RESEARCH ARTICLE

Community structure and monthly dynamics of zooplankton in high altitude rice fish system in Eastern Himalayan region of India

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ABSTRACT

The community structure and seasonal dynamics of zooplankton were examined in high altitude rice fish system of Eastern Himalaya. The study was conducted at fortnight interval from field preparation to harvesting of rice during two seasons of 2013 and 2014. All the standard procedures were followed to obtain relevant quantitative and qualitative data on zooplankton showing, a total of five major communities of zooplankton viz., Cladocera, Copepoda, Rotifera, Protozoa, and Ostracoda were encountered. These comprised of 33 taxa of Cladocera, 11 taxa of Copepoda, 17 taxa of Rotifera, 5 taxa of Protozoa and only one taxon of Ostracoda. Cladocera was the most dominant (29%) while Rotifera (12%) was least abundant. Density of zooplankton communities showed significant ($p<0.05\%$) monthly variation during the rice growing seasons. The computed diversity indices confirmed the presence of diversified zooplankton in the rice fish system. Month wise cluster of similarity index revealed very close species composition at initial and mid phases compared to end phase of the rice growing season. The zooplankton therefore becomes natural food sources of fishes concurrently in the flooded rice fields to enhance unit land productivity.

Keywords: Abundance; Diversity; Dynamics; Richness; Zooplankton.

INTRODUCTION

Rice fish farming system is a very famous and mostly studied seasonal aquatic ecosystem for productivity of rice and fish together (Frei *et al*. 2007) and is recognized as a globally unique agro ecosystem in tropical and sub tropical Asia (Lu and Li, 2006). Though wet rice fields covers the entire spectrum of diverse seasonal freshwater fauna (Fernando, 1977; 1993); however, assessment of zooplankton diversity, species richness, seasonal dynamics, abundance, distribution and ecology was reported till date from Malaysia, India, Sri Lanka, Japan, Philippines, Thailand, Indonesia and Italian rice fields only (Bambaradeniya and Amarasinghe, 2003; Meijen

1940; Neale, 1977; Heckman, 1979; Lim *et al*. 1984; Ali, 1990; Simpson *et al*. 1994; Taniguchi *et al*. 1997; Leoni *et al*. 1999; Rossi *et al*. 2003; Chittapun *et al*. 2009; Bahaar and Bhat, 2013).

In India, the Apatani hill tribes of Eastern Himalaya are habituated in raising fish concurrently as companion crop of rice as their main food source in high rainfall mountainous zone since last 1960 years (Kacha, 2016). This ecofriendly and economically beneficial farmer's practice has made the system unique in the context of aquatic resource utilization (Singh *et al*. 2011). The farmers sometimes use household and agricultural wastes, excreta of domestic animals like pig, cow and goat in the fields as energy subsidy making such farming more sustainable and organic in nature (Saikia and Das, 2004). They also cultivate the field's dykes with various nitrogen fixing vegetables and millets for enhanced productivity. Regarding fish species, three strains of Common carp viz., *Cyprinus carpio specularis*, *C. carpio communis*, *C. carpio nudus* are used to stock just after water accumulation in to the rice fields (Das *et al*. 2007). These stocked fishes practically depend on the natural food sources of the rice fields and farmers hardly use any supplementary fish feed (Ali, 1988; Saikia and Das, 2009). The micro crustaceans, Rotifers and Protozoans in the field water thrive on the dissolved organic matters making the system potentially congenial for rice field fishery (Lemly and Dimmick, 1982; Saikia and Das, 2010). Within a crop cycle, therefore the Apatani farmers could harvest 500.0 kg/ha of fishes and 3.0 tons/ha of rice in an average from their rice fish system (Saikia *et al*. 2015; Li, 1988).

Zooplankton being the naturally available fish food organisms in high altitude rice fields seems to have influencing role towards the development of rice field fishery. The frequently changing nature of rice fields according to the different growth stages of rice provide congenial habitat for rich number of diversified organisms (Heckman, 1979; Simpson and Roger, 1995; Simpson *et al*. 1993). These organisms enter into the field water via irrigation water and air to colonize on different microhabitat of rice fields (Fernando, 1995; 1996). The vertebrate fauna like amphibians, reptiles, birds, mammals and the variety of invertebrate fauna including zooplankton in rice fields can inhabit different drastic agronomic changes of rice field within a very short period of time (Bambaradeniya *et al*. 2004). The zooplanktonic organisms flourish on the energy received from primary producers and become readily available to the different categories of consumers in the rice fields including stocked young carps. Therefore, fish growth and survival is directly influenced by the abundances and diversity of zooplankton which are involved with the process of decomposition and circulation of both allochthonous and autochthonous organic matters (Shil *et al*. 2013; Guangjun, 2013). The micro crustaceans, rotifers and protozoans in the field water thrive on the dissolved organic matters and thus make the system potentially favorable for the rice field fishery development (Lemly and Dimmick, 1982; Saikia and Das, 2010).

From the above perspective, goal of the study is to explore the zooplankton community structure and their seasonal population variability so that judicious strategies of natural resource exploitation may be developed for better rice fish farming in future.

MATERIALS AND METHODS

Study site

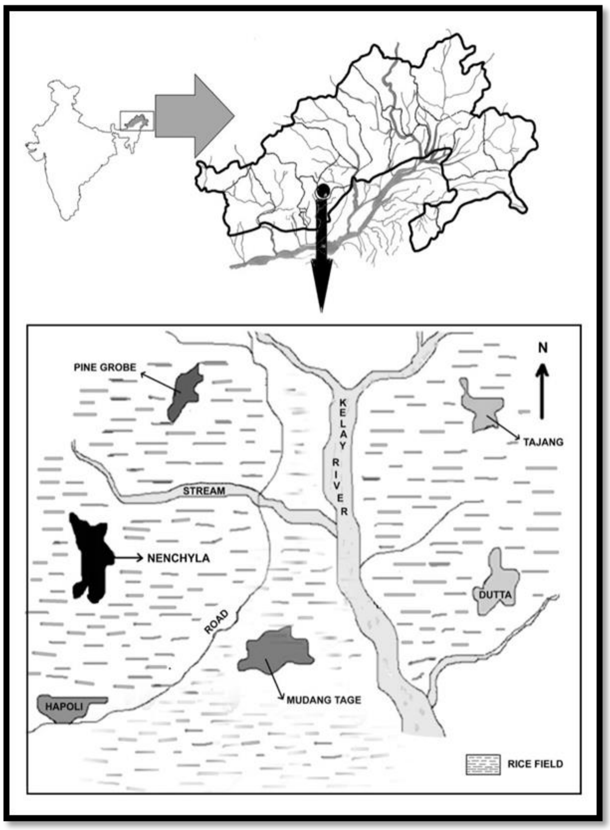


Figure 1. Location Map of the study sites (Redrawn after Saikia *et al*. 2015)

Three high altitude (1800 m above the mean sea level) rice fish culture plots were selected randomly from five villages (Figure 1) namely Pine grobe, Tajang, Nenchalya, Dutta, Mudang tage (altitude:, latitude: 26°50'- 98°21' N and 92°40' - 94°21' E longitude) in Eastern Himalaya.

Field sampling and Analysis

Field sampling started fortnightly from April to September during the two consecutive rice growing seasons of 2013 and 2014 and data were presented separately for both the seasons. Daily rainfall (mm) was recorded from the nearest meteorological station of the plateau. Water parameters like water temperature (WT), water depth (WD), electrical conductivity (EC), total dissolved solids (TDS) and pH were recorded using thermometer (ZPHI-9100 Zico, India Ltd), centimeter scale and digital water analysis kit (SYSTORNICS 371) respectively. On the other hand, dissolved oxygen (DO), free carbon di oxide (FCO_2), nitrate-nitrogen (NO_3-N), phosphate-phosphorus (PO_4-P), total alkalinity (TA) and chloride (Cl^{-1}) were also estimated (APHA, 2012). Plankton were collected by filtering 25 L of field water through standard mesh (size 35 µm) and immediately preserved in 4% formalin. Furthermore, the preserved samples were analyzed using light microscope (Nikon, ECLIPSE E200, Olympus CX4 and Leica DM 5000). The quantitative analyses of zooplankton were done following drop count method (Lackey, 1938). Identification of individual zooplankton was performed following standard keys and monographs of Smirnov (1971, 1996); Needham and Needham, (1972); Tonapi, (1980); Michael and Sharma (1988); Battish, (1992); Edmonson, (1992); Shiel (1995); Subhash Babu and Nayar (2004), Kotov *et al*. (2012; 2013); Sharma and Sharma (2013) and related other related published taxonomical works on various species mostly up to genus level because of intricacy in species confirmation.

Relative abundance [% RA = (n/N) × 100] was computed to generate the percentage composition of zooplankton community where, n = total number of the individual per species under consideration; N = total number of all individuals per station. Attempt has also been made to find out the diversity of zooplankton in the rice field using various indices like Shannon-Wiener diversity index (Shannon and Wiener, 1949); Simpson's dominance index (Simpson (1949); Margelef's richness index (Margelef, 1968) and Buzas Gibson's evenness index (Buzas Gibson, 1969).

All the equations related to the above mentioned diversity indices are mentioned below:

a) Shannon-Wiener diversity index

$$H' = -\sum_{i=1}^{s} \frac{ni}{N} ln \frac{ni}{N}$$

[Where, n_i= number of individuals of taxon i, n= Total number of individuals]

b) Simpson's dominance index

$$D = \sum_{i=1}^{s} \left(\frac{ni}{N}\right)^2$$

[Where, *D*= Simpson's dominance index; *ni*= number of individual of taxon *i*, N= total number of individuals in each species]

c) Buzas-Gibson evenness index

$$e^{\wedge} = \frac{eH'}{S}$$

[Where, $e^{\wedge} =$ Buzas-Gibson evenness index; eH' =

Shannon-Wiener index, calculated using natural logarithms, S = Number of species]

d) Margalef richness index

$$D_{mg} = \frac{S-1}{lnN}$$

[Where, D_{mg} = Margalef richness index;

S= Number of species, N= Total number of individuals in the sample].

Statistical analysis

All the statistical analyses were carried out by using the softwares, PAST version 3.07, SPSS version 21 and Microsoft excel. The month-wise population fluctuations of various zooplankton species were examined using Kruskal-Wallis test. Further, the similarities in species composition of zooplankton communities within months were assessed through the Bray-Curtis cluster analysis. The multiple regression analysis of physico-chemical parameters of rice field water for the zooplankton belonging to different communities was done.

RESULTS AND DISCUSSIONS

Community structure: Abundance and species composition

The findings clearly revealed that zooplankton community structure showed variations in terms of species composition, density, diversity, dominance, richness and evenness with respect to different months. The variations in physico-chemical parameters of rice field water seem to be the major contributor for seasonal abundance of zooplankton in shallow wet rice field situated even in higher altitude. The mean value of water physico-chemical parameters like pH (6.49), WT (27.30°C), WD (16.5 cm), EC (523.62 mgl^{-1}), TDS (302.45 mgl^{-1}), DO (6.32 mgl^{-1}), FCO_2 (12.05 mgl^{-1}), NO_3-N (1.34 mgl^{-1}), PO_4-P (0.14 mgl^{-1}), TA (29.47 mgl^{-1}), Cl^{-1} (36.15 mgl^{-1}) were analyzed and average rainfall (615.95 mm) was also recorded during the whole study period (**Table 1**).

A total of five major communities of zooplankton *viz*., Cladocera, Copepoda, Rotifera, Protozoa and Ostracoda were encountered in the inundated rice fields of Apatani Plateau during the rice growing season. These comprised of 33 taxa of Cladocera, 11 taxa of Copepoda, 17 taxa of Rotifera, 5 taxa of Protozoa and only one taxon of Ostracoda (**Table 2**). Cladocera were represented by family Bosminidae, Chydoridae, Macrothidae, Daphniidae and Moinidae. Copepoda were represented by family Cyclopidae, Diaptomidae, Centropugidae and Canthocamptidae. Ostracoda was represented by a single family Cyprididae. Among the Rotifers, the families were Lecanidae, Brachionidae, Testudinellidae, Dicranophridae, Notommatidae and Asplanchnidae whereas family Arcellidae, Centropyxidae, Difflugiidae and Ophryoglenidae were found under Protozoa. The Cladoceran community was mostly dominated by *Bosmina* sp. and *Chydorus* sp., Copepods were dominated by *Cyclops* sp., *Diaptomus* sp. Furthermore, *Brachionus* sp., *Keratella* sp. under Rotifera and *Arcella* sp. under Protozoa were found as dominant genera during the study period. Relative abundance of zooplankton indicated that Cladocera (29%) was the most dominant community followed by Copepoda (24%), Protozoa (22%), Ostracoda (13%), while Rotifera (12%) showed least dominance during the entire study period (**Figure 2**). The relative abundance indicated that Cladocera was the most dominant as well as diverse zooplankton and the findings also matched with the observation of Ali (1990) from flooded rice field in Malaysia. The presence of aquatic weeds, decomposition of detritus and shallow depth of rice field water (Sharma *et al*. 2012) might be reason for dominance of Cladocera in the rice field of the study area. The incident sunlight and abundant algal communities supported the rapid growth of filter feeding microcrustaceans like *Daphnia* sp. and *Bosmina* sp. in the initial rice growing cycle. Besides, several biotic and abiotic interactions might selectively act on some detritivorous zooplankton like *Alona* sp. and *Chydorus* sp. where Chydoridae became most dominant among Cladocerans was in conformity with the findings of Shah *et al*. (2008). The periphytic associations perhaps influenced the high abundances of the members of Macrothricidae family in the rice fields (Sharma and Sharma, 2014). In addition to available nutrients, the alkaline water of rice field perhaps became one of the reasons for the dominance of *Cyclops* sp. (Kumar *et al*. 2004; Ahmad *et al*. 2011; Bhat *et al*. 2014).

The Bray Curtis cluster analyses depicted that the monthly species compositions of zooplankton in the water logged rice field showed more similarity between April and May, as represented by one cluster, another cluster was represented by June, July and August, the third cluster was represented separately in September (**Figure 3**).

Table 1. Mean value of water physico-chemical parameters among months in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14 (n=45).

Parameters	Mean ± SD
pH	6.49±0.265
WT (°C)	27.30±2.5
WD (cm)	16.5±2.9
EC (µS cm^{-1})	523.62±67.6
TDS (mgl^{-1})	302.45±43.4
DO (mgl^{-1})	6.32±6.5
FCO_2 (mgl^{-1})	12.05±5.4
NO_3-N (mgl^{-1})	1.34±1.2
PO_4-P (mgl^{-1})	0.14±0.184
TA (mgl^{-1})	29.47±9.5
Cl^{-1} (mgl^{-1})	36.15±6.5
Rainfall (mm)	615.95±45.3

Table 2. The checklist of zooplankton from high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14.

Group	Family	Taxa
Cladocera	Bosminidae	*Bosmina* sp.
	Bosminidae	*Bosmina* cf. *tripurae* (Jurine 1820)
	Bosminidae	*Bosmina longirostris* (Muller, 1776)
	Bosminidae	*Bosminopsis* sp.
	Chydoridae	*Chydorus* sp.
	Chydoridae	*Dadaya macrops* (Daday, 1898)
	Chydoridae	*Kurzia longirostris* (Daday, 1898)
	Chydoridae	*Kurzia* sp.
	Chydoridae	*Oxyurella* sp.
	Chydoridae	*Alona* sp.
	Chydoridae	*Disperalona caudata* Smirnov, 1996
	Chydoridae	*Coronatella anodonta* (Daday, 1905)
	Chydoridae	*Alona affinis* (Leydig, 1860) s. lat.
	Chydoridae	*Alona guttata* Sars, 1862
	Chydoridae	*Celsinotum macronyx* (Daday, 1898)
	Chydoridae	*Ephemeroporus barroisi* Richard 1894
	Chydoridae	*Anthalona* sp.
	Chydoridae	*Chydorus sphaericus* (Muller, 1776)
	Chydoridae	*Chydorus ventricosus* Daday, 1898
	Chydoridae	*Chydorus* cf. *ovalis* Kurz, 1875
	Chydoridae	*Pleuroxus denticulatus* Birge, 1879
	Sididae	*Diaphanosoma dubium* (Manuilova, 1964)
	Sididae	*Latonopsis australis* Sars, 1888
	Daphniidae	*Daphnia lumholtzi* Sars, 1885
	Daphniidae	*Ceriodaphnia cornuta* Sars, 1885
	Daphniidae	*Ceriodaphnia* sp.
	Daphniidae	*Simocephalus* sp.
	Daphniidae	*Simocephalus mixtus* Sars, 1903
	Moinidae	*Moina* sp.
	Moinidae	*Moina micrura* Kurz, 1874
	Moinidae	*Moinodaphnia* sp.
	Macrothidae	*Macrothrix* sp.
	Macrothidae	*Macrothrix spinosa* King, 1853
	Macrothidae	*Macrothrix triserialis* (Brady, 1886
Copepoda	Cyclopidae	*Cyclops* sp.
	Cyclopidae	*Mesocyclop* sp.
	Cyclopidae	*Mesocyclop edax* Forbes, 1891
	Diaptomidae	*Diaptomus* sp.
	Diaptomidae	*Limnocalanus* sp.
	Diaptomidae	*Limnocalanus macrurus* Sars, 1863
	Diaptomidae	*Bryocamptus* sp.
	Diaptomidae	*Helodiaptomus* sp.
	Diaptomidae	*Neodiaptomus* sp.
	Diaptomidae	Nauplii of *Cyclops*
	Diaptomidae	Nauplii of *Diaptomus*

Table 2. continued…

Group	Family	Taxa
Rotifera	Asplanchnidae	*Asplanchna sp.*
	Asplanchnidae	*Asplanchna brightwellii* Gosse, 1850
	Brachionidae	*Keratella sp.*
	Brachionidae	*Keratella valga* (Ehrenberg, 1834)
	Brachionidae	*Brachionus sp.*
	Brachionidae	*Brachionus forficula* Wierzejski, 1891
	Brachionidae	*Plationus patulus* (Muller 1786)
	Brachionidae	*Platias quadricornis* (Ehrenberg, 1832)
	Testudinella	*Testudinella patina* (Hermann, 1783)
	Testudinella	*Testudinella striata* (Murray, 1913)
	Dicranophoridae	*Dicranophorus forcipatus* (Muller, 1786).
	Lecanidae	*Lecane sp.*
	Lecanidae	*Lacane ungulata* (Gosse, 1887)
	Lecanidae	*Lacane leontina* (Turner, 1892)
	Lecanidae	*Lacane bulla* (Gosse, 1851)
	Lecanidae	*Monostyla sp.*
	Notommatidae	*Eosphera sp.*
Protozoa	Arcellidae	*Arcella sp.*
	Difflugiidae	*Difflugia sp.*
	Centropyxidae	*Centropyxis sp.*
	Ophryoglenidae	*Ophryoglena sp.*
	Epistylidae	*Epistylis sp.*
Ostracoda	Cyprididae	*Cypris sp.*

Table 3. Month wise diversity, dominance, evenness and richness indices of Cladocera in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

Indices	April	May	June	July	August	September
Diversity index	2.138	2.842	2.869	2.755	2.815	1.298
Dominance index	0.139	0.104	0.102	0.122	0.291	0.323
Evenness index	0.129	0.134	0.385	0.109	0.288	0.188
Richness index	5.672	5.865	5.233	5.025	6.707	5.346

Table 4. Month wise diversity, dominance, evenness and richness indices of Copepoda in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

Indices	April	May	June	July	August	September
Diversity index	1.301	1.391	1.458	1.696	1.485	1.344
Dominance index	0.276	0.210	0.296	0.111	0.222	0.264
Evenness index	0.524	0.537	0.490	0.495	0.670	0.547
Richness index	1.390	1.346	1.648	1.836	2.061	1.638

Table 5. Month wise diversity, dominance, evenness and richness indices of Protozoa in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

Indices	April	May	June	July	August	September
Diversity index	1.263	1.388	1.374	1.132	1.203	1.264
Dominance index	0.234	0.132	0.154	0.265	0.266	0.233
Evenness index	0.707	0.801	0.790	0.620	0.666	0.707
Richness index	0.854	1.559	1.176	1.259	0.926	0.842

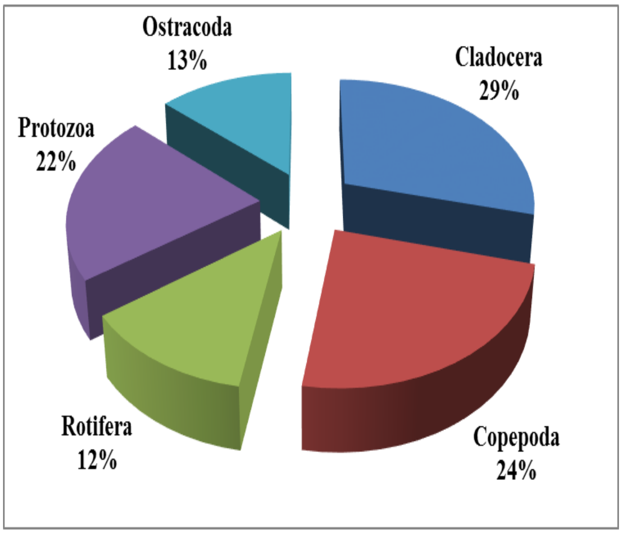


Figure 2. Relative abundance (%) among different communities of zooplankton in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

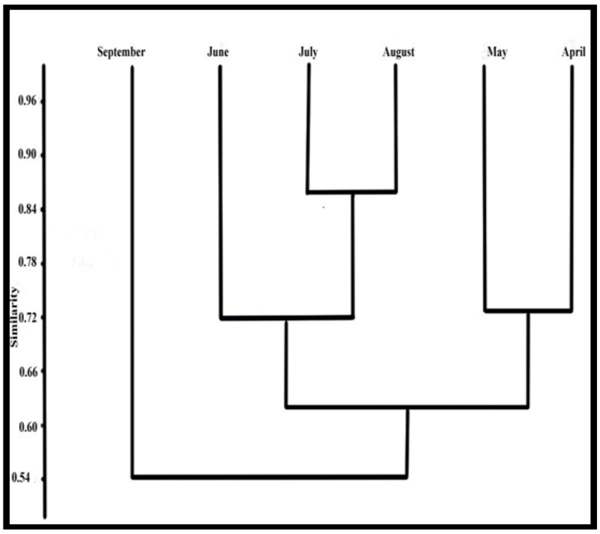


Figure 3. Cluster analysis showing similarity of zooplankton within months in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

The monthly cluster analysis of zooplankton showed that species compositions of April and May were similar which might be because of low density of rice stems, comparatively lower water depth, low canopy cover of rice plant, high density of primary producers and also the high level of nutrients. Species compositions of zooplankton in June, July and August associated in a single cluster was perhaps due to gradually increased field water level, dense canopy cover of rice, maximum number of rice stems along with predatory effect of stocked fishes. However, it is also to be mentioned here that the species compositions of zooplankton in September was in different cluster probably because of some anthropogenic activities by the farmers at harvest.

Community dynamics and diversity of Zooplankton

The mean density of zooplankton (**Figure 4**) was highest in May (452 individuals l^{-1}) followed by June (446 individuals l^{-1}) and lowest in September (89 individuals l^{-1}) in the entire study area. The population density of zooplankton was high from May-July and again it went down from August to till end of the September. The study unfolded that the average population of zooplankton was highest in June probably because of high algal abundance accompanied with heavy rainfall which triggered the growth of certain specific zooplankton genera (e.g. *Bosmina* sp., *Cyclops* sp. and *Cypris* sp.) in summer but declined later in water recession period with the onset of winter. Similar observation was also reported by Kurasawa (1957) and Tripathi *et al*. (2006). The zooplankton population declined at the later stage of rice cultivation (August-September) due to strong predation stress by the stocked fish accompanied by growth stages of the rice plant with full grown canopy that limit entry of sunshine into the field that inhibits the growth of algae suspended in water. The stocked fishes of the rice fields utilize zooplankton as main food resources for their growth and survival (Beisner and Peres-Neto, 2009). This situation in turn, probably led to less amount of total zooplankton at latter stages for scarcity food resources (Bahaar and Bhat, 2013). The findings clearly revealed that zooplankton community structure showed significant variability within a very short period of time under wet rice agro ecosystem. The alteration of the wet phase to dry phase due to seasonality seems quite favorable for re-emergence of dormant zooplankton eggs inside the sediment and probably was an important source for abundant zooplankton (Chittapun *et al*. 2009; Rodrigues *et al*. 2011) in Apatani rice fields. The dispersion of ectozoochory and endozoochory of aquatic birds in foraging time, rich primary productivity and available nutrient content at the onset of the crop cycle enhanced high density of zooplankton in the rice agro-ecosystem (Baltanas, 1992; Figuerola and Green, 2002; Figuerola *et al*. 2003; Lin *et al*. 2003). Moreover, Apatani farmers very frequently used to clear weeds in their wet rice fields that allowed sufficient solar influx into field water enhancing the multiplication of zooplankton.

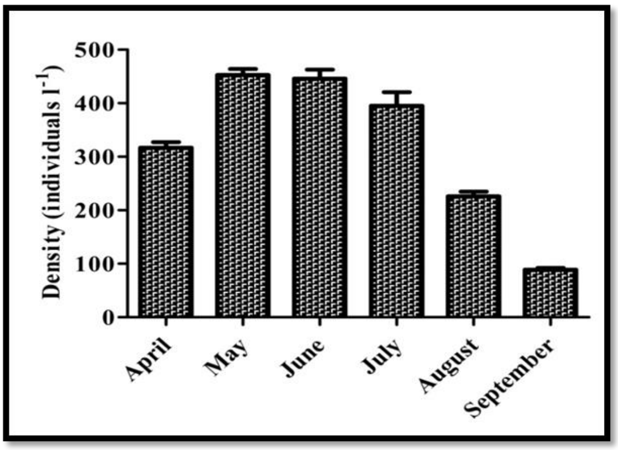


Figure 4. Monthly variations in total density of zooplankton (individuals l^{-1}) in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14.

The Kruskal-Wallis test confirmed that the diverse communities of zooplankton showed significant monthly variation ($p<0.01$). The herbivorous zooplankton devoured by fishes regulated population dynamics of algal communities through their grazing processes (Carpenter *et al.* 1985). It may also be explained that higher population density of suspended algae had increased the population density of zooplankton (Goldyn and Kowalczewska-Madura, 2008). The prey-predator interaction may be considered as one of the most important factors for abundance of zooplankton which is mainly influenced by algal population (Striebel *et al.* 2012). The algae which were persistent in such a situation had probably been fed rapidly by zooplankton during the rice growing season (Gołdyn and Kowalczewska-Madura, 2008). The mean density of Cladocera were maximum in June in 2013 (364 individuals l^{-1}) and 2014 (473 individuals l^{-1}) and the minimum values of 2013 (11 individuals l^{-1}) and 2014 (25 individuals l^{-1}) were in September (**Figure 5**). Besides, the Cladoceran population showed increase in June probably due to relatively high water depth (Saikia *et al.* 2016) which probably minimize the turbidity of rice field water and allowed photosynthesis for the formation of sufficient food resources for them (Viroux, 2002; Santhanam and Perumal, 2003; Jose and Sanalkumar, 2012). It was found that the density of Copepods (**Figure 6**) were maximum in July (129 individuals l^{-1}) and minimum in May (35 individuals l^{-1}) during 2013 while in 2014, highest (142 individuals l^{-1}) density was in August and lowest density was in April (19 individuals l^{-1}). However, the density of Protozoa (141 individuals l^{-1}) and Rotifera (101 individuals l^{-1}) depicted their dominance in May, whereas during September, Protozoa (7 individuals l^{-1}) and Rotifera (5 individuals l^{-1}) exhibited lower population density in 2013 (**Figure 7** and **8**). Monthly variations of Protozoa (15 individuals l^{-1}) and Rotifera (2 individuals l^{-1}) follow similar trend where their lower value was observed in September and their higher values were in May where Protozoa had 100 individuals l^{-1} and Rotifera had 131 individuals l^{-1} during 2014 (**Figure 7 and 8**). In the present findings, it was also noted that the Rotifera and Protozoa diversity and density were high from tillering to end of the transplanting stage of rice (May) and then sharply declined up to harvesting phase (September) in all the rice fields of Apatani Plateau which cohere with the finding of Bahaar and Bhat (2013). The rich diversity of both Protozoa and Rotifera was perhaps due to the higher population of bacteria and low water flow which caused decomposition of household sewages that ultimately enhanced the production rate of organic materials (Kumar *et al.* 2004; Majagi and Vijaykumar, 2009; Dhembare, 2011; Bhat *et al.* 2014, Sharma *et al.* 2014). Additionally, the sufficient sunlight also stimulates the reproductive strategies of Protozoa and Rotifera which might also be ascribed to their maximum diversity and density in May. Conversely, low amount of detritus loading and increased water flow may be one of the causes behind the less population of Protozoa during the end of the rice cropping cycle (Sharma *et al.* 2014).

Table 6. Month wise diversity, dominance, evenness and richness indices of Rotifera in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

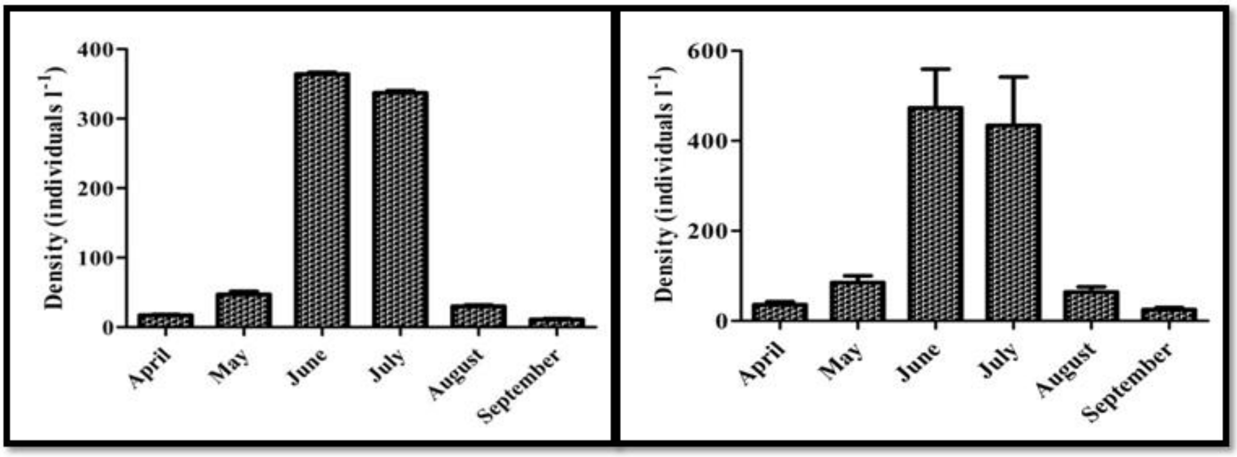
Indices	April	May	June	July	August	September
Diversity index	1.389	1.533	1.426	1.024	1.427	1.040
Dominance index	0.197	0.124	0.176	0.211	0.184	0.222
Evenness index	0.802	0.926	0.942	0.830	0.833	0.557
Richness index	1.022	1.820	1.611	1.276	0.841	1.443

Table 7. Month wise diversity, dominance, evenness and richness indices of Ostracoda in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

Indices	April	May	June	July	August	September
Diversity index	0.000	0.000	0.000	0.000	0.000	0.000
Dominance index	1.000	1.000	1.000	1.000	1.000	1.000
Evenness index	1.000	1.000	1.000	1.000	1.000	1.000
Richness index	0.111	0.213	0.274	0.358	0. 696	0.341

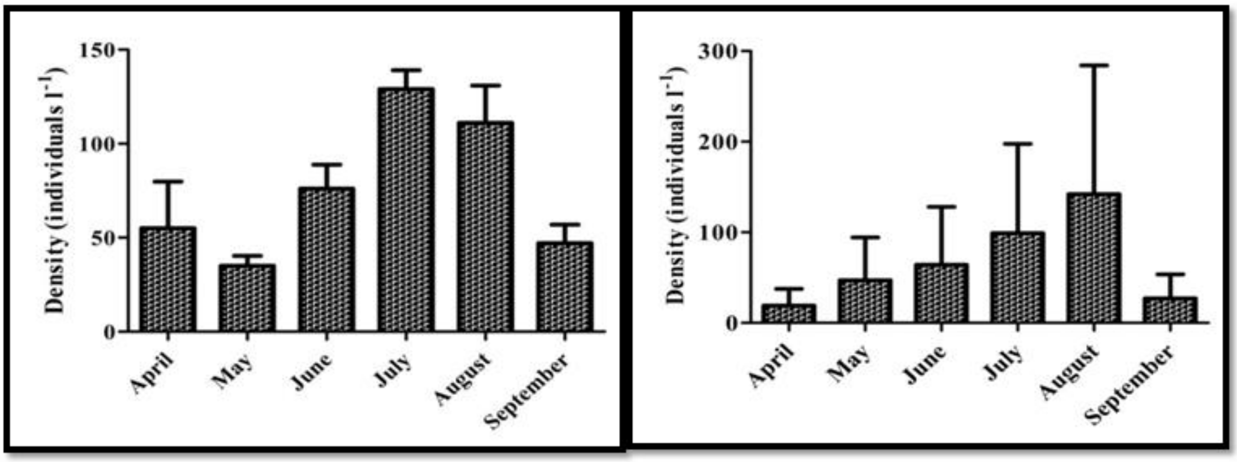
Table 8. Month wise taxa density (individuals l^{-1}) of Cladocera in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

Species	April	May	June	July	August	September
Bosmina sp.	1	4	1	0	3	2
Bosmina tripurae	4	7	59	189	9	4
Bosmina longirostris	5	17	107	30	13	5
Chydorus sp.	2	2	3	1	1	0
Dadaya macrops	1	1	14	1	1	1
Kurzia sp.	0	0	1	1	0	0
Kurzia longirostris	1	1	2	1	1	1
Oxyurella sp.	0	1	5	7	2	2
Alona sp.	0	0	2	0	1	0
Disperalona caudata	1	1	1	1	1	1
Alona affinis	0	1	4	2	1	0
Latonopsis australis	0	1	1	0	0	0
Bosminopsis sp.	1	0	4	1	1	1
Alona guttata	1	2	2	1	1	1
Coronatella anodonta	2	3	1	0	0	1
Celosinotum macronyx	0	1	2	1	1	2
Ceriodaphnia cornuta	0	1	2	1	1	0
Ephemeroporus barroisi	0	2	11	3	2	2
Chydorus sphaericus	4	5	1	1	2	1
Chydorus ventricosus	2	1	2	1	1	1
Chydorus ovalis	1	1	2	2	2	0
Pleuroxus denticulatus	0	4	4	1	1	0
Diaphanosoma dubium	1	0	3	4	1	0
Anthalona sp.	1	2	4	2	0	1
Ceriodaphnia sp.	1	6	2	1	3	0
Daphnia lumholtzi	5	8	4	3	1	1
Simocephalus sp.	1	1	3	1	0	0
Simocephalus mixtus	1	1	3	3	2	1
Moina sp.	2	2	2	1	1	1
Moina micrura	1	1	2	1	1	0
Moinodaphnia sp.	1	4	1	2	1	1
Macrothrix sp.	1	2	3	1	1	1
Macrothrix spinosa	0	2	3	1	1	1
Macrothrix triserialis	0	0	1	1	2	0



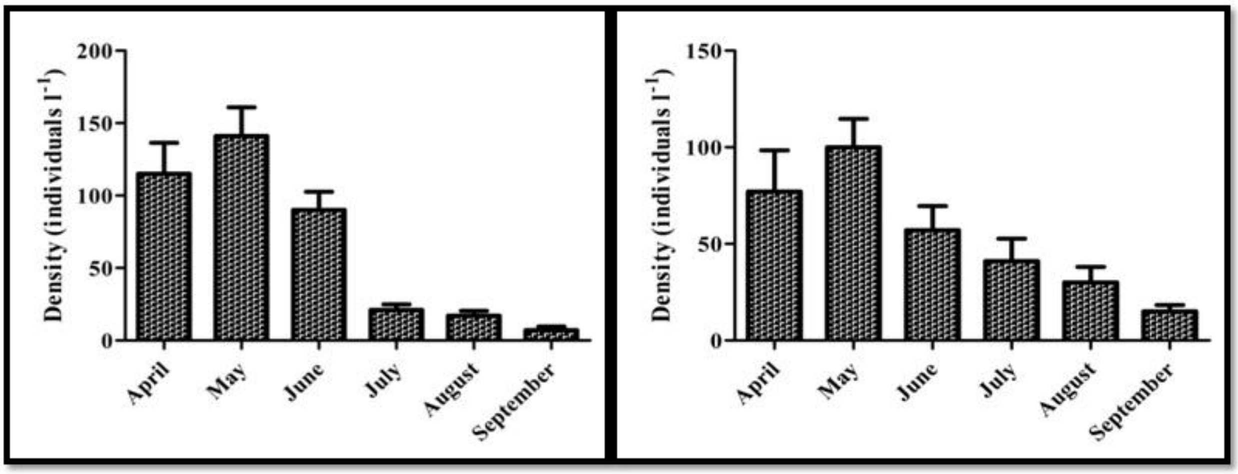
(a) 2013 (b) 2014

Figure 5. Monthly variations in density of Cladocera (individuals l^{-1}) present in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14



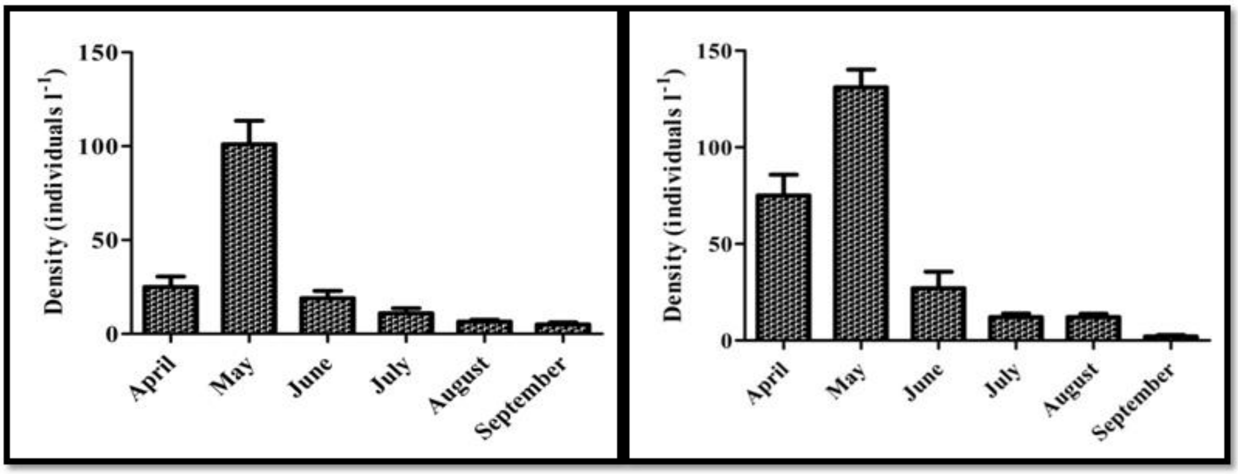
(a) 2013 (b) 2014

Figure 6. Monthly variations in density of Copepoda (individuals l^{-1}) in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14



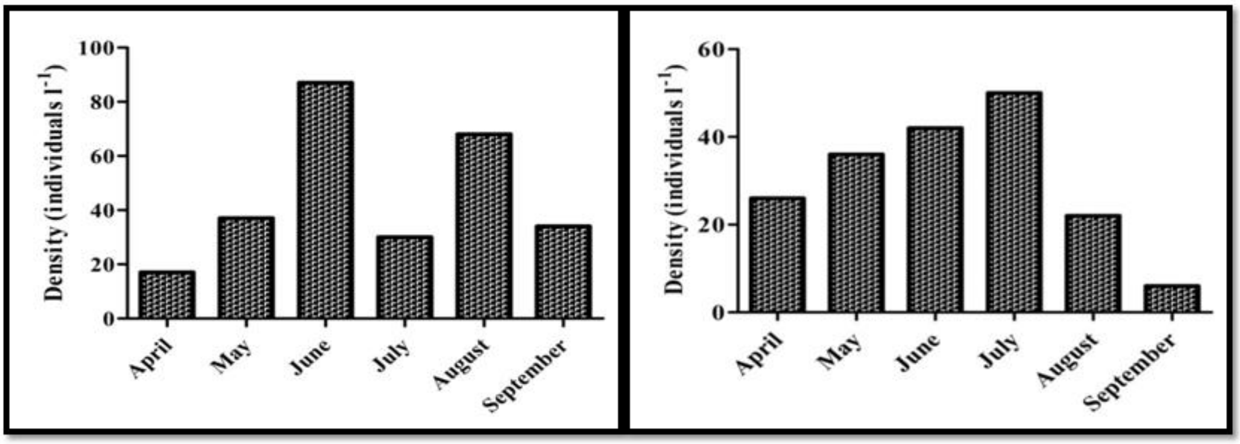
(a) 2013 (b) 2013

Figure 7. Monthly variations in density of Protozoa (individuals l^{-1}) in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14



(a) 2013 (b) 2014

Figure 8. Monthly variations in density of Rotifera (individuals l^{-1}) in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14



(a) 2013 (b) 2014

Figure 9. Monthly variations in density of Ostracoda (individuals l^{-1}) in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

Table 9. Month wise taxa density (individuals l^{-1}) of Copepoda in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

Species	April	May	June	July	August	September
Cyclops sp.	40	16	27	36	56	20
Diaptomus sp.	15	15	26	23	35	11
Nauplli of *Cyclops*	13	4	5	3	3	2
Nauplli of *Diaptomus*	1	0	0	1	4	0
Neodiaptomus sp.	1	3	0	0	3	0
Limnocalanus sp.	3	1	1	1	5	2
Mesocyclop sp.	2	2	5	6	6	1
Bryocamptus sp.	0	0	4	2	2	1
Limnocalanus macrurus	0	0	1	3	3	2
Heloidiaptomus sp.	0	0	0	3	3	0
Mesocyclop edex	0	0	1	0	8	0

Table 10. Month wise taxa density (individuals l^{-1}) of Protozoa in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

Species	April	May	June	July	August	September
Arcella sp.	58	50	32	19	13	7
Epistylis sp.	21	19	5	3	3	1
Diflugia sp.	17	8	10	3	1	1
Centropyxis sp.	5	23	22	4	6	1
Opheroglena sp.	7	9	6	1	1	3

Table 11. Month wise taxa density (individuals l^{-1}) of Rotifera in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

Species	April	May	June	July	August	September
Keratella sp.	18	16	2	1	2	1
Brachionus sp.	18	42	16	3	4	2
Lecane sp.	3	20	2	5	1	1
Eosphera sp.	5	16	1	1	1	0
Asplanchna sp.	6	22	2	2	1	0
Asplanchna brightwelli	0	1	1	0	0	0
Keratella vulga	`1	2	0	0	0	1
Brachionus forficula	1	1	1	0	0	0
Plationus patulus	0	0	0	0	1	0
Platias quadricornis	2	3	1	1	0	0
Eosphera sp.	1	1	1	0	0	0
Testudinella patina	2	2	0	0	1	1
Testudinella striata	1	3	1	1	0	0
Dicranophorus forcipotus	1	1	1	2	0	0
Lecane ungulate	2	1	1	0	0	0
Lecane leontina	5	4	3	0	1	1
Lecane bulla	0	0	0	1	0	0

Table 12 Month wise taxon density (individuals l^{-1}) of Ostracoda in high altitude rice wetlands of Apatani Plateau during the rice growing season of 2013-14

Species	April	May	June	July	August	September
Cypris sp.	13	12	21	25	11	3

The maximum and minimum population density of Ostracoda (**Figure 9**) was found in June (87 individuals l^{-1}) and April, 2013 (17 individuals l^{-1}) respectively. But in 2014 (**Figure 9**), peak value was found in July (50 individuals l^{-1}) and dip values were in September (6 individuals l^{-1}). Cladocerans might have suppressed the population density of Rotifers (Gilbert, 1988; Nogrady *et al*. 1993; Shurin *et al*. 2006; Hulyal and Kaliwal, 2008).

The community diversity, dominance, evenness and richness of different communities of rice field's zooplankton presented in **Table 3-Table 7.** Cladocera showed maximum Shannon-Wiener diversity value (**Table 3**) in June (2.869) and the minimum was in September (1.298). Copepod (**Table 4**) varied from 1.301 (April) to 1.696 (July) whereas Protozoa (1.388) and Rotifera (1.533) showed peak diversity in May while Protozoa (1.132) and Rotifera (1.024) showed least value in July (**Table 5** and **6**). The evenness indices of Cladocera (0.385) and Rotifera (0.942) were high in June (**Table 3** and **5**) whereas Cladocera (0.109) and Protozoa (0.620) showed low evenness in July (**Table 3** and **6**). The peak evenness of Copepoda was in July (0.670) and the least value for evenness of Copepoda (0.490) and Rotifera (0.557) were noticed in June and September respectively (**Table 4** and **5**). Protozoa had the high evenness (0.801) in May (**Table 6**). The evenness value (1.000) of Ostracoda (**Table 7**) indicates equal distribution of the taxa in all the months. The Cladoceran (**Table 3**) were also having the high richness in August (6.707) and the low in July (5.025). The richness of Copepoda (**Table 4**) in the wet rice fields of Apatani Plateau ranged from 1.346 (May)-2.061 (August). Protozoa (**Table 6**) also showed the high richness in May (1.559) and low in September (0.842). Similarly, the richness indices of Rotifera (**Table 5**) were found minimum in August (0.841) and maximum in May (1.82) respectively. Computed species richness and evenness indices assured the congenial habitat for the existing zooplankton communities in the rice fields of the study area. On the other hand, the occasional low evenness of some species might have been caused due to frequent deweeding activities and other related agronomic disturbances within the flooded rice field. The mean density of all the zooplankton taxa belonging to different communities were also calculated (**Table 8- Table 12)** according to different months during the whole study period. Simpson *et al*. (1994) also reported similar observation that high population of Copepods and low population of Ostracods towards the end of the crop cycle. So, predatory action of Copepods might have decreased the abundances of Rotifers in the end phase of rice (Badsi *et al*. 2010). The frequent availability of crustaceans nauplii during the whole sampling periods indicated their active reproductive phases (Sharma, 2011; Bhat *et al*. 2014) in the flooded fields.

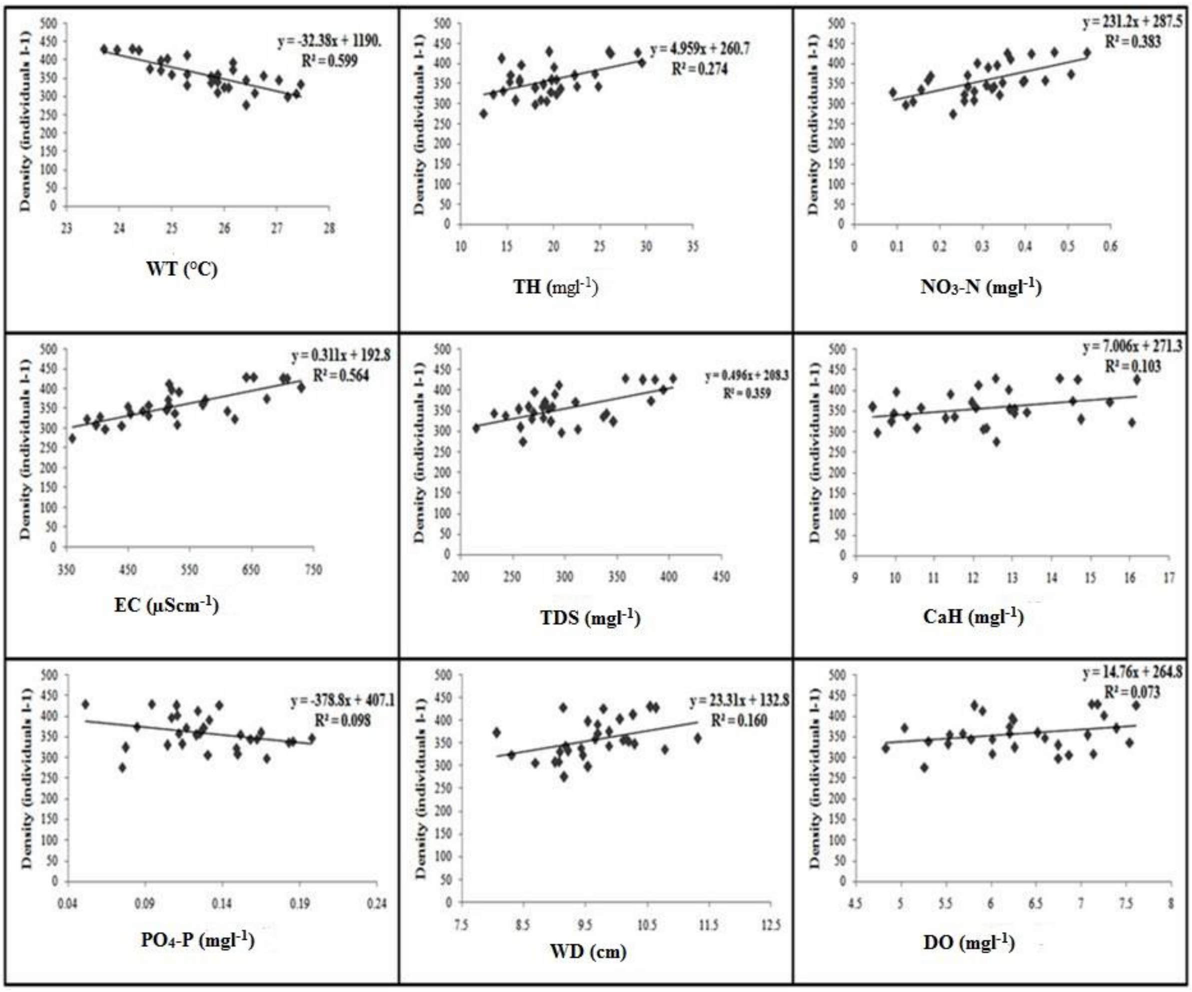


Figure 10. Linear regression between physico-chemical properties of rice field water and total density of zooplankton in the study area

Linear regression analyses between the different physico-chemical properties of rice field water and total density of zooplankton (**Figure 10**) showed positive relation with TH, NO_3-N, EC, TDS, CaH, WD and DO and negative relation with WT and PO_4-P. Zooplankton showed a negative relation with WT, NO_3-N and FCO_2 in the present study which also corroborates with the observation of Sharma (2011); Sharma and Sharma (2011) and Ahmad *et al*. (2012). A positive relation of total density of zooplankton with TH, WD, TDS and EC have been recorded during the study period, which was also drawn by Ramakrishnan and Sarkar (1982); Bhati and Rana (1987); Ahmad and Krishnamurthy, (1990); Kumar and Datta (1994); Jhingran (1997); Hujare, (2005); Ratushnyak *et al*. (2006); Datta (2011); Ahmad *et al*. (2012). The multiple regression analysis determined the overall interaction of different zooplankton communities, viz., Cladocera, Copepoda, Protozoa, Rotifera and Ostracoda with different physico-chemical properties of the rice field water (**Table 13**) during the study seasons. The multiple regression analyses revealed that density of Cladocera was related with increase in WD, PO_4-P, TA, CaH and Cl^{-1} which also corroborated the findings of Tidame and Shinde (2009), Ahangar *et al*. (2012). Copepod density was related with increase in EC, WD and $Cl^{-1}$and decrease in DO, TH and PO_4-P. Rotifera density was related with increase in FCO_2, DO, TDS and TH. Protozoan density was related with decrease in Cl^{-1} and increase in DO, TDS, NO_3-N and FCO_2. Rotifera density showed a positive correlation with TH, TDS, FCO_2 and DO which was agreeable to the view of Hulyal and Kaliwal (2008); Tidame and Shinde (2012); Chandrasekar, (2009); Sharma, (2009); Bera *et al*. (2014); Devi and Kumar (2014); Hussain *et al*. (2016). A negative relation was observed between protozoan density and Cl^{-1} whereas density of Copepoda depicted positive relation with Cl^{-1} which corroborates the findings of Bera *et al*. (2014). The density of Ostracoda was related with increase in EC, PO_4-P, TDS and WD..

CONCLUSION

From the study, it is clearly unfolded that the high altitude rice field environment of Eastern Himalayan region harbors abundant population of zooplankton showing a typical population attributes particularly during the rice growing season. Field water depth being the limiting factor, the population structure of such zooplankton persisted under rice canopy till complete recession of the water with seasonality. All the agro input in this ecosystem with organic manures, decomposed rice stubbles and macrophytes along with biotic and abiotic factors regulate various characteristics of population properties of the zooplankton community in rice fish system. For growth and development, the stocked fishes in the rice field may have utilized and assimilated available aquatic biomass along with zooplankton through trophic interactions. Therefore, high altitude flooded environment of Eastern Himalaya enriched with such natural fish feeds hold sufficient scope to raise fish as concurrent crop of rice in the same field.

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REFERENCES

APHA (2012) Standard method for the examination of water and waste water. APHA, AWWA, WPEC, pp:1360 pp.

Ahangar IA, Saksena DN, Mir MF and Ahangar, MA (2012) Crustacean Community in Anchar Lake Kashmir. *Bulletin of Environment Pharmacology and Life Sciences* 1(7): 18–21.

Ahmad MS and Krishnamurthy R (1990) Preliminary observation of the growth and food of muriel, Channa marulius block of the river Kali in North India. *Journal of Freshwater Biology* 2: 47-50.

Ahmad U, Parveen S, Mola HRA, Habeeba AK and Ganai AH (2012) Zooplankton population in relation to physico-chemical parameters of Dal Diggi pond in Aligarh, India. *Journal of Environmental Biology* 33(6): 1015-1019.

Ahmad U, Parveen S, Khan, AA, Kabir HA, Mola HRA and Ganai HA (2011) Zooplankton population in relation to physico-chemical factors of a sewage fed pond of Aligarh (U.P.) India. *Biology and Medicine* 3(2): 336-341.

Ali AB (1988) Rice fish farming development in Malaysia: Past, Present, and future. Paper presented at the International rice fish farming system Workshop, Ubon, Thailand.

Ali AB (1990) Seasonal dynamics of micro crustacean and Rotifer communities in Malaysian rice fields used for rice fish farming. *Hydrobiologia* 206(2): 139-148.

Badsi H, Ali HO, Loudiki M, Hafa E, Chakli R and Aamiri A (2010) Ecological factors affecting the distribution of zooplankton community in the Massa Lagoon (Southern Morocco). *African Journal of Environmental Science and Technology* 4 (11): 751-762.

Bahaar SWN and Bhat GA 2013 Ecology of Zooplankton in the Rice Field Agro-ecosystems of Kashmir Valley (J and K) India. *International Journal of Water Knowledge* 1(1): 1-5.

Baltanas A (1992) A contribution to the knowledge of the cypridid ostracode fauna (Crustacea, Ostracoda, Cyprididae) on the Iberian Peninsula, and a comparison with adjacent areas. *Archivfür Hydrobiologie Supplement* 90 (3): 419-452.

Bambaradeniya CNB, Edirisinghe JP, Silva DND, Gunatilleke CVS, Ranawana KB and Wijekoon S (2004) Biodiversity associated with an irrigated rice agro-ecosystem in Sri Lanka. *Biodiversity and Conservation* 13(9): 1715-1753.

Bambaradeniya NB and Amarasinghe FP (2003) Biodiversity Associated with the Rice Field Agro-ecosystem in Asian Countries: A Brief Review, Sri Lanka: Working paper 63.International Water Management Institute.

Battish SK (1992) Freshwater Zooplankton of India, Oxford and IBH Publishing Co, pp: 232.

Beisner BE and Peres-Neto PR (2009) Seasonal trophic dynamics affect zooplankton community variability. *Freshwater Biology* 54(11): 2351–2363.

Bera A, Dutta TK, Patra BC and Sar UK (2014) Correlation Study on Zooplankton availability and Physico-Chemical Parameters of Kangsabati Reservoir, West Bengal, India. *International Research Journal of Environment Sciences* 3(12): 28-32.

Bhat NA, Wanganeo A and Raina R (2014) The composition of net Zooplankton species in a tropical water body (Bhoj wetland) of Bhupal, India. *International Journal of Biodiversity and Conservation* 6 (5): 373-381.

Bhati DPS and Rana KS (1987) Zooplankton in relation to abiotic components in the fort moat of Bharatpur. *Proceedings of the National Academy of Sciences, India* 57(3): 237-242.

Buzas IA and Gibson TG (1969) Species diversity: Benthonic Forminifera in western North Atlantic. *Science* 163(3862):72-75.

Carpenter SR, Kitchell JF and Hodgson JR. 1985. Cascading trophic interactions and lake productivity. *Bio Science* 35(10): 634-639.

Chandrasekar S (2009) An Ecological studies on Sarrornagar lake Hyderabad with special reference to zooplankton communities. *Ph.D. Thesis*, Osmania University, Hyderabad.

Chittapun S, Pholpunthin P and Sanoamuang L (2009) Diversity and composition of zooplankton in rice fields during a crop cycle at PathumThani province, Thailand. *Songklanakarin Journal of Science and Technology* 31(3): 261-267.

Das DN, Saikia SK and Das AK (2007) Periphyton in rice–fish culture system: A case study from Arunachal Pradesh, India. *Renewable Agriculture and Food System* 22: 316–319.

Datta, T (2011) Zooplankton diversity and physico-chemical conditions of two wetlands of Jalpaiguri district, India. International *Journal of Applied Biology and Pharmaceutical Technology* 2(3): 576-583.

Devi A and Kumar S (2014) Diversity of Rotifer (Rotifera) With Special Reference to Physico-Chemical Parameters from a Tropical Reservoir, Kullurchandai, Virudhunagar District, India *International Research Journal of Environment Sciences* 3(5): 80-85.

Dhembare AJ (2011) Statistical approaches for computing diversity and density of zooplankton with water factors in Mula dam, Rahuri, MS, India. *European Journal of Experimental Biology* 1(2): 68-76.

Edmonson WT (1992) Freshwater Biology. International books and periodicals supply service, pp: 1248.

Fernando CH (1995) Rice fields are aquatic, semi aquatic, terrestrial and agricultural: A complex and questionable limnology. In Tropical Limnology, Present status and challenges. Eds. Timotius KH and Goltenboth F. Indonesia: Fac. Sci. Nath. Satya Waeana Christan University, Salatiga, pp: 121-148.

Fernando CH (1996) Perspectives in Asian fisheries. In Ecology of rice fields and its bearing on fisheries and fish culture. Eds. de Silva, SS. Manila: Asian fisheries society, pp: 217-237.

Figuerola J and Green AJ (2002) Dispersal of aquatic organisms by water birds: a review of past research and priorities for future studies. *Freshwater Biology* 4**:** 483-494.

Figuerola J, Green AJ and Santamaría L (2003) Passive internal transport of aquatic organisms by waterfowl in Doñana, south-west Spain. *Global ecology and biogeography* 12(5): 427-436.

Frei M, Razzak MA, Hossain MM, Oehme M, Dewan S and Becker K (2007) Performance of common carp, *Cyprinus carpio* L. and Nile tilapia, *Oreochromisniloticus* (L.) in integrated rice–fish culture in Bangladesh. *Aquaculture* 262(2):250–259.

Gilbert JJ (1988) Susceptibilities of ten rotifer species to interference from *Daphnia pulex*. *Ecology* 69(6): 1826-1838.

Gołdyn R and Kowalczewska-Madura K (2008) Interactions between phytoplankton and zooplankton in the hypertrophic Swarze˛dzkie Lake in western Poland. *Journal of plankton research* 30(1): 33–42.

Guangjun LV (2013) Structure and diversity of zooplankton communities in four reservoirs with varying nutrient compositions in the Yangtze River Basin, China. *International Conference on Remote Sensing. Environment and Transportation Engineering*. China: Published by Atlantis Press.

Heckman CW (1979) Rice Field Ecology in North East Thailand. Dr. W. Junk Publishers, pp: 228.

Hujare MS (2005) Hydrobiologial studies on some water reservoirs of Hatkanangale Tahsil (Maharashtra). *Thesis*, Shivaji University, Kolhapur.

Hulyal SB and Kaliwal BB (2008) Water quality assessment of Almatti reservoir of Bijapur (Karnataka state, India) with special reference to zooplankton. *Environmental Monitoring Assessment* 139(1-3): 299-306.

Hussain A, Sulehria AQ, Ejaz M and Maqbool A (2016) Population Dynamics of Rotifers in the Floodplain of River Ravi. *Pakistan Journal of Zoology* 48(1): 215-225.

Jhingran VG (1997) Fish and Fisheries of India. Hindustan Publishing Corpoation, pp: 728.

Jose R and Sanalkumar MG (2012) Seasonal Variations in the Zooplankton Diversity of River Achencovil. *International Journal of Scientific and Research Publications* 2(11): 2250-3153.

Kacha D (2016) The Traditional Way of Paddy-Cum-Fish Culture in Ziro Valley, Arunachal Pradesh (India). *International journal of innovative research and development* 5(5): 18-193

Kotov AA, Jeong HJ and Lee W (2012) Cladocera (Crustacea: Branchiopoda) of the south-east of the Korean Peninsula, with twenty new records for Korea. *Zootaxa* 3368: 50-90.

Kotov AA, van Damme K, Bekker EI, Siboualipha S, Silva-Briano M, Ortiz AA, De La Rosa R and Sanoamuang L (2013) Cladocera (Crustacea: Branchiopoda) of Vientiane province and municipality, Laos. *Journal of Limnology* 72(s2): 81-108.

Kumar A, Tripathi S and Ghose P (2004) Status of Freshwater in 21 century: A Review. In Water Pollution: Assessment and Management, Eds., Kumar A. and G. Tripathi. Delhi: Daya Publishers. pp: 520.

Kumar S and Datta, SPS (1994) Population Dynamics of Cladocera in a subtropical pond, Jamnu. *Indian Journal of Environmental Health* 36(1): 19-23.

Kurasawa H (1957) The weekly succession in the standing crop of plankton and zoobenthos in a paddy field. Part 2. *Miscellaneous reports of the Research Institute for Natural Resources Tokyo* 45: 74-89.

Lackey JB (1938) The manipulation and counting of river plankton and changes in the some organisms due to formalin preservation. *Public health reports* 53: 2080-2098.

Lemly AD and Dimmick JF (1982) Structure and dynamics of Zooplankton communities in the littoral zone of some North Carolina Lakes. *Hydrobiologia* 88(3): 299-307.

Leoni B, Cotta-Ramusino M and Margaritora FG (1999) Seasonal succession of Cladocerans in a rice field in Italy. *Hydrobiologia* 391: 241-247.

Li K (1988) Rice–fish culture in China: a review. *Aquaculture* 71(3): 173–186.

Lim RP, Abdullah MF and Fernando CH (1984) Ecological studies of Cladocera in the rice fields of Tanjung, Malaysia subjected to pesticide treatment. *Hydrobiologia* 113: 99-103.

Lin QQ, Hu R and Duan SS (2003) Reservoir trophic states and the response of plankton in Guangdong Province. *Acta Ecologica Sinica* 23 (6):1101-1108.

Lu J andLi X (2006) Review of rice–fish-farming systems in China-One of the globally important indigenous agricultural heritage systems (GIAHS). *Aquaculture* 260(1-4): 106–113.

Majagi S and Vijaykumar K (2009) Ecology and abundance of zooplankton in Karanja reservoir. *Environmental Monitoring Assessment* 152(1-4): 451–458.

Margalef R (1968) Perspective in Ecological Theory. University of Chicago Press, pp: 111.

Meijen VA (1940) Fish culture in rice fields. Food Industry Publishers, pp: 96.

Michael RG and Sharma BK (1984) Indian Cladocera (Crustacea: Branchiopoda: Cladocera). *Fauna of India and adjacent countries series*, ZSI Calcutta, pp: 262.

Neale JW (1977) Ostracods from rice fields of Sri Lanka (Ceylon). In The 6th International Ostracod Symposium Saalfedeen Austria. Eds. Loffler H and Danielopol DC. The Hague: Dr. W. Junk Publishers. pp: 271-283.

Needham JG, Needham PR (1972) A Guide to the Study of Freshwater Biology. Holden-Day Inc, pp: 87.

Nogrady T, Wallace RL and Snell TW (1993) Rotifera. In Biology, ecology and systematics. Guides to the identification of the micro-invertebrates of the continental waters of the world, Ed. Dumont HJ. The Hague, Netherlands: SPB Academic Publishers, pp: 142.

Ramakrishna M and Sarkar SK (1982) Plankton productivity in relation to certain hydro biological factors in Konar reservoir (Bihar). *Journal of the inland fisheries society of India* 14(1): 58-68.

Ratushnyak AA, Borisovich MG, Vallev VS, Ivanov DV, Andreeva MG and Trushin MV (2006) The hydrochemical and hydrobiological analysis of the condition of the kuibyshev reservoir littorals (Republic of Tatarstan, Russia). *Ekoloji* 15: 22-28.

Rodrigues LHR, Canterle EB, Becker V, Gazulha V, Hamester A and Marques DM (2011) Dynamics of plankton and fish in a subtropical temporary wetland: Rice fields. *Scientific Research and Essays* 6(10): 2069-2077.

Rossi V, Benassi G, Veneri M, Bellavere C, Menozzi P, Moroni A and Mckenzie KG (2003) Ostracoda of the Italian rice fields thirty years on: new synthesis and hypothesis. *Journal of Limnology* 62(1): 1-8.

Saikia R, Ganguly A, Das T and Das DN (2016) Suspended algal communities in high altitude rice wetlands of Apatani Plateau in Eastern Himalaya. *Journal of Biodiversity and Environmental Science* 8(3): 1-11.

Saikia R, Das T and Das DN (2015) Physico-chemical qualities of water in high altitude rice fish farming system of Ziro valley, Arunachal Pradesh, India. *Journal of Environmental Biology* 36: 1153-1159.

Saikia SK and Das DN (2004) 'Aji gnui assonii'–a practice of organic hill farming among the Apatani tribe of Eastern Himalaya. *International Journal of Sustainable Development and World Ecology* 11(2): 211-217.

Saikia SK and Das DN (2009) Feeding ecology of common carp (*Cyprinus carpio* L.) in a rice–fish culture system of the Apatani Plateau (Arunachal Pradesh, India). *Aquaculture Ecology* 43(2): 559–568.

Saikia SK and Das DN (2010) Ecology of terrace wet rice-fish environment and role of periphyton. *Wetland Ecology* 4:102-111.

Santhanam P and Perumal P (2003) Diversity of zooplankton in Parangipettai coastal waters, Southeast coast of India. *Journal of the Marine Biological Association of the United Kingdom* 45(2): 144-151.

Shah AS, Sahid I, Mansor M and Russ O (2008) A note on zooplankton distributions at two different types of water management systems in the Muda rice agro-ecosystem. *Journal of Bioscience* 19(1): 81–90.

Shannon CE and Wiener WJ (1949) The mathematical theory of communication. University of Illinois, pp: 55.

Sharma BK (2009) Diversity of rotifers (Rotifera: Eurotatoria) of Loktak lake, Manipur, North-eastern India. *Tropical Ecology* 50(2): 277–285

Sharma BK (2011) Zooplankton communities of Deepor Beel (a Ramsar site) Assam (N. E. India): ecology, richness and abundance. *Tropical Ecology* 52(3): 293-302.

Sharma BK and Sharma S (2011) Zooplankton diversity of Loktak Lake, Manipur, India. *Journal of Threatened Taxa* 3(5): 1745-1755.

Sharma BK and Sharma S (2014) Faunal diversity of Cladocera (Crustacea: Branchiopoda) in wetlands of Majuli (the largest river island), Assam, North East India. *Opusc. Zool. Budapest* 45(1): 83–94.

Sharma R, Sharma KK, Langer S and Sharma V (2014) Spatio-temporal variations in the community structure of zooplankton fauna of Behlol Nullah (a tributary of river tawi), Jammu, (J and K), India. *Journal of international academic research for multidisciplinary* 2(4):847-862.

Sharma S and Sharma BK (2013) Faunal diversity of aquatic invertebrates of Deepor Beel (A Ramsar site), Assam, Northeast India. Wetland Ecosystem Series, *Zoological Survey of India*, Kolkata, pp: 227.

Sharma V, Verma R, Sharma MS and Gaur KS (2012) A report on the freshwater Cladocera (Crustacea: Branchiopoda) of south Rajasthan (India). *International Journal of Environmental Sciences* 3(1): 275-296.

Shiel RJ (1995) A guide to identification of rotifers, cladocerans and copepods from Australian inland waters. Co-operative research centre for fresh water ecology. Murray-Darling fresh water research centre, pp: 144.

Shil J, Ghosh AK and Rahaman SMB (2013) Abundance and diversity of zooplankton in semi intensive prawn (*Macrobrachium rosenbergii*) farm. *Springer Plus* 2:183

Shurin JB, Gruner DS and Hillebrand H (2006) All wet or dried up? Real differences between aquatic and terrestrial food webs. *Proceedings of the Royal Society of London B: Biological Sciences* 273(1582): 1-9.

Simpson C, Roger A and Grant E (1994) Effects of nitrogen fertilizer and pesticide management on floodwater ecology in a wetland rice field. *Biology and Fertility of Soils* 17(2):138- 146.

Simpson EH (1949) Measurement of diversity. *Nature* 163: 688.

Simpson IC and Roger PA (1995) The impact of pesticides on non targeted aquatic invertebrates in wetland rice fields: A review. In Impact of pesticides on farmer health and the rice environment, Eds., Pingali PL and Roger PA. Philippines: International rice research institute (IRRI*)*, pp: 249-270.

Singh AS, Devi MS, Sagar C, Mandal SC and Barman D (2011) Paddy cum fish culture in north-eastern states of India: A better scope in the exploitation of resources. *World Aquaculture* 58-60.

Smirnov NN (1971) The world Chydorid Fauna (in Russian).USSR Academy of Sciences, Zoological institute Nova series, Leningrad, pp: 539.

Smirnov NN (1996) "Cladocera: The Chydorinae and Sayciinae (Chydoridae) of the world". In Guide to identification of the micro invertebrates of the continental waters of the world, Eds., Dumont, HJ and Nogrady, T. Amsterdam, Netherland: SPB Academic publishing, pp: 197.

Striebel M, Singer G, Stibor H and Andersen T (2012) "Trophic over yielding": Phytoplankton diversity promotes zooplankton productivity. *Ecology* 93(12): 2719-2727.

Subhash Babu KK and Nayar CKG (2004) Cladocera of Periyar lake and adjacent sites, Thekkady, Kerala. *Journal of Bombay Natural History Society* 101(3): 403-414.

Taniguchi M, Toyota K and Kimura M (1997) Seasonal variation of micro crustaceans and microbial flora on their surfaces in the overlying water in a Japanese paddy field. *Soil Science and Plant Nutrition* 43(3): 651-664.

Tidame SK and Shinde SS (2012) Report on correlation of Zooplankton with physico-chemical factors from freshwater temple pond. *Journal of Experimental Sciences* 3(7):13-16.

Tonapi GT (1980) Freshwater animals in India. Oxford and IBH publishing Co. Ltd, pp: 341.

Tripathi RB, Singh I and Tiwari DD (2006) Qualitative and Quantitative study of zooplankton in Seetawar Lake of Shravasti, U.P, India. *Flora and Fauna* 12(1): 37-40.

Viroux L (2002) Seasonal and longitudinal aspects of macrocrustacean (Cladocera, Copepoda) dynamics in a lowland river. *Journal of Plankton Research* 24(4): 281-292.

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