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Ecology of biofouling on *Crassostrea madrasensis* (Preston) (Mollusca: Bivalvia) in a tropical backwater

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Abstract. Ecology of biofouling on the edible estuarine oyster *Crassostrea madrasensis* (Preston) has been investigated in the Ashtamudi Backwater of the southwest coast of India. Fouling was highly conspicuous throughout the year and dominant groups included barnacles, serpulids, bryozoans and modiolids. Intensity of fouling varied from 73 to 179 % on living oyster valves and 65 to 172 % on dead valves with respective annual averages of 118 and 127 %. Substrate selection and settlement of the different groups were mostly opportunistic. Barnacles were the most dominant, living and dead ones collectively contributing to about 26 % of fouling on living valves and 32 % on dead valves. Serpulid fouling was 22 % both on living and dead oyster valves, bryozoans 15 and 12 %, modiolids 11 and 12 % and the miscellaneous groups formed 27 and 20 % respectively. Availability of free settling space and fouling in relation to substrate size were also investigated. Total fouling was very intense on oysters of 25–35 cm^2 size group. Impact of biofouling on oysters and certain earlier studies on the topic are discussed.

Keywords. Biofouling; ecology; intensity; barnacles; *Crassostrea madrasensis*.

1. Introduction

Considerable attention has been paid to study some aspects of marine fouling in Indian coastal waters (Antony Raja 1959; Balasubramanian and Nair 1970; Daniel 1954; Dharmaraj and Nair 1981; Ganapati *et al* 1958; Karande 1968; Menon and Nair 1971; Menon *et al* 1977; Nair 1965; Paul 1942; Santhakumari and Nair 1975; Renganathan *et al* 1982). Most of these studies were directed at determining the nature, composition and dynamics of marine fouling on artificially exposed objects such as coastal installations, navigational structures, fishing and sailing vessels etc. Considering the huge economic loss being incurred in the utility and maintenance of these objects due to the impediments caused by fouling, attempts have been made to formulate preventive measures. Calcareous valves of commercially important and cultivable molluscs such as the oysters and mussels are also severely fouled by a large number of invertebrates causing severe detriments to the host and hindrances to culture operations and post harvest cleaning techniques (Yonge 1966; Mason 1976; Nickolic and Alfonso 1970; Alagarswami and Chellam 1976; Bwothondi and Ngoile 1982).

In the backwaters and estuaries of India wherever suitable habitats are available, the edible estuarine oyster *Crassostrea madrasensis* occurs and it is exploited both for food and lime industry. *C. madrasensis* is easily cultivable with economic feasibility. No comprehensive attempt has so far been made to study the nature and composition of biofouling on edible oysters in Indian waters. Therefore, with a view to gathering basic information, certain aspects of the ecology of biofouling on *C. madrasensis* in the Ashtamudi backwater, southwest coast of India has been investigated for one year and the results are reported here.

2. Materials and methods

Oysters were collected from the central portion of the Ashtamudi Backwater (Lat. 8°53′N–9°02′N; Long. 76°31′E–76°41′E) at random during each fortnight for one year, June 1980 to May 1981. Depth at the collecting site varied from 1·5 to 3 m and the bottom consisted of laterite blocks of varying sizes together with a mixture of silt and mud. Important hydrographical parameters were determined according to standard procedures (Nair *et al* 1983). Oysters were gently washed in 2% formalin to separate free-living associated fauna and none of the attached fouling organisms including mud tubes of certain polychaetes, amphipods etc was allowed to detach. Upper valves (right) of both living and dead oysters were thoroughly examined to obtain a quantitative picture of biofouling by different groups of organisms. Mud tube dwelling forms, algae and unidentifiable fouling were treated as miscellaneous. In the case of barnacles, living and dead ones were separately treated.

Quantitative picture of the total fouled space and space occupied by different groups of organisms was obtained by 'dots method' adapted from random point sampling system (Shin 1981; Sutherland 1977) as explained below. On a square glass plate, 100 cm^2 area was uniformly marked with 400 minute black dots at intervals of 0·5 cm. A space value of 0·25 cm^2 occupies each dot. Right valves of the oysters were placed in a tray exposing the fouled outer face upward. The dotted glass plate was aimlessly placed on the tray and by looking straight on the valve through the plate, the total number of dots over the valve and above each distinguishable group or species of fouling organisms were counted. Countings were repeated 4 to 5 times on each valve changing the position of the plate at random, however, ascertaining that the valve lies within the dotted area invariably. The average number of dots occupied by different groups of biofoulers and by the valve were converted to area by multiplying with 0·25. Right valves of not less than 5 living oysters and 5 dead oysters were examined during every fortnight and monthly averages were calculated. Clean settling space whenever available on the valves was also quantified.

The intensity of fouling (%) was calculated as 100 × the total fouled space/the size of the valve and the intensity of fouling by different groups of organisms as 100 × the space occupied by a particular group/the total fouled area.

3. Results

3.1 *Environmental conditions*

Ashtamudi Backwater, one of the largest among the estuarine systems of the southwest coast of India covers approximately 32 km^2 area with brackish water in southern Kerala. It has a permanent connection with the adjoining Arabian Sea on the west and the Kallada River originating from the Western Ghats empties into the backwater at the northeastern side. The backwater is bordered in certain localities by laterite cliffs and in other portions by coconut plantations on reclaimed land. The floor is covered with sediments of seasonally and regionally varying physico-chemical composition, and laterite blocks of different sizes and shapes. Accounts on the productivity, hydrography, sediment chemistry and other aspects of this backwater ecosystem have been published recently (Nair *et al* 1983, 1984; Dharmaraj and Nair 1979, 1981, 1981a).

Important hydrographic data pertaining to the bottom water of the station from where oysters were collected are presented in table 1. Transparency of the water column also is included. Salinity varied considerably from 11·1 to 27·5 × 10^{-3}. It was relatively low from July to October and high from December to May. Temperature ranged between 28 and 31·8°C and pH between 7·35 and 8·10. Seasonal changes were small in the case of temperature and pH but dissolved oxygen content varied from 0 to 7·4 ml $litre^{-1}$. Although on two occasions dissolved oxygen could not be detected, fairly high values were recorded during a major part of the year. Water was relatively turbid from the second fortnight of April to September with considerable fluctuations. Transparency was high from December to April.

Table 1. Fortnightly variations of relevant hydrographical parameters at the study site.

	Parameters				
Period	Salinity (10^{-3})	Temp (°C)	pH value	Dissolved oxygen (ml/l)	Transparency (cm)
June 1980	25·1	31·5	7·8	6·0	68·5
	18·1	30·3	7·8	6·0	72
July	11·1	29·0	7·4	4·0	44·8
	14·1	28·6	7·9	4·4	53
August	13·5	28·0	7·8	4·5	114
	13·0	28·5	7·7	4·4	73·5
September	13·6	29·4	7·7	6·2	123
	13·8	30·4	7·6	0·0	95
October	12·2	30·5	7·5	0·0	125
	13·3	30·6	7·4	5·1	108
November	23·5	30·2	7·4	5·5	127
	19·6	29·8	7·8	5·7	86
December	23·5	30·8	7·5	7·4	122
	24·9	30·2	7·7	4·3	147
January 1981	23·1	29·6	7·9	4·3	200
	24·0	29·4	8·1	4·5	203
February	27·0	30·3	8·0	5·1	219
	27·5	30·0	7·8	3·6	180
March	27·3	31·4	8·0	5·2	152
	27·5	31·4	7·8	5·2	197
April	27·5	31·8	7·9	6·4	125
	26·8	30·2	8·0	4·5	98
May	27·0	31·6	7·9	4·9	96
	27·3	31·0	7·9	5·3	108

3.2 *Components of biofouling*

Sedentary fouling organisms dominant on oyster valves were barnacles, serpulids, bryozoans, modiolids and less important groups such as sponges, hydroids, other crustaceans, algae etc. Barnacles were represented by only one species namely *Balanus amphitrite communis*. Serpulids consisted of 3 species of tube worms such as *Mercierella enigmaticus*, *Ficopomatus macrodon* and *Pomatoleios* sp. Bryozoans were represented by *Electra crustulenta*, *Victorella pavida*, *Schizoporella cochinensis*, *Bowerbankia* sp and a few as yet unidentified forms. *Modiolus plumicens*, *Modiolus carvolhoi* and *Musculista arcuatula* represented the mussels. Miscellaneous group of foulers consisted mostly of mud tube dwelling species such as the amphipod *Corophium triaenonyx*, the tanaid *Tanais estuarius* and polychaetes such as *Pectinaria* sp and *Polydora ciliata*. A large number of species of epibenthic algae, hydroids including *Halocordyle disticha*, *Ectopleura* sp and others, sea anemones and sponges were also treated as miscellaneous. Several species of associated errant organisms such as isopods, amphipods, polychaetes, flat worms, crabs, shrimps etc were isolated from the oyster biocoenosis an account of which will be published later.

3.3 *Fouling intensity*

Average fouling intensity on living oyster valves was 118 % in a range of 73 to 179 % (figure 1). The same on dead valves was 127 % in a range of 65 to 172 % (figure 1). Very little difference was discernible between intensities of fouling on dead and living valves which was not higher than the variations between individual valves of any one of the categories. This suggests that substrate selection and settlement by different groups of fouling organisms are mostly opportunistic. Fouling intensity on both living and dead

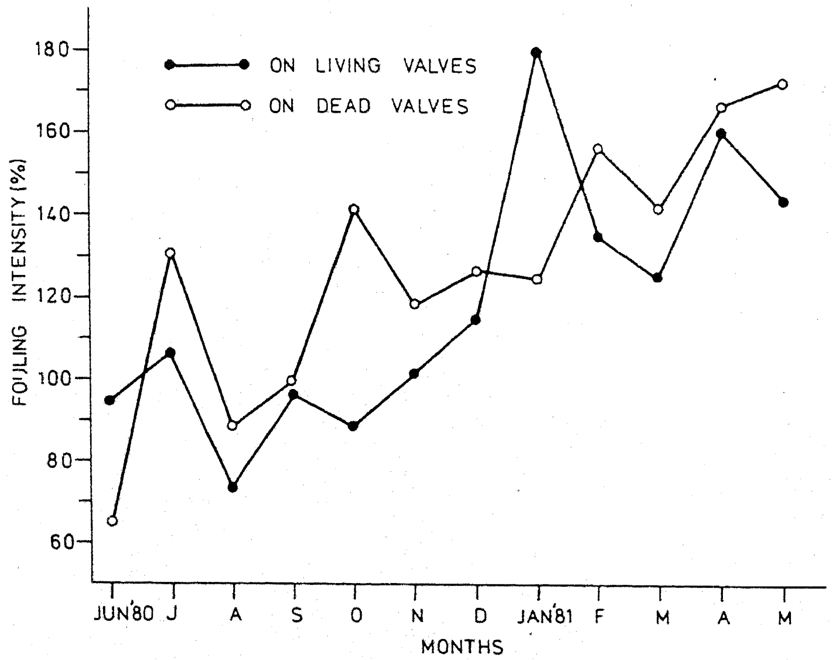


Figure 1. Monthly variations on the intensity of biofouling.

oyster valves was in general low during the first half of the study period when the salinity of the ambient water was low and highly fluctuating. Intensities were, however, below 100% only during June, August and September. During this period other ecological parameters also fluctuated widely.

3.4 *Nature of biofouling by different groups of organisms*

Among the different groups of foulers encountered and individually considered, barnacles were by far the most important, living and dead ones collectively contributing to nearly 26% of the biofouling on living valves and 32% on dead valves (figure 2). Throughout the year living and dead barnacles were discernible on both living and dead valves (tables 2 and 3) although certain individual valves did not harbour any barnacle at all. Barnacles apparently exhibited a selective tendency to foul dead valves more intensively than the living ones. Incidence of dead barnacles was about 6% higher than

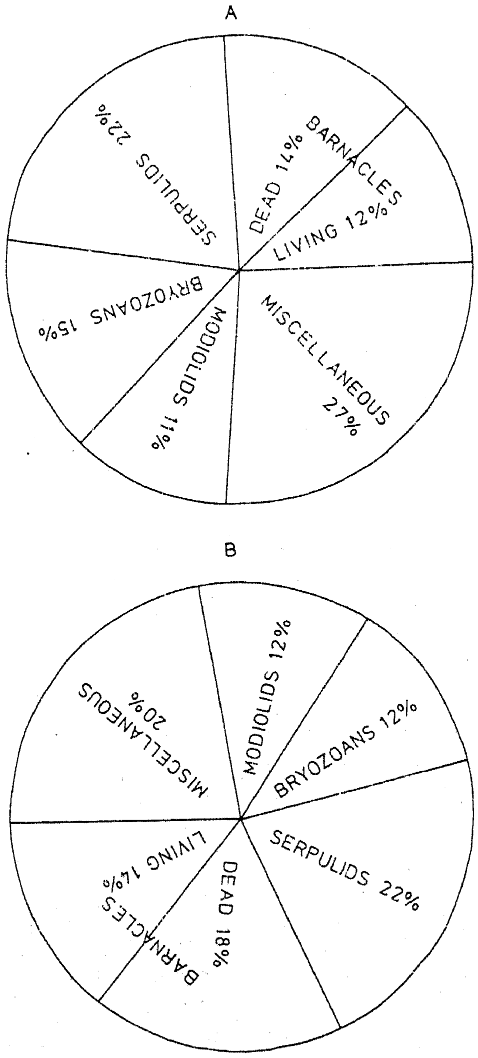


Figure 2. Annual average fouling intensities of different groups of organisms on living oyster valves (A) and on dead valves (B).

that of living barnacles. Adverse ecological conditions, therefore, have little influence on fouling by barnacles although these would have definite influence on the initial settlement of the larvae. Once established on the substratum barnacles are a serious problem in the tropics to oysters. Fouling intensity by living barnacles averaged 12% on living valves and 14% on dead valves. Incidence of empty barnacle tests averaged 14% on living valves and 18% on dead valves. Maximum intensity of fouling by living barnacles on living valves was recorded during March and June and the minimum during November (table 2). On living valves occurrence of dead barnacle tests was lowest during November and highest during August. Fouling by living barnacles on dead valves was lowest during November and highest during August. Incidence of dead barnacles on dead valves was also lowest during November and highest during July (table 3). All these suggest that barnacle fouling was low during November, *i.e.* the northeast monsoon period and highest during the summer.

Table 2. Intensity of fouling (%) by different groups of organisms on living valves.

Period of observation	Fouling organisms					
	Living barnacles	Dead barnacles	Serpulids	Bryozoans	Modiolids	Miscellaneous
June 1980	18	13	27	3	3	36
July	11	23	30	7	3	27
August	13	24	12	24	2	25
September	9	9	24	32	0	26
October	5	14	26	14	17	25
November	3	8	47	19	16	6
December	8	13	13	27	22	16
January 1981	10	12	15	13	14	37
February	7	10	15	5	18	45
March	18	13	23	6	21	20
April	4	15	21	4	11	45
May	37	10	6	26	5	17

Table 3. Intensity of fouling (%) by different groups of organisms on dead valves.

Period of observation	Fouling organisms					
	Living barnacles	Dead barnacles	Serpulids	Bryozoans	Modiolids	Miscellaneous
June 1980	11	17	31	7	2	32
July	14	36	37	2	0	12
August	42	32	4	13	2	7
September	19	19	36	13	4	9
October	5	16	22	25	12	22
November	1	8	33	15	33	11
December	8	15	29	15	23	10
January 1981	4	13	18	15	13	37
February	13	14	22	12	13	27
March	11	16	30	4	29	11
April	6	14	23	5	6	45
May	33	11	7	31	6	13

Serpulid polychaetes amounted to an annual average of 22 % on living and dead valves (figure 2). The difference between their settlement on living and dead valves was not significant. Intensity of serpulid fouling varied from 6 % in May to 47 % in November on living valves and 4 % in August to 37 % in July on dead valves. Serpulids competed strongly for space with barnacles, bryozoans and other foulers. On many instances overcrowding and secondary settlement on earlier settlers were discernible. A negative relationship between fouling by serpulids and barnacles was noticeable in that the period of poor fouling by serpulids coincided with the period of dense fouling by barnacles and *vice versa*.

Encrusting and creeping types of bryozoan colonies were encountered on living (average intensity 15 %) and dead (average intensity 12 %) oyster valves (figure 2). Bryozoan fouling was dense from August to December and in May. Many species of bryozoans flourished over other fouling organisms especially on those with calcareous exoskeleton. Intensity of bryozoan fouling varied very widely on both living and dead valves (tables 2 and 3).

Modiolids were encountered between barnacles, serpulids and also within dead barnacles attached either to other foulers or to oyster valves with byssus threads. Average intensity of fouling on living oysters was 11 % and the same on dead valves was 12 % (figure 2). On living valves the intensity rose up to 22 % in December from 0 in September (table 2). Fluctuations were highly erratic owing to the flimsy byssal attachment. On dead valves modiolid biofouling varied between intensities of 0 and 33 % (table 3).

Miscellaneous groups such as algae, sponges, hydroids, other crustaceans etc were also important and contributed to the fouling biomass. Their incidence was in general slightly more on living oyster valves than on dead ones, the annual average intensity on living valves being 27 % and on dead valves being 20 % (figure 2). It varied from 7 % in August to 45 % in April on dead valves (table 3) and 6 % in November to 45 % in February and April on living valves (table 2). Monthly variations were highly erratic with dense fouling during the highly saline summer months.

3.5 *Availability of settling space*

Even though fouling intensity was above 100 % during most of the months, some clean space was noticeable except in rare cases. Settling space availability on living oyster valves varied from 0 in January and April to 32 % in August (figure 3) with an annual average of 8 %. On dead valves the average was 8 % with a range of 0 to 30 % (figure 3).

3.6 *Fouling in relation to substrate size*

All the living oysters analysed were grouped into five different size classes to delineate if there is any variation in biofouling with the growth of oysters. Surface area of the valves ranged between 14·8 and 71·3 cm^2. Biofouling in relation to size of the oyster valves is presented in table 4. Total fouling intensity was very high on oysters of 25–35 cm^2 size group. It was relatively low on oysters with smaller and larger right valves. Living barnacles exhibited a clear preference to foul oysters of 25–35 cm^2 size group and their incidence was very low on smaller oysters. Incidence of dead barnacles, however, was

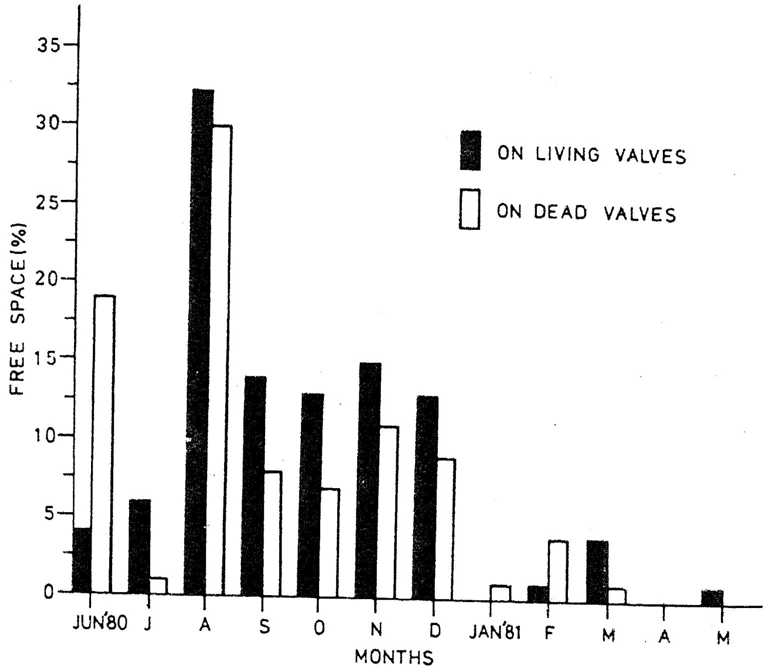


Figure 3. Variations in the availability of settling space.

Table 4. Fouling intensity (%) and availability of free space in relation to substrate size on living oyster valves.

Fouling organisms	Substrate size cm^2				
	15–25	25–35	35–45	45–55	> 55
Living barnacles	8	24	15	15	12
Dead barnacles	23	16	14	16	12
Serpulids	14	31	21	21	30
Bryozoans	13	19	20	15	11
Modiolids	8	14	15	14	9
Miscellaneous	29	33	33	39	33
Total fouling intensity	95	138	118	120	107
Free space	12	3	9	8	2

high on smaller oysters. Serpulid fouling also was heavy in 25–35 cm^2 size group although it was conspicuous on oysters of all size groups. Intensity of bryozoan biofouling was maximum in the size group 35–45 cm^2 and minimum on those above 55 cm^2. The pattern of modiolid biofouling was similar to that of bryozoans with poor intensity on smaller and larger oysters. Miscellaneous groups did not exhibit any preference to the size, however, their intensity was slightly higher in 45–55 cm^2 size group and lower in the smallest size group. Incidence of free space was naturally maximum on smaller oysters and minimum on larger oysters.

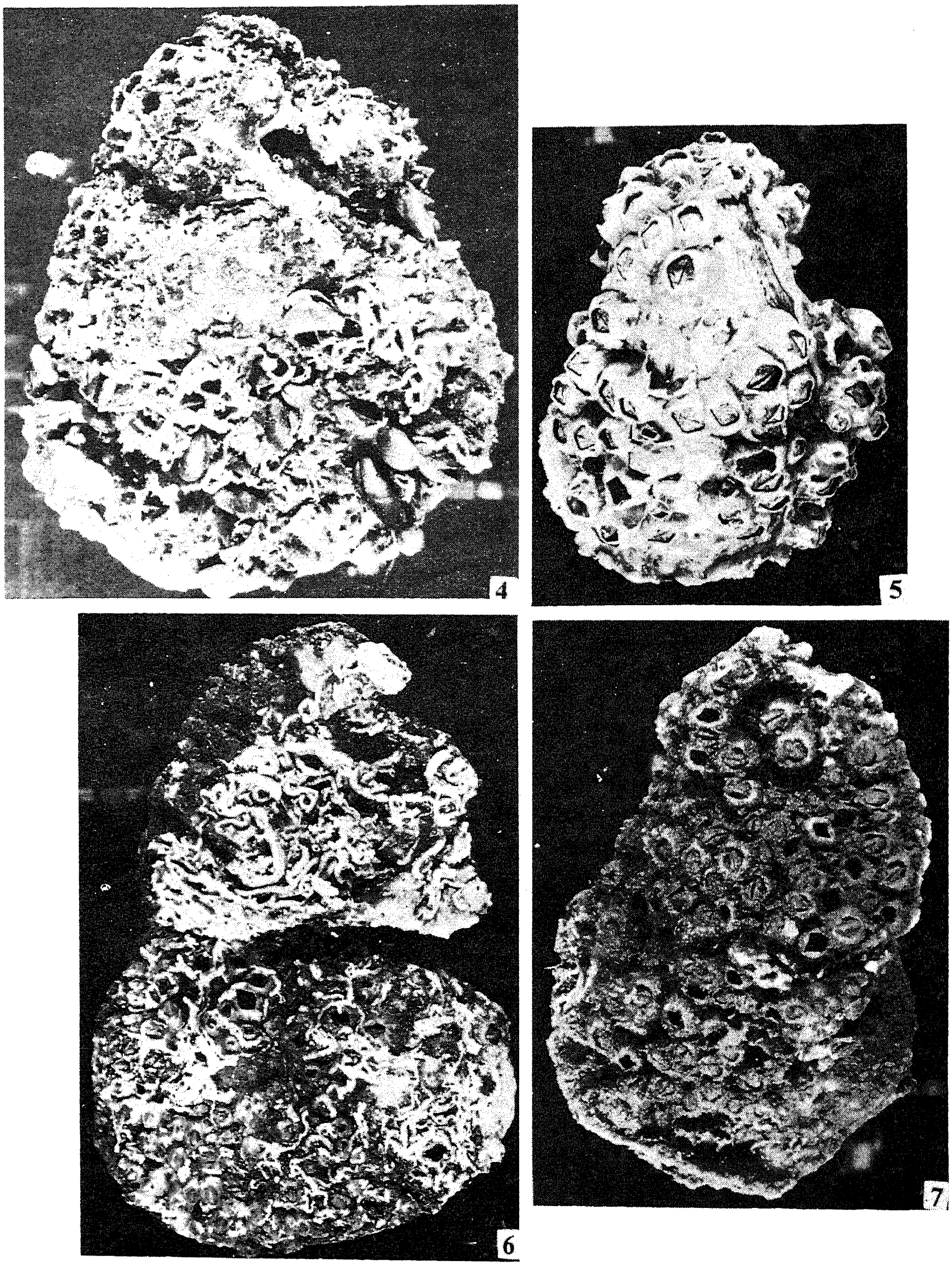
4. Discussion

The ecology of biofoulers and the associated organisms of economically important bivalves has been studied in different parts of the world from time to time on account of its economic importance (Conner 1980; Costa *et al* 1979; Korringa 1951, 1952; Krakatitsa and Kaminskaya 1979; Pinto and Wignarajah 1980; Maurer and Walting 1973; Stephen 1978; Walne 1961, 1974). However, in these studies the quantitative aspects have not been stressed, importance being given to the composition of the fauna, their relative abundance in certain cases and nature of seasonal and spatial variations. Composition of the biofouling organisms encountered in the present study has been somewhat similar to those reported in the above mentioned papers except differences in the dominance of different groups and absence of certain groups such as ascidians. Investigations similar to the present one have been reported on fauna on artificial substrata and epifaunal communities of rocky marine ecosystems (Shin 1981; Harms and Anger 1983; Osman 1977; Dean and Hurd 1980). These reports clearly show that groups of fouling organisms vary widely in their relative abundance and dominance with space and time.

Oyster biocoenosis in the Ashtamudi Backwater consists of a large number of errant and sedentary marine species and a few estuarine forms. Throughout the year sedentary representatives settle and flourish over the valves of oysters forming conspicuous communities (figures 4–7). On account of the meagre quantified data a detailed picture could not be developed so far despite its importance in the culture of mussels and oysters (Bwothondi and Ngoile 1982; Mason 1976; Cho and Frias 1979). Impediments caused by biofouling in the culture of commercial molluscs have been documented among others by Alagarswami and Chellam (1976), Milne (1976) and Nikolic and Alfonso (1970). Interference starts from the initial stages of spat collection and continues till post harvest cleaning of the crop.

One of the factors conducive to the dense biofouling recorded throughout the year is probably the nature of the habitat of the oysters in the Ashtamudi Backwater. Environmental parameters exhibit relatively lesser fluctuations at the bottom than at the surface and the intertidal zone even during the highly unstable monsoon months. During the monsoon also biofouling on oysters growing attached to laterite blocks at the bottom was invariably above 50% in intensity suggesting that clean unfouled oysters never occur in the backwater. One of the reasons for this is the dense occurrence of epibenthic communities in the backwater wherever shores are protected with laterite or granite blocks. Fouling community at the mouth of the backwater is exceptionally rich in species and in density (Dharmaraj and Nair 1981) and this is reflected in the biofouling on oysters as well.

The organisms noticed during the present study seem to have little or no preference specifically for settling over oyster valves. Field observations showed that initial settlement of many species is almost opportunistic because epibenthic faunal assemblages of similar structure and composition exist on laterite walls and all sorts of other hard substrata available in the vicinity. It has further been noticed that dense incidence of major fouling elements such as barnacles, serpulids, mussels etc along laterite embankments represent a perennial source of larvae and prevent fresh settlement of oyster spat and also these, through successive settlement smother the already existing smaller oysters. Such situations have already been recorded by Cho and Frias (1979) while observing oyster settling in Restinga Lagoon, Venezuela. In regions of unmanned aquatic environments these are processes involved in regulating the epifaunal community structure and interspecific relationships. When the phenomena occurs on artificially submerged substrata and cultivable organisms such as oysters and mussels they naturally exert an adverse influence.



Figures 4–7. Different types of fouling communities on oysters; **4.** Dead barnacles, serpulids and mussels, **5.** Barnacles alone, **6.** Dense occurrence of serpulids, bryozoans and miscellaneous groups, and **7.** Barnacles covered over by mud tube dwelling polychaetes and amphipods.

Epifaunal assemblages on oyster valves have many adverse effects on the host. Dense settlement on the right valve would render it to expend more energy than otherwise to open the valve. During growth, shape and size of the oysters are likely to be affected owing to the mechanical effects of foulers crowding over them. Most of the foulers are filter feeders competing with the oysters themselves at the same trophic level for oxygen and food (Yonge 1966; Mason 1976). Crevices created by irregular biofouling growth provide shelter to a diverse group of organisms such as errant polyclads, polychaetes, isopods, amphipods etc some of which are harmful to the oysters (Korringa 1951; Cheng 1967). Crevices filled up with debris and mud lead to colonisation by pathogenic microorganisms contaminating even the flesh of oysters. Certain polychaetes of the family Spionidae burrow into the valves and lead to the formation of mud blisters (Stephen 1978; Joseph 1979). All these harmful effects of biofouling make it necessary that it should be prevented on oysters or atleast controlled to the maximum possible extent.

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