45. Biological Fouling at Port Kakinada, Godavari Estuary, India

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Results of fouling investigations conducted for the first time at the fast-developing intermediate port of Kakinada in Godavari Estuary, Andhra Pradesh during 1983-1984 are presented. The fouling species collected from different structures and craft were identified and listed. Several of the species are reported for the first time from the area and some are new records to the Bay of Bengal. The main species are: the serpulid, *Mercierella enigmatica*; the barnacle, *Balanus amphitrite*; and the bryozoans, *Electra bengalensis, Membranipora amoyensis, Alderina arabianensis*, and *Victorella pavida*. Panel tests (timber and glass; short- and long-term) were conducted at two selected stations (Station I: Kakinada canal, port area; Station II: new fishing harbor) with widely differing hydrographical conditions. The data obtained for one year are presented. Variations in the nature and composition of the fouling communities were found between the two stations. Station I, subjected to extreme salinity fluctuations, typically supported a low number of highly tolerant (estuarine) species, whereas a high number of species and a more complex community structure were found at the more stable Station II. Data on seasonal settling patterns, fouling biomass fluctuations, and growth rates of important species are given and relevant comparisons made with other Indian harbors.

INTRODUCTION

Within the various oceanic developmental programs currently being initiated or intensified in India, studies on marine fouling assume special importance. Although valuable contributions have been made, not even the ten major ports in the country have been studied (Anon. 1983). Because major differences are known to exist in hydrographical conditions and biofouling along the long coast of the country, an immediate need exists for undertaking these studies at the many harbors and ports not yet investigated.

This paper presents the results of the first investigation on biofouling conducted at two sites at Kakinada—a rapidly developing intermediate port on the eastern coast of India.

LOCALITY

Kakinada (16°55'to 17°N, 81°15' to 81°18'E) is the second largest port in Andhra Pradesh, located 160 km south of Visakhapatnam. The town bustles with hectic maritime activities (cargo handling, fishing) and has a rich boat-building tradition dating back to the 13th century. The state's best equipped boat-building yard, responsible for revolutionizing fishing in the region, is located here. The port is at the eastern end of Kakinada Canal, which runs through the town and opens into a naturally-endowed port bay, and is well sheltered by the 28.16 km Hope Island to the south and a 16 km sand bar to the east (figure 1). The last two decades witnessed remarkable growth of fishing and commercial activities at Kakinada. Because the facilities at the old fishing harbor—an old military structure located on the southern bank of the canal—did not meet growing needs, the World Bank aided in the construction of a new one, 8 km north of the inner port, near the Vakalapudi light house. The new fishing harbor, formed by six breakwaters, was designed to accommodate 410 mechanized boats and 15-20 m trawlers. An extensive mangrove system of approximately 10,000 ha, the second largest in the country, exists on the southern side of Kakinada Bay. It is being used for development of a number of brackish-water fish farms.

ENVIRONMENTAL CONDITIONS

The hydrography of Kakinada Bay and the Gautami Godavari estuarine system was investigated by Ramasarma and Ganapati (1967, 1972) and Narasimham (1980). They showed that the characteristic variations are due to the influences of the monsoons (southwest monsoon, June to October; northeast monsoon, late October to December), evaporation (February to May), and a complicated circulation pattern in the Bay of Bengal.

Tides in the area are semidiurnal; maximum spring tide being 1.8 and low tide 0.18 m. Annual rainfall is 101.6 cm, a major portion during the southwest monsoon. During the northeast monsoon, there is only intermittent rain.

STATIONS

Two stations were selected for quantitative studies on the basis of accessibility and variability of environmental conditions (figure 1). The sites are characterized as follows:

Station I. This station is located in the Kakinada canal next to the FTI jetty in the port vicinity. It is 1.5 km from the bar mouth. Depth at the

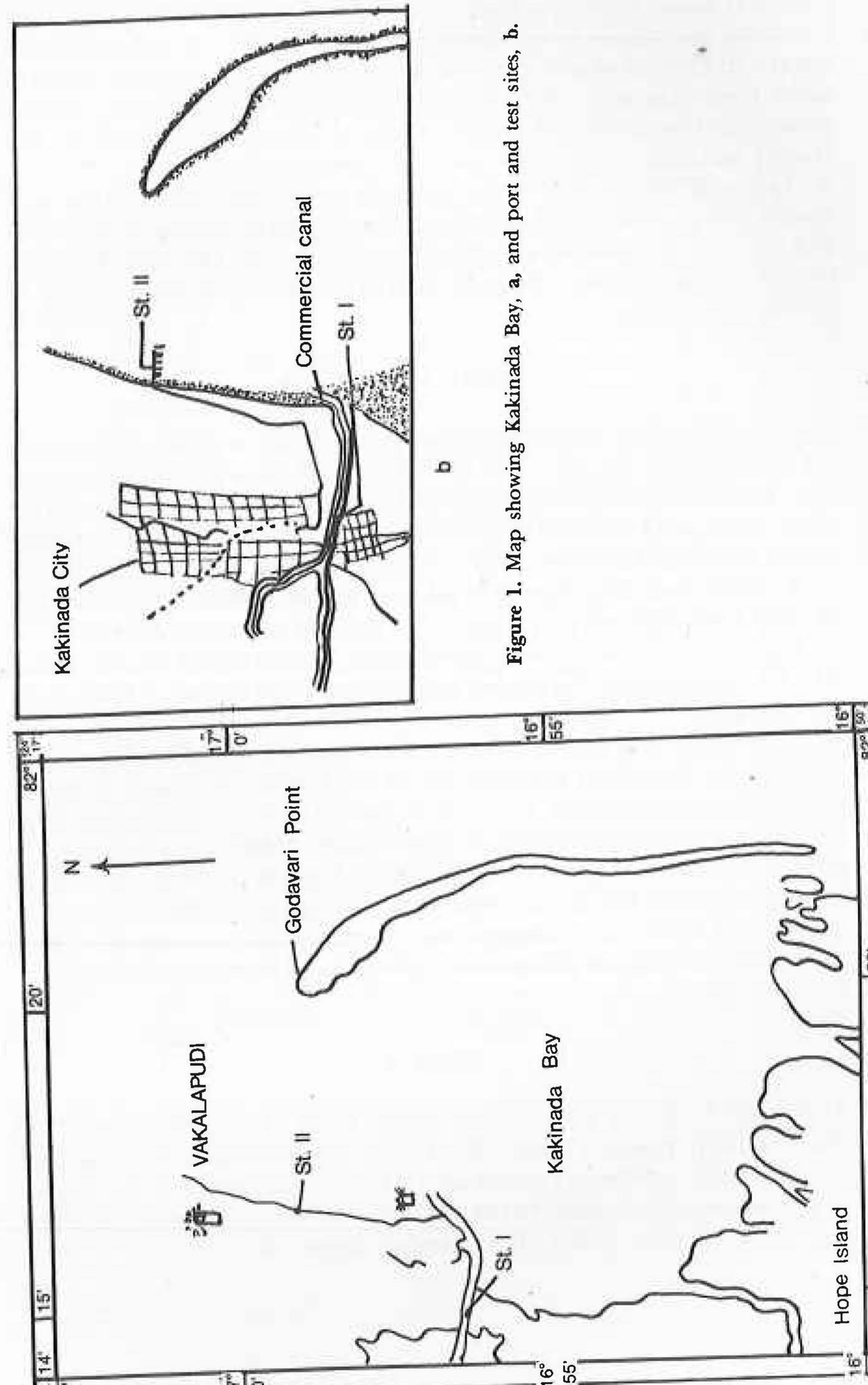

Figure 1. Map showing Kakinada Bay, a, and port and test sites, b.

station is about 2 m. The water at the site of the experiment is turbid. Dredging operations in the channel also contribute to this as do town sewage and release of oil from fishing vessels. Due to the constant input of water from irrigation canals draining into the Kakinada canal, salinity values are comparatively low, they fluctuate between near freshwater and typical brackish water.

Station II. This station is located at the new fishing harbor, 8 km from the bar mouth. Silting and turbidity are negligible and the waters are clear and relatively unpolluted. Depth at the station is 7 m. The water is typical coastal brackish water (Remane 1971), presenting brackish water to marine conditions.

MATERIALS AND METHODS

Timber (*Mangifera indica*) and glass (plain window glass) panels, were kept suspended in wooden racks 0.3 m below the low water mark at the two sites. The sizes of test panels were 15×8×2 cm for wood and 15×8×2 mm for glass. Short- and long-term tests were conducted simultaneously. The study period was from December 1983 to November 1984.

A- Series (monthly, short-term panels). Twelve panels of timber and 12 of glass were exposed and replaced at the end of one month.

B- Series (cumulative, long-term panels). Twelve panels of each material were simultaneously exposed and collected one by one at the end of each month.

Data on settling periods, growth rates, and fouling abundance were obtained by periodical examination of the fouled test panels. Fouling organisms were identified, generally to species level; microscopic fouling and algae were not considered in these studies. Numerical abundance of different species and groups was recorded whenever possible and relative abundance noted. For certain organisms, such as encrusting-creeping bryozoans and hydroids, settlement was recorded semiquantitatively. Biomass of the fouling complex was recorded wet and after oven-drying for 24 hours at 100°C.

RESULTS

At Station I, surface temperature ranged from 25.5 (January) to 31°C (May); salinity from 4.8 (December) to 24.2 ppt (February), and dissolved oxygen from 4.1 (February) to 6.2 ml/l (October). At Station II, the respective values were 27 (October) to 33°C (May), 18.6 (October) to 32 ppt (May) and 3.5 m (March) to 5.8 ml/l (August) (figure 2).

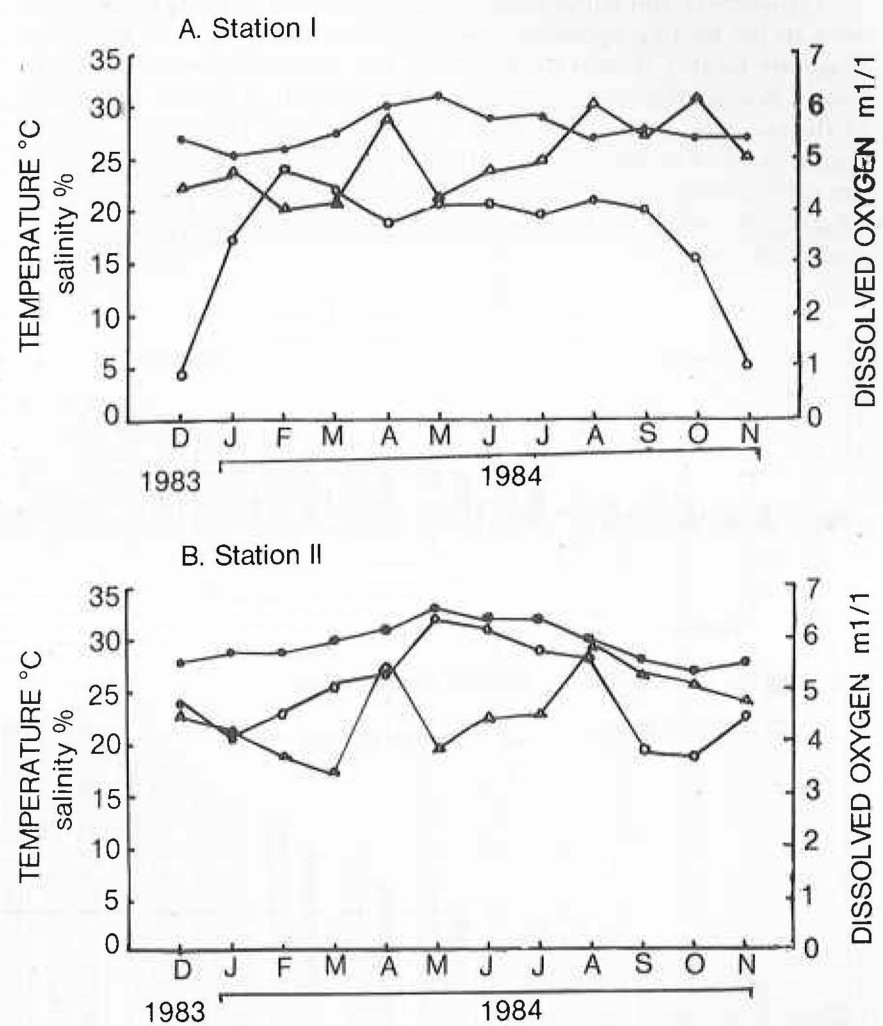

Figure 2. Hydrographical parameters. Station I, **A**; Station II, **B**; Temperature ●——●, salinity o——o, dissolved oxygen Δ——Δ.

Fouling organisms

Figures 3–10 and tables 1–4 provide information and data on the organisms in the fouling communities at Port Kakinada. Many of the species listed are locality records for Kakinada and some are new records for the Bay of Bengal. Relative abundance and settlement of the different species at the two test sites are presented in tables 2 and 3. Dimension measurements attained by important fouling organisms on the immersed panels are given in table 4. The fouling biomasses (wet and dry weights) accumulated on the panels are presented in figures 3-4. A summary of the observations follows.

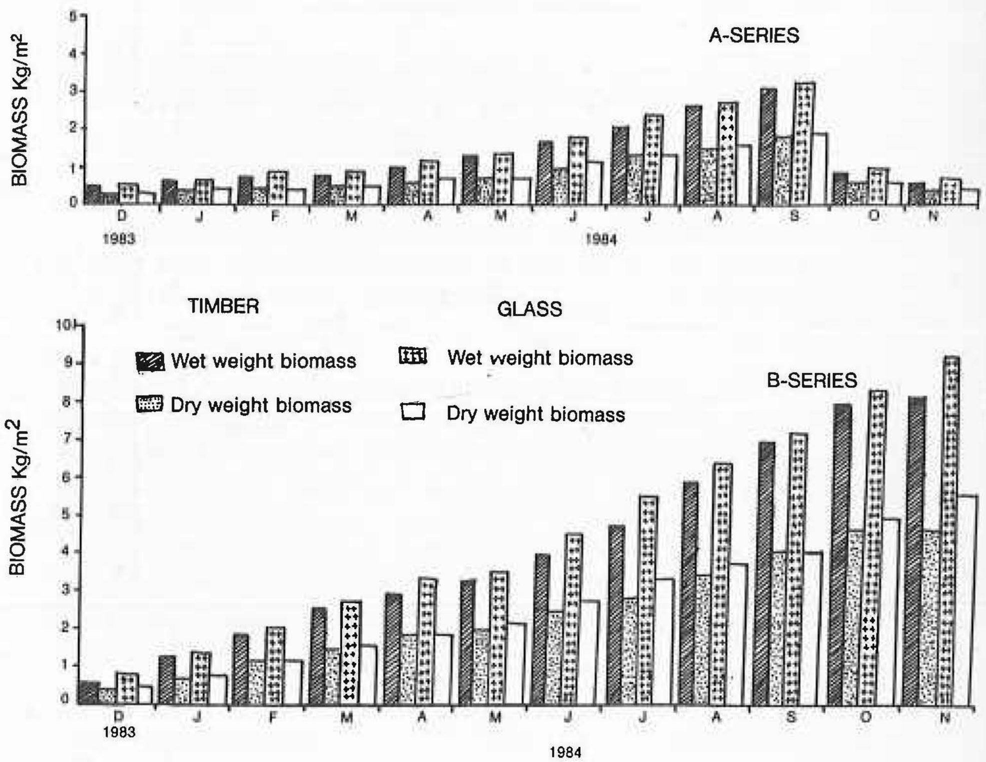

Figure 3. Fouling biomass at Station I.

Coelenterates: The contribution of coelenterates to the fouling communities is not appreciable. They settled only occasionally in negligible quantities. Two species of hydroids, *Bimeria fransiscana* and *Laomedia bistriata,* and the anemone, *Sagartia* sp., were found on panels at Station II. Hydroids, when present, were mostly on the edges of the panels.

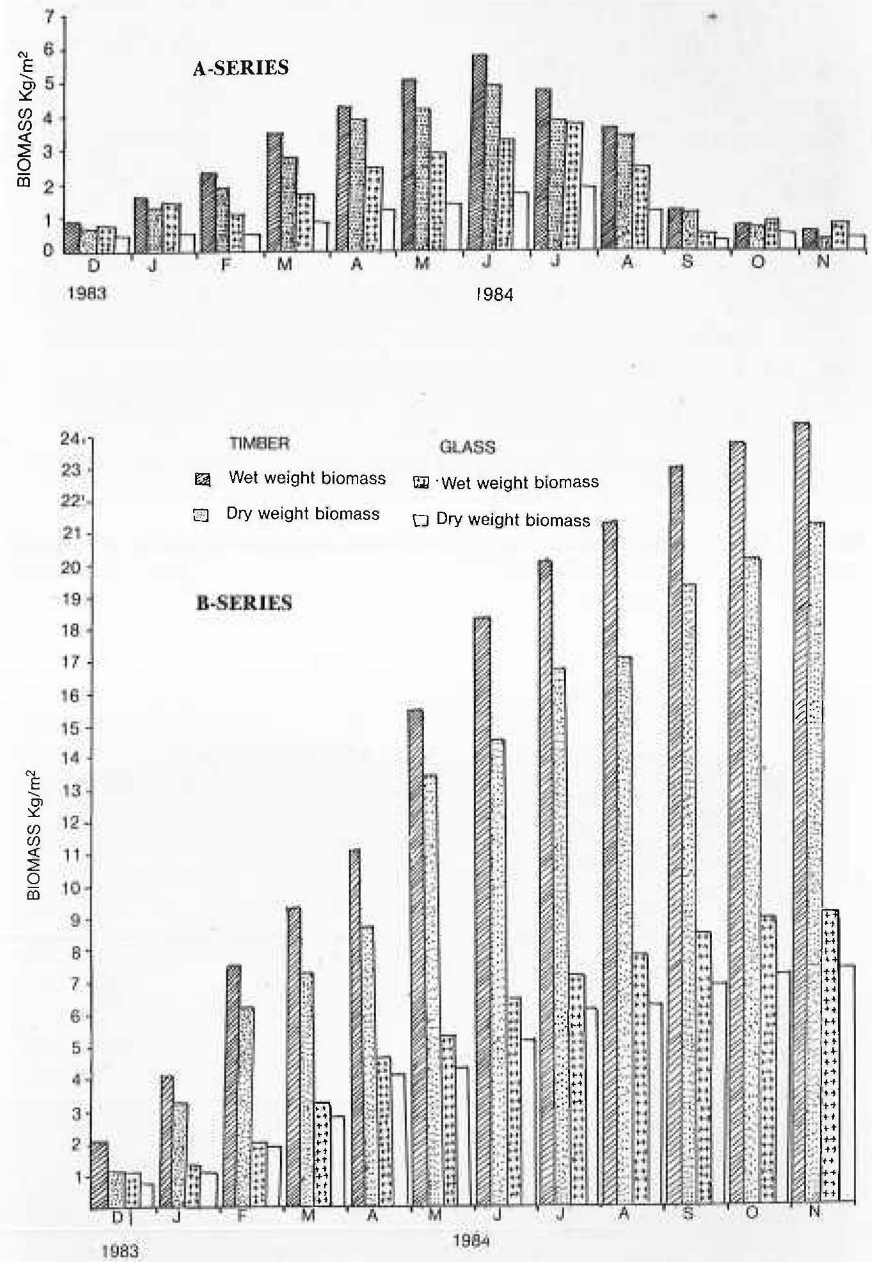

Figure 4. Fouling biomass at Station II.

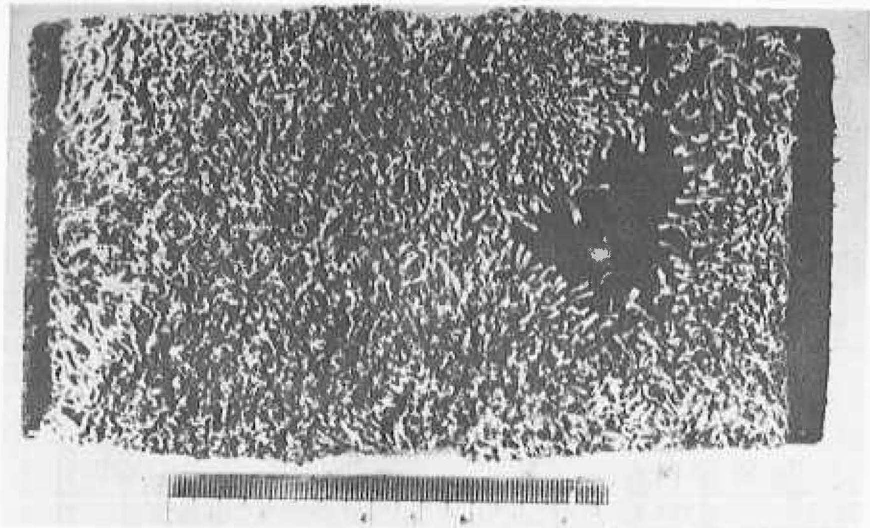

Figure 5. Dense settlement of the serpulid, *Mercierella enigmatica* at Station I. Period of immersion—2 months, timber panel.

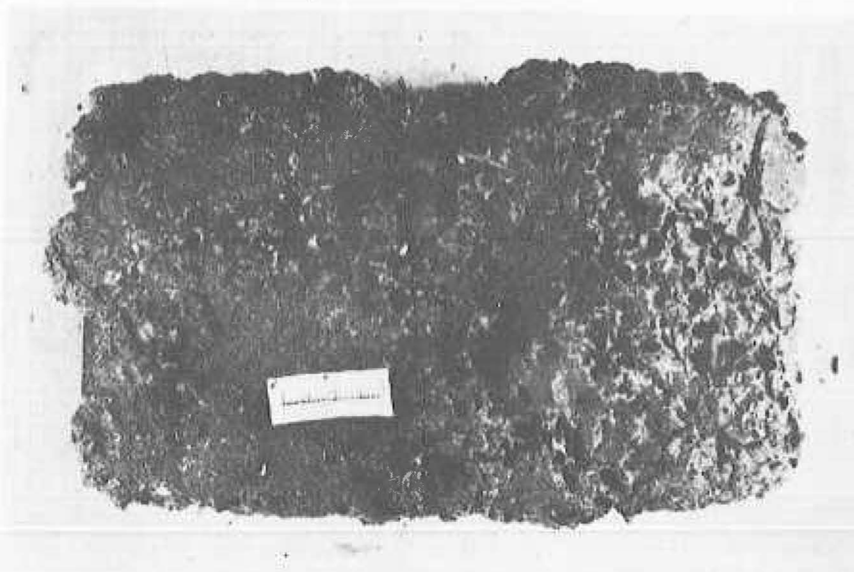

Figure 6. Barnacle coverage on a B-Series panel at Station II. Period of immersion— 4 months, timber panel.

Figure 7. Encrusting bryozoans on a fouling panel at Station II. Period of immersion— 1 month, glass panel.

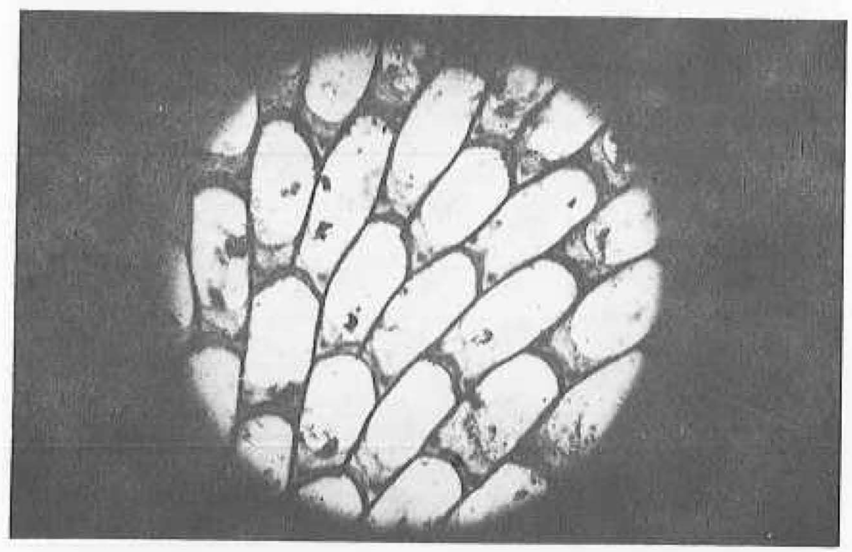

Figure 8. Photomicrograph of *Alderina arabianensis* (× 40).

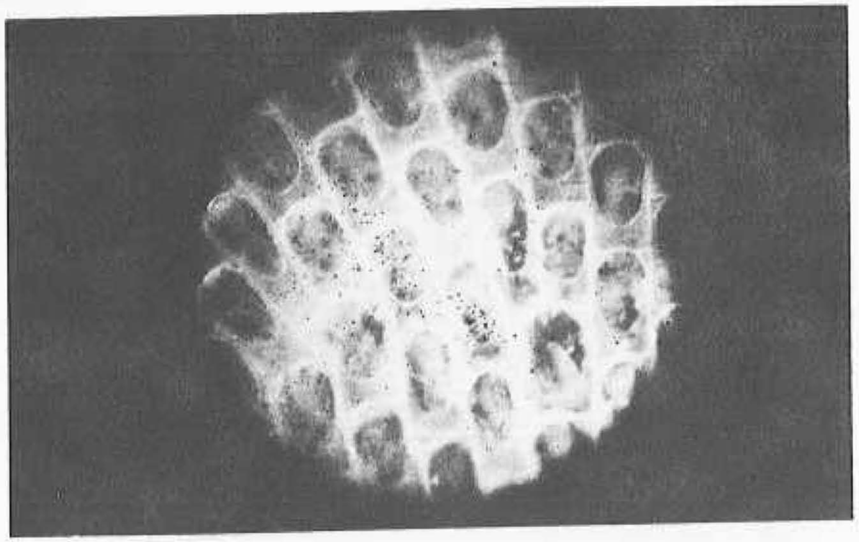

Figure 9. Photomicrograph of *Membranipora amoyensis* (× 40).

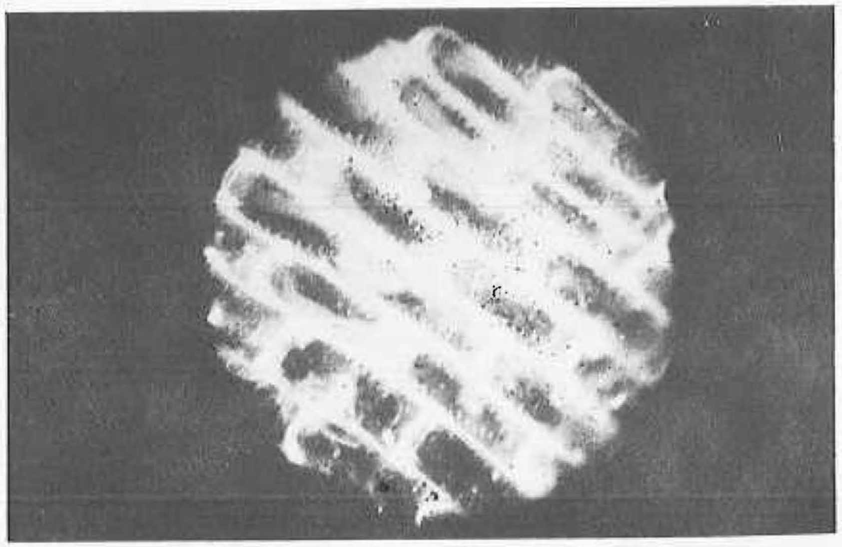

Figure 10. Photomicrograph of *Membranipora annae* (×40).

Table 1. Species of the fouling communities at Kakinada.

Species	Station I Port Kakinada	Station II New Fishing Harbor	Other Structures
Hydroids			
1. *Bimeria franciscana*		×	
2. *Laomedia bistriata*		×	
Bryozoans			
3. *Bowerbankia gracilis*	×		
4. *Victorella pavida*	×		
5. *Membranipora amoyensis*		×	
6. *M. annae*		×	
7. *Alderina arabianensis*		×	
8. *Electra bengalensis*		×	
9. *E. tenella*		×	
10. *Hippoporina* sp.		×	
Serpulids			
11. *Mercierella enigmatica*	×		
12. *Ficopomatus macrodon*			×
Sebellids			
13. *Sebellaria cementarium*	×		
Other polychaetes			
14. *Phylodoce* sp.		×	
15. *Neries* sp.	×		
16. *N. chilkaensis*	×		
17. *N. unifasciata*	×		
18. *Morphysa sanguinea*	×		
Barnacles			
19. *Balanus amphitrite*		×	
20. *B. patelliformis*			×
21. *Megabalanus tintinnabulum*			×
Amphipods			
22. *Maera* sp.	×	×	
23. *Corophium* sp.		×	
Tanaids			
24. *Apseudes avicularia*	×	×	
Isopods			
25. *Sphaeroma walkeri*	×	×	
26. *Cirolana bovini*		×	
Decapods			
27. *Cardiosoma caronifera*		×	
Gastropods			×
28. *Littorina undulata*			×
29. *L. scabra*			×
30. *Nerita chamelon*			×
Pelecypods			×
31. *Ostrea crenulifera*			
32. *Crassostrea gryphoides*		×	
33. *C. madrasensis*		×	

Table 1. continued.

Species	Station I Port Kakinada	Station II New Fishing Harbor	Other Structures
34. *Perna viridis*		×	
35. *Anomma achaeus*		×	
36. *Septifer loculifer*			
Ascidians			
37. *Botryllus* sp.		×	

Bryozoans: These organisms are an important component of fouling at Kakinada and were among the most common forms settling on the panels. Both encrusting and stolonate species were recognized. Of the eight species identified, *Electra bengalensis* and *E. tenella* are locality records to Kakinada, and *Alderina arabianensis, Membranipora amoyensis,* and *M. annae* new records to the Bay of Bengal.

At Station I, the web-like delicate colonies of *Victorella pavida* were often seen on A-Series panels during the low saline months of October, November, December, and January. In the older panels of the B-Series, however, they were seldom seen beyond two months, as they were quickly overgrown by other dominant foulers. *Bowerbankia gracilis* settled in small numbers rather sporadically.

At the new fishing harbor (Station II), luxuriant growths of encrusting bryozoa were often present, at times dominating the fouling communities on monthly panels. The most important were *E. bengalensis, M. amoyensis,* and *A. arabianensis.* These bryozoans settled throughout the year and were particularly abundant during December, January, September, October and November. On the B-series panels, the encrusting bryozoans were found up to the third and fourth months. Occasionally, they were seen settling on other organisms in these older panels, but these colonies never attained the size of the colonies settled on monthly panels.

Polychaetes: The calcareous tube-dwelling serpulid, *Mercierella enigmatica,* was the most important polychaete encountered. It dominated the fouling communities at Station I. Dense, intertwined masses of this species, several centimeters in height, were also seen encrusting the hulls of docked vessels and several harbor structures. On monthly panels at Station I, they settled in large numbers throughout the year, contributing over 90% of the biotic coverage on several occasions. On the older panels of the B-Series, thick compacted masses of this serpulid were found on all panels. When crowded, the tubes exhibited a tendency to grow vertically.

Table 2. Settlement of fouling organisms on panels of A-Series (short-term) and B-Series (cumulative) during December 1983 to November 1984 at Station I.

Species	Surface	D 1983	J	F	M	A	M	J 1984	J	A	S	O	N
A-Series													
Bryozoans	T	A	VC	R	R	R	—	—	—	—	—	VC	A
Victorella pavida	G	A	C	R	R	R	—	—	—	—	—	VC	A
Bowerbankia gracilis	T	R	R	—	—	—	R	—	R	—	R	R	C
	G	R	R	—	—	—	R	—	R	—	R	R	C
Polychaetes	T	40	132	156	195	231	283	391	485	596	706	112	50
Mercierella enigmatica	G	50	145	171	210	242	297	412	500	607	719	120	65
Errant polychaetes	T	6	2	2	1	—	—	—	—	—	2	3	7
(16 to 18)	G	4	2	1	2	—	—	—	—	—	1	3	5
Sebellids	T	4	3	4	—	4	—	—	—	—	2	3	5
Sabellaria cementarium	G	2	2	4	—	.6	—	—	—	—	3	2	4
Arthropods (free living)	T	20	23	25	27	28	—	—	—	29	31	24	20
(22, 24, 25)	G	21	20	19	23	24	—	—	—	30	27	20	18
B-Series													
Bryozoans	T	A	VC	C	—	—	—	—	—	—	—	—	—
Victorella pavida	G	A	VC	C	—	—	—	—	—	—	—	—	—
Bowerbankia gracilis	T	R	R	R	—	—	—	—	—	—	—	—	—
	G	R	R	R	—	—	—	—	—	—	—	—	—
Polychaetes													
Mercierella	T	150	295	436	591	686	775	921	1091	1345	1570	1790	1850
enigmatica	G	193	321	475	628	725	831	1051	1285	1456	1610	1892	2112
Errant polychaetes	T	7	4	4	5	—	—	—	—	—	4	5	9
(16 to 18)	G	5	3	3	4	—	—	—	—	—	5	4	7
Sebellaria	T	—	—	6	—	—	8	—	8	—	—	—	—
cementarium	G	—	—	4	—	—	4	—	4	—	—	—	—
Arthropods (free living)	T	25	26	28	31	35	—	—	—	35	42	35	28
(22, 24, 25)	G	22	24	27	25	31	—	—	—	30	39	31	25

A = abundant (representing settled surface of 50% and above), VC = very common (representing settled surface of 25–50%), C = common (representing settled surface of 10–25%), R = rare (representing settled surface of below 10%) — = absent, T = timber, G = glass panels. Numbers in parentheses correspond to numbers given for species in table 1.

Table 3. Settlement of fouling organisms on panels of A-Series (short-term) and B-Series (cumulative) during December 1983 to November 1984 at Station II.

Species	Surface	D 1983	J	F	M	A	M	J 1984	J	A	S	O	N
							A-Series						
Coelenterata													
Hydroids	T	R	R	R	R	R	R	—	—	—	R	R	R
	G	R	—	—	—	R	R	—	—	R	—	—	R
Sagartia sp.	T	—	—	—	3	5	4	4	—	—	2	4	3
	G	—	—	—	1	2	3	4	—	—	1	2	2
Bryozoa													
Membranipora amoyensis	T	VC	A	C	C	A	R	R	R	R	VC	A	A
	G	A	A	C	C	A	C	R	R	R	VC	A	A
Electra bengalensis	T	A	A	R	R	R	R	R	R	VC	A	A	A
	G	A	A	C	R	R	R	R	C	A	A	A	A
Alderina arabianensis	T	C	A	A	R	R	R	R	R	R	C	A	A
	G	VC	A	A	R	R	R	R	R	R	C	A	A
Other bryozoans (6, 9, 10)	T	R	R	R	C	C	VC	R	R	—	—	R	R
	G	R	R	R	C	C	VC	R	R	—	—	R	R
Polychaeta													
Errant polychaetes (14, 15)	T	18	24	32	36	45	40	25	28	30	35	40	44
	G	15	20	22	28	30	31	15	16	20	18	20	23
Arthropods													
Barnacles													
Balanus amphitrite	T	95	102	113	173	258	291	314	355	340	70	48	72
	G	71	108	119	164	221	267	305	296	255	51	34	38
Other arthropods (22, 23, 24, 25, 26, 27)	T	20	22	35	45	35	44	41	40	35	30	28	32
	G	20	21	32	40	28	20	35	32	24	22	25	26
Mollusca													
Septifer loculifer	T	2	4	5	4	5	5	6	3	4	—	—	—
	G	2	3	3	4	4	4	4	2	1	—	—	—
Ascidians													
Botryllus sp.	T	—	—	—	5	4	5	—	—	—	4	5	3
	G	—	—	—	4	3	4	—	—	—	4	4	2
							B-Series						
Coelenterata													
Hydroids	T	R	R	—	—	—	—	—	—	—	—	—	—
	G	R	R	—	—	—	—	—	—	—	—	—	—
Bryozoans													
Membranipora amoyensis	T	VC	C	C	R	—	—	—	—	—	—	—	—
	G	A	VC	C	C	—	—	—	—	—	—	—	—
Electra bengalensis	T	A	C	C	R	—	—	—	—	—	—	—	—
	G	A	VC	C	R	—	—	—	—	—	—	—	—
Alderina arabianensis	T	A	C	C	R	—	—	—	—	—	—	—	—
	G	A	VC	C	C	R	—	—	—	—	—	—	—
Other bryozoans (6, 9, 10)	T	A	VC	C		—	—	—	—	—	—	—	—
	G	A	VC	C	—	—	—	—	—	—	—	—	—
Errant polychaetes (14, 15)	T	15	26	29	24	26	34	27	28	32	20	42	22
	G	13	24	27	25	23	32	29	26	29	18	17	20
Barnacles													
Balanus amphitrite	T	121	132	165	210	296	322	385	428	465	487	510	531
	G	89	112	134	193	245	305	366	398	433	449	489	502
Other arthropods (22, 27)	T	25	28	40	52	53	35	41	47	43	49	40	23
	G	30	21	41	45	34	23	32	40	39	42	36	21
Mollusca													
Crassostrea madrasensis	T	2	1	2	4	6	4	—	2	3	—	4	6
	G	—	1	1	3	2	3	—	2	1	—	2	2
C. gryphoides	T	—	—	1	2	3	4	2	—	—	—	—	—
	G	—	—	1	1	2	2	1	—	—	—	—	—
Septifer loculifer	T	2	4	5	4	—	3	4	—	—	—	—	—
	G	3	2	3	4	—	2	2	—	2	2	—	—
Anomia achaeus	T	2	3	2	4	3	1	—	—	1	1	—	—
	G	1	2	1	2	2	2	—	—	—	—	—	3
Perna viridis	T	3	5	6	4	5	7	3	—	—	—	—	1
	G	2	4	3	2	3	5	2	—	—	—	—	—
Ascidians													
Botryllus sp.	T	—	—	—	2	1	3	—	—	—	—	—	—
	G	—	—	—	—	1	1	—	—	—	—	—	—

A = abundant (representing settled surface of 50% and above), VC = very common (representing settled surface of 25–50%), C = common (representing settled surface of 10–25%), R = rare (representing settled surface of below 10%) — = absent, T = timber, G = glass panels.
Numbers in parentheses correspond to numbers given for species in table 1.

Table 4. Growth of important fouling organisms at Port Kakinada.

Growth rates of *Mercierella enigmatica* (maximum sizes)

Immersion Period (months)	Tube Length of Largest Individual (mm)	Panel	Remarks
1	20	timber, glass	Overall lengths of calcareous tubes of largest members of relatively straight specimens were measured. Specimens attained maximum sizes on both glass and timber panels.
2	24	timber, glass	
3	32	timber, glass	
6	56	timber, glass	
12	64	timber, glass	

Growth rates of *Balanus amphitrite* (maximum sizes)

Immersion Period (months)	Rostro-carnal Diameter (apical) (mm)	Rostro-carnal Diameter (basal) (mm)	Shell Height (mm)	Panel	Remarks
1	6.0	9.0	11.0	timber	Growth on timber panels more rapid in all observations.
2	7.5	10.2	12.1	timber	
3	8.2	11.3	13.2	timber	
6	10.1	16.3	14.9	timber	
12	13.2	21.5	16.8	timber	

Growth rates of bryozoan colonies (attained in 1 month)

Species	Area Covered (cm^2)	Panel	Remarks
Membranipora amoyensis	17	glass	Largest colony dimensions attained on glass panels. After 1 month, colonies overgrown and no reliable measurements could be taken.
M. annae	8	glass	
Alderina arabianensis	10	glass	
Hippoporina	8	glass	
Electra bengalensis	9	glass	

Barnacles: Balanus amphitrite was the most abundant and dominant of the fouling organisms at Station II. Dense encrustations of this species occurred on almost all monthly and cumulative panels during most of the year. Heaviest settlement was from March-August. In the low saline months of September and October, however, there was a slight decline. On the older panels, the barnacle contribution to fouling exceeded 70%. Occasionally, heavy mortality of barnacles was noticed, possibly due to

overcrowding and interspecific competition. The barnacles did not settle in any significant numbers at Station I.

Other barnacle species, not found on test panels but present on harbor structures were: *Megalobalanus tintinnabulum* and *Balanus patelliformis*. The latter is a new record to Kakinada waters.

Other Organisms: Several species of free-living crustaceans (isopods, amphipods, tanaids, decapods) were seen among the fouling complex. Of these, the amphipods were mostly on panels that accumulated considerable quantities of silt, especially at Station I. Their contribution to the fouling, however, was not significant.

Although six species of bivalves were collected, only a few settled on the test panels. The most important was the oyster, *Crassostrea madrasensis*, at Station II. Its settlement, however, was erratic on both monthly and cumulative panels. The only other bivalve on the monthly panels was *Septifer loculifer. Anomia achaeus, Perna viridis* and *Crassostrea gryphoides*, were occasionally found on the cumulative panels.

The ascidians were represented by only a single species, *Botryllus*, which was occasionally at Station II during the summer months.

Fouling biomass

Figures 3 and 4 present the fouling biomass accumulated on test panels at the two test sites. At Station I, biomass values on A-series timber panels ranged from 0.5 to 3.15 kg/m^2 (wet weight) and 0.28 to 1.87 kg/m^2 (dry weight). On glass panels, the values were 0.535 to 3.2 kg/m^2 (wet weight) and 0.31 to 1.9 kg/m^2 (dry weight). On the B-Series panels, the highest values recorded on timber panels were 8.26 (wet weight) and 4.71 kg/m^2 (dry weight), and on glass panels 9.43 (wet weight) and 5.6 kg/m^2 (dry weight).

At Station II, biomass on A-Series timber panels ranged from 0.6 to 5.8 kg/m^2 (wet weight) and 0.31 to 4.9 kg/m^2 (dry weight). On glass panels, they were 0.52 to 3.8 kg/m^2 (wet weight) and 0.31 to 1.9 kg/m^2 (dry weight). On the B-Series panels, the highest values recorded on timber panels were 23.4 kg/m^2 (wet weight) and 21.2 kg/m^2 (dry weight), and on glass panels 9.2 kg/m^2 (wet weight) and 7.4 kg/m^2 (dry weight).

Other observations

A perusal of table 4 also reveals the differences in settlement and degree of development exhibited by different species on the two surfaces tested of the major fouling species. Bryozoans settled more on the smooth glass plates and barnacles more on the timber. *M. enigmatica*, while settling on both surfaces in considerable numbers, settled in higher numbers on glass panels. Maximum growth rates were found on surfaces where settlement was highest.

DISCUSSION AND CONCLUSIONS

The results of our investigations permit some conclusions to be drawn concerning fouling at Kakinada. Most of the important groups characteristic of fouling assemblages in other Indian harbors occur at this port. Many differences were observed in community structure and dominant taxa between the two stations, which have widely differing environmental conditions.

Port Kakinada: Station I

Fouling at Port Kakinada consisted of a few widely spread taxa, dominated by a single species, *M. enigmatica*. This tube worm is known to occur in the fouling communities of several ports around the world, favoring colonization of brackish-water estuaries, lagoons, and canals (Nelson-Smith 1967). It is generally believed that it originated near the shores of the Indian Ocean or Australia and that its present world-wide distribution occurred through transportation on ship hulls (Nelson-Smith 1967). Although first discovered in India by Fauvel in 1932 in the Ennur brackish waters near Madras, this species was never reported to be a prominent member of the fouling community at the Madras harbor. Neither was it recorded in the harbors of Bombay, Cochin, or Goa, but at Visakhapatnam, Ganapati et al. (1958) found it to be an important fouling species. The almost total dominance *M. enigmatica* achieved at Kakinada Station I throughout the year to the virtual suppression of all other organisms has not been recorded in biofouling studies in Indian waters. It resembles the monospecific dominance of *Mytilopsis sallei* reported in recent years at some of the stations at Visakhapatnam harbor (Morton 1981, Santhakumaran et al. 1983), even though *M. enigmatica* communities at Kakinada never attained the same degree of fouling biomass development achieved by the bivalve. Barnacles and other sedentary forms were often suppressed by massive settlements of this serpulid.

Fishing harbor (Station II)

The biotic community at the fishing harbor, which has cleaner water than the port and almost open-coast conditions, was characterized by a fairly large number of species. The most important fouler was the barnacle, *B. amphitrite*. This species is one of the most successful fouling organisms in Indian harbors (Ganapati et al. 1958, Karande 1967, Cherian 1966, Purushotham and Satyanarayana Rao 1971). A number of low creeping organisms also abounded at this station, especially the encrusting bryozoans. These bryozoans with weak calcareous skeletons were prominent members of the early communities but were eventually replaced by hard biogenetic substrata formed by barnacles. While bryozoans were reported to be among the important components of fouling at Cochin (Menon and Nair 1971), Visakhapatnam (Satyanarayana Rao and Ganapati 1978), and Bombay (Karande 1967), their degree of development at Kakinada was not found at these harbors.

Hydroids, ascidians, and bivalves—abundant in other localities along the coasts of India (Cherian 1966, Morton 1981, Renganathan et al. 1982)—were not important at Kakinada. The poor representation of *P. viridis* on the test panels at Station II was unexpected because this species is commonly found on the walls of submerged quays and rocks along the coast. Perhaps, the bivalve is restricted to sites of the port not yet examined.

Fouling seasons

Although fouling occurs throughout the year, seasonality of settlement and variations in abundance are exhibited by different species. Such fluctuations, however, are more marked in some species. Based upon settling behavior, the fouling species at Kakinada could be grouped into three broad categories: (1) species that settled on test panels throughout the year and exhibited increased frequency in settlement during certain favorable periods of the year (e.g., *M. enigmatica* at Station I; *E. bengalensis*, *A. arabianensis*, *M. amoyenis* and *B. amphitrite* at Station II); (2) species that settled only during some definite periods of the year (e.g., *V. pavida* at Station I); and (3) species whose settlement was sporadic.

It is well known that occurrence and breeding periods of marine organisms largely depend on environmental fluctuations, particularly those involving temperature and salinity. Most authors working in Indian waters suggested that of the various parameters, it is salinity (whose fluctuations are more pronounced) that plays a major role in the settlement and growth of marine organisms (Paul 1942, Daniel 1954, Nair 1967, Menon and Nair 1971, Purushotham and Satyanarayana Rao 1971). In view of this, the distribution of the major fouling organisms at Kakinada was correlated to salinity. From tables 2 and 3 it can be seen that, in terms of number and abundance, the important species were: *V. pavida* and *M. enigmatica* at Station I and *E. bengalensis*, *M. amoyensis*, *A. arabianensis*, and *B. amphitrite* at Station II. As to be expected, these are either typically brackish-water species or euryhaline marine species capable of transgressing into brackish waters with varying degrees of success. Comparisons made with information available from other Indian ports readily revealed that the settling periods and abundance of these species varied considerably from port to port and month to month. However, when correlations were drawn between their occurrence, salinity, and known distribution records, interesting conclusions resulted, detailed below.

Victorella pavida. The settlement of this ctenostome, as mentioned earlier, was confined to the months of October-January at Station I when salinity of the ambient waters ranged between 4.8 and 17.5 ppt. Menon and Nair (1967), who studied its settling periods at Cochin harbor, noted its occurrence from June to January, the monsoon and postmonsoon periods at that harbor. Menon and Nair also noted that lush growths occurred when salinities ranged from 6 to 24 ppt and concluded that *V. pavida* is a typical brackish-water species not encountered in marine localities. Remane (1971), Ryland (1971), and Cook (1968) also considered this species a typical brackish water organism capable of thriving even in oligohaline and mesohaline conditions. It does not, however, seem to have penetrated the polyhaline zone of seawater.

Mercierella enigmatica. Settlement of this species (Station I), although noticed throughout the year, was more pronounced from February to September, when salinities ranged between 19.2 and 24.2 ppt. In an earlier investigation at Visakhapatnam, Ganapati et al. (1958) noted its occurrence all months of the year in stations with salinities of 5.85 to 33.25 ppt, with maximum settlement in April to July, when the salinities were 26.69 to 28.61 ppt. Elsewhere, this cosmopolitan tube worm was found in ports having 1 to 33 ppt salinities (Perkins 1974). However, it does not grow well or become mature at salinities less than 5 or greater than 30 ppt (Perkins 1974). These observations suggest that this species is holeuryhaline, and does best in mesohaline (18 to 30 ppt) waters.

Electra bengalensis, Membranipora amoyensis, and *Alderina arabianensis.* These encrusting bryozoans were found thriving in the coastal brackish waters at Station II during all months, attaining maximum development in months when salinities were between 18.5 and 21.2 ppt. At Visakhapatnam harbor, Satyanarayana Rao and Ganapati (1978) reported *E. bengalensis* throughout the year at a station where salinities fluctuated between 20.1 and 32.8 ppt, but noted its peak occurrence during periods of relatively low salinities (20.1 to 28 ppt). At Cochin harbor, its settlement was restricted to premonsoon periods (February-May) when salinities ranged between 27.6 and 31.5 ppt. Maximum settlement was from February to March, with salinity values of 27.6 to 30.0 ppt (Menon and Nair 1967). In this context, Stoliczka (1869) obtained the type material of this species from a tank where the waters were only a fifth as saline as seawater. Robertson (1921), Cook (1968), Powell (1971), and Satyanarayana Rao and Ganapati (1978) regarded it as a brackish-water species. But Menon and Nair (1967) considered it a typical marine form that never appeared (at Cochin) during extremely low saline periods. All of this indicates that *E. bengalensis* should be considered as an euryhaline marine species that can thrive in mesohaline or even oligohaline conditions, but flourishes in polyhaline waters.

A. arabianensis and *M. amoyensis* have similar settlement patterns and

should be considered as euryhaline marine species of the type described for *E. bengalensis. B. amphitrite* settled throughout the year (Station II), but maximum settlement was from April to August, when salinities varied between 27 and 32 ppt. Settlement of this barnacle was also found year-round at Visakhapatnam, Madras, and Bombay harbors (Purushotham and Satyanarayana Rao 1971). At Visakhapatnam, Ganapati et al. (1958) noted April-May as the peak settlement period when salinities ranged from 29.7 to 33.9 ppt. At Bombay, Karande (1967) reported a considerable drop in their settlement during the monsoon months and peak settlement in February-June and October-November. However, at Madras, Daniel (1954) and Antony Raja (1959) failed to observe any period of intense settlement. At Cochin harbor, where salinity fluctuations are quite marked (0.7 to 35.25 ppt), several authors (Cherian 1966, Santhakumari and Nair 1975) reported no fresh settlements occurring during the monsoons when extremely low saline conditions prevail. In this context, it should be noted that the *B. amphitrite* group of barnacles has several varieties in Indian harbors (Karande 1967) and these may have different breeding periods. However, it appears that *B. amphitrite* is a euryhaline marine species, which reaches brackish waters from the sea and thrives in mesohaline conditions.

Fouling biomass and other observations

A comparison of our biomass data with those available from other Indian harbors (Santhakumaran et al. 1983, Hameed and Balasubramanyam 1977, Renganathan et al. 1982) indicates that fouling at Kakinada can be considered as moderate to moderately heavy. An interesting observation made during our study concerns the development of fouling on the two test surfaces employed. It is generally believed that fouling is less severe on smooth surfaces (Corlett 1948, Pomerat and Weiss 1940), but Crisp and Ryland (1960) felt that no simple generalizations are applicable to the behavior of settling larvae on different surfaces. Some species seem to prefer one surface, some another, and some are indifferent. In our study, the bryozoans showed a marked preference for smoother surfaces (glass) and the barnacles for coarse texture (timber), but *M. enigmatica* was indifferent, as it settled in equal abundance on both.

In conclusion, the present investigation on fouling is of a preliminary nature and considerable scope exists for conducting more detailed studies in the area. Of particular interest would be studies addressing the effects of pollution, silting, larval transport, and the roles of biotic interactions in determining the nature and development of fouling communities. A closer and more intensive examination of the fouling complex over a longer period may reveal a large number of taxa not found in the present study. Detailed studies are also needed on the role of fouling in fishfarming enterprises and coastal industrial establishments, which are rapidly developing in the area. Future efforts will, therefore, be directed towards these and related aspects.

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