CHAPTER I

GENERAL INTRODUCTION
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The term fouling is commonly employed to distinguish the assemblages of animals and plants which grow on artificial or man-made structures from those occurring on rocks, stones and other natural objects. All structures such as wood, steel aluminium, ferrocement, fibre glass, exhibit settlement of marine organisms when they are exposed to sea water. The process of fouling is influenced by various geographical and hydrobiological factors. Dharmaraj and Nair (1981) stated that the composition of the fouling complex exhibit wide temporal and regional variations which are governed mainly by varying hydrobiological conditions and geographic locations. An excellent review of the problem of biofouling has been published by Woods Hole Institute, U.S.A. in its "Marine Fouling and Its Prevention" (WHOI, 1952) which has been updated by Haderlie (1984).

Ships being the important means of transport deserve special attention in the biofouling studies. Some of the harmful effects include enhanced fuel consumption, reduction in ship speed, blockage of sea-chest and fire fighting systems, fouling induced corrosion of the propellers, decreased operational range etc. Figures of expenditure involved in this problem are breath taking. According to a 1975 estimate, the U.S. Navy alone has spent $150 million for the additional fuel to be used to overcome the drag
caused by hull fouling (Haderlie, 1984). It is also reported (Haderlie, 1984) that U.S. Naval ships show an annual 10% increase in fuel consumption between dry dockings, because of the hull and propeller fouling. Microorganisms involved in fouling form a slime layer and induce deterioration of ships. Lewthwaite et al (1985) have reported that a slime layer of 1 mm thickness causes an 80% increase in the skin friction together with 15% loss in the ship speed compared with clean hull.

In the thermal power plants, the intake tubes are concrete lined pipes which get fouled. Haderlie (1984) reports about blocking of these tubes by fouling accumulations. Under dead organisms SRB activity may induce corrosion.

Haderlie (1984); Thornhaug and Marcus (1980), suspect heavy fouling on OTEC platforms. Macrofouling of the hull, cold water pipe and mooring systems may contribute to excessive and unpredictable drag (Haderlie, 1984). According to Chandler (1985) offshore oil and gas platforms are designed to remain for a period of 20-30 years and therefore conventional methods such as antifouling paints, drydocking etc. cannot be employed. Hence fouling accumulates on them (Cox, 1980) Freeman (1977) and Heaf (1981) are of the opinion that higher hydrodynamic loading will be induced because of alteration in the sectional area and surface characteristics.
owing to fouling. In offshore waters, the underwater structures are protected by claddings and cathodic protection systems. The fouling may contribute to corrosion by damaging the protective coating or by reducing the efficiency of cathodic protection (De, 1984). Heavy fouling can prevent the detection of the defects such as cracks or corrosion while safety and structural integrity of the platforms are inspected. Another harmful effect is that the efficiency of oceanographic instruments and devices is reduced in several ways.

It is logical to suggest that fouling may induce corrosion - but there is no consensus as to the direction in which fouling influences corrosion. La Que (1972) is of the opinion that dense and even growth of fouling organisms acts as a protective cover reducing corrosion rates in seawater. But others maintain that fouling organisms facilitate corrosion process (Kamat, 1986).

More or less same events occur everywhere when the development of marine fouling community proceeds. There is a well documented account of succession in the development of a marine fouling community. The adsorption of non-living material is followed by the attachment and growth of bacteria, diatoms and other microorganisms (Floodgate, 1971). Sometimes during the succession, the algal spores and animal larvae settle and develop thereby giving rise to a complex
fouling community. There is evidence to suggest that this fouling sequence is a true ecological succession. Many workers such as Scheer, 1945; Aleem, 1957; Ito, 1959; Haderlie, 1969, 1974 have reported that development of fouling community follows an orderly process in which development of later species is dependent on earlier species preparing their way. Other workers have found the development of fouling communities to be unpredictable and have suggested that early arrivals inhibit further development (Sutherland, 1974; Osman, 1977; Sutherland and Karlson, 1977).

The organisms that constitute the marine fouling community comprise a large assemblage of more than 4000 species of animals and plants (Crisp, 1973). Algae constitute important members of marine fouling community. While describing the composition of primary film in the tropical marine waters of Madras, Daniel (1955) has identified spores belonging to 14 different algal species as components of primary film in addition to diatoms. Further, settlement and metamorphosis of many larval forms of marine invertebrates are known to be influenced by crustose coralline algae (CCA) (Morse et al 1979, Morse et al 1979, Steneck, 1982 Rumrill and Cameron, 1983, Pearce and Scheibling, 1988, Johnson et al 1991). It is often assumed that inducers associated with CCA are produced by the algae (Johnson et al 1991).
Algae also are of major concern for shipping industry (Fletcher, 1980; Callow, 1986). They attach to the substrate by a network of rhizoids (Fletcher, 1976), and are able to penetrate into the substratum and paint film (Moss and Woodhead, 1970). The morphology of algal rhizoids is influenced by the surface relief but there is no evidence to suggest that the chemical nature has any effect on algal settlement (Hardy and Moss, 1979). Algae are found to settle on wide range of both fixed and floating structures causing quite a serious economic problems (Fletcher, 1981). In addition to their reported dominance on the sides of many of larger faster ships (Christie, 1973) they have more recently emerged as major contributors of the waterline community on the support legs of drilling platforms in the North Sea area (Freeman, 1977; Goodman and Ralph, 1979; Ralph and Goodman, 1979). Although a wide range of algae occur as fouling organisms (Fletcher, 1980c), probably the most widely reported alga which is especially common at water line on ships and other structures (Christie, 1973; Christie et al, 1975) is Enteromorpha. The conditions like mode of tanker operation, short days in port for uptake or discharge of oil and gas, routes of tankers from warm tropical waters to temperate waters in short time exclude animal fouling. Hence Enteromorpha species predominate and constitute a serious economic problem (Evans and Christie, 1967). Indeed it was primarily against this genus the organotin range of
antifouling coatings were launched with considerable success (Fletcher, 1981). Biebl (1962) and Christie and Shaw (1968) have demonstrated the tolerance of Enteromorpha to wide extremes of temperature and salinity. The plant shows a considerable capacity for regeneration on tanker hulls, following mechanical underwater scrubbing techniques, basal parts of the thallus left behind after such cleaning as well as detached pieces were shown by Moss and Marsland (1976) to give rise to new thalli in the so called, "bottle-brush" formation.

Although Enteromorpha was eliminated to a large extent by the use of organotin antifouling compositions, other algae like Ectocarpus (brown, filamentous) and Ulothrix (green, filamentous) owing to resistance to organotin compositions became major fouling organisms. Copper tolerant populations of Ectocarpus siliculosus were found to be associated with cuprous oxide in antifouling paints on the hulls of oceanographic vessels thereby causing considerable economic problems (Ann Hull, 1981). The mechanism of tolerance which may operate in copper tolerant populations of Ectocarpus siliculosus have been investigated by Hall et al (1979).

Zongguo et al (1982) studied relationship between velocity of water and distribution of fouling organisms in Dongshan bay. They reported the occurrence of Ulva linza and Enteromorpha intestinalis when flow velocities were 2310 m/hr
and 60 m/hr. According to them, Enteromorpha will go on attaching when the flow velocity is as high as 10.7 chains, which means that a high speed ship will be attacked even when it is moving on at full speed.

In case of ship's hulls, the settlement generally occurs when the vessels are stationary, although seaweed spores can reportedly settle in water-flows up to 10 knots. Spores of smaller macroalgae such as Ectocarpus and Enteromorpha may be brought to the vicinity of offshore installations by reproductive plants, growing on supply or container ships. They may also be source of fouling kelps (e.g. Laminaria, Alaria), on the platforms such as those in North Sea since it is unlikely that motile spores could reach these platforms from coastal populations (Moss et al, 1981). However, it is possible that gametophytes (or even young sporophytes) may be carried over long distances by water currents (Evans, 1988).

According to Callow et al (1976) diatoms are also the important members of marine fouling algal community. They are recognised as important marine foulers occurring regularly on antifouling composition under both test and in service situations (Harris, 1946; Hendey, 1951; Crosby and Wood, 1959; Bishop et al, 1969; Daniel et al, 1980). Slime films on paints are dominated by diatoms intermixed with bacteria, blue green algae and dinoflagellate algae etc. All
these have the ability to produce mucilage, resulting in a semirigid jelly like matrix in which the component organisms are embedded. The diatom *Achnanthes* is frequently the dominant member of the slime occurring on organotin containing antifouling surfaces which prevents attachment of larger algae such as *Enteromorpha* (Callow et al, 1976).

Hardy (1981) has reported about the possibility of corrosion caused by adhesives, extracellular products, chemicals released by organisms which come in contact with the surfaces of structures. According to him damaged plants of *Desmarestia viridis* produce free sulphuric acid. The sites for storage of sulphuric acid in *Desmarestia viridis* according to Eppley and Bovell (1958) are membrane bound vacuoles in the cells of this alga. The studies by Kylin (1938) have indicated that an extract of this alga has a pH value 1.8. Das and Mishra (1985) conducted study on corrosion of welded mild steel and stainless steel plates immersed in seawater containing algae. They found that extent of corrosion damage was found to be greatest in mild steel samples.

Many blue green algae and even some of the larger green algae have been reportedly found to contain the hydrogenase enzyme system. Seaweeds can produce both differential pH cells as well as wide range of potentially corrosive metabolites including sulphuric acid and other acids.
Considerable physical disruption can be caused by larger organisms. The roots and holdfasts of plants and marine algae are known to damage both coatings and the metal itself. The production of malate by Desmarestia viridis is a cause of concern as this product is used as a substrate for culturing sulphate reducing bacteria in laboratory conditions (Hardy, 1981). In India, many workers studied fouling in Indian coastal waters with reference to animal fouling mainly. Reports on algal fouling in Indian waters are meagre. According to Rao (1989) in India, studies on biofouling are restricted to only a few harbours.

The work on biofouling with special reference to fouling algae in Indian waters has been carried out by the following workers: Daniel (1953, 1955 a, 1956, 1956a, 1958); Nair et al (1953); Mathew and Nair (1981); Nair et al, (1984); Sasikumar (1984); Das and Mishra (1985); Chidambaram et al (1989); Kelkar (1989); Ramachandra (1989); Rao (1989).

From the foregoing account it is clear that algae are involved in material deterioration. Much work relating to algal fouling has been carried out in the temperate regions. Aspects like microfouling or primary film formation, biological control, action of antifouling paints, algal spore morphology, cytochemistry of algal spores, biochemistry of adhesion, germination of spores, corrosion, effect of environmental factors etc. have been studied by the workers
throughout the world. However, in India very little attention has been paid to algal fouling. The present work was therefore undertaken in two Indian estuaries namely Waghotana estuary and Mandovi estuary to study the temporal, spatial, substrate induced variations in the algal and diatom flora. Waghotana estuary is reportedly an unpolluted estuary. Studies of fouling algae and diatoms were carried out by employing experimental panels of two metals (Mild steel, aluminium) and two non-metals (fibre glass and glass).

In Mandovi estuary which is a polluted estuary the observations on fouling algae and diatoms were made from the stationary objects (concrete ramp, jetty, static barge, a scrap ferry boat) and moving objects (launch and ferry boat). It is hoped that the work presented in this thesis will be useful as a basic work for undertaking further works in the field of algal fouling in this area.