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A novel approach for quantifying bio-fouling on underwater structures through identification and age estimation of bio- fouling organisms as a mode increase fuel & economic efficiency in shipping vessels.

Lakshmi Narayanan

Ph.D Research Scholar

The Centre of Advanced Study (CAS) in Marine Biology Annamalai University

Prem Anand M

Technical Executive

Pacific Blu Subsea Services (P) Ltd

Abstract

Fouling is the settlement on solid surfaces to the detriment of function. The term "Bio-fouling" describes the accumulation of aquatic organisms such as bacteria, macroalgae, mussels, barnacles and other invertebrates on underwater surfaces. It classifies micro (bacteria and diatoms) and macro-fouling (barnacles, tubeworms, algae, etc.). This study undertakes the bio-fouling study in port anchorage of Kakinada, India. The sample collection was carried out at 17 different parts of the MV TAMARACK, by certified underwater divers collecting the samples for further examination. This study describes the assessment methods, quantitative analysis of macro fouler and their growth level and age determination of dominant fouling organisms. The aim of the study estimates the biological properties of the fouling organisms and the life histories of abundant groups, identifies the associate species, quantifies bio-fouling removal by monitoring the levels and under different environmental conditions, to capture efficacy, which, thereby, provide a solution to a challenge shared among all maritime sectors employing

submerged structures where it leads to substantially increased costs and lowered operational lifespans. It can alleviate operations and increases vessel drag, which in turn increases fuel consumption and exhaust emissions. This study could be a support to find out the solution for controlling the population with discovery of antifouling resistant material. The *Amphibalanus* species and *Megabalanus tintinnabulum* were the dominant species under the family Balanidae followed by mollusc, crustacean and algae, all of which are distributed globally, hence we could not find out the exact origin even though we could conclude that the favourable environment for these species was tropical/ temperate water zones.

Keywords

Bio-fouling, age identification, anti-fouling, Kakinada

Introduction

Marine environment, bio fouling is the undesirable attachment of micro and macro-organisms to living or non-living surfaces submerged in sea water (Limna-Mol, 2009). Barnacle is an important component of the intertidal and also of the marine macro fouling communities (Nellis and Bourget 1996). Mainly it occupied any hard substrata in the marine environment like ship hulls, sonar domes, naval acoustic devices, offshore platforms, several species of acorn barnacles are ranked among the most successful colonizers of the marine littoral zone. Acorn barnacles are some of the most common creatures of the sea shore and have been widely used for studies of inter specific competition, habitat selection by planktonic larva, and life histories (Wehty 1979).

Specification		Details
Name of the ship	-	MV TAMARACK
Type of the ship	-	Bulk Carrier
Monitored location	-	Kakinada (16° 59' 46.0''N 82° 19'09.06 E)
Fauna types	-	Barnacles, algae, oyster, bivalve, crustacean

Taxonomy of *Amphibalanus* species and *Megabalanus tintinnabulum* is complex and several investigators have addressed this issue (Harding 1962; Henry and McLaughlin 1975; Utinomi 1967; Wagh and Bal 1971; Fernando 1990; Yamaguchi 1977). Fernando (1990) worked on the systematic aspects of some fouling barnacles from Indian waters. In east and west coasts of India many of the authors have been reported (Rao and Balaji,

1988; Rajagopal et al., 1990; Srinivas et al., 1992; Swami and Udhayakumar, 2010; Sahu et al., 2011, Shesdev, 2014)

Sampling Location and Methodology

The samples were collected from the underwater of the anchored vessel parts in Kakinada (16° 59' 46.0"N 82° 19'09.2 E) with the anchorage areas around 15 to 20-meter depth (Fig.1). The mature specimens were collected with the support of the certified divers by handpicking method using chisel, The barnacles picked with the help of forceps were transferred to containers, before fixation, containing strong ethanol the sample were sorted in different container(Fig 3), later the specimens were placed on a petri-dish containing tap water to dissect the morphological features of shell plates and other taxonomic features of the particular genera to examine under a microscope.

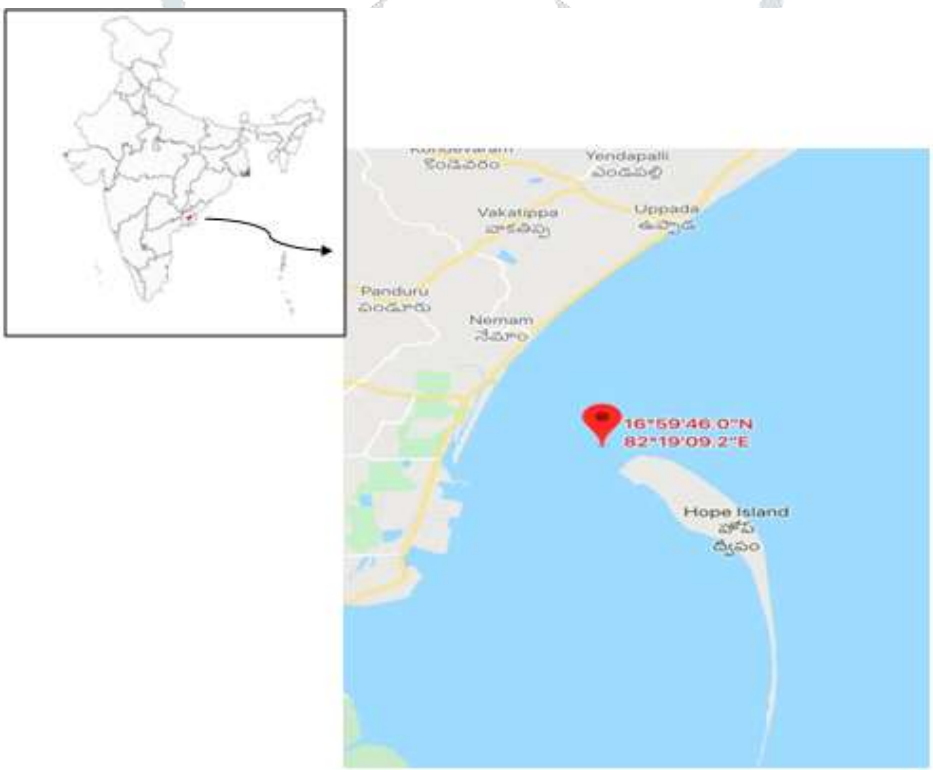

Fig.1. MV TAMARACK at Kakinada port anchorage

Materials and methods

In order to conduct the bio fouling survey works, the following are required to execute the necessary works: (**Fig. 2 & 3**)

- Diving boat
- Global Positioning System (GPS)
- Diving Gears

- Underwater camera
- Sample container
- Ethanol

Fig.2. Sample collection

Fig.3. Collected fouling sample for analysis

Locations of Sample Collected:

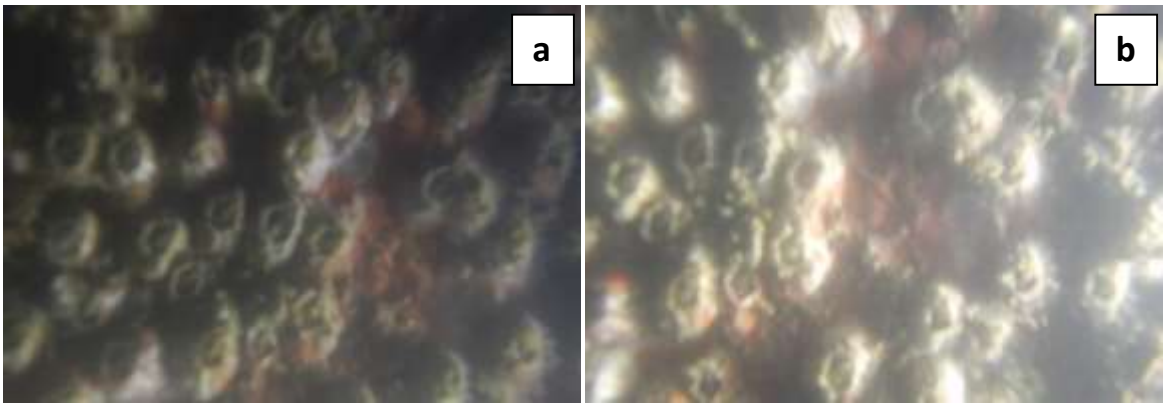

Fig.10(a,b). Dominant growths of Barnacle in Bow side.

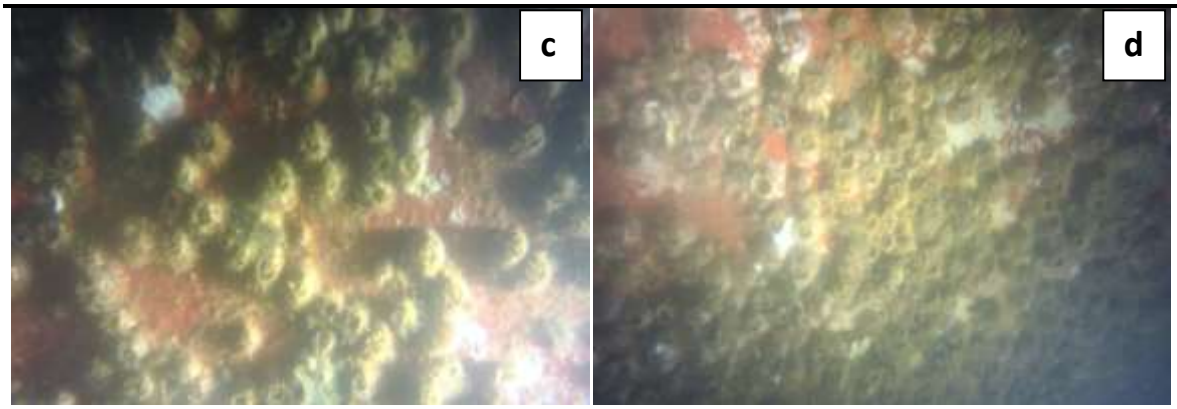

Fig.10(c,d). Barnacle attachment in Stern position with algal growth

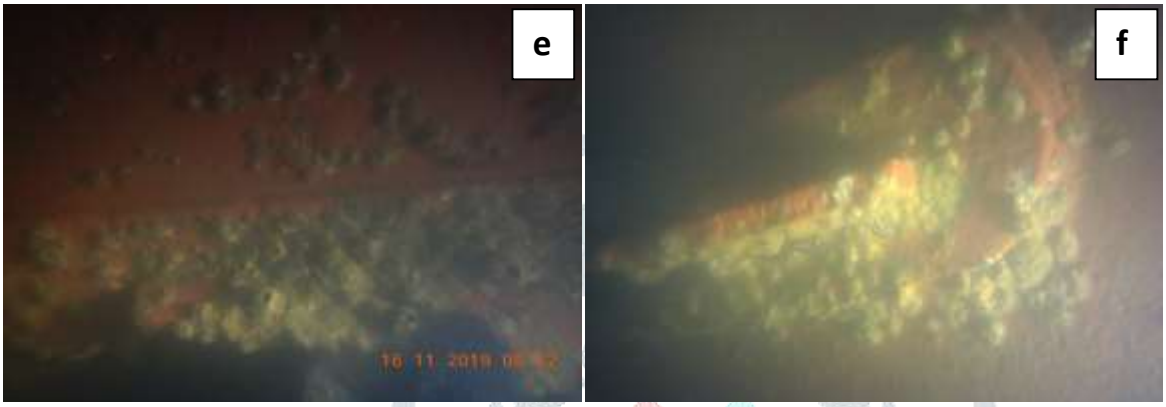

Fig.10(e,f). Barnacle association of Port side of mid ship.

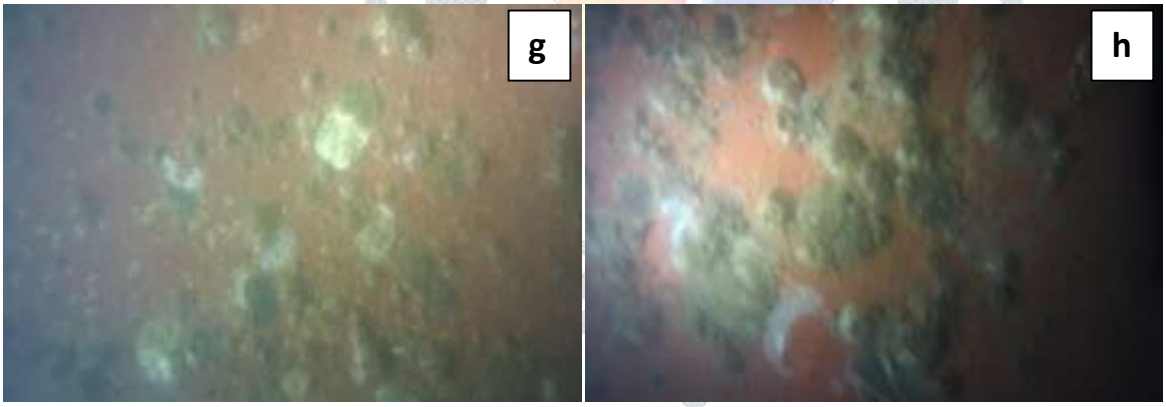

Fig.10(g,h). Starboard side forward MV TAMARACK

Fig.10(i,j). Starboard side mid ship of MV TAMARACK

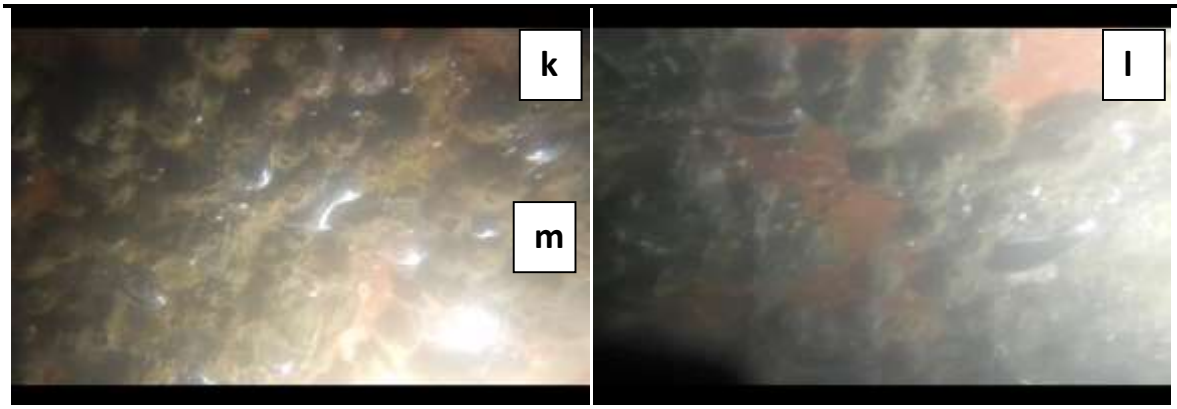

Fig.10(k,l). Flat bottom forward of MV TAMARACK

Fig.10(m,n). Flat bottom mid ship of MV TAMARACK

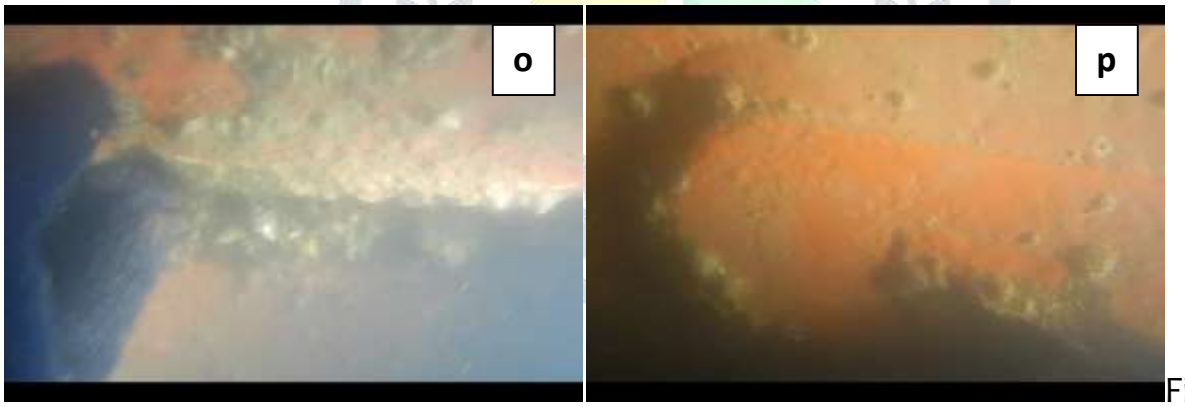

Fig.10(o,p). Bilge keels starboard side of MV TAMARACK

Fig.10(q,r). Port side bilge keel of MV TAMARACK

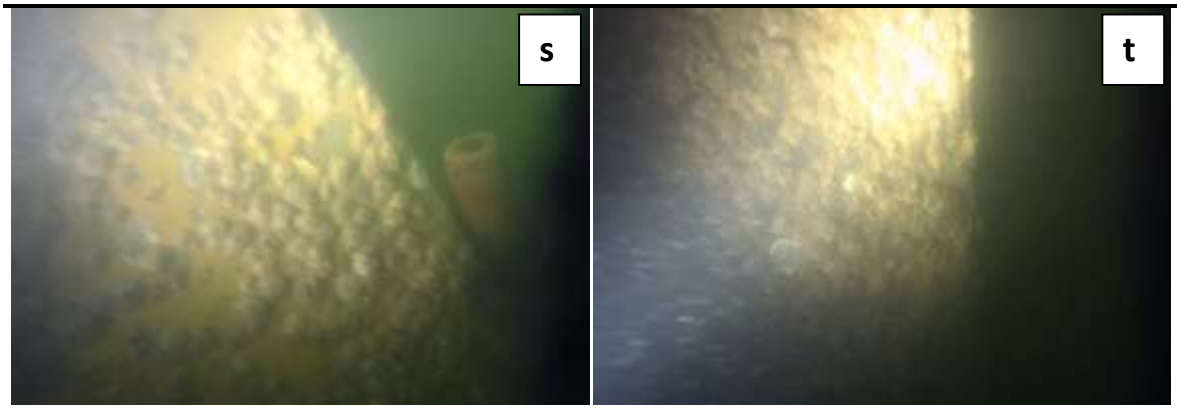

Fig.10(s,t). Propeller of MV TAMARACK

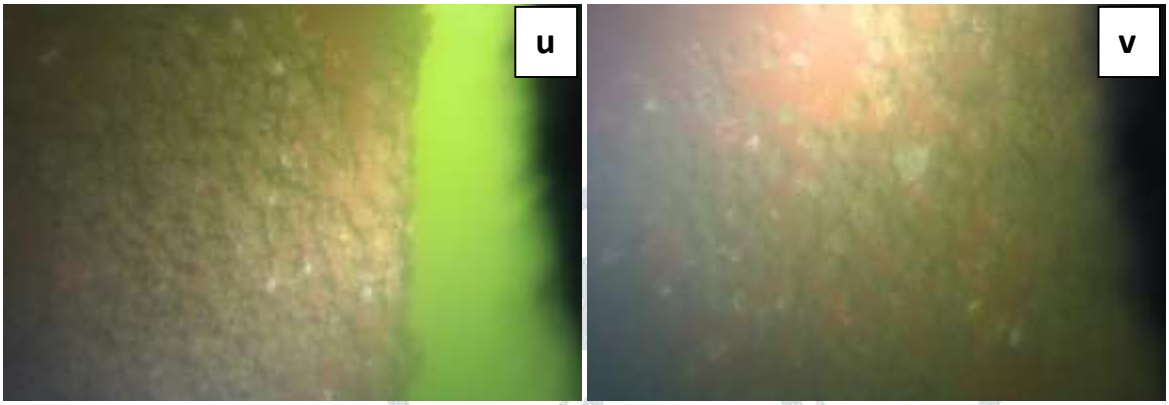

Fig.10(u, v). Rudder of MV TAMARACK

The figures 10- a to v show the field observation image of MV TAMARACK at Kakinada port anchorage.

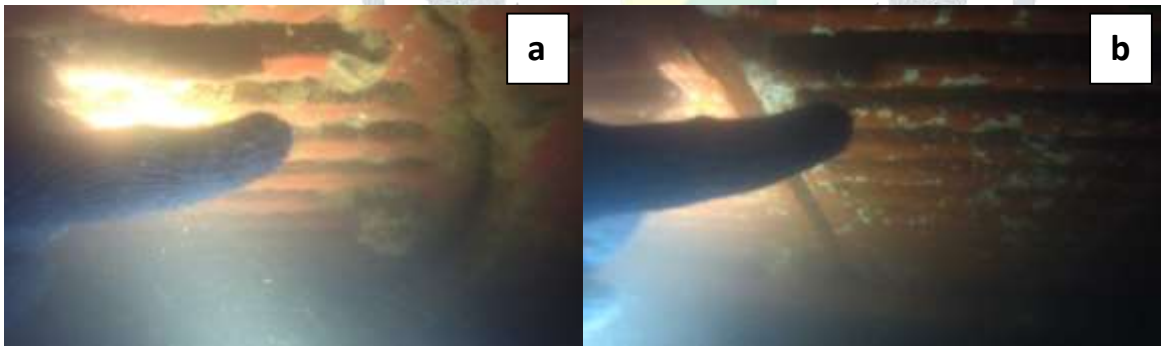

Fig.11 (a to f). Showing few of the positions of before(on left) and after(on right) removing of fouling organisms in MV TAMARACK

RESULTS

Among the 17 different portions of MV TAMARACK at port anchorage surveyed on 16th November 2019, all the portions were found to be hoarded with macro fouler, fauna, hydrozoans, molluscs, crustaceans and algal growths. **(Table 1.)** Acorn barnacles (*Amphibalanus amphitrite* and *Amphibalanus variegatus*) were found to be dominant species. Megabalanus tintinnabulum has also been reported from the vessel. (**Table 2.)**

Sl.No	Portion of Ship	Filed observation
1.	Flat Bottom (FWD)	Abundance of the matured barnacle growth with few individuals of bivalves.
2.	Flat Bottom	Barnacle population with the algal growth and minimum number of bivalve species associations.
3.	Flat Bottom (AFT)	Both barnacle and algae growth was in medium in compare to the other positions.

4.	Bilge Keel STED	Initial growths of barnacles and very less algal association in starboard side.
5.	Bilge Keel Port	Formation of the barnacles and dominant growth of algae populations.
6.	Port Hull(FWD)	Partial Barnacle growth on vertical top side and dense in down side of the vessel with algal association. Some oyster spat also found.
7.	Port Hull (AFT)	Few growths on barnacles with associates the algal growth and other crustaceans noted.
8.	Port Hull (MS)	Only medium sized barnacle association with minimum distribution with algal growth in the rough surface.
9.	Sea chest Port	The dominant growth of the Barnacles and also found some crustaceans
10.	Sea chest STBD	The dominant growth of the Barnacles and also found some crustaceans
11.	STBD Hull (MS)	Well growth barnacles with algal association.
12.	STBD Hull (FWD)	New colonies of barnacles and oysters associated with algal growth.
13	STBD Hull (AFT)	Only few barnacles' association and few oyster spat observed
14.	Bulbous Bow	Mostly dominated by barnacle no other associated fauna and flora was found, the range between 3.5 – 4mm.
15.	Rudder	Maximum growths of algal population with barnacle association.
16.	Propeller	Abundance of the barnacle in ranged between 3mm to 8mm with dominant by algal populations.

17.	Stern	Dense growth of Barnacle population with accumulation of algal growth, the size ranged between 2.3 to 3.2mm.

Table 1. Showing the bio fouling assessment results in various position of the MV TAMARACK .

Systematic position of dominant species

S.No.	Kingdom	Phylum	Class	Family	Genus	Species
1.	Animalia	Arthropoda	Hexanauplia	Balanidae	Amphibalanus	*A. Amphitrite*
2.	Animalia	Arthropoda	Hexanauplia	Balanidae	Amphibalanus	*A. Variegatus*
3.	Animalia	Arthropoda	Hexanauplia	Balanidae	Megabalanus	*M. tintinnabulum*

Table 2. Systematic position of *Amphibalanus* and Megabalanus species

Species description

***Amphibalanus amphitrite* (Darwin, 1854)**

Shell is conical with diamond shaped openings. The orifice is round or slightly toothed. Compartments are externally smooth. Dark purple longitudinal stripes. (**Fig.4**). Its width is usually more than 1/2 its height. Shell consists of ring of overlaying calcareous plates in the form of truncated cone. The length of its spur is about 1/4 of the length of the basal margin, and the spur width is roughly 3/10 of the basal margin. The wall plates vary in number in different species. This particular species has got six wall plates. Rostrum, lateral (left and right), carino-lateral (left and right) and carina. The maximum basal length of barnacle so far measured has been reported to be 20 mm, with a mean life span of 77days. So far the species has been recorded to be distributed from mid-tide

level to sub tidal zone. *A. amphitrite* is one of the common fouling barnacles found on harbour piles and fishing crafts.

Amphibalanus amphitrite with a maximum basal length of 13.1mm (Port side Bilge keel) and minimum basal length of 7.2 mm (Bulbous Bow) has been observed, further the mean basal length of the specimens collected from the 17 portions of MV TAMARACK was calculated to be 11.0mm. (**Table 3.)**

Fig 4. *Amphibalanus amphitrite*

***Amphibalanus variegatus* (Darwin, 1854)**

Shell is conical with a maximum carina -rostral diameter of 22 mm, height 15mm. As these organisms grows in aggregates, they assumed a cylindrical shape, with wide radii, the species showed fine transverse striations and oblique summits. The orifice was relatively larger that has a prominent tooth. The colour of the shell and opercular valves highly varies from light pinkish to blue, red, purple and brown colour. *B. variegatus* has the ability to withstand wide variation in the salinities, silt and chemical wastes. Its distribution ranged from inter tidal to six fathoms. (Pope, 1966). Its has been reported to grow on harbour structures, molluscs and other benthic animals. **(Fig.5)**

Amphibalanus variegatus with a maximum basal length of 16.35mm (flat bottom midship) and minimum basal length of 12.4 mm (flat bottom FWD) has been observed, further the mean basal length of the specimens collected from the 17 portions of MV TAMARACK was found to be 14.1 mm. (**Table 3.**)

Fig. 5 Amphibalanus variegatus

Megabalanus tintinnabulum

Megabalanus tintinnabulum is world-wide in distribution being carried everywhere by ships. The shell is conical with a basal diameter ranging from 30-60mm. The orifice is large and trigonal. The margin is irregularly crenated and the shell surface longitudinally ribbed. The colour of the shell varies from rosy pink longitudinal stripes to dark brown or blackish purple. Radii is broad with oblique summits. **(Fig 6.)**

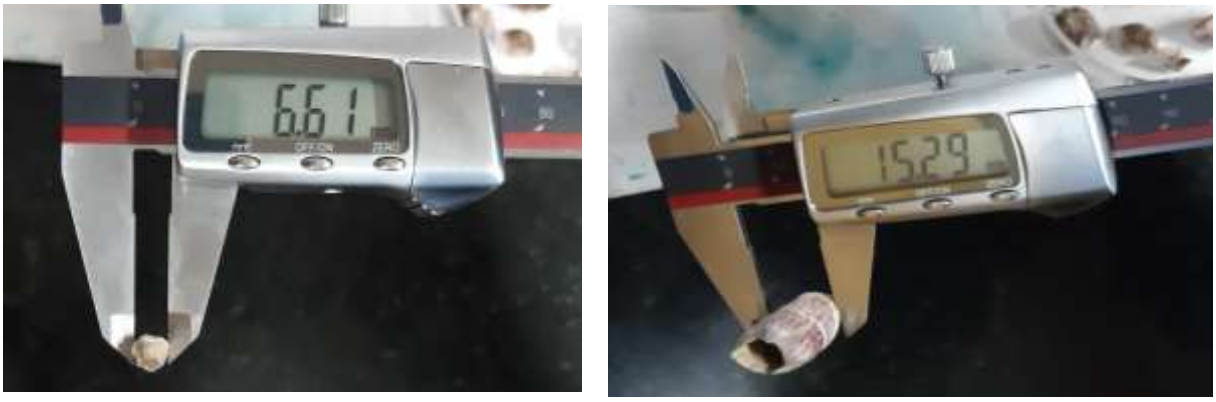

Fig 6. *Megabalanus tintinnabulum*

Other species observed

Organisms including molluscs, crab, hydrozoan on *Megabalanus tintinnabulum* have also been observed on the different portions of MV TAMARACK.

Fig 7. Mollusc

Fig 8. Hydrozoan on *M. tintinnabulum*

Fig 9. Bio-fouled crab (6.08mm)

Estimation of age of barnacle

Age of the barnacles attached to MV TAMARACK was estimated based on Von Bertalanffy growth equation,

$$L = a(1 - be^{-kt})$$

Where L is the mean length of final larval stage; k is the parameters from Von Bertalanffy growth model; t is the time period; a is the maximum asymptotic length; B is the relationship between barnacle maximum size and the size at settlement.

Thus, the mean age of the samples collected were estimated to be approximately **45 days** for ***Amphibalanus amphitrite*** and **59 days** for ***Amphibalanus variegatus.*** **(Table. 4).** It can also be more than the age estimated because, at once the animal attains the adult stage the basal length of the animal halts its growth

A. amphitrite	
Length of Barnacles (in mm)	**Estimated age (in days)**
7.2	**27**
13.1	**54**
10.8	**44**
11.4	**46**
11.9	**49**
12.7	**53**
10.7	**43**
11.8	**48**

9.3	37
12.5	52
11.5	47
11.7	48
10.4	42
10.8	44
9.45	37
10.6	43
9.8	39
11.1	45
11.7	48
11.9	49
12.1	50
12.8	53
10.3	41
10.4	42
7.85	30
12.2	50

Table 3. Measurement of basal lengths and estimated ages ages (by Von Bertalanffy growth equation) of Amphibalanus *amphitrite* collected from MV TAMARACK

A. variegatus	
Length of Barnacles (in mm)	Estimated age (in days)
13.5	56
14.4	61
12.4	51
12.8	53
13.65	57
16.35	71
12.9	54
13.2	55
14.75	63
14.8	63
13.3	55
13.8	58
14.1	59
14.45	61

13.9	58
14.1	59
14.5	61
15.75	68
13.2	55
13.3	55
14.9	63
15.9	68
14.4	61
15.6	67
13.3	55
13.65	57

Table 4. Measurement of basal lengths and estimated ages (by Von Bertalanffy growth equation) of Amphibalanus *variegatus* collected from MV TAMARACK

Megabalanus tintinnabulum

The mean basal diameter growth rate of *Megabalanus tintinnabulum* was reported be 3.15mm/ month according to the study conducted by Coastal Environmental Analaysis (Richardson,2009). From the above study, the age of *M.tintinnabulum at MV TAMARACK* was estimated for the animal with the maximum basal diameter 15.29mm (flat bottom midship) and minimum basal diameter 6.61 mm (Rudder) and therefore, their ages shall be **145 days** and **6 days** respectively.

Conclusion

Biofouling has been a long-standing challenge shared among all maritime sectors employing submerged structures where it leads to substantially increased costs and lowered operational lifespans if not addressed properly. Especially for ships, it can alleviate operations and increases vessel drag, which in turn increases fuel consumption and exhaust emissions. It has also been recognized as a leading vector for global transfers and introductions of marine non-indigenous species. So far, antifouling coating compounds are available as a possible solution to the aforementioned problem. In this study, we developed a protocol for identifying age of bio-fouling organisms, thereby quantifying bio-fouling removal by monitoring the levels and under different environmental conditions, to capture efficacy.

The bio-fouled barnacles and other associated organisms were collected in given specific locations of MV TAMARACK through WoRMS taxonomy database. Overall, the survey reveals Amphibalanus amphitrite, Amphibalanus variegatus and Megabalanus tintinnabulum were the most dominant and well grown species in all the locations and their average ages were 45, 59 and 145 days, respectively. The vessel bio fouling is a major pathway for the introduction of non-indigenous species and transmission of contagious infections.

In order to prevent the above-mentioned issues, the vessels where the bio fouler gets accumulated should be treated with antifouling coating system specially intended to minimise the attachment and settlement of biofouling organisms. If the ages of bio-fouling species are deducted using the methodology in which the study was conducted, it can aid in quantifying the amount of bio-fouling on the submerged structures. This proves to be helpful in calculating the time period in which the removal of bio-fouling needs to be conducted and calculating the magnitude of factors which impact vessel operations and drag, fuel consumption and emissions.

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