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BIOFOULING BY *PERNA VIRIDIS* IN A DEEP SUBMARINE TUNNEL SYSTEM AT KALPAKKAM

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ABSTRACT

A preliminary assessment of biofouling in a seawater tunnel has been made from a study of the fouling biomass collected from different depths in the tunnel and from the trash racks at the tunnel intake. Fouling biomass was found to be dominated by the green mussel *Perna viridis*. Data on size-frequency distribution of mussels indicated the possibility of the entry of juvenile mussels through the intake into the tunnel system. It appears that the mussels moved along the length of the tunnel and grew up in size as it reached the fore-bay end. Biomass of green mussels on the trash racks was found to be 57 kg/m^2 in six months.

INTRODUCTION

MOST of the studies on biofouling in Indian coastal waters over the years have been directed to an understanding of the deterioration of timber in Indian coastal waters. As a consequence of a sustained effort put up by the Forest Research Institute, Dehradun, over this several years, our present understanding in this area is fairly comprehensive (Purushothaman and Rao, 1971 ; Tiwari *et al.*, 1984). Added to this have been the efforts of Naval Laboratories to cope with the problem of biofouling and corrosion on ship hulls (Karande, 1968) as well as the many researches carried out by independent investigators on the problem of boring and fouling in harbours, coastal waters and oceanic islands (Karande, 1978 ; Nair, 1984). The list of references are very exhaustive and what has been cited here are only a selected few. On the other hand, studies on the problem of biofouling in seawater intake conduits of power stations have been relatively very few. Some of the first attempts in this direction have been those of Godwin (1980) and Karande *et al.* (1983) in the coastal waters at Kalpakkam. The magnitude of the problem in temperate waters and the strategies for coping with these have been fairly well documented (Jensen, 1977). Marine growths interfere with the flow of water and some times completely blocks trash racks and strainers. As the fouling community grows some of these organisms break off from the intake conduit surfaces and are carried to the condenser water boxes, quite often blocking the condenser tubes.

The problem of marine growth is found to be particularly severe at Kalpakkam, south of Madras, where a nuclear power station is using seawater for condenser cooling purposes. The dominant fouling organism forming the stable community in the seawater intake conduit at Kalpakkam is the green mussel *Perna viridis* which is found to be growing profusely on the trash racks at the seawater intake and in lesser abundance at a depth of even upto 42 metres in the seawater intake tunnel (Nair *et al.*, 1987).

The authors are grateful to Commander Gupchup and his men from the Eastern Naval Command, Waltair for collecting the samples for our studies from MAPS fore-bay during their diving inspection from 4th to 6th April 1986.

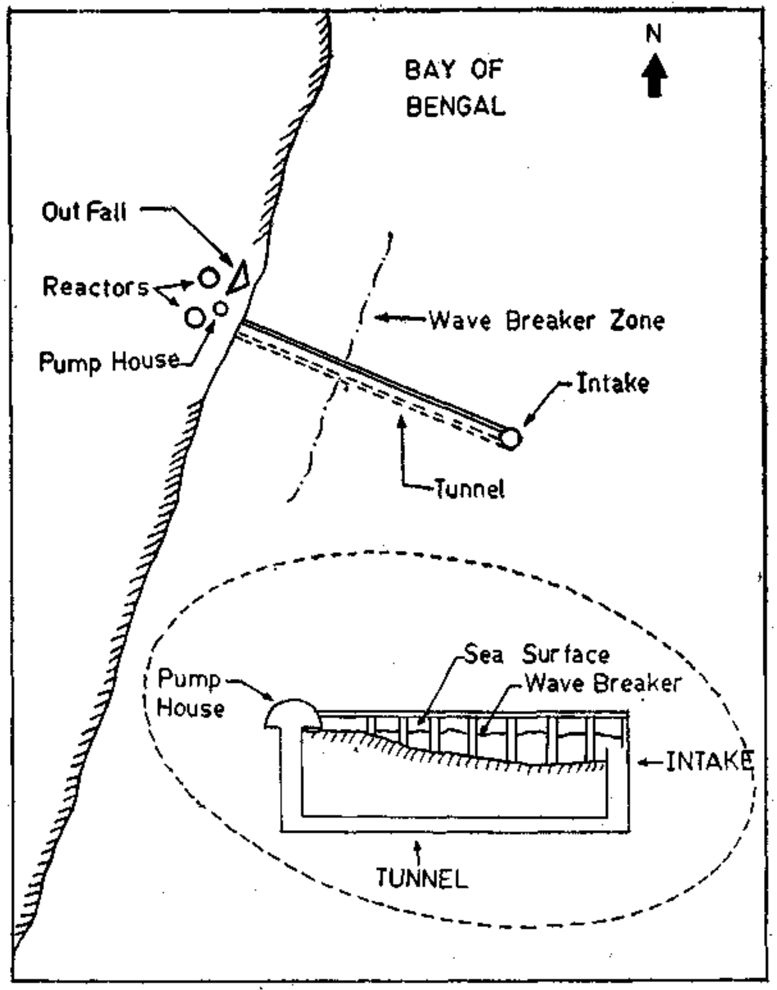

Fig. 1. A schematic diagram showing the MAPS reactors, seawater intake system and the outfall structure.

Seawater Intake System

The Madras Atomic Power Station (MAPS) consisting of two units, each 235 MW(e) uses seawater for condenser cooling as a once-through system. The seawater cooling system consists of an intake structure, located 420 m away from the shore in the sea, a tunnel 468 m long and 54.4 m below mean sea level (MSL), a fore-bay and pump-house, condensers and the out fall stucture (Fig. 1). The tunnel is horse-shoe shaped, 3.8 m in diameter and is connected at seaward end to the surface through a vertical shaft 4.25 m in diameter. At the landward end the tunnel is connected to the fore-bay through another vertical shaft which is 6 m in diameter and 56 m deep. The tunnel slopes from seaward end to the landward end with a slope of 1/250. A schematic diagram of the tunnel is shown in Fig. 2.

Seawater enters the intake shaft through 16 windows each 3.2 m high and 2 metres wide, located radially on the intake structure. From the intake shaft water flows by gravity into the fore-bay. At the fore-bay 12 pumps (6 for each unit) draw seawater and circulate through the condensers and other heat exchangers. The warm water from the heat exchangers is discharged onshore through an outfall structure with a built in facility to change the direction of flow with the aid of sluice gates. The coolant seawater flow when all the 12 pumps are running, works out to be about 3.0 m/sec.

Materials and Methods

A diving team from the Indian Navy examined the fore-bay shaft during 4th to 6th April, 1986 upto a depth of 42 m to assess the extent of fouling on the shaft walls. The divers collected samples of foulants from 3, 15, 30 and 42 m depths. At 42 m foulants from a 40 cm × 30 cm area was also collected to get a quantitative estimate of the biomass. Samples of marine life collected by the divers from the fore-bay shaft walls were examined for their faunistic composition. The bulk sample after taking the weight of the total biomass was preserved in formalin for detailed study. The major groups were later sorted out and identified. The length-frequency distribution of *Perna viridis* (which formed the bulk of the fouling biomass), was also analysed.

On the 8th of April two trash racks were withdrawn from the intake for routine maintenance. These were found to be heavily fouled by mussels. A representative sample of the fouling biomass from the two trash racks were also collected and used for assessing the total biomass, species composition of the fouling complex and length-frequency distribution of the principal foulant *Perna viridis*.

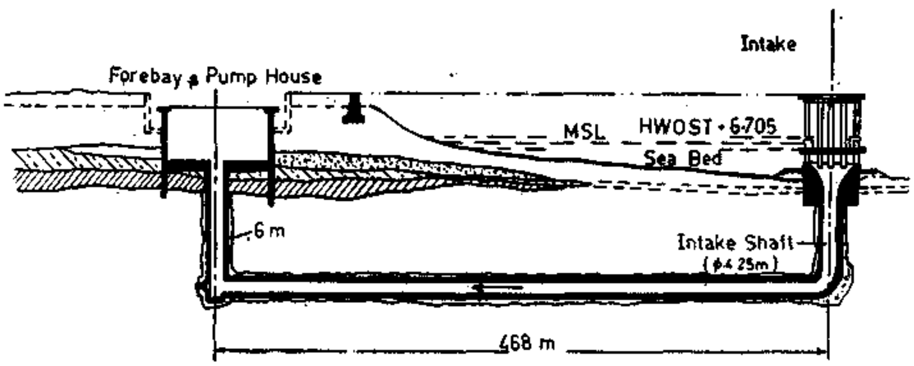

Fig. 2. A schematic diagram of submarine intake tunnel.

Results

Data on the length-frequency distribution of *Perna* collected from different depths as well as a trash rack are given in Fig. 3-7. Data on the relative abundance of different organisms found at different depths in the fore-bay shaft are given in Table 1.

General observation

The divers estimated that the thickness of foulant biomass on the bell-mouth of the onshore shaft was 45 to 60 cm and the growth tapered to a thickness of about 10 cm at a depth of 25 m. At 42 m, the growth was not uniform and hence the thickness could not be estimated. In addition, large quantities of shells, along with black silt was found deposited on the bell area of the shaft. A quantitative sample from about 0.12 m² area has shown a fouling density of 4.3 kg/m² of which about 50% were green mussels.

surfaces. The construction of the tunnel was completed in 1976 and the tunnel remained submerged in seawater since October 1977. The MAPS Unit-I was commissioned in July 1983 and Unit-II in September 1985.

Chlorination for biofouling control

It is common practice to resort to chlorination for control of biofouling in the cooling circuit of power stations. Based on the response of the larval forms of a few selected foulants to chlorine, an intermittent chlorination schedule was adopted for MAPS cooling water since 1979. No serious problem of biofouling was encountered during the start-up and commissioning of Unit-I in July, 1983 and until pumps for Unit II were started up during the pre-commissioning tests in March 1985. During the latter period large quantities of mussel shells (about 50 tonnes) got collected on the travelling screens. Moreover an inspection of condenser water boxes during a shut down of Unit-I in October 1984 showed that many condenser tubes were blocked by green mussel shells.

TABLE 1. *Relative abundance of foulers at different depths*

	Abundance at different depths (per cent of total)							
	3 m		15 m		30 m		50 m	
Types of foulers	No	Wt	No	Wt	No	Wt	No	Wt
Green mussel ..	79.0	90.7	9.1	6.1	14.6	65.17	17.4	58.4
Brown mussel ..	1.4	1.3	16.9	12.5	53.6	8.2	61.8	24.4
Clams ..	—	—	—	—	2.8	19.5	3.3	8.3
Barnacles ..	19.5	7.8	27.3	6.4	23.0	4.4	50.0	6.7
Polychaete ..	—	—	2.6	5.6	7.0	6.0	—	—
Snail ..	—	—	2.1	3.0	—	—	—	—
Crab ..	—	—	4.0	12.0	—	—	—	—
Sea anemones ..	—	—	49.1	7.7	6.0	1.7	15.7	2.0
Oyster ..	—	—	1.3	6.4	—	—	—	

Green mussels (*Perna viridis*), brown mussels (*Perna indica*) and Barnacles (*Balanus tintinnabulam*, *Balanus amphitrite* and other *Balanus* sp.) were found at all depths. In addition, sea anemones, polychaetes (*Hydroides norvegica*), oysters (*Pinctada* sp.), clams (*Arca* sp.), snails (*Thais bufo*) and crabs were represented in the samples although not at all depths. The green mussel shells were often covered with sea anemones, barnacles, polychaetes, hydroids and brown mussels forming a fouling complex.

During 1969 to 1973, when early experiments were done on the choice of condenser tube material for the Madras Atomic Power Project, extensive biofouling due to mussels, oysters and barnacles were observed on submerged

Relative abundance of foulers

From a look at the distribution of numerical and weight-wise relative abundance of different fouling groups (Table 1), it is seen that on the fore-bay shafts, green mussels account for the bulk of the biomass at all depths, although numerically brown mussels out-numbered the green mussels at 15 m and below. Other groups which made significant contribution both in terms of numbers and total biomass were barnacles and sea anemones. On the trash racks the dominance of green mussels was total, although there was a small contribution to the total biomass from the barnacle *B. tintinnabulum.*

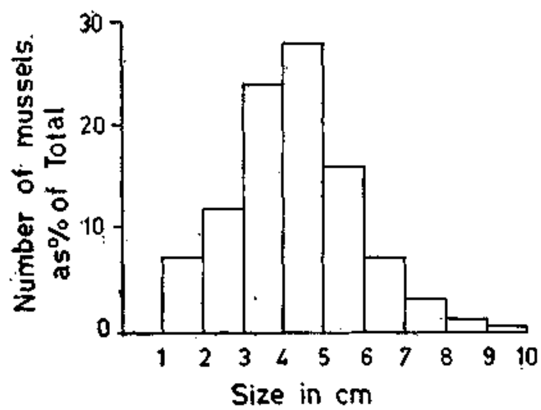

Fig. 3. Size distribution of green mussel at 3 m depth in the fore-bay shaft.

Size distribution of green mussels

The length-frequency distribution along with corresponding age in months of green mussels on a trash rack as well as on the fore-bay shaft at depths of 42 m, 30 m, 15 m and 3 m are given in the Fig. 3-7. An estimate of the age of the mussels was also made based on the study of Godwin (1980). From this data it is clear that green mussels of age groups starting from 1 to 6 months from the bulk of the fouling population on trash racks as well as in the fore-bay. However, mussels less than a month-old were found on the trash rack and mussels older than 6 months (sizes ranging from 6-10 cm) were found at 3 m depth in the fore-bay and there was a progressive increase in the occurrence of older mussels as one proceeded from intake trash racks to 3 m depth in fore-bay shaft. Although the trash racks were submerged in water only for six months, an estimate of the age of the mussels based on their length shows that upto 8 months old mussels are found on the trash rack.

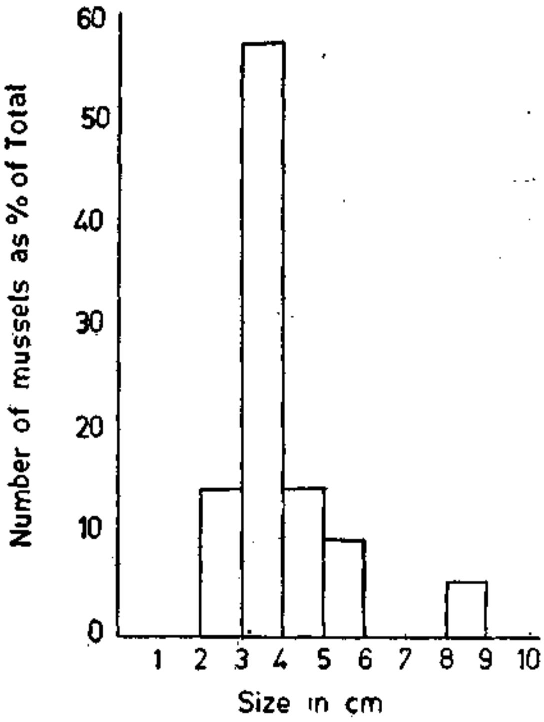

Fig. 4. Size distribution of green mussel at 15 m depth in the fore-bay shaft.

Biomass of green mussels

Mussels collected from two trash racks were used to get an estimate of the biomass build-up in the area. Two trash racks have shown a total biomass build-up of 57 kg/m² and 37.5 kg/m² respectively during a six month period. As there are 16 trash racks each having an area of 6.4 m², the total biomass from trash racks at the maximum build-up rate of 57 kg/m² amounts to a total weight of 5.8 tonnes/6 months. Assuming that at the intake shaft mussel fouling occurs upto a depth of 30 metres at the maximum value of 37.5 kg/m^2, the biomass build-up could amount to about 16 t in six months. In the fore-bay shaft as the diameter of the shaft is bigger (6 m) the biomass build-up at the same rate upto a depth of 30 m could amount to about 32 tonnes. Coincidentally in March 1985 when all the 12 pumps were operated during the start-up and commissioning of Unit II, about 50 tonnes

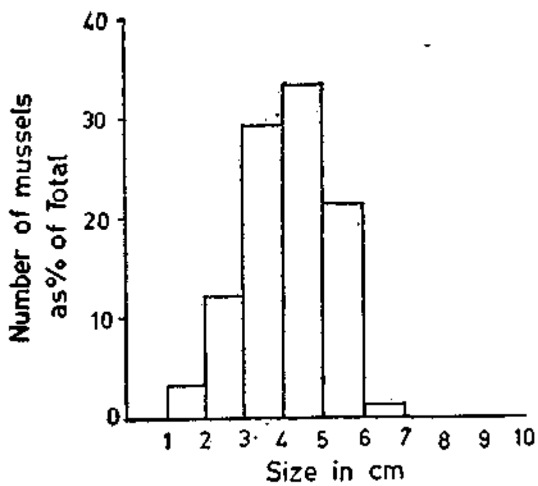

Fig. 5. Size distribution of green mussel at 30 m depth in the fore-bay shaft.

of mussels were collected from the travelling screens. Thus, almost all the green mussel biomass which appeared on the travelling screens can possibly be accounted for by the biomass build-up of green mussels on the fore-bay and intake shafts.

Earlier studies have shown that the average biomass build-up at Kalpakkam (Karande *et al.*, 1983) amounts to 4 kg/m^2/year, with a possible maximum of about 8 kg/m^2/year It was also pointed out that this rate is among some of the highest values ever reported. However, the present data shows a maximum value of 57 kg/m^2 for a six month period on the trash racks. This is far higher than those reported for test panels (25 kg/m^2/year) as well as light ships (40 kg/m^2 in 11 months) from other sea areas (Anon., 1952). However, the present data are very close to and only marginally lower than the very high value (64 kg/m^2 for 21 weeks) reported from the water intake tunnels of a power station in Lynn, Massachusetts (Anon., 1952). Such high

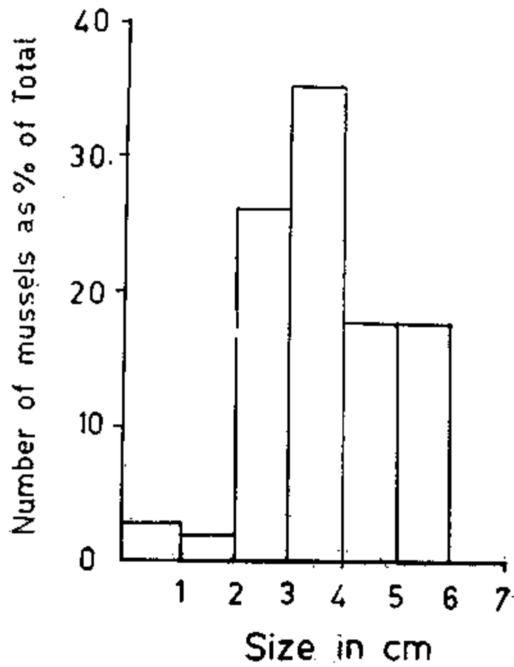

Fig. 6. Size distribution of green mussel at 42 m depth in the fore-bay shaft.

rate of biomass build-up in seawater conduits is possible, because of the flowing water which brings a stream of fresh food incessantly to the sedentary mussels. Since we know that the average primary productivity of coastal waters is of the order of about 2 kg/m^2/year, the observed very high biomass build-up on the sea water conduits points to the potential of such conduits as areas of very high organic production.

Growth of mussels

The rate of growth of mussel *Perna viridis* was studied by Godwin (1980) at Kalpakkam. These studies showed an average growth rate of 4.25 mm/month during February to May, 9.94 mm/month during June to October and 3.46 mm/month during November to January reaching a length of 88 mm in 11 months. The present data showed the presence of a few mussels of about 8 cm length on trash racks which have been put in seawater only six months before, thus amounting to an average growth rate of 12.7 mm/month. The inference from this observation could be either (i) the rate of growth of mussels in the coastal water is higher than those observed prior to the commissioning of the reactors or (ii) juvenile mussels of a few millimetre size have moved from adjoining areas and settled on the trash racks.

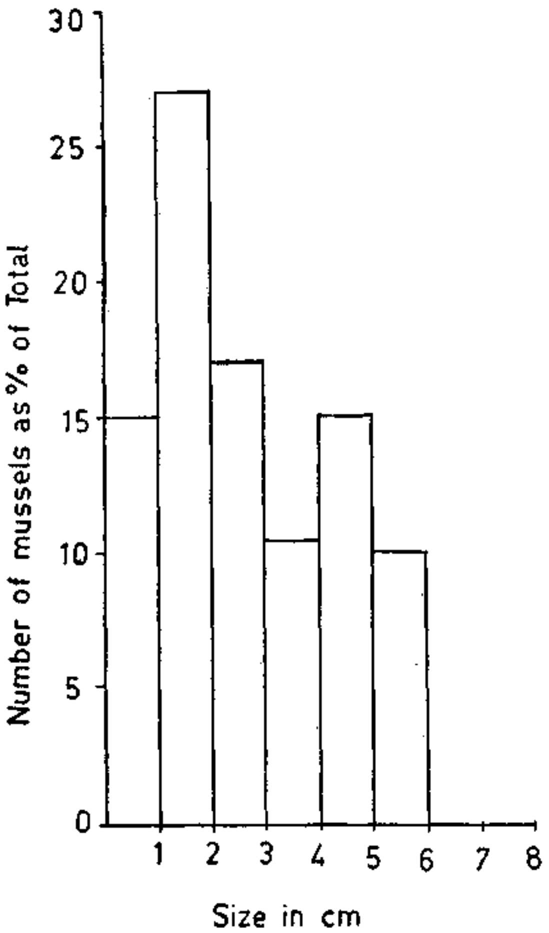

Fig. 7. Size distribution of green mussel on a trash rack at the intake.

Ecology

Marine mussels are generally found in shallow sublittoral waters. On the Indian Coast they have been observed upto a depth of 15 m, although more abundant at shallow depths (Appukuttan and Nair, Per. Comm.). In the present study they have been collected from a depth of upto 42 m. They were found in association with brown mussels, clams, barnacles and sea anemones. Since the seawater tunnel at Kalpakkam is an artificial habitat wherein a depth of 50 m is encountered on the shoreline and velocities of 3 m/sec. exists in the tunnel, the occurrence of mussels at this depth cannot be considered as their natural distribution. However, it is of scientific interest to note that not only green mussels, but brown mussels and several other groups of marine life have colonised this unique, deep habitat.

Discussion

Observation on the type, intensity and seasonal distribution of macrofoulants have been carried out at Kalpakkam during the pre-operational phase of the power plant (Karande *et al.*, 1983). These studies have succeeded in identifying the major groups and their seasonal abundance. These studies have also indicated that barnacles *Balanus* sp. would be the dominant organism to be reckoned with in the cooling system. However, as the power station started drawing water through the seawater tunnel, it was marine mussel (*Perna viridis*) which was found coming increasingly on the travelling screens. The present data on the samples collected from the diving inspections as well as from the trash racks at the intake, clearly demonstrate that tunnel fouling is dominated by *Perna viridis*. This is understandable as mussels are some of the very few animals among the macrofoulants which can withstand a water velocity ranging from 2 to 3 m/sec (Perkins, 1974) which occur in the tunnel during different modes of operation. Moreover, intermittent chlorination which has been practiced at the station has very little impact on these bivalves which close their valves to tide over the periods of chlorination. From the size-distribution of mussels on the trash racks and at various depths, it appears, juvenile mussels are entering the tunnel from seawater end and slowly moving along the tunnel length in the direction of flow, growing up in the process and ending up at intake shaft bell mouth as large size mussels. It is observed that the productivity of mussels is very high in the tunnel, possibly due to the increased food availability as a result of the flow of water. There is also a hint that the rate of growth is higher than the pre-operational period. In addition to the increased availability of food brought by flowing water, an increase in mean temperature could have contributed to their increase in growth rate.

In view of the preponderance of mussels among the fouling community in the tunnel and in view of the well known practice of low level continuous chlorination (exomotive chlorination) for mussel fouling control, this practice has now been adopted as an experimental measure for fouling control in the MAPS tunnel. However, many questions relating to the problem remains to be answered before a viable solution can be worked out. Some of these are (i) continuous chlorination at what level could deter the settlement of mussels ? (ii) since mussels predominate the fouling community, would it not be sufficient to chlorinate only during the mussel spawning season ? (iii) if mussels are displaced, is there a possibility that some other species would enter the scene ? (iv) is low dose chlorination adequate to control condenser slime formation ?

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