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Seasonal Changes of the Major Fouling Organisms in Cochin Harbour

N. U. NAIR and B. MEENAKUMARI

Central Institute of Fisheries Technology,
Cochin-682029, India

코친항에서의 주요 오손부착생물의 계절변화

네어 · 미네쿠마리

인도수산기술연구소

Abstract : Biofouling census in Cochin Harbour, the rank correlation coefficients between the members of the fouling community and their dependence on environmental perturbations are reported. The affinity/coexistance between major taxa of foulers is examined by cluster analysis through the coefficient of correlation. Maximum correlation is observed between polyzoans and tube-dwelling worms. *Modiolus* sp., barnacles and oysters ranked next in their order of coexistence. The higher fouling biomass observed is attributed to the profusion of species, their faster growth and attainment of sexual maturity at an early date in the tropics.

Key words : Fouling economics, Settlement, Test panel community, Growth, Coexistence.

Introduction

The enormous expenditure incurred by several maritime nations of the world for fouling prevention has been documented by several workers(Persoone 1997 ; Baciocco 1984 ; Fisher *et al.* 1975 ; Rao 1977 ; Nair *et al.* 1984). Fouling leads to decrease in ship's speed, increase in weight and hydrodynamic drag of navigational buoys and floating platforms. It interferes with the performance of underwater acoustic devices, clogs the seawater piping systems, affect the heat-exchanger performance in Ocean Thermal Energy Conversion systems and promotes corrosion of metals. The members of fouling community are mostly sessile and the composition of community and environmental perturbations existing in an area influence the status of the individual members and their interactions. The studies of Nair(1967), Nair and Pillai(1977), Meenakumari and Nair(1984), Nair and Nair(1987) deal with the settlement of selected fouling organisms but information on fouling biomass development, the succession in fouling community and their interdependance at Cochin Harbour have not received greater attention. The biology of fouling has shown variation in space and time in Cochin Harbour owing to anthropogenic activities. The present study is carried out to get a detailed insight of the current status of fouling census in Cochin Harbour and the influence of prevailing seasons to assess the deteriorative effects of fouling on system performance and to evolve control measures.

Materials and Methods

The experimental set up and data acquisition system for biofouling census and monitoring followed were basically similar to those of Nair(1967), Nair and Pillai (1977) and Nair and Nair(1987). The study was carried out during January '95 to December 1995. Smooth glass panels of size 1500*mm*×100*mm* kept arranged in a grooved wooden rack was exposed subtidally from

the north oil tanker berth in Cochin Harbour 9°58'N and 76°16'E. Weekly observations were carried out to record fouling settlement, growth and community structure. Rank correlation coefficients between each type of organisms and the environmental parameters were worked out to examine the dependence of biofoulers on hydrological factors. The rank correlation coefficient employed was that of Dixon and Massey (1957). To determine the affinity/coexistance between major groups, cluster analysis dendrogram was employed by finding the coefficient of correlation between the animals present(Snedecor and Cochran 1968).

Results and Discussion

The major fouling organisms encountered at Cochin Harbour were tube-worms, mud-tube dwelling polychaetes, barnacles, bryozoans, bivalves, edible oysters, rock oysters, mussels and several species of small gastropods. The microfouling category was made up of bacteria, several species of diatoms and protozoans. Folliculinids were also encountered but they presented an irregular cycle. The coelenterates settled were colonial hydroids. Caprellids were found in large numbers browsing on them. Few sea-anemones were also recorded. A detailed list of foulers is presented in Table 1. The settlement cycles of the major fouling taxa are presented in Table 2 and the matrix of rank correlation in Table 4. An increasing trend in the number of tube-worms with increasing air temperature, water temperature and salinity is seen from the significant correlation coefficient. In case of *Modiolus* the settlement is found to increase with decreasing turbiduty. Increased settlement of oysters with increased salinity is discernible which in turn is associated with low rain fall. A perusal of hydrological factors(Table 3) and settle-

Table 1. Test panel fouling communities encounted in Cochin Harbour during 1995.

A. Bacteria	D. Coelenterata	*Membranipora sawartii*
Micrococcus sp.	*Obelia bicuspidata*	*Acanthodesia sp.*
Pseudomonas sp.	*Obelia gracilis*	*Nolella paupensis*
Enterobacteria sp.	*Garveia franciscana*	*Electra anomala*
Actinomycetes	*Halocordyl disticha*	*Bowerbankia gracilis*
Bacillus sp.		
Yeast	*E. Annelida*	G. Crustacea
	Hydoides norwegica	Picnogonids
B. Diatoms	*Mercierella enigmatica*	*Metaprotella sp.*
Nitzchia longissima	*Eunice sp.*	*Corophium triaenonyx*
Navicula sp.	*Polydora flava*	*Tanais phileterinata*
Bacillaria sp.	*Polydora ciliata*	*Ampelisca scarbripes*
Melosira sp.	*Ficopomatus macrodon*	*Cirolana bicarinata*
Pleurosigma sp.	*Perinereis capensis*	*Balanus amphitrite communis*
Coscinodiscus excentricus	*Ceratonereis keiskama*	*Balanus amphitrite insignis*
Coscinodiscus sp.	*Nephthys oligobranchia*	
Cyclostella sp.	*Dendronereis zululandica*	H. Mollusca
Rhizosolenia sp.	*Platynereis sp.*	Crassostrea madrasensis
Thallasiosira sp.	Sabellids	*Crassostrea cucullata*
Closterium sp.		*Modiolus carvalhoi*
Licmophora sp.	F. Bryozoa	*Perna viridis*
Biddulphia sinensis	*Electra bengalensis*	*Musculista senhausia*
	Alderina aranianens	*Musculista arcuatula*
C. Protozoa	*Schizoporella cochinensis*	*Acolis sp.*
Zoothamnium sp.	*Victorella pavida*	
Vorticella sp.	*Electra crustulenta*	
Folliculinids	*Conopium reticulum*	

Table 2. Number of major fouling organisms settled on panels at Cochin Harbour during 1995.

Month	Tube-worms	Barnacles	Bryozoans	Modiolus	Oysters
February	22	374	15	8	51
March	15	12	75	12	16
April	30	3in-	90	118	29
May	117	967	20	352	27
June	66	375	21	–	8
July	257	150	361	–	14
August	–	211	69	–	–
September	–	49	39	–	–
October	–	1110	23	–	–
November	10	1302	62	211	–
December	17	1828	17	113	4

Table 3. Distribution of temperature, salinity, dissolved oxygen, turbidity and rainfall during 1995 at Cochin Harbour(1 *m* depth).

Month	Air temp. °C	Surface water temp. °C	Salinity ppt	Dissolved oxygen ml/l	Turbidity ppt	Rain fall mm
January	7.6	27.9	32.5	3.7	14.3	15.0
February	29.7	29.5	33.4	4.9	14.4	30.5
March	31.1	31.2	30.3	3.2	13.5	48.3
April	31.3	31.3	32.2	4.4	15.0	136.2
May	31.6	31.5	30.7	3.3	17.6	294.7
June	29.9	29.7	21.2	4.9	27.0	782.1
July	28.2	28.5	4.5	5.4	21.4	574.1
August	23.9	28.4	2.1	5.1	17.2	370.9
September	28.8	29.4	2.8	3.6	19.5	248.9
October	29.1	28.7	7.2	6.1	16.5	335.5
November	29.8	29.5	12.5	5.6	15.6	180.3

ment pattern of foulers show the obvious influence of air and water temperature, salinity, turbidity and rainfall. The negative relationship between salinity and rainfall and between salinity and turbidity is also interesting. High rainfall is associated with high turbidity of water. Higher turbidity clogs the respiratory structures in filter feeding bivalves which in turn may lead to mass mortality of these animals. The lowered salinity associated with rainfall also acts as a limiting factor and this may be the reason for the declension in settlement of bivalves such as *Modiolus* and oysters during the low saline period. Salinity and turbidity are found to exert maximum influence on settlement. Influence of salinity is more pronounced in tube-worms and oysters and turbidity on *Modiolus*(Table 4). A relationship of the form $y=ab^x$ was found to exist between salinity and tube worms, turbidity and *Modiolus*, and salinity and oysters(y=number of animals settled and x is the relevant hydrographic factor). The plot of log *y* on x is linear as expected(Figs. 1, 2 and 3). The relationship is highly significant in salinity vs log number of tube worms and salinity vs log number of oysters and is only significant in turbidity vs log number of *Modiolus*.

Owing to decreasing salinity, several organisms die out and the areas left bare by these organisms are found later re-colonised by the larvae brought to the site by tidal currents and other water movements(Nair 1965), during post-monsoon period when the salinity of the estuary increases and become slowly identical with that of the adjoining sea. Barnacles and bryozoans exhibited annual cycles in settlement but *Modiolus*, oysters and calcareous tube-worms were absent on experimental panels exposed during the major part

Table 4. Matrix of rank correlation.

	Air temp. °C	Surface water temp. °C	Salinity ppt	Dissolved oxygen ml/l	Turbidity ppt	Rain fall mm
Tube-worms	0.7091*	0.6813*	0.7*	-0.3909	-0.1818	-0.1638
Barnacles	0.6637	0.0545	-0.2546	0.3091	0.1818	0.0818
Bryozoans	0.1454	0.1273	-0.1233	0.0383	0.2455	0.4000
Modiolus	0.3455	0.2815	0.4364	0.1455	-0.6384*	-0.4661
Oysters	0.3409	0.3409	0.8682**	0.5273	0.6500*	-0.6727*
Air Temp. C		0.9909**	0.3909	-0.3545	-0.0645	-0.0884
Water Temp. C			0.3727	-0.4273	-0.0273	-0.5455
Salinity ppt				-0.40130	-0.6000*	-0.7000*
Dissolved oxygen *ml/l*					0.3000	0.4727
Turbidity ppm						0.8909

*Significant at 5% level
**Significant 1% level

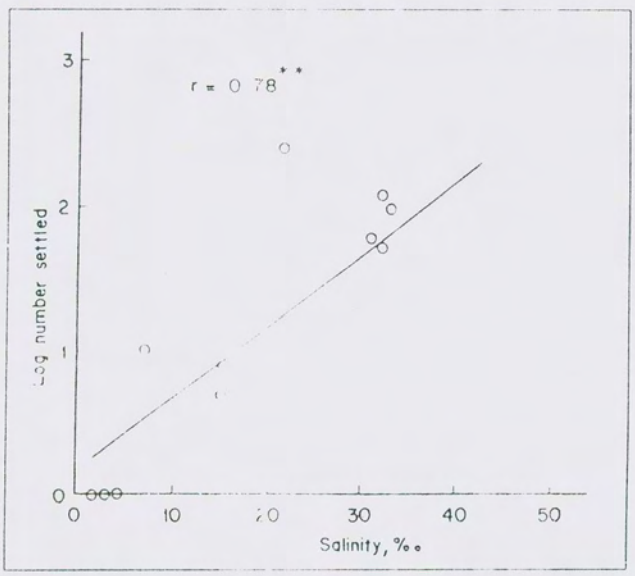

Fig. 1. Relation between salinity and log number of settled tube-worms.

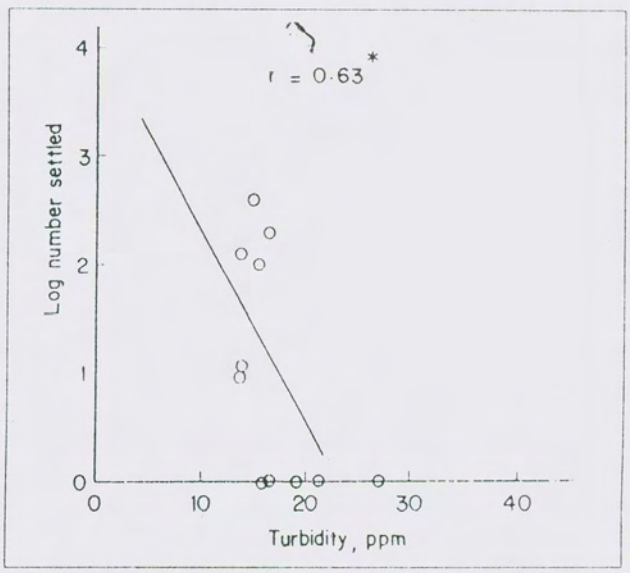

Fig. 2. Relation between turbidity and log number of settled *Modiolus*.

of monsoon period(June-September). A greater tendency to colonise the surface by barnacles and their sporadic settlement was particularly noteworthy during October-December(Table 2). A gradient is also seen in the horizontal distribution of fouling organisms with greater intensity near the barmouth with progressive declension towards the upper reaches of the estuary (Nair 1965). Changes in the distribution of brackish-water animals consequent to fluctuation in salinity were noticed by Nair(1967), Panikkar and Aiyar(1939), Nair(1965), Dharmaraj and Nair(1981), and Meenakumari and Nair(1984).

The clustering dendrogram pattern(Fig. 4) shows maximum correlation between bryozoans and tube-

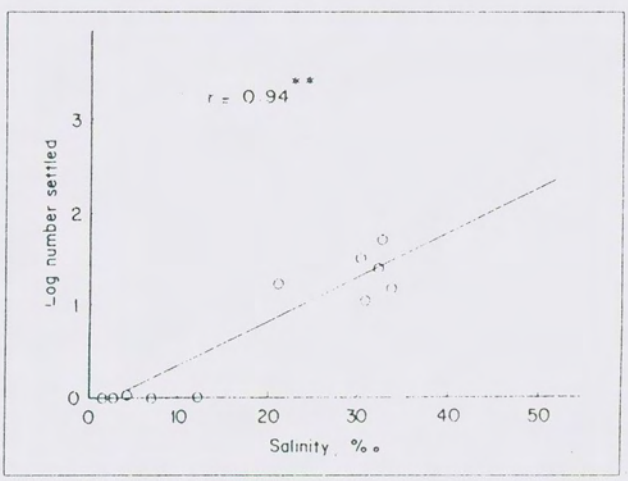

Fig. 3. Relation between salinity and log number of settled oysters.

Table 5. Comparison of growth of certain fouling organisms at different harbours.

Organisms	Authors	Locality	Age days	Growth *mm*
Laomedia bistriata	Ganapati *et al.*(1958)	Visakhapatnam	15	29
L. spinulosa	Paul(1942)	Madras	14	16
Hydroid sp.	Nair(1967)	Cochin	20	20.2
Hydraides norwegica	Paul(1942)	Madras	30	53
H. norwegica	Nair(1967)	Cochin	30	19.4
Serpula vermicularis	Ganapati *et al.*(1958)	Visakhapatnam	31	25
Mercieralla enigmatica	Ganapati *et al.*(1958)	Visakhapatnam	30	18
Pomatoceros triqetor	Nair(1962)	Norway	30	11~12
Tube-worms	Karande *et al.*(1986)	Bombay	30	20
Barnacles	Karande *et al.*(1986)	Bombay	30	12
Balanus amphitrite	Ganapati *et al.*(1958)	Visakhapatnam	36	13
B. amphitrite	Paul(1942)	Madras	32	14
B. amphitrite	Mawatari *et al.*(1954)	Japan	180	18~20
B. amphitrite	Nair(1967)	Cochin	30	12.1
B. amphitrite	Meenakumari & Nair(1988)	Cochin	45	11.0
B. crenatus	Nair(1962)	Norway	210	16.3
Elminius modestus	Skerman(1958)	Auckland	30	2.6
Encrusting bryozoans	Paul(1942)	Madras	30	41×28.2
Membranipora	Ganapati *et al.*(1958)	Visakhapatnam	30	50×50
Membranipora	Nair(1967)	Cochin	30	44.1
Membranipora	Karande et al.(1986)	Bombay	30	25.0
Bowerbankia	Antony Raja(1963)	Madras	30	119×87
C. madrasensis	Karande *et al.*(1986)	Bombay	30	10
C. madrasensis	Paul(1942)	Madras	44	21.5×14
C. madrasensis	Nair(1967)	Cochin	43	17.1×18.9
Modiolus striatulus	Antony Raja(1963)	Madras	40	11.5
M. carvalhoi	Nair(1967)	Cochin	36	11.7

coastal current, he tried to quantify fouling and showed a pattern of decreasing density of settlement from the shore to faraway sea surfaces and also from surface to bottom. Nair and Nair(1987) also showed certain regularities in settlement and growth of foulers at Cochin Harbour. As noted by De Palma(1972), Nair and Nair(1987) observed definite trends in the relative density of fouling attachment. Maximum attachment was during the post monsoon period(November~February) and least during the monsoon period(June~September). Salinity is the master factor in the control of fouling at Cochin. Density of settlement is taken as the index for computing the quantum of fouling debris by Nair and Nair(1987). Studies carried out from various harbours of the world show considerable variation in quality and quantity of fouling depending on climatological and hydrographical factors. WHOI (1952) listed about 2000 species of animals and plants but this number has since been doubled(Crisp 1972). Control measures adopted with advantage in one locality or in one biotic environment may not thus be equally effective in other situations(Karande *et al.* 1986). Coupled with this, widely different materials and methodologies adopted to compute the quantity and quality of biomas generated bring into focus the imperative need for detailed biological investigations of the epibenthic communities as a prelude to effective fouling control.

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worms. *Modiolus*, balanids and oysters rank next in correlation to tube worms and bryozoans in their decreasing order of coexistance. The modulus values of the correlation between the various major groups of animals present on the panels are presented in the matrix diagram(Fig. 5).

Fig. 4. Dendrogram for the correlation coefficient among the fouling groups.

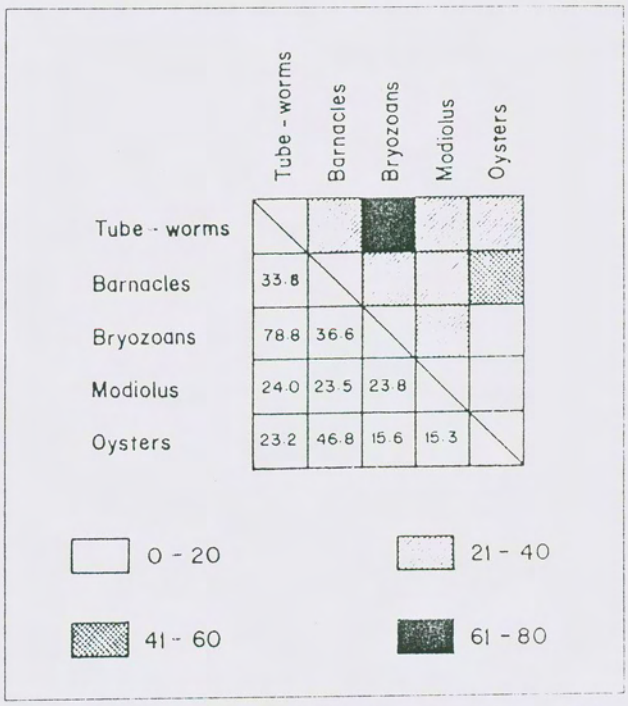

Fig. 5. Matrix diagram depicting the percentage modulus values of major foulers.

The fouling biomass(wet weight) computed for various harbours of India and also for certain world harbours is reported by Karande *et al.*(1986). Biomass accumulated during 40 days at Bombay, Andamans and Madras was 4, 6 and 8 *kg* m^{-2} respectively. For Argentina, Australia, Florida(USA), Hong Kong and Italy the respective figures were 0.5, 0.5, 5.0, 4.0 and 0.2 *kg* m^{-2} yr^{-1}. De(1984) reported for Indian waters, a rate of generation of fouling debris to the order of 6 to 9 *kg* m^{-2} yr^{-1}. As noted by Karande *et al.*(1986) and De(1984) the biomass accumulation in a tropical country like India is much more than what is recorded from several world harbours. This is mainly due to the profusion of animal species and their uninterrupted faster growth and attainment of sexual maturity at an early age(Nair 1965) in the tropical waters. A biomass of 10 *kg* m^{-2} after 10 months was noticed by Karande *et al.*(1986) and sloughing off of organisms thereafter owing to overcrowding and death. They could also record a maximum weight of 16 *kg* m^{-2} in cooling water inlets after 20~24 months. The biomass reported by Pillai and Ravindran(1984) on metallic surfaces is very much higher than what is reported from other Indian Harbours. Karande *et al.*(1986) estimated a fouling growth of about 10.2 *cm* thick in most of the sites of the Indian coasts in a two year period.

Table 5 summarises the comparative growth of certain fouling organisms in different harbours. Comparison of growth for about 30 days, for the various fouling organisms shows that growth at Cochin is somewhat comparable with those at Bombay, Visakhapatnam and Madras. However growth of many fouling organisms, particularly barnacles in many world harbours such as Millport(Pyefinch 1948), Bergen(Nair 1962), Newzealand(Skerman 1958) and Japan(Mawatari *et al.* 1954) is considerably lower than what is recorded from Indian Harbours. Marine biofouling is very severe in Indian tropical waters. De Palma(1972) developed a growth curve nomogram for the prediction of fouling rate under different marine environments. Assuming that larvae generally originate in near shore areas and that they are carried further offshore by

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