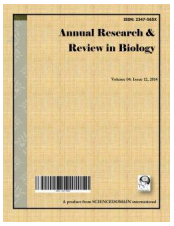

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Water Physico-chemical Characteristics, Species Diversity and Density of Zooplankton in Two Perennial Lakes of Coimbatore City (India)

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Authors' contributions

This work was carried out in collaboration between all authors. Author RK conducted the experiment, performed the statistical analysis and wrote the first draft of the manuscript. Author PSB designed the work, supervised and critically evaluated the manuscript. Author RU assisted technical support in all aspects. All authors read and approved the final version of the manuscript.

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ABSTRACT

In order to assess the suitability of the Ukkadam lake (Lat. 10.99° N and Long. 76.96° E) and the Singanallur lake (Lat. 10.59° N and Long. 77.88° E) of Coimbatore (Tamil Nadu, India) for inland aquaculture, the species diversity and density of zooplankton were assessed for a period of one year (December, 2015 to November, 2016) under four seasons, post-monsoon, summer, pre-monsoon and monsoon. In the Ukkadam lake, a total of 28 zooplankton species, including 7 species of Rotifera, 6 species of Cladocera, 8 species of Copepoda and 7 species of Ostracoda were identified. Their mean density were 4890 ind. l^{-1} for Rotifera, 5338 ind. l^{-1} for Cladocera, 5811 ind. l^{-1} for Copepoda and 8002 ind. l^{-1} for Ostracoda (total of 24042), and their order of dominance were Ostracoda > Copepoda > Cladocera > Rotifera. In the Singanallur lake, a total of 24 zooplankton species, of which 7 species of Rotifera, 6 species of Cladocera, 6 species of Copepoda and 5 species of Ostracoda were identified with the mean density of 3146 ind. l^{-1} for Rotifera, 2492 ind. l^{-1}

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for Cladocera, 2342 ind. l^{-1} for Copepod and 2355 ind. l^{-1} for Ostracoda (total of 10337) in the following order of dominance: Rotifera > Cladocera > Ostracoda > Copepoda. This study revealed that the annual zooplankton abundance was found to be higher in the Ukkadam lake than that of the Singanallur lake (24042 ind. l^{-1} and 10337 ind. l^{-1}, respectively). When looking seasonal variation both the Ukkadam and the Singanallur lakes showed maximum zooplankton abundance during summer season (25989 ind. l^{-1} and 10821 ind. l^{-1}, respectively), followed by post-monsoon (24089 ind. l^{-1} and 9577 ind. l^{-1}, respectively), pre-monsoon (23954 and 10807 in, respectively) and monsoon (20436 ind. l^{-1} and 10142 ind. l^{-1}, respectively). In both lakes, zooplankton was positively correlated with physico-chemical parameters, such as water temperature, pH, salinity and electrical conductivity, and not properly correlated with dissolved oxygen and total dissolved solids. Regarding the diversity indices, considerable degree of differences were seen between these two lakes, the Ukkadam lake showed more diversity and density than those found in the Singanallur lake. When individual lake was considered, considerable degree of differences was seen in the species diversity of each zooplankton group in different season.

Keywords: Diversity; zooplankton density; Rotifer; Cladocera; Copepoda; Ostracoda; Ukkadam lake; Singanallur lake; aquaculture.

1. INTRODUCTION

The physicochemical and biological characteristics of water play an important role in plankton abundance and final yield of aquaculture products. Zooplankton constitutes an important food sources for many omnivorous and carnivorous fishes and also support the necessary amount of protein for their rapid larval growth [1-10]. In any freshwater pond or lake, generally there are four zooplankton groups that can be present: Rotifers and crustacean zooplankton of Cladocera, Copepoda and Ostracoda [11].

Crustacea consists of 52,000 described species belonging to 849 families, 48 orders and 6 classes, but their assessed number is estimated to be much higher [12]. Most of the smaller crustaceans may be found as plankton and thereby occupy an important position in the aquatic food chain. Planktonic crustaceans, such as Copepods, water fleas, and *Artemia* make up a major link in the food chain between the photosynthetic phytoplankton and larger carnivores such as fishes. In aquaculture, zooplankton is therefore one of the primary food sources of fish and prawn larvae.

Rotifers are primarily omnivorous, but some species have been known to be carnivore. They are considered opportunists due to their higher intrinsic rates of natural increase among the major zooplankton groups [13,14]. Cladoceran zooplankton are free living with compound eye, usually a carapace and at least four pairs of trunk limbs which are in most cases broad lobed and fringed on the inner edges with bristles [15]. Copepoda constitutes a dominant zooplankton group in both freshwater and marine habitats. Its domination may be due to their feeding on diatoms, Rotifera and Cladocera and high reproduction capacity [16]. Copepods dominate most of planktonic, benthic and groundwater assemblies [17]. Such an ecological succession is probably mediated by a high morphological plasticity that makes them able to adapt to different habitats and niches [18-20]. Ostracoda are equipped with a low Mg-calcite carapace attached by a dorsal hinge and a ligament [21], and one-third is living in freshwater.

The qualitative and quantitative abundance of zooplankton in a lake are of great importance for successful aquaculture management, as they vary from one geographical location to another and lake to lake within the same geographical location even within similar ecological conditions [22]. The present work was carried out on assessment of physico-chemical parameters, and species diversity and density of zooplankton in two perennial lakes, the Ukkadam and the Singanallur lakes within Coimbatore municipality limit (Tamil Nadu, India) in order to evaluate their suitability for inland aquaculture of fishes and prawns.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The Ukkadam Lake (Lat. 10.99° N and Long. 76.96° E) of Coimbatore city, Tamil Nadu, India, is fed by canals derived from Noyyal River and Selvachinthamani lake located upstream in the north (Fig. 1). River Noyyal is known for pollution due to various anthropogenic activities. This lake

also receives drainage water. This lake has an outlet connection with Valankulam Lake. The Singanallur Lake (Lat. 10.59° N and Long. 77.88° E) of Coimbatore city, Tamil Nadu, India, is fed by canals derived from Noyyal River (Fig. 2). The lake also receives water from Sanganur drain and sewage water. The water can be released through two sluice gates on the lake. In 2010, pipes were laid to connecting the lake to Valankulam Lake (Coimbatore, Tamil Nadu, India) to drain the excess water during floods. The water is released through four sluice gates located on the south side of the lake. Various birds including grebes, painted storks and purple moorhen can be spotted in this lake. Fishing is carried out by local fishermen and enthusiasts.

Fig. 1. Satellite view of the Ukkadam lake (Lat. 10.99° N and Long. 76.96° E), taken from Google Maps

Fig. 2. Satellite view of the Singanallur lake (Lat. 10.59° N and Long. 77.88° E), taken from Google maps

2.2 Analysis of Physico-chemical Parameters

The surface water sample was collected during the early morning hour (6.00 AM - 8.00 AM) once in fortnight for a period of one year from December-2015 to November-2016 at five different sites and pooled to check the on field physico-chemical parameters, such as water temperature (WT), pH, salinity, dissolved oxygen (DO), total dissolved solids (TDS) and electrical conductivity (EC) by using "µP Based Water & Soil Analysis Kit" (Model 1160).

2.3 Qualitative Analysis of the Zooplankton

For qualitative analysis of zooplankton, water samples were collected by Towing method using 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. The identification of zooplankton was made referring the standard manuals, text books and monographs [23-28]. With the help of a compound microscope and photomicrographs were taken using Inverted Biological Microscope (Model Number INVERSO 3000 (TC-100) CETI) attached a camera (Model IS 300). General elements that have been taken to assess all zooplankton groups were body shape and size, relative length of various appendages, including antennae, legs and setae, and presence and relative sizes of spines.

2.4 Quantitative Analysis of the Zooplankton

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 litre 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. Zooplankton sample was segregated/ assorted group (Rotifera, Cladocera, Copepoda and Ostracoda) with the help of binocular stereo zoom dissection microscope.

The sample (1 ml) was taken with a wide mouthed pipette and poured into the counting chamber of the Sedgwick Rafter. After allowing it to settle for 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 liter of water sample was calculated [29], using the 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); 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). 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 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 Lake Water

Data pertaining to the physico-chemical parameters, such as WT, pH, salinity, DO, TDS and EC of the Ukkadam lake and Singanallur lake are presented in Tables 1 and 2. In both lakes, the mean values of water temperature were found to be the maximum during summer season, followed by pre-monsoon, post-monsoon and monsoon. 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. In the Ukkadam lake, the mean value of DO was found to be the maximum during pre-monsoon season, followed by post-monsoon, monsoon and summer, whereas, in the Singanallur lake, the mean value of DO was found to be the maximum during summer, followed by post-monsoon, pre-monsoon and monsoon season. In the case of EC there were also differences between two lakes; in Ukkadam lake the mean value of EC was found to be in the following order: summer > monsoon > pre-monsoon > post-monsoon, whereas, in the Singanallur lake, it was in the order of summer > pre-monsoon >

post-monsoon > monsoon. The overall values for water physicochemical parameters of these two lakes are also presented in Tables 1 and 2. The WT, salinity, DO and TDS were slightly higher in the Ukkadam lake than in the Singanallur lake, whereas pH and EC showed slightly higher values in the Singanallur lake than in the Ukkadam lake water.

During summer the mean salinity was found to be higher in the Ukkadam lake (1.859 ppt) than that of the Singanallur lake (1.589 ppt). The mean DO was found to be higher in the Singanallur lake (7.74 mg/l^{-1}) than that of the Ukkadam lake (6.26 mg/l^{-1}). During this season, no other major differences were seen in physicochemical parameters of these two lakes. During pre-monsoon the mean WT and DO were found to be higher in the Ukkadam lake (26.78°C and 7.63 mg/l^{-1}, respectively) than that of the Singanallur lake (26.05°C and 6.38 mg/l^{-1}, respectively). During this season, no other major differences were seen in physicochemical parameters of these two lakes. During monsoon all physicochemical parameters except the EC were found to be almost similar in both lakes. The EC was found to be higher in the Ukkadam lake (1.638 µS cm^{-1}) than that of the Singanallur lake (0.752 µS cm^{-1}). During this season, no other major differences were seen in physicochemical parameters of these two lakes. During post-monsoon the mean WT and TDS were found to be higher in the Ukkadam lake (26.75°C and 1021 mg/l^{-1}, respectively) than that of the Singanallur lake (25.22°C and 1012 mg/l^{-1}, respectively). During this season, no other major differences were seen in physicochemical parameters of these two lakes. Overall, in the Ukkadam lake, the WT, salinity, DO, TDS and EC were higher during any of the season. Only the DO was found to be higher in the Singanallur lake during summer season.

3.2 Identified Zooplankton Species

From the collected zooplankton samples, 28 species were recorded as Rotifera (*Brachionus rotundiformis, Brachionus calyciflorus, Brachionus caudatus personatus, Brachionus diversicornis, Brachionus rubens, Asplanchna intermedia* and *Asplanchna brightwelli*), Cladocera (*Diaphanasoma sarsi*, *Daphnia magna, Leydigia leydigia*, *Ceriodaphnia cornuta, Moina brachiata* and *Moina micrura*), Copepoda (*Heliodiaptomus viduus*, *Cyclops vernalis*, *Eucyclops speratus*, *Mesocyclops leuckarti, Thermocyclops hyalinus, Mesocyclops edax, Mesocyclops pehpeiensis* and *Macrocyclops albidus*) and Ostracoda (*Eucypris bispinosa*, *Cypris decaryi, Candona candida, Cyprinotus nudus, Heterocypris dentatomarginatus, Prionocypris glacialis* and *Cypris protubera*).

In the Ukkadam lake, a total of 27 zooplankton species was identified qualitatively, which included 6 species of Rotifera (*Brachionus rotundiformis, Brachionus calyciflorus, Brachionus caudatus personatus*, *Brachionus rubens, Asplanchna intermedia* and *Asplanchna brightwelli*), 6 species of Cladocera (*Diaphanosoma sarsi, Daphnia magna, Ceriodaphnia cornuta, Leydigia leydigia*, *Moina brachiata* and *Moina micrura*), 8 species of Copepoda (*Heliodiaptomus viduus, Eucyclops speratus, Mesocyclops edax*, *Mesocyclops leuckarti*, *Mesocyclops pehpeinsis, Macrocyclops albidus, Thermocyclops hyalinus* and *Eucyclops speratus*) and 7 species of Ostracoda (*Cyprinotus nudus*, *Heterocypris dentatomarginatus*, *Cypris decaryi*, *Candona candida*, *Prionocypris glacialis*, *Cypris protubera* and *Eucypris bispinosa*) (Table 3; Figs. 3-6). Zooplankton dominance in the Ukkadam lake was as follows: Copepoda > Ostracoda > Cladocera=Rotifera.

Table 1. Physico-chemical characteristics of the Ukkadam Lake during the study period

Parameter	Post-monsoon (Dec' 2015 - Feb' 2016)	Summer (Mar' 2016- May' 2016)	Pre-monsoon (Jun' 2016- Aug' 2016)	Monsoon (Sep' 2016- Nov' 2016)	Overall average	F-value
WT (°C) *	26.75±1.08^{a}	27.45±0.75^{a}	26.78±1.54^{a}	24.36±0.78^{a}	26.34±1.03	1.93
pH	6.75±0.67^{b}	8.12±0.28^{a}	7.10±0.26^{b}	6.16±0.60^{b}	7.03±0.45	8.4
Salinity (ppt)	0.926±0.060^{bc}	1.859±0.225^{a}	1.258±0.208^{b}	0.682±0.074^{c}	1.181±0.358	33.03
DO (mg/l^{-1})	7.16±0.56^{ab}	6.26±0.14^{b}	7.63±0.61^{a}	6.63±0.46^{a}	6.92±0.44	6.02
TDS (mg/l^{-1})*	1021±24.06^{a}	1023±15.15^{a}	1022±13.18^{a}	1010±10.0^{a}	1016.75±15.60	0.35
EC (µS cm^{-1})	1.127±0.176^{c}	2.356±0.229^{a}	1.528±0.186^{b}	1.638±0.100^{b}	1.662±0.172	27.62

WT, water temperature; DO, dissolved oxygen; TDS, total dissolved solids; EC, electrical conductivity.
Each season 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).
**, Not significant statistically*

Table 2. Physico-chemical characteristics of the Singanallur Lake during the study period

Parameter	Post-monsoon (Dec' 2015-Feb' 2016)	Summer (Mar' 2016-May' 2016)	Pre-monsoon (Jun' 2016-Aug' 2016)	Monsoon (Sep' 2016-Nov' 2016)	Overall average	F-value
WT (°C)	25.22±0.78^{b}	27.38±0.75^{a}	26.05±1.54^{ab}	24.37±1.08^{b}	25.76±1.11	4.19
pH	6.74±0.57^{bc}	8.17±0.36^{a}	7.42±0.47^{ab}	6.12±0.63^{c}	7.11±0.50	8.7
Salinity (ppt)	0.863±0.053^{bc}	1.589±0.243^{a}	1.168±0.216^{b}	0.728±0.063^{c}	1.087±0.144	15.56
DO (mg/l^{-1})	7.16±0.38^{ab}	7.74±0.57a	6.38±0.68^{b}	6.35±0.17^{b}	6.90±0.45	5.60
TDS (g/l^{-1}) *	1012±13.05^{a}	1028±15.20^{a}	1014±24.06^{a}	1011±10.09^{a}	1016.25±15.6	0.42
EC (µS cm^{-1})	1.420±0.136^{c}	2.035±0.224^{a}	1.635±0.174^{b}	0.752±0.115^{b}	1.460±0.162	26.94

WT, water temperature; DO, dissolved oxygen; TDS, total dissolved solids; EC, electrical conductivity.
Each season 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).
**, Not significant statistically*

In the Singanallur lake, a total of 24 species were recorded, in which included all the rotifer species recorded in Ukkadam lake except *Brachionus diversicornis*, which was unique to the Singanallur lake only. All the 6 species of Cladocera recorded in the Ukkadam lake were also present in the Singanallur lake. Two Copepod species (*Eucyclops speratus, Thermocyclops hyalinus*) and two Ostracod species (*Eucypris bispinosa* and *Heterocypris dentatomarginatus*) which have been recorded in the Ukkadam lake, were absent in the Singanallur lake (Table 3; Figs. 3-6). The order of dominance in zooplankton of the Singanallur lake was Rotifera > Copepoda=Cladocera > Ostracoda.

3.3 Zooplankton Density

In the Ukkadam lake, density of zooplankton groups during all climatic seasons were as follow: Ostracoda (8002 ind. l^{-1}) > Copepoda (5811 ind. l^{-1}) > Cladocera (5338 ind. l^{-1}) > Rotifera (4890 ind. l^{-1}) and the overall abundance of zooplankton (including all four groups) was found to be maximum during summer (25989 ind. l^{-1}) followed by post-monsoon (24089 ind. l^{-1}), pre-monsoon (23954 ind. l^{-1}) and monsoon (20436 ind. l^{-1}) (Table 4). The seasonal density of zooplankton was found to be maximum in summer (25989 ind. l^{-1}), followed by post-monsoon (24089 ind. l^{-1}), pre-monsoon (23954 ind. l^{-1}) and monsoon (20436 ind. l^{-1}) with a mean density of 24042 ind. l^{-1} (Table 4).

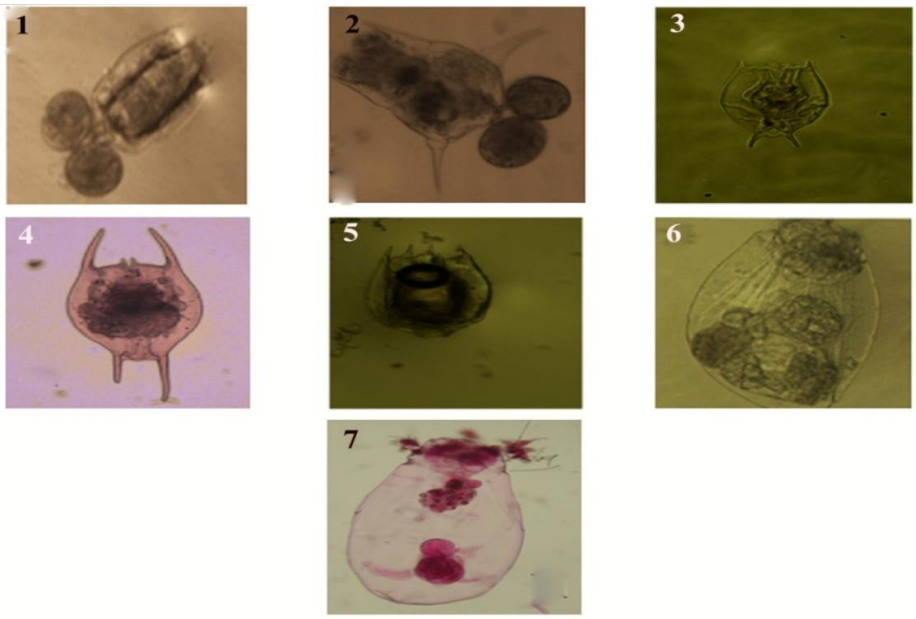

Fig. 3. Group of Rotifer species (400x) identified in the Ukkadam and the Singanallur lakes
1, Brachionus roundiformi; 2, Brachionus calyciflorus; 3, Brachionus caudatus personatus; 4, Brachionus diversicornis; 5, Brachionus rubens; 6, Asplanchna intermedia; 7, Asplanchna brightwelli

Table 3. List of zooplankton species recorded in the Ukkadam and the Singanallur lakes during the study period

Group (Phylum/ Class/Order)	Family	Genus	Species	U no. of species	S no. of species
Phylum: **Rotifera** (7 species; U: 6; S: 7)	Brachionidae (Ehrenberg, 1838)	*Brachionus* Pallas, 1776	*Brachionus rotundiformis* Tschugunoff, *1921**** *Brachionus calyciflorus* Pallas, 1776*** *Brachionus caudatus personatus* Ahlstrom,1940*** *Brachionus diversicornis* Daday, 1883** *Brachionus rubens* Ehrenberg, 1838***	SM: 3 PRM: 5 MN: 4 POM: 6	SM: 4 PRM: 7 MN: 6 POM: 4
	Asplanchnidae (Eckstein, 1883)	*Asplanchna* Gosse, 1850	*Asplanchna intermedia* Hudson, 1886*** *Asplanchna brightwelli* Gosse, 1850***		
Order: **Cladocera** (6 species; U: 6; S: 6)	Sididae (Baird, 1850)	*Diaphanasoma* Fischer, 1850	*Diaphanasoma sarsi* Richard, 1895***	SM: 3 PRM: 5 MN: 4 POM: 6	SM: 3 PRM: 6 MN: 5 POM: 4
	Chydoridae (Stebbing, 1902)	*Daphnia* Muller, 1785	*Daphnia magna* Straus, 1820***		
		Leydigia Kurz, 1875	*Leydigia leydigia* Schodler, 1863***		
	Daphnidae (Straus, 1850)	*Ceriodaphnia* Dana, 1853	*Ceriodaphnia cornuta* Sars, 1853***		
	Moinidae (Goulden, 1968)	*Moina* Baird, 1850	*Moina micrura* Kurz, 1874*** *Moina brachiata* Jurine, 1820***		
Order: **Copepoda** (8 species; U: 8; S: 6)	Diaptomidae (Baird, 1850)	*Heliodiaptomus* Kiefer, 1932	*Heliodiaptomus viduus* Gurney, 1916***	SM: 5 PRM: 8 MN: 6 POM: 7	SM: 3 PRM: 5 MN: 4 POM: 6
	Cyclopoidae (Dana, 1853)	*Cyclops* Muller, 1785	*Cyclops vernalis**** Fischer, 1853		
		Eucyclops Claus, 1893	*Eucyclops speratus* Lilljeborg, 1901*		
		Thermocyclops Kiefer, 1927	*Thermocyclops hyalinus* Rehberg, 1880*		
		Mesocyclops Sars, 1914	*Mesocyclops leuckarti**** Claus, 1857 *Mesocyclops edax**** Forbes, 1891 *Mesocyclops pehpeiensis* *** Hu, 1943		
		Macrocyclops Claus, 1893	*Macrocyclops albidus* Jurine, 1820***		
Class: **Ostracoda** (7 species; U: 7; S: 5)	Cypridiidae (Baird, 1845)	*Cypris* Muller, 1776	*Eucypris bispinosa* Victor and Michael, 1975* *Cypris decaryi Gautier, 1933**** *Cypris protubera* Muller, 1776***	SM: 4 PRM: 7 MN: 5 POM: 6	SM: 2 PRM: 4 MN: 3 POM: 5
		Candona Baird, 1845	*Candona candida* Muller, 1776***		
		Cyprinotus Brady, 1886	*Cyprinotus nudus* Brady, 1885***		
		Heterocypris Claus, 1892	*Heterocypris dentatomarginatus* Baird, 1859*		
		Prionocypris Sars, 1928[86]	*Prionocypris glacialis****		
Total No. of species: 28				27 (28-1)	24 (23+1)

, Ukkadam lake-U; **, Singanallur lake-S; *, Ukkadam and Singanallur lake; SM, Summer; PRM, Pre-monsoon; MN, Monsoon; POM, Post-monsoon*

In Singanallur lake, the density of zooplankton groups during all climatic seasons were as follow: Rotifera (3146 ind. l^{-1}) > Cladocera (2492 ind. l^{-1}) > Ostracoda (2355 ind. l^{-1}) > Copepoda (2342 ind. l^{-1}) and the overall abundance of zooplankton (including all four groups) was found to be maximum during summer season (10821 ind. l^{-1}), followed by pre-monsoon (10807 ind. l^{-1}),

monsoon (10142 ind. l^{-1}) and post-monsoon (9577 ind. l^{-1}) (Table 5). The seasonal density of zooplankton was found to be maximum in summer (10821 ind. l^{-1}), followed by pre-monsoon (10807 ind. l^{-1}), monsoon (10142 ind. l^{-1}) and post-monsoon (9577 ind. l^{-1}), with a mean density of 10337 ind. l^{-1} (Table 5). These data indicated the fact that the production of zooplankton was more than one fold higher in the Ukkadam lake when comapred with the Singanallur lake (Tables 4 and 5). Zooplankton density was positively correlated with water physico-chemical parameters for both lakes (Tables 6 and 7).

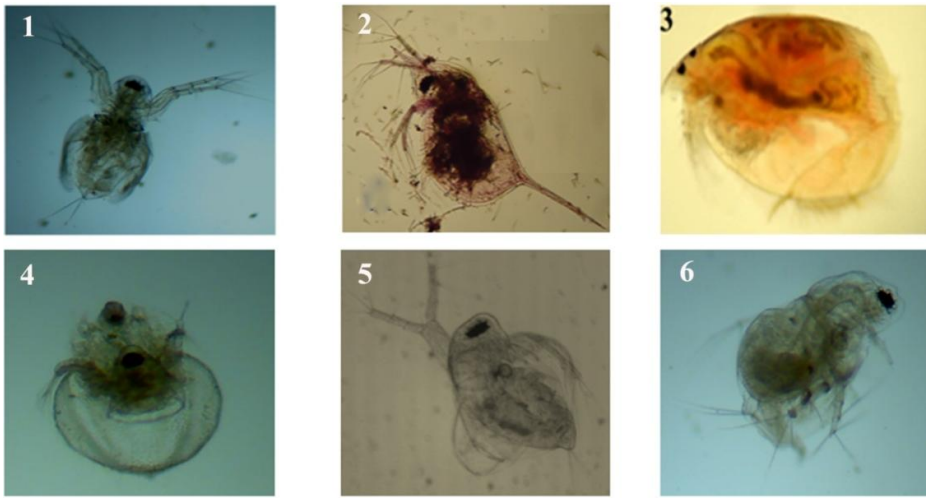

Fig. 4. Group of Cladoceran species (400x) identified in the Ukkadam and the Singanallur lakes
1, *Diaphanosoma sarsi*; 2, *Daphnia magna*; 3, *Leydigia leydigia*; 4, *Ceriodaphania carnuta*; 5, *Moina micrura*; 6, *Moina brachiate*

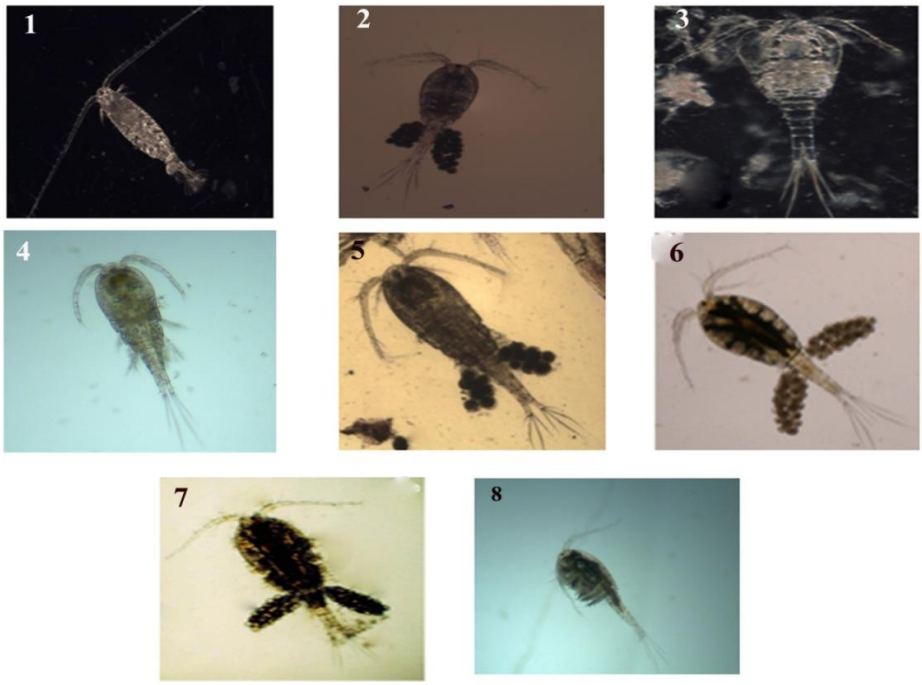

Fig. 5. Group of Copepod species (400x) identified in the Ukkadam and the Singanallur lakes
1, Heliodiaptomus viduus 2, Cyclops vernalis 3, Eucyclops speratus 4, Thermocyclops hyalinus 5, Mesocyclops leuckarti 6, Mesocyclops edax 7, Mesocyclops pehpeiensis, 8, Macrocyclops albidus

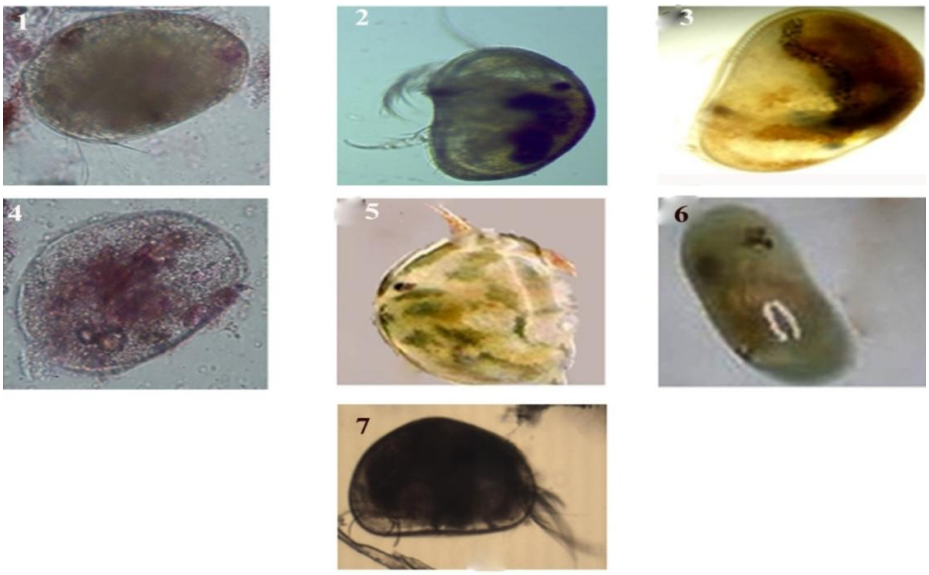

Fig. 6. Group of Ostracod species (400x) identified in the Ukkadam and the Singanallur lakes
1, Eucypris bispinosa 2, Cypris decaryi 3, Candona candida 4, Cyprinotus nudus
5, Heterocypris dentatomarginatus 6, Prionocypris glacialis 7, Cypris protubera

Table 4. Zooplankton density with percentage composition in the Ukkadam Lake during the study period

Plankton group	Density of zooplankton (ind./l)				Mean (ind./l) & %	F-value
	Post-monsoon (Dec' 2015-Feb' 2016)	Summer (Mar'2016-May' 2016)	Pre-monsoon (Jun'2016-Aug'2016)	Monsoon (Sep'2016-Nov'2016)		
Rotifera	4921±254^{a}	5261±317^{a}	4980±314^{a}	4056±259^{b}	4890.0 (20.3%)	9.83
Cladocera	5104±447^{b}	5804±458^{a}	309±320^{b}	4768±327^{c}	5338.2 (22.2%)	27.00
Copepoda	5662±468^{bc}	6053±389^{a}	5972±367^{c}	5146±427^{c}	5811.0 (24.2%)	21.11
Ostracoda	8402±417^{ab}	8871±426^{a}	7693±369^{b}	6466±489^{c}	8002.7 (33.3%)	17.99
Total	24089	25989	23954	20436	24042	

Each season 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 5. Zooplankton density with percentage composition in the Singanallur lake during the study period

Plankton group	Density of zooplankton (ind./l)				Mean (ind./l) & %	F-value
	Post-monsoon (Dec'2015-Feb' 2016)	Summer (Mar'2016-May' 2016)	Pre-monsoon (Jun'2016-Aug' 2016)	Monsoon (Sep'2016-Nov'2016)		
Rotifera*	3274±428^{a}	3211±164^{a}	3187±254^{a}	2913±378^{a}	3146.2 (30.4%)	0.73
Cladocera	1905±316^{b}	2842±273^{a}	2686±274^{a}	2537±332^{a}	2492.5 (24.1%)	5.63
Copepoda*	2171±147^{a}	2414±179^{a}	2397±310^{a}	2388±176^{a}	2342.5 (22.7%)	0.88
Ostracoda*	2227±184^{a}	2354±167^{a}	2537±363^{a}	2304±265^{a}	2355.5 (22.8%)	0.79
Total	9577	10821	10807	10142	10337	

Each season 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)

3.4 Diversity Indices

The calculated seasonal diversity indices values, such as Simpson's species dominance (D), Shannon-Wiener's diversity (H), Buzas and Gibson's evenness (e^H/S) and Margalef's (R1) species richness for each group of zooplankton species recorded from the Ukkadam lake and the Singanallure lake are presented in Tables 8 and 9, respectively. In the Ukkadam lake, for Rotifers and Copepods, a minimum diversity indices for D, H and evenness were observed during

summer, and the R1 for Rotifers and Copepods were seen during pre-monsoon and monsoon, respectively. In the cases of Cladocerans and Ostracods, minimum diversity indices for D, H, evenness and R1 were registered during summer. For Rotifers and Copepods, the maximum diversity indices of D, H, evenness and R1 were recorded during post-monsoon and pre-monsoon, respectively. In the cases of Cladocerans and Ostracods, the maximum diversity indices of D, H and evenness were observed during post-monsoon and pre-monsoon, respectively, whereas, the R1 was registered during monsoon. Therefore, the maximum species diversity indices for zooplankton were observed either during post-monsoon or pre-monsoon, except the R1 for Cladocera and Ostracoda, which were registered during monsoon (Table 8).

In the Singanallur lake, for Rotifers and Cladocerans, the D, H, evenness and R1 were recorded a minimum during summer, and the maximum during pre-monsoon. For Copepods and Ostracods, the D, H, evenness and R1 were recorded the maximum during post-monsoon. The minimum diversity indices of D, H and evenness were observed during summer for Copepods and Ostracods, whereas, a minimum R1 was registered during pre-monsoon and monsoon (Table 9). Among the two lakes, the Singanallur lake showed more Rotifers diversity, whereas the Ukkadam lake showed more Copepods and Ostracods diversity, and almost a similar diversity of Cladocerans was recorded in both Ukkadam and Singanallur lakes (Table 3).

4. DISCUSSION

4.1 Physico-chemical Parameters of Water and Density of Zooplankton

The physico-chemical parameters in water play a significant role in seasonal distribution and species composition of plankton [2-4,9,30,31]. In this study, the recorded higher TDS in the Ukkadam lake can be corroborated with higher density of zooplankton. Moreover, the TDS represents the presence of both organic and inorganic nutrients of the water. Seasonal variations in density of zooplankton have also been reported [32-37]. The physiological activities and life processes, such as feeding, reproduction, movements and distribution of organisms are greatly influenced by water temperature. In this study, the recorded higher WT in the Ukkadam lake can be corroborated with higher density of zooplankton. A rise in temperature leads to the fast chemical and biochemical reactions, and the kinetics of the biochemical oxygen demand is regulated to some extent by water temperature [38]. The R^2 values for WT of the Ukkadam and Singanallur lakes were 0.995 and 0.821, respectively (Tables 6 and 7) indicated the fact that the density of zooplankton was well correlated with water temperature of lakes.

Table 6. The relationship between seasonal fluctuation of physicochemical parameters and zooplankton density in the Ukkadam Lake during the study period

Physicochemical parameters vs. Zooplankton population	Linear regression 'y' – Value	R	R^2	Correlation (Linear Type)	*P* value
Water Temperature	y=1681.70x-20670.75	0.985	0.955	Positive	0.015
pH	y=2585.63x+5433.51	0.918	0.843	Positive	0.082
Salinity	y=3977.64x+18919.41	0.876	0.767	Positive	0.124
DO	y=-268.61x+25475.81	0.070	0.005	No correlation	0.930
TDS	y=-32.99x+57234.73	0.086	0.007	No correlation	0.914
EC	y=1811.86x+20605.23	0.401	0.161	No correlation	0.599

DO, dissolved oxygen; TDS, total dissolved solids; EC, electrical conductivity

Table 7. The relationship between physicochemical parameters and zooplankton density in the Singanallure Lake during the study period

Physicochemical parameters vs. Zooplankton population	Linear regression 'y' – Value	R	R^2	Correlation (Linear Type)	*P* value
Water Temperature	y=422.14x-535.66	0.906	0.821	Positive	0.094
pH	y=484.87x+6888.08	0.716	0.513	Positive	0.284
Salinity	y=1191.17x+9041.94	0.762	0.580	Positive	0.238
DO	y=53.36x+9968.15	0.060	0.004	No correlation	0.940
TDS	y=50.05x-40533.62	0.665	0.442	Positive	0.335
EC	y=612.20x+9442.63	0.550	0.302	Positive	0.450

DO, dissolved oxygen; TDS, total dissolved solids; EC, electrical conductivity

Table 8. Species diversity indices of zooplankton in the Ukkadam lake during the study period

Zooplankton group (No. of species in each season)	Diversity indices	Post-monsoon (Dec' 2015-Feb' 2016)	Summer (Mar' 2016-May' 2016)	Pre-monsoon (Jun' 2016-Aug' 2016)	Monsoon (Sep' 2016-Nov' 2016)	Overall average	F-Value
Rotifera							
Summer: 3	Dominance (D)	0.154±0.006^{a}	0.144±0.004^{d}	0.152±0.005^{b}	0.150±0.004^{c}	0.150±0.004	1.16
Pre-monsoon: 5	Shannon (H)	1.953±0.044^{a}	1.926±0.036^{d}	1.937±0.038^{b}	1.935±0.045^{c}	1.938±0.048	1.82
Monsoon: 4	Evenness_e^H/S	0.977±0.025^{a}	0.949±0.026^{d}	0.973±0.025^{b}	0.971±0.025^{c}	0.967±0.036	0.39
Post-monsoon: 6	Margalef (R1)	0.827±0.045^{a}	0.811±0.045^{b}	0.798±0.043^{d}	0.807±0.043^{c}	0.811±0.049	0.27
Cladocera							
Summer: 3	Dominance (D)	0.157±0.006^{a}	0.143±0.005^{d}	0.154±0.005^{b}	0.153±0.005^{bc}	0.152±0.005	1.17
Pre-monsoon: 5	Shannon (H)	1.957±0.042^{a}	1.927±0.034^{d}	1.937±0.036^{b}	1.933±0.045^{c}	1.938±0.041	1.67
Monsoon: 4	Evenness_e^H/S	0.973±0.023^{a}	0.951±0.026^{d}	0.971±0.023^{b}	0.961±0.024^{c}	0.964±0.037	0.52
Post-monsoon: 6	Margalef (R1)	0.813±0.040^{c}	0.797±0.042^{d}	0.816±0.042^{b}	0.829±0.044^{a}	0.814±0.057	0.24
Copepoda							
Summer: 5	Dominance (D)	0.154±0.005^{b}	0.154±0.007^{d}	0.167±0.006^{a}	0.164±0.005^{c}	0.160±0.005	2.75
Pre-monsoon: 8	Shannon (H)	1.952±0.037^{b}	1.938±0.041^{d}	1.961±0.032^{a}	1.947±0.042^{c}	1.950±0.037	1.59
Monsoon: 6	Evenness_e^H/S	0.972±0.028^{b}	0.961±0.021^{d}	0.983±0.036^{a}	0.967±0.031^{c}	0.971±0.039	0.32
Post-monsoon: 7	Margalef (R1)	0.867±0.029^{b}	0.862±0.024^{c}	0.871±0.029^{a}	0.849±0.026^{d}	0.862±0.052	0.27
Ostracoda							
Summer: 4	Dominance (D)	0.154±0.005^{b}	0.149±0.006^{d}	0.159±0.006^{a}	0.153±0.005^{bc}	0.154±0.004	1.25
Pre-monsoon: 7	Shannon (H)	1.945±0.039^{b}	1.935±0.043^{d}	1.956±0.030^{a}	1.942±0.044^{c}	1.944±0.053	1.21
Monsoon: 5	Evenness_e^H/S	0.968±0.026^{b}	0.959±0.025^{d}	0.976±0.034^{a}	0.962±0.029^{c}	0.966±0.005	0.27
Post-monsoon: 6	Margalef (R1)	0.862±0.027^{b}	0.846±0.026^{d}	0.858±0.025^{c}	0.867±0.027^{a}	0.858±0.043	0.25

Each season value is overall average of mean ± SD (n=15; 5 sites × 3 months).

Each season 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 9. Species diversity indices of zooplankton in the Singanallur Lake during the study period

Zooplankton group (No. of species in each season)	Diversity indices	Post-Monsoon (Dec' 2015-Feb' 2016)	Summer (Mar' 2016-May' 2016)	Pre-Monsoon (Jun' 2016-Aug' 2016)	Monsoon (Sep' 2016-Nov' 2016)	Overall average	F- Value
Rotifera							
Summer:4	Dominance (D)	0.147±0.004^{c}	0.146±0.005^{cd}	0.156±0.006^{a}	0.151±0.005^{b}	0.150±0.004	1.79
Pre-monsoon:7	Shannon (H)	1.939±0.036^{c}	1.932±0.044^{d}	1.956±0.030^{a}	1.941±0.043^{b}	1.942±0.142	1.36
Monsoon:6	Evenness_e^H/S	0.961±0.027^{c}	0.957±0.026^{d}	0.979±0.031^{a}	0.972±0.028^{b}	0.967±0.035	0.32
Post-monsoon:4	Margalef (R1)	0.858±0.026^{c}	0.843±0.025^{d}	0.864±0.028^{a}	0.861±0.027^{b}	0.857±0.046	0.24
Cladocera							
Summer:3	Dominance (D)	0.146±0.004^{c}	0.145±0.004^{cd}	0.152±0.005^{a}	0.149±0.005^{b}	0.148±0.004	1.02
Pre-monsoon:6	Shannon (H)	1.933±0.039^{c}	1.928±0.036^{d}	1.951±0.048^{a}	1.938±0.046^{b}	1.937±0.048	1.21
Monsoon:5	Evenness_e^H/S	0.956±0.025^{c}	0.948±0.024^{d}	0.974±0.026^{a}	0.970±0.025^{b}	0.962±0.027	0.26
Post-monsoon:4	Margalef (R1)	0.801±0.044^{c}	0.798±0.042^{d}	0.826±0.047^{a}	0.819±0.046^{b}	0.811±0.051	0.19
Copepoda							
Summer:3	Dominance (D)	0.153±0.005^{a}	0.142±0.005^{d}	0.147±0.004^{b}	0.144±0.004^{c}	0.147±0.005	1.34
Pre-monsoon:5	Shannon (H)	1.952±0.047^{a}	1.929±0.036^{d}	1.939±0.045^{b}	1.932±0.038^{c}	1.935±0.043	1.13
Monsoon:4	Evenness_e^H/S	0.976±0.027^{a}	0.947±0.023^{d}	0.969±0.024^{b}	0.957±0.026^{c}	0.962±0.041	0.26
Post-monsoon:6	Margalef (R1)	0.825±0.046^{a}	0.820±0.047^{b}	0.797±0.041^{d}	0.803±0.045^{c}	0.812±0.059	0.17
Ostracoda							
Summer:2	Dominance (D)	0.151±0.006^{a}	0.141±0.004^{d}	0.147±0.005^{b}	0.143±0.004^{c}	0.145±0.004	1.84
Pre-monsoon:4	Shannon (H)	1.948±0.045^{a}	1.924±0.031^{d}	1.934±0.042^{b}	1.929±0.039^{c}	1.933±0.037	1.49
Monsoon:3	Evenness_e^H/S	0.967±0.025^{a}	0.944±0.021^{d}	0.963±0.019^{b}	0.954±0.018^{c}	0.957±0.042	0.47
Post-monsoon:5	Margalef (R1)	0.821±0.042^{a}	0.812±0.041^{c}	0.818±0.044^{b}	0.791±0.038^{d}	0.811±0.042	0.42

Each season value is overall average of mean ± SD (n=15; 5 sites × 3 months).

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Mean values within the same row sharing different superscript are significantly different (P<0.05)

The water is generally alkaline in nature due to the presence of carbonates and bicarbonates. Water pH is a function of free carbon dioxide (aqueous CO_2) and carbonates. The photosynthetic activity of phytoplankton increases the pH of water [39]. The pH variation is also attributed to anthropogenic activities like washing of cloths with detergents and mixing of sewage. The R^2 values, 0.843 and 0.513 for the Ukkadam lake and Singanallur lake, respectively (Tables 6 and 7), indicated the fact that the density of zooplankton was well correlated with water pH of respective lakes. However, higher zooplankton density recorded in the Ukkadam lake could be attributed to other factors as well.

Salinity regulates survival, metabolism and distribution of organisms mainly through changes in osmotic pressure and density of the water. It exerts different ecological and physiological effects depending on the interaction with temperature, oxygen and ionic compounds [40]. The higher salinity of water can reduce the diversity and density of plankton abundance [30]. In this study, the higher salinity recorded in summer was due to more evaporation of water due to higher temperature, and, the lower salinity noticed during monsoon was due to lower temperature and also attributed with higher inflow of freshwater. The R^2 values, 0.767 and 0.580 for the Ukkadam lake and Singanallur lake, respectively (Tables 6 and 7) indicated the fact that the density of zooplankton was well correlated with water salinity of respective lakes. The higher salinity recorded in the Ukkadam lake seemed not have affected zooplankton production. Therefore, studies are required with influence of various salinity and zooplankton production.

The DO is one of the most important parameters that reflects the physical and biological processes prevailed in water [41,42]. DO level in water is depending upon the atmospheric air pressure, photosynthetic activity, temperature, salinity and turbulence. The solubility of oxygen increases with decrease in temperature [43]. DO fluctuations occur due to its utilization for decomposition of organic matter and respiration of organisms including zooplankton, phytoplankton and other water plants. The R^2 values, 0.005 and 0.004 for the Ukkadam lake and Singanallur lake, respectively (Tables 6 and 7), indicated the fact that the density of zooplankton was not correlated with water DO of respective lakes. The higher DO recorded in the Ukkadam lake suggest that there may be good numbers of phytoplankton, which might be supported for zooplankton production.

The increased anthropogenic activity, stagnation, evaporation, inflow of drainage water containing large quantity of silt, clay and other materials, decreased inflow of freshwater, and decay of vegetation all raise TDS and affect water quality [44,45]. An excessive 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. The R^2 value, 0.007 for the Ukkadam lake (Table 6) indicated the fact that the density of zooplankton was not correlated with TDS. Although the higher TDS recorded in the Ukkadam lake did not affects the production of zooplankton, rather it supports. However, the R^2 value, 0.442 recorded for the Singanallur lake (Table 7) indicated the fact that the density of zooplankton was moderately correlated with TDS. Therefore, studies are required with influence of various TDS levels including various organic and inorganic nutrients and zooplankton production.

EC is a good indicator of the overall water quality. Unpolluted water possesses low EC [46,47]. The salts in ionic form that dissolved in water and nutrient status are responsible for its EC. The R^2 values, 0.161 and 0.302 for the Ukkadam lake and Singanallur lake, respectively (Tables 6 and 7) indicated the fact that the density of zooplankton was not correlated with EC of respective lakes water. The lower EC recorded in the Singannlur lake suggests that it was less polluted and contains low quantity of organic and inorganic nutrients, which was evident from its low TDS, and therefore, it did not much supports for production of zooplankton when compared to that of the Ukkadam lake. Except for salinity, parameters of water quality in both lakes are within prescribed ranges [46] and WHO [48]: temperature, 24-31°C; pH, 6.5-8.5; salinity, <0.5 ppt; DO, 6-9 mg l^{-1}; TDS, 900-1200 mg l^{-1}.

Fluctuations in water quality parameters and plankton density were similar to those reported for other water bodies [7-10,49]. The primary productivity is responsible for increasing the density of zooplanktons during summer season [50]. Naturally the lower density during monsoon season was associated with lower photosynthetic activities, led to lower primary productivity, which may also be due to dilution effect [51].

4.2 Species Diversity of Zooplankton

Zooplankton species composition and dominance in a particular water body is controlled by several ecological factors, including nutrients load and pollution status. Results about zooplankton abundance in both lakes were similar to those reported for other freshwater bodies [6-10].

In India, 21 species of *Brachionus* have been reported [52,53]. Abundance of *Brachionus* spp., particularly, *B. calyciflorus*, *B. caudatus personatus*, *B. diversicornis* and *Filina longiseta* have been reported as indicators of eutrophication [7,8,33,54-61]. In the present study, among Rotifers, the genus *Brachionus* was found to be higher in numbers, and presence of most of these pollution indicator species suggests that both the Ukkadam and Singanallur lakes are suffering a eutrophication process.

Crustacean zooplankton (Cladocera, Copepod and Ostracoda) holds the highest position both in terms of number of species and as primary consumers in the aquatic food chain. Few Cladoceran genera are planktonic in freshwater bodies, while majority of them are littoral, living among the weed and some of them live on the bottom mud. The presence of *Diaphanosoma*, *Daphnia, Ceriodaphnia* and *Moina* has been recorded in both eutrophic and oligotrophic lakes [62-65]. In the present study, the presence of Cladoceran species of these genera, *D. sarsi*, *D. magna*, *C. cornuta, M. micrura* and *M. brachiata* also suggests that both the Ukkadam and the Singanallur lakes are eutrophicated. Moreover, Ostracod genera, *Cypris* and *Heterocypris* were also present in these lakes, particularly *E. bispinosa,* and *H. dentatomarginatus* only in the Ukkadam lake. However, one species of oligotophic lake, *H. viduus* (Diaptomidae, Cpepoda) also present in these lakes [66].

There are few Cyclopoid and Harpacticoid Copepods that thrive in the pelagic zones of lakes, which serve as sources of food for larvae, juveniles and adults of many fish species [67,68]. Dominance of Copepods indicates that there are high abundance of diatoms (*Bacillariophyceae*) and blue green algae (*Chlorophyceae*), and these phytoplankton groups are important food sources for all the developmental stages of Cyclopoid Copepods [69]. Moreover, abundance of these algae were reported by us in other perennial lakes of Coimbatore city, India [3,4]. Copepods also feed upon Rotifers. In the present study, abundance of more Cyclopoid species of Copepod, *C. vernalis, E. speratus, T. hyalinus, M. leuckarti*, *M. edax*, *M. pehpeiensis* and *M. albidus* indicated the fact that there were live feed for fishes and prawns. Moreover, the recorded quite good number of Ostrocod species, *C. candida, C. nudus* and *P. glacialis* were also indicated the availability of live feed in these lakes. However, during summer and monsoon seasons, particularly the Singanallur lake was oligotrophic in nature, because of very low richness of species.

McDonald [70] stated that the values of indices ranging from 1.5 to 3.4 have low diversity and species richness, with values above 3.5 has high diversity and species richness. The higher value of Shannon's index (H') indicated greater species diversity. The greater species diversity means larger food chain and more cases of inter-specific interactions and greater possibilities for negative feedback control which reduced oscillations and hence increases the stability of the community [71]. Considering results of this research, the present study indicates the fact that the diversity indices were low in both lakes and the zooplanktonic community was not stabilized.

5. CONCLUSION

The water temperature and TDS of these two perennial lakes ensures high abundance and diversity zooplankton, which was obvious during pre-monsoon and post-monsoon seasons. During monsoon period, factors like lower water temperature, pH and salinity might not be in favor of growth of zooplankton due to inflow of more rain water. Density of zooplankton was higher during summer season in both lakes, due to excessive fishing and low water level. The overall density of zooplankton was more than one fold higher in the Ukkadam lake when compared with the Singanallur lake. As the Ukkadam water was better than that of the Singanallur lake, in terms of zooplankton abundance, it can readily be utilized for aquaculture. However, proper monitoring is required. Usually, local people have engaged with conventional capture fishery in these two perennial lakes. As overall water quality was near normal and high zooplankton abundance as live feed was registered in both lakes, if properly managed, they can support aquaculture activities of fishes and prawns.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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