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Physico-chemical characteristics and zooplankton diversity in a perennial lake at Dharmapuri (Tamil Nadu, India)

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Abstract

In order to assess the suitability of the Hale Dharmapuri lake (Latitude 12º8' 54"N and Longitude 78º10' 38"E) of Dharmapuri town (Tamil Nadu, India) for inland aquaculture, this study was conducted for a period of one year (March 2015 – February 2016) under four seasons, post-monsoon, summer, pre-monsoon and monsoon. A total of 29 zooplankton species were identified qualitatively, which includes 10 species of Rotifer, 8 species of Cladocera, 6 species of Copepoda and 5 species of Ostracoda. The mean population of each zooplankton groups from all the seasons recorded was in the following order, Rotifers > Cladocerans > Copepods > Ostracods. This study revealed that the zooplankton productivity was found to be maximum during summer season, followed by pre-monsoon, post-monsoon and monsoon. The population of zooplankton was positively correlated with various physico-chemical parameters, such as water temperature, pH, salinity, dissolved oxygen, total dissolves solids and electrical conductivity of the lake water. Regarding species diversity, no considerable degree of differences was seen in the diversity indices values of each zooplankton group in different season, as all the species was recorded in all the four seasons. However, some degree of difference was seen in the respective index value between different zooplankton groups in each season, because the number of species in each group was varies. As appreciable number of zooplankton species diversity was seen in this lake there is hope for its utilization for inland aquaculture of fishes and prawns, if it is properly managed.

Keywords: Biodiversity, Rotifer, cladocera, copepoda, ostracoda

1. Introduction

The zooplankton contribute significantly to the secondary production of aquatic ecosystem and occupy an intermediate position in the food web by transferring energy from lower trophic level to higher trophic level. Aquatic ecosystem affected by several health stressors including sewage, domestic, industrial and agricultural effluents carrying organic matter with highly toxic substances are significantly depleting biodiversity or loss of biodiversity and its effects are predicted to be greater [1]. Factors such as light intensity, food availability, dissolved oxygen level and predations are affect the population dynamics of zooplankton and also the low pH and higher salinity can reduce their diversity and density [2]. Abiotic substances are essential inorganic and organic compounds, such as water, carbon-dioxide, oxygen, calcium, nitrogen and phosphorus salts, and amino acids and humic acids etc. regulates the growth of zooplankton. The growth and abundance of plankton varies with season, depth, meteorology and water properties, which in turn reflect on diversity of organisms within the ecosystem [3, 4]. There are four types of zooplankton groups, such as Rotifer, Cladocera, Copepoda and Ostracoda**.** Most of them depend largely, on various bacterioplankton and phytoplankton for their food. The many of the larger forms feed on smaller zooplankton, forming secondary consumers. Rotifers are microscopic aquatic animals and soft-bodied metazoans (invertebrates). Cladocerans are primary consumers feed on microscopic algae and fine particulate matter in the detritus, influencing cycling of energy. Copepods comprise a major portion of the consumer biomass in aquatic habitats and play a significant role in food webs both as primary and secondary consumers, and as a major source of food for many larger invertebrates and vertebrates including zooplanktonivorous fishes and prawns [5-8]. Copepods are used as biological indicators for certain ecosystem [9]. Ostracods are of great interest, because of their possible use as indicator species of climate and ecosystem changes [10]. They also found in heavily polluted areas [11]. They are bivalve crustacean found numerous in both freshwater and marine environments.

In fish larvae and prawn, the higher rate of survival is obtained with live food than the refrigerated plankton food [12]. The physico-chemical and biological characteristics of water play an important role in plankton productivity and final yield of aquaculture products [13-21]. The present work was carried out to analyze the physico-chemical parameters, and to assess the species diversity and population density of zooplankton of Hale Dharmapuri lake of Dharmapuri town (Tamil Nadu, India) in order to evaluate its suitability for inland aquaculture of fishes and prawns.

2. Materials and methods

2.1 Description of the study area

The water and plankton samples were collected from a perennial lake, Hale Dharmapuri lake or Ramakkal lake (Latitude 12º8’ 54”N and Longitude 78º10’ 38”E) of Dharmapuri town, Tamil Nadu, India (Fig. 1), for a period of one year from March 2015 to February 2016 at five different sites and pooled. Rain water is the only source of water for this lake. The data were taken on monthly basis and interpreted seasonally, like summer (March - May), pre-monsoon (June - August), monsoon (September - November) and post-monsoon (December - February).

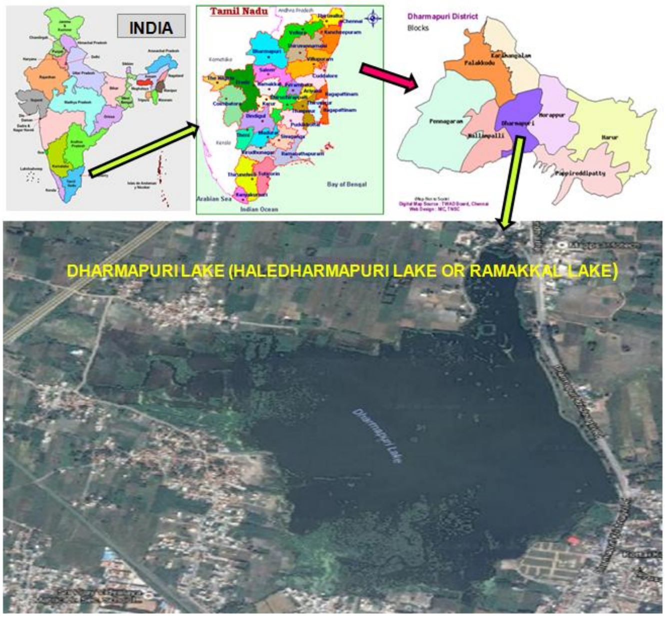

Fig. 1: The satellite view of the study area

2.2 Analysis of physico-chemical characteristics of lake water

The surface water samples were collected in sterile polyethylene bottles and kept in an ice box and transported to the laboratory for the analysis of physico-chemical parameters. The water and plankton samples were collected during the early morning between 6.00 AM and 7.00 AM every month first week from March, 2015 to February, 2016. Air and water temperature, pH, salinity, dissolved oxygen (DO), total dissolved solids (TDS) and electrical conductivity (EC) were estimated by using “µP Based Water & Soil Analysis Kit” (Model 1160).

2.3 Qualitative and quantitative analysis of zooplankton

For qualitative analysis of zooplankton, water samples were collected by towing of Henson’s standard plankton net (150 µm mesh) in zigzag fashion horizontally at a depth of 50 to 100 cm for about 10 minutes with a uniform speed of boat. For the quantitative analysis of zooplankton 100 liters of water was filtered through a plankton net made up of bolting silk (No: 10, mesh size: 150 µm) using a 10 liter capacity plastic container. Immediately after filtering out the water, the plankton biomasses were transferred to polyethylene specimen bottles (100 ml) filled with 5% of formalin (10 ml), the aqueous solution of formaldehyde. Different groups of zooplanktons, Rotifer, Cladocera, Copepoda and Ostracoda were segregated and separated under a binocular stereo zoom dissection microscope using a fine needle and brush. Individual species of plankton was mounted on microscopic slides with a drop of 20% glycerin after staining with eosin and rose Bengal. The identification of zooplankton was made referring the standard manuals, text books and monographs [11, 22-26], using a compound microscope and photomicrographed with Inverted Biological Microscope (Model Number INVERSO 3000 (TC-100) CETI) attached a camera (Model IS 300).

The sample (1 ml) was taken with a wide mouthed pipette and poured into the counting cell of the Sedgwick Rafter. After allowing for settle some time they were counted. At least 5 such counting was made for each group. The species, sex and the developmental stage of the plankton was considered. The average values were taken. Total number of plankton present in 1 litre of water sample was calculated [27] using the following formula:

$N = n \times v / V$

Where,

N = Total number of plankton per liter of water filtered
n = Average number of plankton in 1 ml of plankton sample
v = Volume of plankton concentrated (ml) and
V = Volume of total water filtered (liter)

The population of each group of zooplankton was expressed in average, number of individuals per litre (ind./l).

2.4. Statistical analysis

The data between zooplankton versus physico-chemical characteristics were subjected to correlation and linear regression using IBM-SPSS (v20.0). The different diversity indices such as, species dominance (D), Shannon’s diversity index (H’), species evenness and species richness were calculated using PAST (Paleontological Statistics) software package (PAST, v2.02). Seasonal-wise data were subjected to statistical analysis through one-way ANOVA and subsequent post hoc multiple comparison with DMRT by adopting SPSS (v20.0). All the details of statistical analysis were given in respective tables. The P<0.05 were considered statistically significant by 95%.

3. Results

3.1 Physico-chemical characteristics of the lake water

The mean values of both atmospheric and water temperature were found to be the maximum during summer season, followed by pre-monsoon, post-monsoon and monsoon (Table 1). The mean values of pH, salinity and TDS were also found to be the maximum during summer season, followed by pre-monsoon, post-monsoon and monsoon seasons (Table 1). The mean value of DO was found to be the maximum during monsoon season, followed by post-monsoon, pre-monsoon and summer (Table 1). The mean value of EC was found to be the maximum during summer season, followed by pre-monsoon, post-monsoon and monsoon (Table 1).

Table 1: Physico-chemical characteristics of the Hale Dharmapuri lake during the study period

Parameter	Summer (Mar' 2015-May' 2015)	Pre-Monsoon (Jun' 2015-Aug' 2015)	Monsoon (Sep' 2015-Nov' 2015)	Post-Monsoon (Dec' 2015-Feb' 2016)	Overall average	F-value
AT (°C)	26.07±0.63^{a}	24.85±0.75^{ab}	24.20±0.85^{c}	24.75±0.57^{ab}	24.97±0.79	3.71
WT (°C)	27.38±0.75^{a}	27.05±1.54^{a}	25.22±0.78^{a}	26.37±1.08^{a}	26.51±0.95	2.32
pH	8.02±0.28^{a}	7.45±0.26^{ab}	6.12±0.60^{c}	6.85±0.67^{bc}	7.11±0.82	8.34
Salinity (ppt)	1.958±0.225^{a}	1.185±0.208^{b}	0.751±0.074^{c}	0.928±0.060^{bc}	1.206±0.532	33.03
DO (mg/l)	6.28±0.14^{b}	6.43±0.61^{b}	7.78±0.46^{a}	7.08±0.56^{ab}	6.89±0.69	6.08
TDS (mg/l)	176.93±15.20^{a}	156.88±24.06^{ab}	111.88±13.98^{b}	120.31±35.33^{b}	141.50±30.65	5.00
EC (µS cm^{-1})	2.038±0.229^{a}	1.685±0.186^{b}	0.747±0.100^{c}	1.041±0.176^{c}	1.378±0.589	32.54

AT, atmospheric temperature; WT, water temperature; DO, dissolved oxygen; TDS, total dissolved solids; EC, electrical conductivity.
Each season-wise value is overall average of mean ± SD (n=15; 5 sites × 3 months).
Mean values within the same row sharing different superscript are significantly different (P<0.05). Mean values within the same row sharing same superscript are not statistically significant (P>0.05).

3.2 Quality of zooplankton

In this study, a total of 29 zooplankton species was identified qualitatively, which includes 10 species of Rotifer, 8 species of Cladocera, 6 species of Copepoda and 5 species of Ostracoda (Table 2; Figs. 2-5). Under the phylum Rotifer, the identified 10 species were *Brachionus budapestinesis var punctatus, Brachionus calyciflorus, Brachionus caudatus personatus, Brachionus diversicornis, Brachionus falcatus, Brachionus quadridentatus, Brachionus rubens, Asplanchna brightwelli, Asplanchna intermedia, Filinia longiseta* (Table 2; Fig. 2). Under the sub phylum crustacea, there were 8 species of Cladocerans, 6 species of Copepods and 5 species of Ostracods identified (Table 2; Figs. 3-5). The Cladocerans were *Diaphanosoma sarsi, Diaphanosoma excisum, Daphnia carinata, Daphnia magna, Ceriodaphnia cornuta, Moina brachiata, Moina micrura* and *Moinodaphnia macleayi* (Table 2; Fig. 3). The Copepods identified were *Heliodiaptomus viduus, Sinodiptomus* (*Rhinediaptomus*) *indicus, Eucyclops speratus, Mesocyclops hyalinus, Mesocyclops leuckarti* and *Thermocyclops hyalinus* (Table 2; Fig. 4). The Ostracods identified were *Cypris protubera, Eucypris bispinosa, Strandesia elongata, Cyprinus nudus* and *Heterocypris dentatomarginatus* (Table 2; Fig. 5).

Table 2: List of zooplankton species recorded in the Hale Dharmapuri Lake during the study period

Group	Family	Genus	Species
Rotifer (10)	Brachionidae (Ehrenberg, 1838)	*Brachionus* Pallas, 1776	*Brachionus budapestinesis var punctatus* Hempel, 1896
			Brachionus calyciflorus Pallas, 1776
			Brachionus caudatus personatus Ahlstrom,1940
			Brachionus diversicornis Daday, 1883
			Brachionus falcatus Zacharias, 1898
			Brachionus quadridentatus Hermann, 1783
			Brachionus rubens Ehrenberg, 1838
	Asplanchnidae (Harring and Myers, 1933)	*Asplanchna* Gosse, 1850	*Asplanchna brightwelli* Gosse, 1850
			Asplanchna intermedia Hudson, 1886
	Filinidae (Bartos, 1959)	*Filinia* Bory and Vincent, 1824	*Filinia longiseta* Ehrenberg, 1834
Cladocera (8)	Sididae (Baird, 1850)	*Diaphanosoma* Fischer, 1850	*Diaphanosoma sarsi* Richard, 1895
			Diaphanosoma excisum Sars, 1885
		Daphnia Muller, 1785	*Daphnia carinata* King, 1853
			Daphnia magna Straus, 1820
	Daphnidae (Straus, 1850)	*Ceriodaphnia* Dana, 1853	*Ceriodaphnia cornuta* Sars, 1853
	Moinidae (Goulden, 1968)	*Moina* Baird, 1850	*Moina brachiata* Jurine, 1820
			Moina micrura Kurz, 1874
		Moinodaphnia Herrick, 1887	*Moinodaphnia macleayi* King, 1853
Copepoda (6)	Diaptomidae (Baird, 1850)	*Heliodiaptomus* Kiefer, 1932	*Heliodiaptomus viduus* Gurney, 1916
		Sinediaptomus Kiefer, 1937	*Sinodiptomus* (*Rhinediaptomus*) *indicus* Sewell, 1934
	Cyclopoidae (Dana, 1853)	*Eucyclops* Claus, 1893	*Eucyclops speratus* Lilljeborg, 1901
		Mesocyclops Claus, 1893	*Mesocyclops hyalinus* Rehberg, 1880
			Mesocyclops leuckarti Claus, 1857
		Thermocyclops Kiefer, 1927	*Thermocyclops hyalinus* Rehberg, 1880
Ostracoda(5)	Cyprididae (Baird, 1845)	*Cypris* Muller, 1776	*Cypris protubera* Muller, 1776
		Eucypris Vavra, 1891	*Eucypris bispinosa* Victor and Michael, 1975
		Strandesia Stuhlmann, 1888	*Strandesia elongate* Stuhlmann, 1888
		Cyprinotus Brady, 1886	*Cyprinus nudus* Brady, 1885
		Heterocypris Claus, 1892	*Heterocypris dentatomarginatus* Baird, 1859

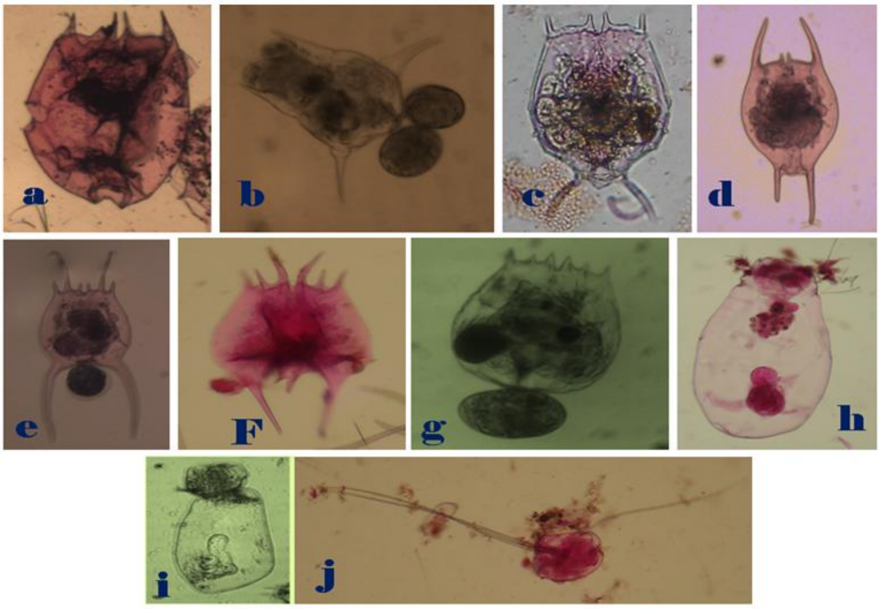

Fig 2: Group of Rotifers observed in the Hale Dharmapuri lake during the study period (*a. Brachionus budapestinesis var punctatus;* b. *Brachionus calyciflorus;* c. *Brachionus caudatus personatus;* d. *Brachionus diversicornis;* e. *Brachionus falcatus;* f. *Brachionus quadridentatus;* g. *Brachionus rubens;* h. *Asplanchna brightwelli;* i. *Asplanchna intermedia;* j. *Filinia longiseta*)

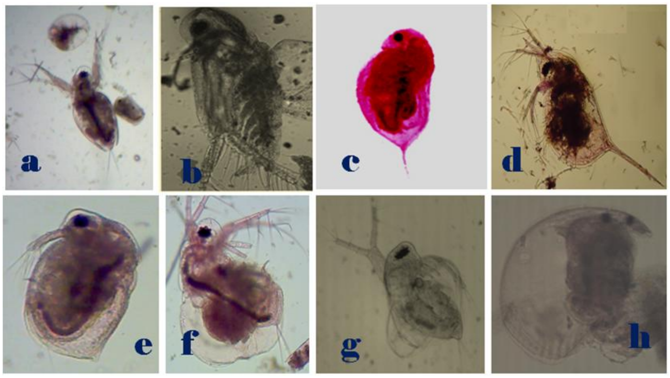

Fig 3: Group of Cladocerans observed in the Hale Dharmapuri lake during the study period (a. *Diaphanosoma sarsi;* b. *Diaphanosoma excisum;* c. *Daphnia carinata;* d. *Daphnia magna;* e. *Ceriodaphnia cornuta;* f. *Moina brachiata;* g. *Moina micrura;* h. *Moinodaphnia macleayi*)

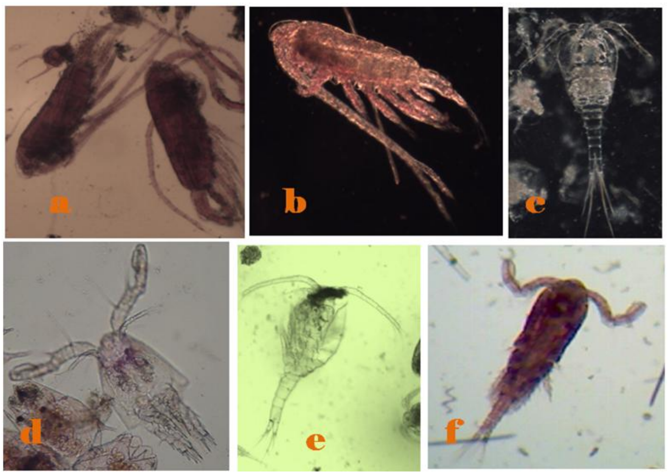

Fig 4: Group of Copepods observed in the Hale Dharmapuri lake during the study period (a. *Heliodiaptomus viduus;* b. *Sinodiptomus (Rhinediaptomus) indicus;* c. *Eucyclops speratus;* d. *Mesocyclops hyalinus;* e. *Mesocyclops leuckarti;* f. *Thermocyclops hyalinus*)

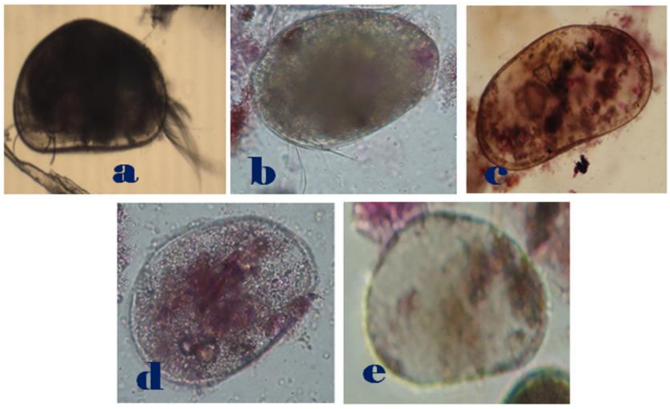

Fig 5: Group of Ostracods observed in the Hale Dharmapuri lake during the study period (a. *Cypris protubera;* b. *Eucypris bispinosa;* c. *Strandesia elongata;* d. *Cyprinus nudus;* e. *Heterocypris dentatomarginatus*)

3.3 Quantity of zooplankton

The population density of zooplanktons from all seasons recorded was in the following order, Rotifers (7066 ind./l) > Cladocerans (5532 ind./l) > Copepods (4553 ind./l) > Ostracods (1958 ind./l) (Table 3). The overall productivity of zooplankton (including all four groups) was found to be maximum during summer season (25080 ind./l), followed by pre-monsoon (20825 ind./l), post-monsoon (17445 ind./l) and monsoon (13092 ind./l) (Table 3). Individual group-wise (Rotifer, Cladocera, Copepoda and Ostracoda) as well the total productivity was found to be maximum in summer, followed by pre-monsoon, post-monsoon and monsoon and the mean population density of zooplankton recorded in this study was 19110 ind./liter (Table 3). In the present study, Rotifer and Ostracoda occupied the first and fourth position of zooplankton respectively in terms of both number of species and total numbers present with a higher population density in summer months, and represented very low species diversity when compared with other groups. Cladocera and Copepod occupied second and third positions respectively (Tables 2 and 3). The population of zooplankton recorded was positively correlated with various physico-chemical parameters of the lake water (Table 4).

Table 3: Zooplankton population density with percentage composition in the Hale Dharmapuri lake during the study period

Plankton group	Population density of zooplankton (ind./l)				Mean (ind./l) & %	F-value
	Summer (Mar' 2015-May' 2015)	Pre-Monsoon (Jun' 2015-Aug' 2015)	Monsoon (Sep' 2015-Nov' 2015)	Post-Monsoon (Dec' 2015-Feb' 2016)		
Rotifer	9675±264^{a}	7762±326^{b}	4389±138^{d}	6441±412^{c}	7066.7 (36.9%)	162.82
Cladocera	6710±253^{a}	5947±174^{b}	4255±265^{d}	5216±215^{c}	5532.0 (28.9%)	62.45
Copepoda	6163±179^{a}	5077±310^{b}	3061±152^{d}	3912±130^{c}	4553.2 (23.8%)	130.92
Ostracoda	2532±197^{a}	2039±132^{b}	1387±78^{c}	1876±129^{b}	1958.5 (10.2%)	33.81
Total	25080	20825	13092	17445	19110	--

Each season-wise value is overall average of mean ± SD (n=15; 5 sites × 3 months).
Mean values within the same row sharing different superscript are significantly different (P<0.05).

Table 4: The relationship between physico-chemical parameters and zooplankton population in the Hale Dharmapuri lake during the study period

Physico-chemical parameters Vs. Zooplankton population	'y' – Value (Linear Type)	R	R^2	Correlation
Atmospheric Temperature	y=2029.873x-44310.593	0.944	0.892	Positive
Water Temperature	y=1718.25x-39170.759	0.970	0.941	Positive
pH	y=1008.723x-801.767	0.485	0.235	Positive
Salinity	y=2694.466x+3116.683	0.848	0.718	Positive
Dissolved oxygen	y=1854.115x-6407.38	0.752	0.565	Positive
Total Dissolved Solids	y=53.399x-1185.826	0.966	0.932	Positive
Electrical Conductivity	y=2414.826x+3043.224	0.839	0.705	Positive

Table 5: Diversity indices of zooplankton in the Hale Dharmapuri lake during the study period

Plankton group	Diversity indices	Summer (Mar' 2015-May' 2015)	Pre-Monsoon (Jun' 2015-Aug' 2015)	Monsoon (Sep' 2015-Nov' 2015)	Post-Monsoon (Dec' 2015-Feb' 2016)	Overall average	F-Value
Rotifer (10 species)	Dominance (D)	0.111±0.005^{c}	0.121±0.006^{c}	0.127±0.008^{a}	0.105±0.003^{ab}	0.116±0.010	8.71
	Shannon (H)	2.305±0.042^{ab}	2.268±0.041^{a}	2.237±0.036^{b}	2.354±0.046^{b}	2.291±0.050	4.43
	Evenness_e^H/S	0.835±0.031^{ab}	0.805±0.023^{a}	0.781±0.017^{c}	0.877±0.034^{bc}	0.825±0.041	7.00
	Margalef (R1)	1.362±0.028^{c}	1.401±0.016^{b}	1.511±0.031^{a}	1.437±0.053^{bc}	1.428±0.063	10.02
Cladocera (8 species)	Dominance (D)	0.156±0.003^{a}	0.157±0.006^{a}	0.158±0.004^{a}	0.154±0.002^{a}	0.156±0.002	0.53
	Shannon (H)	1.954±0.032^{a}	1.953±0.029^{a}	1.945±0.036^{a}	1.961±0.045^{a}	1.952±0.007	0.10
	Evenness_e^H/S	0.882±0.031^{a}	0.881±0.035^{a}	0.875±0.032^{a}	0.888±0.037^{a}	0.882±0.005	0.07
	Margalef (R1)	0.908±0.052^{a}	0.922±0.054^{a}	0.966±0.058^{a}	0.939±0.056^{a}	0.934±0.025	0.61
Copepoda (6 species)	Dominance (D)	0.178±0.002^{c}	0.192±0.006^{a}	0.202±0.008^{bc}	0.186±0.004^{b}	0.190±0.010	10.23
	Shannon (H)	1.756±0.043^{a}	1.722±0.041^{a}	1.699±0.035^{a}	1.737±0.042^{a}	1.729±0.024	1.06
	Evenness_e^H/S	0.965±0.035^{a}	0.933±0.037^{a}	0.912±0.036^{a}	0.947±0.032^{a}	0.939±0.022	1.22
	Margalef (R1)	0.656±0.054^{a}	0.674±0.057^{a}	0.723±0.066^{a}	0.697±0.062^{a}	0.688±0.029	0.70
Ostracoda (5 species)	Dominance (D)	0.222±0.001^{b}	0.228±0.004^{a}	0.222±0.001^{b}	0.216±0.003^{c}	0.222±0.005	10.66
	Shannon (H)	1.552±0.045^{a}	1.541±0.043^{a}	1.554±0.046^{a}	1.562±0.048^{a}	1.552±0.009	0.10
	Evenness_e^H/S	0.944±0.034^{a}	0.953±0.037^{a}	0.946±0.035^{a}	0.953±0.037^{a}	0.949±0.005	0.05
	Margalef (R1)	0.595±0.052^{a}	0.615±0.053^{a}	0.653±0.051^{a}	0.623±0.056^{a}	0.622±0.024	0.61

Each season-wise value is overall average of mean ± SD (n=15; 5 sites × 3 months).
Mean values within the same row sharing different superscript are significantly different (P<0.05). Mean values within the same row sharing same superscript are not statistically significant (P>0.05).

In this study, the calculated seasonal-wise diversity indices values, such as Dominance (D), Shannon (H), Evenness (e^H/S) and Margalef (R1), richness for each group of zooplankton showed no considerable degree of differences (D: Rotifer, 0.105-0.127; Cladocera, 0.154-0.158; Copepod, 0.178-0.202; Ostracoda, 0.216-0.228; H: Rotifer, 2.237-2.354; Cladocera, 1.945-1.961; Copepod, 1.699-1.756; Ostracoda, 1.541-1.562; e^H/S: Rotifer, 0.781-0.877; Cladocera,0.875-0.888; Copepod, 0.912-0.965; Ostracoda, 0.944-0.953; R1: Rotifer, 1.362-1.511; Cladocera, 0.908-0.966; Copepod, 0.656-0.723; Ostracoda, 0.595-0.653), as all the species was recorded in all the four seasons (Table 5). However, some degree of difference was seen in the respective index value between different zooplankton groups in each season, because the number of species in each group was varies, for example, the Shannon (H) diversity index for Rotifers, Cladocerans, Copepods and Ostracods during summer were 2.305, 1.954, 1.756 and 1.552 respectively (Table 5). Similarly, this kind of difference between different groups was recorded in each and every season in all types of diversity indices studied (Table 5).

4. Discussion

4.1 Water quality and zooplankton population

Similar to that of the present study, fluctuations in physico-chemical parameters and plankton population density have been reported by [17-21, 28, 29]. Physico-chemical parameters and quantity of nutrients in water play a significant role in the distribution patterns and species composition of plankton [2, 14-16, 20, 21, 30]. All the metabolic, physiological activities and life processes, such as feeding, reproduction, movements and distribution of organisms are greatly influenced by water temperature. A rise in the temperature leads to the fast chemical and biochemical reactions. The kinetics of the biochemical oxygen demand is regulated to some extent by water temperature [31]. In this study, higher water temperature was recorded in summer and pre-monsoon, which accounted for more plankton productivity.

The natural water is generally alkaline in nature due to the presence of carbonates and bicarbonates. The pH is due to the presence or absence of free carbon dioxide (aqueous CO_2) and carbonates. The higher photosynthetic activity increases production of phytoplankton, which support an increase in pH [32]. The higher pH is also attributed to anthropogenic activities like washing of cloths with detergents and mixing of sewage. In this study, the higher pH recorded in summer and pre-monsoon accounts for good primary and secondary productivity.

The salinity regulates survival, metabolism and distribution of organisms in freshwater ecosystem. It exerts different ecological and physiological effects depending on the interaction with other factors like temperature, oxygen and ionic compounds [33]. It affects organisms, mainly through changes in osmotic pressure and density of the water. The majority of freshwater animals have a low tolerance to any increase in salinity. The higher salinity of water can reduce the diversity and density of plankton production [2]. In this study, the higher salinity recorded in summer was due to more evaporation of water because of higher temperature, and, the lower salinity noticed during monsoon was due to lower air temperature and also attributed with higher inflow of freshwater. In this study, the higher salinity recorded was not affecting the plankton productivity.

The DO is one of the most important parameters that reflect the physical and biological processes prevailed in water [34, 35]. The DO level in natural water depends upon the atmospheric air pressure, photosynthetic activity, temperature, salinity and turbulence. The solubility of oxygen increases with decrease in temperature [36]. The minimum DO recorded in summer was due to its utilization for decomposition of organic matter and respiration of organisms including zooplankton.

The increased anthropogenic activity, stagnation and evaporation of water as a result of higher temperature, inflow of drainage water containing large quantity of silt, clay and other materials, and decreased inflow of freshwater all raises TDS and hampered water quality**.** In summer, most of the vegetation will get decayed, so a rise in TDS is natural [37, 38]. An excess amount of TDS in water tends to disturb the ecological balance due to suffocation of aquatic fauna even in the presence of fair quantity of DO [39]. In this study, the higher TDS recorded during summer and pre-monsoon associated with other water quality supports production of zooplankton.

The salts in ionic form that dissolved in water and nutrient status are responsible for its EC. Natural water possesses low EC but contamination increases its level [39, 40]. EC is a good indicator of the overall water quality. In the present study, the higher EC recorded during summer and pre-monsoon supported plankton production.

4.2 Zooplankton species diversity

Similar to that of the present study, the distribution of various zooplankton species (Rotifers, Cladocerans, Copepods and Ostracods) have been reported in number of freshwater bodies [18-21, 29]. Zooplankton species composition and dominance in a particular water body is controlled by several ecological factors including nutrients load and pollution status.

In the present study, among the Rotifers, the genus *Brachionus* was found to be more in numbers. In India, 21 species of *Brachionus* have been reported [41, 42]. It has been reported that the abundance of *B. calyciflorus* was considered as a good indicator of eutrophication [18, 20, 29, 43]. The thriving of *B. caudates personatus*, *B. diversicornis* and *Filina longiseta* has been considered as an indicator of eutrophication [42, 44-47]. The presence of all these pollution indicator species suggests that the Hale Dharmapuri lake was organically polluted.

Crustacean zooplankton (Cladocera, Copepod and Ostracoda) holds the highest position both in terms of systematic and as secondary consumers in the aquatic food chain.

There are only a few Cladoceran genera are planktonic in the freshwater, while majority of them are littoral, live among the weed and some of them live on the bottom mud. It has been reported that there were 10 species of Cladocera in Sulur Lake, Coimbatore (Tamil Nadu, India) and 14 species in Thoppaiyar Dam (Dharmapuri district, Tamil Nadu, India [19, 20, 29]. The presence of *Diaphanosoma*, *Daphnia, Ceriodaphnia* and *Moina* has been recorded in eutrophic lakes throughout the world [48-51]. The presence of Cladoceran species of these genera suggests that the Hale Dharmapuri lake was eutrophicated.

Copepods comprised of three free living groups, such as calanoida, cyclopoida and harpacticoida [52]. *Sinodiaptomus (Rhinediaptomus) indicus* was one of the common calanoid Copepods reported in South India [53]. There are few cyclopoid harpacticoid Copepods thrive in the pelagic zones of lakes, which are serve as sources of food for larvae, juveniles and adults of many fish species [54, 55]. Copepod domination indicates the fact that there were abundance of diatoms (*Bacillariophyceae*) and blue green algae (*Cyanophyceae*), and these phytoplankton groups are more important food sources for all the developmental stages of cyclopoid Copepods [56]. Copepod also feeds up on Rotifers and Cladocerans [57]. Copepod dominance, particularly calanoids are an indicator of oligotrophic water [58]. In the present study, the absence of calanoida and presence of *Heliodiaptomus*, *Mesocyclops* and *Thermocyclops* suggests that the Hale Dharmapuri lake was eutrophicated. Similar suggestion has been reported in Sulur lake, Coimbatore (Tamil Nadu, India) [19].

Similar to that of the present study, among the all four groups, the occurrence of lower population density and species diversity of Ostracoda have been reported in Hale Dharmapuri Lake (Dharmapuri town, Tamil Nadu), India, in Thoppaiyar reservoir (Dharmapuri District, Tamil Nadu, India) and in Sulur Lake, Coimbatore (Tamil Nadu, India) [18, 19, 29]. In the present study, the presence of *Cypris* and *Heterocypris* suggests that the Hale Dharmapuri Lake was eutrophicated.

5. Conclusion

Overall, this lentic lake was approached eutrophication and was organically polluted since no significant fluctuation in species composition was recorded and all the species was appeared in all the four seasons. However, the nutrient status of the lake ensures plankton productivity. This case was most obvious in summer and pre-monsoon. The effect of over fishing might have led to higher population density of zooplankton in these seasons. While, during monsoon, factors like lower water temperature, pH, salinity and TDS were not in favour of growth of zooplankton due to dilution effect**.** During pos-monsoon, the over predation of zooplankton by the higher trophic members, like planktivorous fishes, because in this season fish population as well as growth would be greater as a result of abundance of food in the form of bacteria, nano-plankton and suspended detritus. As appreciable number of zooplankton species diversity was seen in this lake there is hope for its utilization for inland aquaculture of fishes and prawns, if it is properly managed.

6. References

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