CHAPTER-1
GENERAL INTRODUCTION

1.1. OVERVIEW OF BIOFOULING PROCESS

Biofouling is an undesirable accumulation of organic molecules, microorganisms, plants and animals on the surfaces exposed in an aquatic environment. Fouling is the modification of an immersed, artificial structure and is also a complex mixture of physical, chemical and biological phenomenon. Biofouling is a complex process involving three main stages. The first stage is the formation of conditioning film by the accumulation of organic molecules. During the second stage, microbial biofilms develop on the conditioning film. The final stage witnesses the development of plant and animal communities (Callow, 1996). The fouling process takes place on both living and non-living surfaces in the marine environment and is initiated instantly once a substratum is immersed in the marine waters (Wahl et al., 1994; Steinberg et al., 1997).

Organisms taking part in marine biofouling are primarily the sessile and semi-sessile forms occurring naturally in the intertidal environment. The sessile organisms are of course known for their remarkable adhesive properties, forming very strong bonds to a variety of surfaces ranging from boat hulls to rocks and to other organisms, under a wide range of hydrobiological conditions. From the ecological point of view, the formation of fouling communities on hard surfaces plays a significant role in the productivity and stability of coastal ecosystems. The fouling organisms are interesting because it consists largely of filter and
suspension feeding organism and remove enormous amount of suspended material from the water. These organisms also contribute much to the food chain that is operating in the coastal ecosystem. These biological components may act as a sensitive indicator of negative effects associated with the presence of metals and are good candidates for radiological studies.

However, the fouling organisms are capable of destroying objects made up of different materials such as wood, metals, concrete etc. Biofouling is a pervasive and costly problem for shipping, coastal power plants, desalination plants and oil refineries. Thermal and nuclear power plants are located along the coastline due to the availability of unlimited water source. The choice of seawater as a coolant is not free from problems due to the presence of fouling organisms such as bacteria, filamentous algae, barnacles, tubeworms and mussels in the intake water. Biofouling can cause roughness of submerged marine structures (Chakrabarti, 1991), increase the hydrodynamic loadings, accelerate corrosion of metal surfaces and impede under water inspection and maintenance (Houghton, 1978).

There are four main types of biofouling-induced problem in coastal power plants such as, reduction in flow rate, clogging of condenser tubes, reduction in heat transfer efficiency (Rajagopal et al., 1994) and acceleration of corrosion (Fischer et al., 1984). The environment inside the cooling water tubes provides an ideal location for the settlement of fouling organisms. Some of the conditions, which enhance the development of a macro fouling community are, continuous flow of fresh seawater, reduction in silt deposition (Neitzel et al., 1984), reduction
in competition and predation and a fully protected habitat. Biofouling impairs the integrity of the cooling system components and in extreme cases may even precipitate safety problems in nuclear power plants.

The mussels settled inside the cooling water systems consume dissolved oxygen, phytoplankton and suspended organic matter from the water and release faeces, pseudo faeces and ammonia, thereby considerably altering the water quality (Venugopalan et al., 1991). The changes in the water quality may have some impact on the operation of power plants. The biodeposits released by the mussels may get trapped in the biofilm matrix on the condenser tube, which further reduces the heat transfer efficiency (Jenner et al., 1998).

Billions of dollars are being spent annually world wide as a result of fouling in vessels. The loss of speed and tonnage of ship suffer by the attachment of these organisms is a well-known problem. Fouling of hulls of vessels leads to decrease the speed by 40% or more. As little as 5% fouling on the hull of a ship can increase fuel cost by 17% and 1mm thick layer of slime can cause a 15% loss in ship speed. Biofouling costs the U.S Navy $ 100 million per annum for hull cleaning, paint removal and other environmental compliance measures (Alberte et al., 1992). In India, the cost of cleaning of hulls of merchant navy ships has been estimated to be around $28.6 million.

Biofouling in the nets and cages used in aquaculture is another major problem. The growth of fouling organisms on cages leads to reduction of flow in
water through the cage resulting in oxygen depletion. Biofouling also affects the land-based aquaculture, where the settlement of fouling organisms inside the pipes reduces the pumping. The fouling communities also act as a reservoir for pathogenic microorganisms.

The ecological problems associated with biofouling include pollution of coastal waters due to antifouling agents and bioinvasion. In order to solve the economic problem arises due to fouling the entire coastal industries devoted much money and time for antifouling measures. The total global market for antifouling coatings is approximately $700 million per year (Callow, 1996). All commercial solution to fouling control involves the use of highly toxic compounds. As the majority of fouling is in coastal waters that are important to fisheries, a conflict between fouling control and fisheries productivity exists (Rittschof and Costlow, 1987).

The degree of damage caused by fouling organisms in a region has a definite relation to the hydrographic conditions of that area. Unlike temperate waters, the fouling is heavier in tropical waters as the hydrographical conditions do not normally vary considerably. In tropical waters, the colonization of biofouling communities is also very rapid (Huang et al., 1999). Therefore, the fouling organisms and their settlement periods, growth rate and biomass vary from a region to region and an understanding of these aspects specific to a region is very essential to evolve an economic and safe antifouling system.
1.2. REVIEW OF LITERATURE

Fouling assemblages on artificial substrata have been studied for many decades, not only as a practical problem for biofouling prevention (Holmstrom and Kjelleberg, 1994), but also an empirical model for studying various hypotheses about animals and plants in marine community structure (Schoener, 1974; Mook, 1981; Field, 1982; Oshurkov, 1992; Anderson and Underwood, 1994, Butler and Connolly, 1996).

In India the foundations for studies on biodeterioration were laid by Erlandson (1936), when a detailed survey of boring organisms in Cochin harbour was made. Along the east coast of India, Chennai (=Madras), Visakhapatinam and Tuticorin coastal waters were subjected to intensive studies of various aspects of biofouling.

Paul (1942) has made a detailed study on the growth and breeding habits of some of the common sedentary organisms occurring in Madras Harbour. The biology of fouling community at the Gulf of Mannar and Palk Bay was studied by Kurian (1953). Daniel (1954) has made an elaborate study on the fouling community of Madras harbour. Ganapathi et al., (1958) provided a detailed account of the distribution and growth of the fouling organisms at Visakhapatinam harbour. Wesley (1980) investigated the ecology of coastal fauna around Madras Atomic power plant with special reference to the biofouling community.
Renganathan *et al.* (1982) studied the ecology of marine fouling organisms in Karapad creek of Tuticorin Bay, south east coast of India.

Nair *et al.* (1988) reported the macrofoulants in Kalpakkam coastal waters. The biofouling activity at Kakinada port was studied by Rao and Balaji (1988). Velayudhan (1988) investigated the settlement of barnacles at different depths of a pearl oyster farm at Tuticorin. The fouling community of Kalpakkam coastal waters was studied by Sasikumar *et al.* (1989, 1993).


The biofouling data of buoy structures and underwater sensors deployed along the Indian coast were studied by Jahan *et al.* (2004). Murthy *et al.*, (2004.a) investigated microfouling on titanium and stainless steel surfaces in static and flow conditions in Tuticorin waters. An encrusting form of coral belonging to the genus *Montipora* was reported from the fouling community developed in Gulf of Mannar.

Along the west coast of India Bombay (Mumbai), Goa, Ratnagiri, Mangalore and Cochin waters formed a major arena of biofouling research. A preliminary account of the biology of fouling from Mangalore comes from studies conducted by Menon et al. (1977). Nair and Pillai (1977) observed the influence of slime film on the settlement of certain marine fouling organisms in Cochin harbour.


D’Souza and Bhosle (2003a) analysed the microfouling formed on metallic surfaces exposed in Dona Paula Bay. Biodiversity and seasonal variations of macrofouling species settling on test panels exposed in near shore waters of Mumbai was studied by Swami and Udhayakumar (2004). Dattesh and Anil (2005) studied the recruitment of the barnacle *Balanus amphitrite* and implications of environmental perturbation, reproduction and larval ecology in Dona Paula Bay, Goa.

Marine biofouling has been subject to substantial research efforts throughout the world and numerous published studies are available from marine and coastal waters of various geographic regions. The settlement pattern of *Semibalanus balanoides* in the Isle of Man was studied by Hawkins and Hartnoll (1982). Kay and Butler (1983) studied the stability of the fouling communities on the pilings of two piers in South Australia. Relini (1984) investigated the macrofouling community of Tyrrhenian power station, Italy. Hirata (1987)
investigated the succession of sessile organisms on experimental plates immersed in Nabeto bay, Izu Peninsula, Japan.

A comparative study of biofouling settlements in different sections of Necochea power plant (Argentina) was made by Brankevich et al. (1988). Bailey-Brock (1989) studied the fouling community development on an artificial reef of Hawaiian waters. Fouling and wood boring community distribution on the coast of Rio de Janeiro, Brazil was investigated by Silva et al. (1989).


culture farms in the White Sea. Hsing and Kwang (2002) studied the development of subtidal fouling assemblages on artificial structures in Keelung harbour, Northern Taiwan. Biofilm-forming bacteria settled on glass surfaces suspended at Dae-Ho dike, Korea, was investigated by Kwon et al. (2002). Raveendran and Harada (2001) studied the macrofouling community structure in Kanayuma Bay of Japan.

Stachowitch et al. (2002), investigated the fouling communities of offshore oil platforms in the southern Arabian Gulf (Abu Dhabi). The microfouling on test panels submerged in seawater off Chiba, Japan was studied by Nandakumar et al. (2003). Kashin et al. (2003) studied the fouling communities of hydrotechnical constructions in Nakhoka Bay (Sea of Japan). Whomersley and Picken (2003) studied the long-term dynamics of fouling communities found on offshore installations in the North Sea.

Besides the region specific biofouling assessment, previous studies have resulted in detailed insight into the sequential levels of the fouling process (Clare et al., 1992). The formation of conditioning film on surfaces immersed in marine waters have been reported by Zobell and Allen, (1935) and Wahl, (1989). Various studies and reviews have addressed general features of biofilm development, distribution and its impacts on marine structures (Corpe, 1973; Gerchakov et al., 1977; Baier, 1984; Little, 1984; Chracklis and Escher, 1988; Zutic and Thomaic, 1988; Sharma and Wagh, 1990; Devi, 1995; Smitha et al., 1997; Smitha and Anil, 2000).


1.3. AIMS AND SCOPE OF THIS STUDY

Though considerable literature is available on the problem of biofouling from different parts of Indian waters, lack of similar work on various aspects of biofouling from Kudankulam coastal waters promoted the initiation of the present study. The emerging Nuclear Power Project in this region is the biggest ever undertaken by the Nuclear Power Corporation (India) Ltd. Sea water is being extensively used as a condenser and auxiliary system coolant in electric power
stations around the world. Biofouling is known to be the most problematic area in cooling water systems of power plants and several incidents of plant shut-down due to biofouling have been reported from various parts of the world (Imbro and Gianelli, 1982). Previous investigations invariably show that the biofouling problem varies with the species occurring in a locality and also with climatic and hydrobiological conditions. So that the experience gained from one locality cannot be applied to another without proper investigation.

Solutions to the above problem demanded a detailed study on the structure, settlement pattern and seasonal variations of biofouling community in Kudankulam waters. Hence, the present study is planned with the following objectives (1) to observe the process of biofilm formation, (2) to assess the settlement of macrofouling community, (3) to elucidate the factors which are inducing the settlement of fouling organisms, (4) to analyse seasonal and vertical settlement pattern of macrofouling community, (5) to ascertain the diversity of the fouling organisms using diversity indices, (6) to examine the pattern of colonization and succession, (7) to study the biology of dominant fouling organism, (8) to study the ecology of larval forms of fouling organisms, and 9. to analyse the influence of substrata on the settlement.

The wide range of problems investigated is of paramount importance for Kudankulam Nuclear Power Plant authorities to formulate adequate antifouling strategy. The results also contribute to the baseline biodiversity of this region as the biofouling community appeared to be the representatives of tropical fauna and
flora of intertidal region and may serve as a source material for other ecological studies.

1.4. DESCRIPTION OF THE STUDY AREA

The study area Kudankulam (8°9' 52" N and 77°42' 41" E) is situated about 25 km north east of Kanyakumari, along the coast of Gulf of Mannar (Plate -1a). The climate of the area is arid and is similar to other coastal regions of India. The wind speed is in the range of 6 to 30 km/hr (Meteorological Department, Kanyakumari). The seasons at Kudankulam can be conveniently classified into pre monsoon (June – September), Monsoon (October- January) and post monsoon (February – May). As the study area is situated in the southern most tip of Peninsular India, it receives south west monsoon and north east monsoon. The shore is rocky and mainly inhabited by seaweeds. Five stations were selected along the coast for this study. The locations of the study area are given in plate 1-b. A brief description of the stations selected along with its location is given below.

Station I: Chinnamuttom

This station situated close to Kanyakumari in the east coast (8°5'81" N and 77° 33' 72" E), about 23 km south of the Kudankulam Nuclear Power Project (Plate-2). A fishing harbour is located in this area and it is one of the major fish-landing centres. The site composed of concrete structures and wooden piles, which offer favourable substrata for barnacles, oysters, tube worms and seaweeds.
Station II: Kootapuli

It is a coastal fishing village of Tirunelveli District (8° 8' 75" N and 77° 36'06" E). The shore is rocky and is situated about 10km south of KKNPP. This station is noted for its rich diversity of seaweeds.

Station III: Panchal

A small coastal village situated in between Anu Vijay Township, the satellite town and the Kudankulam Nuclear Power Project site (8° 9' 5" N and 77° 39' 59" E). The rocky shore inhabits an astonishing array of species representing nearly almost all invertebrate phyla and Urochordates. It is about 2km southwest of the Nuclear Power Project. An experimental raft is suspended in this region for the biofouling studies.

Station IV: Idinthakarai

It is located about 5km northeast of the Atomic Power Project (8° 10' 61" N and 77° 44' 78" E). The shore is rocky and has a rich diversity of seaweeds.

Station V: Kuthankuzhi

It is a fishing village and is about 9km northeast of the Atomic Power Project (8° 12' 98" N and 77° 46' 95" E). This station is also rocky and known for its rich diversity of seaweeds.
Plate 1.A. Map showing the study area

Plate 1.B. Map showing five stations