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Seasonal and vertical distribution of macrofoulants in Kalpakkam coastal waters

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Vertical distribution and community succession of macrofoulants were studied in the coastal waters of Kalpakkam for 1 y. Studies were made with teak wood panels of 15 cm × 10 cm. For short–term series, panels were suspended at 1,3,5 and 7 m depths. Long term panels were all suspended at 1 m depth. Fouling organisms observed were barnacles, ascidians, hydroids, polychaetes, bryozoans and mussels. Considerable faunistic and biomass variations were observed both with respect to season and depth. Biomass value was maximum in October at 5 m depth and minimum in February at 3 m depth. Barnacles were the most dominant group and were found occurring almost throughout the year. However, green mussels, a dominant group in MAPS subterranean tunnel, were absent on the experimental panels. Dominant community observed was either ascidians or barnacles. Patterns of ecological succession observed during different periods of the year were not significantly different.

Seawater is often used for condenser cooling in nuclear as well as thermal power plants. Such use leads to colonization of cooling water system by marine life leading to pressure drops in cooling circuit, mechanical damage to pumps and loss in condenser efficiency[1]. The species of foulants and their settlement periods, growth rates and biomass vary from plant to plant and an understanding of these aspects is very essential to evolve an economic and safe antifouling system. Thus, several studies have been made in different sea areas in this context[2-4]. The present paper reports the results of studies on the vertical distribution of macrofoulants with season and depth in the coastal waters at Kalpakkam, where seawater is used for condenser cooling in a nuclear power plant.

The seawater for condenser cooling in the power plant (Madras Atomic Power Station, MAPS) is drawn through a submarine tunnel (468 m long and 3.8 m in diam.) which is located 50 m below the seabed. Surface seawater enters the tunnel through a vertical shaft at the seaward end of the tunnel. At the landward end of the tunnel a similar shaft connects the tunnel to the fore bay and pumphouse. Seawater is pumped at a rate of 35 $m^3.sec^{-1}$ through the condensers and warm water effluents are discharged into the coastal waters through a shore discharge facility.

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Materials and Methods

Teak wood panels (15 × 10 cm) were placed on epoxy coated mildsteel frames suspended from MAPS jetty at a distance of 430 m away from the shore. Three sets of panels, short–term (A series) and long–term (B series and C series) were used for the experiment. The study was conducted during 1987–1988. Short–term panels were used to study the seasonal settlement and long–term panels for studying the succession of fouling communities. While short–term panels were of 15 d duration and were exposed at 4 different depths (1,3,5 and 7 m), B series (24) were all suspended together but were withdrawn one every 15 d. The C series panels (24) were suspended at 15 d intervals and retrieved together after 1 y. Each panel was studied for total biomass (wet weight), species composition, growth rate, numerical abundance and percent coverage (visual method) of the panels by foulants. In arriving at biomass values a control experiment was carried out in the laboratory on water absorption on panels for different duration of exposure and suitable corrections were applied to the weight of the panel. Water absorption contributed to an increase in weight by 38% in 40 d to 71% in 310 d. Duplicate panels were used for calculating water absorption and average values were taken. However, influence of calcareous shells in water absorption rates of the wooden panels was not considered. Simultaneously, surface temperature, salinity and dissolved oxygen measurements were also carried out in the coastal waters following standard methods[5].

Results

List of fouling organisms is given in Table 1. Table 2 gives data on biomass on short-term panels. Hydrographic data collected from the same location by Satpathy[6] are given to relate seasonal differences in hydrography to biofouling (Table 3). Seasonal distribution of major foulant groups at different depths is given in Fig. 1. Seasonal distribution of foulants and their abundance on long-term panels are given in Fig.2. Biomass build up on long term panels is given in Fig.3. Mode of succession at different periods is given in Fig.4.

Seasonal settlement on short-term panels — Major fouling organisms observed during the study were barnacles, hydroids, polychaetes, ascidians, bryozoans, sea anemones and green mussels. In addition to these sedentary organisms, epizoic animals like errant polychaetes, flatworms, amphipods, crabs and juvenile lobsters were also observed. However, polychaetes settled more abundantly on mild steel frames than on the panels.

Barnacles : Among the different groups, barnacles were the most dominant and were found almost throughout the year. Barnacles were represented by *Balanus tintinnabulam tintinnabulam*, *B. variegatus* and *B. amaryllus euamaryllis*. Settlement of barnacles was uniformly high from March to December at 3 m depth. Settlement rates were relatively low at 1 m depth in June and July possibly due to the lowering of surface salinity due to the onset of southwest monsoon rains. Settlement rates were relatively low in February at all depths. Rates of growth measurements indicated that barnacles attain 5 mm size in 17 d in May and 12 mm in 26 d in September.

Hydroids : Hydroids were only second to barnacles in abundance as well as seasonal occurrence and were dominated by *Obelia* sp. A maximum length of 15 mm in 17 d was observed during the study. While hydroids were found at all the depths, they were clearly more abundant and occurred almost throughout the year at 5 m depth. However, hydroids were less abundant or absent during December to January.

Ascidians : Ascidians were also a prominent group among foulants although their occurrence was generally restricted to March–August. *Lissoclinum* sp., *Didemnum* sp. and *Botryllus* sp. were the common species observed. Although, they were found at all depths, maximum abundance was observed at the surface. Ascidians were totally absent from August to December. Although the absence coincides with northeast monsoon period, a clear relationship with onset of northeast monsoon rains could not be established as ascidians were absent from August onwards whereas the northeast monsoon did not set till the beginning of October.

Table 1 — List of fouling organisms

- Coelenterata
  - Companulariidae
    - *Obelia bicuspidata* Clarke
  - Sertularidae
    - *Sertularia* sp
- Annelida
  - Serpulae
  - Serpulinae
    - *Serpula vermicularis* Linnaeus
    - *Hydroides norvegica* Gunnerus
  - Nereidae
    - *Psuedonereis anomala* Gravier
- Arthropoda
  - Pycnogonidae
    - *Pycnogonum indicum* Sunder Raj
  - Cirripedia
  - Balanidae
    - *Balanus tintinnabulam tintinnabulam* Linne
    - *Balanus variegatus* Darwin
    - *Balanus amaryllus* var *euamaryllis* Broch
  - Corophidae
    - *Corophium triaenonynx* Stebbing
- Ectoprocta
  - Membraniporidae
    - *Membranipora* sp
  - Electridae
    - *Electra* sp.
    - *Acanthodesia* sp.
  - Bicellaridae
    - *Bugula* sp.
- Mollusca
  - Pelecypoda
  - Mytilidae
    - *Modiolus modiolus* (L.)
    - *Modiolus undulatus* Dunker
    - *Perna viridis* Linne
    - *Perna indica* Kuriakose
  - Ostreidae
    - *Crassostrea madrasensis* Preston
    - *Ostrea edulis*
  - Littorinidae
    - *Littorina undulata* Gray
  - Muricidae
    - *Thais tissoti* Petit
    - *Thais bufo* Lamarck
- Urochordata
  - Stylidae
    - *Botryllus schlosseri* Pallas
    - *Lissoclinum fragile* Van Name
    - *Didemnum* sp.
- Fishes
    - Gobies and unidentified types

Doripsilla miniata Alder & Hancock, *Caloria militaris* Alder & Hancock, (nudibranchs); *Metaprotella problematica*, *Menippe sp.*, *Calappa* sp., *Tylocarcinus* sp., *Alpheus* sp. (crustaceans) were also observed occasionally.

Sea anemones : Sea anemones, also an important group of foulants on the panels, were found settling

Table 2—Fouling biomass on short–term panels

Period of exposure	Duration (d)	Biomass [g (100 cm)$^{-2}$.d^{-1}]			
		1 m	3 m	5 m	7 m
1987					
2.2 to 19.2	20	7.294	5.372	2.470	1.215
19.2 to 10.3	20	0.413	0.380	1.426	1.213
10.3 to 25.3	16	1.004	0.960	1.137	1.182
25.3 to 8.4	15	1.715	2.493	1.137	0.726
8.4 to 24.4	17	2.000	1.737	1.321	1.439
24.4 to 3.7	← Data not available →				
3.7 to 16.7	15	3.280	2.226	3.530	2.313
16.7 to 20.8	35	2.770	3.250	1.600	1.440
20.8 to 3.9	15	2.140	2.220	1.600	1.440
3.9 to 18.9	16	0.920	5.530	6.930	2.340
18.9 to 14.10	26	2.620	3.470	11.20	3.060
14.10 to 4.11	20	1.790	1.840	4.350	2.770
4.11 to 19.11	16	2.190	2.820	2.030	1.900
19.11 to 4.12	15	2.106	1.780	2.160	2.460
4.12 to 22.12	19	0.970	2.004	1.850	1.250
22.12 to 51.88	14	1.180	1.361	2.090	1.220
1988					
5.1 to 25.1	21	0.780	0.537	0.862	0.680
25.1 to 19.2	25	0.820	0.600	0.500	1.090
19.2 to 15.3	26	1.040	0.950	0.960	1.573

Table 3—Sea surface temperature, dissolved oxygen, salinity and rainfall data for Kalpakkam during 1987*

Period	Water temp. (°C)	Dissolved oxygen (ppm)	Salinity (× 10^{-3})	Rainfall (mm)
Feb.	27.0	6.0	32.15	
	31.0	7.1	32.23	Nil
March	29.0	6.4	33.99	
	28.5	4.8	34.45	0.5
April	32.5	5.6	35.0	
	30.7	6.3	34.45	39.1
May	29.6	5.2	34.56	
	31.0	5.5	35.56	Nil
June	29.0	3.9	34.45	
	—	—	34.45	64.7
July	28.9	5.1	33.99	
	29.9	5.3	35.00	2.1
Aug.	28.0	5.3	33.80	
	27.0	4.0	34.15	68.7
Sept.	27.5	6.2	34.51	
	28.5	5.1	35.04	94.9
Oct.	29.0	5.6	33.80	
	29.9	5.4	30.45	33.7
Nov.	29.3	6.0	29.21	
	27.5	—	27.43	152.3

*Temperature, salinity and dissolved oxygen data were collected at fortnightly intervals and rainfall data were monthly total

from May onwards and formed a group particularly abundant during NE monsoon period. While their rate of growth was 2.5 mm in 20 d in May, they achieved a growth rate of 8 mm in 15 d in October. Like ascidians sea anemones were also very dominant at 1 m depth.

Bryozoans : Erect and encrusting bryozoans were found settling on short–term panels particularly at 1 and 3 m depths. Species observed were *Membranipora* sp., *Bugula* sp. and *Acanthodesia* sp.

Biomass — Seasonal biomass accumulation was characterised by relatively high values during September to December. Such a pattern was evident at all depths. It can also be seen that biomass values were relatively high in February and May as well (Table 2). The period December–January is characterised by relatively low values. Maximum biomass values and pattern of seasonal abundance were significantly different from a previous study[4]. Earlier reports from 1 m depth[4] showed biomass values ranging from 0.45–2.55 g $(100\ cm)^{-2}.d^{-1}$, whereas the present study showed values ranging from 0.41–7.3 g$(100\ cm)^{-2}.d^{-1}$. Consistently high values were observed in May and July at 1 m depth, quite in agreement with the previous study. Sesasonal variation in biomass was less at 7 m as compared to other depths.

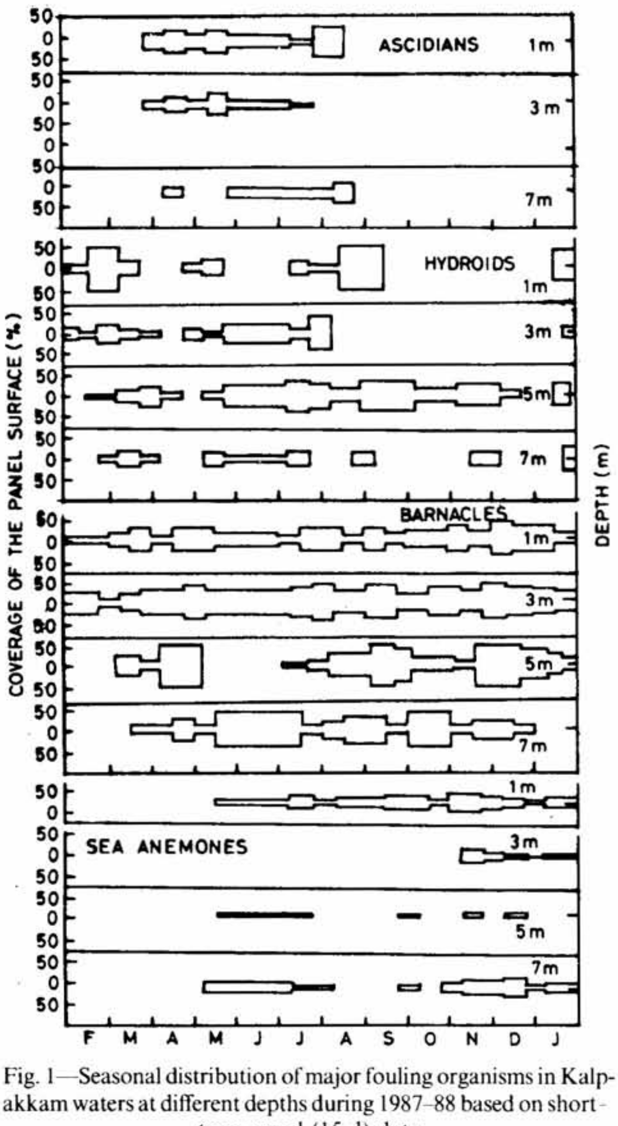

Fig. 1—Seasonal distribution of major fouling organisms in Kalpakkam waters at different depths during 1987–88 based on short-term panel (15 d) data

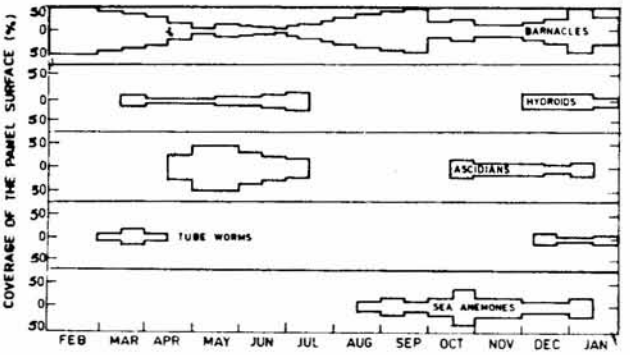

Fig. 2—Seasonal distribution of foulants on long-term panels (B series) during 1987–88

Fouling on long-term panels — Barnacles were the first to settle on long term panels exposed in February. These were followed by hydroids and tubeworms during March–April. During this period barnacle community remained largely unaffected by the secondary settlers. Ascidians began to colonize on the panels during April–June. Fully developed ascidian colonies completely covered the barnacles and other organisms by July. At this stage barnacles and hydroids were seen only at the edges of the panels which were relatively free of ascidians. However, ascidians dropped off during August–October and barnacle settlement was again observed on the panels as the panels were now free of ascidians. Probably the onset of NE monsoon and lowering of surface salinity would have resulted in death and disappearance of ascidians. Co-

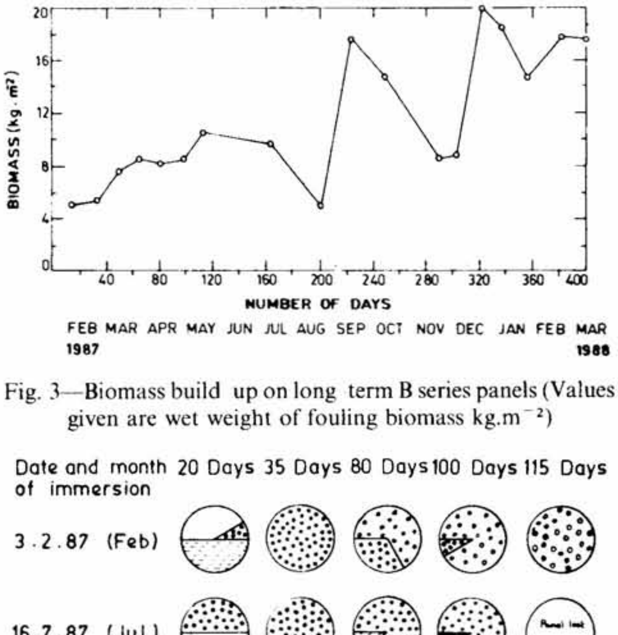

Fig. 3—Biomass build up on long term B series panels (Values given are wet weight of fouling biomass kg.m^{-2})

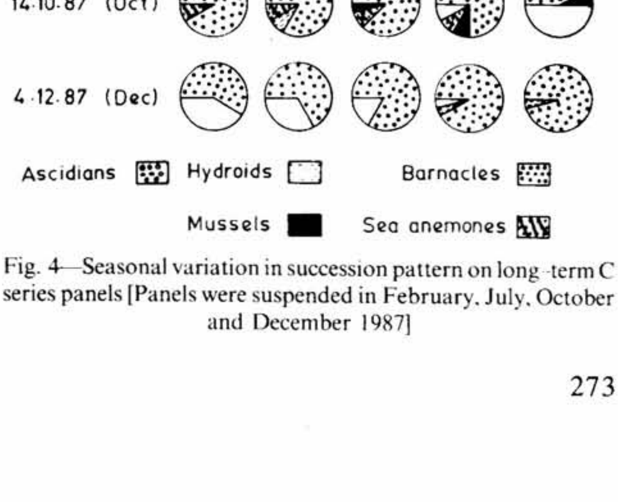

Fig. 4—Seasonal variation in succession pattern on long-term C series panels [Panels were suspended in February, July, October and December 1987]

lonization of sea anemones was also observed during this period. Although, the panels were free of green mussels and polychaetes, these two groups were found on the mild steel frame occassionally.

Long–term panels (C series) suspended in February showed heavy growth of hydroids as a primary settler, whereas on those suspended in July and December, barnacles were primary settlers. Dominant community was found to be different on panels immersed during different months of the year. Ascidians emerged as a dominant community on panels immersed in February whereas on panels immersed in July, October and December, barnacles outnumbered other species.

Biomass values of long–term panels (B series) were characterised by three maxima: after 120 d (April), 230 d (August) and 330 d (December) and also two minima: one after 200 d and another after 300 d. The three maxima possibly represent three stable communities during the year. The first maximum was dominated by ascidians and second and third maxima by barnacles.

Discussion

Colonization pattern of macrofoulants observed during this study showed some similarities to previous studies[7–9] on this coast. In the present study also spawning and settlement of foulants were observed throughout the year. *B. tintinnabulam*, *B. variegatus* and *Obelia* sp. settled on the panels during all seasons and constituted dominant members of the fouling community in Kalpakkam coastal waters. However, green mussels, a major community in the MAPS subterranean tunnel, jetty piles, trash racks and jetty structures were absent from the experimental panels. Considerable variations both in terms of composition of the community and their seasonal abundance were also observed during the present study. Previous studies[4,10] showed peak settlement rates in May and June whereas the present study showed an extension of this period up to September–October. Temporal variability in reproductive cycles was related either directly or indirectly, to seasonal changes in the physical environment[11] including tempeerature, salinity, phytoplankton productivity and light characteristics. During November and December, settlement rates of foulants were reduced to low values, correspondingly biomass values were also low at 1 m [0.97 g(100 cm)$^{-2}$.d^{-1}] and at 7 m [1.2 g(100 cm)$^{-2}$.d^{-1}]. This could be due to the low salinity conditions associated with the NE monsoon period.

The present investigation, where 4 depths were studied so as to ascertain the qualitative and quantitative aspects of fouling, showed continuous settlement of barnacle cyprids at 1 and 3 m depths. Abundant settlement of barnacles in the surface waters could be attributed to favourable hydrographic conditions including optimum illumination. Preferential settlement of barnacles on darkened surfaces was observed by Pomerat and Reiner[12]. However, Brankevich[2] and Anil[13] observed preferential settlement of *B. amphitrite* at better illuminated areas as observed in present study. However, during the periods of peak settlement depthwise variations were not significant. Ascidians and sea anemones also showed good settlement at 1 m depth. However, hydroids were more throughout the year at 5 m depth. Fouling organisms were abundant at intermediate depths rather than near the surface or at maximum depth (1 and 7 m). Maximum fouling biomass on short–term panels was also observed at 3 m depth.

Fouling succession pattern did not show any marked seasonal variations. Hydroids invariably were the primary settlers followed by barnacles. However, ascidians dominated the panel immersed in February. Increased larval abundance of ascidians during this period might be the cause for such dominance. Such interaction of the breeding period of foulants in the development of fouling communities was reported by Chalmer[14]. The biomass build–up of 19.3 kg.m^{-2} in 323 d in Kalpakkam waters is a moderately high value for open coastal waters. It seems reasonable to suggest that such heavy fouling growth during the post–operational period may have a link with the environmental changes following power station operation[7]. Prevalance of moderately warm temperature conditions in the coastal waters[9] for an extended period rather than a sharp summer maximum in April–May which was characteristic of the pre–operational period could be one such causative factor. Moreover, studies based on panel observation at one depth alone may not give a realistic picture of fouling pattern as well as abundance (as was the case in previous studies). This is evident from the notable depthwise differences observed in the present study. It would need a detailed study of the seasonal availability of the larvae of macrofoulants, factors affecting their colonization and succession at different depths and ecological interactions in settlement and survival before the cause of such high biomass build–up can be fully explained.

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