke and Gorley, 2001).

Results

Analysis based on plankton assemblages: A total of 28 plankton species were identified from samples analysed and the rare occurrences of less than 10 nos. l^{-1} were excluded from the data set. Samples with higher total dissolved solids (TDS) had higher numbers of cyanobacteria (cyanophyceae). The most important and dominant phytoplankton in terms of number belonging to the families chlorophyceae, bacillariophyceae, myxophyceae and desmidaceae and zooplankton belonging to copepoda, protozoa and rotifera were

Table 2b. Important limnological characteristics of reservoirs

Environmental variables	PERU	PP	PILL	SAND	GUND	VARA	UPP	ORA	ODA	METT	SULUR	TMT
Water column variables												
Temperature (°C)	26.95±2.40	27±1.0	25.75±2.5	16.5±5.4	28.25±2.5	27.33±0.50	28.33±1.25	29.77±0.35	30.1±0.5	27.9±3.3	28.05±3.3	28±3.3
pH	7.2±0.55	7.9±0.8	7.7±0.3	8±0.5	7.27±0.1	8±0.1	7.86±0.4	7.9±0.35	8±0.4	8.46±1.0	8.49±1.0	7.5±1.0
DO (mg l^{-1})	7.47±1.65	7.05±1.3	8.2±0.8	6.85±1.0	6.9±1.4	7.8±1.3	5.26±0.7	7.3±0.60	8.1±1.3	10.6±1.3	5.47±0.6	7.5±1.0
Conductivity (mS cm^{-1})	17.8±8.5	29.7±3.7	35.2±7.3	63.5±15.0	51.7±13.6	59.2±9.9	112.4±35.5	3142.5±400.0	452.5±60.0	354±42.0	3212±385	26.15±3.1
Total alkalinity (mg l^{-1})	31.5±2.0	65±12.0	60±21.0	66.2±26.6	172.5±87.0	144±6.0	154±33.0	178±83.0	139±38.5	145.4±17.0	141±16.9	22.5±2.7
TDS (mg l^{-1})	11.75±1.6	14.9±2.4	16.8±3.3	30.2±3.6	24±7.0	28.1±5.9	52.5±15.1	2011.2±256.0	289.6±38.4	221.2±26.0	2087±250	17±2.0
PO_4 (mg l^{-1})	0.06±0.01	0.05±0.01	0.07±0.01	0.34±0.07	0.22±0.06	0.7±0.8	0.14±0.02	0.201±0.02	0.149±0.03	1.03±0.1	0.512±0.06	0.12±0.01
NO_3 (mg l^{-1})	0.54±0.06	0.43±0.05	0.32±0.04	0.71±1.4	0.56±0.07	0.72±0.09	0.5±0.06	0.4±0.28	0.828±1.3	0.192±0.02	0.75±0.1	0.65±0.08
SIO_3 (mg l^{-1})	7.1±0.15	5.6±0.30	4.8±1.0	12.9±4.0	8.5±0.45	8.4±0.5	3.2±0.2	10.82±2.3	16.15±7.7	14.2±1.7	14.9±1.8	17.3±2.0
Ca (mg l^{-1})	3.1±0.4	4.3±0.50	7.2±0.9	21.22±2.4	27±3.2	30±3.6	18.9±2.2	79.15±36.0	23.53±8.8	27.2±3.2	20.8±2.5	15.3±1.8
Mg (mg l^{-1})	2±0.2	2±0.20	3±0.4	33±3.0	27±3.2	6±0.7	7±0.8	103.9±50.4	39.54±16.8	13±1.5	29±3.5	25±3.0
Hardness (mg l^{-1})	31±3.7	62±7.4	29±3.5	77±4.0	137±16.4	83±9.9	32±3.8	596±401	207.2±65.0	122±14.6	178±21.0	42±5.0
Regional variables												
Latitude	10°25’	10°16’	11°16’	11°33’	10°47’	11°32’	11°16’	11°10’	11°26’	11°28’	10°13’	10°28’
River	P. pallam	P. Poranthalar	Bhavani	Sandynulla	G. pallam	V. pallam	Uppar	Noyyal	Bhavani	Cauvery	Noyyal	Palar
Const. period	1965-71	1971-78	1962-66	N.A.	1974-78	1974-78	1965-68	1986-94	1936-37	1926-34		1962-67
Basin	Chalakudi	Cauvery	Cauvery	Cauvery	Cauvery	Cauvery	Cauvery	Cauvery	Cauvery	Cauvery	Cauvery	Bharathapuzha
District	Coimbatore	Dindugal	Coimbatore	Nilgiris	Erode	Erode	Erode	Erode	Erode	Salem	Coimbatore	Coimbatore
Catchment area (ha)	1580	25900	119140	4400	7223	6682	90388	221555	5680	4221700	285	8029
Gross capacity(M.Cu.m)	17.56	43.19	44.4	27.47	3.06	3.94	16.31	17.44	1.28	2708.79	17.85	54.8
Water area @ FRL (ha)	290	50	400	263	453	61	453	423	75	15346	33.2	388
Catchment/FRL (C/A)	5.4	50	332.2	16.8	118.4	75	199.5	532.7	69.82	275	8.6	20.7
Morpho-edaphic index (MEI)	1.93	2	1.6	2.89	4.9	6.15	6.73	487	198.72			
Mean depth (m)	6.06	8.3	11.1	10.44	5.01	4.4	3.6	4.12	1.57	23.4	8.5	11.7
Population	4271856	67175	4271856	93921	2574067	2574067	100000	100000	100000	751438	2574067	2574067
Industries	Nil	Nil	Nil	Chemical	Nil	Nil	Nil	Textile	Nil	Chemical	Sewage	Nil
Trophic state												
Index (SD)	57.7	59.7	55.9	63.3	70.6	69.9	85.5	60.2	65.9	62.34	70.88	56.78
Index (TP)	63.19	67.34	65.41	88.2	65.41	98.62	75.41	80.62	76.31	104.19	94.11	73.19

TSI : 40-50 - Mesotrophy; 50-70 - Eutrophy; 70 - >80 - Hypertrophy

PERU - Peruvaripallam, PP - Palar Poranthalar, PILL - Pilloor, SAND - Sandynulla, GUND - Gunderipallam, VARA - Varattupallam, UPP - Uppar, ORA - Orathupalayam, ODA - Odathurai, METT - Mettur, SUL - Sulur, TMT - Thirumoorthy

analysed. The density was expressed in numbers per litre (nos. l^{-1}). Analysis of plankton data by Bray-Curtis similiarity showed two major groups, one minor group and three isolated groups, which are mutually exclusive at 50% similarity, visible in the n-MDS ordination based on species abundance data for all the 22 reservoirs (n = 22) at stress value of 0.15 for 2D (Fig. 2). In total, the n-MDS analysis showed similar dispersal of reservoirs associated with their location while some separated explicitly from the main group presenting specific species composition and abundance. The results of SIMPER analysis compared groups between high rainfall WG region reservoirs and PL region reservoirs, where the different assemblages are apparent (Table 3). An intermittent spread of RS reservoirs in the n-MDS graph apparently indicates the overlapping presence of characteristic species of plain and Western Ghats regions (Fig. 3). ANOSIM confirmed there is overall significant difference (3.9%) between the groups with global R value, 0.174.

Western Ghats reservoirs

Pair-wise tests of ANOSIM showed that WG reservoirs differ from PL reservoirs significantly (R: 0.234, p: 4.5%) (Table 4). The larger presence of green algae, *Selenastrum* spp. with moderate presence of bacillariophyceae, *Navicula* spp*.*, *Ankistrodesmus* spp., *Nitzschia* spp. and *Synedra* spp. forming 62.02% in WG reservoirs gave them an average similarity of 47.36%. The average dissimiliarity between the WG and PL reservoirs was 64.45% due to the absence of blue green species, *Microcystis aeruginosa* and *Spirulina* spp. and desmids *Cosmarium* spp, and *Staurastrum* spp. in WG reservoirs, which were dominant in PL reservoirs. The Bray-Curtis similarity at 50% and the n-MDS ordination based on Bray-Curtis clearly distinguished the differences between the WG and PL reservoirs.

Plain land reservoirs

The 9 PL reservoirs studied were similar due to the dominance of *Microcystis aeruginosa* which contributed 16.54%. The bacillariophyceae group consisting of *Navicula* spp*.*, *Nitzschia* spp., *Scenedesmus* spp. and *Synedra* spp. contributed 62.71%. In general the n-MDS displayed a spatial distribution of reservoirs in proportion to the magnitude of anthropogenic pressure. Krishnagiri,

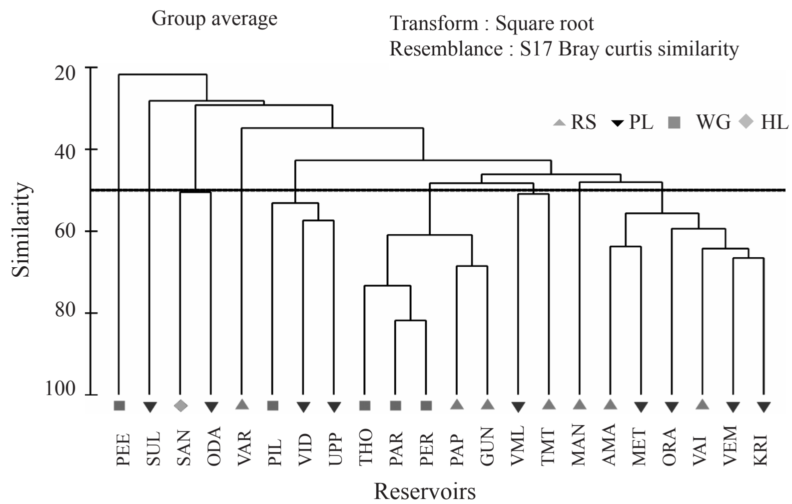

Fig. 2. Non-metric multidimensional scaling (n-MDS) plot comparing the similarity of plankton assemblages between reservoirs

Vembakottai, Mettur and Orathupalayam were comparable presenting plankton composition at 58.5% similarity noticeable in MDS ordination. The other reservoirs Vidur, Uppar and Wellington located at the far eastern part of Tamil Nadu, solely fed by north-east monsoon differed from the main PL group whereas Sulur and Odathurai were dissimilar, with *Microcystis aeruginosa* blooms indicative of hyper-eutrophic status due to influx from city sewage and agriculture run-off.

Rain shadow reservoirs

Rain shadow reservoirs were similar by 46.27% due to dominance of *Navicula* spp., *Nitzschia* spp., *Microcystis* spp., *Brachionus* spp., *Selenastrum* spp., *Synedra* spp., *Scenedesmus* spp., *Tabellaria* spp. and *Diaptomus* spp. which cumulatively contributed 69.91%. RS reservoirs were not significantly different from WG, PL or HL. However, RS differed from WG by 57.75% with the conspicuous presence of *Microcystis* spp., *Spirulina* and *Cyclops* spp. and from PL by 57.99% with poor presence of blue green species. These water bodies were oligotrophic with pollution indicator species. RS reservoirs, Pechiparai and Varattupallam were disimiliar at 50% from the core RS group.

Environmental parameters

The cluster analysis based on Euclidean distances divided the reservoirs into 2 major groups and 3 isolated mutually exclusive groups (Fig. 4) which is evident in n-MDS ordination (Fig. 5). Group 1 consisted of the WG reservoirs, Parambikulam, Thoonakadavu, Peruvaripallam, Pechiparai and Pilloor, RS reservoirs, Manimuthar, Amaravathy, Thirumoorthy and Palar-Poranthalar. These water bodies, particularly the WG reservoirs, are located at the head stream of rivers or tributaries

Table 3. Similarity percentages - species contributions by one way analysis

Group RS	Average similarity: 46.27%	
Species	Contrib%	Cum.%
Navicula	13.17	13.17
Nitzshia	9.70	22.88
Microcystis	8.86	31.73
Brachionus	7.89	39.62
Selenastrum	7.11	46.73
Scenedesmus	7.08	53.81
Synedra	5.98	59.79
Diaptomus	5.59	65.38
Tabellaria	4.54	69.91
Group PL	Average similarity: 40.83%	
Species	Contrib%	Cum. %
Microcystis	16.54	16.54
Navicula	14.66	31.20
Nitzshia	10.83	42.03
Scenedesmus	10.44	52.47
Synedra	10.23	62.71
Selenastrum	8.71	71.42
Spirulina	6.26	77.68
Group WG	Average similarity: 47.36%	
Species	Contrib%	Cum.%
Navicula	16.21	16.21
Selenastrum	16.15	32.36
Ankistrodesmus	10.32	42.68
Nitzshia	10.25	52.93
Synedra	9.10	62.02
Brachionus	7.06	69.09
Diaptomus	6.89	75.98

Contd........

Table 3 contd...

Groups RS & PL Average dissimilarity = 57.99%

Species	Group RS Av. Abund	Group PL Av. Abund	Av. Diss	Diss/SD	Contrib%	Cum.%
Nitzshia	44.70	114.59	4.84	0.84	8.34	8.34
Microcystis	48.22	96.57	4.52	1.30	7.80	16.14
Synedra	32.43	81.86	4.22	1.35	7.27	23.41
Tabellaria	27.65	72.85	4.09	0.76	7.05	30.46
Spirulina	25.08	49.14	3.24	1.47	5.59	36.05
Scenedesmus	39.15	53.41	3.07	1.19	5.29	41.33
Navicula	57.38	65.58	2.67	1.42	4.61	45.94
Selenastrum	46.34	35.35	2.67	1.27	4.61	50.55
Staurastrum	12.49	33.24	2.62	0.76	4.52	55.07
Brachionus	38.69	10.73	2.47	1.01	4.27	59.34
Diaptomus	32.09	19.08	2.13	0.94	3.68	63.01
Daphnia	27.10	9.86	1.98	1.15	3.42	66.43

Groups RS & WG Average dissimilarity = 57.75%

Species	Group RS Av. Abund	Group WG Av. Abund	Av. Diss	Diss/SD	Contrib%	Cum.%
Selenastrum	46.34	94.08	6.59	1.65	11.42	11.42
Microcystis	48.22	2.83	4.16	1.43	7.21	18.62
Navicula	57.38	67.32	3.82	1.22	6.61	25.23
Ankistrodesmus	23.70	51.91	3.58	1.55	6.19	31.42
Tabellaria	27.65	37.09	3.05	1.25	5.28	36.70
Brachionus	38.69	31.68	2.83	1.01	4.90	41.60
Scenedesmus	39.15	24.01	2.82	1.08	4.89	46.49
Nitzshia	44.70	43.56	2.80	1.25	4.85	51.33
Diaptomus	32.09	22.26	2.49	0.85	4.31	55.65
Spirulina	25.08	0.00	2.34	1.15	4.06	59.70
Kirchenierella	7.65	24.38	2.28	1.20	3.95	63.65
Daphnia	27.10	13.45	2.25	1.08	3.89	67.54

Groups PL & WG Average dissimilarity = 64.45%

Species	Group PL Av. Abund	Group WG Av. Abund	Av. Diss	Diss/SD	Contrib%	Cum.%
Microcystis	96.57	2.83	6.83	1.64	10.60	10.60
Selenastrum	35.35	94.08	6.39	1.67	9.91	20.51
Nitzshia	114.59	43.56	5.53	0.90	8.58	29.09
Tabellaria	72.85	37.09	4.88	0.85	7.58	36.67
Synedra	81.86	30.72	4.86	1.30	7.54	44.21
Ankistrodesmus	9.80	51.91	3.84	1.44	5.96	50.17
Scenedesmus	53.41	24.01	3.78	1.04	5.87	56.04
Spirulina	49.14	0.00	3.70	1.01	5.74	61.78
Navicula	65.58	67.32	3.63	1.22	5.64	67.42
Staurastrum	33.24	4.73	2.39	0.70	3.72	71.13
Nostoc	25.92	26.37	2.20	1.02	3.41	74.55

and are perennial. They present a trophic state between mesotrophic to early eutrophic due to low phosphorous condition, low hardness and high transparency. Group 2 include the PL reservoirs Odathurai, Vembakottai, Krishnagiri, Vidur, and Wellington, which are exposed to severe anthropogenic stress, and the RS reservoirs, Gunderipallam, Varattupallam and Vaigai, of which the first two are located on the eastern slope of the Eastern Ghats. Mettur, Sandynulla, Orathupalayam and Sulur behaving distinctly from each other exhibit distinctive characteristics being specifically inflicted by point and non-point source pollution. PL reservoirs normally

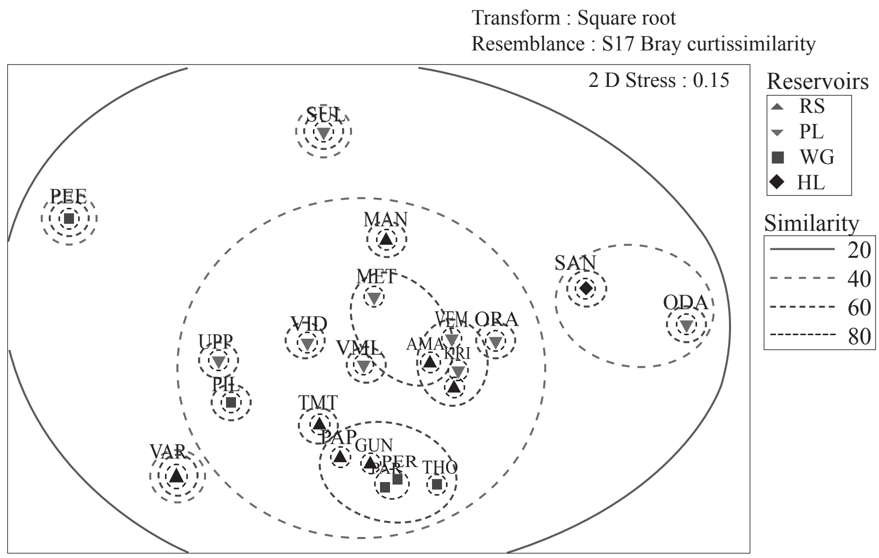

Fig. 3. Dendrogram depicting groups of reservoirs based on plankton species diversity

located on the main river, are nonperennial and subjected to severe anthropogenic stress. These water bodies tend to show eutrophic to hyper-eutrophic state characterised with high specific conductivity, high phosphorous concentration and low transparency. The PL reservoirs are shallow and subjected to frequent drawdown for irrigation purpose. The trophic state TSI (SD) indicated that WG reservoirs and many RS reservoirs were in eutrophy stage I and PL reservoirs were in eutrophy stage II whereas TSI (TP) indicated that most of the PL reservoirs were in hyper-eutrophy stage II.

Table 4. Average dissimilarity between groups of reservoirs in Tamil Nadu, India using SIMPER analysis

Factors	Average similarity (%)	Average dissimilarity (%)		ANOSIM
WG	47.36	WG PL	64.45	R=0.234**
PL	40.83	RS WG	57.75	R=.0.159
RS	47.26	PL RS	57.99	R = 0.046

** *Significant*

From PCA, of all reservoirs sampled, the combined eigen values of the two first axes of the ordination (5.36 and 2.37) accounted for 59.4% of the total variance of which 41.2% was explained by the transparency (Table 5). PC1 is rooted in transparency while PC2 is positively correlated with pH, DO and all nutrients (phosphates,

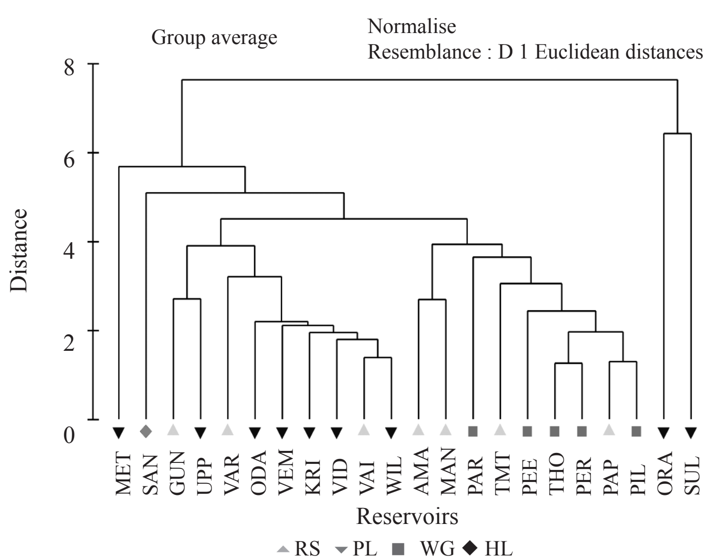

Fig. 4. Non-metric multidimensional scaling (n-MDS) plot comparing the euclidian distance of environmental variables between reservoirs

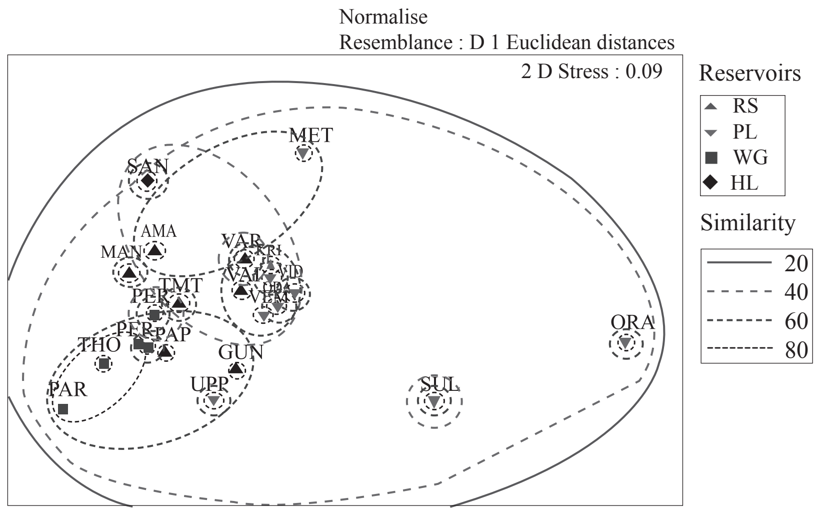

Fig. 5. Dendrogram depicting groups of reservoirs based on environmental variables

nitrates and silicates). Since nutrients are the limiting factors, this axis describes ion concentration (Fig. 6).

BIOENV analysis (Table 6) indicated that the best correlation was for all taxa of plankton species using only three limnological variables *viz.*, temperature, specific conductivity and hardness. The optimal match of the biotic pattern with the 3-variable combination shows correlation of $\rho_w = 0.413$. The next best correlation $\rho_w = 0.373$ was with similarities based on 4-variable set, temperature, specific conductivity, hardness and nitrate. In order to analyse whether the phytoplankton groupings could be more effective, BIOENV analysis was repeated using only phytoplankton at genus level. The best correlation was with similarities based on temperature, specific conductivity, hardness and inorganic phosphate. Again it

Table 5. Eigenvalues, percent explained variance and variable coefficients

Eigenvalues

PC	Eigenvalues	% Variation	Cum. % Variation
1	5.36	41.2	41.2
2	2.37	18.2	59.4
3	1.17	9.0	68.4
4	1.03	8.0	76.4
5	0.983	7.6	84.0

Eigenvectors
(Coefficients in the linear combinations of variables making up PC's)

Variable	PC1	PC2	PC3	PC4	PC5
Temp.	-0.170	-0.030	0.301	-0.527	0.347
pH	-0.286	0.311	0.093	0.223	-0.200
DO	-0.011	0.388	-0.143	0.203	0.736
Transparency	0.287	-0.293	-0.203	0.133	0.318
TA	-0.329	0.008	0.489	-0.135	-0.075
TDS	-0.318	-0.322	-0.199	0.271	-0.094
Sp. conductivity	-0.319	-0.324	-0.196	0.271	-0.091
PO_4	-0.193	0.401	0.179	0.460	0.038
NO_3	-0.077	0.278	-0.632	-0.316	-0.127
SIO_3	-0.249	0.358	-0.227	-0.121	-0.137
Ca	-0.364	-0.161	-0.008	0.063	0.252
Mg	-0.352	-0.017	-0.167	-0.344	0.032
Hardness	-0.367	-0.253	-0.101	-0.008	0.270

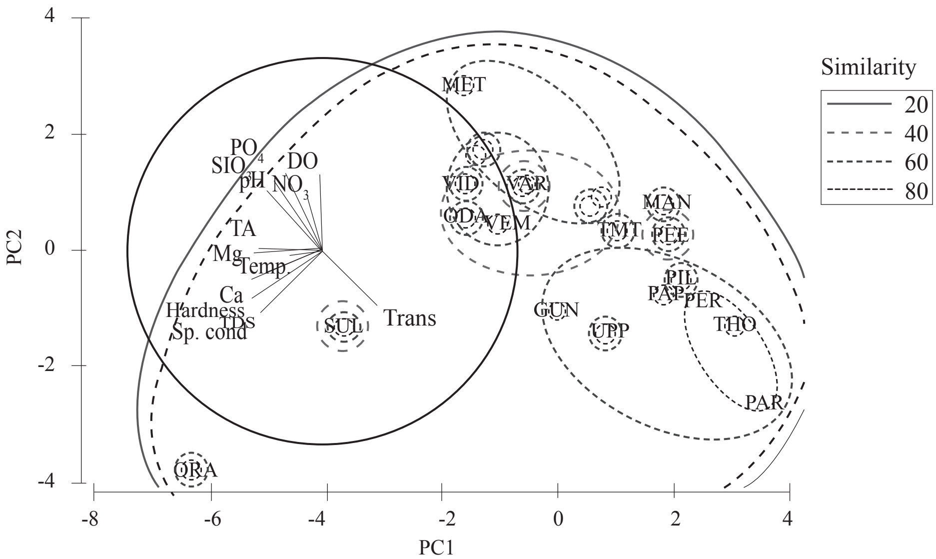

Fig. 6. PCA ordination with environmental variables

Table 6. Best results of biota and/or environment matching (BEST) by Spearman Rank correlation method

No. of variables	Correlation coefficient	Selected variables
3	0.413	Temperature, Specific conductivity, Hardness
4	0.373	Temperature, Specific conductivity, Hardness, Nitrate
4	0.367	Temperature, Specific conductivity, Hardness, Phosphate
4	0.363	Temperature, Specific conductivity, Hardness, Silicate

was repeated with zooplankton alone, which supported the same 3-variable combination of temperature, specific conductivity and hardness.

Discussion

The n-MDS analysis based on plankton assemblages and environmental parameters substantiated the different types of surface waters from reservoirs of Tamil Nadu State, India largely as WG reservoirs and PL reservoirs. The RS reservoirs were distributed in both groups, presenting combinations of plankton assemblages similar to the major group associated with. Ordination through euclidian distance outlined through environmental parameters clearly showed that RS reservoirs located in the southern tip behaved like WG reservoirs while on the northern side, being on the eastern slope, they were similar to PL reservoirs.

In general WG reservoirs are deep, perennial and dammed at the start of the origin of the river. They are typified by oligotropic to mesotropic tendency mainly due to lower phosphorous content and high transparency. With little anthropogenic stress, these reservoirs harbour the characteristic oligo species in chlorophyceae, *Selenastrum* and *Ankistrodesmus* and mesotrophic species in bacillariophyceae, *Navicula* spp., *Tabellaria* spp. and *Nitzshia* spp. Having the largest catchment area of 119140 ha in the WG region, Pilloor gives higher allochthonous input forcing the reservoir to eutrophy- I state in certain seasons.

The PL reservoirs are small and shallow with low residence time, drying up in summer. These are constructed across the lower stretch of the main river and are subjected to severe anthropogenic stress. Human interference thus has a major impact on the plankton assemblage and water chemistry of these reservoirs. The PL reservoirs in the plains are dominated by pollution indicator species, cyanophyceae, *Microcystis aeruginosa, Spirulina* spp. followed by bacillariophyceae, *Navicula, Nitzschia, Scenedesmus* and *Synedra* spp. including desmidaceae, *Staurastrum* spp. and *Cosmarium* spp. *Microcystis* spp. bloom is commonly observed during monsoon (September to November) in most PL reservoirs studied which are stressed by sewage and agriculture run-off. The plain reservoirs, Odathurai and Sulur showed hyper-eutrophic tendency with the presence of *M. aeruginosa* in many seasons. Odathurai is a very small embankment receiving water from Bhavani River passing through many villages and small towns which release agricultural and sewage rich in phosphorous which leads to the bloom of cyanophyceae. Blooms were also observed in Sandynulla, a high altitude reservoir which receives effluents from adjacent protein product industry. The ubiquitous blooms of *Microcystis* and replacement of oligo-mesotrophic species by eutrophentic species in reservoirs have been reported in Peninsular India (Sreenivasan,1972; Raju, 1972; Zafar, 1986; Rani *et al.,* 2009) and across the world (De Figueiredo *et al*., 2006; Tolotti *et al*., 2006; Cabecinha *et al.,* 2008a). Low diversity and high density of plankton is a common phenomenon observed in eutrophic reservoirs (Baiao and Boavida, 2005; Zafar, 1986). The results observed in the present study are consistent with earlier studies on reservoirs which suggested geological properties as the ultimate variable that determines the composition of aquatic community assemblages on a larger spatial scale while on a smaller scale, reservoir size, temperature, elevation and human interference influenced water quality gradients such as nutrients, BOD, COD and turbidity (Cabecinha *et al*., 2008b). The reservoirs investigated during the present study are mainly used for hydroelectric power and irrigation, which fluctuates the water level, disturbing the standing crop of plankton.

The intrinsic chemical properties of the reservoirs specific to their respective geological characteristic of the catchment area seem to get transformed to various levels of trophic status at different levels of pollution across the river course from west to east of the state. This is apparently depicted in ordination as many reservoirs stand separated from the main group geographically fixed and confirmed the trophic status determined by the trophic state index (OECD Model), which also characterises the stressor gradients of these reservoirs. The changes in community structure along trophic gradients are reported in several studies (Gulati, 1990; Lysche, 1990; Karabin and Ejsmont-Karabin, 1991; Caramujo and Boavida, 2000; Jeppesen *et al*., 2000; Baiao and Boavida, 2005).

Plain reservoirs built across run-off rivers is in the eutrophy II state during most period of the year and is evidently highly contaminated by domestic and industrial influx. The differences in retention time and water depth have a great impact on how eutrophication manifests. According to Vollenweider models, lakes with high water retention time (generally deeper lakes) will have a lower nutrient concentration than lakes with a very low retention time (GIG, 2007). In general, secchi depth and total phosphorus concentration were comparable with those reported in previous surveys (Boavida and Marques, 1996). In the present study, major grouping of reservoirs by PCA, can be best explained by the first two axes *i.e.*, PC1 describing transparency and PC2 a combination of nutrients. It is apparently visible that the disturbance gradient was distinct with various levels of human disturbance concomitant with alterations in environmental variables and phytoplankton assemblages, which divided the plain reservoirs in to several groups and many individual reservoirs with distinctive species composition. In support of the present results, Negro and De Hoyos (2005) reported that mineralisation (conductivity and alkalinity) was the most important factor influencing distribution of zooplankton in reservoirs while the trophic state was the second most important. Phytoplankton in Spanish reservoirs are mainly influenced by the water mineral content and trophic state (Margalef *et al*., 1976; Sabater and Nolla, 1991; Riera *et al*., 1992; De Hoyos *et al*., 2004). BIOENV confirmed that hardness and specific conductivity are the main factors for the distribution pattern of reservoirs identified through plankton composition.

The population of zooplankton (*Brachionus, Daphnia, Diaptomus* and *Cyclops*) was very high in WG reservoirs. Desmids were seen in high conductivity gradient reservoirs like Parambikulam and Thoonakadavu. Rotifer and diatom populations depend on the trophic status of the reservoir, which is limited by geographical location, morphological, physical and chemical factors (Margalef *et al*., 1976; Negro and De Hoyos, 2005). Most of the reservoirs studied were dominated by phytoplankton and in the mesotrophic reservoirs (mainly WG reservoirs) planktivorous fishes were found to predate on phytoplankton leading to the dominance of *Brachionus, Keratella* (rotifers), *Cyclops, Diaptomus*, nauplii (copepods) and *Daphnia* (cladocera). A positive relationship was observed between trophic status and zooplankton abundance in the present study, as suggested in several other studies (Bays and Crisman, 1983; Pace, 1986; Canfield and Jones, 1996; Attayde and Bozelli, 1998).

Rain shadow reservoirs (RS) with longer period of residence time are mostly located in the tributaries at the head water, receiving water from south-west monsoon. They exhibit mesotrophic to eutrophic tendency mainly due to low transparency and high phosphorous concentration. They were represented by a diverse composition of meso-eutraphentic species associated with different morphological and physicochemical characters. Substantial differences in water chemistry between the two groups (PL and WG) suggest that the geological characteristics of the water shed assume importance. The results observed in the present study are consistent with several earlier studies which report geological properties as the ultimate variable that determines the composition of aquatic community assemblages on a larger spatial scale. In the present study, the BIOENV indicated that specific conductivity, hardness, temperature and secchi disc transparency were consistently the most influential, limnological variables that determine the ecological status of the reservoir. Although only three limnological variables contributed to the optimal correlation by BIOENV, the axes identified by the PCA ordination were correlated with other set of variables. However BIOENV indicated the next positive correlation with nutrients which are substantiated by PC2 axis.

Results of the study indicated that Western Ghats reservoirs are mesotrophic with dominance of chlorophyceae while rain shadow reservoirs are advanced mesotrophic. Reservoirs of the plains are meso-eutrophic or hyper-eutrophic during monsoon with myxophyceae bloom. The seasonality of phytoplankton is closely related to the changes in water parameters, temperature and the monsoon phenomena. The geographical and climatic framework of the region thus determines plankton species composition in the reservoirs of Tamil Nadu.

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