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STUDIES ON THE DISTRIBUTION AND SUCCESSION OF SEDENTARY ORGANISMS OF THE MADRAS HARBOUR*

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INTRODUCTION

IN recent years importance has been laid on the study of sedentary organisms of enclosed waters as these cause considerable damage to the submerged piles, pillars and buoys and impede navigation due to their accumulation on ships' bottom. Interest in the study of these organisms was first initiated by Visscher (1927) and was followed by several workers (Coe, 1932 ; Johnson and Miller, 1935 ; Coe and Allen, 1937 ; Zobell, 1938 ; Edmondson and Ingram, 1939 ; Pomerat and Reiner, 1942 ; McDougall, 1943 ; Edmondson, 1944 ; Richard and Clapp, 1944 ; Graham and Helen, 1945 ; Fuller, 1946 ; Pomerat and Weiss, 1946 ; Weiss, 1948 ; Pyefinch, 1948) whose observations reveal that the more important of the physico-chemical factors influencing the composition and abundance of the sedentary communities are temperature, salinity, light, current, pollution, phosphate-nitrite contents, nature of substratum and depth. Among the recent investigations may be listed the studies of Allen and Wood (1950), Smith, Williams and Davis (1950), the contribution of Woods Hole Oceanographic Institution (1952), Ralph and Hurley (1952) and Knight-Jones and Clifford Jones (1955).

Observations on the ecology of sedentary organisms on the Indian coast are meagre. A preliminary survey of marine boring organisms of Cochin harbour was made by Erlanson (1936). Paul (1942) studied the growth and breeding of certain sedentary organisms of Madras harbour. Kuriyan (1953) observed in the Gulf of Mannar marked variation in the settlement of sedentary organisms. Daniel (1954) studied the seasonal variations in the settlement of fouling organisms in the Madras harbour and commented upon the abundance and succession of sedentary communities. He also studied the influence of different environmental factors on the settlement of barnacles (Daniel, 1955 a & b ; 1957 a & b ; 1958). At Vizagapatnam harbour, Ganapati *et al.* (1958), working on the biology of fouling, listed the different species and made notes on the seasonal abundance, rate of growth and sizes at sexual maturity of some important foulers. Compared to the extensive work carried out in temperate and subtropical regions on the influence of environmental factors on the sedentary organisms, our knowledge regarding them in the tropical regions is very limited. An attempt has been made here to partially fill this gap and as a preliminary to this, a study of the distribution of the sedentary organisms on different substrata has been made.

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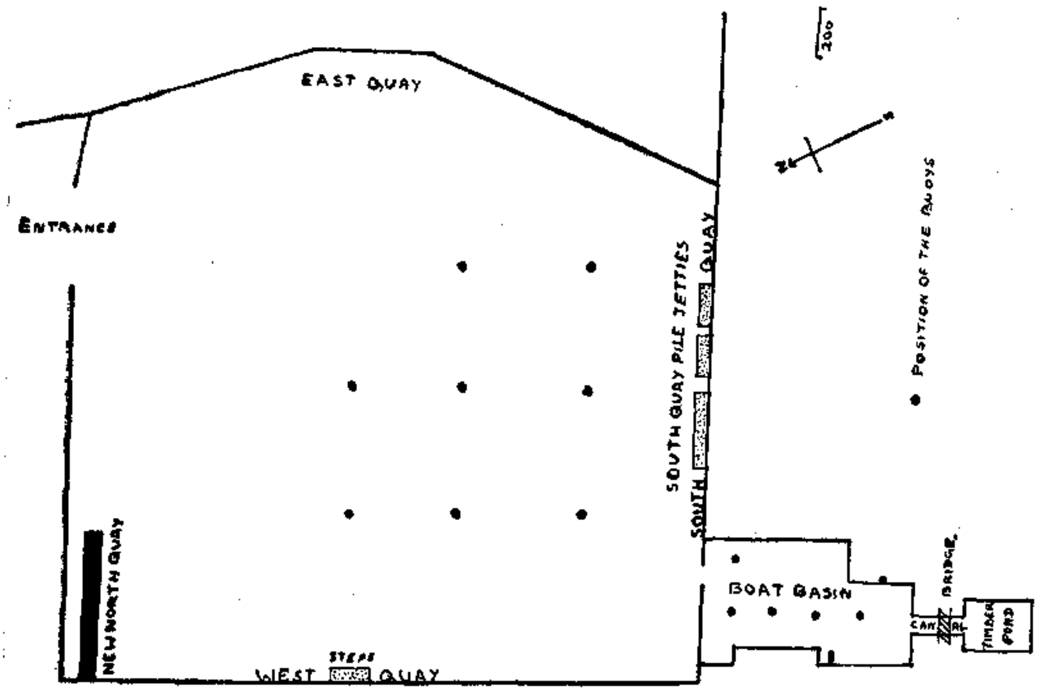
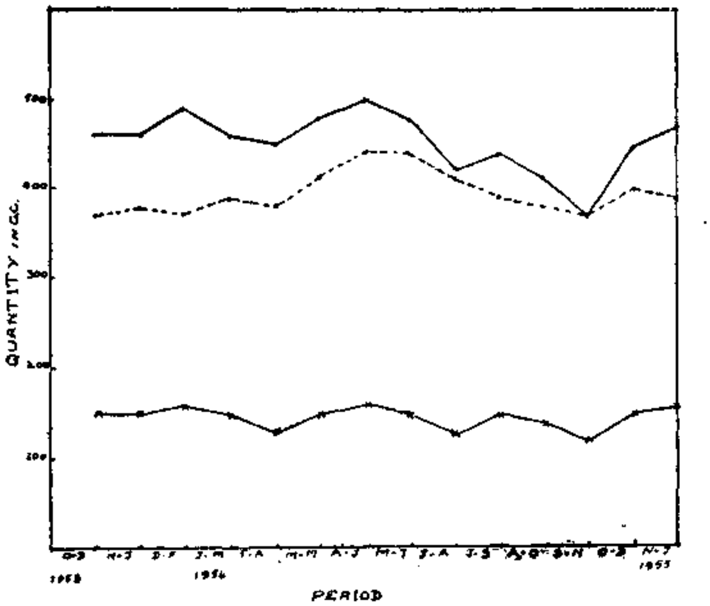


FIG. 1. The sketch of the Madras Harbour showing the different stations referred to in the text.



FI.G 2. The intensity of attachment at the three stations.
o——o Boat Basin ; o . . . . o New North Quay ; x——x Canal,

Another interesting observation recorded by workers in this field is the sequence of sedentary communities. Scheer (1945) distinguished two events in such a sequence, namely, seasonal progression and true ecological succession. Daniel (1954) suggested the existence of true ecological succession in Madras harbour. However, the present investigations revealed certain differences from those observed by Daniel (1954) which prompted a further study on the aspect.

MATERIAL AND METHODS

This work was carried out at the Madras University Zoology Laboratory during the years 1953 to 1955. Different regions in the harbour (Fig. 1) were chosen and observations were made in the course of a year (1954) on the composition of the sedentary communities in each area. By this method it was possible to classify the sedentary organisms in relation to the different substrata. A quantitative estimation of the settled organisms was made by scraping off the animals adhering to an area of 64 sq. in. and determining their volume by displacement method.

The influence of environmental factors other than depth on the settlement of the organisms was studied using wooden planks, measuring $10'' \times 8'' \times \frac{3}{4}''$, vertically suspended by means of stout galvanised wires and nailed to the walls and piers. An iron weight attached to the lower end of the panels ensured their vertical position. These planks were examined once a fortnight and the animals settled on them were counted by the method adapted by Weiss (1948).

For the study on the influence of depth, small panels $6'' \times 6''$ with $\frac{1}{2}''$ thickness were found most convenient. Six such panels were tied to a long coir rope by means of two wires at different depths, namely, at 3′, 5′ 7′, 9′ and 12′ from the water level and one at the surface. The rope was weighted down by a stone weight and kept permanently fixed at a particular spot in Boat Basin. Under the water, due to buoyancy, the panels occupied horizontal positions. Simultaneous observations were made on the eastern concrete wall of the Boat Basin which was completely scraped of all organisms for about 7′ in length and 14′ in depth. A marked wooden frame of 15′ in length was fixed close to this area, one end of which was sharpened and driven into the mud while the other end was nailed to the wall at the surface of water. At the beginning of every month, all the organisms that had settled on an area of 36 sq. in. at the different depths were scraped into a bottle and brought to the laboratory, care being taken to collect only during low tide. After recording data, the animals that had settled on the frame were completely scraped off. The volume of the total population thus scraped from the area of 36 sq. in. was estimated by the method of displacement.

Observations on the hydrographical conditions of the harbour waters were made at two locations, New North Quay and Boat Basin. The values presented in Table I are averages of four or five records taken each month during July 1953 to December 1954.

TABLE I

Physical and Chemical characteristics of the Madras harbour.
(NNQ : New North Quay ; BB : Boat Basin.)

Month	Temp. °C		Salinity ‰		pH		Oxygen content cc/litre		Nitrite mg. NO_2/litre		Phosphate mg. P_2O_5/litre	
	NNQ	BB	NNQ	BB	NNQ	BB	NNQ	BB	NNQ	BB	NNQ	BB
1953												
Jul.	28.2	28.2	32.8	32.6	8.3	8.3	3.1	3.1	.0026	.0026	.030	.039
Aug.	28.3	28.3	33.2	33.2	8.1	8.1	3.8	3.8	.0027	.0027	.030	.031
Sept.	29.1	29.1	33.4	33.0	8.2	8.2	3.8	3.9	.0026	.0027	.029	.029
Oct.	28.5	28.5	25.1	21.6	8.3	8.3	4.0	4.1	.0028	.0028	.032	.039
Nov.	27.6	27.6	27.1	26.8	8.3	8.3	4.0	4.6	.0033	.0034	.041	.043
Dec.	27.1	27.1	27.2	27.0	8.4	8.4	4.2	4.3	.0025	.0025	.039	.039
1954												
Jan.	27.3	27.3	29.1	29.0	8.4	8.4	4.4	4.4	.0027	.0028	.043	.048
Feb.	27.2	27.2	30.5	29.9	8.4	8.4	4.0	4.1	.0028	.0030	.039	.041
Mar.	28.4	28.4	31.1	31.2	8.2	8.2	3.7	3.7	.0030	.0030	.042	.048
April	28.6	28.6	31.4	31.4	8.2	8.2	3.8	3.5	.0018	.0020	.043	.050
May	29.7	29.7	32.8	33.0	8.3	8.3	3.9	3.7	.0030	.0030	.046	.057
June	28.4	28.4	33.1	33.0	8.2	8.2	4.0	4.1	.0025	.0027	.043	.048
July	28.7	28.7	33.5	33.4	8.1	8.1	4.0	4.1	.0040	.0040	.029	.030
Aug.	28.8	28.8	33.7	33.5	8.2	8.2	4.2	4.2	.0035	.0039	.031	.034
Sept.	28.1	28.1	32.4	32.0	8.3	8.3	3.9	4.0	.0029	.0029	.029	.031
Oct.	28.2	28.2	25.6	20.5	8.3	8.3	4.1	4.1	.0031	.0032	.030	.030
Nov.	27.0	27.0	28.1	27.4	8.2	8.2	4.1	4.0	.0033	.0033	.038	.040
Dec.	27.2	27.2	28.3	28.0	8.4	8.4	4.2	4.2	.0039	.0037	.037	.038

ENVIRONMENT

A brief description of the Madras harbour where the present investigations were carried out, is given by Paul (1942). Daniel (1954) has described the salient environmental features of New North Quay and Boat Basin. Hence, in the following account only the features of other regions inside the harbour, which are not covered by the above two workers, are presented.

The *West Quay* extends for about 2500′ and its wall is constructed of huge rocks and stones. At certain places the wall supports wharfs and other structures set for the prevention of the ships dashing against it. The wall is exposed to sunlight.

The *South Quay*, about 1500′ in length, is constructed in the same manner as the West Quay. There are three pile jetties called South Quay screw pile jetties, made of concrete and supported underneath by concrete pillars and iron bars which are shaded from direct sunlight. The surface water is rendered impure with coal particles and other refuse from the ships. The ships which are stationed in front of these pile jetties prevent direct wave action on these jetties.

The *East Quay* extends for about 3000′ and presents almost the same conditions as the West Quay but there are no wharfs and other structures.

In *Boat Basin* during the rainy months of October and November there is considerable admixture of impure and fresh water drained out from the workshop and the fire station situated at the southern end of the Basin. Hence, during these months the water here is subjected to a lowering of salinity (Table I).

OBSERVATIONS

Distribution of Sedentary Organisms

For purpose of description, the harbour region is divided into three stations, (I) the Main harbour, (II) the Boat Basin and (III) the Timber pond. The symbols H, L, G, S and R given in brackets after each species, denote more than 30%, between 15 and 30%, 10 and 15%, 5 and 10% and below 5% respectively of the total amount of organisms collected from an unit area. The quantitative estimates given represent organisms settled on an area of 64 sq. in. during 3 months period of March to May.

I. Main Harbour :

The fauna of this region can be divided into three sub-divisions based on the nature of substratum, viz., fauna of (*a*) concrete substrata, (*b*) rocky substrata and (*c*) the buoys. The New North Quay and the South Quay screw pile jetties are the two stations which are constructed of concrete. The West, South and East Quay form the rocky substrata and the sedentary fauna of the buoys is described from the settlement on the eight buoys stationed in the centre of the harbour (Fig. 1).

(a) *Fauna of Concrete Substrata.*—This consists of *Reniera inflexa* (R), *Laomedea spinulosa* (R), *Crisia* sp. (G), *Bowerbankia* sp. (S), *Membranipora* sp. (G), *Hydroides norvegica* (H), *Serpula vermicularis* (L), *Dasychone cingulata* (S), *Modiolus striatulus* (L), *M. undulatus* (R), *Ostrea madrasensis* (G), *O. cuculata* (R), *Mytilus viridis* (S), *Balanus amphitrite variegatus* (H), *Cynthia* sp. (G), *Botryllus* sp. (G), *Botrylloides* sp. (G) and *Perophora* sp. (S).

Although the New North Quay and the South Quay screw pile jetties are constructed of the same material, the environmental features are different, as mentioned earlier. However, in the variety of settlers there is not much difference except that *D. cingulata* and *Perophora* sp. are absent and only small numbers of *M. striatulus*, *Cynthia* sp., *Botryllus* sp. and *Botrylloides* sp., are present at the pile jetties. The volume of the settled organisms, namely, 200 c.c. at New North Quay and 210 c.c. at pile jetties also does not show much difference between these two stations.

(b) *Fauna of Rocky Substrata.*—*H. norvegica* (L), *M. viridis* (S), *O. cuculata* (H), *B. amphitrite variegatus* (L), *Botryllus* sp. (R), and *Botrylloides* sp. (R) are found on the rocky substrata below the low tide level and the intertidal area is characterised by the presence of large numbers of oyster and a few barnacles only. It is of interest to note, that except the colonial ascidians none of the other forms settled on the rock oysters. The volume of the sedentary animals is only 145 c.c. compared to 200 to 210 c.c. of the concrete substrata. In the variety of settlers too there are marked differences, for, while as many as 18 species are represented on the concrete walls, only 7 species are found on the rocky substrata. Except for *O. cuculata,* which settle in larger numbers on the rocky walls compared to their poor representation on the concrete substrata, the relative abundance of the other species is less than that of concrete walls.

(c) *Fauna of the Buoys.*—The buoys of this region had all the forms mentioned under concrete substrata in slightly increased numbers, the exception being the absence of rock oysters and the presence of small numbers of *Polycarpa* sp. Among the eight buoys, those which are located towards the South Quay had a larger quantity of the organisms, namely, 240 c.c. compared to 220 c.c. of the buoys towards north.

II. **Boat Basin :**

In the absence of rocky walls in this region, the fauna can be classified under two divisions, (*a*) fauna of the buoys and (*b*) fauna of concrete substrata.

(a) *Fauna of the Buoys.*—This is represented by *R. inflexa* (G), *Crisia* sp. (L), *Bowerbankia* sp. (L), *Membranipora* sp. (G), *Hydroides norvegica* (H), *Serpula vermicularis* (L), *D. cingulata* (H), *M. striatulus* (L), *M. undulatus* (S), *O. madrasensis* (L), *M. viridis* (G), *B. amphitrite variegatus* (H), *Polycarpa* sp. (G), *Cynthia* sp. (G), *Botryllus* sp. (R) and *Botrylloides* sp. (R). While all the forms represented on the buoys of the main harbour settle on the buoys of this region, it is seen that *R. inflexa*, *Crisia* sp., *Bowerbankia* sp., *D. cingulata*, *M. striatulus* and *Polycarpa* sp., are found in larger numbers. *D. cingulata* which are present only in small numbers at the New North Quay are found in huge numbers on the buoys of the Basin. *Polycarpa* sp. also show a marked difference in their abundance between similar substrata of the two regions. The quantity of the sedentary population is more on these buoys than those of main harbour amounting to as much as 280 c.c.

(b) *Fauna of Concrete Substrata.*—The eastern and western walls enclosing the Boat Basin present appreciable differences in the variety of the sedentary organisms. Only at the southernmost portion of the eastern wall of the Basin there is good settlement of the sedentary fauna which is characteristic of the buoys. The walls of the western side, where the depth is only 4′ at low-tide level, however, show only barnacles and oysters. As on the concrete substrata of the main harbour, on the south-eastern walls of the Basin also there are only small numbers of *R. inflexa* and *D. cingulata*. However, the rock oyster which are present only in fewer numbers at the New North Quay and pile jetties, are present in good numbers on the walls of the Basin. The total amount of attachment of organisms, namely, 180 c.c., is slightly less than that of similar substrata of the main harbour.

III. **Timber Pond :**

This region can be divided into two sections, the concrete walls of the Boat Basin Canal and that of the Timber pond.

Fauna of Concrete Walls.—This includes *L. spinulosa* (G), *Bowerbankia* sp. (R), *D. cingulata* (S), *M. striatulus* (S), *M. viridis* (G), *O. madrasensis* (G), *O. cucu-*

lata (G) and *Cynthia* sp. (R). While all these forms are represented on the walls of the Canal, the walls of the Timber pond are characterised by poor settlement of organisms, being represented by *L. spinulosa, O. madrasensis* and *O. cuculata*. As much as 160 c.c. of settled material is obtained from the unit area of the Canal walls as against 65 c.c. from the pond walls. Compared to similar substrata in the other regions of the harbour, the walls of the pond show the least amount of attachment.

Thus, it is seen that, almost the same variety of organisms settle both at the main harbour and Boat Basin but the relative abundance of certain organisms show some differences. The main harbour is colonised by larger numbers of *B. a. variegatus, O. cuculata* and *Botryllus* sp. than in the Boat Basin. The latter station supports, on the other hand, more of *R. inflexa, Crisia* sp., *Bowerbankia* sp., *D. cingulata, O. madrasensis, M. striatulus* and *Polycarpa* sp. A marked feature is the scarcity of *D. cingulata* at the main harbour compared to its huge settlement at Boat Basin. The sedentary fauna of Timber pond is much less varied, being represented by only three species as against eighteen in the other two regions.

As the quantitative values given in the preceding pages were estimated only during March to May, a study on the relative quantity of settled organisms in the various stations of the harbour throughout a year was considered necessary in order to find differences if any, during the various quarters. At the end of every three months of exposure the organisms settled on the two faces of the test panels were scraped and the volume of the total animal population was estimated. The values given in Fig. 2 are average of four records. It is seen that comparatively greater attachment takes place in the Boat Basin where the volume ranges between 370 c.c. and 500 c.c. The attachment is so poor in the Timber pond that the volume ranges from 120 c.c. to 160 c.c. only. It is also noticed that the attachment is maximum during April to June with a minimum during September to November. This agrees with the observations of Ganapati *et al.* (1958) who reported a similar trend during March to May and October respectively.

INFLUENCE OF ENVIRONMENTAL FACTORS

The variations in the nature of sedentary animal communities are governed by several factors. Marked lowering in salinity is known to affect the sedentary organisms leading to a decrease in their number (Edmondson and Ingram, 1939; McDougall, 1943; Weiss, 1948). In the Madras harbour the salinity ranges from 27°/₀₀ to 34°/₀₀ except in October when it is 20.5°/₀₀ in Boat Basin and 25.6°/₀₀ at New North Quay in 1954. During this period of low salinity there is marked fall in the quantity of organisms at the Basin while in the North Quay the values do not differ so much (*vide* Fig. 2). Erlanson (1936) has reported a similar effect on the boring organisms of Cochin harbour. The records taken by Ganapati *et al.* (1958) show decreased salinity values during October which coincides with a fall in the fouling intensity. It is not clearly known whether at Vizagpatnam this fall is due to lowered salinity or some other factor.

The water in the Boat Basin is moderately polluted and this pollution may be partially correlated with the greater sedentary population at this station as observed by Weiss (1948), Smith *et al.* (1950), Daniel (1954) and Ganapati *et al.*

(1958). Though there is no marked increase in the nitrite content, the water in the Boat Basin has a slightly higher Phosphate content. In the absence of any influx of land drainage or sewage into the Basin which are known to increase the nutrients markedly, the values do not show appreciable difference from those of New North Quay. However, there is the possibility of higher concentration of organic detritus at the Basin released from the crushed organisms of the boat scrapings. This may account for the difference as it has been shown by Coe and Fox (1944) that ' the disintegrated bodies of the free living organisms that perish doubtless supply more nutritive material, namely, organic detritus '. But it should not be mistaken that the pollution alone is the causal factor for the more pronounced fouling at the Basin, for as Daniel (1954) has indicated, periodic exposure to bay water and frequent release of a large number of the larvae of sedentary organisms from the boats and buoys hauled up for scraping also contribute to the increased settlement at the Basin.

Earlier workers have shown that the porosity or fibrous nature of the substratum enhances the settlement and non-porous, non-fibrous hard substrata are characterised by poor accumulation (Pomerat and Weiss, 1946 ; Pyefinch, 1948). It has also been shown that sedentary fauna of rocky coast is limited to only a few varieties, chief of which are the rock oysters and barnacles. The present investigations have shown that the porous concrete substrata of the harbour support a richer fauna both in variety as well as in quantity than the rocky walls for, while 180-210 c.c. of settled material is obtained from an unit area of concrete substrata, the value from the rocky walls is only 145 c.c. However, the wooden panels colonise a heavier settlement than the concrete substrata being more porous and fibrous (*vide* Table III).

Continuous observations carried out for over a year on the influence of depth show that most of the sessile organisms of the harbour prefer 3-7 ft. level decreasing at the 9 ft. zone and are absent at 12 ft. depth (Table II).

Two categories of distribution can be easily recognised, (1) those which are more or less restricted to the upper 5 ft. of the water column but numerically more at the 3 ft. level represented by *R. inflexa*, *L. spinulosa*, *Crisia* sp., *Bowerbankia* sp., *Membranipora* sp., Pycnogonids and *Botryllus* sp. and (2) the other organisms which settle at all depths upto 12 ft. but in greater number at certain levels than others. While barnacles, tubiculous polychaetes and the motile isopods and amphipods accumulate in greater numbers at 5 ft., the bivalves, *M. viridis*, *M. striatulus*, *M. undulatus* and *O. madrasensis* prefer 7 ft. for maximum attachment. While the surface level is occupied by algal growth, probably due to better illumination in the surface waters, the lowermost test panels are characterised by the presence of only a few hardy sessile species such as *H. norvegica*, *D. cingulata*, *M. striatulus*, *B.a. variegatus*, *M. viridis* and *O. madrasensis*.

Simultaneous observations made on the concrete walls of the Boat Basin showed that organisms get attached in lesser numbers there, except *M. viridis* and *O. madrasensis*. But for this difference, the selection of levels and the distribution of the animals in their respective zones are similar to that found on the test panels.

A quantitative estimation of settled organisms on an unit area of concrete walls and wooden panels (Table III) also confirms the results obtained in the pre-

TABLE II

The total number of organisms at the end of the observation periods at each depth level.

(EP : Experimental panels ; C : Control.)

(Area : Surface panel—36 sq.in ; Other panels—72 sq.in.)

Name of the organisms	Period of obser-vation	Surface		3′		5′		7′		9′		12′	
		EP	C	EP	C	EP	C	EP	C	EP	C	EP	C
Reniera inflexa.	3- 4-54- 30- 6-54	5	3	18	10	7	3	—	—	—	—	—	—
Laomedea spinulosa.	5-10-53- 9-11-53	12	3	18	9	10	4	8	—	3	—	—	—
Crisia sp.	19-10-53- 19- 1-54	13	10	46	35	30	23	—	—	—	—	—	—
Bowerbankia sp.	19-10-53- 19- 1-54	7	5	20	19	16	13	—	—	—	—	—	—
Membranipora sp.	12-10-53- 7-12-53	4	2	12	9	10	7	—	—	—	—	—	—
Hydroides norvegica & *Serpula vermicularis*	5-10-53- 7-12-53	70	60	190	160	370	310	230	210	130	120	65	50
Dasychone cingulata	12-10-53- 19- 1-54	60	20	305	75	380	100	240	50	120	25	40	—
Modiolus striatulus	19- 1-54- 17- 4-54	30	20	110	70	155	125	260	200	70	40	20	—
Modiolus undulatus	30- 3-54- 30- 6-54	25	5	70	35	90	60	85	60	15	10	—	—
Mytilus viridis	30- 3-54- 30- 6-54	10	4	29	27	32	35	35	40	28	32	13	16
Ostrea madrasensis	27- 2-54- 30- 5-54	7	12	25	32	29	40	37	47	20	30	8	17
Teredo sp.	19- 1-54- 3- 4-54	3	—	10	—	23	—	17	—	3	—	—	—
Balanus amphitrite	5-10-53- 7-12-53	80	75	350	320	475	410	320	290	195	205	105	110
Isopods	7-12-53- 12- 3-54	50	60	120	120	290	300	105	75	35	40	—	—
Amphipods	7-12-53- 12- 3-54	70	75	280	320	420	500	215	220	75	40	25	20
Pycnogonids	7-12-53- 12- 3-54	35	15	5	—	—	—	—	—	—	—	—	—
Cynthia sp.	7-12-53- 27- 2-54	24	20	80	50	120	105	50	35	25	15	—	—
Polycarpa sp.	7-12-53- 27- 2-54	12	10	47	40	62	50	31	25	19	17	—	—
Botryllus sp.	30- 3-54- 30- 5-54	7	5	17	15	9	10	—	—	—	—	—	—

vious observation that there is maximum settlement between 5 to 7 ft. below which it slowly decreases culminating in poor settlement at 12′ depth and that the rate of settlement is faster upto the first three months after which it is slow. The observations on the panels could not be carried out for more than eight months as they

TABLE III

The quantitative difference in the amount of settled material at different depths expressed in c.c.
(Area : 36 sq.in.)

Date of observation	Volume displaced from experimental panels						Volume displaced from the control					
	Surface	3′	5′	7′	9′	12′	Surface	3′	5′	7′	9′	12′
12-10-53	8	9	9	11	11	8	6	6	8	8	8	5
2-11-53	50	55	60	50	50	45	40	45	56	50	50	35
3-12-53	135	135	150	145	100	75	122	125	135	130	90	60
4- 1-54	225	220	250	240	180	85	210	215	235	225	160	65
1- 2-54	250	260	300	290	215	95	245	250	275	260	200	80
1- 3-54	260	270	305	295	230	100	260	265	285	275	225	85
2- 4-54	280	280	315	300	250	115	270	280	290	285	230	90
5- 5-54	290	295	320	315	255	120	285	290	295	295	230	90
5- 6-54	295	300	320	320	260	125	295	295	300	300	235	95
3- 7-54	—	—	—	—	—	—	295	300	300	305	245	95
2- 8-54	—	—	—	—	—	—	300	300	310	310	250	100
6- 9-54	—	—	—	—	—	—	300	305	315	310	250	100
4-10-54	—	—	—	—	—	—	300	305	315	310	250	100
6-11-54	—	—	—	—	—	—	300	305	315	315	250	100

were washed away, but the observations on the concrete wall were carried out for a longer time.

The results obtained elsewhere are of interest for comparing with the results recorded at Madras. McDougall (1943), working at Beaufort observed that, in the case of the polyzoan, *Bugula neritina* and the serpulids the attachment was maximum at the bottom levels of 6½-8½ ft. At Maine, the polyzoans were abundant at 15 ft. depth (Fuller, 1946). The local polyzoans and serpulids however prefer 3 ft. and 5 ft. respectively. McDougall (1943) also noted that though the settlement of the oyster, *Ostrea virginica* was intense at 9 ft. level, only those settled at the intertidal level survived. At Madras the settlement and survival were maximum at 7 ft. zone. Regarding the barnacles, *Balanus eburneus* has been shown to favour the low water mark by Sumner, Osbourn and Cole (1911). The observations of McDougall (1943) reveal that the settlement of the same species was intense at 2-3 ft. but the adult population was greater at the intertidal level. In the case of *B. amphitrite* and *B. improvisus* settlement was greater at Beaufort at 1½-2 ft. below low water level (McDougall, 1943). At Madras harbour *B.a. variegatus* prefers 5 ft. level for maximum settlement. Similarities are, however, found in the distribution of the ascidians in that they prefer a depth of 4 to 5 ft. at Beaufort and 3 to 5 ft. at Madras. Thus, it is seen that the attachment of sedentary organisms at particular levels differs in different forms even among allied species.

In the experiments conducted with the test panels certain differences were noticed in the nature of fouling on the upper and lower surfaces of the horizontal panels (Table IV).

TABLE IV

The number of organisms settled on the Upper (U) and the Lower (L) surfaces at the end of the observation period (Referred to in Table I) at each level.

Name of the species	Face	Surface	3′	5′	7′	9′	12′
Reniera inflexa	U		7	2	—	—	—
	L		11	5	—	—	—
Laomedea spinulosa	U	—	8	4	3	—	—
	L	12	10	6	5	—	—
Crisia sp.	U	—	14	10	—	—	—
	L	13	32	20	—	—	—
Bowerbankia sp.	U	—	—	—	—	—	—
	L	7	20	15	—	—	—
Membranipora sp.	U	—	4	3	—	—	—
	L	4	8	7	—	—	—
Hydroides norvegica & *Serpula vermicularis*	U	—	90	120	90	60	50
	L	120	100	250	140	70	15
Dasychone cingulata	U	—	90	110	65	50	25
	L	60	215	270	175	70	15
Modiolus striatulus	U	—	40	80	170	55	20
	L	30	70	75	90	15	—
Modiouls undulatus.	U	—	33	40	40	10	—
	L	25	37	50	45	5	—
Mytilus viridis.	U	—	13	16	20	21	10
	L	10	16	16	15	7	3
Ostrea madrasensis	U	—	13	16	23	12	8
	L	7	12	13	14	8	—
Teredo sp.	U	—	7	15	10	3	—
	L	3	3	8	7	—	—
Balanus amphitrite	U	—	130	110	105	95	70
	L	80	280	365	215	100	35
Isopods	U	—	70	130	40	15	—
	L	50	50	160	65	20	—
Amphipods.	U	—	130	220	100	25	10
	L	70	150	200	115	55	15
Pycnogonids.	U	—	—	—	—	—	—
	L	35	5	—	—	—	—
Cynthia sp.	U	—	25	50	21	13	—
	L	24	55	70	29	12	—
Polycarpa sp.	U	—	20	22	13	8	—
	L	12	27	40	18	11	—
Botryllus sp.	U	—	5	4	—	—	—
	L	7	12	5	—	—	—

It is seen from the table that except *L. spinulosa* and *R. inflexa* which do not show marked difference in their settlement on the two faces, the other organisms prefer the lower surface of the panels. However, it is seen that while barnacles and serpulids prefer the lower surface of all the panels except those at 9 to 12′ depth, bivalves are more on the upper surface of those panels suspended below 5 ft. Many theories have been put forward explaining these differences like positive geotropism and negative phototropism (Pomerat and Reiner, 1942 ; Gregg, 1945), mechanical hindrances due to sedimentation of silt on upper surfaces (McDougall, 1943 ; Fuller, 1946) and swimming position of larvae at the time of attachment (Doochin and Smith, 1951), but the one that applies to a particular organism may not apply to another. Hence, McDougall (1943), even after recording the settlement data of the larvae of sessile species, was forced to the conclusion that the factors which govern the vertical zonation of both the larvae and adults are obscure.

There is some evidence to suggest that, the water currents may affect the settlement and survival of the sedentary organisms, thus, accounting for the differences in the quantity of the organisms at the three stations. The velocity of tidal flow at the entrance of the harbour is about 1.5 knot and 1.0 knot in the interior parts like the Boat Basin. The New North Quay is the nearest station to the entrance where the immediate impact of onrushing currents is felt. In this region there is great accumulation of barnacles while the other organisms are less abundant. On the other hand, the Boat Basin permits settlement in larger numbers of almost all the sedentary forms occurring in the harbour. It appears, therefore, that the force of currents at New North Quay may have an inhibitory effect on the settlement of organisms other than barnacles for which different limiting velocities for the attachment have been shown (Smith, 1946 ; Doochin and Smith, 1951 ; Daniel, 1958). This is further supported by the fact that on the buoys larger quantity of sedentary organisms accumulate on the face that is turned away from the currents. Since the buoys are liable to certain rotation along with the current, experiments were also conducted to confirm the above assumption by vertically suspending two sets of panels at 5′ level, one side of the panel facing the current (north) and the other away (south) for one set and the second set of panels was immersed in such a way that the edges of the panels faced the current, exposing both the sides to equal water flow, *i.e.* the sides of the panels facing east and west respectively. Care was taken to ensure the vertical position of the panels and prevent them rotating along with the current. It is seen from Table V that the face away from the onward flow of water was favoured by the organisms and that there are no marked differences in the settlement on the two sides facing east and west.

Succession of Communities

Observations have been carried out for one year from December 1953 to December 1954 both at New North Quay and Boat Basin. Portions of pillars and buoys of the two stations were scraped of all the organisms and periodical visits were made to observe the changes. In addition to this, experimental panels were also suspended at these two stations. Repeated observations on the test panels and scrapings of other substrata revealed that all those organisms appearing on the natural structures attached on the panels also. Continuous study on the same area for more than six months was not possible on the natural structures of the

TABLE V

The difference in the number of organisms settled on the different faces of vertically suspended pan

(N—North ; S—South ; E—East ; W—West. Average of 6 panels)

Date of observation	No. of days of suspension	Face	*Crisia* sp.	*Bowerbankia* sp.	Serpulids	*D. cingulata*	*M. striatulus*	*M. viridis*	*O. madrasensis*	*B. amphitrite*	Isopods & Amphipods	*Polycarpa* sp.	*Cynthia* sp.
3-4-'54	7	N	—	—	72	—	—	—	—	205	35	—	—
		S	10	—	87	—	—	—	—	225	70	—	—
		E	2	—	30	—	—	—	—	120	25	—	—
		W	7	—	40	—	—	—	—	130	20	—	—
10-4-'54	14	N	—	—	160	—	—	—	—	225	60	—	—
		S	17	—	200	—	—	—	—	285	100	—	—
		E	5	—	130	—	—	—	—	195	45	—	—
		W	10	—	145	—	—	—	—	215	50	—	—
24-4-'54	28	N	—	—	190	—	—	—	—	195	70	—	—
		S	20	5	230	10	—	—	—	255	160	—	—
		E	12	2	170	7	15	—	—	175	70	—	—
		W	13	1	190	3	12	—	—	235	90	—	—
8-5-'54	42	N	8	3	180	30	5	—	—	170	100	5	—
		S	23	6	225	40	25	10	5	225	230	15	25
		E	13	2	180	20	20	3	3	155	90	2	8
		W	16	3	195	30	12	7	—	195	75	4	7
15-5-'54	49	N	8	5	180	50	25	—	—	175	115	5	—
		S	27	7	225	70	40	12	10	230	270	20	35
		E	17	2	140	45	35	5	4	140	65	6	10
		W	18	6	170	55	50	8	3	170	130	9	11
29-5-'54	63	N	10	7	160	90	52	3	—	175	170	9	16
		S	29	8	190	120	85	15	12	235	380	20	40
		E	18	4	130	70	60	6	4	140	140	12	13
		W	21	8	150	90	85	8	4	170	150	14	16
12-6-'54	77	N	12	8	160	120	65	5	—	185	180	19	27
		S	31	10	190	180	120	17	13	240	400	24	43
		E	20	5	130	100	60	10	4	150	170	18	20
		W	21	8	150	130	90	12	5	175	190	21	23
26-6-'54	91	N	13	8	130	140	80	7	3	185	200	20	30
		S	33	13	160	230	140	23	20	260	390	30	63
		E	20	6	120	120	80	11	5	150	120	20	25
		W	21	8	150	140	110	14	7	175	180	21	30
3-7-'54	98	N	13	10	130	160	80	10	5	185	200	20	35
		S	35	15	160	260	140	30	23	240	400	40	70
		E	20	6	120	140	83	11	5	150	125	21	30
		W	21	8	140	160	112	14	7	180	175	21	30

two stations since, once in six months the substrata are cleared up by the local authorities. At Boat Basin, however, a year's study was carried out on the bottom of a condemned launch.

At New North Quay: Observations for a month on the settlement of sedentary organisms at this station reveal the same events as observed by Daniel (1954). After one month, however, *M. striatulus* and *Cynthia* sp. start attaching. During the next month, while the polyzoans and the serpulids dwindle, the barnacles grow well along with *Cynthia* sp. and *M. striatulus* until the appearance of colonial ascidians like *Botryllus* sp., *Botrylloides* sp. and *Perophora* sp. and the bivalves, *M. viridis* and *O. madrasensis.* The settlement of these forms limit the settlement of barnacles. It is only at the end of three months that the fouling complex reaches its peak compared to the six-week period reported by Daniel (1954). After four months of exposure, most of the attached forms like the simple ascidians and *M. viridis* are lost leaving behind the barnacles and the encrusting colonial ascidians only. If the fouling climax here is dominated by barnacle community at the end of 4 months, it is due to the direct wave action at the Quay which washes away the well-grown bivalves and ascidians. Observations on the buoys and the South Quay screw pile jetties of the main harbour lend support to this, for, the members of the sedentary fauna settled on them at the end of six months are barnacles, serpulids, bivalves, simple and compound ascidians.

At Boat Basin: The changes here are different from those observed at New North Quay. The initial exposure for a period of three weeks results in a few differences in the variety of settlers in different months of the year. Along with the barnacles and serpulids which appear throughout the year, during the months of August, September and November *Crisia* sp., in the months of December, January and February *D. cingulata* and in the months of March, April and August *M. striatulus* appear on the three weeks old substrata.

Heavier settlement and rapid growth produce different effects during the following periods in the sequence of communities at Boat Basin. The barnacles, serpulids and the polyzoans thrive well till the end of five weeks after which the growth of *D. cingulata* is so rapid that they almost stifle out the serpulids and polyzoans. At the end of ten weeks, the exposure site gives a picture entirely different from that exposed for half the period. For, by this time, *R. inflexa, M. striatulus* and ascidians have attached themselves and started thriving well, the barnacles being overgrown by *D. cingulata.* By the end of the third month, *O. madrasensis* and *M. viridis* attach. The fouling community is now composed of low-grown barnacles, *Crisia* sp., *H. norvegica, D. cingulata, M. striatulus, O. madrasensis, Cynthia* sp. *Polycarpa* sp., *Botryllus* sp., *Botrylloides* sp. and *R. inflexa.* Further exposure does not result in leaving barnacles alone on the substrata as at New North Quay but the fouling complex as such flourishes well. However, in course of time, due to excessive weight of individuals and mechanical disadvantages of poor adhesion in a limited area, the simple ascidians and *M. viridis* fall off. The spaces vacated by these are again subjected to competition among the prevalent larvae at that time for attachment. The barnacles, though they are overgrown by the other organisms, succeed in competing with others. Their larvae are, however, incapable of attaching themselves over the full-grown fouling community due to the slippery and slimy substrata offered by the ascidians. In spite of this, a few larvae succeed in establishing themselves on the bivalves.

Further exposure results in the growth of green algae over this community if it develops at the low water level, otherwise, once the fouling complex has reached its peak, which may be attained in four months, other organisms fail to attach themselves and only the motile species take shelter in the crevices between the sessile organisms. Those which are found at the end of one year period are *B.a. variegatus*, *D. cingulata*, *H. norvegica*, *M. striatulus*, *M. viridis*, *O. madrasensis* and the colonial ascidians.

Similar changes are, however, considerably modified below 7′ of the low-tide level, where the bivalves predominate and the luxuriant growth of *D. cingulata*, characteristic of upper levels, is markedly poor. Characteristic features during the early stages are the growth of barnacles and *M. striatulus*, after which the community is crowded by the green mussels and the oysters which thrive well along with the barnacles. The polyzoans, which appear before the attachment of the bivalves at the higher levels, are relatively negligible at this level. Still deeper down the presence of silt and mud prevents much settlement and any such sequence that is apparent at the higher levels is absent at this depth.

The presence of such luxuriant growth of *D. cingulata* at Boat Basin and the important part played by them as well as by the sessile bivalves, *M. striatulus*, *M. viridis* and *O. madrasensis* in the development of fouling community are the salient features. In addition to this, the time taken for the various changes in the sedentary communities is found to be of longer duration than has been observed in the previous studies (Daniel, 1954). It is seen that the apparent order of succession is not uniform in both the stations for the sequence noted on similar substrata of separate regions, namely, New North Quay and Boat Basin, and the ultimate composition of fouling complex present marked differences.

At Vizagapatnam harbour there appears to be a certain sequence in the appearance of fouling organisms upto two months after which the panels showed only an increase in number and size of the organisms already settled (Ganapati *et al.*, 1958). Since the observations are limited only to a portion of a year it is not possible to compare the results except for one fact that barnacles appear at Vizagapatnam only at the end of second month whereas at Madras they start settling on the fourth day itself.

The factors affecting the changes in the fouling complex are varied and complex. Seasonal progression and ecological succession are the two problems distinguished by the workers in the development of fouling community. Two criteria suggested by Shelford (1930) and later modified by Scheer (1945) are the dropping out of early settlers to be replaced by later arrivals and the presence of some of the earlier forms to provide a condition favouring settlement of later forms. It is also known that in succession particular community must dominate at a particular time leading to a climax. However, Aleem (1958) observed that the different organisms once they settle are not subsequently eliminated from the system but their abundance may vary. Smith *et al.* (1950) contended that the changes in the fouling community are governed by the relative influence of factors, like concentration of larvae, intensity of attachment, growth rate, longevity and duration of breeding seasons and the interaction of these factors may modify or reverse succession.

Ruling out seasonal progression, Daniel (1954) stated that there is a definite ecological succession at Madras harbour. However, it is seen from the above account that at Madras there is no clear cut succession as obtained in California (Coe and Allen, 1937), Newport (Scheer, 1945) and Australia (Allen and Wood, 1950) where, a true ecological succession, with a well defined community dominating at every stage leading to a climax recognised by a single community, has been recorded. Though the breeding of most of the species is continuous throughout the year at Madras and the same events are seen in the development of sedentary fauna irrespective of the season, there are intensities of breeding periods during which the relative amount of larvae ready for attachment is high (Paul, 1942; Daniel, 1954). Consequently, even during initial exposure of three weeks period, it is seen that along with barnacles and serpulids varied forms like, *Crisia* sp., *D. cingulata* and *M. striatulus* also appear. Apart from the presence of primary film of diatoms and bacteria, these organisms do not depend upon the presence of prior fouling. The settlement of later forms is so rapid as to obliterate the subsequent phases for, it is known that, constant settling down of generations of organisms of even of a single species, production of several offsprings in a year and their rapid growth are features known to exist in Madras (Paul, 1942). Smith *et al.* (1950) have observed that all organisms attached at some period of the year during the initial month of exposure depending upon the intensities of breeding and were not dependent upon the previous settlement of other forms. They further state that '*At Miami, the long breeding seasons and variability in intensity* of attachment and growth rates result in a condition intermediate between seasonal progression and ecological succession but without seasonal tendencies'. Although exact conditions may not exist in Madras harbour, the close similarity between the observations at Miami and Madras cannot be missed, for, the factors like long breeding periods and variations in intensity of attachment are recorded in Madras harbour also (Daniel, 1954). Hence it may be suggested that at Madras the ecological succession, if any, is not true, regular and definite but is considerably modified under the prevailing ecological conditions.

SUMMARY

1. The distribution of sedentary organisms at three selected stations of Madras harbour is described.

2. It is seen that, the composition of the sedentary fauna in different stations of the harbour is not similar. In Boat Basin there is a quantitative increase in the number of organisms.

3. A study of the influence of environmental factors such as salinity, water currents, pollution, nature of substratum and depth has been made. It is seen that marked lowering in salinity affects the sedentary organisms, that the direct impact of water currents does not favour a dense settlement of organisms, that pollution of the medium enhances the settlement, that the wooden substrata support a richer sedentary fauna than the concrete and rocky substrata and that the optimum level of settlement and survival differs for different organisms.

4. An examination on the sequence of sedentary communities in different stations shows that the ecological succession, if any, is not regular and definite but considerably modified under the prevailing ecological conditions.

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