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Dr. Debansu Sekhar Pramanik
Department of Zoology, D. R. Nayapalli College, Bhubaneswar-751012, Odisha

Swati Sucharita Mohanty
Department of Bioscience and Biotechnology, F. M. University, Balasore

Correspondence
Dr. Debansu Sekhar Pramanik
Sr. Lecturer, Department of Zoology, D.R. Nayapalli College, Bhubaneswar-751012, India.

Seasonal variation of primary productivity of Bay of Bengal at Chandipur-on Sea, Odisha

Debansu Sekhar Pramanik, Swati Sucharita Mohanty

Abstract
Seasonal variation of primary productivity (Gross Primary Productivity and Net Primary Productivity) was measured from January 2010 to December 2011, for a period of two years at five stations along Chandipur, Bay of Bengal, Odisha. Gross and Net primary production were least (GPP =153.48 and 147.25, NPP = 106.36 and 99.57 $gCm^{-2}d^{-1}$) during winter season in both the years. Average value of Gross primary production ranged between 171.25$gCm^{-2}d^{-1}$ and 181.39$gCm^{-2}d^{-1}$. Community respiration was found to be lesser from December to February where as higher values were observed during March to May in 2010 and 2011. Analysis of variance showed significant differences within seasons ($F = 38.04$, $P \leq 0.01$) in 2010 and ($F = 13.18$, $P \leq 0.01$) 2011. Correlation coefficient and probable errors for both the productivity with hydrological parameters was estimated temporally and spatially and the result indicated that temperature and transparency were major determinants controlling rate of primary production.

Keywords: Primary productivity, Chandipur, Bay of Bengal, Community respiration (CR)

1. Introduction
Coastal regions are the most productive ecosystems of the world, exemplified by the fact that coastal habitats provide feeding and reproduction ground for approximately 90% of the world's marine fish catch [1]. Within the vast fluid space of the seas, the bulk of the photosynthesis is carried out by microscopic alga- the simple but often remarkably beautiful, taxonomically and metabolically diverse cells of the phytoplankton. Related species of algae live on sediments and on a variety of other surfaces including a truly exotic habitat, the hides of whales [1, 2]. Phytoplankton is one of the initial biological component from which the energy is transferred to higher organisms through food chain [2, 3] thus referred as the primary producers. Primary production studies are concerned with the evaluation of the capacity of an ecosystem to build up, at the expense of external energy both radiant and chemical of high potentials for further transformation and flow to higher system levels [4]. The primary productivity of a water body is the manipulation of its biological production and forms the basis of the ecosystem functioning [4]. The process is centrally important to ecological processes and biochemical cycling and plays an important role in energy and organic matters available to the entire biological community [4, 5]. It is thus surprising, if not disconcerting as discussed by Williams that there is no consensus on a definition of planktonic primary productivity or its major components, net and gross primary production [6, 7].
The data on primary production from the Bay of Bengal is very meager. The Danish Galathea Expedition during her round-the-world cruise, made some measurements across Indian Ocean through the equatorial current system and the Bay of Bengal, of which two stations were from Andaman Sea. It was observed that in the eastern part of Bay of Bengal, the lower boundary of the photosynthetic layer was between 84-99 m and the stations located on the shelf were characterized by a high rate of production [2, 3, 5].
Productivity of marine and fresh water habitats including fishing grounds has been surveyed by several investigators like Prasanna kumar *et al.*, [6-10] but in this respect Bay of Bengal at Chandipur in Odisha being a tropical large basin (nearly equal to 1.25 times higher than Arabian sea) still paid less attention. As primary productivity plays an important role in energy and organic matters available to entire fish community, so the present study is an attempt to understand the seasonal cycle of the physical processes that are responsible for bringing about the observed variability in the primary productivity of Chandipur coast to study the seasonal variation of primary production in relation to some hydrological factors during 2010 and 2011.

2. Materials and Methods
2.1 Study site
The study site Chandipur (Fig.1), Bay of Bengal lies between latitude 21^0 3'-21^0 47' N and longitude 86^0 02'-87^0 20' E in the Balasore district of the state Odisha, India. The coastal plain of Chandipur is narrow and the river Budhabalanga opens to Bay of Bengal at Balaramgadi. It is one of the most important fish landing base of Odisha. The shelf water along the bay is nearly isothermal and within a range of 27-29 ^{0}C.The region receives 1600-1800 mm annual rainfall and experiences tropical monsoon climate with high temperature of 39-41 ^{0}C during summer [11]. Salinity of the Sea water varies seasonally with adequate rainfall due to south west monsoon, from June to September and some irregular rainfall during post-monsoon.

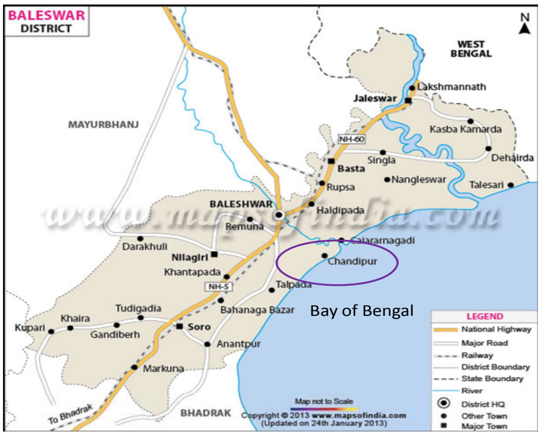

Fig 1: Map showing study site Chandipur on sea (Source- map of India)

2.2 Sampling of water
Water samples were collected in triplicates in each month from five stations as Balaramgadi (st 1), Chaumukh (st 2), Hanskara (st 3), Bahabalapur (st 4), Mahisali (st 5) located along 25 km stretches of Chandipur coast. Duplicate sets of experimental bottles of 200ml capacity each were filled with sample water, tied to a rope suspended by floats and left in water at the predetermined level. The sample in the first bottle was used immediately to determine the initial level of dissolved oxygen (DO) content followed by Wrinkler's volumetric method [12]. The light and dark bottles were incubated under water for a period of 24 hr at a depth of 10 cm and dissolved oxygen was measured. Primary productivity was calculated by oxygen method [13]. Oxygen values were converted to carbon values by applying the equation suggested by Thomas *et al.*, 1980.

Primary productivity (mg C) = O_2 (ml) x 0.536/PQ

Where PQ represents respiratory quotient which has a compromised value of 1.25.The value of 0.536 represents a constant to convert oxygen value (mg l^{-1}) to carbon value (gC l^{-1}).

Along with above, the field measurement of water parameters was done during whole study period. The water temperature was measured in situ by a mercury thermometer (0.1 ^{0}C graduation), pH (ELICO make, model 120), transparency (Secchidisc, cm) and salinity by practical units of standard method [13].

2.3 Data Analysis
Pearson's correlation coefficient and corresponding probable error (PE) were calculated to establish the relationship among water parameters (temperature, transparency, pH, salinity and dissolve oxygen) and dependent variables (GPP and NPP) both station wise and season wise. Two way analysis of variance (ANOVA) (Station x Season) of the dependent variables was conducted by 'statistical package for the social sciences (SPSS version 16.0).

3. Results
Annual range of GPP varied from 221.41gCm^{-2} day^{-1} (at st-1) to 197.1gCm^{-2} day^{-1} (at st-5) during summer season in 2010 (Fig.2a). In 2011 GPP (202.0gCm^{-2} day^{-1}) was found maximum at st-4 and minimum value (197.2gCm^{-2} day^{-1}) at st-3 in summer months (Fig.2b). Both GPP and NPP values were found to be higher in summer (221.4gCm^{-2} day $^{-1}$ and 144.2cm^{-2} day^{-1}) whereas lower values were marked in winter (143.6gCm^{-2} day^{-1}, 96.1g Cm^{-2}day^{-1}). Annual range of community respiration (CR) varied from 39.4gCm^{-2}day^{-1} to 78.8gCm^{-2} day^{-1} in 2010-2011. CR was found to be lesser from December to February where as higher values were observed during March to May. Average annual values of GPP and NPP in all the five stations demarcated that st-1 showed both higher values of GPP and NPP than others in 2011. No particular trend was observed in seasonal variations of NPP. On comparison of the monthly variations, an increasing trend was observed from September to February which is in agreement with Dash *et al*, [15].

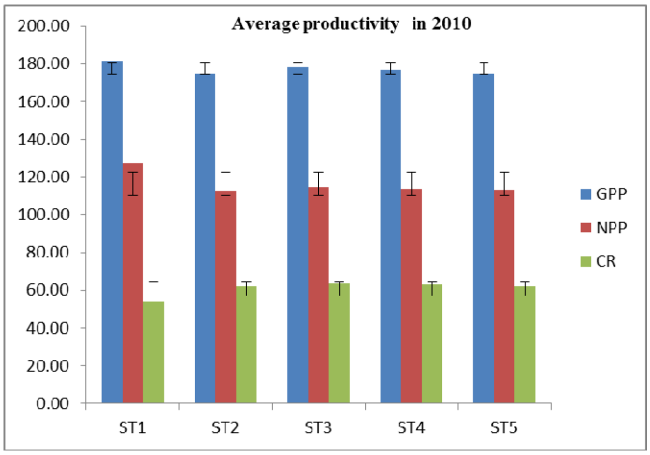

Fig 2a: Average productivity in the year 2010 at Chandipur

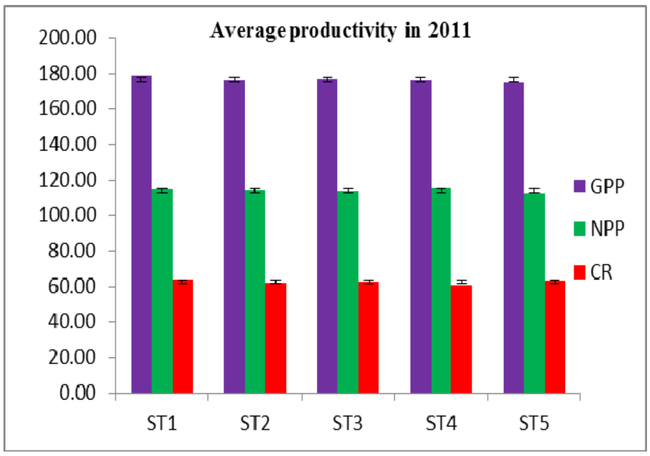

Fig 2b: Average productivity in the year 2011 at Chandipur

In 2010 annual range of water temperature varied from 17.3 – 30 ^{0}C and in 2011 the upper and lower limits varied from 15-31 ^{0}C. Minimum water temperature was found in the month of January (17 ^{0}C at st 3) and maximum (31 ^{0}C at st 1) in the month of May. Water transparency was varied between 100cm (January 2010, February 2011 and March 2011) and 25cm

(July 2010 and 2011) with a mean value of 61.1 ± 26. 5 cm. No significant difference was observed among months (F = 5. 152, P ≤ 0.01). The average pH value was found to be 8.48 ± 0.04 with variation of maximum value 9.73 ± 0.04 at station 4 in the month of March 2010 and 7.23 ± 0.2 as minimum at station 3 in July 2010. The average value of salinity in both the years showed a marked difference in the month of July (24%) to March (35%) and salinity values were inversely related to rain fall.

The ratio between NPP: GPP as well NPP: CR was calculated for 5 stations. No seasonal trend was observed for the ratios. The maximum value of NPP: GPP was found to be 0.703 at st-1 whereas the minimum of 0.643 at st-4 within two years study. NPP: CR was estimated and highest value of 2.491 at st-1 was found in 2010 and lowest of 1.865at st-4. In 2011 NPP: CR showed highest value of 1.997 at st-4 and lowest of 1.849 at st-5. CR% of GPP was accounted for 20-40% in both the years which showed a good index [9]. The NPP: CR showed the value above 1in all the seasons in both the years which was in accordance with previous works of Dash *et al.* [15]. Seasonally, highest value of NPP: GPP (0.773) was observed during winter and lowest of 0.601 in summer (2010). In 2011, the highest NPP: GPP was observed (0.728) in winter season whereas, lowest of (0.618) in post monsoon. The higher value of NPP: CR, (2.700) was found during winter season in 2011. Maximum CR% of GPP was calculated to be 39.920 in summer (2010) and 38.852 in summer 2011.In 2010, the minimum CR% of GPP was observed (27.392) in post monsoon and 27.243 in winter season during 2011.

Two way analysis of variance (ANOVA) was calculated to study the effect of stations and seasons on primary production for both the years (Table 1& 2). No significant difference of GPP and NPP in seasons was marked (F = 38.04; P ≤ 0.01; F = 13.18, P ≤ 0.01; F = 36.24, P ≤ 0.01 and F = 12.02, P ≤ 0.01) for both the years.

Table 1 Two way of analysis (Station x Season) of GPP and NPP for 2010

Parameters	Source	Sum Square	df	Mean Square	F	Sig.
GPP	Station	389.31	4	97.32	0.359^NS	0.836
	Season	30977.07	3	10325.69	38.04**	0.000
	Station X Season	7665.53	12	402.15	2.075*	0.042
	Error	10855.59	40	271.39		
	Total	49887.51	59			
NPP	Station	1905.22	4	476.30	2.458^NS	0.061
	Season	7665.99	3	2555.33	13.18**	0.000
	Station X Season	4825.82	12	56.96	0.294^NS	0.987
	Error	7751.81	40	193.79		
	Total	22148.86	59			

NS-Not significant at 5% level
** Significant at 5% level

Table 2 Two way of analysis (Station x Season) of GPP and NPP for 2011

Parameters	Source	Sum Square	df	Mean Square	F	Sig.
GPP	Station	81.596	4	20.399	0.063^NS	0.992
	Season	34942.83	3	11647.61	36.245**	0.000
	Station X Season	194.84	12	16.23	0.051^NS	1.000
	Error	12854.16	40	321.354		
	Total	48073.44	59			
NPP	Station	88.54357	4	22.136	0.086^NS	0.986
	Season	9228.27	3	3076.09	12.02**	0.000
	Station X Season	243.52	12	20.294	0.079^NS	1.000
	Error	10236.29	40	255.907		
	Total	19796.64	59			

NS- Not significant at 5% level
** Significant at 5% level

The coefficient correlations and probable errors for both GPP and NPP with hydrological parameters were calculated station wise and season wise. Both GPP and NPP showed positive correlation with water temperature, transparency and salinity. Temperature showed positive correlation in all most all the stations in both the years (Table 3 & 4).

Table 3 Coefficients of correlation and Probable errors for both GPP and NPP with hydrological Parameters at five stations of Chandipur in 2010

Parameters	Station1		Station2		Station3		Station4		Station5	
	GPP	NPP	GPP	NPP	GPP	NPP	GPP	NPP	GPP	NPP
Temp	0.359 0.170	0.515 0.143	0.009 0.195	-0.055 0.194	0.307 0.176	0.203 0.187	0.128 0.192	0.092 0.193	-0.202 0.187	-0.186 0.188
Trans	-0.312 0.176	-0.437 0.158	-0.264 0.181	-0.224 0.185	0.144 0.191	0.173 0.189	-0.271 0.180	-0.294 0.178	0.363 0.169	0.360 0.169
pH	-0.283 0.179	-0.385 0.176	-0.317 0.175	-0.294 0.178	0.062 0.194	0.068 0.194	-0.291 0.178	0.046 0.194	0.361 0.169	0.349 0.171
Salinity	-0.022 0.195	-0.345 0.171	-0.131 0.191	-0.079 0.193	0.020 0.195	0.006 0.195	0.175 0.189	0.045 0.194	-0.223 0.185	-0.206 0.186
DO	-0.191 0.188	-0.414 0.161	-0.272 0.180	-0.213 0.186	-0.024 0.195	-0.011 0.195	-0.324 0.174	-0.375 0.167	0.094 0.193	0.043 0.194

Table 4 Coefficients of correlation and Probable errors for both GPP and NPP with hydrological Parameters at five stations of Chandipur in 2011

Parameters	Station1		Station2		Station3		Station4		Station5	
	GPP	NPP	GPP	NPP	GPP	NPP	GPP	NPP	GPP	NPP
Temp	0.235 0.184	0.223 0.185	-0.214 0.186	0.040 0.194	0.231 0.184	0.262 0.181	-0.233 0.184	-0.249 0.183	0.254 0.182	0.285 0.179
Trans	-0.362 0.169	-0.326 0.174	0.148 0.190	-0.191 0.188	-0.202 0.187	-0.211 0.186	-0.027 0.195	-0.008 0.195	-0.298 0.177	-0.330 0.173
pH	0.063 0.194	0.040 0.194	0.147 0.190	-0.212 0.186	-0.412 0.162	-0.438 0.157	-0.040 0.194	-0.040 0.194	-0.447 0.156	-0.451 0.155
Salinity	0.082 0.193	0.081 0.193	0.050 0.194	-0.202 0.182	-0.048 0.194	-0.034 0.194	0.168 0.189	0.169 0.189	0.014 0.195	0.051 0.194
DO	-0.022 0.195	-0.006 0.195	-0.012 0.195	-0.210 0.186	-0.054 0.194	0.003 0.195	0.016 0.195	-0.019 0.195	0.053 0.194	-0.009 0.195

Transparency showed positive correlation with GPP and NPP (r =0.144.PE =0.191 and r =0.173,PE =0.189) at station 3 in 2010 and at station 5 (r =0.363,PE =0,160 and r =0.360,PE =0.169) in2010.pH showed positive correlation (r =0.063,PE =0.194 and r =0.040,PE 0.194) at station 1 in 2011.However,positive correlation(r =0.062,PE =0.194 and r =0.068,PE =0.194) of pH with GPP and NPP was observed at station 3 in 2010.Salinity showed positive correlation with GPP and NPP at stations in both the years. Dissolved oxygen showed negative correlation with GPP and NPP. No significant correlation either of GPP or NPP with all the water parameters like water temperature, transparency, pH, salinity and DO were observed in all the seasons (Table 5 & 6).

Table 5: Season wise coefficients of correlation and probable errors for both GPP and NPP with hydrological parameters during 2010

Parameters	Season1		Season2		Season3		Season4	
	GPP	NPP	GPP	NPP	GPP	NPP	GPP	NPP
Temp	0.035 0.174	0.240 0.164	-0.031 0.174	-0.169 0.169	-0.041 0.174	-0.126 0.171	0.056 0.174	0.081 0.173
Trans	0.036 0.174	-0.121 0.172	-0.043 0.174	-0.088 0.173	0.034 0.174	0.124 0.171	-0.015 0.174	-0.071 0.173
pH	-0.132 0.171	-0.283 0.160	-0.106 0.172	0.085 0.173	0.061 0.174	0.133 0.171	0.019 0.174	-0.053 0.174
Salinity	-0.167 0.169	-0.329 0.155	0.041 0.174	-0.205 0.167	0.232 0.165	0.205 0.167	0.010 0.174	-0.003 0.174
DO	-0.070 0.173	-0.269 0.162	-0.059 0.174	-0.139 0.179	-0.117 0.172	-0.070 0.173	-0.006 0.174	-0.066 0.173

Season 1 = summer, Season 2 = winter, Season 3= Monsoon and Season 4 = Post Monsoon

Table 6: Season wise coefficients of correlation and probable errors for both GPP and NPP with hydrological parameters during 2011

Parameters	Season1		Season2		Season3		Season4	
	GPP	NPP	GPP	NPP	GPP	NPP	GPP	NPP
Temp	0.018 0.174	-0.033 0.174	0.028 0.174	0.000 0.174	0.038 0.174	0.144 0.171	-0.046 0.174	0.203 0.167
Trans	-0.035 0.174	0.033 0.174	0.006 0.174	-0.027 0.174	0.016 0.174	0.019 0.174	0.052 0.174	-0.228 0.165
pH	-0.021 0.174	0.033 0.174	0.096 0.173	0.079 0.173	0.118 0.172	0.101 0.172	-0.139 0.171	-0.452 0.139
Salinity	0.408 0.145	0.436 0.141	-0.100 0.172	-0.152 0.170	-0.292 0.159	-0.252 0.163	0.051 0.174	-0.118 0.172
DO	-0.066 0.173	0.008 0.174	0.177 0.169	0.137 0.171	-0.093 0.173	-0.139 0.171	-0.271 0.161	-0.475 0.135

Table 7: Annual primary productivity in certain marine environments (Ref: Bulletin of ICAR by P V Nair, 1970)

Sl. No.	Locality	Production ($gCm^{-2}d^{-1}$)	Reference
1	Gulf of Mannar (Inshore within 10 m depth)	745	Prasad and Nair, 1963
2	Cochin Back waters	281	Qasim *et al*., 1968
3	West coast of India	434	Nair *et al*., 1968
4	East coast (continental shelf)	230	Nair *et al*., 1968
5	Mandapam reef	2500	Pillai and Nair 1969

Winter showed positive correlations of GPP and NPP with transparency, salinity and DO (r = 0.043, PE = 0.17; r = 0.041, PE = 0.17 and r = 0.059, PE = 0.17) in 2010 in contrast to year 2011 (r = 0.028, PE = 0.17; r = 0.096, PE = 0.17 and r = 0.177, PE = 0.16). But temperature showed negative correlation with GPP and NPP during winter season (r = 0.031, PE = 0.17 and r = -0.169, PE = 0.16) in the year 2010. During post monsoon salinity and DO showed negative correlations with GPP and NPP (r = -0.292, PE = 0.15; r = -0.252, PE = 0.16; r = -0.093, PE = 0.17 and r = -0.139, PE = 0.17). Seasonal variation of GPP, NPP and CR was calculated and GPP showed higher value (205.46) in summer (2010) and comparatively lower value was studied in winter (153.48) of 2010.But NPP showed lower value (103.95) during monsoon season in 2010.In 2011, the maximum values of GPP, NPP and CR (200.41, 124.88 and75.53) was observed in summer season and the minimum values of GPP, NPP and CR was calculated (147.25, 99.57 and 47.69) in winter season.

4. Discussion

Primary production, in general is regulated by the availability of sunlight and nutrients [15, 16]. In tropical aquatic basins where sunlight is not usually a limiting factor except during overcast conditions, the biological production is limited by the availability of nutrients and hence it is important to analyze the nutrient fields. The rate and extent of organic production in any ecosystem are controlled by several environmental factors and the cumulative effects of all these result in the primary production [7]. The temperature plays a much diminished role when conglomerated with low light intensity, high turbidity with flood water during monsoon which results the lower production [7, 9, 17-19]. In aquatic ecosystem, various environmental parameters like water temperature, transparency, pH, salinity and dissolved oxygen would affect primary production [16, 19].

In the present study higher productivity values were marked in summer months and lower during winter irrespective of stations and the seasonal variation was also related to temperature and photoperiod [15, 16]. It is obvious that water temperature influences the growth of aquatic weeds and algal blooms [20] and the growth is also enhanced by surrounding air temperature [10]. The productivity values (GPP & NPP) were positively correlated with high light intensity in summer accelerating the rate of photosynthesis in ocean water. This is in accordance with Mohapatra and Patra [9, 18, 19] and they had demonstrated that lower and higher water temperature might produce large differences in primary productivity of tropical marine ecosystem of Bay of Bengal. These findings suggest that water temperature is the major factor influencing primary productivity.

According to Singh [21] higher production is not governed by a single factor and there are certain physicochemical and biological factors which in fact control the rate of production in marine ecosystem (Table 7). The present findings suggested about direct correlation between temperature, transparency and productivity which was also demonstrated earlier by Mohanty (2000) [6, 19, 22-24]. The lower values of productivity were observed in winter and monsoon season and this might be due to low penetration of light and low light intensity in winter and high rainfall during monsoon because phytoplankton bloom formed in earlier summer months get disturbed due to heavy surface run-off of organic matters which in turn did prevent light penetration. In our study, the higher values of CR were reported in summer season and lower during winter. The decreased value during winter season was linked with low water temperature and reduced light [5, 15] and the values showed a systematic seasonal pattern.

Not much data are available on the primary productivity of Bay of Bengal. According to Nair [25] extensive investigations during different seasons are necessary in order to get a true picture of the productivity of Bay of Bengal as monsoon shift has considerable influence on the hydrography and productivity of this area. LaFond [26] had stated that the areas of highest plankton concentration were found nearshore on the northern and eastern sides of the Bay. The depth of euphotic zone was 45-66 meters at the western regions indicating low productivity [25]. The production rate was on the average $0.19gCm^{-2}d^{-1}$ in the deeper part while shelf waters were characterized by high rate of production $0.63gCm^{-2}d^{-1}$. However Nair [25] had stated that the level of organic production would high towards the coast and becomes less seaward. Our study confirmed the low production rate ($197.1gCm^{-2}d^{-1}$) which might be due to upwelling and low light penetration during monsoon and winter. Prasad [27] had estimated that the annual net production of the Indian Ocean (3.9×10^9 tonnes of carbon) which was about one fifth of the world Oceanic production. The average net production for the western half of the Indian Ocean ($0.24gCm^{-2}d^{-1}$) was little higher than the eastern half ($0.19gCm^{-2}d^{-1}$). Further, productivity of different Oceans and shelfs were estimated by different authors (Table 7).

The ratio of net and gross primary production is essential for the evaluation of the amount of gross product available to the consumers [21]. The ratio of NPP: GPP as well as NPP: CR showed higher values during winter which were in accordance with Madhupratap [7]. Higher values of NPP: CR in summer accounted for more penetration of light into water bodies as well as suitable water temperature which favored abundance of planktons and more photosynthetic activities [15].

5. Conclusion

The highest production during summer season at st-1 in 2010 and lowest during winter st- 5 in 2011 in Chandipur, Bay of Bengal was observed during the course of present study. Further the productivity was controlled by various ecological factors like temperature, transparency, salinity and DO. Temperature being the important factor was also coupled with transparency. Significant negative correlations of productivity with transparency and monsoon season suggested that the light penetration and organic material load were the major important factors in determining primary productivity.

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