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ASSOCIATIVE DEPENDENCE AMONG PLANKTON AND MACROPHYTES AS POLLUTION MARKERS AT TROPICAL LENTIC ENVIRON, GUJARAT, INDIA

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Abstract

The present research was undertaken at three sampling stations of Gomti catchment, Central Gujarat, India, to study dominance, interaction, and interdependence among biotic components (phytoplankton, zooplankton and aquatic macrophytes). The phytoplankton population was represented by 39 genera and 48 species belongs to family Bacillariophyceae (21 species), followed by Cyanophyceae (7), Cholorophyceae (18), and Euglenophyceae (2). In total, seven classes of zooplankton were represented by 36 genera and 39 species. Zooplankton dominance was reflected by class Ciliophora (16 species), followed by Zooflagellata, Rhizopoda and Rotifera (6 each), and Cladocera (3),and least by Copepoda and Ostracoda (1 species each). Of 16 species of aquatic macrophytes, 3 (18.75%) were abundant, 4 (25%) common, and 9 (56.25%) were rare. The indices (Palmer, Nygaard's, and Macrophyte index) were determined to delineate the interdependent relationship among studied biotic components. Strong association was observed between Chlorophyceae and Bacillariophyceae, Ostracods and Ciliophorans, and Cladocerans and Bacillariophyceans. The detailed results of indices and interdependent associations among biotic components are discussed. The information provided herewith makes an insight for better understanding of the environmental aspects to be addressed effectively for the better protection, conservation, and management of Gomti reservoir, Gujarat, India.

Keywords: Associative dependence, Phytoplankton, Zooplankton, Aquatic macrophytes, Pollution indices, Macrophyte index

Introduction

Increase in human population and tourism causes tremendous changes in the aquatic ecosystem; which may lead to qualitative and quantitative alterations in abiotic and biotic composition of water body (Christer and Lars, 2002). The littoral zone of an aquatic body may experience differing patterns in concentrations of nutrients and pollutants caused by anthropogenic loads (Dave, 1992; Drake and Heaney, 1987), Plankton as the primary producers act as chief constituent of ecological pyramids; few genera aid as biological indicators of water quality (Odum, 1971; Patrick, 1971). Plankton has been used recently as an indicator to observe and understand changes in the ecosystem because it seems to be strongly influenced by climatic features (Beaugrand *et al*., 2000; Li *et al*., 2000). The use of phytoplankton as biological indicators of pollution is represented by the occurrence of pollution tolerant algal species in the water body (Palmer, 1969). Moreover, Nygaard's trophic state index can be a handy tool in determining the status of pollution in lakes. Further, it involves only algal identification and the detailed analysis of physiochemical parameters can be omitted (Nygaard, 1976). The grazing pressure depends on the zooplankton composition, since the nature of food selection varies among herbivores taxa. Food selection by zooplankton is a significant mechanism to control the overall phytoplankton communities (Prins *et al*., 1995). The linkage and interdependence between phytoplankton and zooplankton is a dynamic process, mainly controlled by ecological and biological factors, which affect the growth and interaction among each community (Abdel *et al*., 2006). Aquatic macrophytes are one of the potent candidates as limnological indicators (Arnulf, 1999). Over several years, they react slowly and progressively to gradual changes in nutrient conditions reflecting the pollution status of a water body. In Scandinavian wetlands, aquatic macrophytes were found to reflectthe overall nutrient status of adjacent habitats, and were effectively used as biological indicators (Suominen, 1968; Uotila, 1971). The present research highlights the associative dependence among biotic components, preferably phytoplankton, zooplankton and aquatic macrophytes, which may be used as pollution markers in freshwater ecosystem.

Materials and methods

Study Area

Dakor Sacred Wetland (DSW), District Anand, Gujarat, India, is the hot-spot tropical pilgrimage wetland; located at 22.75^0 N latitude and 73.15^0 E longitude, with an average elevation of 49 meters (~160 feet) above mean sea level; temperature ranges from 12 ^{0}C (Winter) to highest 34 ^{0}C (Summer)with an average annual precipitation of 808.84 mm per year (World Weather Online, 2008). Human population of Dakor pilgrimage spot is around 23,784 with an average literacyrate of 76%. Reportedly, 70-80 lakhs of devotees visit this sanctified shrine annually (Census Commission of India, 2004). The study area is adjacent to one of the most worshiped temple of Deity Lord Krishna, and is one of the pilgrim sources of attraction for the people not only from India but also from every parts of the world (Figure 1).

Figure 1. Dakor Sacred Wetland (DSW), Central Gujarat, India

Sampling

Collections of planktons were carried out at three pre-decided fixed sampling stations at monthly intervals over one year (three consecutive seasons) from June 2012 to May 2013. Plankton samples were procured with the aid of plankton nets (size) from the possible euphotic zone of hydrological regime covering each geographical intersection of terrains and cross-sectional landscapes.The samples were preserved in 4% formalin on-site, and subsequently brought to the laboratory for identification. Phytoplankton were identified with an aid of a light compound binocular microscope (Almicro), using standard monographs and manuals (Desikachary, 1959; Edmondson, 1963; Philipose, 1976; Prescott, 1984; Anand, 1998), and zooplankton were identified using standard published literature (Tonapi, 1980; Pennak, 1994; Edmondson, 1998; Battish, 2000).Aquatic macrophytes were examined in context of their morphological and taxonomical characters, and identified upto species level using standard published literature (Cooke, 1908; Cottam and Curtis, 1956; Mishra, 1974, Hutchinson, 1975; Shah, 1978; Biswas and Calder, 1984).

Results and discussion

In total, 48 species of phytoplankton, represented by 39 genera and four families (Chlorophyceae, Cyanophyceae, Bacillariophyceae, Euglenophyceae)were observed, of which peak numbers were noted at D3 (62.5%, n= 30), followed by D2 (52.08%, n= 25),and least at D1 (39.5%, n= 19). In case of zooplankton, 39 species, 36 genera and seven groups were reported;

highest at D2 (61.53%, n= 24),followed by D3 (58.97%, n= 23) and least at D1 (46.15%, n=18). Besides, 16 species of aquatic macrophytes represented by 13 genera and 12 families were documented at DSW.

To delineate the tropic status of the studied tropical wetland, aquatic pollution indices such as Palmer Index (Palmer, 1969), Nygaard's Trophic State Index (Nygaard, 1976) and Macrophytes Index (Arnulf, 1999)were derived. Besides, biotic components (phytoplankton, zooplankton and aquatic macrophyte) were statistically correlated to demarcate the inter-relationship and interdependence among them to draw a conclusion on how these biotic components prevail and linked to extrapolate the overall trophic status, hygiene and vitality of aquatic ecosystem.

Palmer Index

Palmer (1969) made the first foremost attempt to recognize and categorize a list of genera and species of algae tolerance to organic pollution. In accordance, a score list of 60 genera and 80 species were tolerant to organic pollution. A pollution index factor was assigned to each genus and species by determining the relative number of total points scored by each algal species. According to Palmer (1969), scores of 20 or more indicates the high intensity of organic pollution in an aquatic body.

Following are the numerical values for pollution classification (Palmer, 1969),
0-10= Lack of organic pollution
10-15= Moderate pollution
15-20= Probable high organic pollution
20 or more = Confirms high organic pollution

The pollution tolerant genera and species belonging to four groups of algae (Chlorophyceae, Cyanophyceae, Bacillariophyceae and Euglenophyceae) from three permanent sampling stations of Dakor Sacred Wetland (DSW) were recorded (Soni and Thomas, 2013). According to Palmer algal rating, all study sites were having a pollution score list of more than 20, indicating high rate of organic pollution therein. Site 1 accounted with maximum (29) pollution score, compared to Site 2 (26) and Site 3(21) (Table 1). Of the reported algal indicator genera, *Ankistrodesmus sp., Oscillatoria sp., Nitzschia sp., Scendesmus sp.* and *Synedra sp.*, were dominantly observed at all study sites. Prominent chlorophycean genera *viz. Pandorina sp.*and *Volvox sp.* boomed the magnitude in eutrophic freshwater ponds (Hans, 1988). Species such as *Oscillatoria sp., Euglena sp., Scenedesmus sp., Chlamydomonas sp., Navicula sp., Chlorella sp., Nitzschia sp.* and *Ankistrodesmus sp.* are well-flourished into organically polluted water, substantiated by previous studies of Ratnasabapathy (1975), Gunale and Balakrishnan (1981), Jafari and Gunale (2006), and Sanap (2007). Patrick (1965) stated that *Euglena* and *Oscillatoria* are highly pollution tolerant genera, and therefore they are the most reliable indicators of eutrophication process. *Euglena*, the most tolerant algal taxon, was reported from Sites D1 and D2, and was found to be present in the most polluted aquatic body, enriched with excess nutrients, overloaded by an intense organic pollution, due to uncontrolled disposal of plastic commodities by pilgrims (Soni and Thomas, 2013a).

Table 1.Palmer Index Score (DSW)

Genus	Index	D1	D2	D3
Anacystis	1			
Ankistrodesmus	2	2	2	2
Chlamydomonas	4			
Chlorella	3	3	3	
Closterium	1		1	
Cyclotella	1			1
Euglena	5	5	5	
Gomphonema	1		1	1
Lepocincilis	1			
Melosira	1			
Micractinium	1			
Navicula	3	3		3
Nitzschia	3	3	3	3
Oscillatoria	5	5	5	5
Pandorina	1			
Phacus	2	2		
Phormidium	1			
Scendesmus	4	4	4	4
Stigeoclonium	2			
Synedra	2	2	2	2
Total		29	26	21

* D1, D2, D3: Sampling stations

Nygaard's Trophic State Index (1976)

After studying the pollution algal indicator genera at DSW using Palmer (1965), trophic state of was delineated using Nygaard's Trophic State Index (1976). The Trophic State Index (TSI) was determined using following:

Myxophycean Index = Myxophyceae/Desmidaceae

Chlorophycean Index = Chlorococcales/ Desmidaceae

Euglenophycean Index = Euglenophyceae/ Myxophyceae +„ Chlorophyceae„

Compound Co-efficient = (Myxophyceae + Bacillariophyceae + Chlorophyceae + Euglenophyceae)/Desmidaceae

The rating of the Trophic State Index (Nygaard, 1976) is as follows (Table 2):

Table 2. Rating of Trophic State Index (Nygaard, 1976)

TSI	Oligotrophic	Eutrophic
Myxophycean	0.0 – 0.4	0.1 – 3.0
Chlorophycean	0.07	0.2 – 9.0
Euglenophycean	0.0 – 0.2	0.0 – 1.0
Compound Co-efficient	< 0.01	0.01 – 1.0

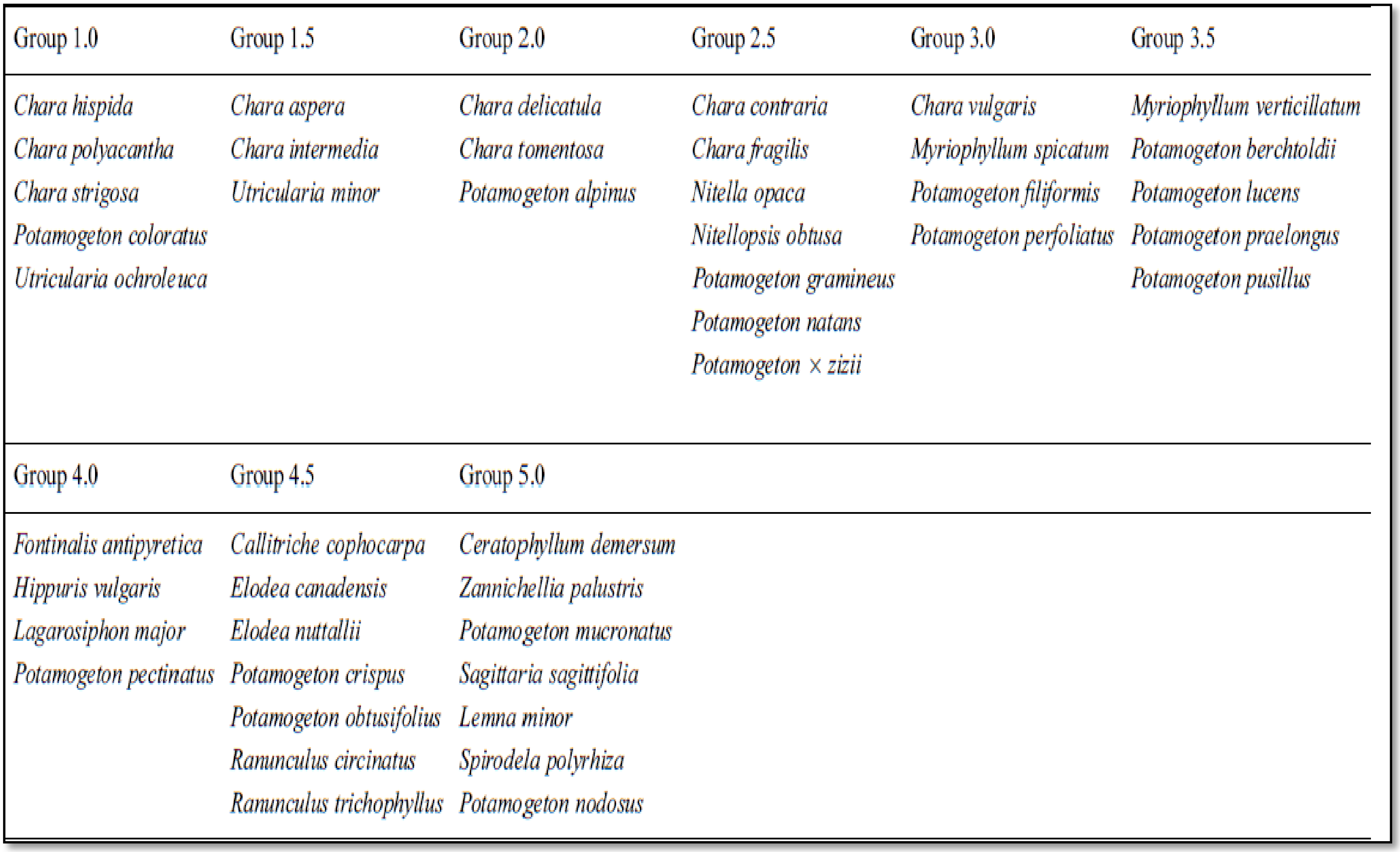
The derivatives of Nygaard's index for all the observed phytoplankton reflected that except Myxophycean Index, all other (Chlorphycean, Cyanophycean and Bacillairiophycean) indices exceeded the maximum tolerance limit, indicating the DSW as a highly eutrophic aquatic body (Table 3), as reported by Santlal and Mehta (2014), Bhavnagar, Saurashtra Peninsula, India.

Table 3.Nygaard's Index for DSW

Nygaards Index	D1	D2	D3
Myxophycean Index	0	0	0
Chlorophycean Index	7	9	13
Euglenophycean Index	9	10	13
Compound Co-efficient	16	20	26

Macrophyte Index

Aquatic macrophytes can act as remarkable indicators of water pollution along the littoral zone of water body. Based on this, Macrophyte Index was designed using 45 different submerged indicator species; six different classes of Macrophyte Index representing various degrees of nutrient status and pollution loads were derived (Arnulf, 1999). Species allocated to group 1.0 indicates 'oligotrophic status (require minimal concentration of nutrients for survival)', group 5.0 - eutrophic condition (nutrient-rich), and remnant intermediate groups represents the 'transition between these two extremes (Figure 2).



Group 1.0	Group 1.5	Group 2.0	Group 2.5	Group 3.0	Group 3.5
Chara hispida	*Chara aspera*	*Chara delicatula*	*Chara contraria*	*Chara vulgaris*	*Myriophyllum verticillatum*
Chara polyacantha	*Chara intermedia*	*Chara tomentosa*	*Chara fragilis*	*Myriophyllum spicatum*	*Potamogeton berchtoldii*
Chara strigosa	*Utricularia minor*	*Potamogeton alpinus*	*Nitella opaca*	*Potamogeton filiformis*	*Potamogeton lucens*
Potamogeton coloratus			*Nitellopsis obtusa*	*Potamogeton perfoliatus*	*Potamogeton praelongus*
Utricularia ochroleuca			*Potamogeton gramineus*		*Potamogeton pusillus*
			Potamogeton natans		
			Potamogeton × zizii		

Group 4.0	Group 4.5	Group 5.0
Fontinalis antipyretica	*Callitriche cophocarpa*	*Ceratophyllum demersum*
Hippuris vulgaris	*Elodea canadensis*	*Zannichellia palustris*
Lagarosiphon major	*Elodea nuttallii*	*Potamogeton mucronatus*
Potamogeton pectinatus	*Potamogeton crispus*	*Sagittaria sagittifolia*
	Potamogeton obtusifolius	*Lemna minor*
	Ranunculus circinatus	*Spirodela polyrhiza*
	Ranunculus trichophyllus	*Potamogeton nodosus*

Figure 2.Group allocations of macrophytes (Arnulf, 1999)

Of 16 species of aquatic macrophytes, *Lemna minor*was observed in water of D3, *Potamogeton nodosus* in D1 (group 5.0 – eutrophic), and *Chara vulgaris* (group 3.0) at all study sites (Table 4). The distribution and occurrence of the reported aquatic plants symbolize the ‘meso-eutrophic status’ of the study area. Similar index for determining the trophic state in context of macrophyte status was applied by Krausch (1964) at North-East Germany, preceded by Trapp (1995) at North Germany.

Table 4. Profile of aquatic macrophytes at DSW

Aquatic Macrophyte	Family	D1	D2	D3	Occurrence*
Chara vulgaris L.	Characeae	+	+	+	A
Ipomoea aquatic Forsk.	Convolvulaceae	-	+	+	C
Ipomoea carnea Jacq.	Convolvulaceae	-	+	+	C
Hydrilla verticillata (L.f.) Royle	Hydrocharitaceae	-	-	+	R
Vallisneria spiralis L.	Hydrocharitaceae	-	+	-	R
Lemna minor L.	Lemnaceae	+	+	+	A
Marsilea quadrifolia L.	Marsileaceae	-	-	+	R
Nelumbo nucifera Gaertn.	Nelumbonaceae	-	+	+	C
Nymphaea lotus L.	Nymphaeaceae	-	-	+	C
Phragmites australis (Cav.) Trin. ex Steud.	Poaceae	-	-	+	R
Polygonum glabrum Willd.	Polygonaceae	-	+	-	R
Polygonum glaucum Nutt.	Polygonaceae	-	-	+	R
Eichhornia crassipes (Mart.) Solns.	Pontederiaceae	+	+	+	A
Potamogeton crispus L.	Potamogetonaceae	+	-	-	R
*Potamogeton nodosus*Poir.	Potamogetonaceae	+	-	-	R
Typha angustifolia L.	Typhaceae	-	-	+	R

* A: Abundant, C: Common, R: Rare

Correlation Matrix

Intra-dependence between Plankton

Phytoplankton bloom is strongly influence by nutrient enrichment, which decreases drastically under the adverse effect of intensive grazing (Havens, 1991; Mellina *et al*., 1995). The grazing pressure depends on the zooplankton composition, since the nature of food selection varies among herbivores taxa. Food selection by zooplankton is a significant mechanism to control the overall phytoplankton communities (Prins *et al*., 1995). Zooplankton has an effective role in regulating the rate of accumulation of phytoplankton or even prevents it. However, some zooplankton is important stabilizers of planktonic population (Aziz *et al*., 2006). This explains the significant correlation between dominant zooplankton groups (Zooflagellata, Rhizopoda, Ciliophora, Rotifera, Copepoda, Cladocera and Ostracoda) and predominant phytoplankton groups (Chlorophyceae, Cyanophyceae, Bacillariophyceaeand Euglenophyceae) at DSW.

Of the four reported families of phytoplankton, three families (Cholorophyceae, Cyanophyceae, Bacillariophyceae) were found to be correlated positively among one another. Of these, Chlorophyceaen members exhibited very strong correlation (r=0.980), followed by moderate correlation (r=0.500) between Cyanophyceae and Bacillariophyceae, and least (r=0.330) between Chlorophyceae and Cyanophyceae (Table 5) (Figure 3).

Table 5.Correlation matrix between phytoplankton at DSW

Phytoplankton	Chlorophyceae	Cyanophyceae	Bacillariophyceae	Euglenophyceaee
Chlorophyceae	1.000			
Cyanophyceae	0.330	1.000		
Bacillariophyceae	0.980	0.500	1.000	
Euglenophyceaee	-0.980	-0.500	-1.000	1.000

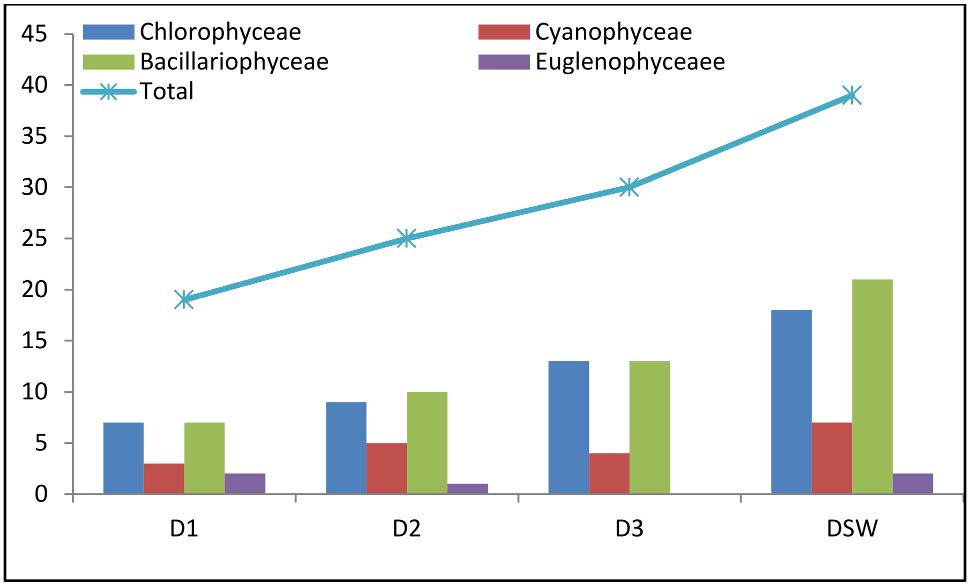


Figure 3. Phytoplankton profile at DSW

Amongst seven reported groups of zooplankton, three groups (Ciliophora, Ostracoda, Cladocera) were found to be correlated positively among one another. As the investigated wetland is phytoplankton dominant-type (Soni and Thomas, 2013b,c).Ciliophorans were found abundant and frequent due to higher concentration of chlorophyll and total organic carbon concentration (Tomasz, 2010). Of these, Ciliophora and Ostracoda members exhibited very strong correlation (r=0.920), followed by moderate correlation (r=0.870) between Cladocera and Ostracoda and least (r=0.600) between Ciliophora and Cladocera (Kerfoot and De Angelis, 1989) (Table 6) (Figure 4).

Table 6. Correlation matrix between zooplankton at DSW

Zooplankton	Zooflagellata	Rhizopoda	Ciliophora	Rotifera	Copepoda	Cladocera	Ostracoda
Zooflagellata	1.000						
Rhizopoda	0.000	1.000					
Ciliophora	-0.110	0.000	1.000				
Rotifera	-0.500	0.000	-0.800	1.000			
Copepoda	0.000	0.000	0.000	0.000	1.000		
Cladocera	-0.870	0.000	0.600	0.000	0.000	1.000	
Ostracoda	-0.500	0.000	0.920	-0.500	0.000	0.870	1.000

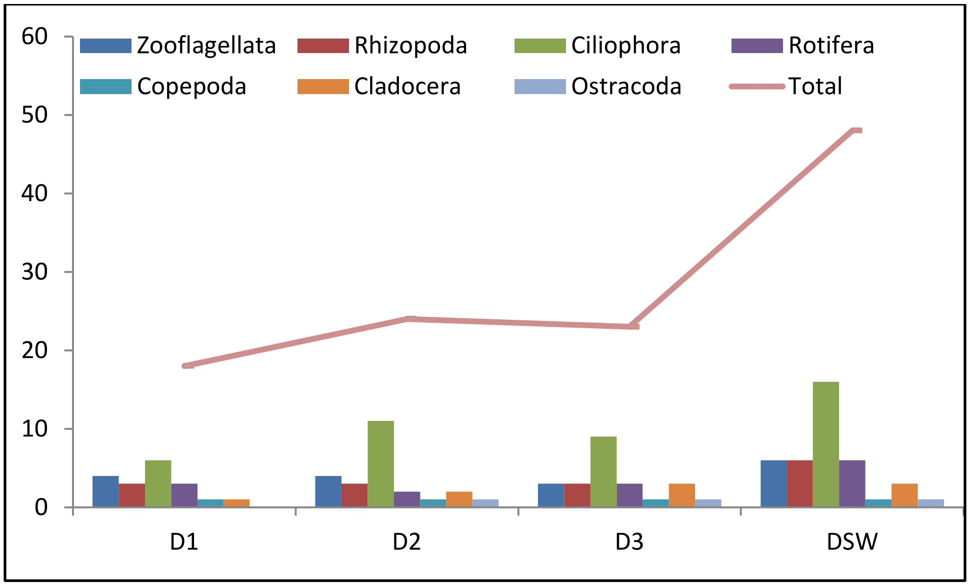


Figure 4. Zooplankton profile at DSW

Inter-dependence between Plankton

Most of the groups of zooplankton showed positive correlation with phytoplankton groups, the reason could be zooplankton aggregate frequently in depths of actively dividing phytoplankton (Alan, 1976). Moreover, temperature, food quantity and food quality in terms of algal morphology are the prime factors that influences the zooplankton growth and their abundance (Bottrell, 1975; Vijverberg, 1980; Gulati and De Mott, 1997; Lennon *et al.*, 2001; Acharya *et al.*, 2004; Hessen, 2006, 2008; Ravet and Brett, 2006; Martins *et al.*, 2009; Seinderdorf *et al.*, 2010). Cladoceran group showed maximum (r=1.000) correlation with diatoms, as Cladocerans mostly prefer diatoms as their substrate for attachment and survival in the adapted aquatic body (Evelyn and Roger, 1994).Wetlands harbor few numbers of Copepods, enhancing the phytoplankton abundance (David *et al.*, 2000). Our findings showed the optimistic correlation between Chlorophycea (r=0.982) and Cladocera. Chlorophycean members contain considerable amount of fatty acid composition for hastening their metabolic processes (Jarunan *et al.*, 2005), and becomes a source substrate as one of the chief nutritive elements for

Cladocerans; thus increasing their feeding tendency and dependency on Chlorophycean taxa (Gunnel *et al*., 1990). High positive correlation (r=0.866) was also observed between Ostracoda and Cyanophyceae, and Bacillariophyceae. Ostracoda were observed in all the types of water (fresh, brackish, saline)(Table 7). Latter are more affected to change in physico-chemical as well as biological factors of water, and can be considered as a very good indicator of alteration in status of an aquatic body (Okan and Gary, 2000). Zooplankton was found to be more dependent on Bacillariophyceae, followed by Cyanophyceae, Chlorophyceae, and least dependant on Euglenophyceae.

Table 7.Correlation matrix between plankton at DSW

Plankton	Chlorophyceae	Cyanophyceae	Bacillariophyceae	Euglenophyceae
Zooflagellata	-0.945	0.000	-0.866	0.866
Rhizopoda	0.000	0.000	0.000	0.000
Ciliophora	0.434	0.993	0.596	-0.596
Rotifera	0.189	-0.866	0.000	0.000
Copepoda	0.000	0.000	0.000	0.000
Cladocera	0.982	0.500	1.000	-1.000
Ostracoda	0.756	0.866	0.866	-0.866

Good score of correlation was noted between phytoplankton and zooplankton, which implies the direct dependence of zooplankton on phytoplankton, depicting the clear scenario of inter-dependence and obligatory association among different biotic groups as a part of ecological food chain and food-web. This alliance could be more elaborated by the nutrient excreted by zooplankton, which may stimulate the persistence of resistance, and grazing on phytoplankton (Sommer *et al.,* 2003).

Commensal association among biotic components

Phytoplankton showed strong positive correlation (r=0.971) with macrophytes, followed by medium correlation (r=0.810) between phytoplankton and zooplankton, and the least association (r=0.645) between zooplankton and macrophytes (Table 8) (Figure 5). Zooplankton probably may have strong influences on phytoplankton over shorter time-scales, and may indirectly influence the phytoplankton abundance and nutrient availability by facilitating growth of submerged macrophytes (Hanson and Butler, 1994). Fewer predation, low food availability, or amalgamation of both, may be the probable reasons for less zooplankton abundance in the studied wetland (Ellen and Bund, 2002). The occurrence of macrophytes increases the surface area available for periphyton (Blindow, 1987); which affects nutrient competition between phytoplankton and bacteria/periphyton. Furthermore, the release of organic carbon compounds from macrophytes accelerates the bacterial production, and thus indirectly stimulates phytoplankton population (Wetzel and Sondergaard, 1998). Passive effects are likely to contribute to the generally low nitrogen concentrations, often occurred in the presence of macrophytes. Oxic–anoxic gradients are relatively abundant inside macrophyte beds; increasing denitrification, and reducing the abundance of phytoplankton in the aquatic body (Weisner *et al*., 1994; Erikkson and Weisner, 1997, 1999). The studied wetland harbors few macrophytes due to eutrophic condition (Van and Prins, 1985), and hence comparatively poor denitrification and low oxic-anoxic gradient, resulting in high numbers of phytoplankton. The presence and ordination of phytoplankton communities differed and varied as per the availability of aquatic macrophytes (Nioriko *et al*, 2003).

Table 8.Correlation matrix between biotic components at DSW

Biotic Components	Phytoplankton	Zooplankton	Macrophytes
Phytoplankton	0.000		
Zooplankton	0.810	0.000	
Macrophytes	0.971	0.645	0.000

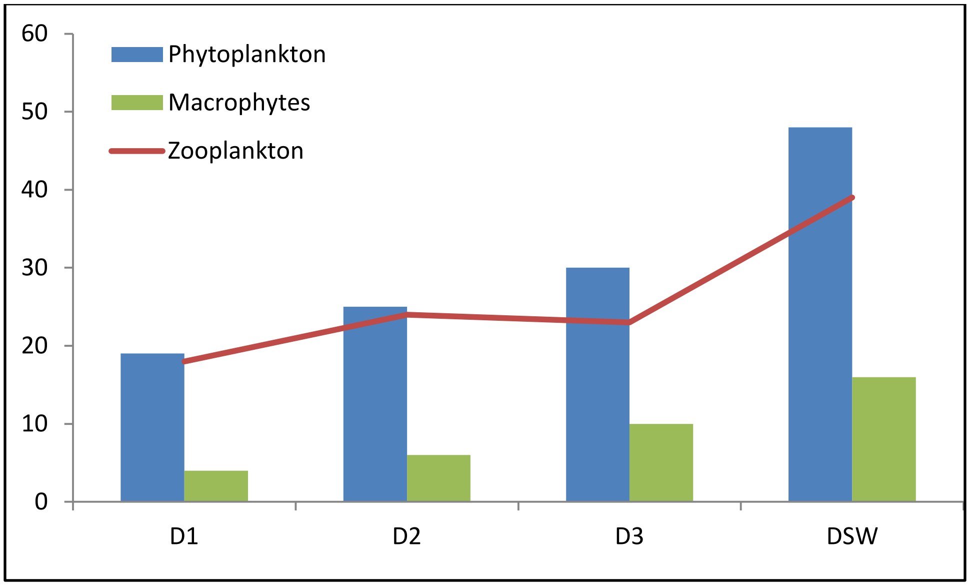


Figure 5.Associative dependence between biotic components

Conclusion

From the present work, it can be remarkably affirmed that among plankton Chlorophycean taxa are more dependent on zooplankton. This could be probably due to rich fatty acid composition harbored by Chlorophycean members, which may aid as an important and limiting nutritional factor for predation by zooplankton. Euglenophycean members were found profoundly dependent on Zooflatellates, as prominent markers of mutualism. Pollution indicator species (*Euglena*, *Oscillatoria*, *Navicula*, *Nitizchia*, *Cyclops*, *Daphnia*, *etc*.) dominated the hydric regime, further drawing a remarkable and indissoluble line to eutrophic state of study area. Macrophyte indicators (*Eichhornia crassipes, Lemna minor*, *Potamagoteon nodusus*) were frequent and abundant, signifying DSW to be highly eutrophic, enriched with over-loaded quanta of anthropogenic nutrient inputs. Intrusion by point and non-point sources is often claimed, and are the most grave and accentuating threats to ecological sustainability of water body. There is also a growing awareness of the pivotal role of flow regime as a key driver of biodiversity of freshwater wetland. Unwarranted anthropogenic loads may alter habitat characteristics at varying spatio-temporal scales, and the impact of this on species distribution and abundance, as well as composition and diversity of different biotic communities. To overcome such momentous problems, aquatic science needs to move with manipulative or experimental phase, by either restoring the biotic communities, or taking away the obnoxious and harmful weeds along with non-invasive species, to measure the ecosystem response at a broad scale.

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References

Acharya, K., Kyle, M. and Elser, J.J., 2004.Effects of stoichiometric dietary mixing on Daphnia growth and reproduction.Oecologia.138: 333–340.

Alan, R.L., 1976. Interactions between zooplankton and phytoplankton profiles in the eastern tropical Pacific Ocean. Deep Sea Research. 23: 729-754.

Anand, N.,1998. Indian Freshwater Microalgae. Bishen Singh Mahendra Pal Singh, Dehra Dun., India.

Arnulf, M., 1999. Aquatic macrophytes as tools for lake management. Hydrobiologia. 395/396: 181–190

Aziz, N.E.A., and Gharib, S.M., Dorgham, M.M., 2006. The interaction between phytoplankton and zooplanktonin a Lake-Sea connection, Alexandria, Egypt. International Journal of Oceans and Oceanography. 1 (1):151-165

Battish, S.K., 2000. Freshwater Zooplankton of India. Oxford and IBH Publishing Co. Pvt. Ltd., Calcutta.

Beaugrand, G.F., Ibanez and P.C., 2000. Reid, Spatial, seasonal and long-term fluctuations of plankton in relation to hydro climatic features in the English channel, Celtic Sea and Bay of Biscay. Marine Ecology Progress Series. 200: 93–102.

Biswas, K. and Calder, C.C., 1994. Handbook of Common Water and Marsh Plants of India and Burma, xvi + 216, Bishen Singh Mahendra Pal Singh (Dehra Dun).

Blindow, I., 1987. The composition and density of epiphyton on several species of submerged macrophytes-neutral substrate hypothesis tested. Aquatic Botany. 29:157–168.

Bottrell, H.H., 1975. The relation between temperature and duration of egg development in some epiphytic Cladocera and Copepoda from the River Thames, Reading, with a discussion of temperature functions. Oecologia.18: 63–84.

Census Commission of India. 2004. Retrieved on 1st November, 2012. http://en.wikipedia.org/wiki/Dakor#cite_ref-0

Christer, B. and Hansson, L.A., 2002.Environmental issues in lakes and ponds: current state and perspectives. Environmental Conservation. 29 (3): 290–307.

Cottam, G. and Curtis, J.T., 1956. The use of distance measures in phyto sociological sampling. Ecology. 37: 151-160.

Dave, G., 1992. Sediment toxicity and heavy metals in eleven lime reference lakes of Sweden. Water, Air and Soil Pollution. 63: 187–200.

David, G.A., Cobelas, M.A., Rojo, C. and Carrillo, S.S., 2000. The significance of water inputs to plankton biomass and trophic relationships in a semi-arid freshwater wetland (central Spain). Journal of Plankton Research. 22 (11): 2075-2093.

Desikachary, T.V., 1959. Cyanophyta. Indian Council of Agriculture Research, New Delhi.

Drake, J.C. & Heaney, S.I., 1987. Occurence of phosphorus and its potential remobilization in the littoral sediments of a productive English lake. Freshwater Biology. 17: 513–523.

Edmondson, W.T., 1963. Freshwater Biology. John Wiley & Sons, Inc.

Ellen, V.D., Bund, W.J.V.D., 2002.Impact of submerged macrophytes including charophytes on phyto- and zooplankton communities: allelopathy versus other mechanisms. Aquatic Botany. 72: 261–274.

Erikkson, P.G., Weisner, S.E.B., 1997. Nitrogen removal in a wastewater reservoir: importance of denitrification by epiphytic biofilms on submerged vegetation. Journal of Environmental Quality. 26: 905–910.

Erikkson, P.G., Weisner, S.E.B., 1999. An experimental study on effects of submerged macrophytes on nitrification and denitrification in ammonium-rich aquatic systems. Limnology Oceanography. 44: 1993–1999.

Evelyn, E.G., and Roger, W.B., 1994. Seasonality, substrate preference and attachment sites of epizoic diatoms on cladoceran zooplankton. Journal of Plankton Research. 16 (1): 53-68.

Gulati, R.D. and DeMott, W.R., 1997. The role of food quality for zooplankton: remarks on the state-of-the-art, perspectives and priorities. Freshwater Biology. 38: 753–768.

Gunale, V.R., and Balakrishnan, M.S., 1979. Schizomerisleibleinii Kuetz. As an indicator of eutrophication. Biovigyanam. 5: 171-172.

Gunnel, A., Lisa, L., Michael, B. and Curt, F., 1990. Lipid composition and food quality of some freshwater phytoplankton for cladoceran zooplankters. Journal of Plankton Research. 12 (4): 809-818.

Hans, W. P., 1988. Nuisance phytoplankton blooms in coastal, estuarine and inland waters Limnology Oceanography. 33 (4, Part 2): 823-847.

Hanson, M.A., and Butler, M.G., 1994. Responses of plankton, turbidity, and macrophytes to biomanipulation in a shallow prairielake. Canadian Journal of Fisheries and Aquatic Sciences. 51: 1180–1188.

Havens, K.E., 1991. The importance of rotiferan and crustacean zooplankton as grazers of algal productivity in a freshwater estuary. Arch. Hydrobiol. 122: 1-22.

Hessen, D.O., 2006. Determinants of seston C:P-ratio in lakes. Freshwater Biology. 51: 1560–1569.

Hessen, D.O., 2008. Efficiency, energy and stoichiometry in pelagic food webs; reciprocal roles of food quality and food quantity. Freshwater Review. 1: 43–57.

Hutchinson, G.E., 1975. A treatise on limnology, v.3.Limnological botany. John Wiley and Sons, New York, London, Sydney, and Toronto.xii + 660 p.

Jafari, N.G. and Gunale, V.R., 2006. Hydrobiological Study of Algae of an Urban Freshwater River. Journal of Applied Science of Environmental Management. 10 (2): 153-158.

Jarunan, P., Piyawan, S. and Thidarat, N., 2005. Fatty acids composition of 10 microalgal species. Songklanakarin Journal of Science and Technology. 27 (6): 1179-1187.

Kerfoot, W. C., and DeAngelis, D.L., 1989. Scale-dependent Dynamics: Zooplankton-and the Stability of Freshwater Food Webs. TREE. 4 (6):167-171.

Krausch, H.D., 1964. The plant communities of the Stechlin sea area.I. The companies of the open water. Limnologica. 2: 145-203.

Lennon, J.T., Smith, V.H. and Williams, K., 2001. Influence of temperature on exotic Daphnia lumholtzi and implications for invasion success. Journal of Plankton Research. 23: 425–434.

Li, M. A., Gargett and Denman, K., 2000. What determines seasonal and inter-annual variability of phytoplankton and zooplankton in strongly estuarine systems? Application to the semi-enclosed estuary of Strait of Georgia and Juan de Fuca Strait. Estuarine, Coastal and Shelf Science. 50: 467–488.

Martins, C.D., Sperfeld, E. and Wacker, A., 2009. Colimitation of a freshwater herbivore by sterols and polyunsaturated fatty acids. Proceedings of Royal Society B: Biological Sciences. 276: 1805–1814.

Mellina, E., Rasmussen, J.B., and Mills, E.L., 1995. Impact of Zebra mussels (Dressenapolymorpha) on phytoplankton cycling and chlorophyll in lakes. Canadian Journal of Fisheries and Aquatic Sciences. 52: 2553-2579.

Mishra, K.C., 1974. Manual of Plant Ecology, oxford and IBH publishing co. New Delhi, pp. 491.

Noriko, T., Kadono, Y., Fukushima, M., Nakagawa M., Kim B.H.O., 2003. Effects of aquatic macrophytes on water quality and phytoplankton communities in shallow lakes. Ecological Research. 18 (4): 381-395.

Nygaard, G., 1976 . Talverne from Danish Phytoplanton. Gyledondal. Pp. 25.

Odum, E.P., 1971. Fundamentals of Ecology. 3rd Ed., WB Saunders Co., Phil, USA, p. 574.

Okan, K. and Gary, V., 2000. Distribution and ecology of freshwater ostracoda (crustacean) collected from springs of Nevada. Idaho and Oregon: A preliminary study. Western North American Naturalist. 60 (3): 291-303.

Palmer, C.M., 1969. Composite rating of algae tolerating organic pollution. Journal of Phycology. 5: 78-82.

Patrick, R., 1965. Algae as indicator of pollution: A biological problem in water pollution Third seminar 1962.Robt. A. Taft. Sanitary Engineering Center, Publ. Hlth. Serv. Publs.Wash. 223-232 pp.

Philipose, M.T., 1967. Chlorococcales. Indian Council of Agriculture Research (ICAR), Krishi Bhawan, New Delhi.

Prescott, G.W., 1984. The Algae: A Review. Koenigstein, Otto Koeltz Science Publishers, 436p.

Prins, T.C., Escaravage, V., Smaal, A.C. and Peters, J.C.H., 1995. Nutrient cycling and phytoplankton dynamics in relation to mussel grazing in a mesocosm experiment. Ophelia. 41: 289-315.

Ratnasabapathy, M., 1975. Biological aspects of Wardieburn sewage oxidation pond. Malaysian Science. 3: 75-87.

Ravet, J.L. and Brett, M.T., 2006. Phytoplankton essential fatty acid and phosphorus content constraints on Daphnia somatic growth and reproduction. Limnology Oceanography. 51: 2438–2452.

Sanap, R.R., 2007. Hydrobiological studies of Godavari River up to Nandur-Madhmeshwar dam, Nashik, Maharashtra. Ph. D. thesis, University of Pune, India.

Santlal, J. and Mehta, S., 2014. Occurrence of freshwater algae and water quality in Bhavnagar, Gujarat, India. Journal of Biology and Earth Sciences. 4 (1): B6-B20.

Seidendorf, B., Meier, N., Petrusek, A., Boersma, M., Streit, B. and Schwenk, K., 2010. Sensitivity of Daphnia species to phosphorus-deficient diets. Oecologia. 162: 349–357.

Shah, G.L., 1978. Flora of Gujarat State. Vols. I & II. Sardar Patel University Press, Vallabh Vidyanagar, Gujarat.

Sommer, U., Sommer, F., Santer, B., 2003. Daphnia versus copepod impact on summer phytoplankton: functional compensation at both trophic levels. Oecologia. 135: 639–647.

Sondergaard, M., 1988. Seasonal variations in the loosely absorbed phosphorus fraction of the sediment of a shallow and hypertrophic lake. Environmental Geology Water Science Journal. 11:115–121.

Soni, H.B and Thomas, S., 2013. Preliminary Observations on Phytoplankton at Sacred Palustrine Habitat, Central Gujarat, India. International Journal of Environment. 2 (1): 115-126.

Soni, H.B. and Thomas, S., 2013a. Historical Perspectives and Future Perceptions of Sacred Pilgrimage Spot of Central Gujarat, India – A Case Study of Gomti Water Tank. Present Environment and Sustainable Development. 7 (2): 47-57.

Soni, H.B. and Thomas, S., 2013b. Occurrence of Zooplanktons at Sacred Palustrine Habitat, Central Gujarat, India, With Conservation and Management Strategies. International Journal of Environment. 3 (1): 111-121.

Soni, H.B. and Thomas, S., 2013c. Preliminary Data on Occurrence of Zooplanktons of Freshwater Lentic Ecosystem – A Case Study of Dakor Sacred Wetland, Central Gujarat, India. International Journal of Environment. 1 (1): 46-55.

Suominen, J., 1968. Changes in the aquatic macroflora of the polluted Lake Rautavesi, SW-Finland. Annales Botanici Fennici. 5: 65–81.

Tomasz, M., 2010. Periphytic Ciliates in Three Shallow Lakes in Eastern Poland: A Comparative Study between a Phytoplankton-Dominated Lake, a Phytoplankton-Macrophyte Lake and a Macrophyte-Dominated Lake. Zoological Studies. 49 (5): 589-600.

Tonapi, G.T., 1980. Freshwater Animals of India. Oxford and IBH Publishing Co., New Delhi.

Trapp, S., 1995. Aquatic plants Bremer lakes and their relationship to water quality. Abh Nature. Association Bremen. 3: 165-177.

Uotila, P., 1971. Distribution and ecological features of hydrophytes in the polluted Lake Vanajavesi, S-Finland. Annales Botanici Fennici. 8: 257–295.

Van, V.W. and Prins, T. C., 1985. On the relationship between the growth of algae and aquatic macrophytes in brackish water. Aquatic Botany Journal. 21: 165-179.

Vijverberg, J., 1980. Effect of temperature in laboratory studies on development and growth of cladocera and copepoda from Tjeukemeer, the Netherlands. Freshwater Biology. 10: 317–340.

Weisner, S., Eriksson, G., Graneli, W., Leonardson, L. 1994. Influence of macrophytes on nitrate removal in wetlands. Ambio. 23: 363–366.

Wetzel, R.G., Sondergaard, M., 1998. Role of submerged macrophytes for the microbial community and dynamics of dissolved organic carbon in aquatic ecosystems. In: Jeppesen, E., Sondergaard, M., Christoffersen, K. (Eds.) The Structuring Role of Submerged Macrophytes in Lakes. Springer, New York, pp. 133–149.

World Weather Online.2008. Online Web Source. Accessed on 1 November 2012 http://www.worldweatheronline.com/dakorweather/gujarat/in.aspx?day=21