Variations in phytoplankton assemblages in different aquaculture systems in coastal waters of Goa

Article *in* Indian Journal of Geo-Marine Sciences · January 2018

Manju Lekshmi
Indian Council of Agricultural Research

Sreekanth gb
Indian Council of Agricultural Research

N. P. Singh
Indian Council of Agricultural Research

Vennila Alagarsamy
ICAR-Sugarcane Breeding Institute, Coimbatore, India

Indian Journal of Geo Marine Sciences
Vol. 47 (01), January 2018, pp. 35-45

Variations in phytoplankton assemblages in different aquaculture systems in coastal waters of Goa

N. Manju Lekshmi[1], G.B. Sreekanth[1], Narendra Pratap Singh[1], A. Vennila [2], R. Ratheesh Kumar[3] & P.K. Pandey[4]

[1]ICAR–Central Coastal Agricultural Research Institute, Ela Old Goa, Goa- 403402, India
[2] ICAR-Sugarcane breeding Institute, Seeranaickenpalayam, Coimbatore, Tamilnadu, 641007, India
[3] ICAR-Central Marine Fisheries Research Institute, Seven Bunglows, Mumbai, 400061, India
[4]College of Fisheries, Central Agricultural University Lembucherra, Agartala, 799210, India

*[Email id: manjuaem@gmail.com]

Received 12 February 2016 ; revised 06 April 2016

The dynamics of phytoplankton were studied corresponding to the environmental conditions in different aquaculture systems from coastal waters of Goa for a period of two years. A total of 45, 39, 51 and 24 species were identified from open water system (OWS) with mussel culture, semi-enclosed water system (SEW) with mussel culture, SEW with multispecies culture and OWS with multispecies culture, respectively. Diatoms and dinoflagellates were the major groups in all the culture systems. Nutrients, chlorophyll-a, phytoplankton biomass and diversity were significantly higher in semi-enclosed systems. This observation in semi-enclosed systems is inferred as a reaction to driving forces like polymixis, water-level changes and nutrient loading due to less flow rate in the system.

[**Keywords**: Semi-enclosed water system, Open water system, Phytoplankton, Species diversity, Canonical correspondence analysis]

Introduction

The production dynamics of an estuarine environment is primarily determined by the diversity and biomass of phytoplankton. Density and diversity of phytoplankton groups in the ecosystem determines the primary production[1]. Phytoplankton community indicates the quality of estuarine waters because they promptly respond to the environmental changes and in turn, influence the environment. Moreover, the phytoplankton abundance and species composition in an estuarine ecosystem are closely linked to various physico-chemical and biological factors as well as interactions among them[2]. Hence, the composition of phytoplankton needs to be understood in order to quantify the production dynamics of coastal ecosystems.

Phytoplankton composition shows huge variability among seasons[3] and even in similar geographical locations[4] in coastal ecosystems. Estuarine area is strongly influenced by seasons and the changes associated with its onset have marked effects on the phytoplankton production and food-web dynamics[5]. Phytoplankton diversity and biomass in an ecosystem is also determined by the environmental characteristics[6]. The relationship between different environmental factors and phytoplankton community is of paramount importance and thus, their interactions can be understood[7]. However, due to their high diversity, taxonomic complexity and high regeneration, community interactions of coastal phytoplankton are poorly understood even though such organisms form the basis of many coastal food webs[8].

Phytoplankton composition in aquaculture especially shrimp culture, integrated aquaculture systems and composite fish culture are studied extensively[10]. However, there are limited studies which simultaneously compared the composition of phytoplankton in different aquaculture systems and their relationship with the environmental factors. In view of all these facts, a study was carried out to assess the phytoplankton assemblages in aquaculture systems of finfishes (pearlspot, *Etroplus suratensis* and red snapper, *Lutjanus argentimaculatus*) and shellfish (green mussel, *Perna viridis*) in open as well as semi-enclosed estuarine areas of Goa. This study was carried out to understand the phytoplankton composition in different aquaculture systems (open water and semi-enclosed water system) and to identify the relationships between the phytoplankton assemblage and environmental variables in aquaculture systems.

Material and Methods

A total of four aquaculture systems in coastal areas were selected: open water system with mussel culture (OWSM), open water system with multispecies culture (OWSMS), semi-enclosed water system with mussel culture (SEWM) and semi-enclosed water system with multispecies (red snapper and pearl spot) (SEWMS). In semi-enclosed systems, water flow from the estuaries is controlled by means of sluice gates and the open waters in the coastal areas are considered as open water system which has direct connection with the estuaries. OWSM and SEWM are connected to Zuari estuary and OWSMS and SEWMS are connected to Terekhol estuary of Goa (Fig. 1).

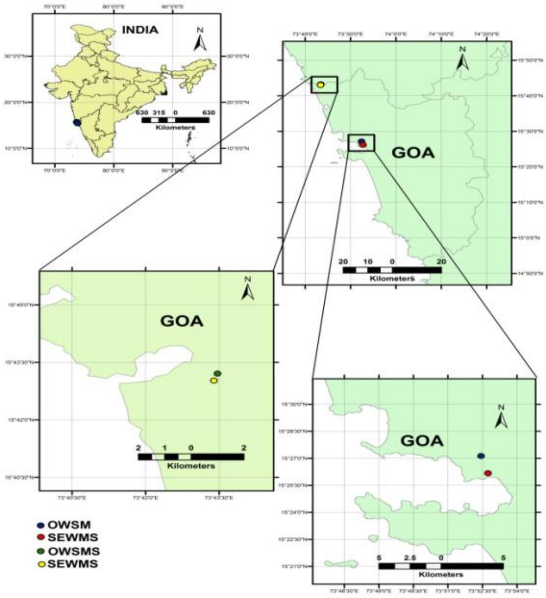

Fig.1- The map showing the different culture systems

Phytoplankton, water and sediment samples were collected from all the four sites in triplicates during morning hours between 8.00 and 9.00 h on a monthly basis from each culture system at a fixed location during November, 2013 to October, 2015.A calendar year was divided into 3 main seasons; pre monsoon (February to May), monsoon (June to September) and post monsoon (October to January).

The physical parameters such as temperature (TEMP in °C), pH, salinity (SALINITY in ‰) and dissolved oxygen (DO in mg/l) and chemical parameters such as ammonia-nitrogen; NH_4^+-N (AmN in mg/l), nitrate; NO_3^--N (NITRATE in mg/l), nitrite; NO_2^--N (NITRITE in mg/l); orthophosphate; PO_4^{3-}-P(AP in mg/l), total suspended solids (TSS in mg/l), dissolved organic matter (DOM in mg/l), biochemical oxygen demand (BOD in mg/l), chlorophyll-a (CHLA in µg/l**)** were estimated from water samples and available nitrogen (SEDAN in kg/ha), total organic carbon (SEDOC in %), electrical conductivity (SEDEC in mS/cm) and pH (SEDPH) were estimated from sediment samples.

Water temperature was recorded using a digital multi thermometer (EXTECH 407907RTD, China). Salinity was determined by using a refractometer (EXTECH RF41, China). The pH was measured using a portable digital pH meter (Eutech Instruments, Malaysia). For estimation of chemical parameters, water samples were kept in clean plastic bottles, loaded into an ice box and transported to the laboratory. Ammonia-nitrogen was determined by using salicylate method, nitrate by cadmium reduction method, nitrite by diazotization method and orthophosphate by ascorbic acid method[11]. To estimate chlorophyll-*a*, water samples were filtered on the same day of collection and further, the chlorophyll-*a* concentration was estimated using the standard procedure [12]. The DO, BOD, DOM, SEDAN, SEDEC and SEDPH were estimated using standard methods[13].

Phytoplankton samples were collected by filtering 25 litres of water through plankton nets (mesh size No 30, mesh size-48 µm) and preserved with 4% neutral formalin solution. The volume of each sample was concentrated to 50 ml and sub samples of 1 ml were transferred into a Sedgwick Rafter chamber and 1 ml of each concentrate was counted under an Olympus stereozoom SZX7 microscope (Model CX 41) at 40X magnification[13]. Total phytoplankton density was calculated as cells/litre. Taxonomic identification of phytoplankton was carried out by using standard protocols[14].

The phytoplankton assemblages were analysed in relation to prevailing environmental conditions using diversity indices. Three indices (Shannon Wiener diversity index, Margalef's richness index and Heip's evenness index) were calculated using PAST software[15]. The mean and standard error for the biodiversity indices were calculated in different culture systems using the PROC MEANS procedure of SAS[16]. Further, a two way ANOVA followed by Tukey's HSD were used to compare the diversity indices in different culture systems using PROC GLM procedure of SAS[16].

A canonical correspondence analysis (CCA) integrating the environmental variables which showed significant difference between the systems in ANOVA and 5 phytoplankton groups (green algae, blue green algae, diatoms, dinoflagellates, *Euglena*) was carried out to find out their relationships with environmental variables[17]. Monte Carlo test was used to evaluate the significant relationship between environmental variables and species data. Significance of the CCA axes was tested with 999 permutations. CCA was run constrained to each environmental variable in turn to determine the amount of variation that can be accounted for that variable.

Results

The environmental variables of water and sediment varied across different culture systems. Chlorophyll-*a* was highest in SEWM and the lowest in OWSMS. There was no significant difference in Chl-*a* between OWSMS and OWSM. The values of AP were highest in SEWM and lowest in SEWMS. There were no significant difference in AP between OWSMS and OWSM (Table 3). The nitrate concentration in water was highest in SEWM and lowest in OWSMS. Nitrite values were highest in SEWM and lowest in OWSM. SEDPH was highest in OWSM and lowest in SEWMS (Table 1).

Highest values of DO were recorded in OWSM and lowest in SEWMS. While values of BOD were the highest in SEWMS and the lowest in OWSMS. The DOM was highest in SEWM and lowest in OWSMS. Similarly, a highest value of water temperature was recorded in SEWMS and lowest in OWSMS (Table 1). TSS values were highest in SEWMS and lowest in OWSM. Salinity values were the highest in SEWM and lowest in OWSMS. SEDEC was the highest in SEWMS and lowest in OWSMS. However, there was no significant difference in values of water temperature, TSS, salinity, SEDPH and SEDEC across different culture systems (Table 3).

Phytoplankton density was significantly different among different culture systems and seasons. Highest density was observed in the pre-monsoon period in semi-enclosed systems. In open water systems, density was maximum during the monsoon period. Salinity was minimum during the monsoon period in all the systems. Dissolved oxygen was high during monsoon in all the sites. All the physico-chemical parameters of water and sediment showed significant difference between the seasons and the diversity indices of phytoplankton such as abundance, richness, evenness and dominance also showed significant difference across various seasons (Table 3).

Phytoplankton diversity and abundance showed significant difference between the different culture systems. While comparing the diversity of phytoplankton species in different culture systems, the maximum diversity, species richness and abundance were observed in SEWMS. The evenness was similar across all the culture systems (Table 1). In OWSM, a total of 45 species of phytoplankton belonging to 33 families were recorded. In SEWM, a total of 39 phytoplankton species belonging to 28 families were recorded. In SEWMS, a total of 51 phytoplankton species from 36 families were recorded and in OWSMS, a total of 24 species from 18 families were observed. Diatoms were dominant among the phytoplankton groups which contributed to 50% of the species richness in all the culture systems. The richness of dinoflagellates was highest in SEWMS (15 species) and lowest in OWSMS (2 species) (Table 4). Monthly mean values of phytoplankton abundance were also higher for diatoms in all the systems (Fig. 2). Blue green algae and diatoms were highest in OWSMS among all the culture systems (Fig. 2). Dinoflagellates and green algae were the highest in SEWMS and SEWM and lowest in OWSM and OWSMS. The abundance of blue green algae was lowest in SEWMS.

High value of diversity and richness in SEWMS was due to the diversity of diatoms and dinoflagellates. Phytoplankton diversity values in different culture systems were ranged from 2.15 to 2.54 while overall richness values were ranged from 0.87 to 1.411 (Table 1).

The CCA was significant (P=0.004, Monte Carlo) and eigen values of the axes1

(λ_1=0.04) and axis2 (λ_1=0.01) explained 98% of the cumulative variance in species data and 92% of the relation between species and environmental data (Table 6). In CCA biplot, the length of the environmental arrows points their relative importance to each axis. Environmental arrows represent a gradient, where the mean value is located at the origin, and the arrow points in the direction of its increase (Fig. 3). Blue green algae were positively correlated with the concentration of AP. The blue green algae were abundant when the concentration of AP was higher in OWSMS. The Green algae was abundant when the concentration of ammonia, BOD, TSS and temperature were on the higher side as evident in SEWMS (Fig. 3). The range of abundance of phytoplankton species is presented in table 5.

Table 1-Mean and standard error values of physico-chemical parameters and diversity indices for different culture systems

Parameter	OWS-MS	OWS-M	SEW MS	SEW M
CHLA	2.41±0.01^{c}	2.46±0.01^{c}	2.75±0.01^{b}	3.13±0.01^{a}
PD	2.89±0.05^{b}	2.99±0.05^{b}	3.48±0.06^{a}	3.33±0.06^{a}
AP	0.27± 0.01^{b}	0.28±0.03^{b}	0.2±0.01^{c}	0.32±0.02^{a}
NITRATE	1.18±0.02^{bc}	1.13±0.01^{c}	1.25±0.01^{b}	1.31±0.01^{a}
DO	4.86±0.05^{a}	4.92±0.03^{a}	4.23±0.03^{c}	4.44±0.01^{b}
BOD	3.24±0.1^{b}	3.26±0.1^{b}	4.1±0.09^{a}	4±0.1^{a}
AmN	0.09±0.004^{bc}	0.06±0.003^{c}	0.19±0.004^{a}	0.12±0.002^{b}
DOM	1.57±0.1^{a}	1.65±0.1^{a}	1.69±0.1^{a}	1.7±0.1^{a}
Temp	29.02±0.5^{a}	29.35±0.4^{a}	30.52±0.4^{a}	29.17±0.1^{a}
TSS	112.2±1.1^{a}	109.8±2.1^{a}	143.74±1.3^{a}	135.44±1.8^{a}
Salinity	25.5±0.3^{c}	26.6±0.3^{b}	27.6±0.2^{ab}	28±0.3^{a}
NITRITE	0.45±0.01	0.41±0.03	0.46±0.02	0.46±0.01
SEDpH	7.6±0.01^{a}	7.68±0.01^{a}	7.51±0.03^{a}	7.57±0.05^{a}
SEDEC	7.61±0.5^{a}	8.9±0.8^{a}	13.85±1.1^{a}	11.55±1.2^{a}
SEDOC	0.32±0.03^{a}	0.29±0.02^{a}	0.28±0.02^{a}	0.29±0.3^{a}
SEDAN	155.98±2.41^{a}	159.98±2.41^{a}	163.07±34.58^{a}	160.07±34.58^{a}
Shannon	2.17±0.08^{b}	2.15±0.11^{b}	2.54 ± 0.1^{a}	2.15±0.11^{b}
Evenness	0.81±0.02^{a}	0.81±0.02^{a}	0.79 ±0.02^{a}	0.81±0.02^{a}
Richness	0.87±0.04^{b}	0.97±0.13^{b}	1.411±0.15^{a}	0.96±0.12^{b}

Same superscript shows that there is no significant difference between culture systems

Discussion

Nitrogen is generally considered as a nutrient with greatest potential to limit phytoplankton productivity in estuaries and coastal marine systems[18]. Nitrates are the most oxidized forms of nitrogen and the end product of the aerobic decomposition of organic nitrogenous matter[19]. The availability of the nitrate will augment the growth of phytoplankton[20]. In this study, nitrate and ammonium values were the highest in semi-enclosed systems and the lowest in open water systems. It is reported that the possible way of nitrate entry into the water body is through oxidation of ammonia nitrogen to nitrite and nitrate[21]. Further, Chlorophyll-*a*, orthophosphate and plankton density were also significantly high in semi-enclosed systems compared to open water systems. It was reported that the water exchange is more than the required levels in aquaculture systems and thus, nutrients will be discharged from these systems before they can be assimilated[22, 23]. In semi-enclosed systems, the water discharge was controlled in comparison with open water systems. This might have resulted in the higher values of

Table 2- Mean and standard error for physico-chemical parameters of water and sediment between seasons

OWS MS				OWS -M			SEW-MS			SEW-M		
Parameter	Pre monsoon	Post monsoon	Monsoon	Pre-monsoon	Post-monsoon	Monsoon	Pre-monsoon	Post-monsoon	Monsoon	Pre-monsoon	Post -monsoon	Monsoon
PD	5.11±0.04	5.23±0.04	6.57±0.08	3.1±0.05	3.11±0.04	3.23±0.04	10.07±0.06	9.79±0.13	10.02±0.01	3.64±0.05	3.59±0.03	3.33±0.09
AP	0.25±0.01	0.28 ±0.01	0.29±0.01	0.28±0.01	0.25±0.01	0.25±0.01	0.03±0.01	0.04±0.01	0.03±0.03	0.34±0.01	0.34±0.01	0.27±0.03
CHLA	2.11±0.02	2.01±0.06	2.22±0.13	2.66±0.06	2.81±0.02	2.51±0.06	3.06±0.10	1.20±0.07	2.20±0.29	3.32±0.07	3.23±0.09	2.85±0.14
NIT	1.16±0.03	1.17±0.02	1.2 ±0.03	1.11±0.03	1.06±0.03	1.17±0.02	0.81±0.06	1.53±0.1	1.11±0.15	1.3±0.02	1.4±0.02	1.23±0.05
DO	4.57±0.05	4.9±0.06	5.31±0.31	4.51±0.08	4.57±0.05	4.9±0.06	4.80±0.14	4.72±0.11	4.90±0.07	4.45±0.04	4.61±0.11	4.73±0.05
BOD	3.31±0.04	3.08±0.06	2.47±0.16	3.55±0.06	3.31±0.04	3.08±0.06	4.81±0.10	4.93±0.13	4.92 ±0.14	3.3±0.05	3.09±0.13	3.63±0.26
AmN	0.09±0.01	0.06 ±0.03	0.03±0	0.07±0.01	0.09±0.01	0.11±0.03	0.49±0.1	0.34±0.06	0.50±0.07	0.2±0.02	0.25±0.02	0.14±0.03
DOM	1.69 ±0.13	1.62±0.14	1.4±0.08	1.69±0.16	1.65±0.13	1.62±0.14	1.48±0.07	1.63±0.17	1.59 ±0.06	1.29±0.1	1.95±0.19	1.92±0.25
TEMP	29.69±0.23	28.86±0.22	28.5±0.15	29.5 ± 0.15	29.69±0.23	28.86±0.22	31.00±0.46	30.63±0.18	29.92±0.06	29.44±0.33	29.07±0.2	29±0.37
TSS	126.8±4.15	124.17±4.96	85.49±7.22	108.29±6.78	96.8±4.15	124.17±4.9	145.88±4.	134.75±6.6	150.58±2.6	89.65±10.3	123.24±5	104.51±9.5
Salinity	31.77±0.61	28.31±0.77	16.38±2.9	32.04±0.54	31.77±0.61	28.31±0.77	28.00±0.71	29.75±0.41	28.17±0.98	28.5±0.5	27.29±1.3	16.38±3
NITRITE	0.38±0.02	0.41±0.02	0.55±0.06	0.43±0.02	0.38±0.02	0.41±0.02	0.39±0.04	0.44±0.03	0.46 ±0.03	0.36±0.03	0.47±0.04	0.61±0.02
SEDPH	7.78±0.02	7.6±0.04	7.43±0.04	7.7±0.02	7.78±0.02	7.6±0.04	7.57±0.09	7.45±0.03	7.50±0.06	7.72±0.03	7.53±0.06	7.46±0.04
SEDEC	12.36±0.13	5.76±0.8	4.72±1.01	14.29±0.28	12.36±0.13	5.76±0.8	18.68±0.85	16.51±1.10	18.35±1.05	10.55±0.3	5.18±0.5	4.59±1.04
SEDAN	158.1±1.78	158.07±3.37	220.09±27	150.5±0.65	158.1±1.78	158.07±3.3	147.44±7.8	170.47±3.6	158.97±5.3	160.78±16.	134.08±5.	217.01±28
SEDOC	0.34 ± 0.01	0.31±0.05	0.31±0.03	0.24±0.01	0.24±0.03	0.31±0.05	0.23±0.01	0.21±0.01	0.22±0.01	0.22±0.02	0.44±0.08	0.21±0.03

*PD-log transformed phytoplankton density

Table 3- Mean sum of squares in ANOVA for physico-chemical parameters of water and sediment and diversity indices between seasons and culture systems

Source	df	AP	AmN	PD	B0D	DOM	DO	NITRATE	NITRITE	Salinity	CHLA
Season	**2**	0.004^{*}	0.056^{*}	0.822^{**}	6.434^{**}	2.89^{**}	23.94^{**}	0.292^{**}	0.01	3494.75^{**}	0.736*
System	3	0.414*	0.909**	8.361^{**}	11.363**	0.11	24.944**	1.963**	0.01	228.81**	14.84**
R^2		0.338	0.247	0.417	0.273	0.05	0.502	0.49	0.54	0.53	0.325

Source	df	SEDAN	SED EC	SED OC	SEDPH	TSS	TEMP	A	R	E	D
Season	**2**	36958.01**	1532.86**	0.28**	2.03**	548.69**	13.82**	3997^{**}	3.9854^{**}	0.0316^{*}	2.077^{**}
System	3	783.07	0.12	0.01	0.05	20.97	0.16	2995**	1.1632^{**}	0.0028	0.7358^{**}
R^2		0.09	0.54	0.14	0.22	0.05	0.09	0.76	0.61	0.15	0.48

*p<0.05, **p<0.01, A-abundance, R-richness, E-evenness, D-diversity

Table 4- Phytoplankton groups observed from the different culture systems

OWSM				SEWM			
Group	Class	No. of Families	Species			No. of Families	Species
Blue green algae	Cyanophyceae	4	6	Blue green algae	Cyanophyceae	3	5
Diatoms	Bacillariophyceae	12	17	Diatoms	Bacillariophyceae	8	13
	Fragillariophyceae	4	4	Diatoms	Fragillariophyceae	1	2
	Coscinodiscophyceae	5	7	Diatoms	Coscinodiscophyceae	7	7
Dinoflagellates	Dinophyceae	2	4	Dinoflagellates	Dinophyceae	3	6
Euglena	Euglenophyceae	1	1	Euglena	Euglenophyceae	1	1
Green algae	Chlorophyceae	2	2	Green algae	Chlorophyceae	3	3
	Zygnematophyceae	2	3	Green algae	Zygnematophyceae	1	1
	Charophyceae	1	1	Green algae	Ulvophyceae	1	1
Total		33	45			28	39
SEWMS				OWSMS			
Group	Class	No. of Families	Species	Group	Class	No. of Families	Species
Blue green algae	Cyanophyceae	3	5	Blue green algae	Cyanophyceae	4	5
Diatoms	Bacillariophyceae	10	16	Diatoms	Bacillariophyceae	7	10
	Fragillariophyceae	1	2		Fragillariophyceae	0	0
	Coscinodiscophyceae	6	7		Coscinodiscophyceae	1	1
Dinoflagellates	Dinophyceae	10	15	Dinoflagellates	Dinophyceae	1	1
Euglena	Euglenophyceae	1	1	Euglena	Euglenophyceae	1	1
Green algae	Chlorophyceae	3	3	Green algae	Chlorophyceae	3	5
	Zygnematophyceae	2	2		Zygnematophyceae	0	0
	Ulvophyceae	0	0		Ulvophyceae	1	1
Total		36	51			18	24

Table 5- Range of phytoplankton species types in the present study

Order	Family	Species	Range cells L^{-1}
Chroococcales	Chroococcaceae	*Chroococcus* sp.	0-2540
Chroococcales	Cyanophyceae	*Coccochloris* sp.	0-15510
Chroococcales	Microcystaceae	*Microcystis* sp.	0-25000
Nostocales	Oscillatoriaceae	*Oscillatoria* sp.	0-22500
Nostocales	Oscillatoriaceae	*Oscillatoria salina*	0-22500
Nostocales	Oscillatoriaceae	*Oscillatoria princeps*	0-15260
Oscillatoriales	Cyanophyceae	*Lyngbya* sp.	0-35540
Oscillatoriales	Phormidiaceae	*Trichodesmium erythraeum*	0-12500
Spirunales	Spirulinaceae	*Spirulina platensis*	0-15510
Chromulinales	Chromulinaceae	*Chromulina* sp.	0-10050
Cymbellales	Cymbellaceae	*Cymbella* sp.	0-7340
Centrales	Chaetocerotaceae	*Chaetoceros breve*	0-32500
Fragilariales	Fragilariaceae	*Diatoma* sp.	0-22500
Fragilariales	Fragilariaceae	*Fragillaria* sp.	0-3580
Naviculales	Naviculaceae	*Gyrosigma balticum*	0-10070
Naviculales	Naviculaceae	*Navicula* sp.	0-18010
Naviculales	Naviculaceae	*Navicula transitans*	0-36600
Naviculales	Naviculaceae	*Navicula festiva*	0-37500
Bacillariales	Bacillariaceae	*Nitzchia longissima*	0-18300
Bacillariales	Bacillariaceae	*Pseudo-nitzchia pungens*	0-12500
Naviculales	Neidiaceae	*Neidium* sp.	0-2500
Centrales	Triceratiaceae	*Odontella* sp.	0-15000
Centrales	Triceratiaceae	*Odontella mobiliensis*	0-10000
Centrales	Triceratiaceae	*Odontella sinensis*	0-7500
Naviculales	Pinnulariaceae	*Pinnularia rectangulata*	0-2500
Naviculales	Plerosigmataceae	*Pleurosigma cuspidatum*	0-22530
Naviculales	Scoliotropidaceae	*Scoliopleura* sp.	0-5560
Surirellales	Surrirellaceae	*Surrirella* sp.	0-27500
Naviculales	Stauroneidaceae	*Stauroneis* sp.	0-27550
Thalassiophysales	Catenulaceae	*Amphora* sp.	0-7500
Thalassiophysales	Catenulaceae	*Amphora graeffei*	0-25470
Fragilariales	Fragilariaceae	*Meridion circulase*	0-2500
Fragilariales	Fragilariaceae	*Synedra* sp.	0-12580
Fragilariales	Fragilariaceae	*Synedra acus*	0-7500
Thalassionematales	Thalassionematceae	*Thalassionema nitzschioides*	0-7500
Licmophorales	Licmophoraceae	*Licmophora ehrenbergii*	0-2500
Desmidales	Coscinodiscaceae	*Coscinodiscus lorenzianus*	0-35000
Thalasiosirales	Stephanodiscaceae	*Cyclotella* sp.	0-17500
Hemiaulales	Hemiaulaceae	*Hemialus sinensis*	0-10000
Coscinodiscales	Hemidiscusceae	*Hemidiscus* sp.	0-25050
Melosirales	Melosiraceae	*Melosira* sp.	0-7600
Melosirales	Melosiraceae	*Melosira indulata*	0-17500
Rhizosoleniales	Rhizosolenaceae	*Rhizosolenia* sp.	0-20000

Rhizosoleniales	Rhizosolenaceae	*Rhizosolenia imbricata*	0-7700
Thalasiosirales	Stephanodiscaceae	*Stephanodiscus* sp.	0-25000
Thalasiosirales	Thalasiossiraceae	*Thalasiossira condensata*	0-5000
Peridinales	Ceratiaceae	*Ceratium* sp.	0-17010
Peridinales	Ceratiaceae	*Ceratium lineatum*	0-12500
Peridinales	Ceratiaceae	*Ceratium furca*	0-10000
Peridinales	Ceratiaceae	*Ceratium longipes*	0-7500
Peridinales	Gonyaulacaceae	*Gonyaulax spinifera*	0-2500
Prorocentrales	Procentraceae	*Prorocentrum* sp.	0-7560
Prorocentrales	Procentraceae	*Prorocentrum micans*	0-15030
Euglenales	Euglenaceae	*Euglena* sp.	0-35000
Chlorococcales	Hydrodictyceae	*Pediastrum* sp.	0-15000
Sphaeropleales	Selenestraceae	*Ankistrodesmus* sp.	0-10000
Ulotricales	Ulotrichaceae	*Ulothrix* sp.	0-7560
Trebouxiophyceae	chlorellaceae	*Chlorella* sp.	0-30000
Chlamydomonadales	Chlorophyceae	*Dunaliella salina*	0-7510
zygnematales	Zygnemataceae	*Zygnema* sp.	0-10300
zygnematales	Zygnemataceae	*Spirogyra* sp.	0-10030
Desmidiales	Closteriaceae	*Closterium* sp.	0-7540

nitrate, ammonium, TSS and DOM in semi-enclosed aquaculture systems. It is reported that phytoplankton diversity and abundance are strongly correlated with physico-chemical parameters of water [24, 25, 26]. Moreover, the plankton biomass and composition in shallow water bodies will be higher, as a reaction to driving forces like polymixis, water-level changes, nutrients loading due to less flow rate and high loading of organic materials to the system[27]. These factors might have contributed to the higher availability of nutrients and thereby more phytoplankton production in semi-enclosed systems than in open water systems.

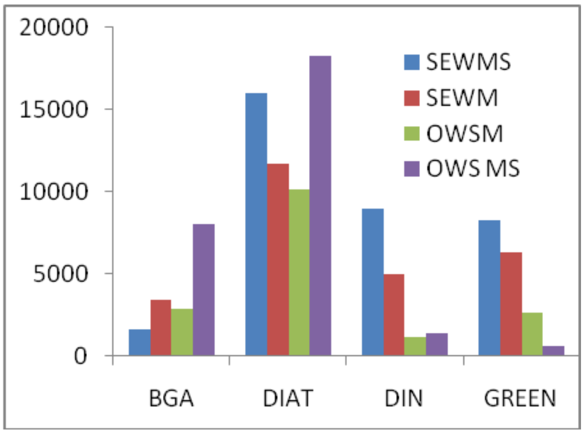

Fig.2- The mean values for abundance of phytoplankton groups

In this study, lower values of DO were observed in semi-enclosed system corresponding to higher temperature and higher salinity. Salinity and temperature are important parameters which influence the dissolved oxygen in the water. In semi-enclosed systems, the high evaporation rates may increase the salinity[28]. It has been reported that an increase in temperature and salinity will reduce the dissolution of oxygen in water[29]. Moreover, being a partially enclosed system with limited water flows, the temperature of semi-enclosed water body will be higher due to high absorption of solar radiation. Therefore the lower values of DO will always result in higher values of BOD which is also observed in semi-enclosed systems[30].

While comparing the semi-enclosed systems, the parameters like Chorophyll-a, orthophosphate, nitrate, dissolved oxygen and salinity showed higher value in SEWM than in SEWMS. The values of parameters like BOD, ammonia-nitrogen were more in SEWMS. Normally high stocking density leads to accumulation of organic nutrients. Therefore, there will be an abundance of phytoplankton. Species such as shellfish (green mussel, *Perna viridis*) that occupy intermediate trophic levels filters excess phytoplankton and reduce the chances of eutrophication. Multispecies aquaculture with finfish and shellfish create balanced systems for environment remediation, economic stability and social acceptability[31]. *Hence* properly managed multi-species aquaculture with the inclusion of filter feeders accelerates aquaculture production without detrimental side-effects[32].

While analysing the seasonal pattern in physico-chemical properties, dissolved oxygen was high during monsoon which might be due to the cumulative effect of higher wind velocity coupled with heavy rainfall and the resultant freshwater mixing or it may be also due to photosynthesis[33]. In this study, salinity was high during pre monsoon and low during the monsoon season, at all the sites. Higher values during pre monsoon could be attributed to the high degree of evaporation[34]. Physico-chemical parameters of water and sediment, and diversity indices of phytoplankton such as abundance, richness, evenness and dominance showed significant difference between seasons. Seasonal variation in the physico-chemical parameters of the culture system might have influenced the distribution and abundance of phytoplankton[6].

Table 6- Canonical coefficients of environmental variables and diversity indices with the first two axes of CCA

Variable	Axis 1	Axis 2
Salinity	-0.01	0
NITRITE	0	0.15
AmN	0.73	0
BGA	-0.69	0.39
Diatoms	0.15	0.18
Dinoflagellates	0.92	0.07
GREEN	0.94	0.07
AP	-0.81	0.49
CHLA	-0.12	0.42
NITRATE	0.12	0.94
DO	-0.06	-0.1
BOD	0.94	-0.35
DOM	-0.18	0.41
TEMP	0.89	-0.46
TSS	0.83	-0.4

From this study, diatom was found to be dominant in all the culture systems and similar results were reported from coastal and estuarine waters along the south west coast of India[35]. In CCA, green algae were abundant in SEWMS where ammonia nitrogen, BOD, TSS and temperature were on the higher side. The composition of phytoplankton community of closed systems was in agreement with earlier reports that blue-green algae and green algae dominate most tropical water bodies[36, 37]. It is reported that flexibility in the physiology and behaviour of Chlorophyceae tolerates environmental changes compared to other species[38]. Therefore, the abundance of green algae in semi-enclosed system can be correlated to their tolerance to these stressful parameters. It is also reported that high water temperature, phosphate, nitrate, low DO and CO_2 support the growth of Chlorophyceae and diatoms[39, 40]. Perhaps, this could be the reason for the abundance of Chlorophyceae and diatoms in higher concentrations of phosphate, nitrate and DO in both the sites.

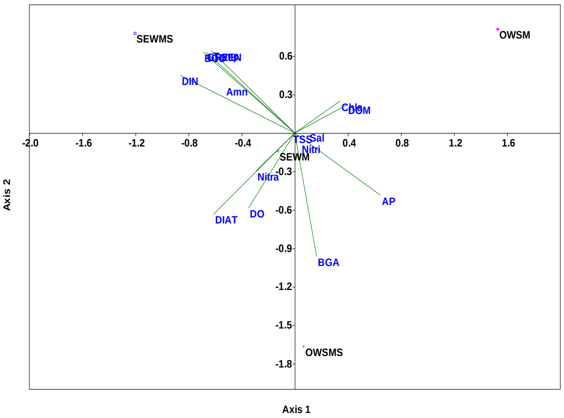

Fig.3- CCA biplot for species abundance and environmental variables

Semi-enclosed systems are land locked systems with sluice gates for regulating water flow and hence, the flow rate to the system can be controlled. Owing to this flow pattern, a constant flow is lacking and hence, nutrient accumulation may be more in this system and thereby an increase in the phytoplankton production. Generally green algae and blue green algae are dominant in water bodies with high amount of nutrients say in semi-enclosed systems. Thus, such aquaculture systems require the population of plankton feeding groups like mussels and pearlspot can regulate the nutrient loading and thereby phytoplankton bloom in coastal waters.

Conclusion

The baseline information of the phytoplankton distribution and abundance generated from this study can be useful in further ecological assessment and monitoring of these coastal aquaculture systems. Phytoplankton community, a source of organic carbon and energy for higher trophic levels, ultimately determines the success of semi-enclosed aquaculture systems. Thus, the understanding of phytoplankton dynamics is central to understand their influence in aquaculture systems and selection of species for these systems. Being rich in semi-enclosed water bodies in its coastal belt of Goa, which were utilised for shrimp aquaculture, have caused a serious setback due to disease outbreaks. Therefore, utilising these semi-enclosed waterbodies for multispecies aquaculture will provide scope for the farmers to find an alternative that could promise comparable profits.

Acknowledgements

This study was carried out with scientific and technical support from Indian Council for Agricultural Research, Ministry of Agriculture, Govt. of India. Authors express our heartfelt thanks to the Director, ICAR-CIFE.

References

1. *Karolina* H, Anna G & Indrani K, *Phytoplankton* species assemblages and their relationship to hydrographic factors—a study at the old port in *Mangalore,* coastal Arabian Sea, *Indian J. Mar. Sci.*, 38(2) (2009) 224-234.
2. Patil J S & Anil A C, Variations in phytoplankton community in a monsoon influenced tropical estuary, *Environ. Monit. Assess.,* 182 (2011) 291–300.
3. Baliarsingh S K, Srichandan S, Pati S K, Sahu K C, Dash S K, Aneesh A L & Srinivasa Kumar T, Phytoplankton community structure along offshore transects of some Indian estuaries of east coast: An experience with a summer cruise, *Indian J. Geo Mar. Sci.*, 44(5) (2015) 01-14.
4. Dehadrai P V & Bhargava R M S, Distribution of chlorophyll, carotenoids and phytoplankton in relation to certain environmental factors along the central west coast of India, *Mar. Biol.*, 17(1972) 30 – 37.
5. Devassy V P & Goes J I, Phytoplankton community structure and succession in a tropical estuarine complex central west coast of India, *Est. Coast. Shelf Sci.*, 27(1988) 671–685.
6. Gabriel U I, Benedict O O & Irom B O, Plankton distribution and diversity in tropical earthen fish ponds, *Environ and Nat Resour. Res.*, 3(3) (2013) 45-51.
7. Caron D A & Countway P D, Hypotheses on the role of the protistan rare biosphere in a changing world, *Aq. Microb. Ecol.*, 57 (2009) 227-238.
8. Kleiber M, Body size and metabolic rate, *Physiol. Rev.*, 27(1947) 511-541.
9. Lea Carolina de O C, Joao A X, Luis Fernando de M N, Ana Maria V de A, Wilson W J & Mario R C F, Polyculture of *Litopenaeus vannamei* shrimp and *Mugil platanus* mullet in earthen ponds, *R. Bras. Zootec.*, 42(9) (2013) 605-611.
10. Mohanty R K, Kumar A, Mishra A, Panda D K & Patil D U, Water Budgeting and Management: Enhancing Aquacultural Water Productivity, *Res. Bull. Dir Water Manage.*, 63 (2014) 1-70.
11. Adams V D, Water and wastewater examination manual (Lewis Publishers Inc. Michigan, USA) 1990, pp. 247.
12. Lobban C S, Chapman D J & Kremer B P, Experimental Phycology: A laboratory manual (Cambridge University Press, Massachusetts) 1988, pp. 38–39.
13. APHA US Standard methods for the examination of water and wastewater, 19th edition, American Public Health Association, Washington DC, 2005.
14. Subrahmanyan R, Studies on the phytoplankton of the west coast of India. *Indian Acd. Sci.,* 50 (1959) 113-252.
15. Hammer O, Harper D A T & Ryan P D PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaentologia Electronica*, 4(1) (2001) 9.
16. SAS Institute, *SAS/STAT. User's Guide, Version 9.2, 4th ed. Vol. 1.* SAS Institute, Cary, NC, (2012).
17. Ter Braak CJF, Canonical Correspondence Analysis: A New Eigenvector Technique for Multivariate Direct Gradient Analysis, *Ecology*, 67 (1986) 1167-1179.
18. Ryther J H & Dunstan W M, Nitrogen, phosphorus and eutrophication in the coastal marine environment, *Science*, 171(1971) 1008-1013.
19. Rudresh K, Seasonal variation of nitrate in natural water of Bangalore north, *Int. J. Adv. Res.*, 2 (11) (2014) 1120-1122.
20. Reynolds C S, *The ecology of freshwater phytoplankton* (Cambridge studies in ecology. Cambridge University Press, Cambridge) 1984.
21. Rajasegar M, Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming, *J. Envt. Bio.*, 24 (2003) 95-101.
22. Mohanty R K, Jena S K, Thakur, A K & Patil D U, Impact of high-density stocking and selective harvesting on yield and water productivity of deepwater rice-fish systems, *Agri. Water Manage.*, 96(12) (2009) 1844-1850.
23. Boyd C E, Tucker C S, Mcnevin A, Bostick K & Clay J, Indicators of resource use efficiency and environmental performance in fish and crustacean aquaculture, *Rev. Fish. Sci.*, 15(327) (2007) 360.
24. Moss B, *Ecology of freshwaters: Man and medium* (Oxford, Blackwell Scientific Publ., 2nd ed, : London, UK) 1988.
25. Scheffer M, *Ecology of Shallow Lakes* (Chapman & Hall, London) 1998, pp. 357.
26. Demir N & Kirkagac M U, Plankton composition and water quality in a pond of spring origin in Turkey, *Limnology*, 6 (2005) 189–194.
27. Borics G, Grigorzky I, Szabo S & Padisak J, Phytoplankton associations in a small hypertrophic fish pond in east Hungrary during a change from bottom-up to top-down control, *Hydrobiologia*, 424 (1-30) (2000),79-90.
28. Arthur R. Miller, Ecological Balance in Semi-Enclosed Seas, *Envtl. Aff. L. Rev*, 2(1) (1972), 191-204.
29. Vijayakumar S, Rajan K M, Mridula R M & Hariharan V, Seasonal distribution and behavior of

nutrients with reference to tidal rhythm in the Mulki estuary, southwest coast of India, *J. Mar. Biol. Ass. India*, 42 (2000) 21-24.

30. Surana R, Gadhia M & Ansari E, Assessment of physico-chemical characterstics and pollution status of Tapi estuary at Dumas jetty, Surat, *Int. J. Inno. Res. in Sci,, Eng. and Tech*, 2 (10) (2013) 5351-5357.
31. Chopin T, Buschmann A H, Halling C, Troell M, Kautsky N, Neori A., Kraemer G P, Zertuche-Gonzalez J A, Yarish C & Neefus C, Integrating seaweeds into marine aquaculture systems: a key toward sustainability, *J. Phycol.*, 37 (2001) 975–986.
32. Chopin T, Robinson S, Sawhney M, Bastarache S, Belyea E, Shea R, Armstrong W, Stewart & Fitzgerald P, The AquaNet integrated multi-trophic aquaculture project: rationale of the project and development of kelp cultivation as the inorganic extractive component of the system, *Bull. Aqua. Asso.Canada*, 104(3) (2004) 11-18.
33. Saravanakumar A M, Rajkumar J, Sesh Serebiah & Thivakaran G A, Abundance and seasonal variations of zooplankton in the arid zone mangroves of Gulf of Kachchh-Gujarat, West coast of India, *Pak. J. Biol. Sci.*, 10 (2007) 3525-3532.
34. Sampathkumar P and Kannan L, Seasonal variations in physicochemical characterstics in the tranquebar, Nagapattanam region south east coast of India, *Pollut. Res.*, 17(1998) 397-402.
35. Gowda G, Gupta T R C, Rajesh K M, Gowda H, Lingadhal C & Ramesh A M, Seasonal distribution of phytoplankton in Nethravathi estuary, Mangalore, *J. Mar. Biol. Ass. India*, 43 (2001) 31-40.
36. Adebisi A A, The physico-chemical hydrology of tropical seasonal river upper Ogun River, *Hydrobiologia*, 79 (1981) 157-165.
37. Ajani E K, Effects of biotic and abiotic components of the habitat on fish productivity in Lagos Lagoon, Nigeria, Ph.D Thesis University of Ibadan, 2001.
38. Silva E I L, Phytoplankton characteristics, trophic evolution and nutrient dynamics in an urban eutrophic Lake: Kandy Lake in Sri Lanka, in: Restoration and management of tropical eutrophic lakes, edited by M. V. Reddy (Oxford and IBH Publishing) 2004, pp. 219-260.
39. Harish, Limnology of ponds and lakes of Mysore, Karnataka, India, Ph.D. Thesis, Mysore University, 2002.
40. Nirmal Kumar J I, Kumar R N & Bhatt I, Study of Cultural Eutrophication in relation to the plant diversity of Wetland Rathreshwar in central Gujarat, in: *Aquatic Biodiversity Scenario*, (Discovery Publication House, New Delhi), 2005, pp. 152-170.