ASEAN Journal on Science & Technology for Development
Vol. 35, No. 1-2, 2018, 37-42
DOI 10.29037/ajstd.471
RESEARCH

Biofouling Community Structure in a Tropical Estuary of Goa on the West Coast of India

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KEYWORDS
Barnacle
Biofouling
Encrusting bryozoans
Mandovi estuary
Polychaete

ABSTRACT Biofouling community structure was studied in a tropical monsoon-influenced Mandovi estuary in Goa, west coast of India. Monthly, seasonal and yearly observations on biofouling on polyvinyl chloride (PVC) panels immersed at subsurface water level were recorded and photographed from May 2012 to September 2013. The barnacle *Balanus amphitrite* was the dominant fouling organism followed by calcareous polychaetes. The settlement and recruitment of barnacles took place year-round, with the exception of July 2012 and June 2013 (monsoon months). However, their peak abundance was observed during the later months of monsoon (August and September). Polychaetes were dominant during late post-monsoon and pre-monsoon months (December 2012 to April 2013). Silt and slime were observed throughout the observation period. Comparing the fouling pressure of barnacles in the two monsoon seasons (2012 and 2013), fouling was more intense during the monsoon of 2013, indicating an inter-annual variation in the fouling community.

1. INTRODUCTION

Biofouling, the attachment and growth of organisms on submerged, man-made surfaces, has plagued ship operators for at least 2500 years. Accumulation of biofouling, comprising barnacles and other sessile marine invertebrates, increases the frictional resistance of ships' hulls, resulting in an undesirable increase in power and fuel consumption required to make speed.

The economic costs incurred by the presence of biofoulers, such as barnacles, mussels and algae on the underwater hulls of ships are high, because the weight or burrowing activity of the organisms can damage structures, clog intakes and slow vessels, resulting in expensive dry-docking, increased drag, higher fuel consumption and corrosion (Clarke 1995; Baker et al. 2004; Floerl 2005). Invasions by non-indigenous species are a major force of global change, resulting in significant ecological, economic, and human health impacts.

The ocean-going vessels can be thought of as "biological islands" for species that dwell in harbors and estuaries, since they provide substrate for the settlement of species associated with fouling communities (Godwin 2003). Fouling on vessel hulls creates entirely new transfer pathways for biological communities across substantial biogeographical barriers, and the dispersal of marine organisms by shipping has long been used in interpreting the biogeography of marine invertebrates, often in retrospect once a foreign species is established (Foster & Willan 1979; Carlton & Geller 1993). In fact, the primary pathway identified for marine non-indigenous organism introductions is biofouling on ships, although the transport of organisms in ballast water is also recognized as a major vector for the inadvertent transfer of many shallow water benthic non-indigenous and harmful organisms around the globe (Carlton & Geller 1993; Ruiz et al. 2000; Godwin & Eldredge 2001; Gollasch 2002; Coutts & Taylor 2004).

The transport of non-indigenous species by commercial shipping typically results in port environments becoming major points of biotic invasion, with a greater density and diversity of organisms (Wasson et al. 2001; Hewitt et al. 2004). Vessels acquire the majority of hull fouling while moored in coastal ports, these environments acting as hubs of domestic and international shipping movements (Carlton 1987). Stationary vessels provide substrata for the settlement of fouling species, including protected recesses that can be occupied by both sessile and mobile fauna (Godwin 2003). On the basis of the above considerations, and that the Mormugao port receives ships of many kinds originating elsewhere in India and other countries of the world, a survey was planned to determine biofouling in Mandovi estuary adjacent to the Mormugao port.

2. MATERIALS AND METHODS

PVC panels (20x10 cm) were exposed at the subsurface level from an existing jetty at the Mandovi estuary (a tropical monsoon influenced) in Goa, located along the west coast of India (Figure 1). Observations were carried out every month for a period of 17 months from May 2012 to September 2013. Analysis of fouling panels was carried out using Photogrid software. The exposure period includes monthly, seasonal and yearly (entire observation duration) duration. The panels were photographed by using an Olympus digital camera (EPL 1 series) in the field. The images obtained were cropped using a picture editing software (Microsoft Office Picture Manager). This was

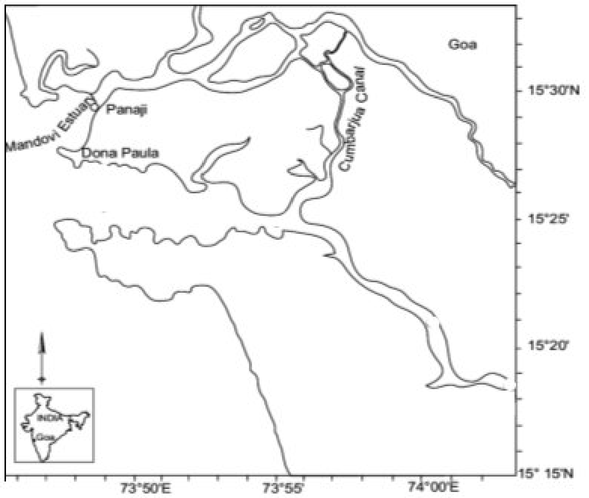

Figure 1. Location of Mandovi estuary in Goa on the west coast of India.

done for framing the panels in their entirety (i.e. by using the 'crop' function in the software). The images were resized (under CS Photoshop, this is located under 'Image' in the toolbar) so that the image aspect ratio is the same as the actual panel physical dimensions (which is 10 cm by 20 cm). Saved images were kept in folders according to the field assessment date. Further the images were cropped to 1.3 cm from all the sides, to reduce edge effect when estimating the overall surface percentage coverage on the panel. Edge effect affects overall settlement count because organisms have shown a tendency to settle on the edges. The final cropped image was rotated clockwise and saved for further analysis and scoring using Photogrid 1.0 software (http://www.photogrid.netfirms.com) (Holm et al. 2008). After scoring, the files were exported as .CSV files and data were processed using MS Excel.

2.1 Monthly observations

PVC panels (20x10 cm) in triplicate were exposed at subsurface depth fitting on to a PVC frame and imaged after a duration of one month. Similar observations were carried out every month from May 2012 to September 2013.

2.2 Seasonal observations

The seasons were earmarked as Monsoon (June to September), Post-monsoon (October to January) and Premonsoon (February to May). Observations of fouling were carried out during these seasons. PVC panels (20x10 cm) in triplicate fitted on a PVC frame were submerged below a jetty in the beginning of the season (1st month of the respective season, i.e., June during monsoon, October during post-monsoon and February during pre-monsoon). Observations were made at the end of every month over four months till the end of each season. Fresh PVC panels in triplicate were suspended at the beginning of the next season and observed as explained above.

2.3 Yearly observations

PVC panels (20x10 cm) in triplicate were exposed at the beginning of the observation (May 2012) and the panels were observed and imaged every month and these observations were continued monthly till the end of the experiment for 17 months till September 2013.

Abbreviations used: Silt–Si; Absorbed detritus and early stage biofilm/slimes. Slime–Sl; late stage biofilm with microalgae, cyanobacteria and low form algae. Incipient fouling–IF; recently settled, early/juvenile stage macrofouling. Algae–MAG; fully established macroalgae. Cnidaria– Cn. Attached forms of hydrozoans (hydroids, etc.). Encrusting bryozoans–EB; colonial animals forming an encrusting layer over the surface, e.g., *Membranipora* sp. and arborescent bryozoans. Upright bryozoans–Br; upright, bush-like bryozoan colonies e.g., *Bugula* sp. Barnacles–Barn; hard shelled crustacean that cements itself permanently to substrata, and is often difficult to remove. Calcareous polychaetes–Pcal; including calcareous tubeworms in the families Serpulidae and Spirorbidae. Molluscs–Mol; typical examples include oysters, mussels, and vermetids. Sponges–Sp; colonial organisms, often brightly colored. Maybe be encrusting or erect. Tunicates–Ctun; colonial or solitary forms of sea squirts. Unknown hard–Unk; undetermined hard fouling; Unknown soft–Unk; undetermined soft fouling.

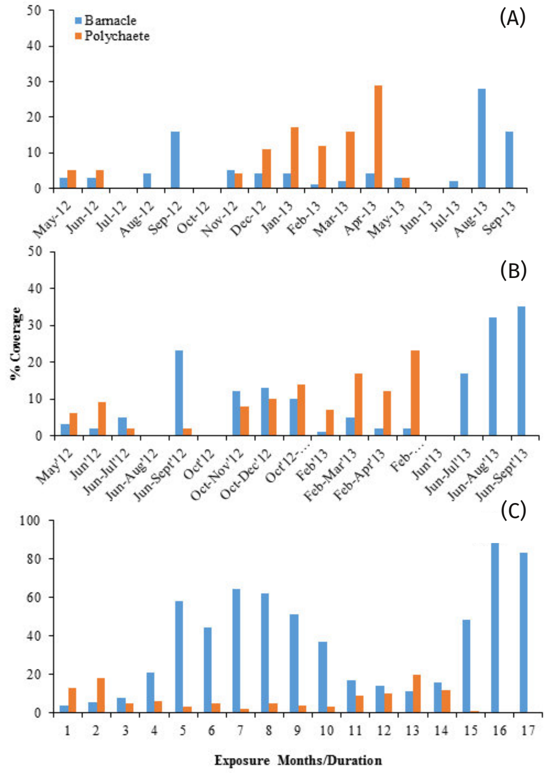

Figure 2. Variation in the percentage coverage of barnacles and polychaetes in Mandovi estuary, Goa, India. (A) Monthly panels; (B) seasonal panels; (C) yearly panels.

3. RESULTS

Among the hard foulers, barnacles were the dominant fouling organism, followed by serpulid polychaetes with calcareous tubes (Figure 2). The settlement of barnacles was observed round the year irrespective of the season, with the exception in July 2012 and June 2013 (monsoon months). Interestingly, peak recruitment of barnacles was observed during the later months of monsoon (September 2012; also August and September 2013). The serpulid polychaete *Hydroides* sp. was the dominant fouler during December 2012 to April 2013 (late post monsoon and premonsoon months; see Figure 2A). Silt and slime was observed throughout the observation period. When compared to the monsoon season of 2012 and 2013, the fouling by barnacles was more during monsoon 2013, indicating an inter-annual variation in the fouling com-

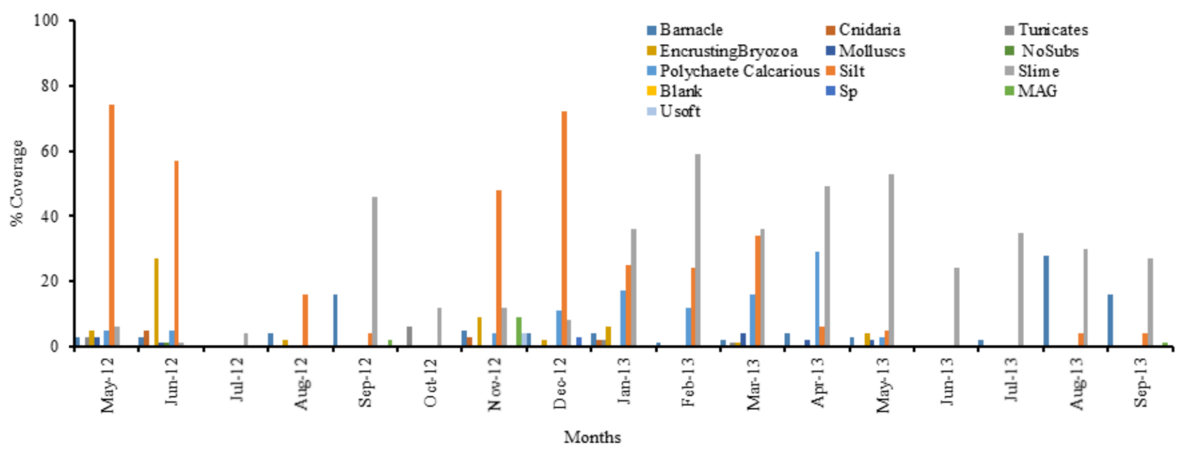

Figure 3. Variation in the fouling community structure on monthly panels in Mandovy estuary, Goa.

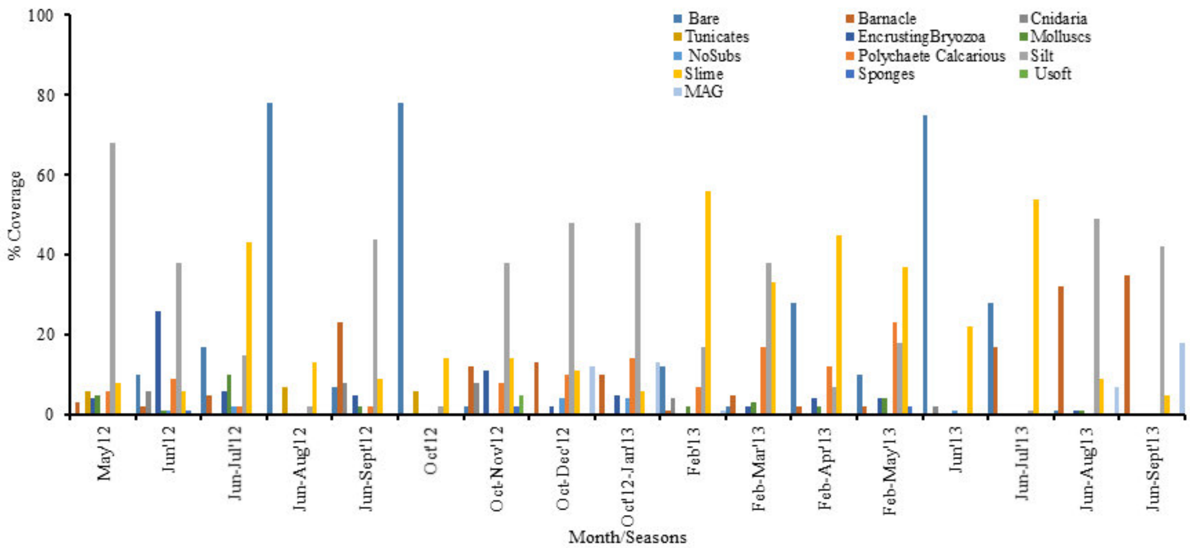

Figure 4. Variation in the fouling community structure on seasonal panels in Mandovy estuary, Goa.

munity. In monsoon 2012, contributions by encrusting bryozoans, mollusks and polychaetes were considerable and other groups such as cnidarians, tunicates, algae, sponges etc., were present in the fouling community, although their contribution to overall cover was negligible.

3.1 Biofouling on monthly panels

The monthly panels dominated by slime and silt (Figure 3). Hard fouling communities observed on the monthly panel varied with exposure month. *Hydroides* sp. dominated during December 2012 to April 2013 (late post monsoon and pre-monsoon seasons). However, barnacles were observed throughout the observation period, except during July 2012 and June 2013. Higher percentage coverage by barnacles was observed during September 2012 (16%) and August and September 2013, 28 and 16% respectively when compared to other hard fouling communities (Figure 2A). Percentage coverage by encrusting bryozoans was observed during June 2012 (Figure 3). Other organisms such as cnidarians, tunicates, mollusks and algae were also observed on the panels, but their contributions to overall cover were negligible. In general fouling was reduced during monsoon months, as indicated by higher bare area on the panel (Figure 3). Higher percentage coverage of slime was observed during late post-monsoon (January 2013) and pre-monsoon months (February to May 2013).

3.2 Biofouling on seasonal panels

Percentage coverage by silt and slime exceeded more than 50% on the panels during all the seasons throughout the observation duration (Figure 4). Among the soft foulers, algae were observed during post monsoon 2012 (October–December 2012 – 12% and October 2012–January 2013 – 13%) while in 2013 it was during late monsoon season (June-September 2013 – 18%) (Figure 4). Among the hard foulers, barnacles and serpulid polychaetes were dominant (Figure 2B). During late post-monsoon 2012 and pre-monsoon 2013 percentage coverage by polychaetes was high, whereas during monsoon 2012 and 2013 barnacles dominated the hard fouling community (Figure 2B), with maximum coverage of barnacles observed on the panels exposed from June–August 2013 and June-September 2013 followed by June–September 2012. During post monsoon (October 2012 to January 2013) percentage coverage by barnacles, encrusting bryozoans and calcareous polychaetes was almost similar (Figure 4).

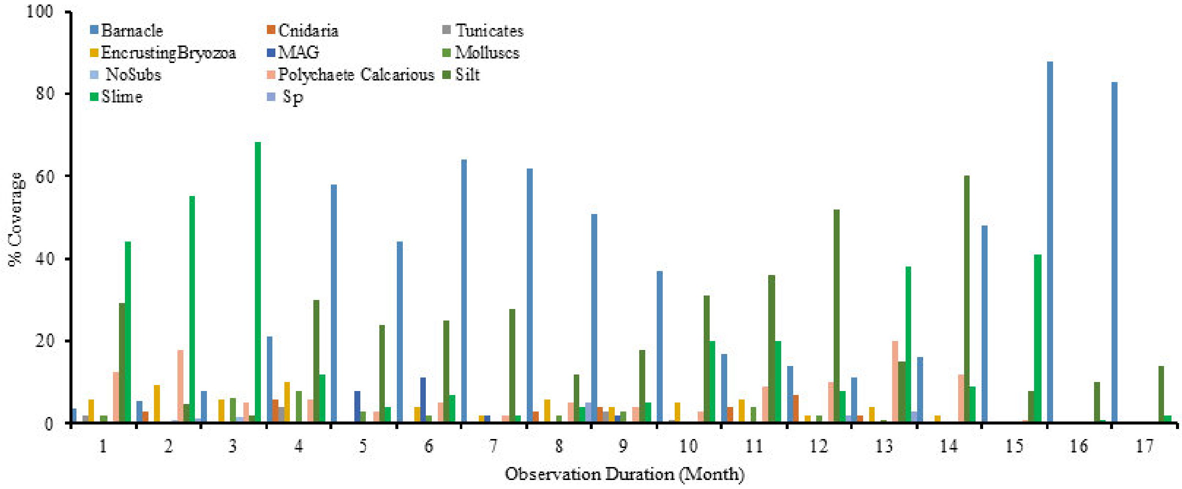

Figure 5. Cumulative assessment of fouling community structure on yearly panels in Mandovy estuary, Goa.

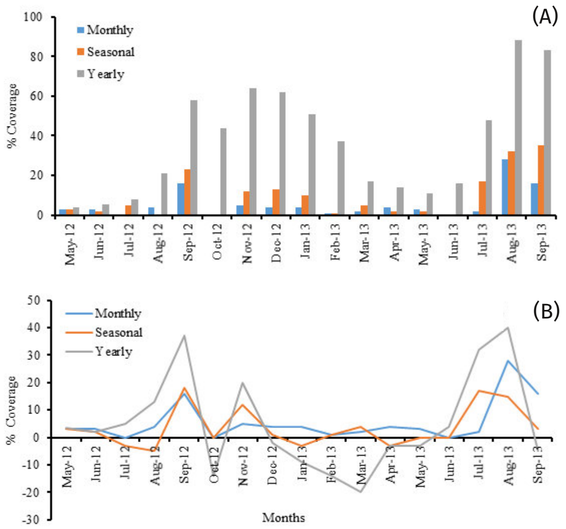

Figure 6. Variation in barnacle cover at Mandovi estuary in Goa. (A) Percentage cover of barnacles on monthly, seasonal and yearly panels; (B) percentage coverage change in barnacles on monthly, seasonal and yearly panels.

3.3 Biofouling on yearly panels

In general, on yearly panels the percentage coverage by slime was high during first three months of exposure, after which the percentage coverage of silt was higher than the slime (Figure 5). Barnacles were the dominant fouling organisms on the panels throughout the exposure duration. They were comparatively fewer in number during early monsoon months (May to July 2012) and their percentage coverage only started increasing from August 2012 (21%) to November 2012 (64%) during the post-monsoon season (Figure 2C). From January 2013 (51%) onwards the percentage coverage of barnacles decreased to 11% in May 2013 (pre-monsoon season). In general, during pre-monsoon season (March 2013–May 2013) the barnacle coverage was low. However, with the commencement of monsoon season (2013) an increase in the percentage coverage of barnacles was observed (16% in June 2013 to 88% in August and 83% in September 2013) (Figure 2C). Comparing the two monsoon seasons (2012 and 2013), fouling by barnacles was greater during 2013 monsoon compared to 2012. The other hard fouling communities observed on these panels were calcareous polychaetes, encrusting bryozoans and mollusks. The percentage contribution of calcareous polychaetes was higher during May and June 2012 (13 and 18% respectively) and again in April and May 2013 (10 and 20% respectively). It was observed that with an increase in the barnacle fouling, other communities decreased in cover. The contribution of other fouling organisms such as cnidarians, tunicates, encrusting bryozoans and mollusks was negligible.

The percentage coverage by barnacles on monthly, seasonal and yearly panels showed wide variation in the fouling (Figure 6A). When the percentage change in barnacle cover on seasonal and yearly panels was compared, it was noticed that maximum percentage change was observed on yearly panels, followed by seasonal panels (Figure 6B). A maximum of 40% increase and 20% decrease in barnacle percentage coverage was observed on yearly panels during August 2013 and March 2013 respectively (Figure 6A). Whereas on seasonal panels the increase was 18% and decrease was 5% in the percentage coverage when compared to the previous month coverage. This indicates that the already existing population on the panel plays an important role in the settlement and recruitment of barnacles. This is true, as the percentage coverage of barnacles on the monthly panel (maximum of 28%) did not exceed the percentage coverage (maximum of 40%) on yearly panels. In general the increase in the percentage coverage of barnacles was observed during monsoon months (Figure 6B).

4. DISCUSSION

Recruitment of macrofouling community in tropical waters is a year-round phenomenon (Anil 1986; Desai 2002; Desai & Anil 2005; Gaonkar 2012). Barnes (1972) stated that in boreal regions the fouling community varies considerably according to the season of substrate immersion. In tropical regions it is largely non-seasonal although some influence of freshwater run off arising from monsoon conditions is evident (Venkat et al. 1997). However, localities that are influenced by seasonal variations in fresh water runoff, mainly during monsoon season, could be exceptions. When the area of study is located in a tropical estuary influenced by fresh water run-off during the monsoon and also experiencing wide variations in salinity due to semidiurnal tides, the macrofouling assemblage on the substratum will be greatly impacted by such environmental perturbations. The observations on the fouling on PVC material indicated a seasonal variation in the macrofouling community. The salinity showed drastic variation with the seasons. During the pre and post-monsoon seasons, salinity ranged between 33 to 36.7 psu and 28.2 to 35 psu respectively, whereas during monsoon the salinity range was between 4.0 and 31.5 psu. This indicated a salinity stress during monsoon season, and only organisms tolerant of euryhaline conditions can survive, settle and recruit in the fouling community. The barnacle *Balanus amphitrite*, which is the most dominant fouling organism encountered in this study is an euryhaline and eurythermal species (Crisp & Costlow 1963; Iwaki 1981; Anil et al. 1995; Desai & Anil 2005). This species showed year-round recruitment on the panels with maximum recruitment during late monsoon months during both the years (2012 and 2013). An earlier study carried out to determine the recruitment pattern of this barnacle in the Zuari estuary (which lies adjacent to the Mandovi estuary) also indicated year-round recruitment, with a peak in their recruitment during the month of August (late monsoon). This may be attributed to the break in the monsoon that is often followed by a phytoplankton bloom (mainly *Skeletonema costatum*), inducing the release of larvae by the adult barnacles (Desai & Anil 2005). Year-round recruitment was attributed to year-round breeding and presence of cirripede larvae (nauplii and cyprids) in the natural environment throughout the year. The calcareous polychaete tubeworm, *Hydroides* sp. was the next most dominant hard fouling community after barnacles and they were maximum during December 2012 and August 2013. During monsoon 2012 the percentage coverage by encrusting bryozoans and molluscs was considerable followed by calcareous polychaetes. This indicates the seasonal variation in the pattern of fouling.

Monthly panels were dominated by slime and silt compared to seasonal and yearly panels, and the percentage coverage by slime was greater during warmer months (pre-monsoon). The bacteria and their byproducts combined with detritus and algae constitute what is commonly referred as a 'slime film' (Horbund & Freiberger 1970). This film is usually the first form of fouling to appear on a submerged surface. The formation of slime films takes days or weeks to develop (Cundell & Mitchell 1977; Mitchell & Kirchmann 1984). This may the reason for slime and silt dominating on the monthly panels. In contrast, slime formation on seasonal and annual panels is followed by settlement and recruitment of macrofouling organisms such as barnacles, bryozoans and polychaetes, which were observed in the present study.

In general fouling was less intense during monsoon season. The study area is a tropical estuary. In estuaries, fresh water is mixed with seawater due to tides, wind effects and other physical processes. During the monsoon season when high fresh water influx occurs due to rainfall, only organisms (both adult and larval forms) that can withstand large fluctuations in salinity are able to survive. Desai & Anil (2005) reported low numbers of *B. amphitrite* larvae in the plankton as well as poor recruitment of this barnacle during monsoon as compared to non-monsoon months. However, when macrofouling intensity is compared between monsoons of 2012 and 2013, it was observed that fouling was higher during monsoon 2013 when compared to 2012 indicating an inter-annual variation in the fouling communities during similar seasons. Typically a trade-off between phytoplankton blooms and release of larvae by marine invertebrates occurs (Barnes 1972; Starr et al. 1991; Desai & Anil 2005). Phytoplankton blooms have been reported during the monsoon breaks in this region (Devassy 1983; Gopinathan 1972). Such a phenomenon will typically influence the spurt in settlement of fouling organisms. However, the break in monsoon is not well defined and it may vary from days to more than a week or two.

During post-monsoon, percentage coverage of barnacles, bryozoans and polychaetes on the PVC panels was almost similar. With the retreat of the monsoon season, environmental conditions become stable in an estuary. Desai & Anil (2005) showed that such conditions were correlated to a higher growth rate in barnacles in a study carried out in the Zuari estuary. During late post-monsoon and pre-monsoon periods, polychaetes had a greater presence on seasonal panels. Similar observations were made by Venkat et al. (1997) at a tropical coastal environment in Mangalore port also located on the west coast of India. Earlier studies have reported higher settling and recruitment capacities by tube dwelling polychaetes compared to barnacles (Barnes 1972; Sebastian & Kurian 1981). Polychaetes bred throughout the year as reported by Venkat et al. (1997), although their presence in the macrofouling community was not year-round. They observed higher settlement of polychaetes on the panels during post monsoon followed by pre-monsoon. However, a mismatch in the larval population in the plankton and their settlement on the panels during a particular month or season was also observed. Desai & Anil (2005) noted a similar pattern in the barnacle *B. amphitrite* in the Zuari estuary, wherein a spurt in recruitment was observed during the monsoon months. This was attributed to the release of larvae in response to a phytoplankton bloom during the monsoon break. The return of the monsoon then resulted in the mortality of settled populations.

Barnacle cover dipped during the pre-monsoon but showed an increase with the commencement of monsoon. During pre-monsoon air and surface water temperatures were higher compared to the post-monsoon season. Desai et al. (2006) reported low concentrations of chlorophyll a during this time, possibly with adverse effects on both larval development and survival of settled populations. Ritz & Crisp (1970) reported slow growth in barnacles during summer and this was attributed to decreased food availability and concomitant increase in air and sea-surface temperatures. Southward (1955) showed that surface water temperature affected the growth rate of barnacles by influencing their rate of cirral beating and feeding. On yearly panels, cumulative observation for the entire duration showed that the barnacle *B. amphitrite* was the most dominant fouling organism in the region irrespective of the season.

ACKNOWLEDGMENTS

We thank the ASEAN Committee for Science and Technology (COST) and Ministry of External Affairs, India for their generous support. We thank Director, CSIR-NIO for his support and encouragement. The contents of this manuscript were first presented at the ASEAN-India international conference on the extent of transfer of alien invasive organisms in South/Southeast Asia region by shipping, held in Chiang Mai, Thailand from 26 to 28 November 2013.

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