Turkish Journal of Fisheries and Aquatic Sciences 16: 767-777 (2016)
www.trjfas.org
ISSN 1303-2712
DOI: 10.4194/1303-2712-v16_4_03

RESEARCH PAPER

Correlation of Phytoplankton Biomass (Chlorophyll-*a*) and Nutrients with the Catch Per Unit Effort in the PFZ Forecast Areas of Northern Bay of Bengal during Simultaneous Validation of Winter Fishing Season

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Received 29 Mar 2016
Accepted 02 June 2016

Abstract

The paper discusses the correlation between the Catch per Unit Effort (CPUE) of fishes with the phytoplankton biomass (chlorophyll-*a*) and nutrients in the West Bengal marine fishing zone (northern Bay of Bengal) during the post-monsoon season of 2010-11 and 2011-12. A total of 12 Potential Fishing Zone forecasts were simultaneously validated on board, covering 70 random samplings points wherein the physico-chemical parameters were also measured. A strong positive correlation of the CPUE with phytoplankton biomass was observed. The CPUE also positively correlated with the essential nutrients like dissolved inorganic phosphate (DIP), dissolved inorganic nitrate (DIN) and silicate. Four components were figured out in the principal component analysis out of 11 environmental variables. The first component primarily consisted of salinity, Secchi depth (positive loadings), turbidity and dissolve oxygen (DO) (negative loadings). Increases in component 2 were associated with increases in nutrients (silicate, nitrate and phosphate). The CPUE was much higher (8.15±6.08 kg/hour) in the PFZ forecast zones compared to the areas outside the forecast area (3.51±1.61 kg/hour).

Keywords: Catch per unit effort, northern Bay of Bengal, phytoplankton biomass, PFZ forecast, nutrient.

Introduction

India has a coastline over 7200 km long. It is bestowed with significant fish resources. In order to explore and exploit these natural resources from the point of view of the Indian economy, the Indian National Center for Ocean Information Services (INCOIS) operates nation-wide and has popularized the Potential Fishing Zone (PFZ) forecast with the help of Remote Sensing and GIS technologies. The PFZ forecast methodology was developed at the Space Applications Centre, Indian Space Research Organization and validated in collaboration with the Fishery Survey of India and other national fisheries institutes and state fisheries departments. INCOIS generated the PFZ forecast based on satellite-derived data of Sea Surface Temperature (SST) and chlorophyll-*a*. Satellite remote-sensing provides synoptic views of the ocean and is capable of detecting mesoscale features through thermal infrared and visible sensors; hence, it can be useful for locating potential fishing zones (PFZs) (Solanki *et al.*, 2005). Apart from the physical processes which are extracted from SST, chlorophyll-*a* or phytoplankton biomass, spots of weak SST gradients also act as indicators for locations of fish schools in tropical oceans (Ali *et al.*, 2010). Natural variations in fish stocks are caused by complex interactions of oceanic, physical, chemical and biological processes (Solanki *et al.*, 2003). Such species channel energy and nutrients from planktonic primary and secondary producers to top predators thus play an important role in regulating ecosystem dynamics (Frederiksen *et al.*, 2006). Conservative characteristics such as temperature and salinity are not influenced by the primary productivity of the system, but non-conservative characteristics such as dissolved oxygen, nutrient and chlorophyll-*a* concentrations are regulated directly or indirectly (Manasrah *et al.*,, 2006). Although the abundance of fish can be correlated with environmental variables, the actions and interactions of these variables are often so complex that the causal relationships cannot be demonstrated unequivocally (Ansari *et al.*, 2003). The Bay of Bengal (BOB) is unique because of its large seasonal freshwater input, which makes the waters layers of the northern part of this bay less saline and highly stratified. The BOB is a cyclone-prone region and these episodic events are likely to churn up the area, injecting nutrients to the shallow euphotic zone (due to lesser light intensity owing to frequent prevalence of cloud cover and turbidity arising from

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sediment influx) and thereby enhancing production in the upper layers (Madhupratap *et al.*, 2003).

There are several authors' work on PFZ validation through direct or indirect methods, viz. Solanki *et al*. (2003); Choudhury *et al*. (2007); Srinivasa *et al*. (2008); Pillai and Nair (2010); Solanki *et al*. (2010); Chandran *et al*. (2004); Deshpande *et al*. (2011); Nammalwar *et al*. (2013); Bhaware *et al*. (2013). However, studies related to validation of the PFZ advisory from the biophysical point of view are rarely reported.

Compared to the other parts of BOB and the Arabian Sea, the northern BOB is comparatively less studied from this perspective. Only a handful of authors like Shah *et al.* (2008) are known to have conducted researches on phytoplankton and related nutrient distribution in the Bangladesh part, Manna *et al.* (2010) at Indian Sundarbans, Vijayakumaran (2005) at Visakhapatnam, Madhupratap *et al.* (2003) in central and western Bay of Bengal. Nutrient dynamic studies of the Bay of Bengal region has been done by different authors, viz. Gordon *et al.* (2002) and Prasanna *et al.* (2007). Ansari *et al.* (2003) studied the marine fish catch and physico-chemical parameters in the Goa coast of India. They performed principal component analysis (PCA) and found that dissolved oxygen (DO), chlorophyll-*a*, macrobenthic density, sediment-pH and particulate organic carbon (POC) are of primary importance, whereas salinity, temperature, zooplankton density, macrobenthic biomass and pH are of secondary importance among environmental factors controlling the temporal variations in trawl catches in the bay-estuarine system of Goa.

Maes *et al.* (2004) carried out statistical modeling of 15 commonest fish among the Scheldt estuarine species of Belgium in relation to environmental influence and fish population dynamics. They established that DO was the most important predictor of fish abundance, suggesting that the estuary had suffered from poor water quality during the survey. Temperature, salinity, freshwater flow, suspended solids and chlorophyll-*a* concentrations were minor determinants of fish abundance. Kupschus and Tremain (2001) found the basis of fish aggregation in different environmental aspects in the subtropical estuary of the Indian River Lagoon, Florida. They suggested that distributions of the more mobile organisms are influenced more by physical conditions than by biological interactions. Lanz *et al.* (2009) found that the SST gradient was more strongly associated with the abundance of the species, they studied; but except the northern Anchovy the SST did not have a significant effect on other species.

The objectives of the present study were to establish the relation between physico-chemical parameters of the sea water (nutrient and phytoplankton biomass) and CPUE in the PFZ forecasted area of the northern BOB off the West Bengal coast and to find out the difference of CPUE within and beyond the PFZ forecast areas. It was also intended to explore the interaction between biophysical factors and the fish aggregation that can be used for the generation of the PFZ advisory.

Materials and Methods

Study Area

The study was conducted in the northern part of the Bay of Bengal off the West Bengal coast (Figure 1). This estuarine portion of the Bay of Bengal is very dynamic in nature. Shallow transition zones between freshwater and marine environments provide nursery areas for juveniles and wintering or spawning grounds to which mature individuals return on an annual basis (Maes *et al.,* 2004). It is endowed with the world's second largest hydrological basin that is the Ganga-Brahmaputra-Meghna (GBM) river basin (Heileman *et al.,* 2010). Huge sediment load from this GBM system has given rise to the world's largest mangrove ecosystem i.e. Sundarbans (shared by India and Bangladesh) lays in its vicinity.

BOB is situated in the tropical monsoon belt and it is profoundly influenced by the monsoon rains, storm surges, cyclones, super cyclones, tsunamis and so forth (Heileman *et al.,* 2010). Monsoon rains and flood waters produce a warm, low-salinity, nutrient and oxygen-rich layer extending to a depth of 100-150 m; this layer floats above a deeper, more saline, cooler layer which does not change significantly with the monsoon (Dwivedi and Choubey, 1998). Coastal and estuarine ecosystems are exposed to great environmental variability (Maes *et al.,* 2004). The Sundarbans Estuary has also been identified as a nursing ground for various types of estuarine and marine fish species. The nutrient concentration of the Sundarbans Estuary of northern Bay of Bengal is also high because of the inflow of the Ganga-Brahmaputra-Meghna system and the decomposition of mangrove litter. Mangrove dominated estuarine systems act as a source of nutrients and the source strength of nutrients is controlled by the input of litter and sediment-associated nutrients that are released during estuarine transport (Mukhopadhyay *et al.,* 2006). Fisheries of the Bay of Bengal Large Marine Ecosystem target a wide range of species, including sardine, anchovy, scad, shad, mackerel, snapper, emperor, grouper, pike-eel, tuna, shark, ornamental reef fish, shrimp, bivalve shellfish and seaweed (Preston 2004).

Sampling Strategy

The present study was conducted by means of onboard validation of the INCOIS generated PFZ forecasts at selected transects by analyzing the physico-chemical parameter of the ambient sea water. A total number of 12 forecasts were simultaneously

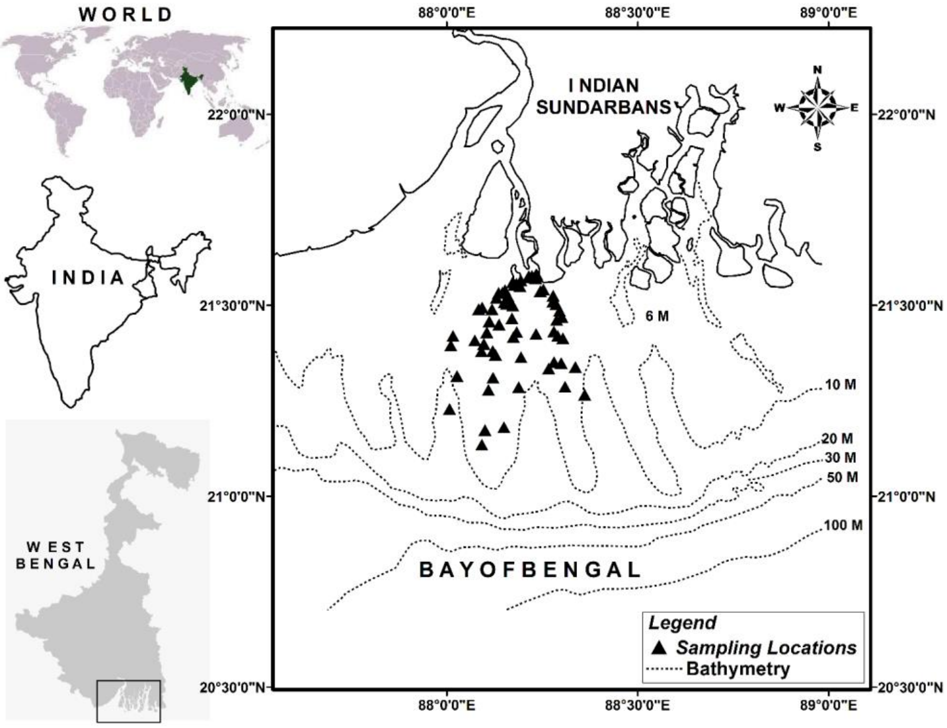


Figure 1. Sampling locations map and bathymetry of the study area, Sundarbans estuary off West Bengal coast, India in the northern Bay of Bengal. Depth contours are in meters.

validated during the winters of the years 2010 to 2012 in the northern Bay of Bengal by hiring fishing boats from the Frasergunje Fishing Harbour, West Bengal, India. All the boats were fitted with six-cylinder 160 HP engines, were 56-59 feet in length and displaced 30-35 tonnes of water, with a carrying capacity of 25-30 tonnes on average. All the validations were conducted using gill nets. The fishing boats were used to survey the PFZ and non-PFZ areas with the help of the Global Positioning System (GPS). The route the cruises made was tracked by Garmin Oregon 300 GPS. The CPUE in its basic form can be defined as the total catch divided by the total fishing effort in a given period, or in formula $U = C/f$ (Gulland 1983), in which U denotes the CPUE, C denotes the total catch and f stands for the total fishing effort. The CPUE was calculated in kg per hour. In order to understand the relation between water quality, phytoplankton biomass (chlorophyll-*a*) and CPUE, different physico-chemical parameters of seawater were analyzed. Water samples were collected in washed glass bottles from two to three centimeters below the surface. The engine of the boats was stopped for fifteen minutes before each sampling in order to provide the ambient water mass to attain equilibrium. SST, pH, salinity, DO, water depth, Secchi depth, turbidity and the nutrients (DIN, DIP and Silicate) were measured on board. All the samples taken on a single day were collected in one-hour interval from morning (07:00 hour) to afternoon (15:00 hour). The sampling was done from November to March every year, starting on 2010 and continuing up to 2012.

Instrumentation and Analysis

pH and water temperature were measured using the multi-kit (WTW Multi 340 i Set, Germany) fitted with the WTW SenTix 41-3 probe (for pH), whereas salinity was measured using the WTW Tetracon325 probe attached to the same multikit. Water samples were fixed immediately after sampling by Winkler I and II, and dissolved oxygen (DO) was measured immediately afterwards by Winkler's iodometric titration method.

In-vivo chlorophyll-*a* was estimated instantaneously by AquaFluor handheld fluorometer (Turner Designs). The fluorometer was calibrated before each cruise by a well preserved standard chlorophyll-*a* solution which was prepared from its lyophilized form (Sigma chemicals, Product no. C6144-1MG).

Turbidity was measured by Eutech Turbidity Meter TN 100 and euphotic depth was determined using a Secchi disk.

Nutrients were measured on spot photometrically using an instrument named Spectroquant Nova 60 (Emerck, Germany). Specific chemical test kits were used for measurement of dissolved nutrients like nitrate (part no.1.14773.0001), phosphate (part no. 1.4848.0001), silicate (part no. 1.14794.0001), ammonia (part no. 1.14752.0001) and iron (part no. 1.14761.0002).

All the statistical analyses were done by using SPSS 16.0 statistical software and graphs were prepared in Origin 6.1. The Pearson type of correlation test was applied in the present study.

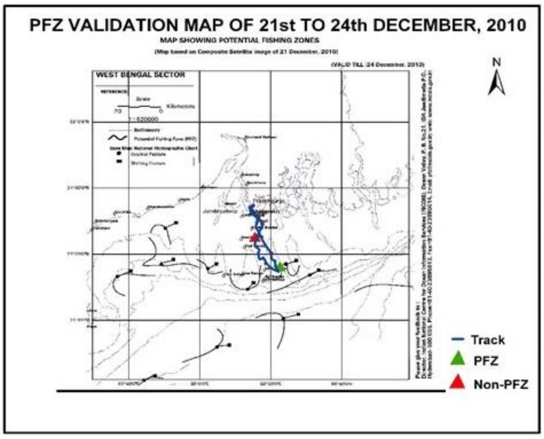
Results and Discussion

PFZ Validation

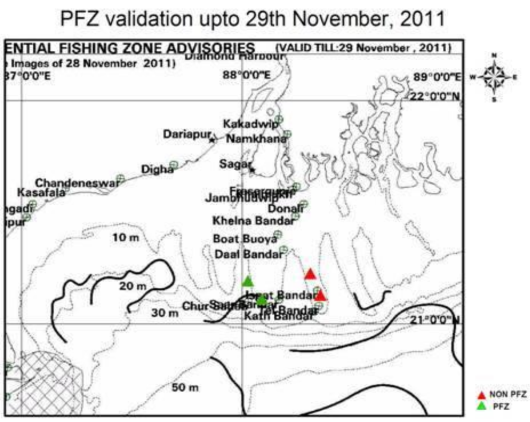
The 12 simultaneous validation or direct validation of the PFZ along with the nutrient dynamic in relation to the fish catch of the estuarine water of the northern part of the Bay of Bengal was studied during the winter fishing season (November to March) between 2010 and 2012. The study area of the northern Bay of Bengal off West Bengal coast is a shallow region (depth ranged between 1.0 m to 32.0 m) due to the high sediment load of the GBM basin with a varying range of nutrient concentration. The PFZ and non-PFZ validations of the five days are shown on Figure 2 that contains the catch zone for PFZ and non-PFZ along with the details of fishing viz. gear, fishing days, number of haul, fishing hour, type of fish caught, CPUE and cost. All the validation was conducted by gill net fishery. It is clearly observed that the catch is higher in the potential fishing zone in comparison to non-potential fishing zone. The CPUE values in PFZ and non-PFZ zone are represented in Figure 3. Similar results have also been estimated by different authors, like Choudhury *et al*. (2007); Deshpande *et al*. (2011); Nammalwar *et al*. (2013) and Bhaware *et al*. (2013). Deshpande *et al*. (2011) validated the PFZ advisory using direct and indirect methods. Choudhury *et al*. (2007) estimated about two to three fold increase in fish catch in the integrated PFZ areas during validation experiment. Hilsa Shad (*Tenualosa ilisha* Hamilton 1822), Silver Pomfret (*Pampus argenteus* Euphrasen 1788), Cat fish (*Arius* sp.) and Indian Mackerel (*Rastrelliger kanagurta* Cuvier 1816*)* were the key species of the catch. During the validation of the PFZ forecast we also collected the environmental variables along with the catch details. The structure and abundance of bay-estuarine fish communities are greatly influenced by a wide variety of environmental variables (Ansari *et al*., 2003).

Physico-Chemical Variables

Table 1 reflects the data of physico-chemical parameters analyzed during this study period. The mean salinity of the seawater was found to be 23.81±1.99 ppt in the post monsoon period, which is quite low in salinity. The mean temperature of the surface water was 24.18±2.01°C during 08:30 to

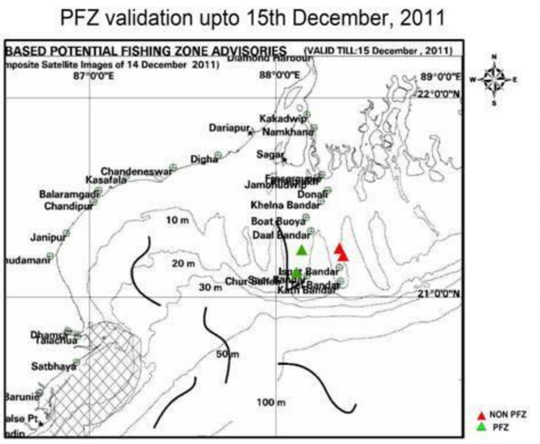


Fish Catch Details against PFZ forecast 21.12.10-24.12.10	PFZ	Non-PFZ
Type of fishing	Gill net	Gill net
Duration of total trip (days)	4	5
No. of hauls	9	5
No. of fishing hour	78	90
Total catch(kg)	550	430
CPUE (kg/hour)	7.05	4.78
Major fish species	*Pampus argenteus*, Cat Fish	*Rastrelliger Kanagutra*
Approximate Cost (Rs.)	82,500	43,000

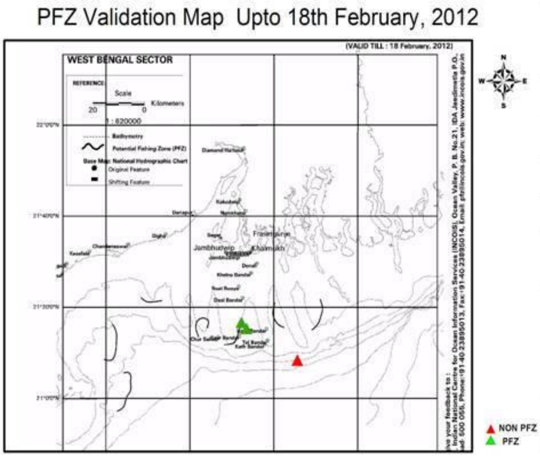


Fish Catch Details against PFZ forecast (valid up to 29.11.11)	PFZ	Non-PFZ
Type of fishing	Gill net	Gill net
Day	1	1
No. of hauls	2	2
No. of fishing hour	14	10
Total catch(kg)	110	25
CPUE (kg/hour)	7.86	2.5
Major fish species	*Tenualosa ilisha* *Pampus argenteus*	*Tenualosa ilisha* Cat Fish
Approximate Cost (Rs.)	18,500	4,500

Figure 2. Simultaneous validation of potential fishing zone with comparison of non-potential fishing zone.



Fish Catch Details against PFZ forecast (valid up to 15.12.11)	PFZ	Non-PFZ
Type of fishing	Gill net	Gill net
Day	1	1
No. of hauls	2	2
No. of fishing hour	9	11
Total catch(kg)	30	20
CPUE (kg/hour)	3.33	1.81
Major fish species	*Tenualosa ilisha, Cat fish*	*Chinese Pomfrate,* Cat Fish
Approximate Cost (Rs.)	4,500	1,200



Fish Catch Details against PFZ forecast (valid up to 18.02.12)	PFZ	Non-PFZ
Type of fishing	Gill net	Gill net
Day	1	1
No. of hauls	2	1
No. of fishing hour	16	5
Total catch(kg)	105	20
CPUE (kg/hour)	6.56	4
Major fish species	*Hilsa megaloptera, Cat fish*	*Hilsa megaloptera*
Approximate Cost (Rs.)	6,300	1,200

Figure 2. Continued.

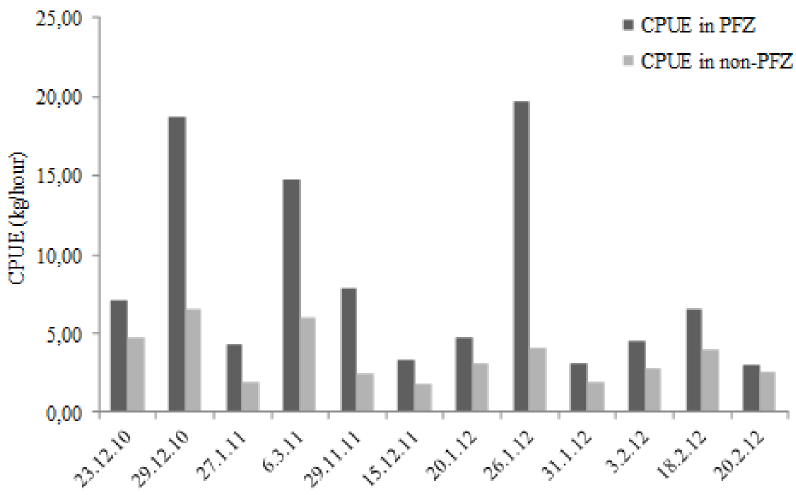


Figure 3. CPUE inside and outside of the PFZ during the simultaneous validation.

13:00 hour. The Figure 4 shows a comparison between in situ SST and MODIS Aqua derived SST, which exhibits a similarity. Satellite derived temperature data was used for PFZ prediction. Phytoplankton abundance and temperature are considered important variables controlling the fish population (Solanki *et al.*, 2010). Secchi depth transparency exhibited values from 39.0 cm to 420.0 cm. Mean dissolved oxygen (mg/l) content was found to be 4.61±0.91.

No particular trend in terms of magnitude was observed for chlorophyll-*a* (including pheophytin-a) and the nutrients (DIN, DIP and silicate) along the longitudinal route of sampling, neither any significant pattern for dissolved oxygen change could be observed. Knowledge about the relative importance of

Table 1. Statistical details of the Physico-chemical parameters and CPUE of North Bay of Bengal, West Bengal during the winter fishing season of 2010 to 2012

	N	Range	Minimum	Maximum	Mean	Std. Error	Std. Deviation
pH	70	0.60	8.02	8.62	8.22	0.01	0.10
Salinity (ppt)	70	7.90	19.90	27.80	23.81	0.24	1.99
Turbidity (NTU)	70	92.00	4.00	96.00	29.8	2.25	18.9
DO (mg/l)	70	3.96	3.27	7.23	4.61	0.11	0.91
SST (°C)	70	9.60	18.80	28.40	24.2	0.24	2.01
Secchi_Depth (cm)	70	381.00	39.00	420.00	99.62	8.10	67.8
Depth (m)	70	31.00	1.00	32.00	12.23	0.59	4.90
Silicate (mg/l)	70	1.77	0.36	2.13	0.95	0.04	0.36
Phosphate (mg/l)	70	1.03	0.01	1.04	0.21	0.03	0.21
Nitrate (mg/l)	70	1.10	0.10	1.20	0.56	0.040	0.33
Chl *a* (mg/l)	70	4.57	1.56	6.13	3.55	0.16	1.36
CPUE (kg/hour)	70	11.34	1.56	12.90	5.91	0.347	2.90

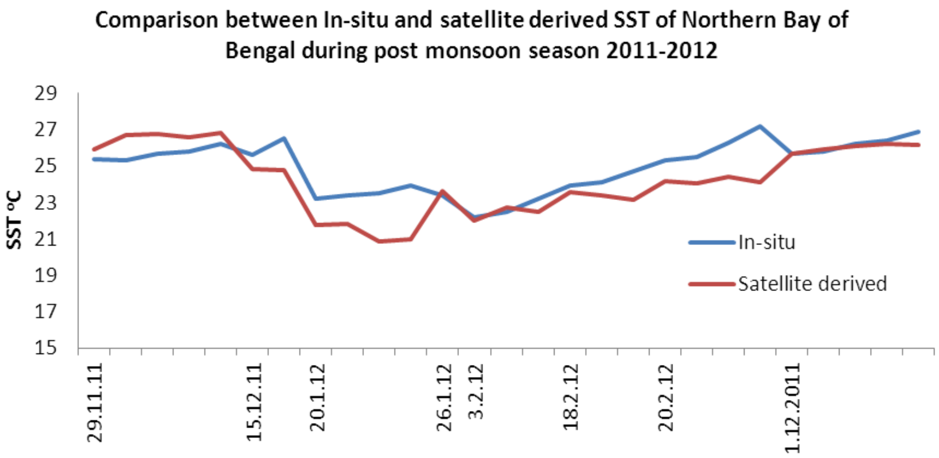


Figure 4. Graph showing the comparison between in-situ measured SST and MODIS derived SST of northern BOB.

the biological and environmental influences upon fish assemblages in estuaries is a crucial consideration in choosing the most accurate and precise estimates of single species stocks (Kupschus and Tremain 2001). The variations of environmental variables during the simultaneous validation were exhibited in Figure 5 along with the standard deviation. The salinity was highest on 6th March, 2011 (27.80 ppt) and it is found to increase from late post monsoon to early pre monsoon.

Relation between Catch and Environmental Variables

In the present study the CPUE was positively correlated (R=0.748, P<0.0001) with phytoplankton biomass (Figure 6). Nutrient-rich water supports the increase in phytoplankton biomass, which is the cause of fish aggregation.

The CPUE was also positively correlated with the dissolved inorganic phosphate (DIP) (R=0.357, P<0.002) (Figure 7), dissolved inorganic nitrate (DIN) (R=0.659, P<0.0001) (Figure 8) and silicate (R=0.425, P<0.0001) (Figure 9). Manna *et al.* (2010) found positive correlation of chlorophyll-*a* with the nitrogen, silicate and phosphate in the Indian Sundarbans Estuary. The nutrient level of seawater is a significant factor for increase in the fish catch. Hoyer *et al.* (2002) found the relationship between chlorophyll-*a* and the nutrient content. The CPUE has also been observed to be much higher (8.15±6.08) within the PFZ forecast zones than outside of the forecast area (3.51±1.61) (Figure 3). However, the overall CPUE has been observed to be decreasing (R=0.80) in recent years (2008-2011) due to overfishing, increased fishing effort and a lack of proper management practice (Dutta *et al.*, 2014).

Nutrient input to the sea may occur anthropogenically or naturally through physical, chemical and biological processes (Manasrah *et al.*, 2006). In order to protect and manage estuarine fish stocks properly, resource managers must understand

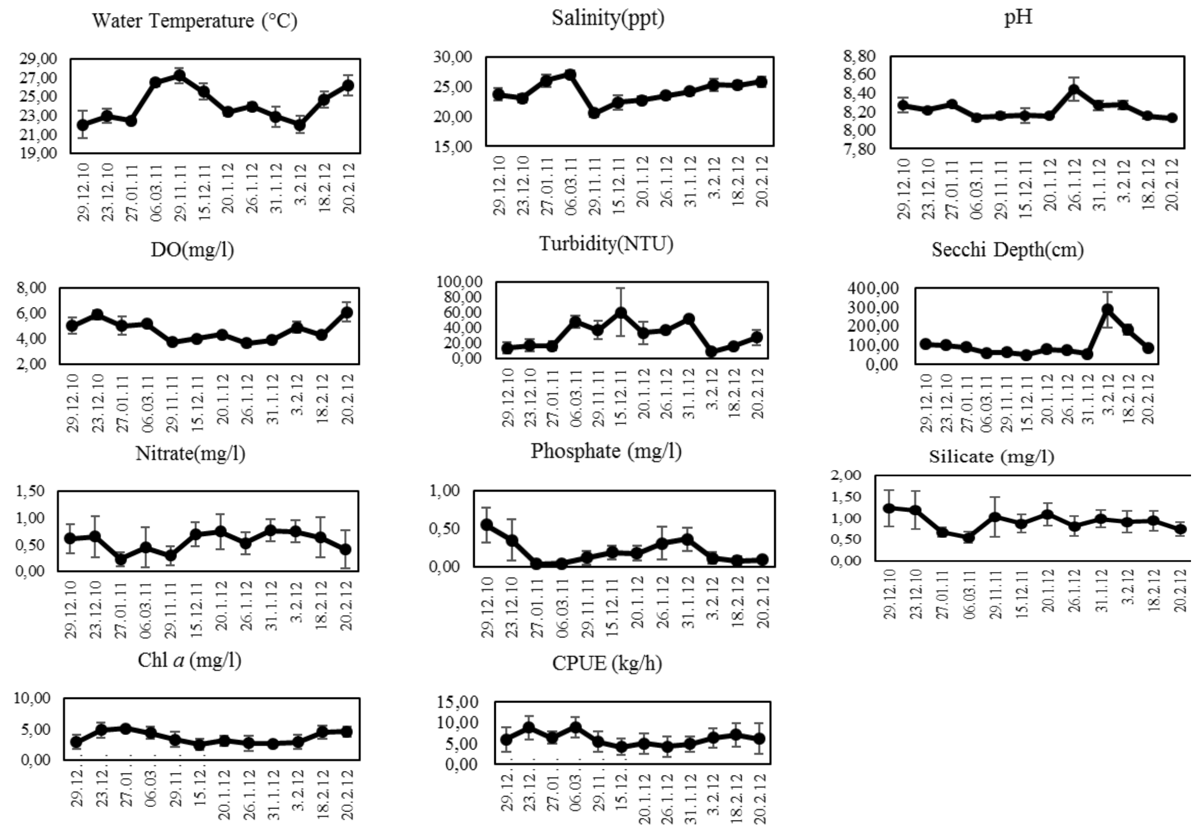


Figure 5. Variations in various environmental variables in Bay of Bengal estuarine system of West Bengal during the study period. Mean water temperature (C); salinity; pH, dissolved oxygen (DO) (ml/l); turbidity (NTU); Secchi depth (cm); nitrate (mg/l); phosphate (mg/l); silicate (mg/l); chlorophyll-a (mg/l) and CPUE (kg/h). Vertical bars represent standard deviation.

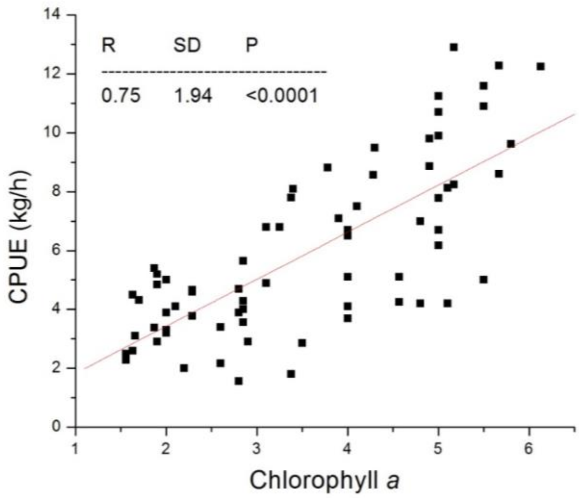


Figure 6. Relationship between CPUE and chlorophyll-*a* in NBOB during post-monsoon season of 2010-12 (n=70).

and characterize the factors that influence the distribution and abundance of the species of interest (Kupschus and Tremain, 2001). Environmental factors not only facilitate fish assemblage but are also important for the management of fish resources through ecosystem based fishery management.

Physico-chemical Variable Groupings

The Principal Component Analysis (PCA) was executed among the 11 physico-chemical variables. The Kaiser–Meyer–Olkin (KMO) value was 0.550 and Bartlett's sphericity tests approximate Chi-Square was 257.2 and degree of freedom (df) is 55. Hence it

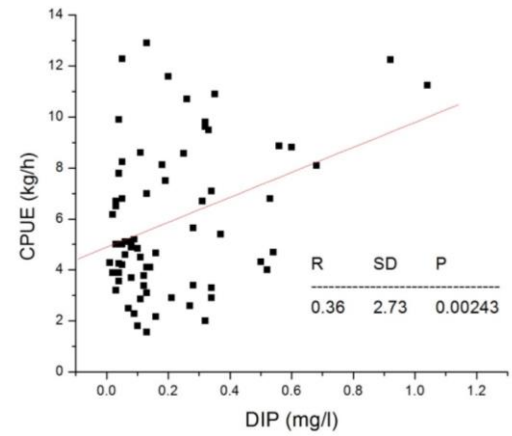


Figure 7. Relationship between DIP and CPUE in NBOB during post-monsoon season of 2010-12 (n=70).

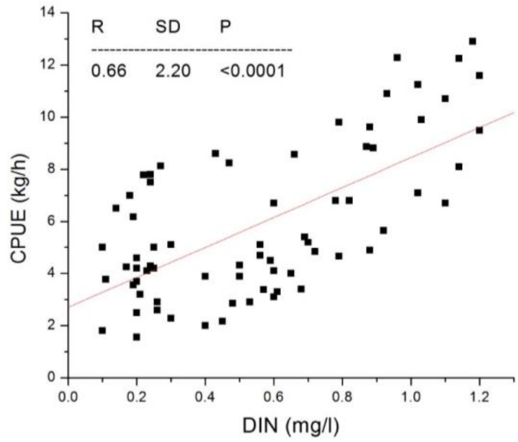


Figure 8. Relationship between DIN and CPUE in NBOB during post-monsoon season of 2010-12 (n=70).

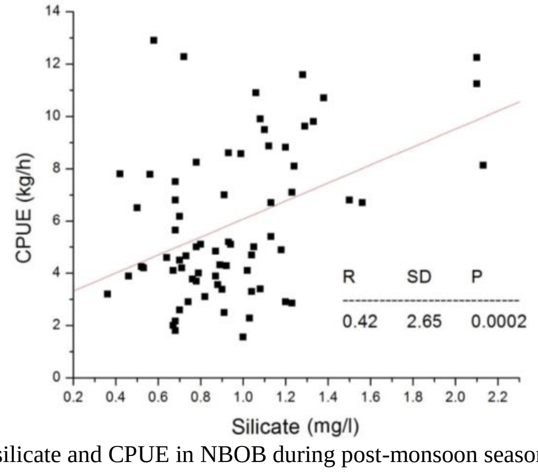


Figure 9. Relationship between silicate and CPUE in NBOB during post-monsoon season of 2010-12 (n=70).

can be stated that the data was mediocre for factor analysis. The total environmental variation was reduced to four components identified for further consideration based on eigen coefficients represented by each component (Table 2). The first master component termed physical properties dependent accounted for 24.1% of the observed environmental variations. This component primarily consisted of DO and Secchi depth (positive loadings), and turbidity and SST (negative loadings). The abundance of juvenile fish in estuarine systems may be due to the presence of turbid water which has been linked to reduced predation pressure (due to poor visibility), shelter and increased food resources (Blaber and Blaber, 1980).

Component 2 accounted for 21.01% of the

environmental variation and was termed salinity and nutrient dependent. Decreases in component 2 were associated with decreases in temperature. Increases in component 2 were associated with increases in nutrients (silicate, nitrate and phosphate). The schools of fish correlate with nutrient-rich waters, as well as circulation patterns such as temperature fronts (Choudhury *et al.*, 2007). Component 3 was termed chlorophyll-*a* dependent and accounted for 16.46% of environmental variation. Increases in component 3 were associated with increases in SST, chlorophyll-*a* and depth (positive loadings) and decreases in pH (negative loadings). Rise of SST stimulate the productivity of phytoplankton. The loading values of parameters in component 4 are lower than 0.5. Therefore, we did not consider component 4. The two component plot in rotated space has been shown on Figure 10. Component 1 consists of physical factors (DO, salinity, Secchi depth, depth) and chlorophyll-*a* and component 2 consists of nutrients (silicate, phosphate, nitrate) and pH.

Conclusions

On the whole it can be inferred that fish aggregation was mostly influenced by the nutrient of the sea water in the northern part of the BOB. Apart from the nutrient concentration, Chl *a*, DO, salinity and Secchi depth were also important factors for fish aggregation. So, these factors could also be included for the generation of PFZ advisory, laterally SST and Chl *a* concentration. It is obvious that in the coastal waters of northern BOB, salinity was very low in winter compared to other parts of the bay. Variations

Table 2. Principal component coefficients for 11 environmental variables coefficients>0.30 are included)

	Component			
	1	2	3	4
pH		0.305	-0.745	
Salinity	0.497	-0.532		0.466
Turbidity	-0.678	0.366		0.381
DO	0.511	-0.507		
SST	-0.582		0.557	
Secchi Depth	0.623	-0.322		-0.377
Depth			0.525	-0.458
Silicate	0.406	0.646	0.456	
Phosphate	0.441	0.764		
Nitrate	0.498	0.546		
Chl *a*	0.488		0.550	0.401
Percent variation	24.13	21.01	16.46	9.19

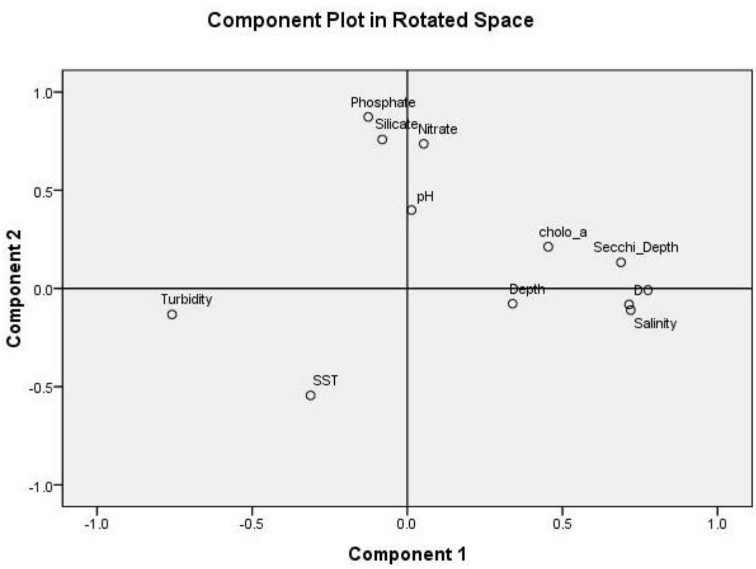


Figure 10. Component plot in rotated space, component 1 consist of physical factors (DO, salinity, Secchi depth, depth) and chlorophyll-*a* and component 2 consist of nutrients (silicate, phosphate, nitrate) and pH.

in salinity, runoff and precipitation regions seemed the most dominant factors for changes in fish assemblage, mainly by the displacement of estuarine habitats and by influencing the migration and recruitment of several species (Nyitrai *et al.*, 2012). The CPUE was high in the PFZ than non-PFZ. Along with the SST gradient and chlorophyll-*a* concentration in sea water, the nutrient was also the cause of fish aggregation which leads to economic growth due to increased CPUE and perennial demand for fish as a rich source of animal protein. The drop in CPUE has become a severe concern nowadays. A proper management approach can improve the catch in the long run. Catch and effort must have a restricted limit in accord with the calculation of proper stock assessment.

Acknowledgements

The authors are grateful to the fishermen from West Bengal coast for their help during data collection. The authors also readily acknowledge the invaluable contribution of the Indian National Center for Ocean Information Services (INCOIS) for funding the Potential Fishing Zone (PFZ) validation project, for conducting the present study.

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