

Studies on the settlement and succession of macrofouling organisms in the Kalpakkam coastal waters, southeast coast of India

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Study was carried out to evaluate the fouling pattern, dominant species and their seasonal succession in waters of east coast of India. Three series (weekly, monthly and cumulative) of teak wood panels were exposed to coastal waters. There is wide variation in the colonization of the biofoulers on the weekly panels. The lowest and the highest numbers of organisms observed were between 1 and 136 per cm², respectively. Dominance of barnacles (12.4-99%) on weekly panels was found throughout the year. Sizeable contribution (~7% of the total density) of oyster settlement was observed for the first time from this locality. Pattern of ecological succession observed was barnacles - hydroids - sea anemones - ascidians and finally green mussels. Weekly results, available for the first time for this locality, form the baseline data for future reference and impact assessment studies. Biofouling biomass (g. per 100 cm²) of weekly panels varied between 1 and 11, however, a steep increase in biomass was observed in cumulative panels. These biomass values compared well with earlier results. Total number of fouling taxa observed was only 30. A shift in the peak settlement period of green mussels, was observed as compared to the earlier report. Environmental parameters such as salinity, chlorophyll and phytoplankton density appeared to have significant ($p \geq 0.01$) contribution on biofouling settlement.

[Keywords: Biofouling pattern, succession, seasonal variations, East coast of India, Bay of Bengal]

Introduction

Coastal power plant, is very susceptible for biofouling problems. The methodology of biofouling studies such as, size of panel, duration of exposure, panel material, location of exposure etc used for biofouling studies largely remain similar by many workers¹. Many studies have been carried out in this regard from Kalpakkam coast, south east coast of India, due to its importance to the existing Madras Atomic Power Station (MAPS)²⁻⁴. Based on the above studies, a low dose continuous chlorination regime was suggested to overcome the biofouling problems at MAPS. This control regime has been successful to a large extent.

Biofouling problem is not only site specific, but also have been reported to be different for two different power plants drawing same source of cooling water⁵. The last study of biofouling in the area was conducted almost 20 years ago. Thus, the present study was carried out with the following objectives; to determine a) the present seasonal settlement pattern of biofoulers, dominant species and breeding pattern, b) any change, as compared

to that of earlier reported data and c) the role of physico-chemical characteristics of coastal water on biofouling. Dissolved oxygen (DO) & chlorophyll-*a* (chl-*a*) concentration were noticed during the post-tsunami period^{6,7} ie after the year 2004. Thus, the possible change in coastal biodiversity pattern concomitant with change in coastal water quality further fueled the interest for the biofouling studies in the aftermath of tsunami. Present study also examines changes in settlement pattern, diversity, biomass and population density between pre-and post-tsunami period.

Materials and Methods

Kalpakkam (12° 33' N Lat. and 80° 11' E Long.) is situated about 70 km south of Chennai city (Old name-Madras) (Fig. 1). MAPS uses seawater at the rate of 35 m³sec⁻¹ for the purpose of cooling the condenser and other auxiliary systems. After extracting heat, the heated seawater (~ 7 °C more than the ambient) is released into the sea. The seawater temperature has two maxima (April/May & August/September) and two minima (December/January & June/July)^{8,9}

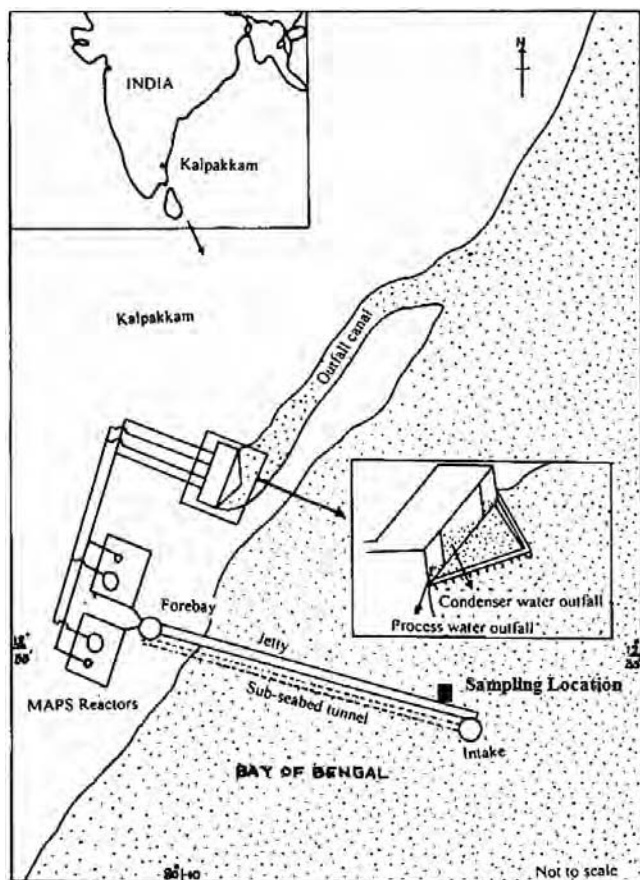


Fig. 1—A schematic diagram of the study area

The present study was carried out between May 2006 to April 2007 in the coastal waters of Kalpakkam, in the vicinity of MAPS. The study area is located at the intake of MAPS Jetty (Fig. 1). Water depth at the study site is ~8 m. Teak wood panels (each 12 × 9 × 0.3 cm) were suspended on epoxy coated mild steel frames from MAPS jetty. The panels were suspended at 1 m below the lowest low water mark, approximately 400 m away from the shoreline. Three series of observations (weekly, monthly and cumulative at 30 d intervals) were made. During each observation the exposed panels were replaced with new panels for weekly and monthly series, whereas the cumulative panels were retrieved continuously, one during each month from the 12 panels suspended at the beginning of the study. Panels from all the three series were brought to lab for assessment of species composition, number of organisms, growth rate, both % of number and % of area coverage of different groups and biomass (g. per 100 cm²). Fouling concentration of weekly panels was assessed by counting the foulants available on it with the help

of a magnifying lens. From each side randomly 10 counts (1 cm² area-10 no.s) were done. Barnacles (the fast growing and most dominant organism on weekly panels) attached were of size < 0.5 mm on weekly panels, and hence 1 cm² is spacious enough for attachment of a good no. of organisms, which are of below 0.5 mm. However, for monthly panels the size of organisms are quite large compared to weekly panels, thus it was counted by dividing one side of the panel into 4 parts and calculated accordingly. The growth rate was recorded by measuring the size of macrofoulers. Barnacles and sea anemones were measured diameterwise. Similarly, organisms such as, bivalves (mussels, oysters, other bivalves), hydroids, polychaetes were measured length-wise and ascidians were measured by estimating the area covered by them on the panels. Total biomass was calculated using a correction factor due to the absorption of water by the panels for specified time periods. Weekly & monthly observations were considered under short-term and that of cumulative was under long-term observation. Besides, species diversity (D), species richness (R) and evenness (J) indices were calculated using the

following formulae, $\left(D = - \sum_{i=1}^S P_i \log_e P_i \right)^{10}$, where,

P_i = Proportion of individuals in the ith species;

$\left(R = \frac{S-1}{\log_e N} \right)^{11, 12}$, where, S= Number of species in the population & N= Number of individuals in the

population and $\left(J = \frac{D}{\log_e S} \right)^{13}$, where, D = species

diversity respectively. In addition, sea water samples were collected for the estimation of water quality parameters such as pH, salinity, dissolved oxygen (DO), turbidity and chlorophyll-*a* and nutrients such as, nitrite, nitrate, ammonia, total nitrogen (TN), silicate, phosphate and total phosphorous (TP). Water temperature was measured at the site using a mercury thermometer of ±0.1 °C accuracy. Salinity was measured using Knudsen's method¹⁴. Estimation of DO was carried out following the Winkler's method¹⁵. pH was measured using a pH probe (Cyberscan PCD 5500) with accuracy of ±0.01. Turbidity was measured using Turbidity meter (Cyberscan IR TB100) with accuracy of ±0.01 NTU. Chl-*a* and nutrients

were analyzed following the standard methods of Parsons *et al.*¹⁵ using a double beam UV visible spectrophotometer (Chemito). Data (physico-chemical parameters) were grouped into 3 periods as mentioned earlier i) July-September, ii) October-January and iii) February-June.

Results

Hydrography and nutrient

Hydrographical parameters showed pronounced seasonal variations during the course of investigation (Fig. 2). Temperature, varied from 26.0 (Aug) to 31.8°C (May) indicating an annual gradient of ~5.8°C. A decreasing temperature trend was observed from May-August (pre-monsoon) coinciding with beginning of SW monsoonal rain. Again it increased from September and showed another peak during October coinciding with withdrawal of SW monsoon. From October, it decreased and reached a valley in November coinciding with the peak precipitation period during NE monsoon. pH ranged between 8.00 and 8.30 with maximum value during NE monsoon period. Salinity ranged from 24.91

(November) – 35.90 psu (May), which showed a unimodal oscillation. The lowest salinity value, as expected, coincided with peak precipitation period during NE monsoon. DO values fluctuated between 4.2 and 6.1 mg l⁻¹. Turbidity values varied between 9.21 and 21.42 NTU and that of chl-*a* varied between 1.42 and 7.51 mg m⁻³.

The variation in nitrite (0.09-1.56 µ mol l⁻¹) and nitrate (0.26-3.74 µ mol l⁻¹) content was found to be almost similar. Relatively high values of nitrogenous nutrients and silicate were obtained during and early post-NE monsoon months (January/February) (Fig. 3). Phosphate (0.14-0.82 µ mol l⁻¹) and total phosphorous (0.28 and 1.49 µ mol l⁻¹) did not increase during NE monsoon period unlike other nutrients.

Seasonal settlement pattern of biofoulers on panels

Fouling Community

A list of organisms collected from test panels are given in Table 1. A total of 30 taxa were involved in the fouling process at Kalpakkam coastal waters during the present investigation.

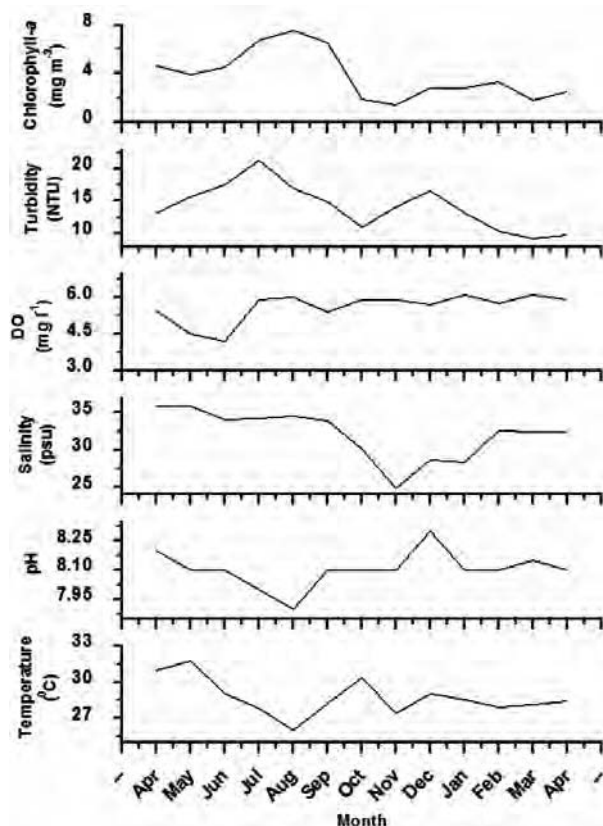


Fig. 2—Seasonal variations in hydrographical parameters

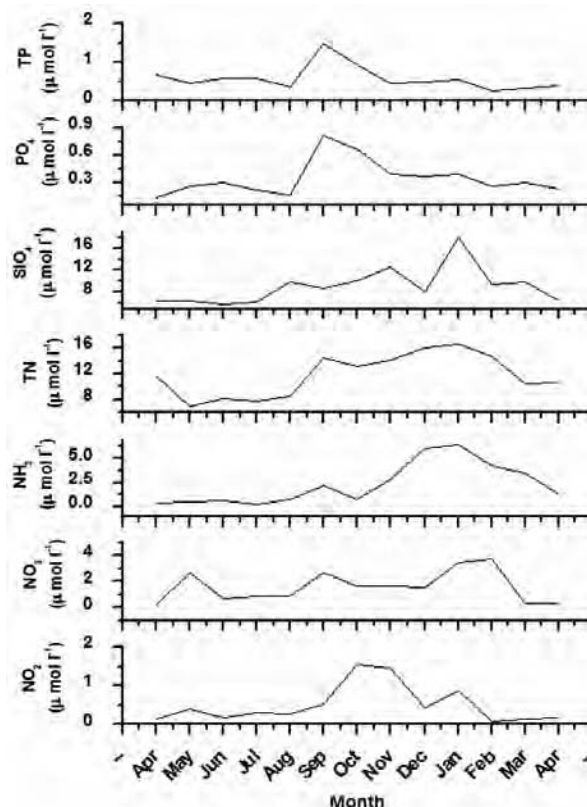


Fig. 3—Seasonal variations in nutrients

Table 1—List of fouling organisms observed on the test panels suspended in the Kalpakkam coastal waters.

Coelenterata			
Campanulariidae	<i>Obelia bidontata</i>	Clarke	
	<i>Obelia dichotoma</i>	Linnaeus	
	<i>Clytia gracilis</i>	M.Sars	
Aiptasiidae	<i>Aiptasia</i> sp		
Annelida			
Nereidae	<i>Pseudonereis anomala</i>	Gravier	
	<i>Platynereis</i> sp		
Serpulidae	<i>Serpula vermicularis</i>	Linnaeus	
	<i>Hydroides norvegica</i>	Gunnerus	
Sabelidae	<i>Daychone</i> sp		
	<i>Sabellistarte</i> sp		
Arthropoda			
Pycnogonidae	<i>Pycnogonium indicum</i>	Sunder Raj	
Balanidae	<i>Balanus amphitrite</i>	Darwin	
	<i>Balanus reticulatus</i>	Utonomi	
	<i>Balanus tintinnabulum</i>	Linnaeus	
	<i>Balanus variegatus</i>	Darwin	
Corophidae	<i>Corophium madrasensis</i>	Nayar	
	<i>Corophium triaenonyx</i>	Stebbing	
Amphithoidae	<i>Paragrubia vorax</i>	Chevreux	
Ectoprocta			
Membraniporidae	<i>Membranipora</i> sp		
Electridae	<i>Electra</i> sp		
	<i>Acanthodesia</i> sp		
Mollusca			
Mytilidae	<i>Perna viridis</i>	Linnaeus	
	<i>Perna indica</i>	Kuriaose	
	<i>Modiolus undulatus</i>	Dunker	
Olividae	<i>Olivancillaria gibbosa</i>	Born	
Ostreidae	<i>Crassostrea madrasensis</i>	Preston	
	<i>Ostrea edulis</i>		
	<i>Saccostrea cucullata</i>	Born	
Urochordata			
Didemnidae	<i>Didemnum psammathodes</i>	Sluiter	
	<i>Lissoclinum fragile</i>	Van Name	

Short-term (weekly and monthly) observation:

A wide variation was observed in the number of settled organisms on weekly panels. Major fouling organisms were barnacles, hydroids, ascidians, oysters, sea anemones and green mussels. In addition, some epizotic animals like errant polychaetes, flat worms, amphipods, crabs were also found. Number of organisms, number of species and % of area coverage are presented in Table 2.

The lowest and the highest numbers of foulants for weekly panels were 1 (November) and 136 per cm² (October) respectively (Fig. 4a). Fouling intensity was relatively high during summer and SW monsoon period, whereas during NE monsoon period, negligible intensity was observed. In monthly observation, the minimum (12 per cm²) and the maximum (69 per cm²) population density were noticed during January and September respectively (Fig. 4b). From July to September (SW monsoon) an increasing trend in fouling intensity was observed, whereas from October (NE monsoon), it declined till January and after which it increased. Fouling density and salinity almost followed similar pattern.

Percentage (%) of area coverage on weekly panels varied widely between 0.08 and 100% (Fig. 4c), whereas, in case of monthly panel, it varied a little (89 – 100%). In monthly panel, 100% area coverage was found during July – August, November – January and March (Fig. 4b). However, during weekly survey, maxima (80 – 100%) were attained in August – September and November.

*Variation in seasonal settlement of fouling organisms***Green Mussels**

Green mussels were found to be the most important constituent of the fouling community. These were not found on the weekly panel, but were attached to the mild steel frame. However, during monthly survey, their settlement varied from 0.08 – 14.07 % with sparse colonization during July-September and with vigor settlement during April (Table 3).

Barnacle

Barnacles were the most dominant fouling organism and their accumulation on the panels was observed throughout the year. Four species namely, *Balanus amphitrite*, *B. tintinnabulum*, *B. reticulatus* and *B. variegatus* were recorded. On weekly panels, barnacle settlement was continuous with peaks from

Table 2—Comparison of present fouling data with earlier reported values

	Nair <i>et al.</i> , 1988	Sasikumar <i>et al.</i> , 1989	Sasikumar <i>et al.</i> , 1990	Rajagopal <i>et al.</i> , Present study 1997	Weekly (0.185-29)x10 ³	Monthly (2–15) x 10 ³	Cumulative (0.166– 63) x10 ³
No. of organisms (x 10 ³ per 230 sq. cm)	----	----	----	----			
No. of species	----	21	----	105	30		
% of Area coverage		62 (Dec.) - 100% (Jul. - Aug.) - Monthly	53 (Nov.)-100% (Apr.,Jul.- & Aug.) - Monthly	34 (Feb.) – 72% (Oct.) - Monthly	0.08 (Nov.) - 100 % (Aug.)	89 (Oct.)-100% (Jul./Aug.)	100%
Biomass (g/ 100 sq. cm)	43 d - 33; 128d - 52; 150 d - 135	56d - 90; 120d - 105; 150d - 1000	45d - 32; 60d - 52; 130d - 50; 160d - 138	56d - 750; 125d -1870; 150d - 1750	1 –11	17 – 46	28d - 77; 56d -97; 112d - 185; 150- 648
Peak settlement	Ascidians-May Sea anemone (Sep. - Oct.) green mussels - September onwards	Ascidians (Mar. - Aug.) Sea anemone - NE monsoon	Ascidians (Apr. - Aug.) Sea anemone (Feb. - Oct.)	Green mussels (Apr. - Aug.)			
Diversity indices SD SR E	----	----	1.21(125d)-1.69 (75d) 0.04(150d) - 0.11(65d)	----	SD (0.05-0.96) SR(0.11-0.69) E (0.08 - 0.99)	SD(0.5-1.55) SR(0.45-1.0) E (0.26-0.74)	0.43(150d) -1.60(56d) 0.36(150d) -0.80(56d) 0.31(150d) -0.73(56d)
Succession	Barnacles, hydroides sea anemone, ascidians, green mussels	Barnacles, hydroides ascidians, sea anemone, green mussels	Barnacles, hydroides, ascidians, sea anemones, green mussels	Barnacles, ascidians, green mussels	----	----	Barnacles, hydroides, sea anemone, Ascidians, green mussels
Climax community	Barnacles	Green Mussel (<i>Perna viridis</i>)	Ascidians	Green Mussel (<i>Perna viridis</i>)	----	----	Green mussels

Table3—Percentage (%) composition of fouling organisms during monthly observations in the coastal waters of Kalpakkam

	Barnacles	Mussels	Oysters	Crustaceans	Hydroides	Polychaete worms	Flat worms	Sea anemones
July	75.36	1.73	--	--	22.51	--	--	0.42
August	37.29	5.68	7.18	22.47	23.13	0.22	0.30	3.74
September	5.86	0.59	0.22	85.82	6.67	0.15	0.10	0.58
October	33.09	--	--	64.12	1.66	0.47	0.24	0.42
November	76.52	--	--	19.44	2.62	0.11	1.30	--
December	85.24	2.81	0.06	1.84	8.66	0.63	0.55	0.23
January	65.03	0.62	0.02	14.02	16.66	1.77	0.82	1.07
February	49.81	0.08	0.02	11.29	37.28	1.07	0.50	--
March	59.05	0.65	--	21.97	17.33	0.31	0.54	0.21
April	55.97	14.07	0.04	29.78	--	0.05	0.03	0.06

June-July and November-March. In case of monthly panels, large numbers were observed during July, November-December and March-April. Maximum weekly and monthly growth (diameter) obtained were 0.5-1 mm and 2-3 mm respectively.

Hydroids

Hydroids, dominated by *Obelia* sp., were only second to barnacles in abundance as well as in seasonal occurrence. They started appearing on the panels after 5d of immersion. A maximum length of 5 mm on weekly panel and 17 mm on monthly panel was observed. Hydroid %

composition varied between 0.64 & 81.62% and 1.66 & 37.28% during weekly and monthly investigations respectively.

Ascidians

Didemnum psammathodes and *Lissoclinum fragile* were the ascidian species encountered during the present observation. Occurrence of ascidians was restricted to March-April and June-August, with peak during March-April on weekly panels. In monthly observation it dominated in March-April and June-July, with maximum density during June.

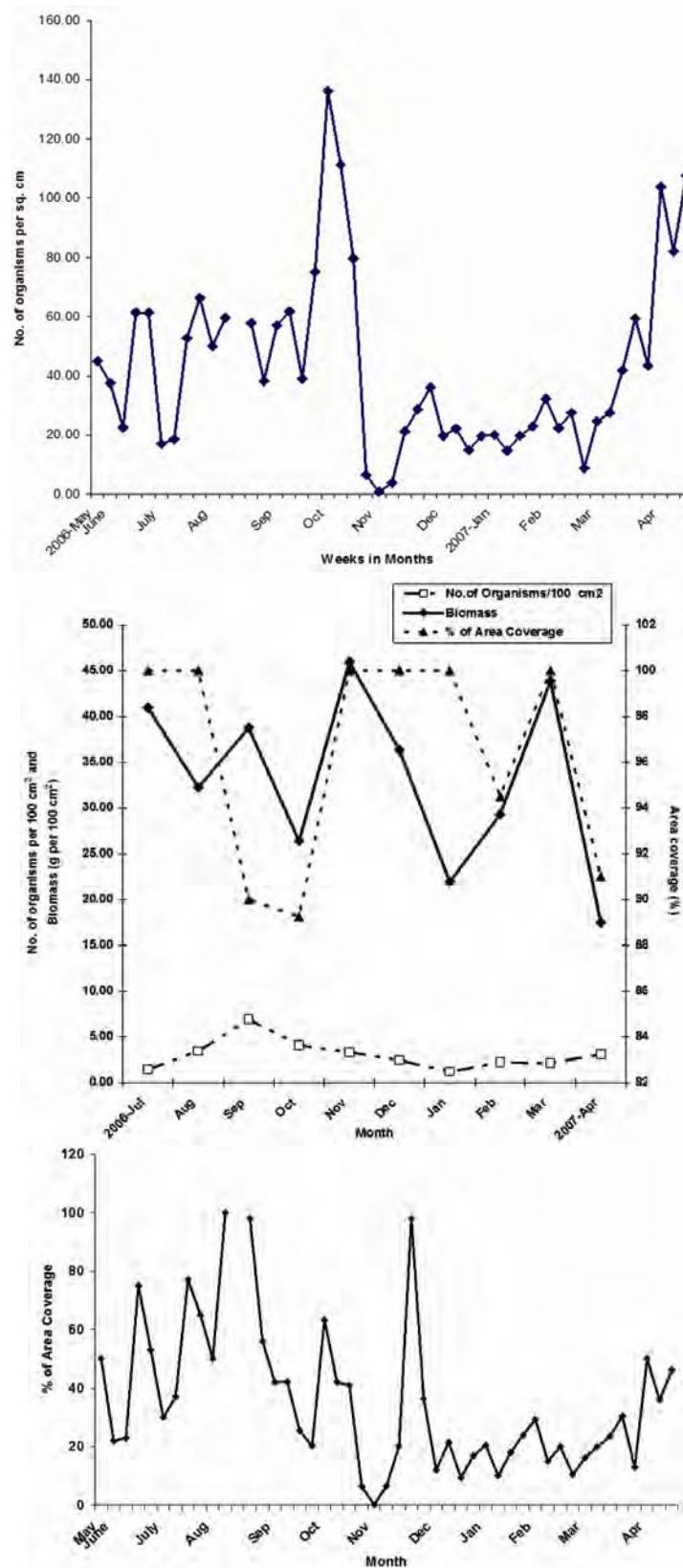


Fig. 4—(a) Variations in settlement pattern of biofouling organisms on weekly panels (b) Variations in no. of organisms, biomass and % of area coverage on monthly panels (c) Variations in % of area coverage on weekly panels

Sea anemones

Sea anemones were represented by *Sertularia* sp. and *Aiptasia* sp. These started settling from September/October and were abundant during NE monsoon period. Their growth rate (diameter) was 1.5 mm in 7 d and 8 mm in 30 d observation.

Seasonal settlement on long-term (cumulative) panels

During the present observation, Long-term panels were studied up to 150 days after which panels were lost due to entanglement of the frames and could not be retrieved. In the Kalpakkam coastal waters, considerable settlement of barnacles, green mussels and ascidians were observed on the long-term panels. Apart from these, colonization of hydroids, oysters and sea anemones was also observed. In addition to these sedentary organisms, epizoid animals like errant polychaetes, flat worms, amphipods, crabs were also observed. Peak settlement period of foulants, succession and climax community are represented in Table 2. Fouling succession was very prominent during the long-term observation as compared to weekly and monthly observation. Barnacles were the first to settle on the long-term panels and by May they were followed by hydroids and polychaete worms. During this period, barnacle populations remained largely unaffected by the secondary settlers. Ascidians began to colonize on the panels in June. Fully developed ascidian colonies completely covered the barnacles and other organisms by July and they remained until the end of August. Green mussels started appearing from August, whereas the peak colonization of mussels was observed from September onwards and was maintained till mid-November.

Barnacle composition initially increased up to 56 d and subsequently reduced significantly on the long-term panels as follows (15%, 28%, 13% and 5% on 28 d, 56 d, 112 d and 150 d old panel respectively). Green mussels, which were absent up to 28 days, started appearing subsequently and occupied 41% by 56d and reached 90% by 150d. Accumulation of juvenile green mussels occurred after 28 days along with the pre-existing community consisting of barnacles, hydroids, oysters, polychaete worms, flat worms and sea anemones. Mussels attained 0.5-1 cm in size by 56 d and from 112 d, the panels were fully covered with adult green mussels of size 3-5 cm. (Fig. 5 a, b, c). The relative abundance of different fouling community observed for 28 d, 56 d, 112 d and 150d are given in Fig. 6. (a, b, c & d).



(a)



(b)



(c)

Fig. 5—(a) A view of a weekly panel (b) A view of a monthly panel (c) A view of 112 d old panel, covered with green mussels (*Perna viridis*)

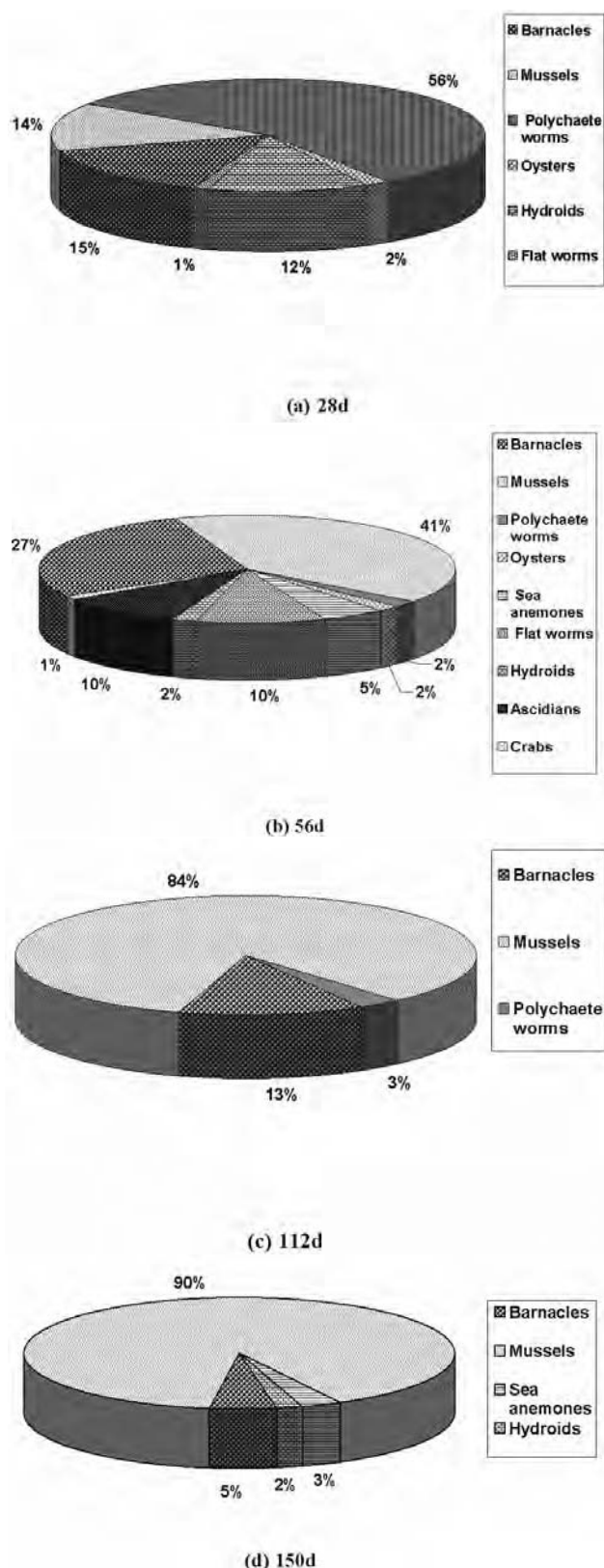


Fig. 6—Relative abundance of fouling organisms for (a) 28 d, (b) 56 d, (c) 112 and (d) 150d old panels exposed to Kalpakkam coastal waters

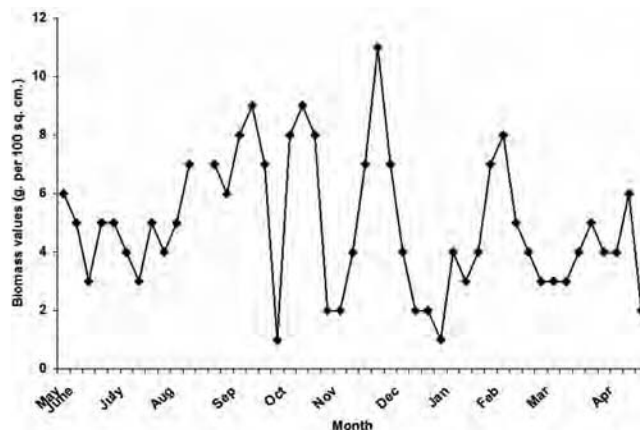


Fig. 7—Variations in biomass on weekly panels

Biomass

Biomass values (g. per 100 cm²) of weekly panels ranged from 1-11 (Fig. 7) with the lowest and the highest during the months of November and December respectively. In the monthly observation, the lowest (17) and the highest (46) were observed in April and November respectively (Fig. 4b). In case of cumulative panel, a steep increase in biomass was observed from 28 d (77), 56 d (97), 112 d (185) to 150d (648) (Table 2).

Discussion

The total number of benthic taxa found (30) during the present investigation (Table 1) is comparable with that of the observation of Sasikumar *et al.*³. A few species of fishes observed by Sasikumar *et al.*³ were not found on our panels. In contrast, Rajagopal *et al.*⁴ have reported almost 3.5 times higher number of fouling species (105) from the same location. In this regard, it is imperative to mention here that values with wide variations have been reported from both east and west coast of India. For example, 121 taxa from Visakhapatnam harbour and 37 taxa from Kakinada¹⁶, which are situated in the east coast. From west coast, 42 and 65 taxa from Goa¹⁷ and Cochin harbour¹⁸ have been reported respectively. It is unclear why these studies with similar methods from the same location formed such large differences in diversity. Further detailed investigations are needed.

Hydrographical parameters showed pronounced seasonal variations during the course of investigation (Fig. 2). Temperature, an important hydrographical parameter, which influences almost every chemical and biological interaction, increased marginally from April to May followed by a sharp decline during June to August. Subsequently it showed an increasing trend

Table 4—Correlation between biofouling and hydrographical parameters

Correlation matrix (Pearson)

Variables	No of organisms	Biomass	% Area coverage	Temp	pH	Salinity	DO	Turbidity	Chl- a	Phyto density
No of organisms	1									
Biomass	0.359	1								
% Area coverage	0.504 ^b	0.518 ^b	1							
Temp	0.197	-0.271	-0.292	1						
pH	-0.023	-0.475 ^b	-0.432 ^b	0.116	1					
Salinity	0.515 ^b	0.047	0.452 ^b	0.195	-0.325	1				
DO	-0.160	-0.004	-0.128	-0.381 ^c	0.119	-0.430 ^b	1			
Turbidity	-0.090	-0.065	0.445 ^b	-0.307	-0.150	0.073	-0.276	1		
Chl- a	0.458 ^b	-0.098	0.502 ^b	-0.016	-0.259	0.685 ^a	-0.332	0.423 ^b	1	
Phyto density	0.442 ^b	0.139	0.465 ^b	-0.196	-0.264	0.547 ^a	-0.145	0.355	0.839 ^a	1

a- $p \geq 0.001$; b- $p \geq 0.01$; c- $p \geq 0.05$

from September to October and decreased from November till the beginning of April. It is well known that the sea surface temperature depends to a large extent on the atmospheric temperature. The present observation is supported by the fact that, in the southeast coast of India, air temperature shows a bimodal oscillation with two peaks, one during April/May and another during September/October⁹.

The maximum value of pH observed, coincided with NE monsoon period during which not only the precipitation, but also the discharges from the nearby backwaters affect pH and salinity significantly. As expected, the lowest salinity value coincided with the local maximum precipitation period (NE monsoon period) and also with the maximum influx of fresh water from the two nearby backwaters. Additionally, relatively low saline reverine water from north also deepens the salinity during this period¹⁹. The highest salinity value coincided with the peak summer. Similar trend has also been reported earlier²⁰. DO showed an irregular pattern of distribution except for the fact that during NE monsoon period, relatively high values were observed, as expected, due to input of oxygen rich freshwater. A significant negative correlation ($p \geq 0.01$) between salinity and DO supported the above observation (Table 4). Turbidity exhibited a bimodal oscillation with one peak during July (pre-monsoon) and another during December (NE monsoon). This could be attributed to the relatively high phytoplankton density during pre-monsoon and heavy silt-laden freshwater influx during NE monsoon seasons, respectively. A significant positive correlation ($p \geq 0.01$) between turbidity and chlorophyll was testimony to the above observation during pre-monsoon period.

Although, the trend observed for turbidity during present study was more or less similar to earlier reports, absolute values appeared to be higher than earlier reports²¹. Chl-*a* values were the lowest during November/December (NE monsoon) and highest during August/September (SW-NE monsoon transition). Relatively high concentration of chl-*a* during summer and pre-monsoon period might be due to relatively stable as well as optimal conditions of salinity, temperature, light, nutrient levels (conducive for production of copious amount of phytoplankton) etc prevailed during these periods. Depletion of chlorophyll concentration during monsoon period could be a result of low saline conditions. The above observation is also strengthened by the significant positive correlation ($p \geq 0.001$) obtained between chlorophyll and salinity indicating that salinity plays pivotal role in phytoplankton density of Kalpakkam coastal water (Table 4). The present trend as well as magnitude agrees with the earlier studies from the same locality²². In contrast, chl-*a* values (maximum) reported by Rajagopal *et al.*²³ were relatively high (2 times) as compared to others.

Nutrient values showed pronounced variation throughout the study period (Fig. 3). Relatively high concentration of almost all nutrients was observed during monsoon period as compared to rest of the year. This could be attributed to the addition of nutrient rich fresh water from the backwaters into the coastal waters. The two backwaters, which are part of the ecosystem at this location, receive various wastes (domestic, agricultural etc.) from the nearby township and villages and thereby get enriched with nutrients. These backwaters are opened to the coastal water during the NE monsoon period resulting in influx of the nutrient rich fresh water into the coastal milieu,

which enhances nutrient levels in the coastal water. Low values were observed during post- monsoon and pre-monsoon period (April - August). This could be attributed to their utilization by phytoplankton, as evident from the high chlorophyll values observed during the same period. Relatively high values of nitrogenous nutrients were obtained during early post-monsoon months (January / February) (Fig. 3), which coincided with the blooming of *Trichodesmium erythraeum*, a nitrogen-fixing Cyanobacteria. During the month of September, increased levels of phosphate was observed, which could be due to the phenomenon of upwelling, an event that generally occurs during pre-monsoon (August – September) period along the Indian east coast²⁴⁻²⁷.

Seasonal settlement pattern of biofoulers on panels

The seasonal settlement of foulants on short-term panels was found to be quite different from that of the long-term panels. The weekly panels showed marked variation in density of organisms. The lowest density was found during NE monsoon period. This could be due to the lowering of salinity level in the surface water during the above period, as about 750 mm of rainfall is received at Kalpakkam during NE monsoon. Moreover, with the onset of NE monsoon, the sea water current reverses from north to south as a result of which low saline riverine water from northern Bay of Bengal (BOB) coupled with the monsoonal precipitation deepens the salinity to the lowest during this period at this location¹⁹. It is known that salinity plays a crucial role in the growth, development and diversity of macro-foulants in the marine environment. Additionally, a relatively low temperature, which is not favorable for bio-growth was also prevailed during this period. We speculate that substantial reduction in salinity and temperature along with enhanced suspended matter prevailed during NE monsoon period could have contributed to the low fouling density and diversity observed during this time. A relatively high fouling intensity on weekly panel was observed during summer and SW monsoon period coinciding with stable salinity, temperature and low turbidity, which was conducive for promoting large settlement of macrofoulants. This period also experienced highest phytoplankton count in this locality. This corresponds with the positive correlation value obtained between salinity & fouling density ($p \geq 0.01$) and chlorophyll/phytoplankton density & organism density ($p \geq 0.001$) (Table 4). This showed that abundance of fouling organism at

this locality was regulated mainly by two important factors namely, salinity and phytoplankton. Previous studies² showed peak settlement rates in May and June, whereas in the present study, an extension of this period up to September – October was observed. The present differences could be due to the temporal variability in reproductive cycles, which are related either directly or indirectly to seasonal changes in the physical environment³.

A close look at the present physico-chemical and biological characteristics of the Kalpakkam coastal water reveals reduction in phytoplankton density, chlorophyll concentration and enhancement in suspended matter including that of nutrient in the recent past particularly after the Tsunami⁶. A detailed impact of the Tsunami on the coastal milieu is reported elsewhere⁶. Possibly these changes are also typified in the change in macrofoulant settlement pattern as observed during the present study. A significant difference was observed between successive weeks (Fig. 8a & b), with respect to number of foulers, % of area coverage, growth rate etc.

Although, intensity of biofouling was low during NE monsoon period, the period of low salinity, however, the highest % of area coverage was observed in weekly panels during the same period, despite the fact that salinity and % of area coverage are positively correlated. Similarly, turbidity and % of area coverage showed a positive correlation, in spite of the fact that high turbidity generally does not support abundant settlement. This contradiction suggests that the period of low salinity and high turbidity was favorable for settlement of organisms like barnacle, which settles throughout the year, resulting in an increased area coverage during adverse conditions like low salinity and high turbidity. Considering the fact that no weekly data was available from this location, this forms the baseline for future reference as well as impact studies.

Variation in seasonal settlement of fouling organisms

Barnacles

Among the different groups of fouling organisms, barnacles are reported to be the most important component and breed throughout the year^{2, 30}. In this study also, barnacles were found to be the most dominant fouler and were present throughout the year which corroborates the finding of Nair *et al.*² and Sasikumar *et al.*²⁹ from this location during mid 80's. On weekly panels, settlement was continuous with



Fig. 8—Variations in fouling pattern observed on the test panels between two successive weeks. (a) From 8th - 15th June, 2006, (b) From 15th - 22nd June, 2006

peaks during June-July and from November-March. Settlement of barnacle is favored in light illuminated area^{3,4 & 30}. Considering that southeast coast of India receives good illumination throughout the year, this would have supported the settlement of barnacle throughout the year. In case of monthly panels, large numbers of barnacles were observed during July, November - December and March-April. Although fouling density was high during September/October, barnacle population was lowest in September. Settled green mussels prior to September established their dominance on the panel, thereby not facilitating barnacle settlement from September. Dominance of other foulants over barnacles and its territorial behavior itself could be the cause of their population reduction³¹. The settlement pattern of barnacles during the present study was similar to previous studies reported from Kalpakkam coastal waters^{2,4}. In contrast to the present study as well as that of Nair *et al.*² and Rajagopal *et al.*⁴, relatively low barnacle settlement during June - July has been reported by Sasikumar *et al.*³. This disparity among different studies as far as peak settlement period is concerned, could be attributed to the variation in the influence of environmental parameters on breeding cycle of the organisms.

Maximum growth rate of barnacles on weekly and monthly panel was observed during June and July respectively. The present observation matches with those of Iwaki *et al.*³² in Matoya Bay and Sasikumar *et al.*³ from this locality. Although, Nair *et al.*² have reported a relatively high growth rate as compared to the above report, however, the period of maximum growth rate matches with the present study.

Hydroids: The peak settlement of hydroids was during July-August (SW monsoon) and January-March. The accumulation of this group was

prominent on the edges of the panels. Selection of edges by the hydroids for their settlement could be due to the location, which was found to be favorable for their filtration. On the other hand, had they settled on the panel surface, their growth could have been crowded by other foulers. The present observation parallels the findings of Nair *et al.*² and Sasikumar *et al.*³. Interestingly, Rajagopal *et al.*⁴ reported peak settlement of hydroids during NE monsoon, an observation contrary to the present study as well as those of Nair *et al.*² and Sasikumar *et al.*³.

Ascidians

Ascidians are a very important group of fouling organisms having a world-wide geographical distribution³³. It has been reported that in temperate waters only a single generation is established each year, in contrast to two to four generations per year in tropical waters³⁴. During the weekly observation of the present study, the occurrence of ascidians was generally restricted to March-April and June-August, with peak settlement during March-April. Monthly observation also showed the dominance of ascidians in March-April and June-July, but with maximum density during June. This revealed that for almost seven months of the year, ascidians did not settle on panels. In the south west coast of India (New Mangalore port), their appearance on panels was restricted only to 4 to 5 months in an year. Results of this study coupled with that of Khandeparker *et al.*³⁵ clearly demonstrate that ascidians are a dominant group of macrofouling community in the Indian coastal water during pre-monsoon and late post-monsoon months. Such dominance of ascidians during a certain period of weekly and monthly observation could be attributed to the increased larval density & their ability

to undergo dedifferentiation and redifferentiation during that period³⁶. Total absence of ascidians was encountered from September to December. This showed that early pre-monsoon to early post-monsoon period is not conducive for ascidian settlement at this coast. Even before the onset of NE monsoon, reversing of current (September/October) from north to south takes place, which brings low saline water³³. Ascidians have short larval life cycle lasting for a few hours and are very sensitive to minor variation in salinity content. Khandeparker *et al.*³⁵ while studying the correlation between ascidian larval availability and their settlement have clearly demonstrated that ascidian larvae were not available during monsoon and early post-monsoon in coastal water. Salinity, during monsoon period in Mangalore coastal water, decreased marginally (~33 psu), whereas at this location it decreased significantly (~25 psu). As a pure marine form, ascidians are not able to survive at low salinity³⁷. Thus, it was not surprising to observe total absence of ascidian on the panel during September–December period at this location. In contrast, observations of ours as well as those of Nair *et al.*² and Sasikumar *et al.*³ are not in agreement with that of Rajagopal *et al.*⁴, who have reported the presence of ascidians throughout the year including the unfavorable NE monsoon period.

Sea anemones

Sea anemones are soft bodied conspicuous members of the marine fouling community. The observation of heavy colonization of sea anemone during September/October to NE monsoon period agrees with the earlier reports²⁻⁴.

Green Mussels: Green mussels are one of the most important constituents of the fouling community. The first peak of green mussel settlement coincided with the seasonal temperature and salinity maxima of the present study. Rajagopal *et al.*⁴ have also reported the maximum green mussel settlement during relatively high temperature and salinity condition. However, the second peak was observed corresponding to the maximum phytoplankton density and relatively high salinity during August–September, indicating the significant influence of the availability of food resources and salinity on the larval abundance and settlement of mussels^{38,39}. Paul⁴⁰ had also recorded the settlement of this species in Madras harbor during March to November with a distinct peak during August - September. The trend observed in settlement of mussels corroborates the findings of Seed⁴¹ and

Myint and Tyler⁴², who have explained in their classical papers the role of temperature, salinity and food availability on mussel breeding periodicity.

Other Fouling Organisms

Other fouling organisms observed include bryozoans (Ectoprocta), oysters, polychaete worms & flat worms etc and some other crustaceans such as, crabs (both larvae and juveniles), amphipods & juvenile lobsters. Settlement pattern of bryozoans (Ectoprocta) did not show any definite trend in their temporal variation on short-term panels. However, Rajagopal *et al.*⁴ have noticed bryozoan settlement during January–May, with peak colonization during February–March, when other fouling recruitment was less. Khandeparker *et al.*³⁵ have reported heavy settlement of bryozoan during December–March from New Mangalore Port. Appearance of juvenile oysters (*Crassostrea madrasensis*, *Ostrea edulis*) was observed in almost all the months, with peak settlement during August. However, during weekly survey they did not appear at all. The present study recorded considerable contribution (maximum, ~7%) by oysters to the fouling community during August on monthly panels. Price *et al.*⁴³ have stated that the growth of oysters was the highest in August i.e. after their spawning, when glycogen reserves are restored. We are unable to explain the cause of non-availability of oysters during the earlier studies²⁻⁴. Though the peak settlement of polychaete worms (*Serpula vermicularis*, *Hydroides norvegica*) (0.05-2.1%-Monthly and 2 - 56% - cumulative) was observed in January during monthly observation, its availability as temporary settler was noticed during most part of the study period. Khandeparker *et al.*³⁵ have also reported the year-round breeding activity of this organism from west coast of India. During the initial period of cumulative observation (28d), polychaete was found to be dominant, which gradually disappeared during the subsequent days. Flat worms were found to settle in relatively less numbers compared to other foulants on short-term panels. Settlement of sponges, clams and snails were also occasionally noticed on the panels. Other crustaceans (amphipods, juvenile lobster, crab juveniles) started appearing from August with high abundance during September. Macroalgae was absent during the present investigation, which might have been due to competition for space, predation and grazing⁴⁴. Earlier workers too have not reported the settlement of macroalgae on the exposed panels from this locality.

Seasonal settlement on long-term (cumulative) panels

Long-term observation showed distinct fouling succession. Barnacles were the first settlers on the long-term panels. Hydroids and polychaete worms settled next during the month of May. Barnacle population remained unaltered by the secondary settlers during this period. By June, ascidians started appearing on the panels and by July, they fully covered the barnacles and other organisms. Sasikumar *et al.*²⁹ have also reported the similar pattern of stable point as that of Sutherland⁴⁵ in ascidian colonization on long-term panel. Disappearance of this group was noticed from the month of September, which could be due to the dominance of other fast growing foulers such as green mussels. Sasikumar *et al.*³ has also observed similar pattern of colonization on long-term panels.

During the present study, green mussels were the climax community. This could be due to the fast growing and competitively superior green mussels establishing their dominance on panel surfaces such that other fouling organisms are left with little space to settle. Richmond and Seed⁴⁶ have also reported that these competitively dominant species are often successful due to their large body size, fast growth rate, extended longevity and prolonged larval life. Interestingly both Nair *et al.*² and Sasikumar *et al.*³ have not reported settlement of green mussel on their test panels, which did not match the observations of ours and Rajagopal *et al.*⁴.

Biomass

The lowest and highest biomass values for weekly panels were obtained in the months of November and December respectively, which could be attributed to the difference in peak settlement period of macrofoulants contributing more to the fouling biomass. In spite of the influence of NE monsoon, the highest value was observed during November (Monthly biomass) and December (Weekly biomass), which could be attributed to the elimination of most of the organisms due to unfavourable ambience condition such as low salinity, high turbidity, low phytoplankton density etc and survival of the most tolerant foulers such as barnacles and green mussels. This exclusion of organisms can lead to reduction in intra- and inter-specific competition, which ultimately facilitates the growth of better adapted foulants⁴⁷. Thus, barnacles and green mussels were found to contribute maximum to the total fouling biomass during the above period.

The abrupt increase in biomass in 150d old panel is due to the dominance of green mussels during October. It is worth comparing the present data on short-term and long-term panels with those of Nair *et al.*², Sasikumar *et al.*³ and Rajagopal *et al.*⁴. Biomass (g. per 100 cm²) observed on short-term panels (15-30d) exposed by Sasikumar *et al.*³ ranged from 1 to 7 and Nair *et al.*² under similar condition observed a biomass ranged from 9 to 51. Karande *et al.*⁴⁸ have reported 45 biomass on 30 days exposed wooden panel from Kalpakkam coast. In contrast, Rajagopal *et al.*⁴ observed a biomass ranged from 130 to 640, a phenomenal increase. The present values ranged from 17 to 46 (30d) and 1 to 11 (7d) compares well with Karande *et al.*⁴⁸, Nair *et al.*² and Sasikumar *et al.*³. Reports of higher values than that of Rajagopal *et al.*⁴ have been observed even from temperate waters (Trondheim, Norway-760 g. 100 cm²) (Unpublished data). Such wide variations in biomass values could be due to an array of factors such as differences in exposure mechanism, substratum, time of exposure and dynamism of environmental variables.

Diversity indices

The diversity indices showed wide variations between weekly and monthly surveys. During weekly observations, species diversity was minimum (0.32) and maximum (0.84) in February and September respectively. The lowest (0.11) and highest value (0.41) of species richness was observed in May and October respectively. The minimum and maximum values for evenness were 0.32 (December) and 0.85 (May) respectively. However, the highest species diversity occurred on 56 d (1.60) panel and a steep reduction was noticed on 150 d (0.43) panel during which green mussels almost dominated the fouling community. Although, it is logical to attribute the dominance of green mussels to the observed low diversity values, the role of the competition among dominant species for space, predation & grazing, larval abundance and settlement and survival of a superior & better-adapted community by eliminating other species can not be ignored^{29,49}.

Conclusion

Wide variations in settlement pattern of biofouling organisms were observed in the coastal waters of Kalpakkam during the present study. Fouling density, diversity, area coverage

and their biomass were significantly influenced by salinity, chlorophyll content, phytoplankton density and turbidity. A minor deviation in succession of macrofoulants was noticed as compared to the earlier studies. Appearance of oysters on the panels was encountered in significant numbers (~7%) unlike previous studies from this coast. A visible shift in the peak settlement period of green mussel (*Perna viridis*), the dominant as well as climax species, was presently observed (September–November) as compared to earlier studies (April–August). In view of this, chlorination regime needs to be strengthened during September to November instead of April to August. It is suggested that long-term investigation on biofouling needs to be carried out a) to confirm the present trends and b) to obtain possible changes due to climate change.

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