Available online at: www.mbai.org.in doi: 10.6024/jmbai.2015.57.1.01693-08

Fouling load in a tropical Indian harbor: spatial and temporal pattern

S. K. Pati and M. V. Rao*
Zoological Survey of India,Western Regional Centre, Vidya Nagar, P.C.N.T Post, Akurdi, Pune - 411 044,Maharashtra, India.
*Wood Biodegradation Centre (Marine), Institute of Wood Science and Technology, Beach road, Andra University P O, Visakhapatnam - 530 003, India.

*Correspondence e-mail: : sameer_pati@yahoo.co.in

Received: 03 Aug 2011, Accepted: 29 Jan 2015, Published: 15 Mar 2015

Original Article

Abstract
Biofouling is a serious problem in marine environment particularly in tropical waters. Among various quantitative methods of fouling estimation, biomass built up is a reliable one. Thus, fouling biomass on monthly and cumulative wooden panels was quantified at three stations, namely, Slipway Complex, Ore Berth and Marine Foreman Jetty of Visakhapatnam harbour for a period of two years from February 2007 to January 2009. Average fouling load on monthly panels was highest at Ore Berth (1.705 kg.m^{-2}) and Marine Foreman Jetty (0.933 kg.m^{-2}) during 1st and 2nd years, respectively and lowest at Slipway Complex (0.340 kg.m^{-2} and 0.340 kg.m^{-2}) during both the years. This spatial variation was significant (P/%) during 1st year only that too for Slipway Complex alone. This parameter was relatively high during 1st year than 2nd year at Ore Berth and Marine Foreman Jetty, but *vice versa* at Slipway Complex. Temporal variations at the said stations were insignificant except for Ore Berth. Fouling biomass on cumulative panels was highest at Marine Foreman Jetty (18.878 kg.m^{-2}) and lowest at Ore Berth (0.592 kg.m^{-2}). Present report of fouling load from Visakhapatnam harbour was the highest biomass ever recorded on wooden panels in India.

Keywords: *Biofouling, fouling biomass, Visakhapatnam harbour*

Introduction

Biofouling is a universal phenomenon in marine environment, especially along the coasts; affecting a wide array of structures (made of a range of materials) introduced by man for exploiting the vast resources of the seas. In general, fouling problem is acute in tropical waters than temperate waters because of warmer temperatures that support continuous breeding and recruitment of fouling organisms (Nagabhushanam and Alam, 1988). India being a tropical nation, naturally experiences a comparatively high degree of fouling activity almost all along its shores throughout the year. Considering the magnitude of fouling and concomitant economic losses (Holmstrom *et al.,* 1996 and Callow, 2002), several studies were initiated in India. Among several others, recent studies on biofouling are that of Sriyutha Murthy *et al.* (2008) and Sahu *et al.* (2008) at Kalpakkam; Satheesh and Godwin Wesley (2008a and 2008b) at Kudankulam; Sreeja (2008) at Kochi; Patil and Anil (2008) and Gaonkar *et al.* (2010) at Goa. The success in controlling fouling depends upon generation of quantitative information such as growth, biomass, numerical abundance, density, percentage cover, etc. of the organisms concerned as such knowledge is essential for estimating the fouling potential of a given area (Satheesh, 2006). However, biomass built up is a reliable and better index of fouling development than any other type of quantitative estimation (Lewis, 1981). Thus, fouling load was quantified on spatial and temporal scale at Visakhapatnam harbour (17° 40´N and 83° 16´E) in the Andhra Pradesh state of India (Fig.1). Visakhapatnam harbour is a polluted water body mainly due to eutrophication but with a decreasing gradient from inner harbour to outer harbour (Tripathy *et al.,* 2005).

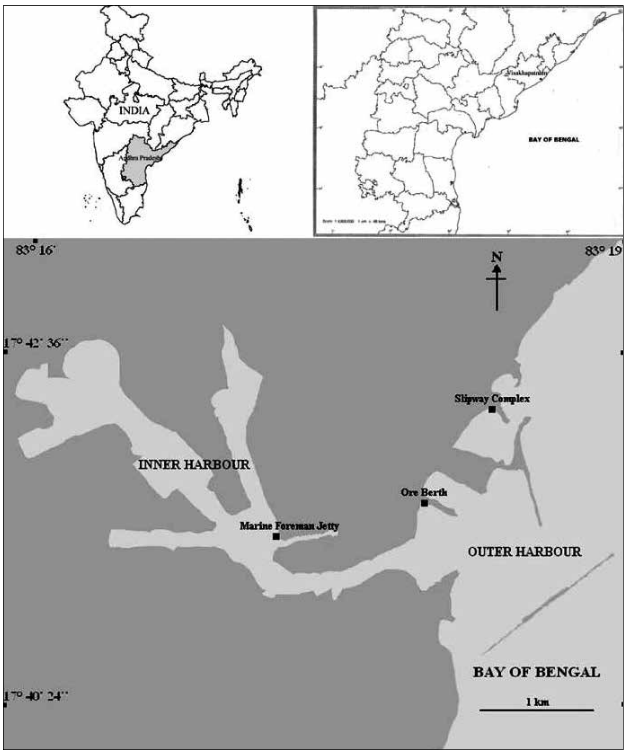

Fig. 1. Map of Visakhapatnam harbour.

Material and methods

Wooden test panels (150×80×20mm) of *Bombax ceiba* for monthly observations and *Pinus roxburghii* for yearly cumulative observations were deployed at Slipway Complex, Ore Berth and Marine Foreman Jetty of Visakhapatnam harbour in the form of vertical ladders containing 6 panels each. One panel laid in the intertidal zone and remaining panels at subtidal zone for two years from February 2007 to January 2009. In order to quantify fouling load, fouling accumulation on each panel was carefully removed and wet weight taken.

A single factor ANOVA followed by 'Student-Newman-Keuls multiple-range test' (Woolf, 1968) was conducted on monthly fouling biomass from the three stations to find out any differences among them within each year and between the two years at each station using Ms Excel 2007.

Results

Fouling load on monthly panels at Slipway Complex during 1st year ranged from ~0 kg.m^{-2} in June '07 to 1.265 kg.m^{-2} in December '07 averaging at 0.340 kg.m^{-2}; from 0.280 kg.m^{-2} in August '07 to 2.797 kg.m^{-2} in July '07 with a mean of 1.705 kg.m^{-2} at Ore Berth and from 0.443 kg.m^{-2} in March '07 to 3.187 kg.m^{-2} in May '07 with an average of 1.608 kg.m^{-2} at Marine Foreman Jetty (Table - 1). During 2nd year, fouling load at Slipway Complex varied from 0.080 kg.m^{-2} in January '09 to 1.114 kg.m^{-2} in July '08 averaging at 0.390 kg.m^{-2}; from ~0 kg.m^{-2} in June '08 to 0.443 kg.m^{-2} in September '08 with a

Table 1. Fouling biomass (kg.m^{-2}) on monthly panels at three stations in Visakhapatnam harbour from February 2007 to January 2009

Months and year	Slipway Complex	Ore Berth	Marine Foreman Jetty
Feb-07	0.501	ND	ND
Mar-07	0.233	ND	0.443
Apr-07	0.303	2.296	0.944
May-07	0.196	1.445	3.187
Jun-07	0.000	ND	1.136
Jul-07	0.291	2.797	2.855
Aug-07	0.350	0.280	1.783
Sep-07	0.198	ND	2.657
Oct-07	0.210	ND	0.489
Nov-07	0.181	ND	2.108
Dec-07	1.265	ND	0.482
Jan-08	0.346	ND	ND
Minimum	0.000	0.280	0.443
Maximum	1.265	2.797	3.187
Mean	0.340	1.705	1.608
Feb-08	ND	ND	ND
Mar-08	0.211	ND	ND
Apr-08	0.211	ND	ND
May-08	0.150	ND	ND
Jun-08	1.054	0.000	0.392
Jul-08	1.114	0.210	0.000
Aug-08	0.734	0.156	1.386
Sep-08	0.181	0.443	1.189
Oct-08	0.251	0.271	3.534
Nov-08	0.120	0.151	0.241
Dec-08	0.181	0.186	0.271
Jan-09	0.080	0.351	0.452
Minimum	0.080	0.000	0.000
Maximum	1.114	0.443	3.534
Mean	0.390	0.221	0.933

mean of 0.221 kg.m^{-2} at Ore Berth and from ~0 kg.m^{-2} in July '08 to 3.534 kg.m^{-2} in October '08 with an average of 0.933 kg.m^{-2} at Marine Foreman Jetty (Table 1).

Fouling load on cumulative panels at Slipway Complex during 1st year ranged from 1.672 kg.m^{-2} on 2 month old panel (mop) to 6.392 kg.m^{-2} on 6mop and 4.137 kg.m^{-2} on 8mop to 10.838 kg.m^{-2} on 2mop during 2nd year (Table 2). The same at Ore Berth varied from 1.132 kg.m^{-2} on 3mop to 4.055 kg.m^{-2} on 5mop during 1st year and ~0 kg.m^{-2} on 2mop to 0.592 kg.m^{-2} on 5mop during 2nd year (Table 2). At Marine Foreman Jetty, this biological parameter ranged from 2.867 kg.m^{-2} on 2mop to 18.878 kg.m^{-2} on 4mop during 1st year whereas the same extended from ~0 kg.m^{-2} on 2mop to 5.512 kg.m^{-2} on 8mop during 2nd year (Table 2).

Table 2. Fouling biomass (kg.m^{-2}) on cumulative panels at three stations in Visakhapatnam harbour

	Slipway Complex		Ore Berth		Marine Foreman Jetty	
Exposure span (in months)*	First year	Second year	First Year	Second year	First year	Second year
2	1.672	10.838	1.625	0.000	2.867	0.000
3	4.265	5.361	1.132	0.241	7.033	3.373
4	4.883	7.470	3.776	0.346	18.878	0.879
5	3.245	8.584	4.055	0.592	11.385	2.907
6	6.392	6.772	ND	0.070	3.356	3.449
7	5.226	7.770	ND	ND	10.208	5.366
8	3.076	4.137	ND	ND	11.886	5.512
9	3.985	5.430	ND	ND	5.908	ND
10	2.377	ND	ND	ND	6.957	ND
11						
12	5.978	ND	ND	ND	ND	ND
Minimum	1.672	4.137	1.132	0.000	2.867	0.000
Maximum	6.392	10.838	4.055	0.592	18.878	5.512

* periods of panel exposure at each station and year do not correspond

Discussion

Spatially, fouling load was highest at Ore Berth and Marine Foreman Jetty during 1st and 2nd years, respectively whereas the same was lowest at Slipway Complex during both the years. Variation in fouling load among the three stations was proved to be highly significant during 1st year, but not during 2nd year (Table 3). Post ANOVA for 1st year further showed that significant difference in fouling load existed in the case of Slipway Complex alone (Fig. 1).

Temporally, this biological parameter was relatively high during 1st year than 2nd year at Ore Berth and Marine Foreman Jetty, but vice versa at Slipway Complex. Variance of fouling load between the years at each station revealed that the difference was statistically significant only in the case of Ore Berth (Table 4).

Table 3. ANOVA (Single-factor) of fouling biomass on monthly panels among stations during both years in Visakhapatnam harbour Study.

Period	Source of variation	SS	df	MS	F	P value	F critical
1st year	Among stations	10.89	2	5.44	8.51***	0.00	3.42
	Within stations	14.71	23	0.64			
	Total	25.59	25				
2nd year	Among stations	2.26	2	1.13	2.47	0.11	3.40
	Within stations	10.96	24	0.46			
	Total	13.21	26				

***-Highly significant

Fouling load on monthly panels at the three stations was negligible (~0) during certain months which is either due to no recruitment or negligible colonization of individuals within the short span of a month. Maximum fouling load on monthly panels was found to be very high at Marine Foreman Jetty followed by Ore Berth. This is due to heavy recruitment of the invasive bivalve *Mytilopsis sallei* (Recluz, 1849) at the former and barnacles at the latter (Fig. 2b,c). In contrast, very low fouling load was recorded at Slipway Complex due to profuse recruitment of light forms such as serpulids and sabellids (Fig. 2a).

Similar to that on certain monthly panels, fouling load on a few cumulative panels, especially 2mop at Ore Berth and Marine Foreman Jetty was found to be almost negligible due to least fouling or even its absence. Fouling load on cumulative panels was found to be extremely high at Marine Foreman Jetty due to heavy recruitment and dominance of *M. sallei* as explained in the preceding paragraph (Fig. 2f). Anthropogenic load in port water would stimulate development of specific fouling communities which are characteristic with a high biomass and a limited set of eurybiont forms (Koryakova *et al.,* 2002 and Zvyagintsev *et al.,* 2004). Unlike monthly panels, cumulative panels at Slipway Complex showed higher fouling load ranking next to Marine Foreman Jetty because of heavy recruitment of additional species such as barnacles, oysters and ascidians over the stretch of time (Fig. 2d). Fouling load on cumulative panels at Ore Berth was least among the three stations, particularly because recruitment of heavy forms like bivalves and ascidians was absent or just representative, if at all took place (Fig. 2e).

Generally, fouling load is expected to aggregate from 1st to nth month in direct correlation with the immersion period of the panels. However, fluctuating results indicate that certain

Table 4. ANOVA (Single-factor) of fouling biomass on monthly panels between years at three stations in Visakhapatnam harbour

Station	Source of variation	SS	df	MS	F	P value	F critical
SWC	Between years	0.01	1	0.01	0.12	0.73	4.32
	Within years	2.58	21	0.12			
	Total	2.59	22				
OB.	Between years	5.87	1	5.87	15.58***	0.00	4.96
	Within years	3.77	10	0.38			
	Total	9.64	11				
MFJ	Between years	2.03	1	2.03	1.68	0.21	4.49
	Within years	19.32	16	1.21			
	Total	21.34	17				

***-Highly significant

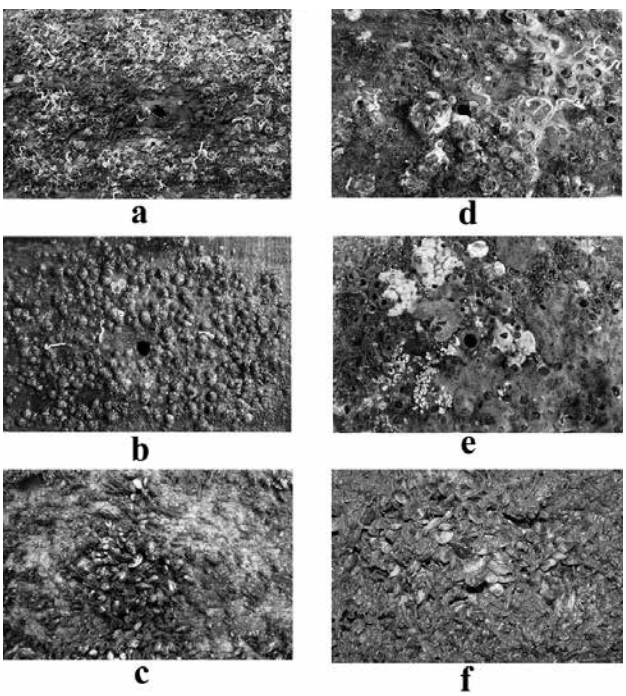

Fig. 2(a-f). Fouling on wooden panels in Visakhapatnam harbour (a-f). a. monthly panel at Slipway Complex; b. monthly panel at Ore Berth; c. monthly panel at Marine Foreman Jetty; d. cumulative panel at Slipway Complex; e. cumulative panel at Ore Berth; f. cumulative panel at Marine Foreman Jetty harbour.

animals were dislodged from the panels due to sloughing off, etc. in due course of time and fresh recruits appeared in their place subsequently. This may especially hold good because certain forms like hydroids, bryozoans have very short life cycles (Smedes, 1984). Similar observations were reported by Relini *et al.* (2000) while studying fouling ecology on an offshore buoy in the Mediterranean. Comparison of present data with the past studies on fouling biomass built up (on wooden panels) in India (Karande *et al.,* 1983; Sasikumar *et al.,* 1989; Rajagopal *et al.,* 1990 and Satheesh and Godwin Wesley, 2008b) revealed that fouling load is highest at Visakhapatnam harbour.

Acknowledgements

The authors are thankful to the authorities of the Indian Council of Forestry Research and Education; Ministry of Shipping, Road Transport and Highways (Government of India); National Institute of Oceanography (Goa) and Visakhapatnam Port Trust for various supports.

References

Callow, M. E. and J. A. Callow. 2002. Marine biofouling: A sticky problem. *Biologist*, 49: 10-14.

Gaonkar, C. A., S. S. Sawant, A. C. Anil, K. Krishnamurthy and S.N. Harkantra. 2010. Changes in occurrence of hard substratum fauna: A case study from Mumbai harbour, India. *Indian J. Mar. Sci.*, 39 (1): 74-84.

Holmstrom, C., S. James, S. Egan and S. Kjelleberj. 1996. Inhibition of common fouling organisms by pigmented marine bacterial isolates. *Biofouling*, 10: 251-259.

Karande, A. A., A. K. Sriraman and R. Viswanathan. 1983. Marine biofouling in seawater tunnel. Technical Report, NCML/BARC, Bombay, p. 1-24.

Koryakova, M. D., V. M. Nikitin, A. Yu. Zvyagintsev and L. S. Belogurova. 2002. Effect of polluted harbor waters on fouling and biocorrosion of steel. *Russian J. Mar. Biol.*, 28 (2): 127-131.

Lewis, J. A. 1981. A comparison of possible methods of marine fouling assessment during raft trials. Technical Reports, MRL-R-208, Material Research Laboratory, Department of Defence, Australia.

Nagabhushanam, R. and S. M. Alam. 1988. An Overview of Research on Marine Biodeterioration in Indian Waters. In: M-F, Thompson, R. Sarojini and R. Nagabhushanam (Eds.), *Marine Biodeterioration- Advanced techniques applicable to the Indian Ocean. Oxford & IBH Publishing* Co. Pvt. Ltd. p. 13-32.

Patil, J. S. and A. C. Anil. 2008. Biofilm diatom community structure from copper and cupronickel substrates: i*nfluence of exposure period and season. International Conference on Biofouling and Ballast Water Management,* February 05 to 07, 2008, National Institute of Oceanography, Goa. p. 50. (Abstract).

Rajagopal, S., J. Azariah and K. V. K. Nair. 1990. Ecology of fouling organisms in Edaiyur backwaters, Kalpakkam *Mahasagar*, 23: 29-41.

Relini, G., M. Relini and M. Montannari. 2000. An offshore buoy as a small artificial island and a fish-aggregating device (FAD) in the Mediterranean. *Hydrobio*l., 440: 65-80.

Sahu, G., K. K. Satpathy, M. V. R. Prasad and R. Venkatesan. 2008. Seasonal succession of biofouling communities in coastal waters of Kalpakkam in the vicinity of a nuclear power plant, east coast of India. *International Conference on Biofouling and Ballast Water Management,* February 05 to 07, 2008, National Institute of Oceanography, Goa. p. 57. (Abstract).

Sasikumar, N., S. Rajagopal and K. V. K. Nair. 1989. Seasonal and vertical distribution of macrofoulants in Kalpakkam coastal waters. *Indian J. Mar. Sci.*, 18: 270-275.

Satheesh, S. 2006. A study on the marine fouling community of Kudankulam coastal waters. Ph. D. Thesis, Manonmaniam Sundaranar University, Tirunelveli, India.

Satheesh, S. and S. Godwin Wesley. 2008a. Seasonal variability in the recruitment of macro fouling community in Kudankulam waters, east coast of India. *Estuarine, Coastal & Shelf Sci.*, 79: 518-524.

Satheesh, S. and S. Godwin Wesley. 2008b. Vertical distribution of macro-fouling community in Kudankulam coastal waters, Gulf of Mannar (east coast of India). JMBA2-Biodiversity Records: 1-6.

Smedes, G. M. 1984. Seasonal changes and fouling community interaction. In: J.D. Costlow and R.C. Tipper (Eds.), *Marine biodeterioration: an interdisciplinary study.* Naval Institute Press, Annapolis, Maryland. p. 155-160.

Sreeja, A. 2008. Chromated copper arsenate (CCA) treatment for rubber wood preservation and its impact on the aquatic biota. Ph. D Thesis, Cochin University of Science and Technology, Cochin.

Sriyutha Murthy, P. Veeramani, M. Ershath, K. Ravichandran and V. P. Venugopalan. 2008. Biofouling community in cooling circuits of a coastal power plant. *International Conference on Biofouling and Ballast Water Management,* February 05 to 07, 2008, National Institute of Oceanography, Goa. p. 55. (Abstract).

Tripathy, S. C., B. A. V. L. Kusuma Kumari, V. V. Sarma and T. V. Ramana Murty. 2005. Evaluation of trophic state and plankton abundance from the environmental parameters of Visakhapatnam harbour and near-shore waters, east coast of India. *Asian J. Microbiol. Biotech. Environ. Sci.*, 7 (4): 831-838.

Woolf, C. M. 1968. *Statistics for biologists-Principles of biometry.* D. Van Nostrand Company, Inc., Princeton, pp. 359.

Zvyagintsev, A. Yu., O. M. Korn and Kulikova. 2004. Seasonal dynamics of pelagic larvae of the fouling organisms in conditions of thermal pollution. *Russian J. Mar. Biol.*, 30 (4): 266-277.