ASPECTS OF MARINE FOULING IN WESTERN CAPE WATERS

PART I: THE COLONIZATION OF METALS AND PLASTICS BY MACROFOULING ORGANISMS IN SIMONSBAY

PART II: EFFECTS OF PRIMARY FILM FORMATION ON THE SETTLEMENT OF MACROFOULING ORGANISMS

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NB [illegible] — the [illegible]

J.R. Henschel

Additional Comments

Page 15	Third paragraph, line 1, sequentially not sequentually
Page 21	Line 6, occasion not accasion
Page 31	Table 2.2 and various other tables in the thesis. It is conventional to have the generic and specific names of the various taxa in italics or alternatively underlined.
Page 67	Line 2 - coccoliths not cocoliths. Also coccoliths are not organisms but are the calcitic components that cover the exterior of certain organisms called coccolithophorids.
Page 69	Line 17, algal not algae
Page 141	Rather unusual to use the term ocular microscope rather than either light or optical microscope.

I would like to make the suggestion that another method for controlling the establishment of diatoms in the primary film would be to include germanium dioxide in the experiments. It is commonly known that in liquid culture 6 mg l^{-1} of GeO_2 will inhibit the growth of diatoms as it affects silicon metabolism.

Galileo: "I maintain that the only aim of science lies therin: to lighten the burden of man's existence ..... I have written a book on the mechanics of the universe, that is all. What becomes of it does not concern me."

Leben des Galilei, Berthold Brecht

Wat is die verste wat die boog kan span,
noeveel kan hierdie taaie pees verdra ... ?
sal die vering van geloof
nou nog 'n laaste pyl
laat spring en stort,
(waar konsentries-swart die sirkels van die brein
'n klein heelal omspan),
en feilloos tot die kern dring ... ?

Vraag van die Boogskutter, Ernst van Heerden

ASPECTS OF MARINE FOULING IN WESTERN CAPE WATERS

Contents

A. PREFACE

This work consists of two independent parts. The first part, which reports on the long-term biological fouling of various artificial materials immersed in the sea, was carried out for the the Institute for Maritime Technology while undergoing national service in the South African Navy, and is submitted here with the permission of I.M.T. In Part II, which was conducted at the University of Cape Town, the early events in marine fouling are examined and some interactions between the community levels are considered. This study follows some of the avenues explored in an earlier study by de Chalain (1979).

A list of some specific abbreviations used in this report is given on the last page, which can be folded out for purposes of cross-reference.

B. ABSTRACT

Two independant investigations into aspects of marine fouling were conducted in Simonsbay and Table Bay during 1979 to 1981.

The development of macrofouling communities on six test materials was examined at 10m and 20m depths in Simonsbay for periods ranging from one month to one year. Community development was similar on inert non-reactive materials, aluminium, stainless steel, fibre glass and polyvinylchloride, but was reduced on non-wettable silicon rubber and corrodable mild steel. Macrofouling was characterized by seasonal succession with minimum colonization rates during winter, when adverse weather and low temperature conditions prevailed. The nature of fouling differed with depth. At 10m depth, mussel and barnacle-dominated communities developed rapidly, while at 20m depth, ascidian and barnacle-dominated communities developed more slowly.

The role of primary film formation in the colonization of substrata by invertebrates was investigated in short-term studies conducted in Simonsbay and Table Bay. Surface-bound antibiotics, streptomycin and penicillin, were used to inhibit bacterial proliferation, while a herbicide, diuron, was employed to prevent diatom growth. The colonization by invertebrates was monitored on these surfaces and compared to surfaces where primary film development was normal, or where it was advanced by pre-culturing in laboratory seawater. It was found that invertebrates attached soon after panel exposure and that differences in the degree of primary film development were of little consequence to their settlement. The apparent discrepancy of these observations with previous findings is discussed, with special reference to the location of test sites in relation to mature communities.

C. PART I: THE COLONIZATION OF METALS AND PLASTICS BY MACROFOULING ORGANISMS IN SIMONSBAY

THE COLONIZATION OF METALS AND PLASTICS BY MACROFOULING ORGANISMS IN SIMONSBAY

1. PROJECT OUTLINE

1.1. INTRODUCTION

The dispersive phase, such as a larva or spore, allows many marine sessile organisms to colonize new localities. For example, the planktonic cyprid larva of acorn barnacles, drifts and swims about in search of a suitable solid surface. This search may be active, in response to certain environmental cues, or passive, relying on the movement of surrounding water. The larva may respond to a shadow by swimming down the light gradient, in which case it is likely to come into contact with a solid surface. The larva swims against the water current, thus slowing down its motion relative to the surface, before it anchors with its antennule. By alternating attachment with its antennules, the cyprid can walk over the surface to explore the chemical, physical and biological properties of potential habitats. Certain stimuli, or the lack of them, may influence the larva to leave to continue its search elsewhere. Other stimuli may cause the cyprid to initiate the "settlement response": orientation; secretion and mixing of various components of a glue, to cement the animal to the substratum; metamorphosis, the assumption of an adult shape and mode of life. The barnacle is now committed to its location and its physical, chemical and biological surroundings. It has to contend with competition for space from other sessile organisms, with predation, physical disturbances, and unfavourable environmental conditions.

The colonization events of many species of sedentary marine invertebrates are similar to the general procedure outlined above, although the cues that influence each stage may be different for each species (Crisp 1974, 1976; Meadows and Campbell, 1972).

When a group of coexisting organisms, that interact with each other and with the environment, is seperable from other groups in an ecological survey, it is known as a community (Mills, 1969). If such a group has developed on an artificial (man-made) surface, it is referred to as a fouling community. Since the earliest days of shipping, fouling has presented problems, which, to date, have not been entirely eliminated. Apart from increasing the frictional resistance of the ship hull and decreasing the thrust of the propellors, they may block up intake pipes, decrease the efficiency of sonar equipment, hydrophones, mine triggering devices or current meters, or increase the drag and weight of structures to undesirable levels (Fitzgerald, 1947, Moritz, 1943 and Urick, 1962 in De Palma, 1974; De Palma, 1978; Stubbings, 1961; U.S. Naval Institute, 1952). Furthermore, fouling can enhance the deterioration of surfaces by physical (undercutting - Griffith and Bultman, 1980; boring - De Palma, 1976; penetration - Moss, 1979), chemical (oxygen concentration and acid production - Costello, 1969) or electrochemical means (galvanic cell action - La Que, 1969).

To date, a variety of methods have been used, tested or suggested to eliminate fouling. These are aimed at the three stages of colonization: before contact, before fixation and after metamorphosis and include measures to:-

(a) Prevent contact

(i) High water velocity and turbidity to make attachment impossible (Houghton, 1970; Walton-Smith, 1942).

(ii) Kill the larvae with chlorine or other chemicals in solution (Fava, 1968; US Naval Institute, 1952).

(iii) Provide unfavourable light conditions to prevent the "shadow response" (Thorson, 1964; Weiss, 1947).

(iv) Filter the seawater that flows through a system (Springer, 1977).

(v) Confine maritime activities to non-reproductive seasons in temperate waters (U.S. Naval Institute, 1952).

(b) Prevent fixation and metamorphosis.

(i) Inhibition or absence of stimuli releasing settlement. If cues which elicit the settlement response are known, it should be possible to devise means of countering these. Physical and chemical properties of the substratum surface, of conspecifics, of other previous colonizers and of the primary film (bacteria, diatoms, protozoa and fungi) have been implied (Crisp, 1976; Crisp and Meadows, 1963; Goodbody, 1961; Knight-Jones, 1953; Meadows and Campbell, 1972; Mitchell et.al., 1977). It may be possible to find substances that mimic hormones or enzymes that inhibit metamorphosis (Baker & Evans, 1973; Christie, Evans and Shaw, 1970; Clitheroe and Evans, 1975; Mortlock , 1969).

(ii) Discouraging settlement of hard-shelled foulers by encouraging development of soft-bodied competitors. For example: Ralph and Goodman (1979) and Houghton (1978) suggested that hydrozoa may be used to discourage fouling by mussels and barnacles; Kamenskaya (1977) noted that tubiculous amphipods prevented fouling by barnacles and mussels; Rastetter and Cooke (1979) found that blue-green algae and diatoms may exclude other foulers in nutrient-rich waters.

(c) Remove colonizers

(i) Impregnation with toxins (heavy metals, salts and organic compounds) that reduce the lifespan of attached organisms. Antifouling paints have the widest applicability of all the methods discovered so far (Aoki and Wada, 1978; Crisp, 1965; Saroyan, 1969; US Naval Institute, 1952), but their lifespan is limited. In a review, Springer (1977) noted that antifouling paints "retard but do not control biofouling".

(ii) Physical removal of fouling by using manpower or mechanical devices, like a shuttle-brush system.

(iii) Prevent adhesion by using low-energy smooth and unwettable surfaces (Griffith and Bultman, 1980; Loeb, 1978), self-polishing coatings or chemicals preventing the adhesion of barnacle cement (Saroyan, 1969).

(iv) Kill foulers by local temperature fluctuations (Granam, Stock and Benson, 1977) or intermittent ultraviolet radiation (Plotner, 1968 in De Palma, 1974).

Until recently, antifouling research had concentrated almost entirely on (a) and (c) i.e. either preventing the settling organisms from coming into contact with a surface or killing them after settlement. Ways of inhibiting metamorphosis or inducing the larvae to leave before metamorphosis (b) are at this stage still difficult to impose and are, in fact, mostly speculative. It is felt that it may eventually be possible to manipulate biological properties of the fouling community to prevent its growth. This could present a long-term antifouling solution, with minimum environmental impact and a reduction in maintenance and financial burdens.

The Institute for Maritime Technology (IMT) provides a technical service with the ultimate goal of improving the operational efficiency of the South African Navy (SAN). A project was therefore designed under the aegis of IMT to evaluate the fouling conditions in Simonsbay and to test the susceptibility to fouling of materials which are frequently used in underwater naval applications. The seasonal occurrence of settling organisms and the long-term development of the fouling community were monitored at two depths, 10m and 20m, and compared to previous brief studies in Simonsbay undertaken at depths of less than 2m, by McClurg (1969) and Day (1972).

In this report, some environmental and substratum characteristics are outlined before the fouling community is examined by means of a numerical analysis to compare some of the factors involved. In later chapters, each of the main factors, namely time of year, duration of exposure, depth of immersion and substratum material are described and discussed seperately. Finally, an attempt is made to identify and compare community patterns on each of the substrata used.

Note: (a) Distinction is made between "settling organisms" before metamorphosis, and "sessile organisms", members of a fouling community.

(b) Various meanings for "species diversity" exist in the literature (Hurlbert, 1971; Sanders, 1968). As used in the present context it is equivalent to species richness: number of species present in a sample (irrespective how many individuals were recorded in the sample; see also Schoener et al, 1978).

1.2. METHODS:

1.2.1. Field Stations

All of the field work was carried out at 10m and 20m depths in Simonsbay (approx. 34°11'S by 18°26'E) at three experimental sites, which were selected on the basis of accessibility (Chart 1.2.1.1.). The main experimental racks were anchored at 20m depth at 1,5km offshore (Site 1) and 10m depth at 0,2km offshore (Site 2). Another station (Site 3), off the naval dockyard wall at 10m depth, was used for carrying out short term experiments. Previous studies by McClurg (1969) and Day (1972) at less than 2m below the waterline were carried out 0,1 - 0,2km offshore in the Simonstown Yacht Basin.

1.2.2. Substratum Materials

Six test materials, which are commonly used in sub-littoral marine engineering, and are commercially available, were chosen for the experiments. The three metals and three plastics were :-

a)Aluminium alloy : D 54 S marine grade (AL)
b)Stainless steel : 316L marine grade (SS)
c)Mild carbon steel (MS)
d)Silicon Rubber : Silastic RTV 3120 (SR)
e)Fibre glass : Araldite M epoxy resin (FG)
f)Poly Vinyl Chloride (PVC)

The plates were 10-15mm thick and 20 x 20cm in dimension, except where otherwise stated e.g. 50 x 50mm plates were used in short experiments at Site 3.

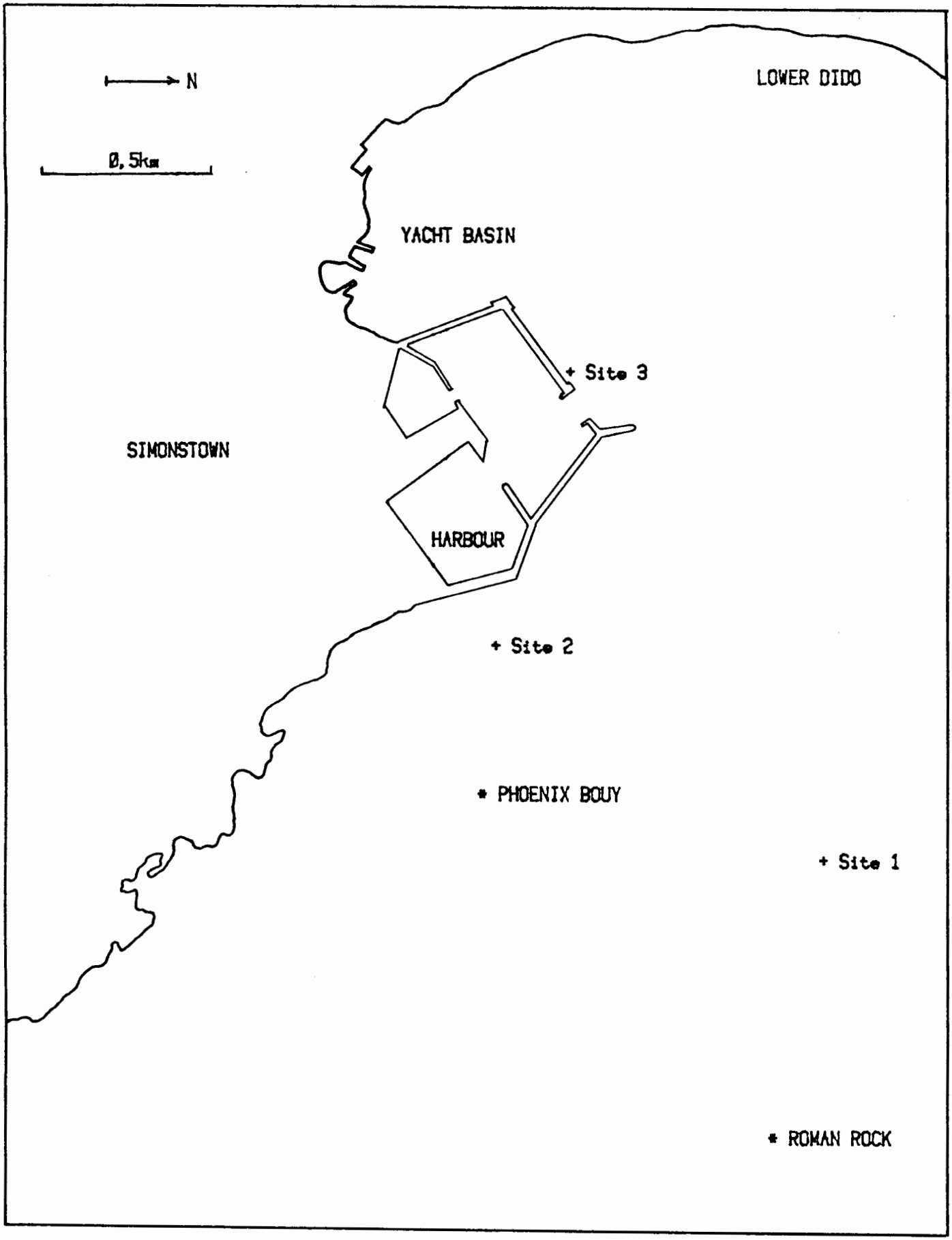


Chart 1.2.1.1: Location of experimental sites in Simonsbay.

1.2.3. Exposure Racks

Frames for carrying up to 30 test plates were constructed of fibreglass M-resin. Since the fibreglass frames proved to be too fragile to support the plates longer than 6 months, reinforcements were later constructed out of PVC piping, which, due to its higher flexibility, was more roobust. Each frame was suspended norizontally about 1,5m above the sea-bed from a mooring cable, which was kept taut between two inflatable Arlesund bouys and a 2-tonne concrete block anchor. The entire structure was free to turn about its own axis by a swivel at the base (fig 1.2.4.1.). By opening snap-shackles, divers could detach the frame from the mooring cable and bring it to the surface.

The plates, mounted perpendicular to the plane of its frame, acted as fins to keep the frame parallel to the water current, thus minimizing possible effects that might have arisen due to differences in water flow between the plates.

1.2.4. Fieldwork procedure

To satisfy the statistical requirements, it was decided to use three replicate plates for every test so that each of the frames at a station held one of the replicates. The panels were attached in a random location to minimize material interaction. Originally, coded labels were glued or tagged onto the plates for identification purposes. Later, when this technique proved inadequate because of loss of some labels, a more satisfactory method of cutting indentation codes into the plate edges, was applied.

It was intended to monitor the seasonal variation of settlement on panels that were recovered a month after immersion during each month of the year. In addition, the development of the fouling community was to be followed by removing plates after three, six and twelve months' exposure. However, due to the strain imposed on the frames during plate recovery and replacement, which resulted in severe degradation and, eventually, in the loss of two frames at Site 1, it was necessary to modify the fieldwork procedure.

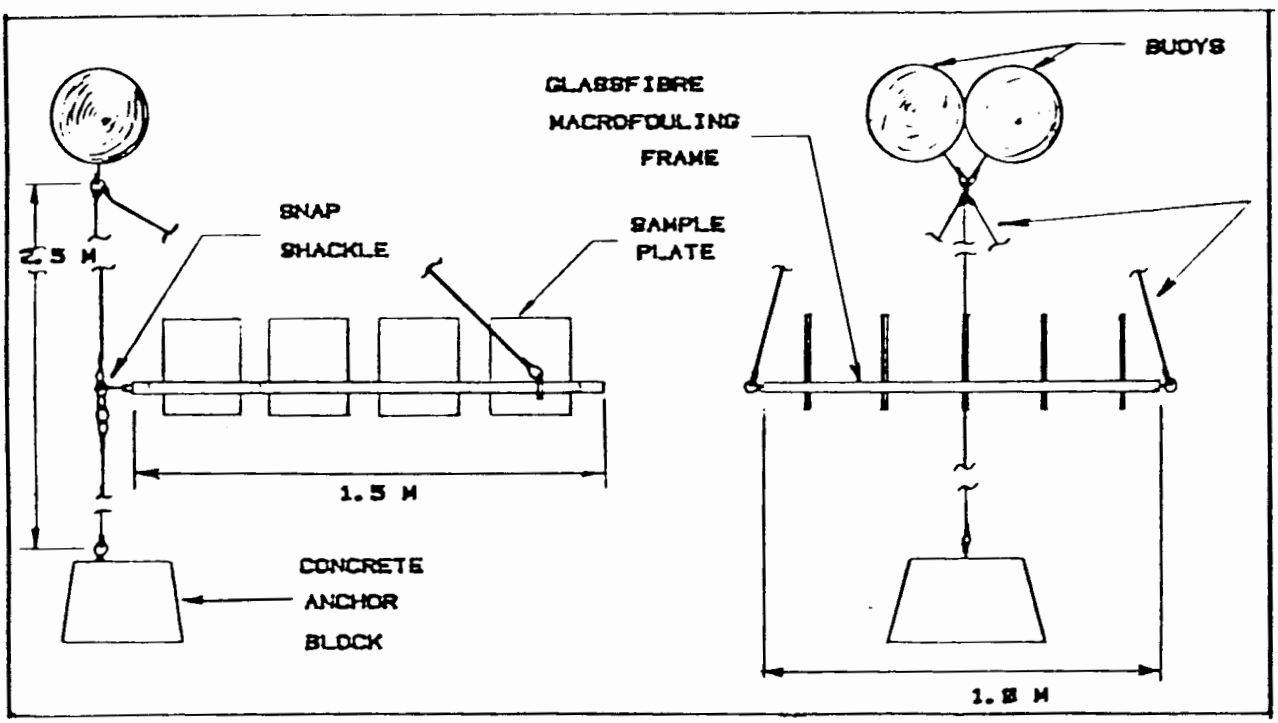


Fig 1.2.4.1: Exposure rack deployment.

The final pattern of plate exposure was thus:

a) Immersion for 1 month during each month between June and November 1979.

b) Three-month exposures during June to August 1979, December to February and March to May 1980.

c) Nine- and twelve-month exposures during June 1979 to February 1980 and June to May respectively.

1.2.5. Environmental Conditions

Some physical and chemical parameters were monitored periodically, usually once a week, at Site 1,2 and 3 over the period January 1979 and May 1980. Water samples were taken approximately one metre above the sea bed with a Nansen bottle. Subsamples were stored in plastic bottles and kept frozen until they could be processed in the laboratory at the Division of Sea Fisheries, using their standard methods.

1.2.5a. Temperature

A protected reversing thermometer attached to the Nansen bottle was used to record temperature.

1.2.5b. Salinity

Water samples were passed through an Autolab Model 601 Mk3 Salinometer to determine the salinity.

1.2.5c. Phosphate (PO_4)

The concentration of reactive phosphate was determined colourimetrically with 660nm light, after ammonium molybdate reagent and ascorbic acid were allowed to react with the sample. The determination was run relative to distilled water, using filtered low-phosphate seawater blanks.

1.2.5d. Silicate (SiO_3)

Specific quantities of distilled water, hydrochloric acid, molybdate and tartaric acid reagents were added to the sample and mixed with air, the reaction proceeding at fixed temperature. Colourimetric determination was made at 660nm using distilled water as a blank.

1.2.5e. Nitrate (NO_3)

The sample was mixed with ammonium chloride and air, before the debubbled mixture was reacted with sulphanilimide reagent and N-1-Naphthylene dihydrochloride. The nitrate concentration was determined from the absorbance at 520nm using distilled water blanks.

1.2.5f. Ammonia (NH_3)

After the sample was diluted with deionized water, subsamples were reacted sequentially with phenol and sodium nitroprusside reagents at 4°C, then with trisodium citrate, sodium hydroxide plus sodium dichloroisocyanurate reagents at 60°C. Ammonia-free water was used for the reagents and the reaction proceeded at low light conditions in acid-cleaned air. Finally, absorbance was measured at 620nm.

1.2.5g. Water movement

An ANDERAA current meter was used to obtain a continuous (at 15 minute intervals) record of water velocity and temperature at Site 3 during two periods of four weeks in September 1979 and March 1980.

1.2.6. Substratum Characteristics

1.2.6.1. Chemical constituents

1.2.6.1a. Elemental Analysis

The six substrata were subjected to a qualitative analysis using an Energy Dispersive X-ray Analyzer (KEVEX) unit attached to the Cambridge S180 Electron Microscope at the University of Cape Town. The analytic procedure was as described by de Chalain (1979). This entailed polishing the surfaces to a mirror finish on a Metaserv Universal rotary polishing wheel, and mounting for Scanning Electron Microscope viewing and elemental analysis.

1.2.6.1b. Atomic Absorption of metals

Samples of aluminium, stainless steel and mild steel were dissolved in aqua regia ($3HCl$: $1HNO_2$) and subjected to analysis by a Varian-Techtron 1200 Atomic Absorption Unit in the SA Navy Materials Laboratory.

1.2.6.2. Surface Texture

1.2.6.2a. Centre Line Average

By traversing a stylus for 2,5cm in various directions over a substratum surface, the average height deviation from the arithmetic mean, or centre-line average was measured with a Talysurf Modulated Carrier Instrument (Reason, 1970).

In a review of current techniques for measuring surface roughness, Thomas (1979) regarded the stylus method, in spite of a few limitations, to be a general measure of surface texture. The centre line average is useful in the present context because it approximates the amplitude of the component waves at the order of magnitude which might affect the settlement and adhesion of invertebrate larvae (see Crisp, 1976).

1.2.6.2b. Surface Roughness at the Micro Level

A technique for describing the micro-structure of material surfaces at the order of magnitude of constituents of the primary film (bacteria, diatoms and nanoplankton), was devised by de Chalain (1979). Using the scanning electron microscope (SEM), he generated waveforms by linear scans across the surface. The waveforms were stored by tape recorder and played back into a Nicolet Search Oscilloscope to digitize selected data parameters. This data was processed with statistical techniques, used for wave-data, to obtain a single dimensionless value, the coefficient of variation. This value describes the overall degree of variation about the mean of linear surface contours at a high resolution.

1.2.6.3. Hydrophobicity

The wettability or hydrophobicity of surfaces was described by measuring the contact angle of a water drop on the surface (Zisman, 1964; de Chalain, 1979.) The advancing contact angle, when moving the liquid boundary over a dry surface, and receding contract angle, when moving the liquid boundary over a previously wetted surface, were determined on surfaces of each material before and after 48 hours' exposure to sea water. The details of the measurement technique are presented by de Chalain (1979). After thoroughly cleaning the surface by ultrasonification in 100% ethanol, a drop was placed on the horizontal surface with a syringe. By adding or withdrawing water through the syringe, the drop boundaries could be advanced or receded respectively. The drop profiles were photographed and the edge of the images digitized by computer (Hewlett-Packard 9872A peripheral). By processing this data, the contact angle could be calculated.

1.2.6.4. Colour Reflectance

The colour of materials in the visual range was quantified by determining the percent reflectance of various colours of light relative to its reflectance from white magnesium carbonate. A Sheen Instruments Inc. Colourimeter was used for this purpose. Since the oxidation of metal surfaces can change their colour, this determination was repeated with dry, cleaned metal plates after one month's exposure to the sea.

1.2.7. Laboratory procedure

After retrieval of the test panels, these were placed into separate plastic bags containing fresh sea water, and stored vertically in 20 litre plastic buckets. The material was preserved in formalin, which was added to the water surrounding the plates to a final concentration of 5 percent. The quantity and nature of the attached fouling community was analysed as described below.

1.2.7.1. Biomass

The wet weight of the plates was determined after letting the water run off for at least 15 seconds. The original weight of the clean plate was substracted to obtain a value for fresh biomass.

1.2.7.2. Volume

All replicate plates were immersed togetner or sequentially in a graduated container, partially filled with a known quantity of water. The change in water level represents the volume of biofouling after the known plate volume is substracted. Only mean readings of all replicate plates were recorded.

1.2.7.3. Species Identification

A convenient system of organism classification was devised to facilitate the laboratory work. Ease of recognition, frequency of occurrence or size were used as practical guidelines. Details of these species or groups are shown in Table 2.2(a).
Although not all species could be positively identified, the diversity of all sedentary organisms occurring on a panel was recorded. For furtner analysis the species were classified in the system described above. The following references were consulted to identify organisms: Polychaetes - Day, 1967; Amphipoda - Griffitns, 1976; Hydrozoa - Millard, 1975; Algae - Simons, 1976; Other - Day, 1974.

1.2.7.4. Cover

The horizontal surface area occupied by each of the species groups and collectively by all organisms, was estimated in one percent units. Small wire frames were used as a guide.
In cases where some of the organisms had become detached from a plate due to handling activities, the percent area of the plate that was undisturbed was estimated. This value was later used to compensate for the loss of organisms. All plates, where less than 33% of the area was undisturbed, were discarded.

1.2.7.5. Census of Organisms

The plates were examined under water with a dissecting microscope at a magnification of 6 to 25 times.. The microscope was mounted on a horizontal displacement frame that allowed forward, backward, left or right movement over the sample without loss of focus.
The relative abundance of all species or groups was noted, but the non-sessile species were excluded in further determinations. A wire frame, 2,5 x 2 0cm, was laid across the centre of a plate and individuals of numerous or very small organisms contained within this subsample area were counted. Where individuals were relatively few and scattered, or large of size, totals were obtained for the whole area of the plate ($400cm^2$). Some colonial species were analyzed by multiplying the estimated area covered by a colony by the number of their units per unit area. Each vertical stalk of hydrozoa and of arborescent (filamentous) bryozoa was counted as a unit.

1.2.8. Data Analysis and Statitics

The primary processing of data was done with an Interdata 8/32 computer. Later the processed data was transferred for further analysis onto the UNIVAC 1100 at the University of Cape Town, and to a Hewlett-Packard 9825 desktop computer with 9872A plotter and 9885 disc drive peripherals.

1.2.8.1. Analysis of Variance (ANOVA) and Student-t Test

Shapiro and Wilk's method and Bartlett's χ^2-method were used to test for normality and homogeneity of variances respectively. According to these tests the assumptions for data normality and homogeneous variances were often not satisfied. This was partly the result of zeros in some cells, due to the absence of some species in samples. Arcsine and logarithmic transformations were applied for percent cover and wet weight data respectively. This improved the validity of the assumptions, although in some cases they were still not satisfied at $P < 0,01$.

Although samples should be independant, visual interpretation of the distribution of organisms showed that for some species, notably compound ascidians (Diplosoma) and black mussels (Choromytilus), the two sides of a plate or adjacent sides of two plates were sometimes apparently influenced by the proximity of the other.

Furthermore, due to the gregarious settling behaviour of some species and rapid expansion of some colonies replicate samples could be at different stages of community development at the time of plate retrieval. The relatively small sample size (maximum of 6), sometimes with unequal replicates (due to the loss of samples, see 1.2.4), could thus result in a very high variance, making statistical testing difficult.

The ANOVA and Student-t tests thus had to be applied at high significance levels only. Results for the ANOVA ($P < 0.005$) were obtained by treating the data with a computer package on the UNIVAC 1100 (STATJOB.NWAY1; developed at the Academic Computing Center, University of Wisconsin-Madison). A modification of Scheffe's approximation was applied where the number of replicates was incomplete.

1.2.8.2. Cluster Analysis

Field and McFarlane (1968) and Field (1970, 1971) showed that a technique for cluster analysis, using Czekanowski's coefficient (coeff. = $2W/(A+B)$; where A and B are the scores for a species in two samples and W is the smaller score of the two samples) with the Bray-Curtis measure of similarity on log-transformed data, can produce useful results for examining the distribution of organisms. Dendrograms were produced using results generated by computer software developed by the academic staff of the University of Cape Town.

2. RESULTS AND DISCUSSION

2.1. THE ENVIRONMENT AND SUBSTRATUM

2.1.1. Environmental Conditions

Marine benthic organisms have various requirements for the physical environmental conditions such as illumination, temperature, food supply, nutrients, current velocity and salinity. These factors may determine the survival, competitive ability and seasonal abundance patterns of organisms, but are essentially all independent of the benthic community (Calder & Brehmer, 1967; Christie & Evans, 1975; Long 1972 & 1974; Scheer 1945; Russ 1977; Walton-Smith, 1941).

The annual temperature regimes will to a large extent determine what type of a community can develop at a site. De Palma (1978) used various environmental characteristics, including temperature regimes (and depth, exposure time and distance from shore), to forecast the type and degree of fouling in a region. This was varified by Schoener, Long and De Palma (1978). Earlier, Millard (1952), working in Table Bay, not far from the present study site, attributed the type of fouling recorded in that region to the small temperature range, so that there is no true "off-season". The temperature extremes can limit fouling but if the temperature does not fluctuate markedly, other factors could determine the type of fouling in an area.

Although the interaction of various environmental conditions may be very complex, it was felt that a description of the environment might assist in explaining regional and temporal differences in the formation and development of the fouling community.

The seasonal patterns of surface water characteristics in False Bay are apparently governed by the predominating wind regimes. In summer, warm (16-20°C) low-nutrient Agulhas Current water enters False Bay and flows slowly (0,2 knots) in a clockwise direction round the bay (Atkins 1970a, 1970b). Occasionally, under the influence of strong south-easterly winds, upwelling at the south-eastern boundary of the bay can give rise to cold nutrient-rich surface water (11-14°C; 10-20uM nitrate and silicate), which may displace the warmer surface water for as far as Dalebrook, in the north-west corner of False Bay (Cram, 1970; Cliff, 1979). In winter the clockwise current pattern is modified and cold South Atlantic Ocean water is driven into the bay by the predominating north-westerly winds. Although upwelling may occur on the western boundary between Cape Point and Miller's Point, just south of Simonstown, the importance of this is not known (Day, 1970). Heavy precipitation may result in an increase of fresh water outflow from Sandvlei, Zeekoevlei and Eerste Rivier into the north of False Bay during this period. Eventually, the winter temperatures throughout False Bay are uniformly low (13-15°C) up to a depth of 50 metres (Atkins, 1970a).

2.1.1.1. Temperature

The overall seasonal trends of temperature regimes described for False Bay (Atkins, 1970a; de Chalain, 1979), were evident at the three experimental sites in Simon's Bay (fig. 2.1.1.1. & 2.1.1.a-c). In the winter months, May to September, the temperature was less than 14,5°C with a minimum of 11,4°C in May. During spring, summer and early autumn the weekly temperature records at each site could vary considerably. At Site 2 and 3, 10m depth, the temperature exceeded 14,5°C with a maximum of 21°C. However, at Site 1, 20m depth, cold water (11,3-14°C) was sometimes sampled during March to April. This was possibly a result of the onset of north-westerly winds, which may cause an upward and westward shift of the cold bottom layer due to the eastward displacement of the surface water in False Bay (Atkins, 1970b). This would agree with the suggestion of Day (1970) that upwelling may take place south of Simon's Bay during this time of the year.

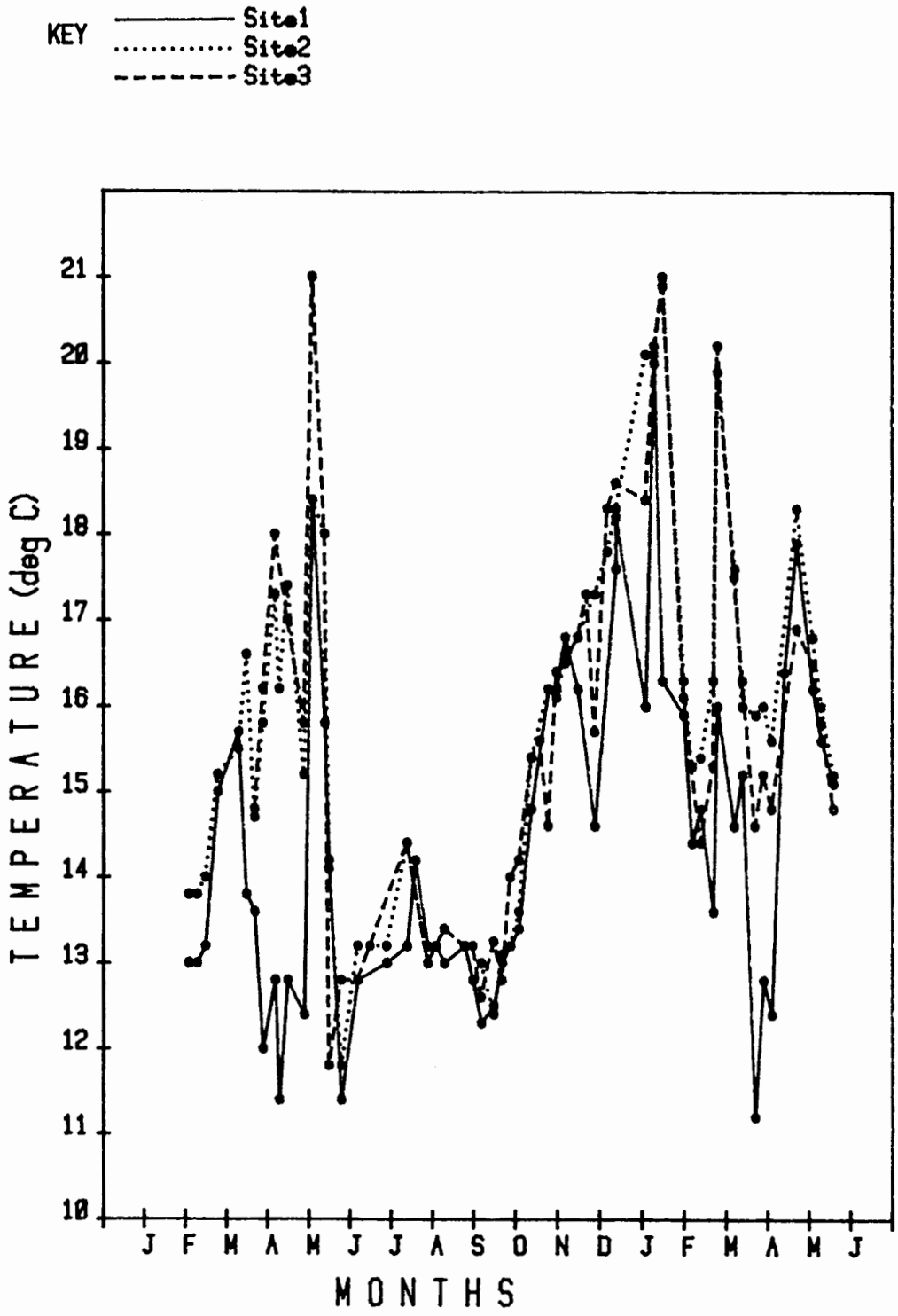


Fig 2111 : Temperature readings (deg C) recorded weekly at Site 1 (20m), 2 & 3 (10m depth).

2.1.1.2. Salinity

The samples analyzed in this study show no clear seasonal differences, although Atkins (1970a) described seasonal trends of salinity in False Bay generally, with maximum values during summer and minimum during spring in the Simonsbay vicinity. Fluctuations in the flow of small streams from Glencairn and Dido Valley apparently have no major influence in the study area.

With salinity ranging from 34,8 to 35,4 ppth, this factor is considered to be stable for the purposes of this report.

2.1.1.3. Nutrients

On the whole, the concentration of nutrients, orthophosphate (0,5 - 3uM), nitrate (0,1 - 10uM) and silicate (0,2 - 12uM) was low, characteristic of Agulhas Current and South Atlantic Ocean water (Cliff, 1979).

For the purposes of this investigation it suffices to note that there appear to be no regional or seasonal differences, except that the nitrate concentrations sometimes appeared to be higher at Site 1 than at Site 2 and 3. This may have been the result of the influence of deep water, since high nutrient concentrations (above 10uM) sometimes coincided with the periods of colder temperature (below 14°C). Although the nutrient concentrations, especially nitrate, may sometimes be below concentrations which might limit biological activity (e.g. October - November 1979), these conditions did not last very long and should thus not have had an indirect effect on the settlement of organisms (Yull-Rhee, 1978). The occurrence of occasional phytoplankton blooms may explain the observed variability and short-term depletion of nutrients (Cliff, 1979).

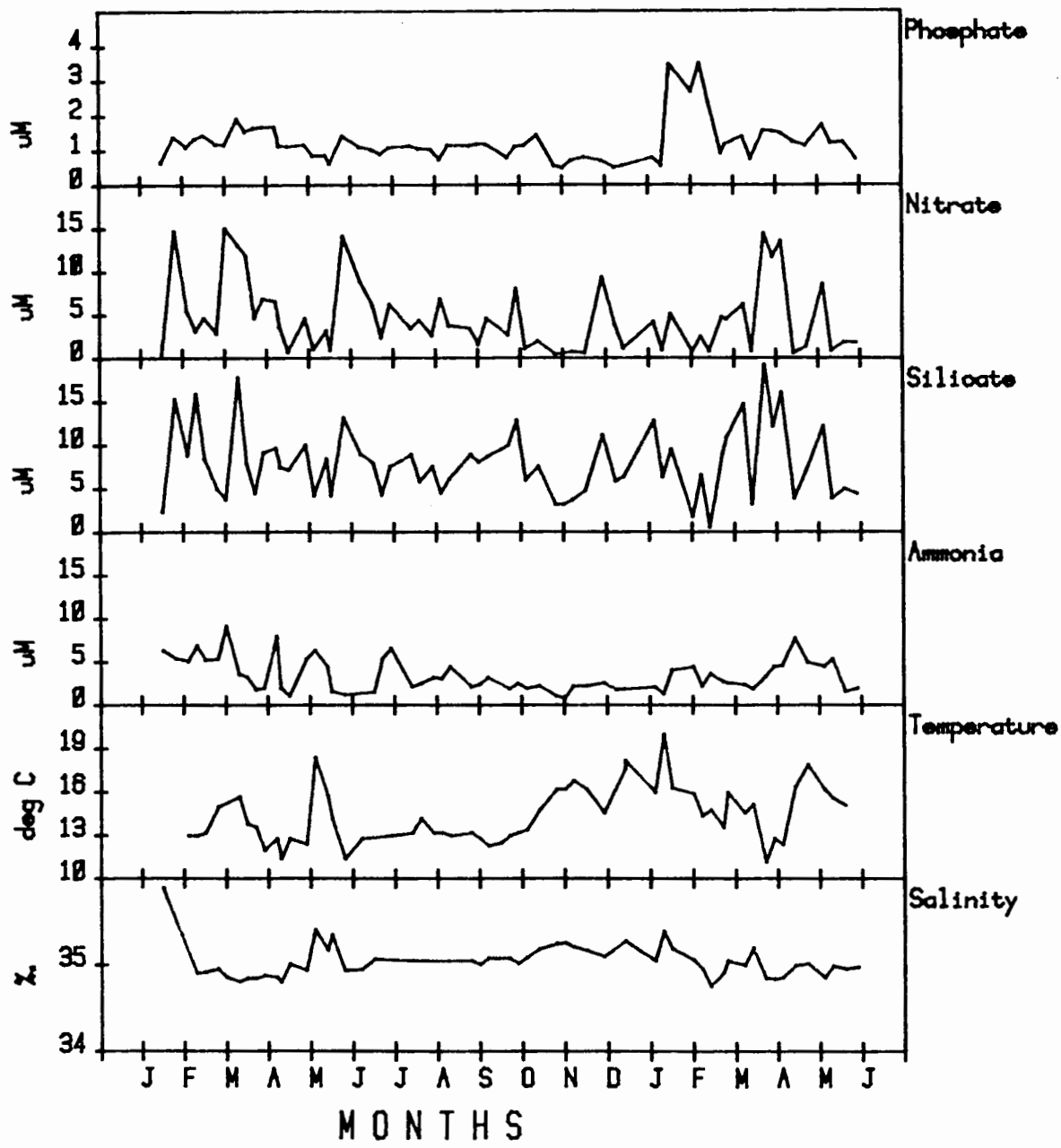


Fig 211a : Environmental conditions at Site 1 (depth = 20m) monitored weekly between January 1979 and June 1980.

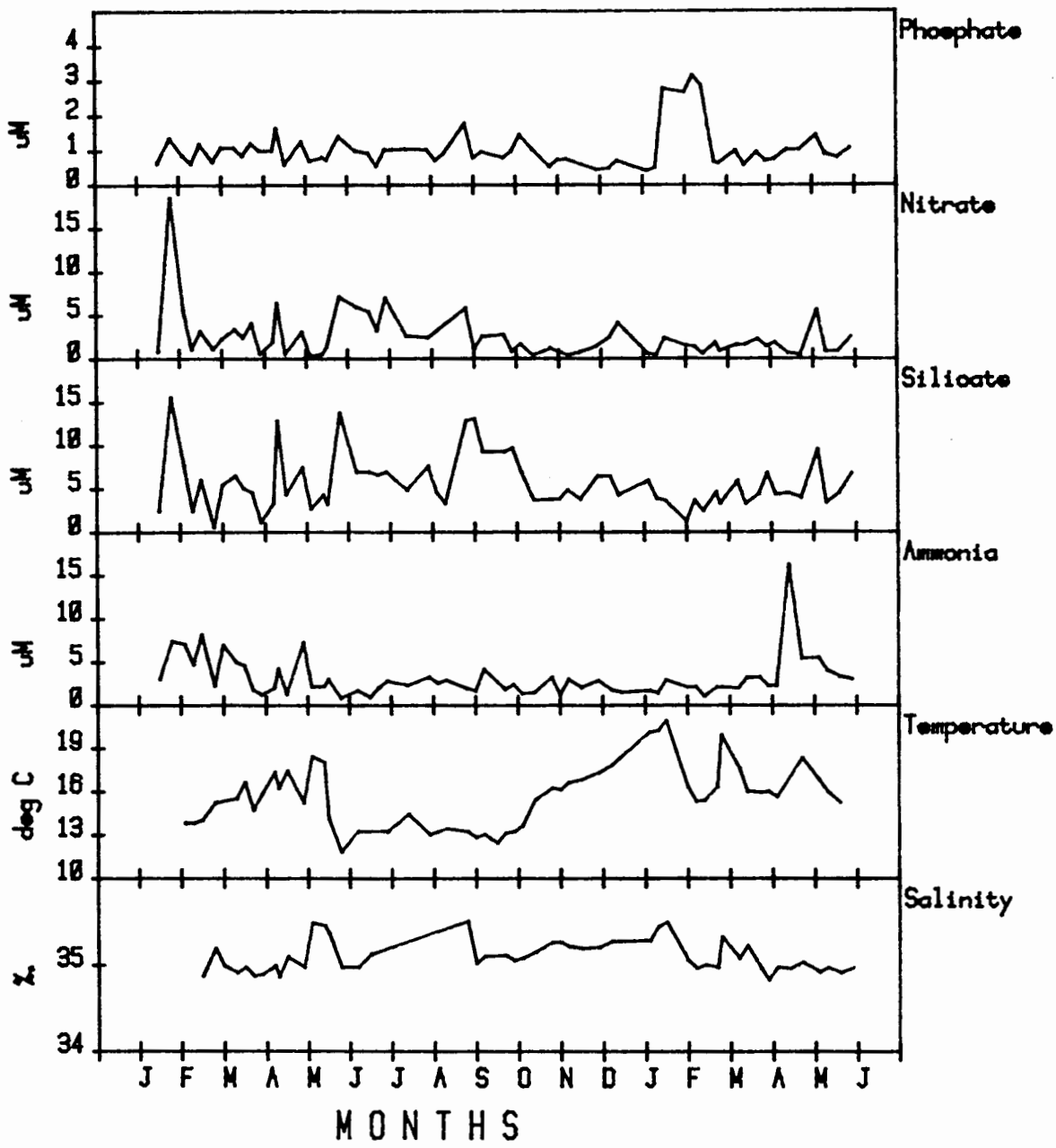


Fig 211b : Environmental conditions at Site 2 (depth = 10m) monitored weekly between January 1979 and June 1980.

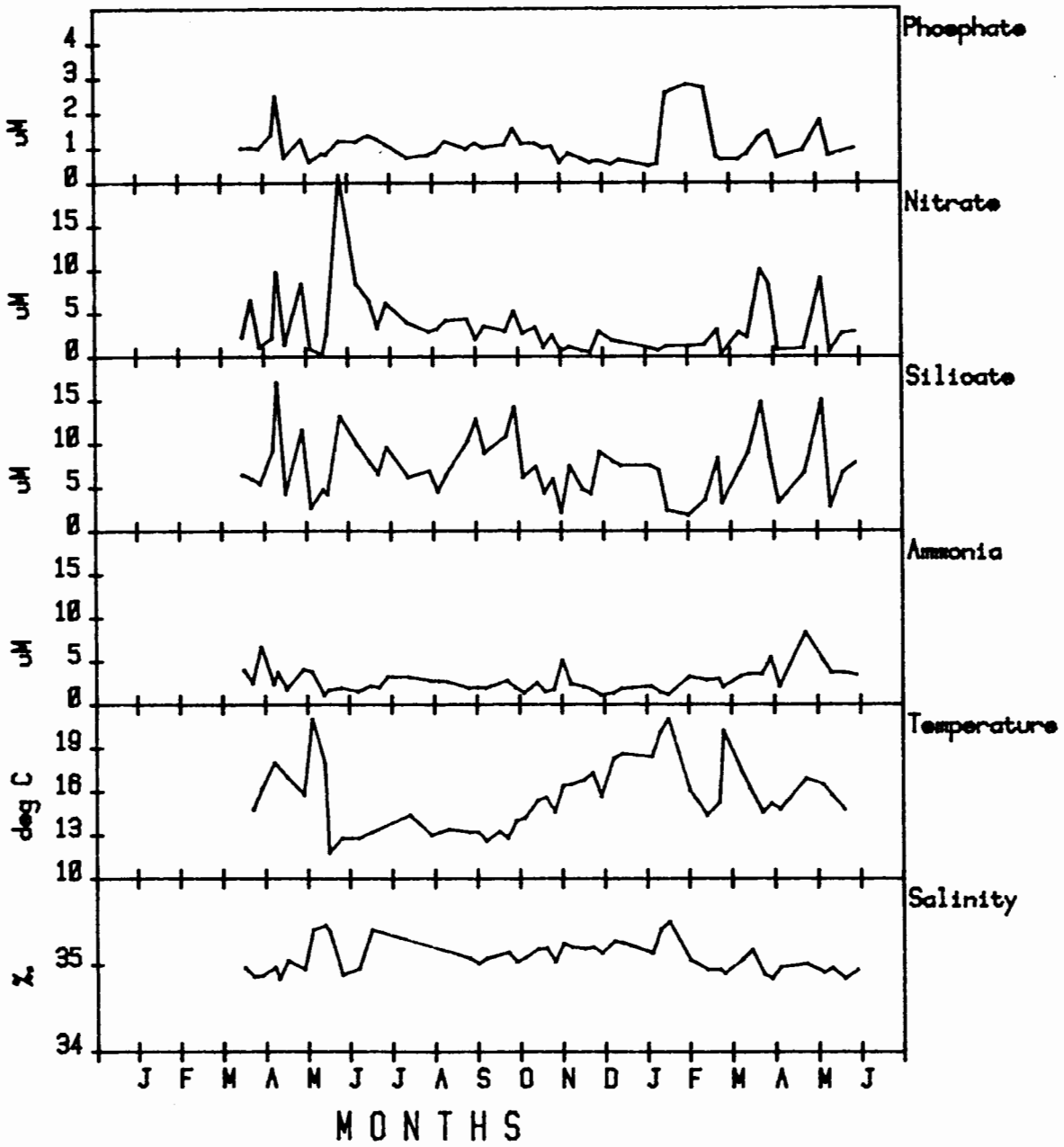


Fig 211c : Environmental conditions at Site 3 (depth = 10m) monitored weekly between January 1979 and June 1980.

Since ammonia is an excretory product of marine animals, its concentration should be directly proportional to the local animal biomass and inversely proportional to the rate of uptake by phytoplankton and macrophytes. Usually, the recorded levels were in the expected range of 0,5uM NH_3 (Cliff, 1979), but during late summer to autumn, the ammonia concentration would on occasion rise well above 5uM upto a maximum of 16,1uM recorded in April 1980 at Site 2. This elevation could be due to the apparent increase in the number of fish and squid in Simonsbay during this period, according to local fishermen. Personal observations of the effects of grazing on the sublittoral fouling community, especially barnacles, confirm that the local activity of demersal fish apparently rose to a maximum between March to May (see Plate 2.2.2e & f).

2.1.1.4. Water movement

Although no measurements of current speed were made at the two main field stations, the effect of wave action is believed to be negligible at the experimental depths. Furthermore, the prevailing current speed should have been relatively slow as is indicated by the presence of sludge on the seabed at Site 2 (10m). Recordings with an Anderaa Current Meter made at Site 3 (10m) during September 1979 and March 1980, showed that the speed was less than 0,1m/sec for more than 95% of the time, the maximum being 0,6m/sec. It is important to note that rapid fluctuations of water movement were not recorded in that period.

Since the experimental racks were free to swivel in the direction of the prevailing current, the conditions of water flow around all test panels is assumed to be similar. Spurious water movements, which can cause physical disturbance of the fouling community (Dayton, 1971) at surface levels or on ships' hulls, should not have played a major role in the present study.

2.1.1.5. Illumination

Light seems to play a major role in the settling behaviour of many species and is a limiting factor in the development of marine algae (Crisp 1974 & 1976; Day, 1977; Thorson, 1964; Walton-Smith, 1941). Day (1977) suggested that the photonegative response of many settling marine larvae may be a mechanism of avoiding direct competition for space with algae. Light conditions, which are subject to rapid change in the surface layer between 0-20m depth (Kirk, 1977), should thus be a factor in explaining differences in community composition at the two experimental depths (Walton-Smith, 1941).

2.1.2. Substratum Characteristics

When a clean surface is exposed to the sea it is a combination of characteristics inherent to the substratum material and to its subsequent interaction with the environment that may, by physical or chemical means, determine whether an organism, in the settling stage of its development, will settle when it encounters this surface. Once an organism has settled, other physical and chemical characteristics may determine its longevity.

Many species have an exploratory phase which follows the instant of contact with a solid surface (Crisp, 1974, 1976; Meadows & Campbell, 1972). Although the complexity of this important phase has not been fully determined, not even for barnacles, the most intensely studies animals in this respect, it is known to be influenced by the following substratum characteristics:- a) colour and light reflectance, b) surface texture, c) wettability, d) surface chemistry. Certain of these parameters were measured and the results, presented on figure 2.1.2.1a & b, are discussed below.

2.1.2.1(a) Light and Colour Reflectance

The response of larvae to light in the last stages of their swimming phase, can determine the surfaces they will make contact with before testing its suitability for attachment. Thorson (1964) showed that many species, including most arthropod, coelenterate, bryozoan and ascidian larvae, change from being photopositive to photonegative, which means that they tend to move down the light gradient to slightly darker or shaded areas. This does not imply that these animals will not settle on brightly illuminated or light-coloured surfaces, because once larvae in the settlement stage make contact with a solid surface, tactile and chemoreceptive responses come into play (Crisp, 1976). The intensity and spectrum of reflected light can thus be a factor in explaining differences in the constitution of initial fouling communities on substrata of various colours (Visscher & Luce, 1928).

The relative amount of light reflected from aluminium and stainless steel before exposure was 2-3 times as high as that of a polished glass surface (standard). Due to corrosion, mild steel already had a dull surface before the experiment began. After four weeks of exposure, aluminium was covered by a grey layer of oxide and its surface reflected about one percent as much light as previously. Stainless steel, however, remained relatively shiny and after a year's exposure to the sea, still reflected about 50% as much light as the original surface. Apart from the fibre glass resin, which could be shiny in places, where it reflected about 25% as much light as a polished glass pane, the plastics had a dull surface.

The more light of a particular colour is reflected from a surface, the lighter the surface will appear. The six materials are described in terms of the reflectance of six primary colours from their surface (fig. 2.1.2.1.a). Since all metals were darker after exposure, due to oxidation, the final colour (after immersion for 1 month) should be used when comparing the materials. Three categories can be distinguished, based on the colour and glass reflectance:-

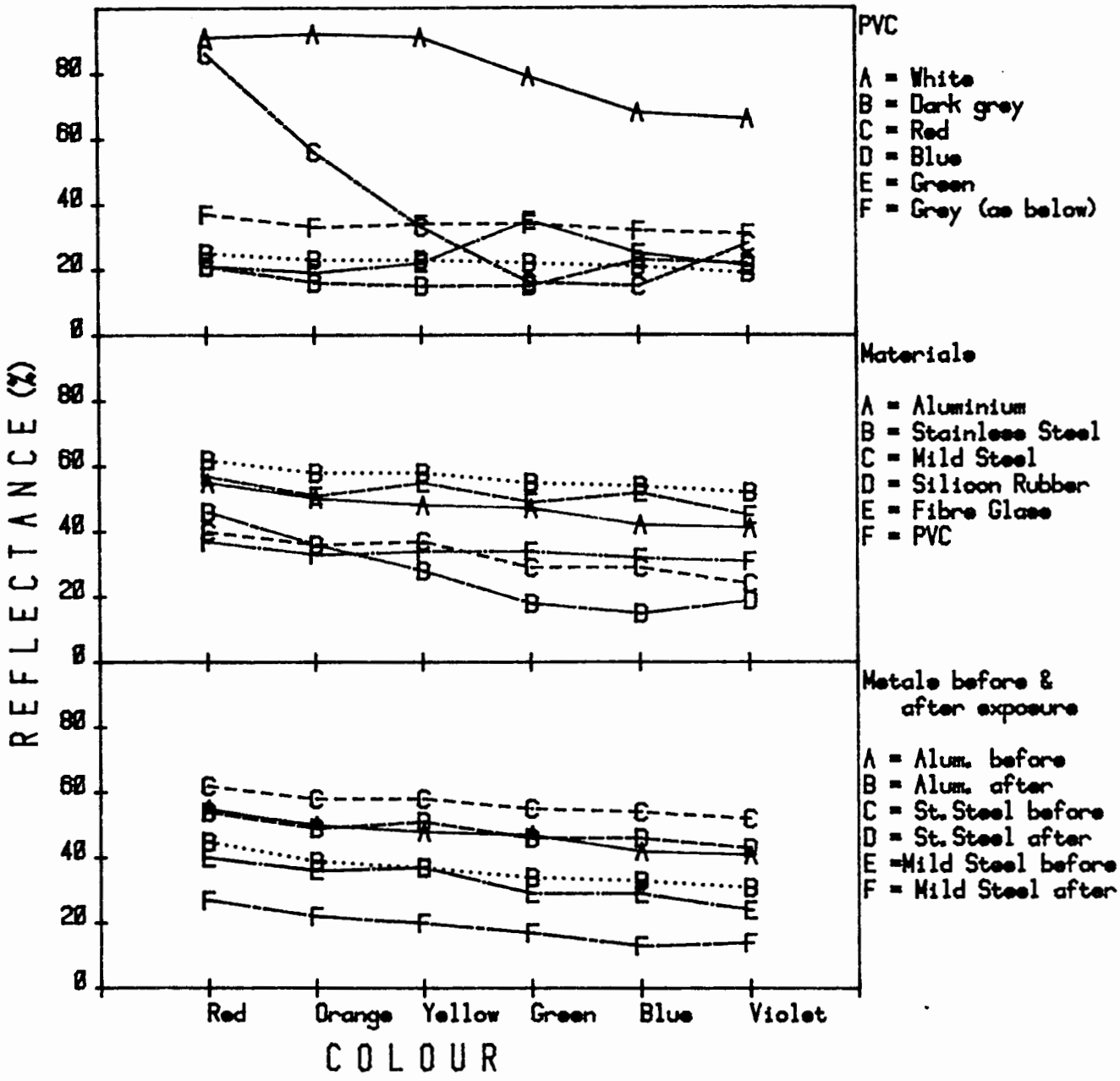


Fig 2121a: Colour reflectance of coloured PVC plates (top), different materials (middle) and of three metals before and after exposure to seawater (bottom). Magnesium Carbonate was used as a standard (100%).

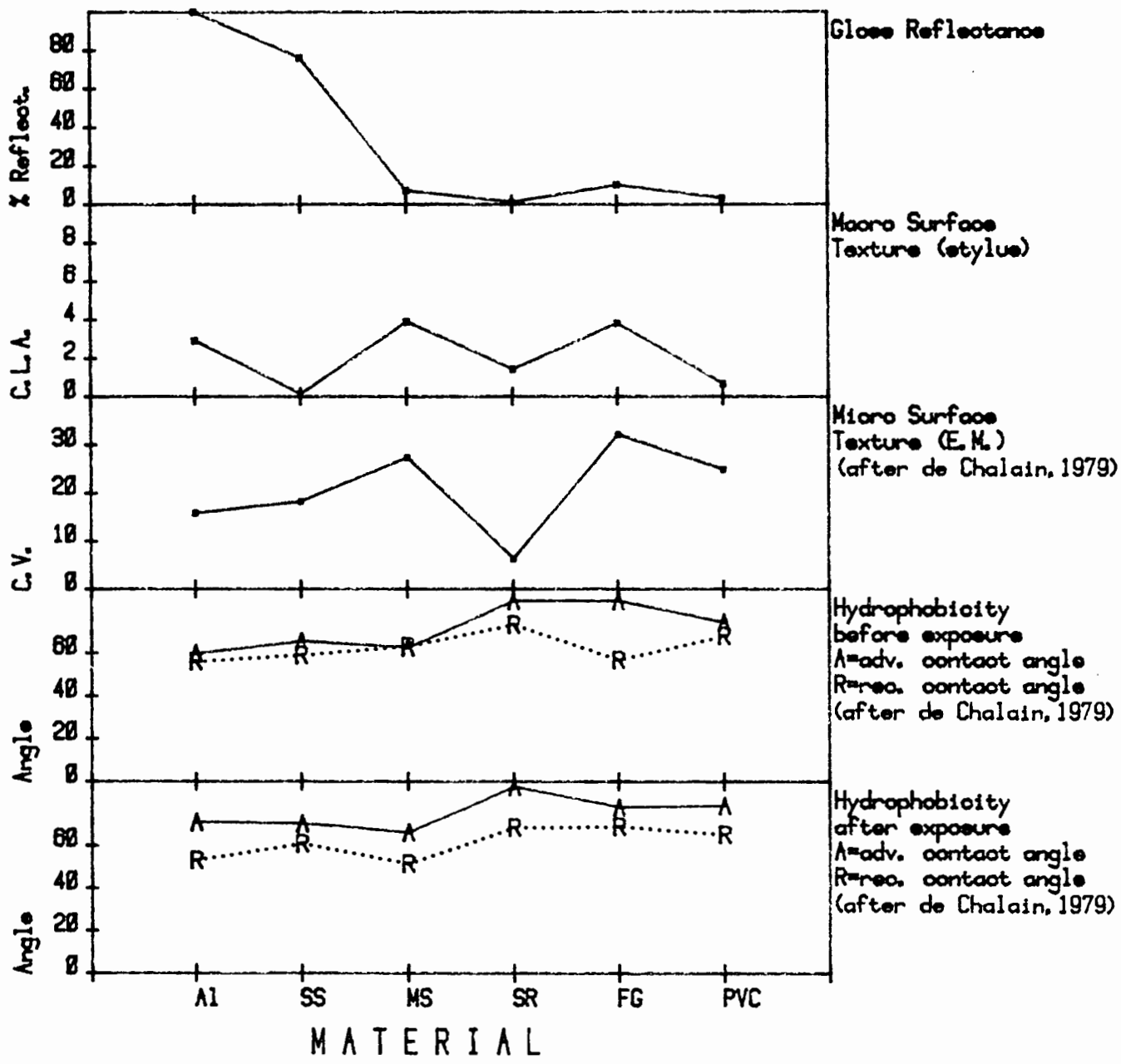


Fig 2121b : Surface characteristics of the different materials.
Top: Gloss Reflectance (%) using Glass as standard (33%).
Second: Surface Texture (Centre Line Average) as measured by stylus.
Third : Surface Texture (Coefficient of Variation) as measured by E.M.
Bottom two: Hydrophobicity expressed in advancing (A) and receding (R) contact angles of materials before and after exposure.

(a) Light: Silver-coloured shiny stainless steel;
Cream-coloured fibre glass

(b) Dull : Grey PVC; Grey aluminium

(c) Dark : Rust-brown mild steel; Red silicon rubber.

2.1.2.1(b) Surface Texture

In comparing the fouling on surfaces of different roughness, biologists have seldom defined what is meant by "smooth" or "rough". A reasonable criterion for a smooth surface would be the absence of surface irregularities big enough to provide a hold-fast or partial shelter for settling organisms. Surface texture could influence many settling organisms during the exploratory phase. Many larvae are thought to avoid smooth surfaces, exceptions including the genera Tubularia, Bugula and Spirorbis (Crisp, 1976). Intertidal algae settle indiscriminately, but their growth and survival is dependant on surface roughness (Harlin et.al., 1977). Conversely Christie, Evans & Callow (1975) observed that Enteromorpha spores preferentially attached to rough surfaces.

A visible impression of surface texture can be gained from the micrographs presented by de Chalain (1979). A technique of quantifying surface texture at the scale of these micrographs (500 - 5000X) was devised by him. His results are presented here as the coefficient of variation (CV) of wave profiles scanned across the surfaces (fig. 2.1.2.1.b). These measurements are compared to the centre line average (CLA), another dimensionless variable, used to express roughness at a scale visible by naked eye.

The rubbery nature of the silicon rubber plates caused the stylus to vibrate when it traversed the surface. However, in visual examination of the plates and micrographs, silicon rubber surfaces appear very smooth, the CV being much lower than that of other materials. A very fine network of cracks, too small to be detected by the stylus or by naked eye, gives stainless steel a slightly rough appearance at the micro level. Aluminium has a slightly undulating (corrugated) surface

in places. Oxidation products make it appear rough at high magnification. The PVC surface is manufactured with numerous slight scratches and at 500X magnification, pits and concavities are visible, although these are too small to be recorded by the stylus. The surface of mild steel is uneven and flaky at a much larger scale, due to corrosion. Soon after immersion this condition increases so that the CLA value is above 10. Fibre glass, although relatively smooth in some places, is very rough in others. During manufacture, epoxy resin was poured onto sheets of fibrous material, leaving an undulating surface, with pits where air bubbles hardened and fibres were left exposed.

2.1.2.1(c) Hydrophobicity

Wettability, which is directly proportional to "free surface energy" (depending on the hardness and melting point of a solid; Zisman, 1963 in de Chalain, 1979) can influence an organisms affinity for a surface. Eiben (1976), Müller, Wieker and Eiben (1976) and Loeb (1978), working with marine bacteria, algae, hydrozoa and bryozoa, showed that these organisms had a clear perference for the hydrophobic materials and indicated that other organisms may behave likewise. They suggested that organisms with hydrophobic surfaces would be attracted to hydrophobic substrata because of their tendency to reduce the surface area in contact with water. The situation is, however, complicated by the fact that bioadhesion is reduced on low-energy surfaces (Baier, Shafrin & Zisman, 1968). It may appear, therefore, that, although some organisms are attracted to hydrophobic substrata, they will not adhere firmly. Loeb (1978) concluded that highly hydrophobic substrata may be valuable for anti-fouling measures, not because they are resistant to fouling, but because of the poor adhesion of fouling organisms.

Measurements of advancing and receding contact angles of water drops on surfaces of the six materials were presented by de Chalain (1979), his results being summarized here in figure 2.1.2.1b. In terms of wettability, the materials can be divided into metals and plastics, the latter having a higher hydrophobicity ($P < 0,05$). Since the wettability may change after exposure to seawater, the measurements were repeated after 48 hours immersion. The two groups, metals and plastics,

still differed significantly ($P < 0,05$). The contact angle hysterisis, the difference between advancing (maximum) and receding (minimum) contact angles, increased on all materials except on fibre glass. This is because on all materials, except on fibre glass, where the opposite was true, the advancing contact angle increased and the receding angle decreased, although these differences were not significant. de Chalain (1979) concluded that adsorbed molecular fouling, which had taken place during the 48 hours immersion, changed the hydrophobic properties of these substrata.

If adhesion of macro organisms is a function of surface energy as is indicated by Baier, Shafrin and Zisman's research (1968), it should be noted that in this respect silicon rubber should have a very low surface energy after prolonged exposure (four weeks or more), because organisms adhered weakly to it (easily became detached).

2.1.2.1(d) Chemical Analysis

Adsorbed organic substances (Weinof & Loeb, 1974) can include chemical releasing agents which induce exploring larvae to settle and metamorphose (Crisp & Meadows, 1962; Eiben, 1976; Knight-Jones & Crisp, 1953; Marshall, Stout & Mitchell, 1971; Müller & Buchal, 1973; Müller, Wieker & Eiben, 1976).

The nature of such adsorbed molecules could depend on the chemical structure of the substratum material. The element components of the six materials, as determined by de Chalain (1979), are listed in table 2.1.2.1. None of the materials contained high concentrations of toxic heavy metals. de Chalain (1979) found that the rate and degree of leaching of copper (4,5-33,9 gl^{-1}), cadmium (0-0,88 gl^{-1}) and zinc (35,8-59,8 gl^{-1}) were low, but that they could be concentrated 3000 to 4000 times by the primary film, sometimes rising well above the concentration levels considered toxic for some algae (Gadd & Griffiths, 1978). He concluded that these toxins were, however, deposited as biologically inactive inorganic metal salts, as extracellular organic complexes or as complexes with metal corrosion products. In the present investigation it is therefore assumed that, as far as the important macrofouling organisms are concerned, toxins did not approach harmful levels on the six test materials.

Table 2.1.2.5: Elemental analysis of the six substratum materials: A summary of the results obtained by de Chalain (1979) using an Energy Dispersive X-ray Analyzer (KEVEX) and an Atomic Absorption Unit.

Material	Main Constituents	Other components	Trace elements
Aluminium	Al	Mg	Cu
Stainless Steel	Fe, Cr, Ni	Mn, Mo	C, Al, Si, S
Mild Steel	Fe	C, Mn	Mo, Ni
Silicon Rubber	Si	Fe	Cl, Ca
Fibre Glass	Si, Al, K	Cl, Ca	Cu
Poly Vinyl Chloride	Cl	Al, Si, Ca, Ti	Fe

2.2. THE FOULING COMMUNITY

The four main factors, which this report on macrofouling is concerned with, are:-

a) Time of year.
b) Duration of substratum exposure.
c) Depth of immersion.
d) Substratum material.

Each of the factors will be dealt with in seperate sections, but substratum material is also discussed alongside each of the other three.

To familiarize the reader with the fouling organisms, a list of sessile species (table 2.2a) and non-sessile species (table 2.2b) is presented. The general relative abundance of all these organisms is presented in the appendix (table 4.2.1).

Note: (a) Certain abbreviations are used in this section. These are as follows:

(i) AL, SS, MS, SR, FG & PVC refer to the six materials: aluminium, stainless steel, mild steel, silicon rubber, fibre glass and polyvinylchloride.

(ii) Where data from different exposure periods, depths and different materials is compared, these variables are sometimes directly referred to, although it is, of course, the foul growth that is meant. e.g. "A weighed more than B" would mean that the macrofouling community on A weighed more per unit area than that on B.

(b) On graphic presentations the following system was sometimes used:- Although the X-variables represent a series of independant treatments (e.g. substratum material or time period), the data points are linked by a straight line. This does not imply a gradation from one to the other, but has been done to assist in the visual interpretation of data.

Table 2.2(a):- Sessile sublittoral fouling organisms in Simonsoay

Class	Group	Species
Hydrozoa	Sertulariidae	Sertularella arcuscula also: Amphisbetia operculata
	Tubulariidae	Tubularia warreni
	Plumulariidae	Plumularia setacea, P. lagenifera
		Nemertesia cymodocea
	Campanulariidae	Campanularia integra
		also: Obelia dichotoma
		(Eudendriidae:) Eudendrium sp.
Actiniaria	Sea-anemone	Anthothoe stimpsoni
		also: Bunodosoma capensis
Polychaeta	Sabellidae	Megalomma quadrioculatum
	Terebellidae	Nicolea macrobranchia
	Serpulidae	Hydroides elegans, Spirorbis sp.
	Other Polychaetes	Spionidae, other species
Cirripedia	Balanus amphitrite	
	Balanus maxillaris	
	Balanus trigonus	
Peracarida	Amphipoda (tubiculous)	Ericthonius brasiliensis
		also: Corophium acherusicum
		Ischyrocerus spp.
		Jassa falcata
		Aora sp.
		(Tanaidacea:) Tanais philetaerus
Bryozoa	Pale encrusting bryozoa	Membranipora spp.
		also: Escharoides contorta
		Figularia fissa
		Cryptosula pallasiana
		Gigantopora polymorpha
		Cellepora cylindriformis
		Beania spp.
	Dark encrusting bryozoa	Watersipora sp., Chaperia sp.
	Pale filamentous bryozoa	Menipea triseriata, also: M. crispa
	Dark filamentous bryozoa	Bugula neritina, also: B. dentata
	Stolonial bryozoa	Aetea sp?
Pelecypoda	Black mussel	Choromytilus meridionales
	Ribbed mussel	Aulacomya sp.
	Saddle oyster	Anomia sp.
	Other bivalves	Saxicava arctica, Tapes corrugata
		also: Tellimya rotunda
		Chlamys tinctus
		Gregariella sp.
		Lima rotundata

Tunicata	Purple compound ascidians	Diplosoma macdonaldi also: Botrylloides sp.
	Grey compound ascidians	Diplosoma listerianum
	Red bait	Pyura sp.
	Transparent sea-squirt	Ciona intestinalis also: Corella eumyota
	Greenish sea-squirt	Ascidia sydneiensis
	Other simple ascidians	Microcosmus sp., Molgula sp. Styela costata
Green & Brown Algae	Small balloons	Colpomenia sinuosa
	Small tufts	Ectocarpus sp.
	Other algae	Dictyota sp., Bryopsis sp. Ecklonia maxima, Ulva sp.
Red Algae	Red algae	Polysiphonia sp., Champia sp. Agardhinula sp?, other species
Diatoms	Colonial diatoms	Licmophora flabellata
Porifera	Sponge	Leucosolenia arachnoides?

Table 2.2(b):- Non-sessile organisms associated with a sublittoral fouling community in Simonsbay

Class	Group	Species
Polychaeta	Aphroditidae	Lepidonotus semitectus
	Nereidae	Nereis operta
	Other Polychaetes	Phyllodocinae, Syllidae
		Phoeloe minuta, Lumbrinereis sp.
Crustacea	Isopoda	Cirolana obtusispina
		Cymodocae comans
	Amphipoda	Paramoera capensis, Caprella cicur
		Laetmatophilus purus
		Amaryllis macrophthalma
	Decapoda	Plagusia chabrus, Jasus lalandii
		Diogenes sp., other species
Arachnida	Pycnogonida	Tanystylum brevipes
Gastropoda	Nudibranchia	Facelina olivacea, Janolus capensis
		Archidoris granosa, Doto sp.
	Other gastropods	Argobuccinum argus, Oxystele sp.
		Crepidula porcellana
		Polycera nigrocea, Fissurella mutabilis
Cephalopoda	Octopus	Octopus granulatus
Echinoderm	Crinoidea	Comantnus wahlbergi
		Annametra occidentalis?
	Echinoidea	Parechinus angulosus
	Asteroidea	Marthasterias glacialis
	Ophiuroidea	Ophiothrix triglocnis
	Holothuroidea	Thyone sp.
Sipunculida	Peanut-worm	
Platyhelmintnes	Flat-worm	Thysanozoon sp.
Nemertea	Proboscis-worm	Lineus sp.?

2.2.1. Numerical analysis

In this section the contrasts and interactions between the factors will be described with respect to the numbers of fouling organisms.

The thirty six species and species groups of sessile organisms can be of different magnitudes of size and can occupy different micro-habitats. For example, a single individual of the simple ascidian, Pyura, can occupy more volume and surface area than a thousand zooids of the compound ascidian, Diplosoma. However in assessing the degree to which each of the four factors influences a species or species group, the emphasis should be on the numbers of individuals, rather than their relative importance as far as fouling severity is concerned. To examine the actual details of the community constituents, the various components should not be weighted or arranged in an "impact hierarchy" (Field, pers. comm.). A weighted analysis is carried out in later sections, where the space occupied by the main community components is compared. Hurlbert (1971) sounds a note of caution that neither abundance, nor space occupation necessarily determine the importance of a species per se, but that its importance is related to the effect it has on the productivioty of all other species in the community.

In presenting the numerical data, it has been split up according to substratum material and site. Each data matrix for all organisms on each replicate sample of a specific material, which had been exposed at a site (see fig. 2.2.1.1.a-m), was processed with cluster analysis. This was designed to show:-

(i) the similarity of replicates relative to seperate treatments
(ii) the contrast or similarity of different treatments i.e. various times and duration of exposure.

This analysis, the results of which are presented on dendrograms in the appendix (fig. 4.1.3.1.a-m), is complementary to the data presented in figure 2.2.1.1.a-m, so that the visual interpretation of these figures could assist in explaining the main contrasts or similarities identified between the temporal treatments.

In a similar way, the data was divided according to time and duration of exposure so that the substratum materials at both depths of exposure could be compared. This would show:-

(i) whether replicates of materials were more alike to each other than to other materials

(ii) the contrast of communities at different depths on different materials.

The results of this analysis are presented on dendrograms in appendix figure 4.1.3.2a-l, and are interpreted here along with figure 2.2.1.1a-m to identify the organisms that were apparently responsible for producing the main contrasts.

The way tables 2.2.1.1 & 2, which show the results of the visual interpretation, were derived at can be illustrated by an example for aluminium at Site 1. The dendrogram on appendix figure 4.1.3.1.a shows that all replicates from June and July had less than 25% similarity to samples from other months. An examination of the corresponding figure 2.2.1.1.a shows that this high contrast (or dissimilarity) can be attributed to fewer species and lower numbers of organisms during June and July. Of the other samples, the exposure periods of three months, December to February, nine and twelve months had, collectively, 73% dissimilarity (27% similarity) with all other periods (figure 2.2.1.1.a), much of this apparently being due to differences in the relative numbers of Balanus trigonus and Pyura. In a similar way, by identifying further groups that are in contrast with other groups on the dendrograms in figures 4.1.3.1 & 2 and cross-referring to the corresponding figure 2.1.1.1 to locate some of the main sources of dissimilarity, tables 2.2.1.1 & 2 were drawn up.

This method, although a useful statistical technique for seperating the impact of various factors, does not include a significance test. Conclusions can therefore only be drawn where replicate samples were more alike to each other than to other samples or where clusters contained a mixture of samples from compatible treatments (e.g. material X exposed at site Y for 1 month during September to November). However, where replicate samples were scattered over many clusters, linked at a low similarity level, nothing can be said about them or they appear as "mixed" on tables 2.2.1.1. & 2.

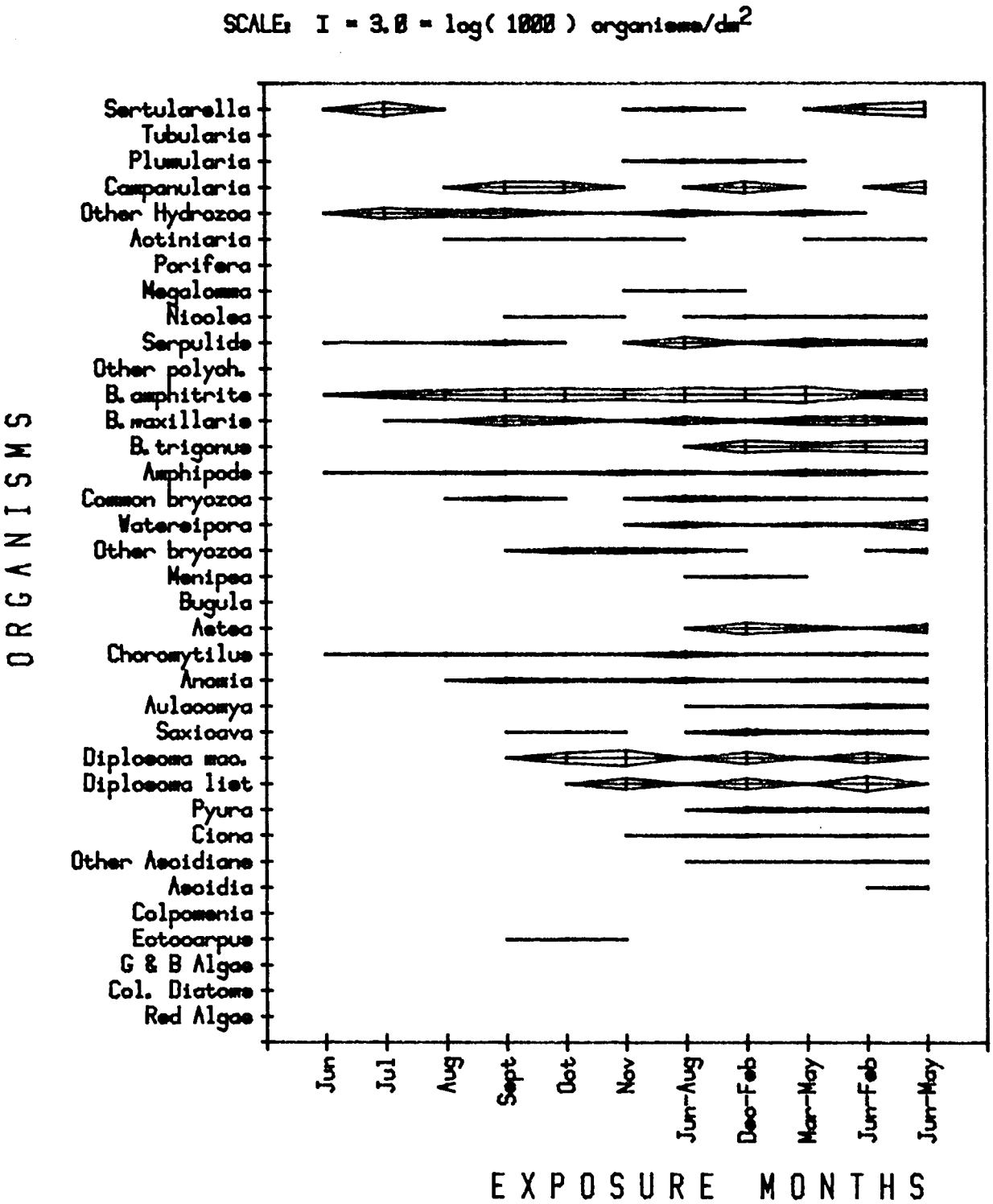


Fig 2211a : Number of organisms (log[X+1]) that settled on Aluminium plates which were immersed at Site 1 (20m) during different months.

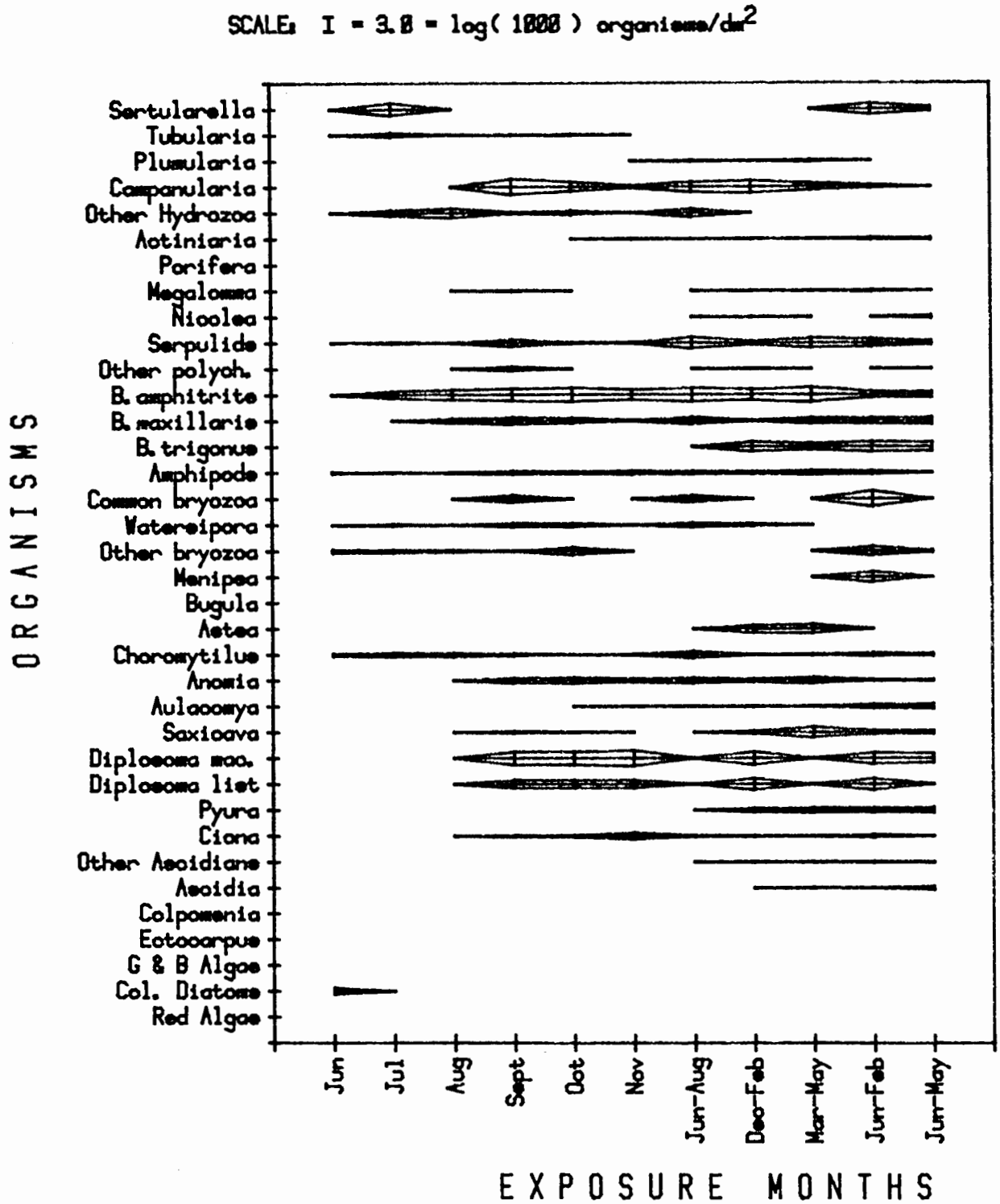


Fig 2211b : Number of organisms (log[X+1]) that settled on Stainless Steel plates which were immersed at Site 1 (20m) during different months.

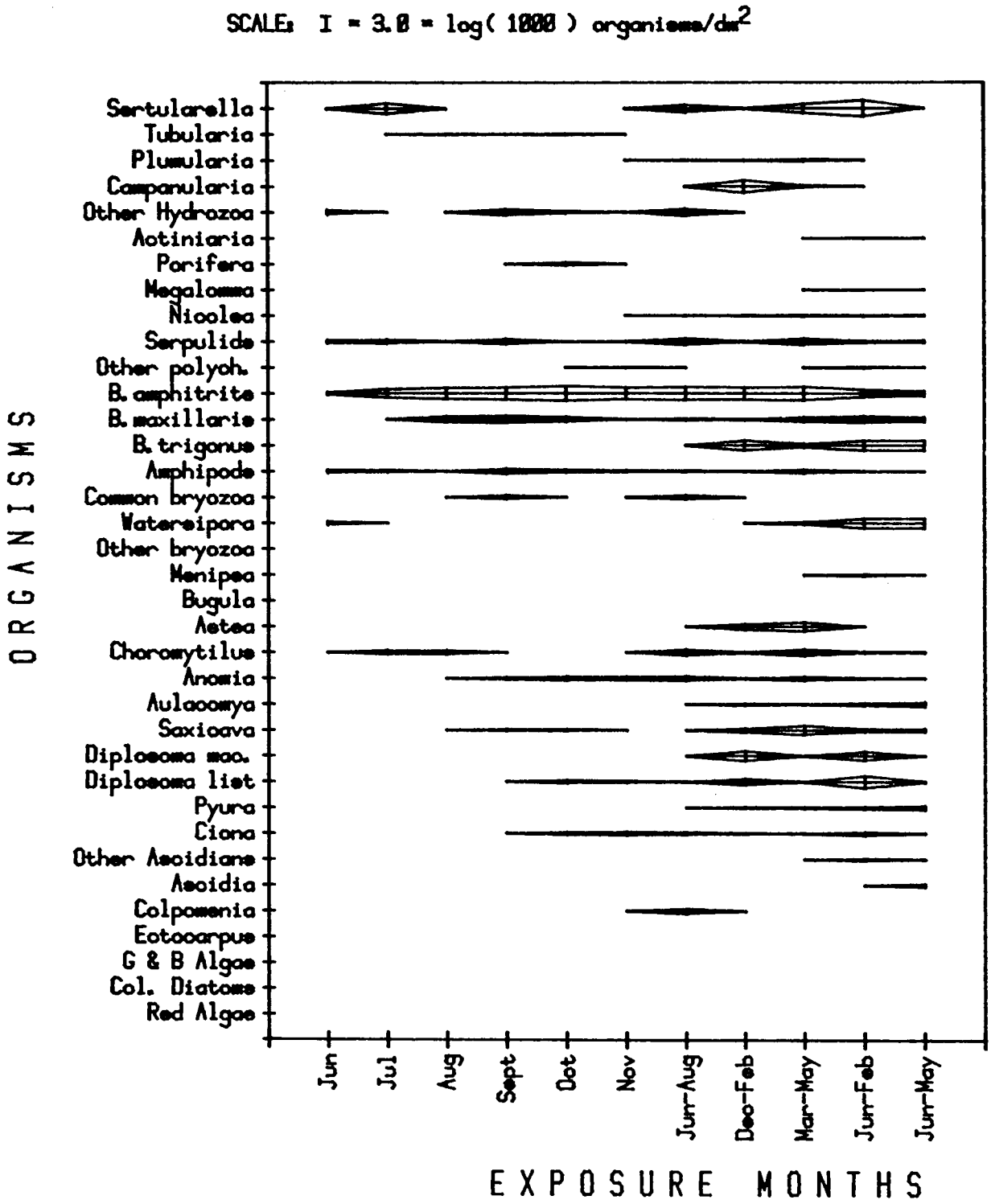


Fig 2211c : Number of organisms (log[X+1]) that settled on Mild Steel plates which were immersed at Site 1 (20m) during different months.

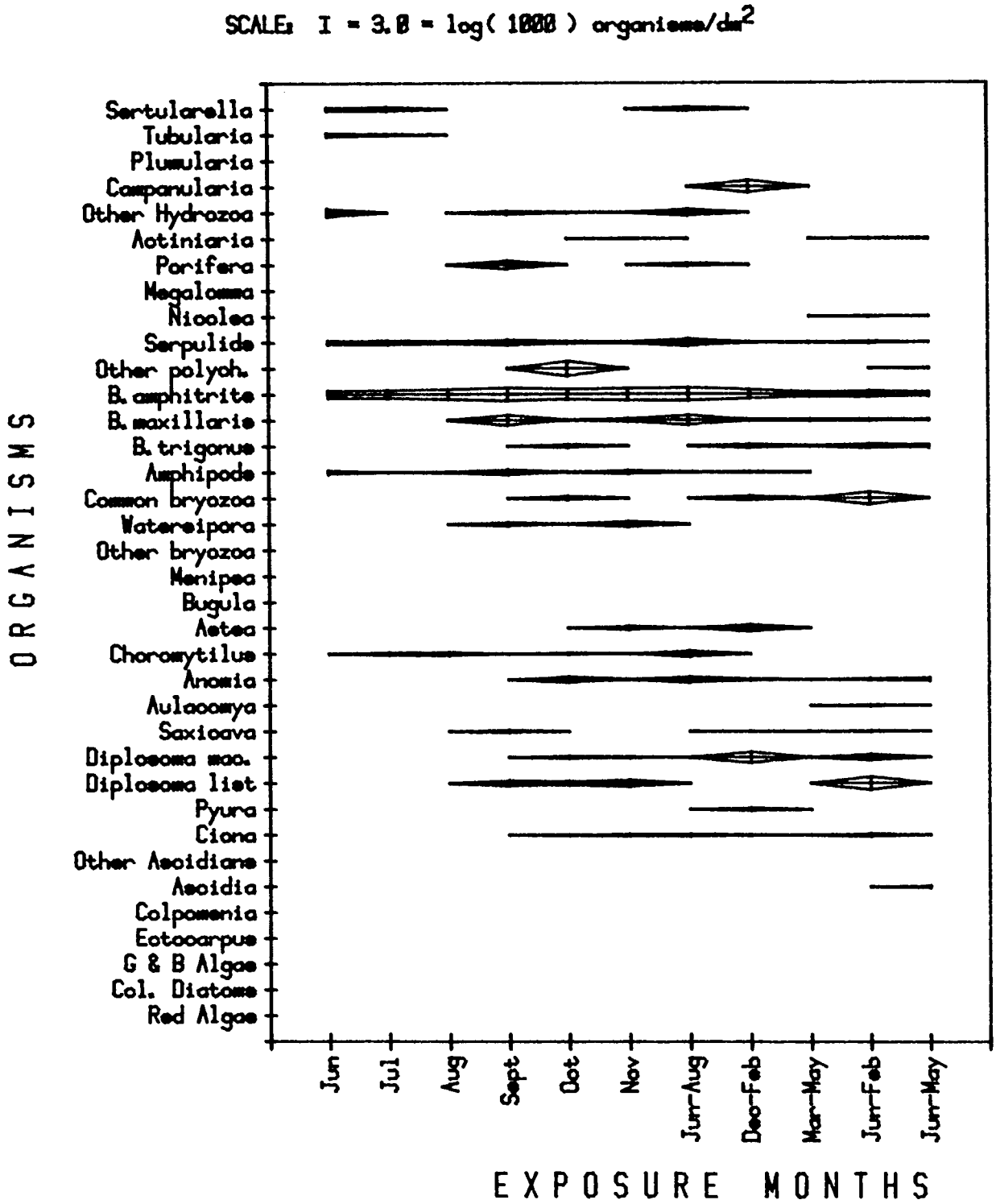


Fig 2211d : Number of organisms (log[X+1]) that settled on Silicon Rubber plates which were immersed at Site 1 (20m) during different months.

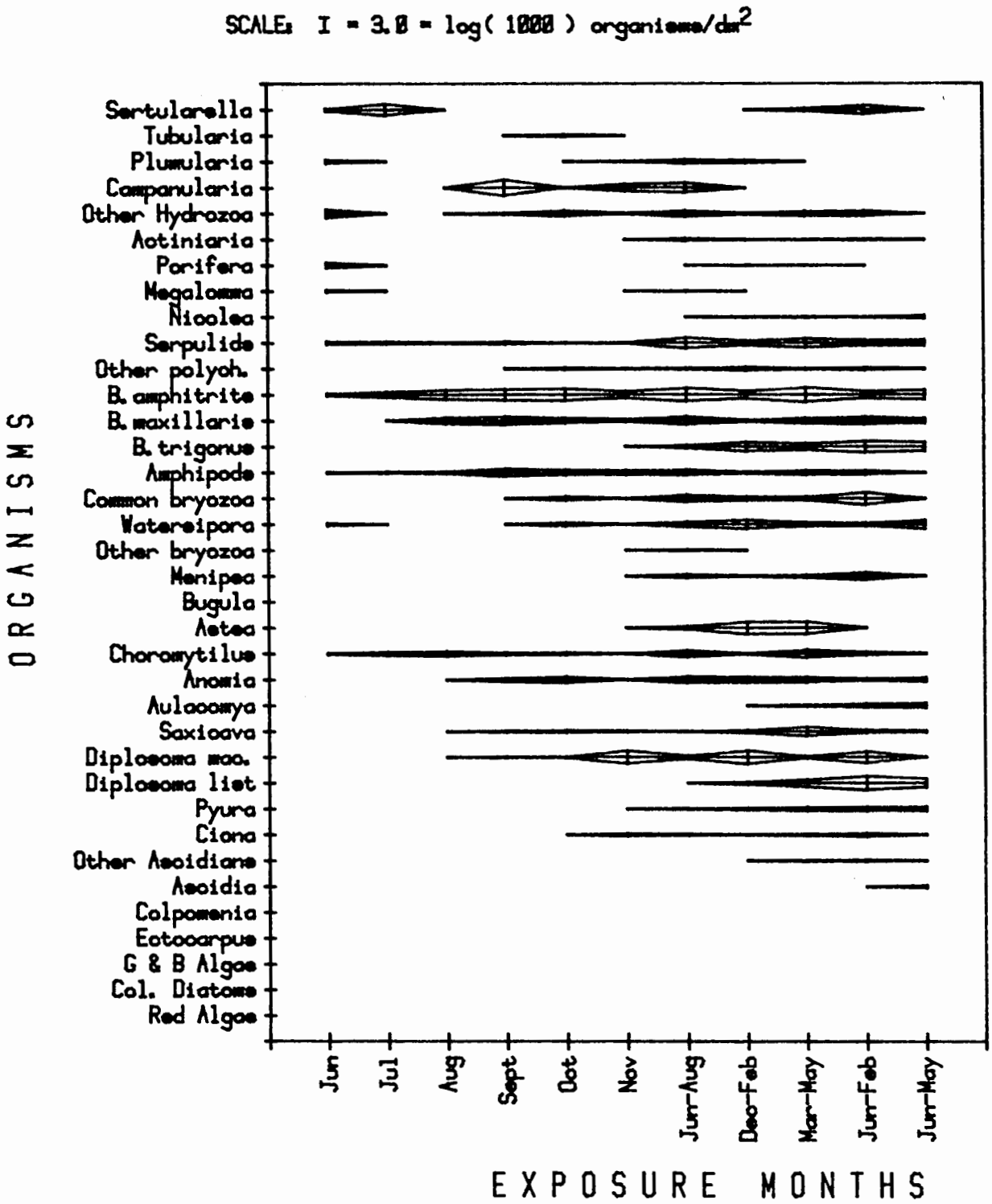


Fig 2211e : Number of organisms (log[X+1]) that settled on Fibre Glass plates which were immersed at Site 1 (20m) during different months.

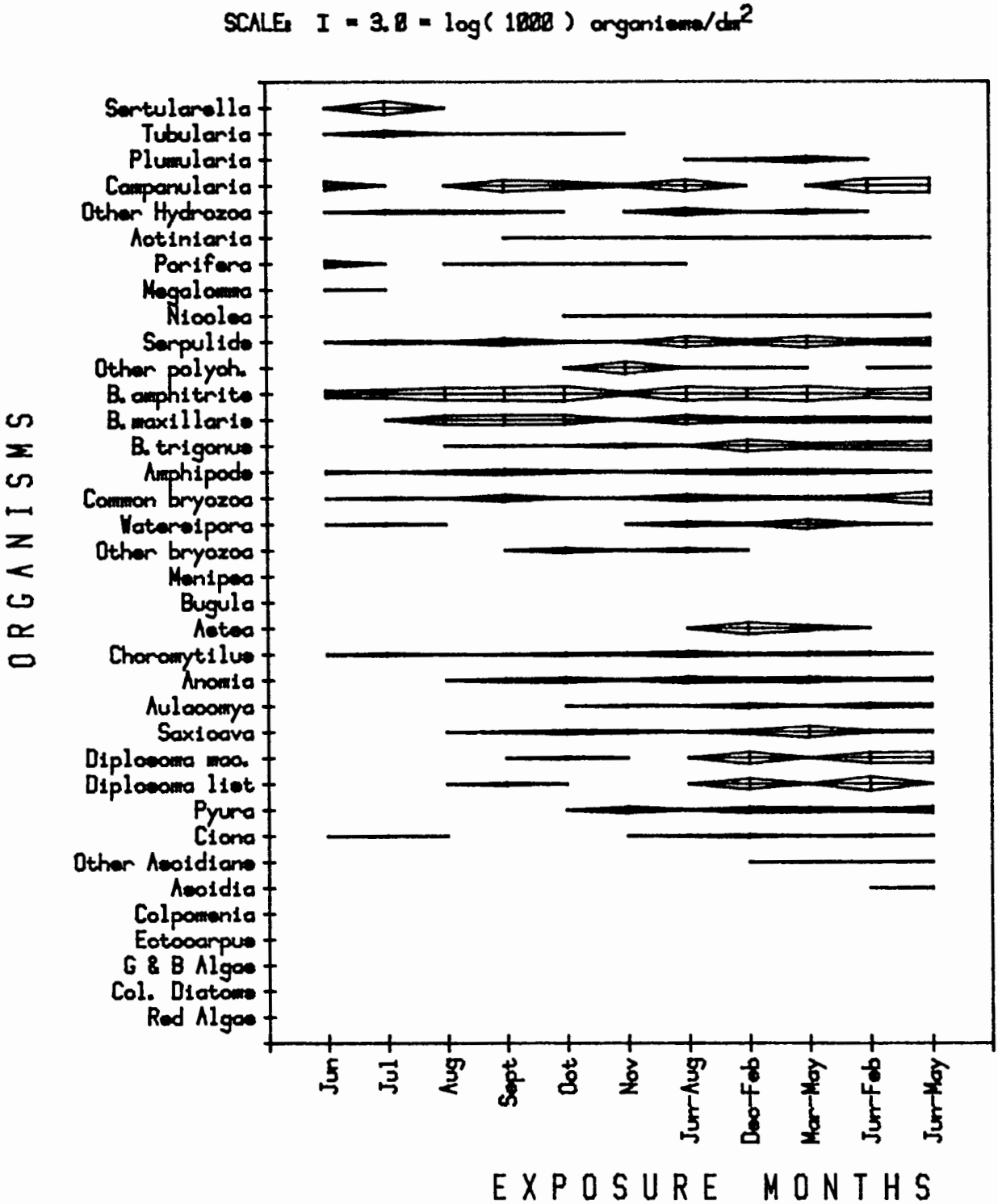


Fig 2.11f : Number of organisms (log[X+1]) that settled on P.V.C plates which were immersed at Site 1 (20m) during different months.

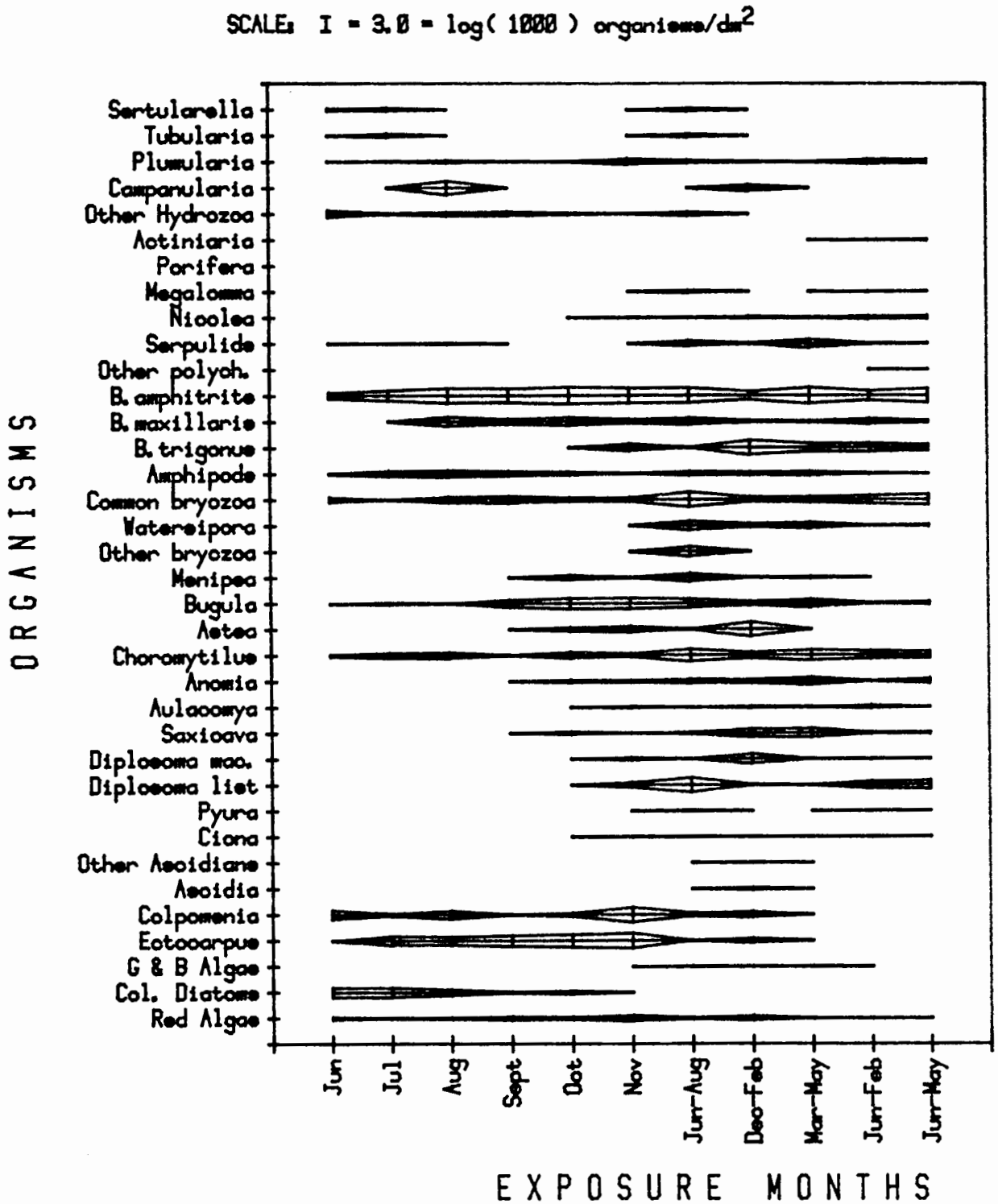


Fig 2211g : Number of organisms (log[X+1]) that settled on Aluminium plates which were immersed at Site 2 (10m) during different months.

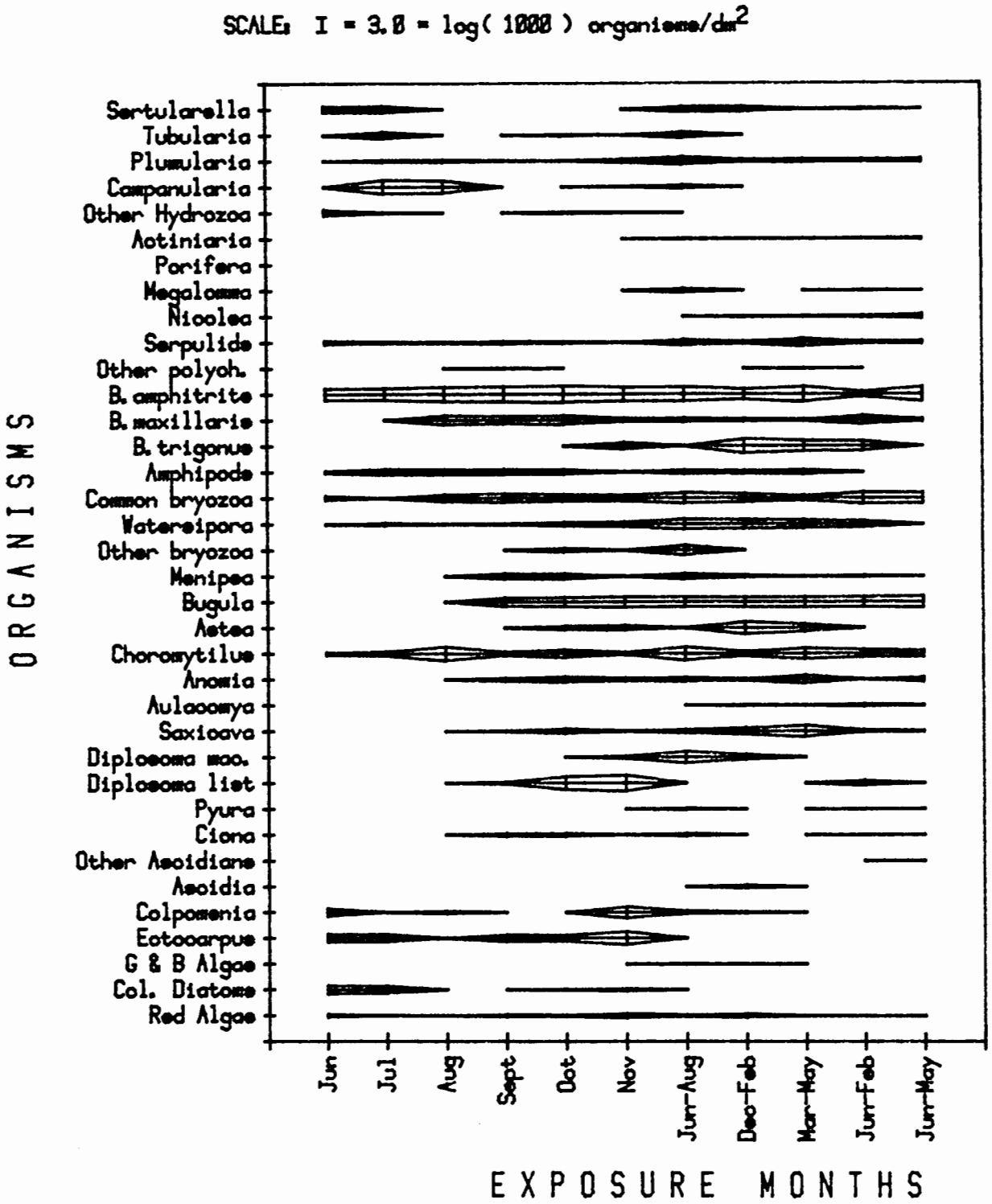


Fig 2211h : Number of organisms (log[X+1]) that settled on Stainless Steel plates which were immersed at Site 2 (10m) during different months.

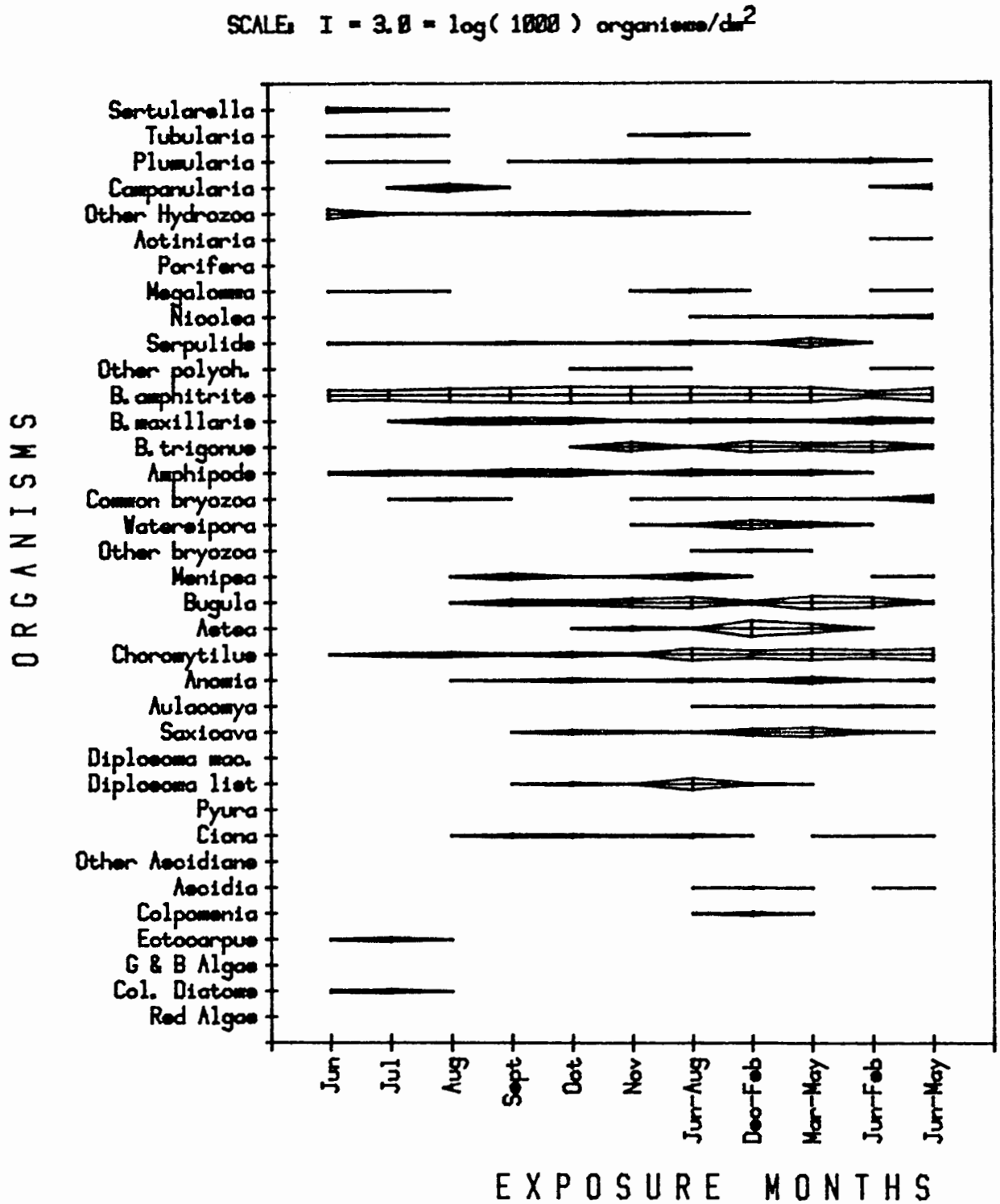


Fig 2211i : Number of organisms (log[X+1]) that settled on Mild Steel plates which were immersed at Site 2 (10m) during different months.

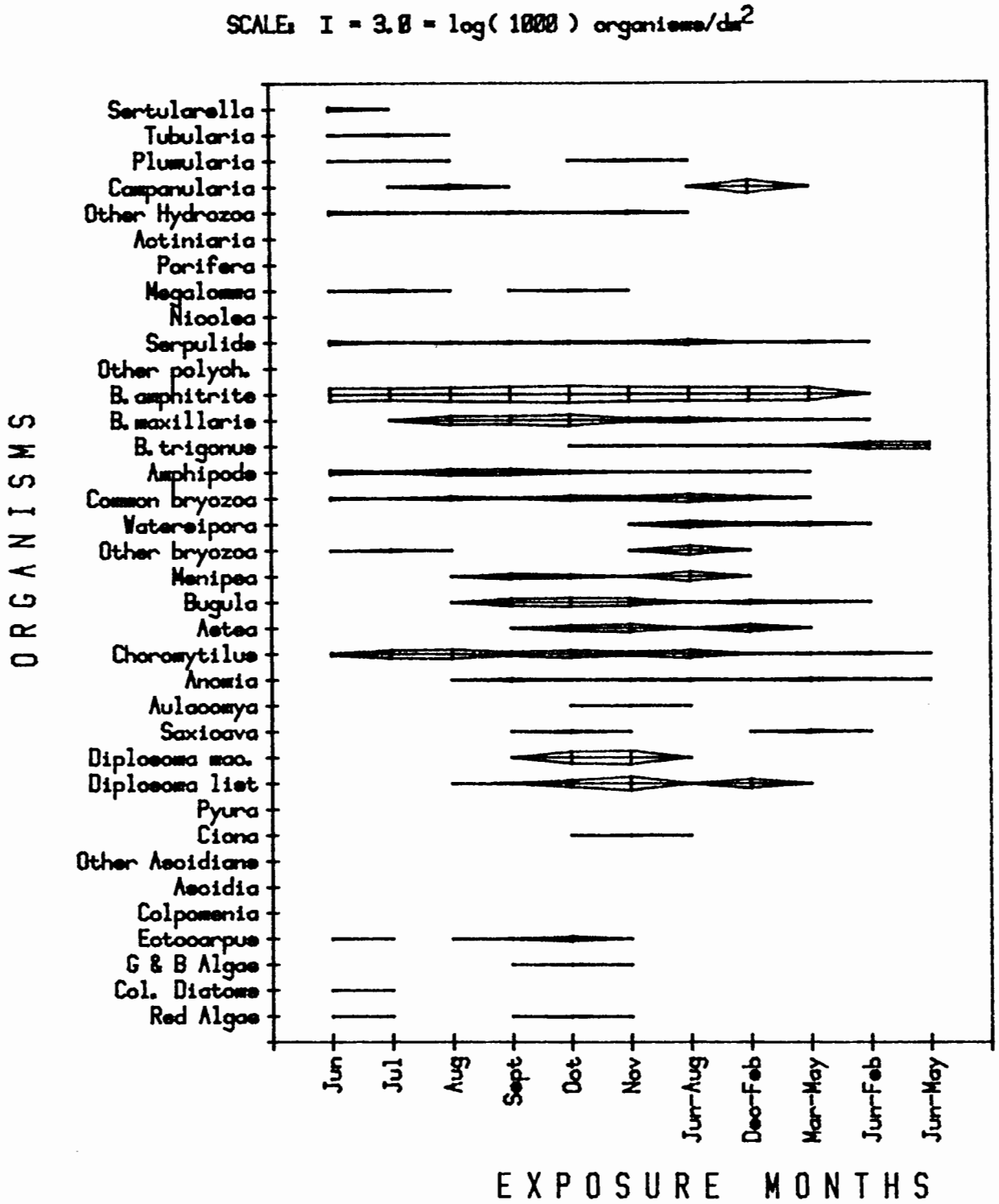


Fig 2211k : Number of organisms (log[X+1]) that settled on Silicon Rubber plates which were immersed at Site 2 (10m) during different months.

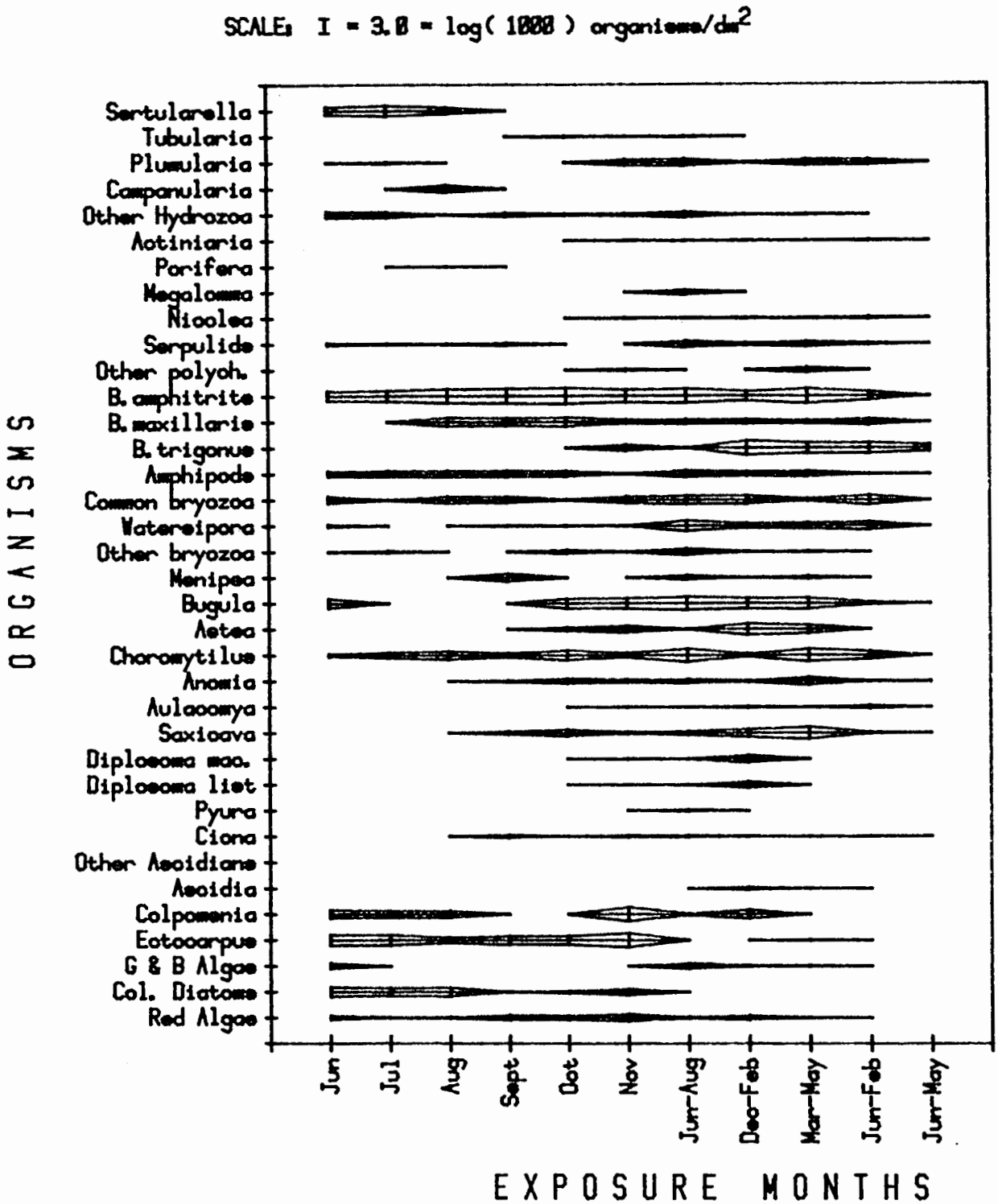


Fig 22111 : Number of organisms (log[X+1]) that settled on Fibre Glass plates which were immersed at Site 2 (10m) during different months.

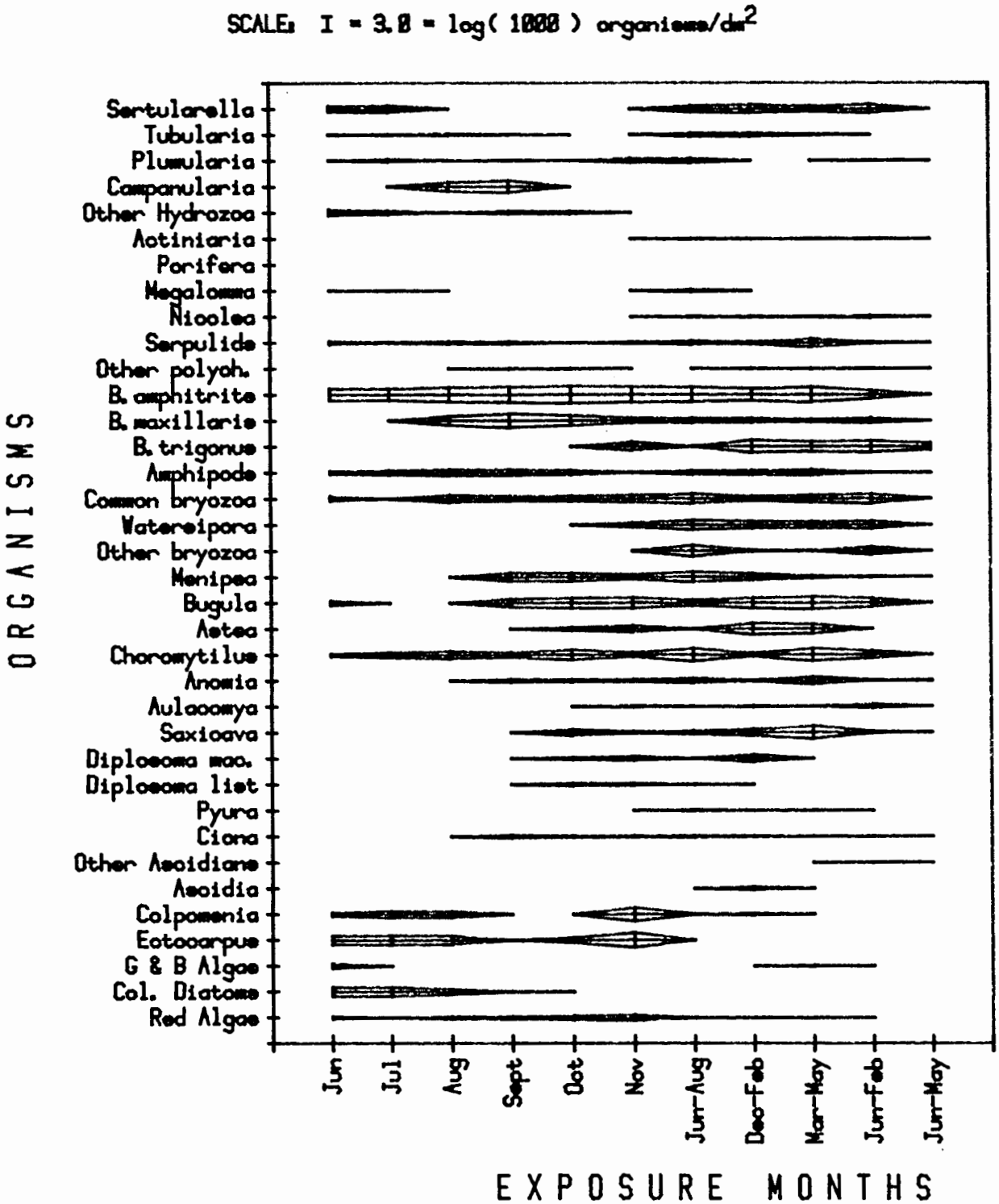


Fig 2211m : Number of organisms (log[X+1]) that settled on P.V.C. plates which were immersed at Site 2 (10m) during different months.

In interpreting table 2.2.1.1., emphasis should be laid on the major contrasts. Sometimes the clustering was inconsistent and differences are difficult to identify e.g. Silicon Rubber in various time periods at both sites. Similarly, when comparing the materials and sites (table 2.2.1.2.), the differences between contrasting elements, especially between AL, SS, FG & PVC, were not easily apparent and usually involved differences between the less important fouling organisms.

When comparing the different times and durations of panel exposure, the clusters were sometimes similar for different materials. These consistent clusters are important for identifying seasonal or successional trends. For example, on all materials exposed at Site 1, the fouling constituents after the three periods, December to February (3 months), June to February (9 months) and June to May (12 months), were similar to each other. They were in contrast to many of the other elements mainly because more Balanus trigonus and more ascidians and possibly less Balanus amphitrite were present. This may indicate that the prevailing fouling conditions during summer (December to February) favour the development of the type of community developing on panels exposed for 9 and 12 months. This suggests that the long-term development of the community may not be a true causal succession, but is probably a seasonal succession depending on breeding season and patch history (space availability). Such a situation would agree with the findings of McClurg (1969) in Simonsbay and Millard (1952) in Table Bay.

The more important contrasts identified for all materials, except silicon rubber, at Site 1 (table 2.2.1.1.a), are:-

(i) June and July differ markedly from other months because few species and few individuals settled during these months.

(ii) The community constituents after three months, December to February, nine months and twelve months were similar and differed from other exposure periods by having more Balanus trigonus and ascidians.

(iii) Although more Hydroides elegans and Campanularia integra settled during September and less Balanus and more Diplosoma during November, the four one-month exposure periods, August, September, October, November, were broadly similar.

(iv) The 3-month exposure periods, June to August and March to May, differed from other periods because more Hydroides elegans, Choromytilus meridionales and Balanus maxillaris had settled, and differed from each other because more Balanus trigonus, Saxicava arctica and Tellimya rotunda were present during the latter period.

At Site 2, the general grouping of exposure periods was not so similar on different materials as at Site 1. The major contrasts, except for silicon rubber, were:-

(i) Fewer organisms settled during June to July, so that these two months are in contrast to later months.

(ii) More Choromytilus, serpulids and Diplosoma and less algae were present after 3, 9 and 12-month exposure periods than after 1-month periods.

(iii) Bivalves and filamentous bryozoa were responsible for much of the contrast between the 3-month and other exposure periods.

(iv) The 12 and 9-month exposure periods were generally fairly similar to each other, but differed by there being more B.amphitrite and less B.trigonus on AL, SS and MS and less Choromytilus and B.amphitrite and more B.trigonus on FG and PVC during the latter.

(v) August, September and October were fairly alike and could only be seperated at high similarity levels.

(vi) November differed from the other 1-month exposure periods because of peak settlements of algae, the onset of the Balanus trigonus settling period and a decline in bivalve numbers.

Contrasts are more difficult to identify when comparing the substratum materials and sites for each exposure period. The main features that can be seen on table 2.2.1.2. are:-

(i) The fouling communities at Site 1 and Site 2 were markedly dissimmilar because more algae, bryozoa and Choromytilus and less ascidians occured at the latter.

(ii) It is difficult to identify consistent contrasts between materials at Site 1 after one month's exposure.

(iii) At Site 2, SR and MS differed from other materials after one month's exposure, because very few algae were attached to them.

(iv) Although differences could be identified in some months, the contrasts between fouling communities on AL, SS, FG and PVC after one month's exposure were not consistent. It therefore appears that the initial settlement response of most organisms does not seem to differ on these substrata.

(v) SR is in high contrast to other materials at both sites after 3, 9 and 12-month exposure periods because the fouling community does not appear to develop beyond the stage reached after one month.

(vi) All other materials exposed for 3 months did not seem to be in high contrast to each other, although MS could differ by the number of barnacles and serpulids.

(vii) After 9 and 12 months at Site 1, more Campanularia appeared to settle on PVC and more Sertularella on AL than on other materials. In general the contrasts between the fouling communities on all materials, except SR, at each site, were not consistent.

Table 2.2.1.1.

Contrasts of clusters identified in dendrograms (fig. 4.1.3.1.a-m). Results from replicate panels of each material are compared relative to time and duration of exposure. In each of the cells, the contrasts are shown in their hierarchy of importance. (e.g. The expressions following the label 'a' are in higher contrast or at a lower similarity level than those following 'b'.)

Expressions and abbreviations are defined as follows:-

"rest" = all elements not appearing in previous parts of the expression or at a higher contrast level

"mixed" = replicate samples of the element are scattered and not much alike to each other.

Jun, Jul, Aug, Sep, Oct, Nov = month of one-month exposure

JA3 = 3-month exposure, June to August
DF3 = 3-month exposure, December to February
MM3 = 3-month exposure, March to May
1 = all 1-month periods of exposure
3 = 3-month periods of exposure
9 = 9-month exposure, June to February
12 = 12-month exposure, June to May
\+ = contrasting species associated with first element
\- = contrasting species associated with second element.

Table 2.2.1.1.a - Site 1

Material	Level	+ Elements	- Contrasting Elements	Contrasting Organisms
AL	a	Jun	rest	few species, low numbers
	b	Jul	rest	few species, low numbers
	c	12,9,DF3	rest	+B.trigonus, +Pyura
	d	12	9,DF3	+Sertularella, +Chaperia, -Diplosoma
	e	9	DF3	-Aetea, -Campanularia, +Sertularella
	d'	Nov	MM3, JA3, Aug, Sep, Oct	+Diplosoma
	e'	Aug	Sep, JA3, MM3	-Serpulids, -B.maxillaris
	f	JA3	MM3	-B.trigonus, +Serpulids
		Sep, Oct	mixed	-
SS	a	Jun	rest	few species, low numbers
	b	Jul, Aug	12, 9, 3 Sep, Oct	few species, low numbers
	c	12, 9, DF3	MM3, JA3	+Diplosoma, -Serpulids
	d	DF3	12, 9	-Sertularella, +Campanularia, -Bryozoa
	e	12	9	-Bryozoa
	d'	MM3	JA3	+Saxicava, +B.trigonus
		Sep, Oct, Nov	mixed	-
MS	a	Jun	rest	few species, low numbers
	b	12, 9, DF3	rest	+Diplosoma, +B.trigonus
	c	DF3	12, 9	+B.amphitrite, +Campanularia
	d	12	9	-Sertularella, -Diplosoma, +Ascidia
	c'	MM3, JA3, Jul	Aug, Sep, Oct, Nov	+Sertularella
	d'	Jul	MM3, JA3	-B.amphitrite, -Anomia, -Saxicava
	e'	MM3	JA3	+Saxicava, +Aetea
	d"	Oct, Nov	Aug, Sep	+Hydrozoa, -Serpulids, -Choromytilus
	e"	Oct	Nov	+B.maxillaris
	e"'	Aug	Sep	-Serpulids, -Hydrozoa
SR	a	12,9	rest	-Balanus
	b	DF3	rest	+Diplosoma macdonaldi, +Campanularia
	c	MM3, Jun, Jul, Aug	JA3, Sep, Oct, Nov	-B.maxillaris, -Diplosoma listerianum,
	d	MM3	Jul, Aug	-Hydrozoa
	d'	Nov	JA3, Sep, Oct	?
	e	Sep	JA3, Oct	?
	f	JA3	Oct	?

	a	Jun, Jul	rest	few species, low numbers
	b	12, 9, DF3	rest	+B.trigonus, -B.amphitrite
	c	DF3	12,9	-Diplosoma listerianum, -Bryozoa, +Aetea
	d	12	9	-Sertularella, -Bryozoa, -Diplosoma mac
FG	c'	MM3, JA3	Aug, Sep, Oct, Nov	+Choromytilus, +Serpulids
	d'	MM3	JA3	+Aetea, +Saxicava, +B.trigonus
	d"	Aug	Sep, Oct	-Anomia
	e	Sep	Oct	+Campanularia
	a	Jun, Jul	rest	+Sertularella, -Balanus, -Ascidians
	b	12, 9, DF3	rest	+Diplosoma, +B.trigonus
	c	DF3	12, 9	+Aetea, -Campanularia
	d	12	9	+Bryozoa, -Diplosoma listerianum
PVC	c'	Nov	MM3, JA3, Aug, Sep, Oct	+Pyura, -Balanus, +Polycnaetes
	d'	MM3, JA3	Aug, Sep, Oct	+Bryozoa, +Serpulids, +Choromytilus
	e	MM3	JA3	+Saxicava
	e'	Aug	Sep, Oct	-Campanularia, -Anomia
	f	Sep	Oct	+Serpulids

Table 2.2.1.1.b - Site 2

Material	Level	+ Elements	- Contrasting Elements	Contrasting Organisms
AL	a	Jun	rest	-B.amphitrite, -Ectocarpus
	b	12, 9, 3	1	+Serpulids, +Choromytilus, +Diplosoma, -Colpomenia, -Ectocarpus
	c	DF3	12, 9, JA3, MM3	+B.trigonus, +Aetea
	d	MM3, JA3	12, 9	+Serpulids, +Bugula, +Choromytilus
	e	MM3	JA3	+B.trigonus, -E.Bryo, +Saxicava, -Diplosoma
	e'	12	9	+B.amphitrite, +E.Bryo
	c'	Jul	Aug, Sep, Oct, Nov	-B.maxillaris
	d'	Nov	Aug, Sep, Oct	+Colpomenia, +B.trigonus
	e"	Sep	Aug, Oct	-Colpomenia, -Choromytilus
	f	Aug	Oct	-Bugula, +Campanularia
SS	a	Jun, Jul	rest	-B.maxillaris, -Bryozoa, -Bivalves
	b	Jun	Jul	-Campanularia, +Colpomenia
	b'	Nov	rest	+Diplosoma, +Ectocarpus, +Colpomenia
	c	MM3, DF3, 9	12, JA3, Aug, Sep, Oct	+B.trigonus
	d	9	MM3, DF3	-B.amphitrite, +B.maxillaris, +E.Bryo
	e	DF3	MM3	-Saxicava, +Aetea
	d'	JA3	12, Aug, Sep, Oct	+Diplosoma, +Watersipora, +Plumularia
	e'	Aug	12, Sep, Oct	+Choromytilus, -Bugula, +Campanularia
	f	12	Sep, Oct	-Algae
MS	a	Jun	rest	few species, low numbers
	b	12, JA3, Aug, Sep, Oct	9, MM3, DF3, Nov	+B.trigonus
	c	12, Aug	JA3, Sep, Oct	-Bugula, +Campanularia
	d	12	Aug	+Choromytilus, +E.Bryo
	d'	JA3	Sep, Oct	+Diplosoma, +Choromytilus, -B.maxillaris
	e	Sep	Oct	-Bivalves, +Menipea
	c'	9	MM3, DF3, Nov	-B.amphitrite, +B.maxillaris
	d"	Nov	MM3, DF3	-Watersipora, -Aetea, -Bivalves
	e'	MM3	DF3	+Bugula, +Serpulids, -Aetea

	a	12,9	rest	+B.trigonus, -other species
	b	Nov, DF3	rest	+Diplosoma, +Aetea
	c	MM3, Jun, Jul	Aug, Sep, Oct	-B.maxillaris
SR	d	Jul	MM3, Jun	?
	e	MM3	Jun	?
	d'	Oct	Aug, Sep	?
	e'	Aug	Sep	?
	a	12, 9, MM3, DF3	JA3, 1	+B.trigonus, -Algae
	b	12,9	MM3, DF3	-Bugula, -Aetea, -Saxicava
	c	12	9	-B.amphitrite, -Choromytilus, -E.Bryo
	c'	MM3	DF3	+Bivalves, -Plumularia, -Colpomenia
FG	b'	Jun, Jul, Nov	JA3, Aug, Sep, Oct	+Colpomenia, +Ectocarpus, -B.maxillaris
	c"	Nov	Jun, Jul	-Sertularella, -Amphipods, +Colpomenia
	d	Jun	Jul	+Bugula
	c"'	JA3	Aug, Sep, Oct	+E.Bryo, -B.maxillaris, +Polychaetes
	d'	Sep	Aug, Oct	+Menipea, -Choromytilus
	e	Aug	Oct	-Saxicava, -Hydrozoa
	a	Jun, Jul	rest	-B.maxillaris, -E.Bryo, -Bivalves
	b	12	rest	-B.amphitrite, -Bivalve
	c	9, MM3, DF3 Nov	JA3, Aug, Sep, Oct	+B.trigonus
PVC	d	Nov	9, MM3, DF3	+Algae, -Sertularella
	e	9	MM3, DF3	-Saxicava, -Aetea, +E.Bryo
	f	MM3	DF3	+Serpulids +Choromytilus
	d'	JA3	Aug, Sep, Oct	+E.Bryo, -B.maxillaris
	e'	Aug	Sep, Oct	-F.Bryo
	f'	Sep	Oct	+Campanularia, +Saxicava

Table 2.2.1.2.

Contrasts of clusters identified in dendrograms (fig. 4.1.3.2.a-l). Results from replicate panels from each period of exposure are compared relative to substratum material and depth of immersion. Expressions are as defined for table 2.2.1.1. Site 1 = all samples from 20m depth; Site 2 = all samples from 10m depth.

Material	Level	+ Elements	- Contrasting Elements	Contrasting Organisms
June	a	PVC1, SR1, MS2, SR2	AL2, SS2, FG2, PVC2	-Algae
	b	PVC1	SR1, MS2, SR2	+Campanularia
	b'	AL2	PVC2, SS2, FG2	-B.amphitrite
	c	FG2	SS2	+Bugula
		AL1, SS1, MS1, FG1	mixed	-
July	a	Site 1	Site 2	-Algae
	b	FG2, SS2	SR2, MS2	+Algae
		Site 1	mixed	-
August	a	Site 1	Site 2	-Algae
	b	AL1, SR1	PVC1, FG1, MS1	-B.maxillaris
	c	PVC1	MS1, FG1	+Bryozoa
	b'	PVC2, FG2, AL2	MS2, SR2, SS2	+Algae
Sept	a	Site 1	Site 2	-Algae, -Bryozoa
	b	SS1	AL1, MS1, SR1, FG1, PVC1	+Diplosoma
	c	PVC1	MS1, SR1	+Campanularia, +B.trigonus
	d	MS1	SR1	-Porifera
	b'	AL2	PVC2, FG2	+Ectocarpus, -Bivalves
	c'	FG2	PVC2	-Campanularia, +Bugula
		AL1, FG1	mixed	-
Oct	a	Site 1, MS2	rest Site 2	-Algae, -Bryozoa
	b	SR1	MS2	+Polychaetes, -Bugula
	b'	SR2	AL2, SS2, FG2, PVC2	-Ectocarpus, +Diplosoma mac.
	c	PVC2, SS2	FG2, AL2	?
		AL1, SS1, MS1, FG1, PVC1	mixed	-
Nov	a	Site 1	Site 2	-Algae, -Bryozoa
	b	SR2, MS2	AL2, SS2, FG2, PVC2	-Algae
	c	AL2	FG2	+Diplosoma
		Site 1	mixed	-

Jun-Aug	a	Site 1, SR2	rest Site 2	-Algae, -Choromytilus
	b	SR2	Site 1	+Bryozoa
	c	MS1	rest Site 1	-Serpulids, -B.maxillaris
	d	SR1	SS1, FG1, PVC1	-E.Bryo
	b	MS2	FG2, SS2	-Hydrozoa, +Diplosoma list.
		SS1, FG1, PVC1 AL1	mixed	-
Dec-Feb	a	SR2	rest	-B.trigonus
	b	Site 1	Site 2	-Algae
	c	FG1	AL1, SS1, MS1, PVC1	+E.Bryo
	d	PVC1	MS1, AL1	-Campanularia
		MS1, AL1, SS1	mixed	-
		Site 2	mixed	-
Mar-May	a	SR1	rest	few species, low numbers
	b	SR2	rest	few species, low numbers
	c	AL1	Site 2	-Bivalves, -Bugula
	d	SS1, FG1	Site 2	-Bryozoa, -Choromytilus
	e	FG2	AL2, MS2, PVC2	?
	f	AL2	MS2, PVC2	-Aetea
	g	PVC2	MS2	+B.trigonus
Jun-Feb	a	SR2	rest	few species, low numbers
	b	Site 1	Site 2	-Choromytilus, +Ascidians
	c	SR1	Site 1	-Balanus
	d	PVC1	AL1, SS1, MS1, FG1	+Campanularia, -Sertularella
	e	SS1	AL1, MS1	+Bryozoa, +Serpulids
	f	MS1	AL1	+Chaperia
		Site 2	mixed	-
Jun-May	a	SR1	rest	few species, low numbers
	b	Site 1	Site 2	-Choromytilus, +Hydrozoa, +Ascidians
	c	PVC1	AL1, SS1, MS1, FG1	+Bryozoa, +Campanularia
	d	AL1	SS1, MS1, FG1	+Sertularella, +Aetea
	c'	PVC2, MS2	AL2, SS2, FG2	?
	d'	PVC2	MS2	-Choromytilus, -B.amphitrite
	d"	SS2	AL2, FG2	?

2.2.2. Time of year

If the experiments are repeated during different times of the year, are the results for each material and each site different? In temperate waters, where seasonal temperature fluctuations are evident, many benthic species have seasonal reproductive patterns. A seasonal progression of fouling organisms, especially of those with a short longevity, is therefore the normal pattern at temperate latitudes (Sutherland & Karlson, 1977; Schoener, Long & De Palma, 1978).

The nature of the initial fouling community may determine its further development. Day (1977) noted that since the size of an organism can influence its level in the "dominance hierarchy" in terms of space and persistence, the individuals that settle early on a colonizable patch would be at a competitive advantage to ones that settle later. The season during which colonization is initiated could thus be important for the nature of the final community (Kawahara, 1963, 1965; Sutherland and Karlson, 1977).

To compare data obtained from plates which had been exposed for four weeks during each month between June and November and from plates exposed for three months during June to August, December to February and March to May, the following system was adopted:-

(i) Substratum materials and time of exposure at each depth are compared for wet weight, volume, percent cover and number of species. The data is presented as interaction plots of material versus time and incorporates the 95% confidence limits of the student-t test i.e. where the confidence limits do not overlap, the mean values are significantly different. The outcome of the ANOVA tests is shown as "significant" or "non-significant" ($P < 0,005$) next to each graph.

(ii) Opposite each page of photographs, the data for that set of panels is summarized. This includes the data of abundance and degree of coverage by each organism group, shown on the four figures following the photographs, and incorporates some of the trends shown for individual species in figure 2.2.1.1.a-m.

2.2.2.1. Exposure for one month

(a) Weight - figure 2.2.2.1.a

At a depth of 20m, the weight values were usually low and not significantly different over the six months. Some replicates differed markedly to explain the variability and high mean values in September on SS, SR, FG & PVC plates and on AL & SS in November. Although the data was even more variable at 10m, many of the values from AL, SS, FG & PVC plates were significantly higher in August to November than in June and July. At both depths, all replicate and monthly values for MS were low. In contrast, SR was very variable.

(b) Volume - figure 2.2.2.1.b

No replicate readings of volume were made (only means of all sample replicates), but the general trends of the mean values were similar to those obtained for weight (above).

(c) Cover - figure 2.2.2.1.c

At Site 1, plate coverage was generally low, except on some AL & SS panels in November. In all months, PVC had high values at Site 2, significantly higher than MS & FG and non-significantly higher than other materials. The values of AL, SS, MS & SR were higher during October and November than during September, but on FG and PVC, cover was similar during all months.

(d) Species diversity - figure 2.2.2.1d

In September, more species settled on plates of all materials at 20m, than during June, July, August and November. On AL, SS, FG and PVC, the October values were higher than those obtained during June to August. At 10m depth, the species diversity on MS & SR did not change in different months, but on the other materials, the October and November values were higher than those during other months. Unlike as at Site 1, diversity was low in September.

(e) General

To summarize, at Site 1 (20m) the weight, volume and cover did not differ much between materials and between months. The high variability of replicates during September to November was largely due to the rapid growth of Diplosoma colonies. More species settled during spring, September and October, than during winter.

On AL, SS, FG & PVC at Site 2 (10m), the weight values were higher in August to November than in June and July. Cover, although similar in all months for FG & PVC, was higher in October and November than in September on other materials. Of all the materials, PVC often had the highest cover, weight and volume values during September to November, while those of MS were usually low. More species were present during October and November than during other months, although on MS & SR the diversity was no higher in summer than in winter.

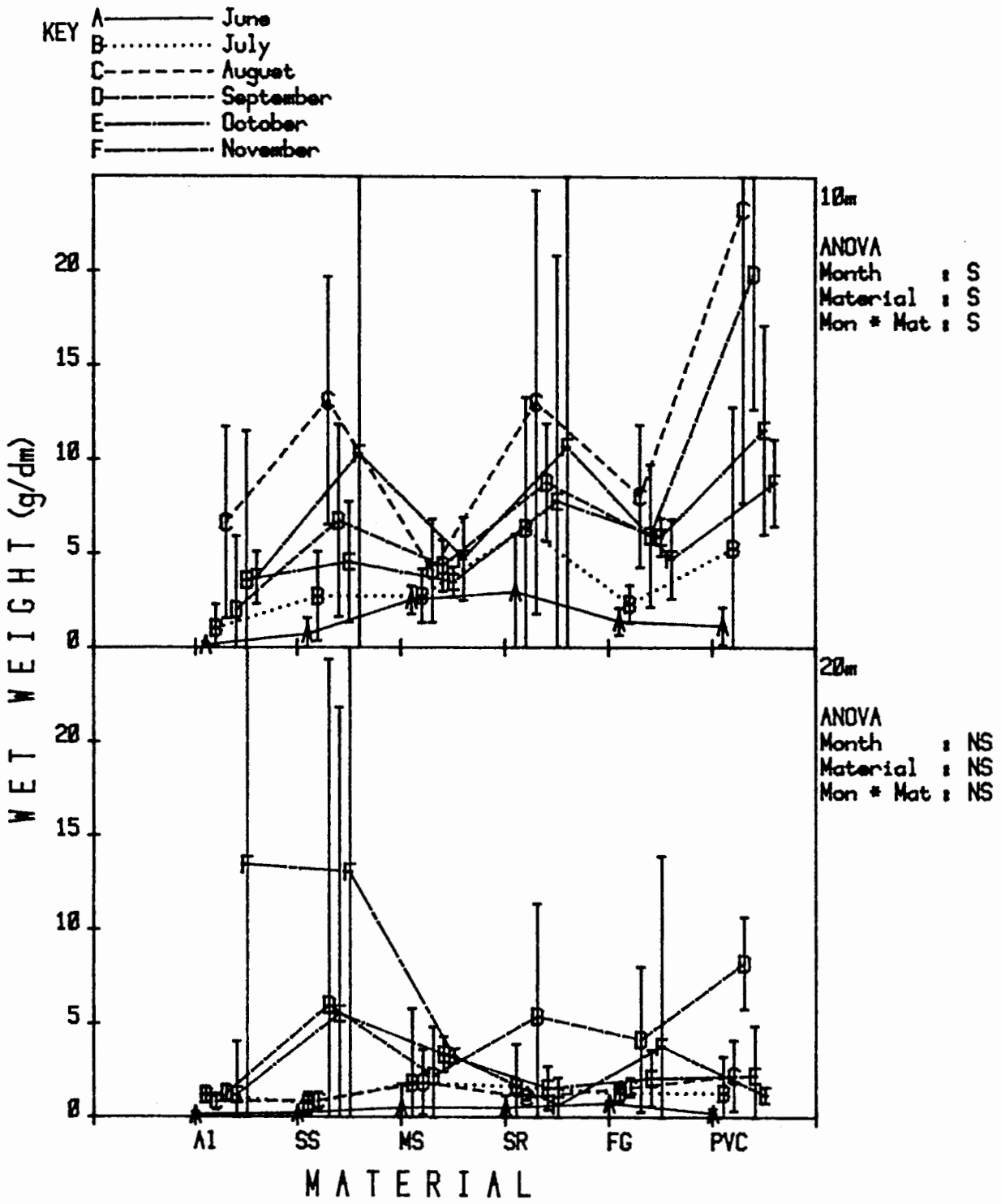


Fig 2221a: Interaction plots of substrate material vs. month of exposure for wet weight (±95 C.L.). Significance in the ANOVA was tested at the .5% level. (S = significant ; NS = not significant)

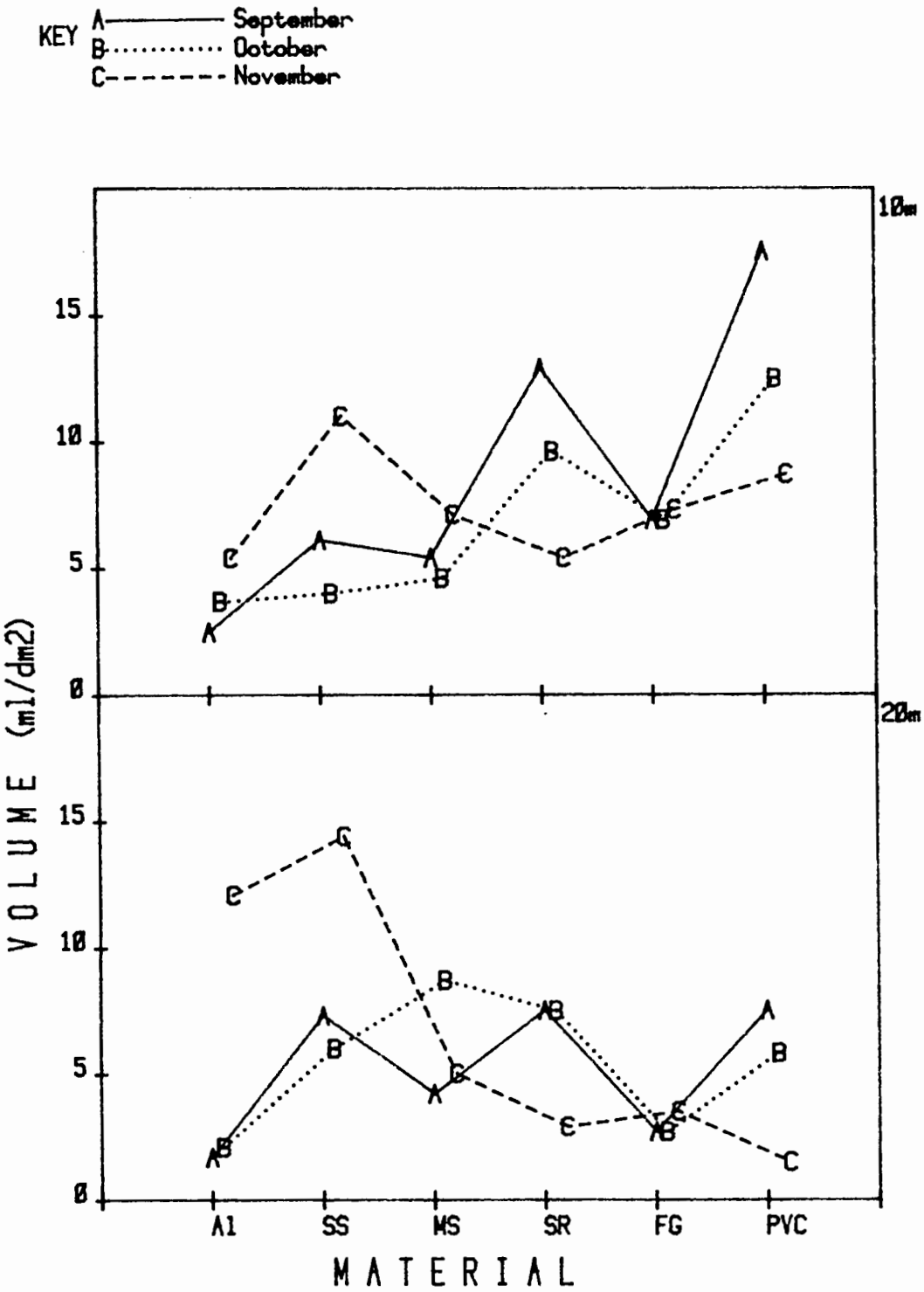


Fig 2221b: Interaction plots of substrate material vs. month of 1-month exposure for volume of fouling organisms.

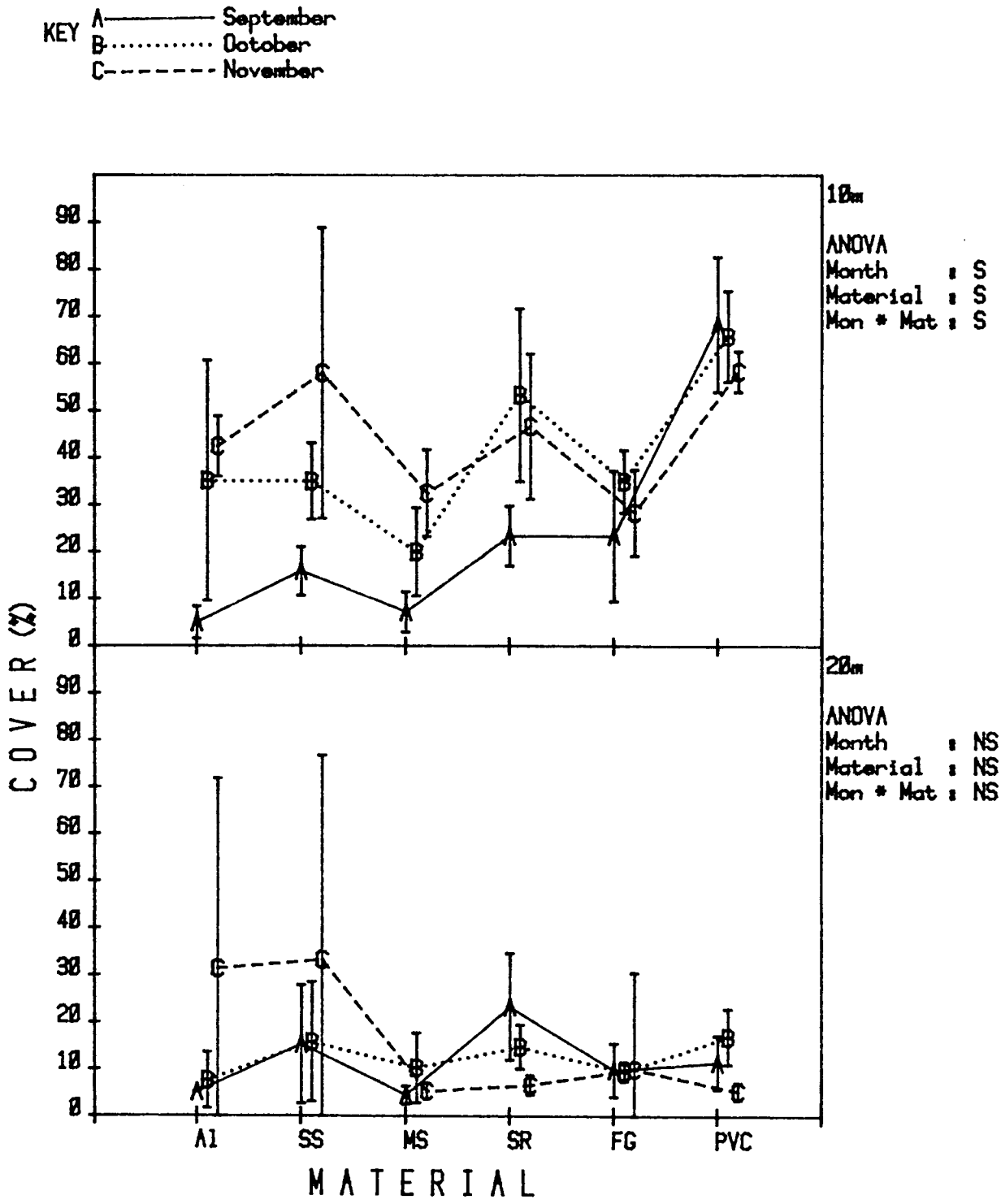


Fig 2221c: Interaction plots of substrate material vs. month of exposure for percent plate cover (±95% C.L.). Significance in the ANOVA was tested at the .5% level. (S = significant ; NS = not significant)

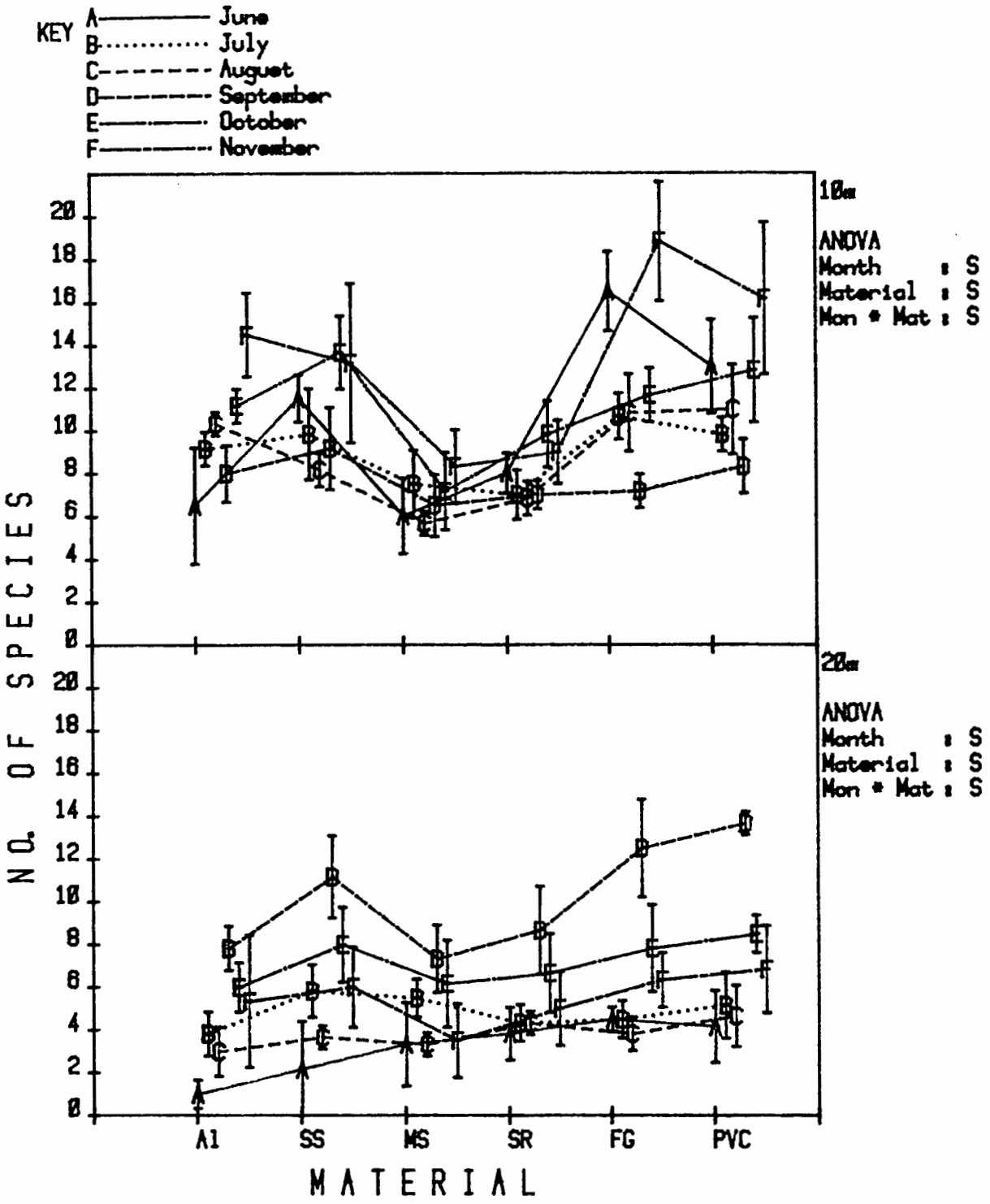
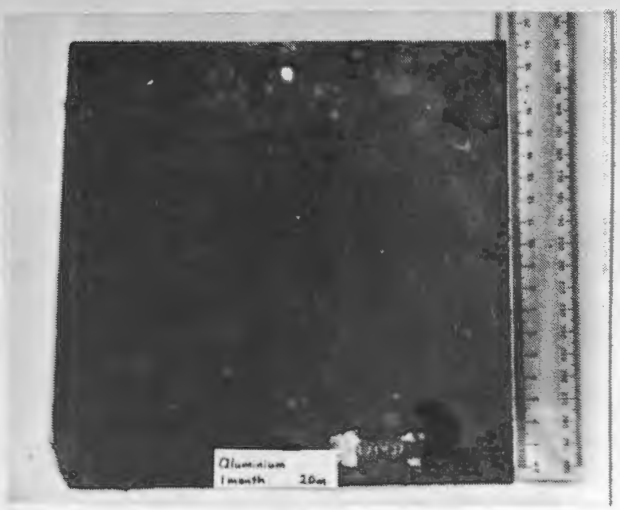
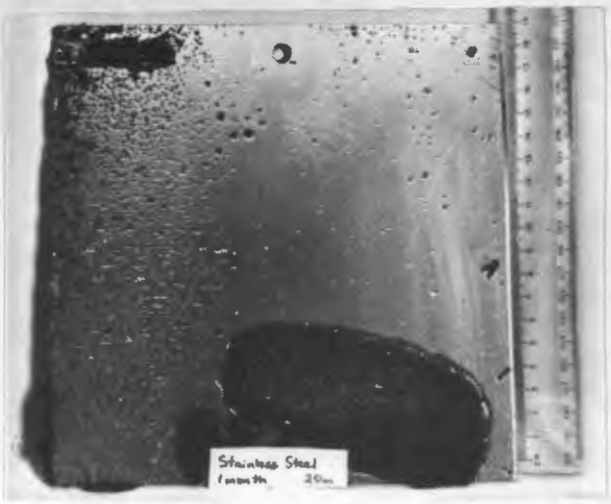
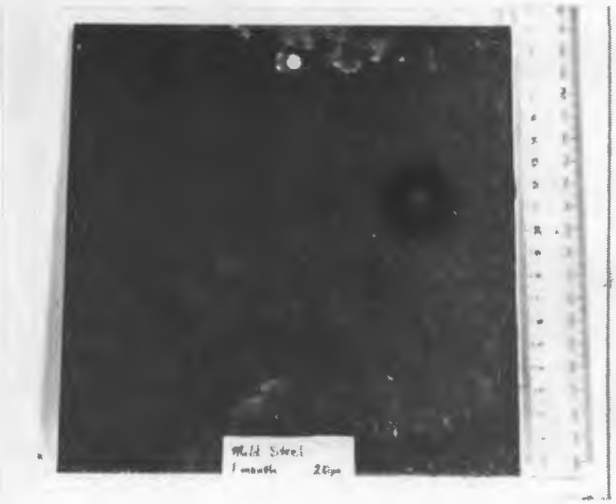
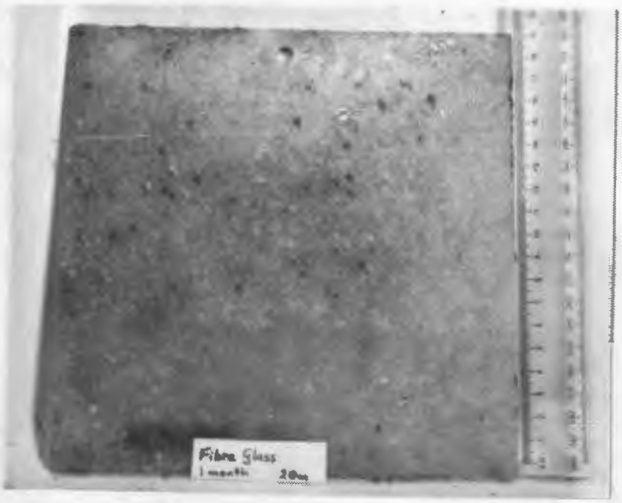


Fig 2221d: Interaction plots of substrate material vs. month of exposure for species diversity of sedentary organisms (±95% C.L.). Significance in the ANOVA was tested at the .5% level. (S = significant; NS = not significant)









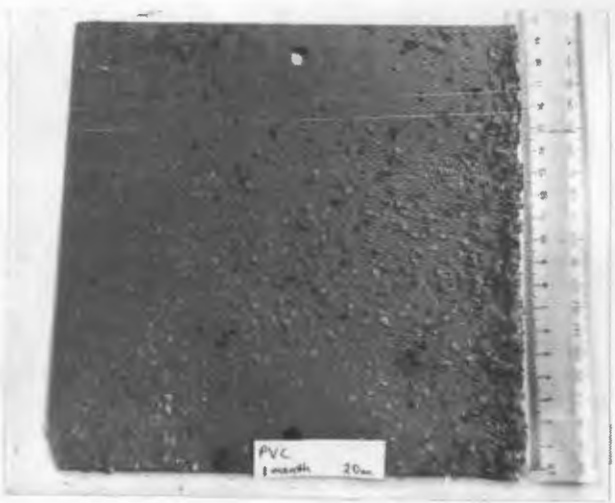
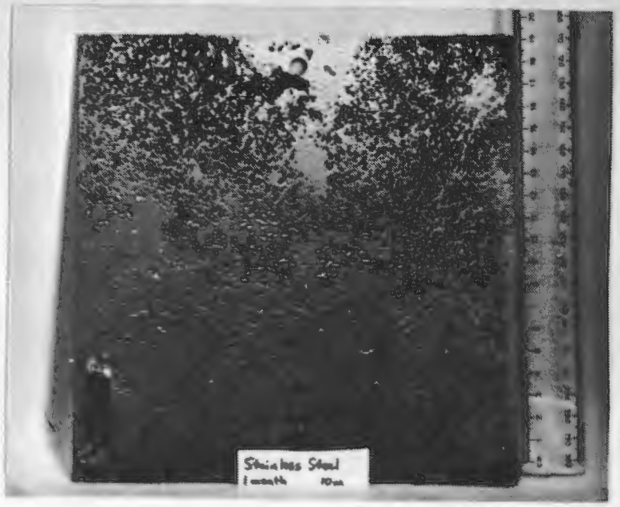
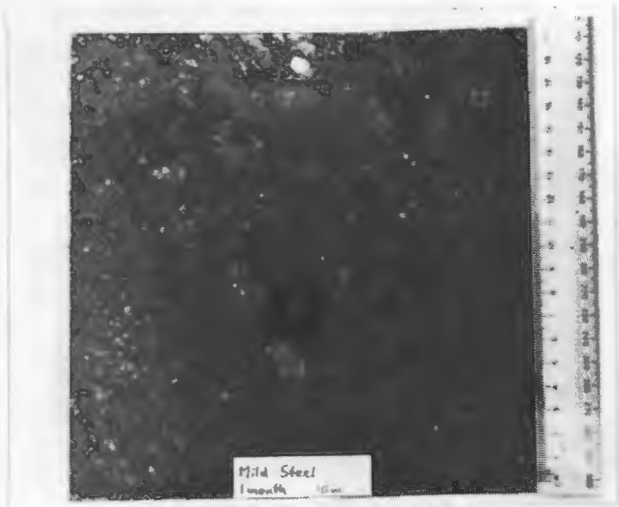


Plate 2.2.1a : Exposure at 20m during November 1979.

(f) 1 month at Site 1 - Plate 2.2.1.a

After the plates had been immersed for one month, a large number (sometimes exceeding 2000/dm^2) of very small barnacles, mostly Balanus amphitrite, had settled on them especially during spring. Note the concentration of barnacles towards one edge of each plate. Once settled, a colony of Diplosoma sp (see SS), could spread rapidly over much of the surface, usually on stainless steel, aluminium and sometimes fibre glass. Although hydrozoa, especially Campanularia integra, were common in earlier months, mainly July and September, few were recorded during November. The peak occurrence of serpulids, Hydroides elegans, and of tubiculous amphipods was during September, of bivalves during September to October and of simple ascidians during November, but the numbers of ascidians were relatively low.





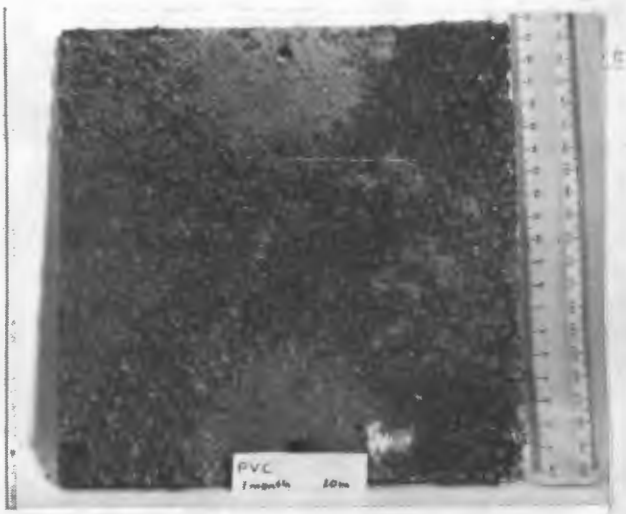


Plate 2.2.1b : Exposure at 10m during November 1979.

(g) 1 month at Site 2 - Plate 2.2.1.b

These photographs, taken in poor light conditions, show that Balanus amphitrite settled very numerously (upto 4000/dm^2, often more than 3000/dm^2). Except on PVC, individuals were, however, usually very small and much surface area was left open. The "edge effect" was less pronounced at Site 2, but can be seen on the aluminium and PVC plates. The dark growth on the silicon rubber plate was a colony of Diplosoma sp., which also seemed to favour stainless steel surfaces. Microalgae were numerous (100-1500/dm^2) on all but the mild steel and silicon rubber plates, but are too small to be visible on plate 2.2.1b. Short filaments of Bugula neritina were seen frequently during September to November, but Choromytilus spat were more numerous in August and October than during other months.

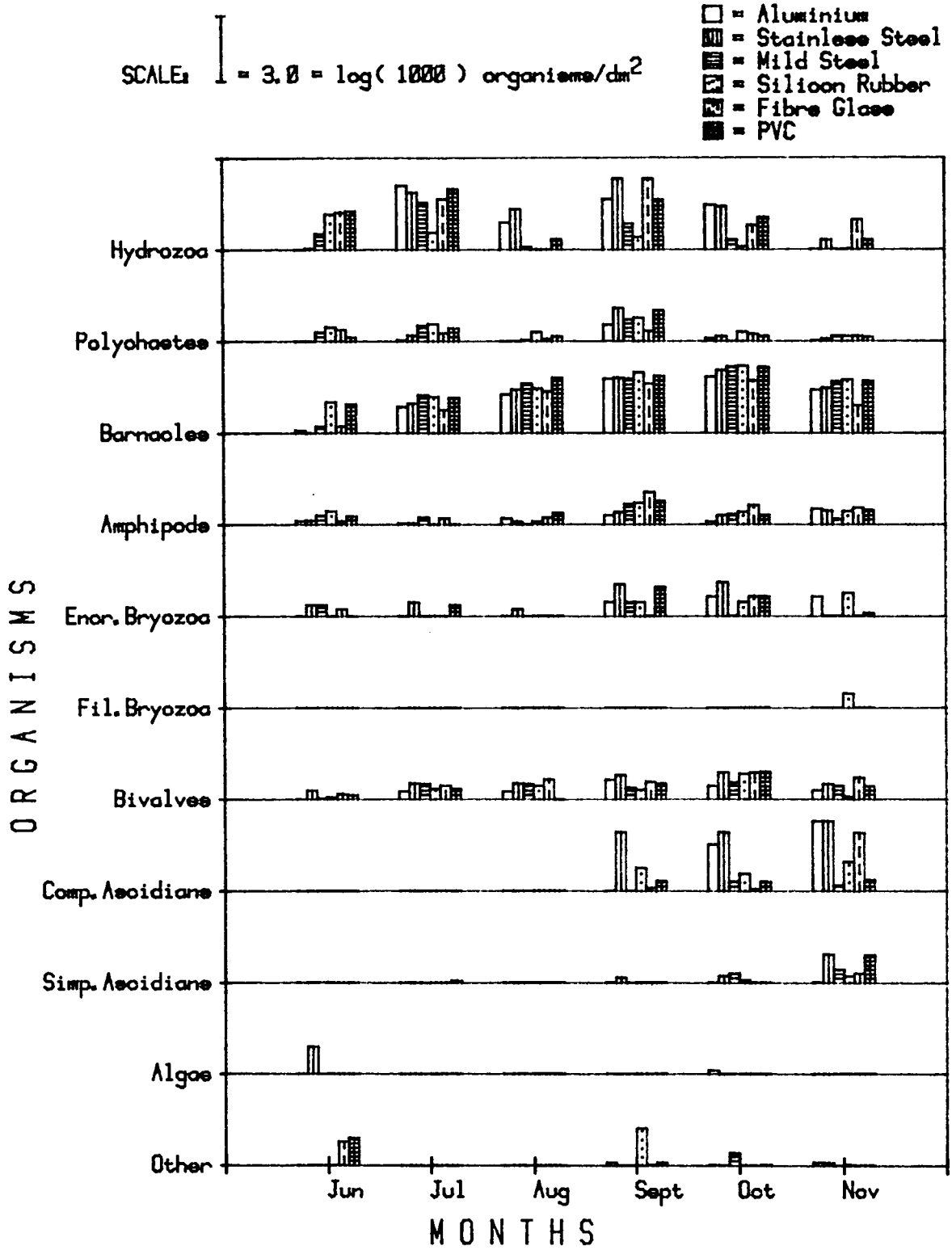


Fig 2221e : Number of organisms (log[X+1]) that settled on panels exposed for 1 month during successive months at Site 1 (20m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

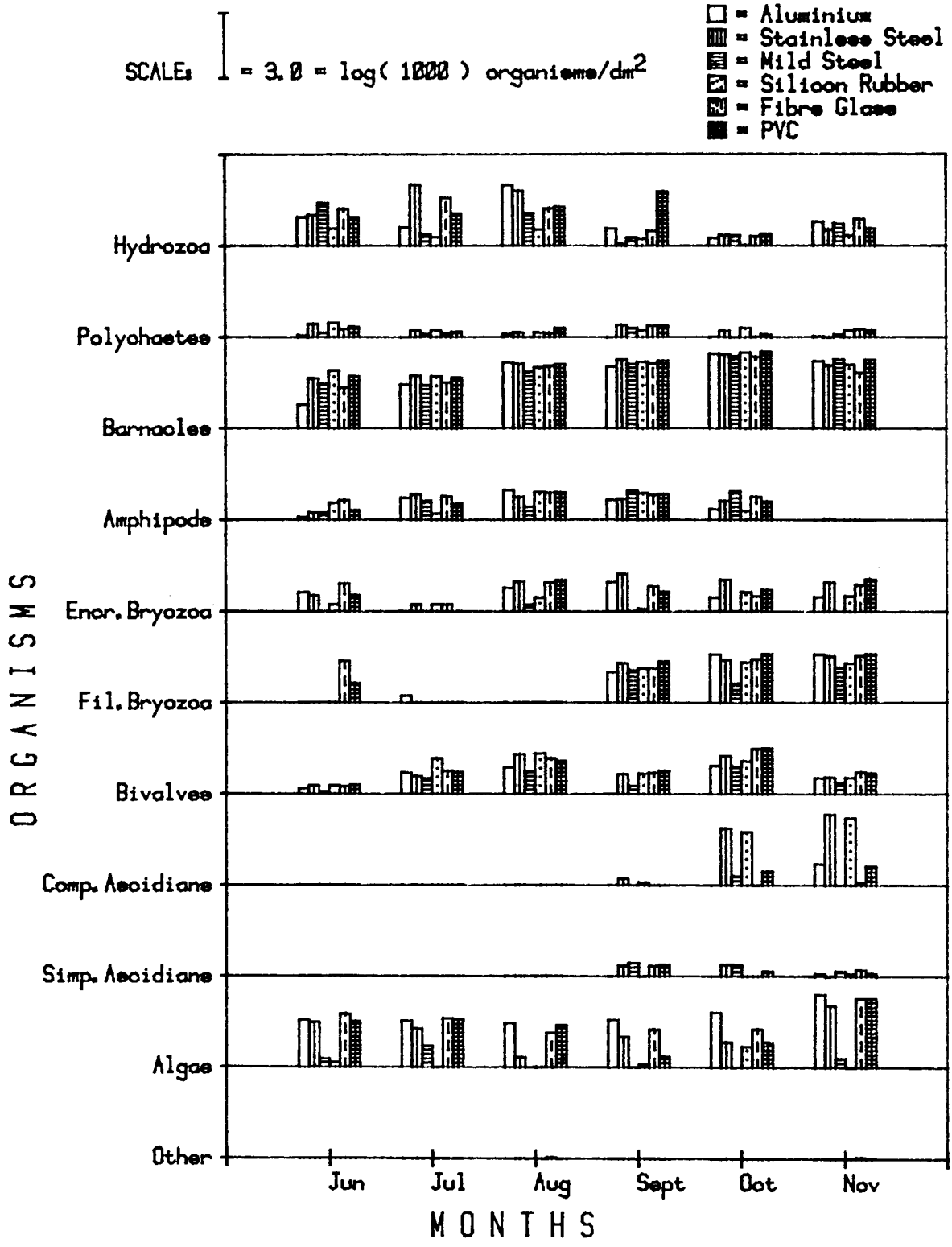


Fig 2221f : Number of organisms (log[X+1]) that settled on panels exposed for 1 month during successive months at Site 2 (10m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

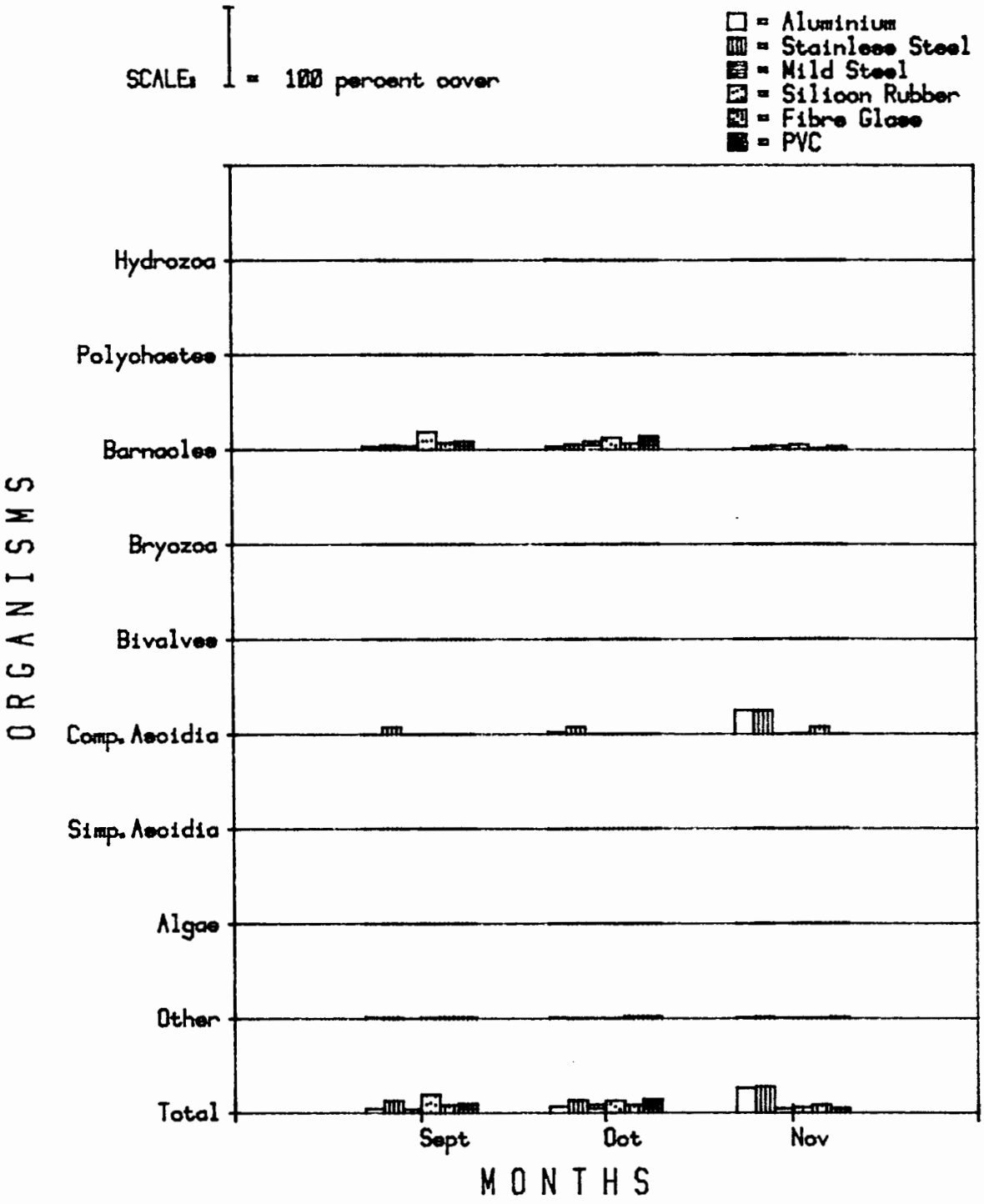


Fig 2221g : Percent cover by fouling organisms of panels exposed for 1 month at Site 1 (20m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

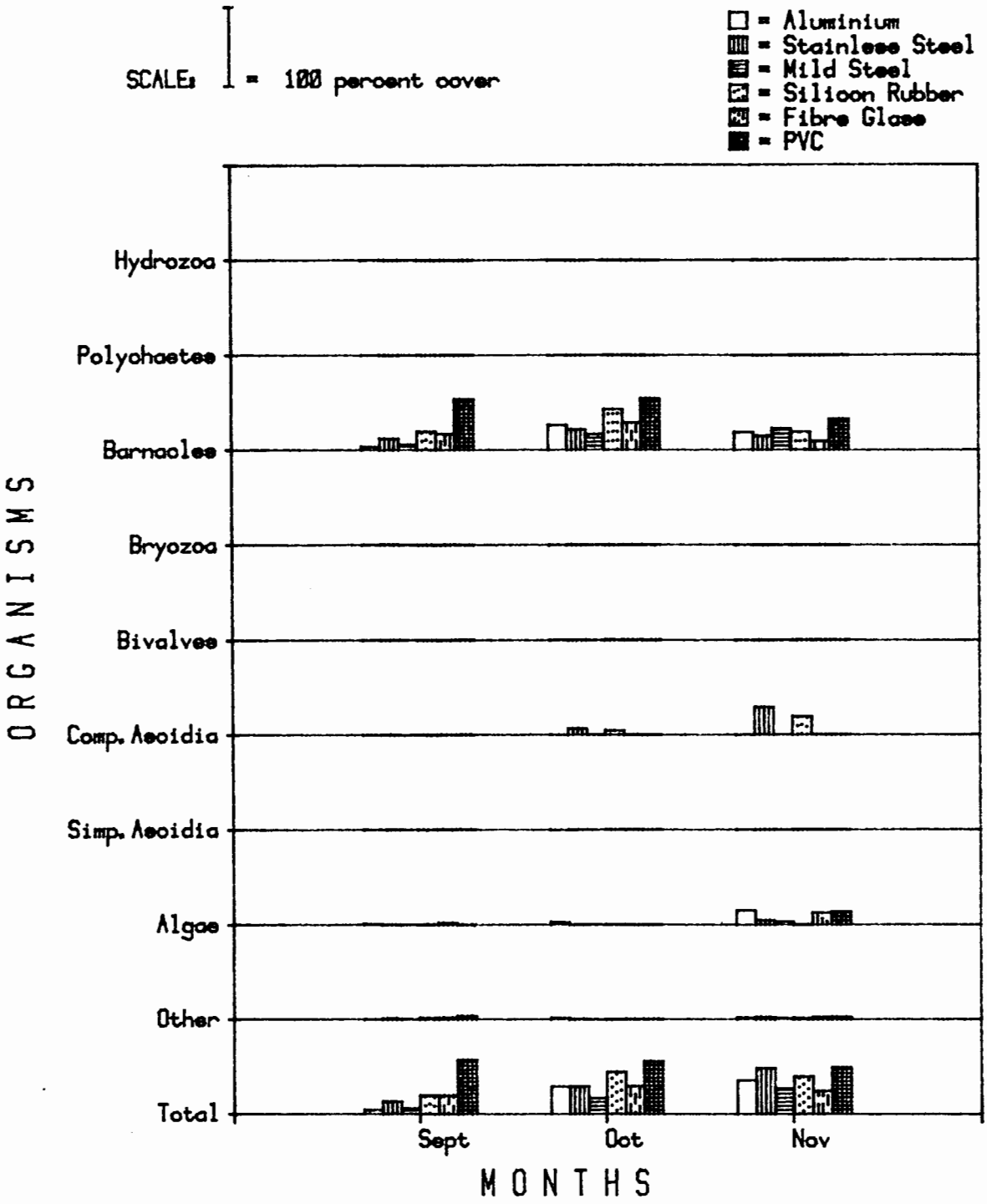


Fig 2221h : Percent cover by fouling organisms of panels exposed for 1 month at Site 2 (10m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

2.2.2.2. Exposure for three months

(a) Weight - figure 2.2.2.2.a

The confidence limits were sometimes so wide at both sites that the differences outlined below were not significant, although the means could differ markedly. At Site 1, the weight of foul growth was less on SR than on other materials during December to February and March to May, but in June to August, when all values were low, this difference was not apparent. Whereas the values for December to February and March to May were of a similar magnitude at both sites, the weight was lower at Site 1 during June to August and higher at Site 2 in this period than during other periods, especially on SS, FG & PVC.

(b) Volume - figure 2.2.2.2.b

The mean values of volume had very similar trends as the mean weight. The non-significant differences outlined for weight, above, were also evident for volume.

(c) Cover - figure 2.2.2.2.c

Although the variability of cover was high at 20m, it was significantly different during different months and on different materials. The cover on SR was much less in all months and on MS in June to August than on the other materials. All except SR plates had lower coverage in June to August than in other periods, although this difference was only significant for AL. At Site 2, the temporal values were much closer to each other but the cover was higher during June to August than during March to April for SS, FG & PVC plates. All SR values were very low. MS was also lower than other materials, but this was only significant during June to August.

(d) Species diversity - figure 2.2.2.2.d

During June to August, less species settled on AL, SS, MS & PVC plates at Site 1 than during other periods, although this difference was only significant for PVC. At both sites, fewer species occupied SR than AL, SS, FG & PVC, but this was only significant at Site 1. Usually the species diversity on MS was non-significantly less than on other materials.

(e) General

The values of weight, volume, cover and species diversity were lower on SR, and to a lesser extent on MS, than on other materials, especially at Site 2. Although differences were seldom significant, weight, volume, cover and species diversity of AL, SS, FG & PVC were usually lower during June to August at Site 1, and weight, volume and cover higher at Site 2, than during other periods.

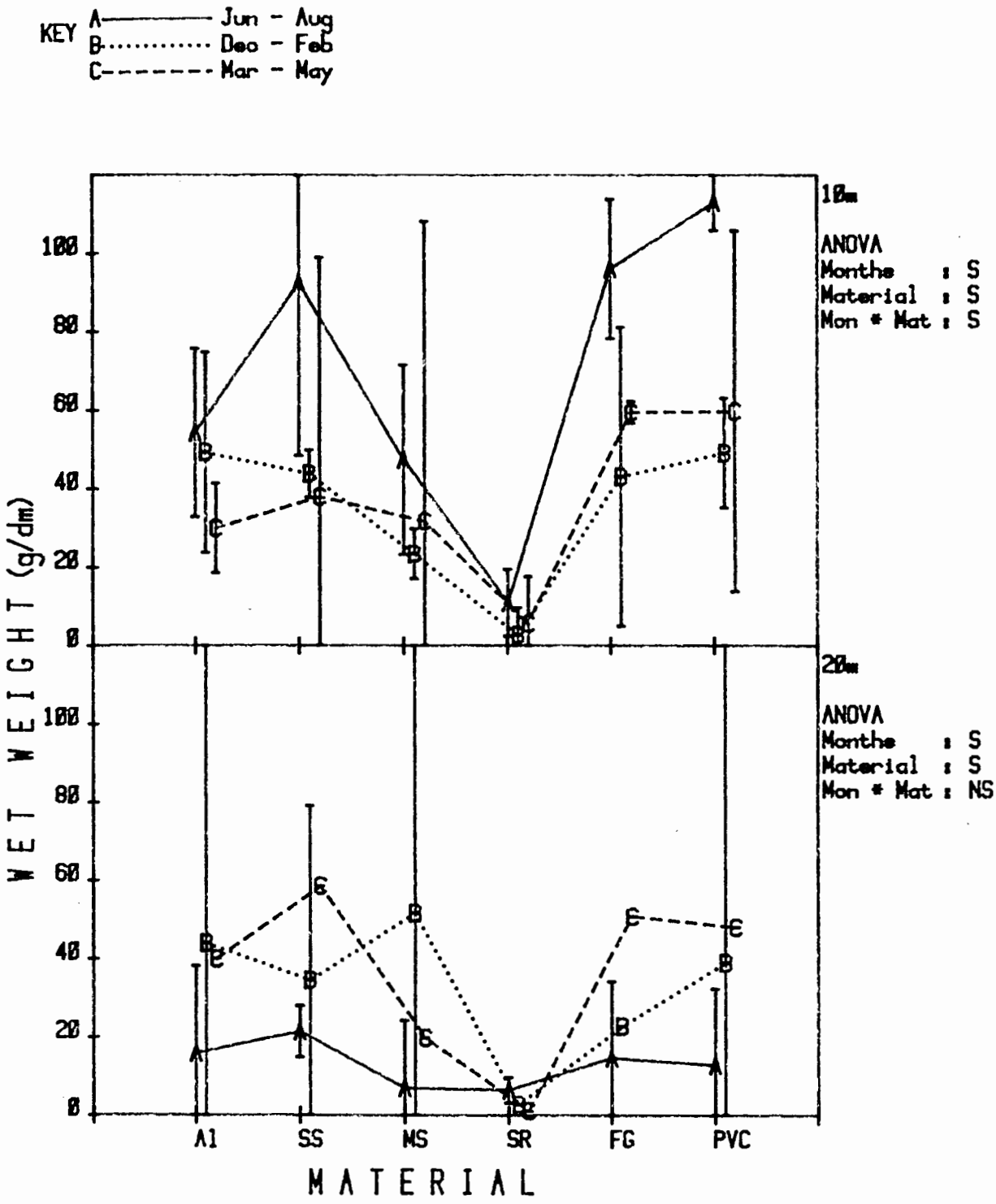


Fig 2222a: Interaction plots of substrate material vs. months of 3-month exposure for wet weight (±95% C.L.). Significance in the ANOVA was tested at the .5% level. (S = significant ; NS = not significant)

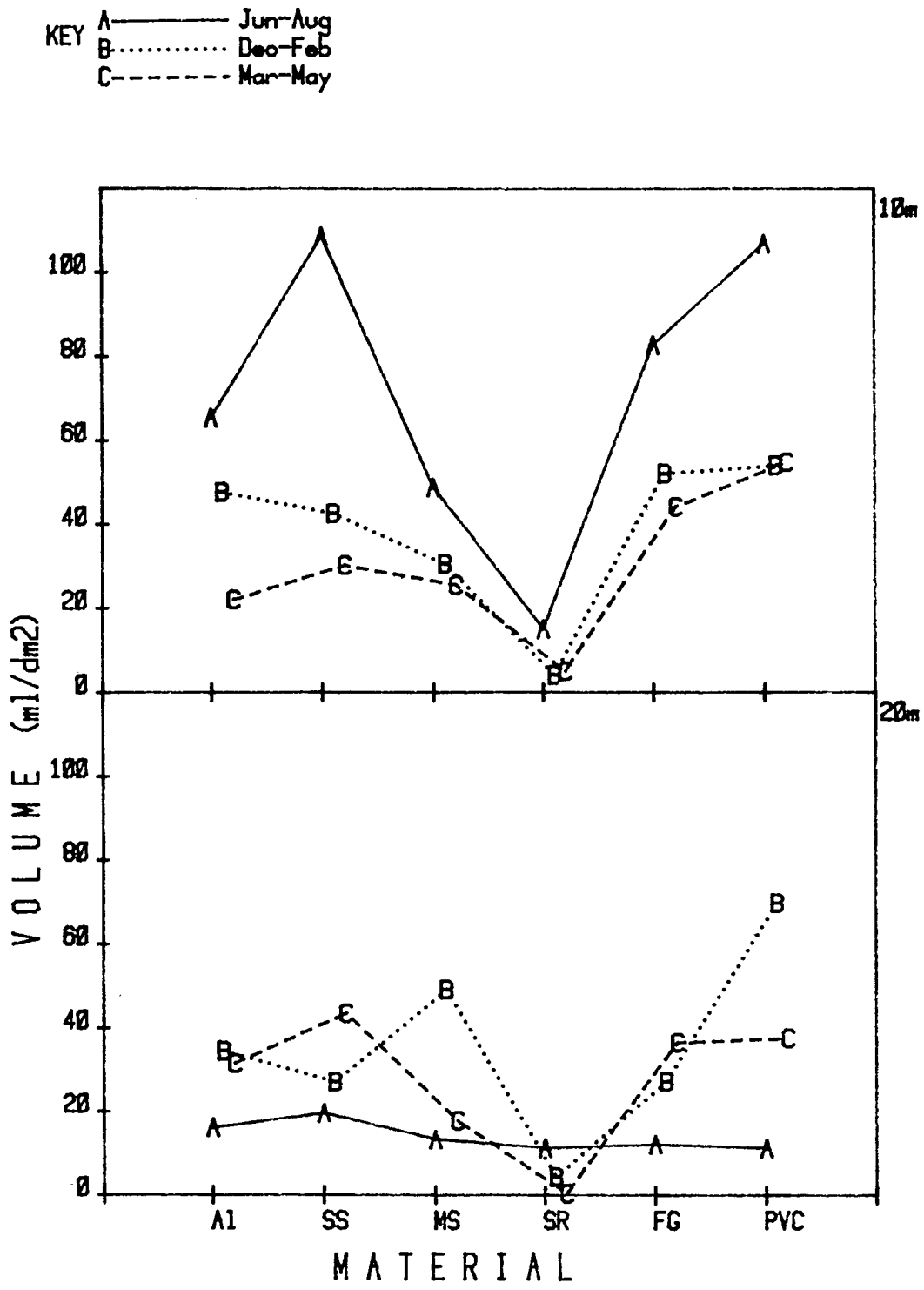


Fig 2222b: Interaction plots of substrate material vs. month of 3-month exposure for volume of fouling organisms.

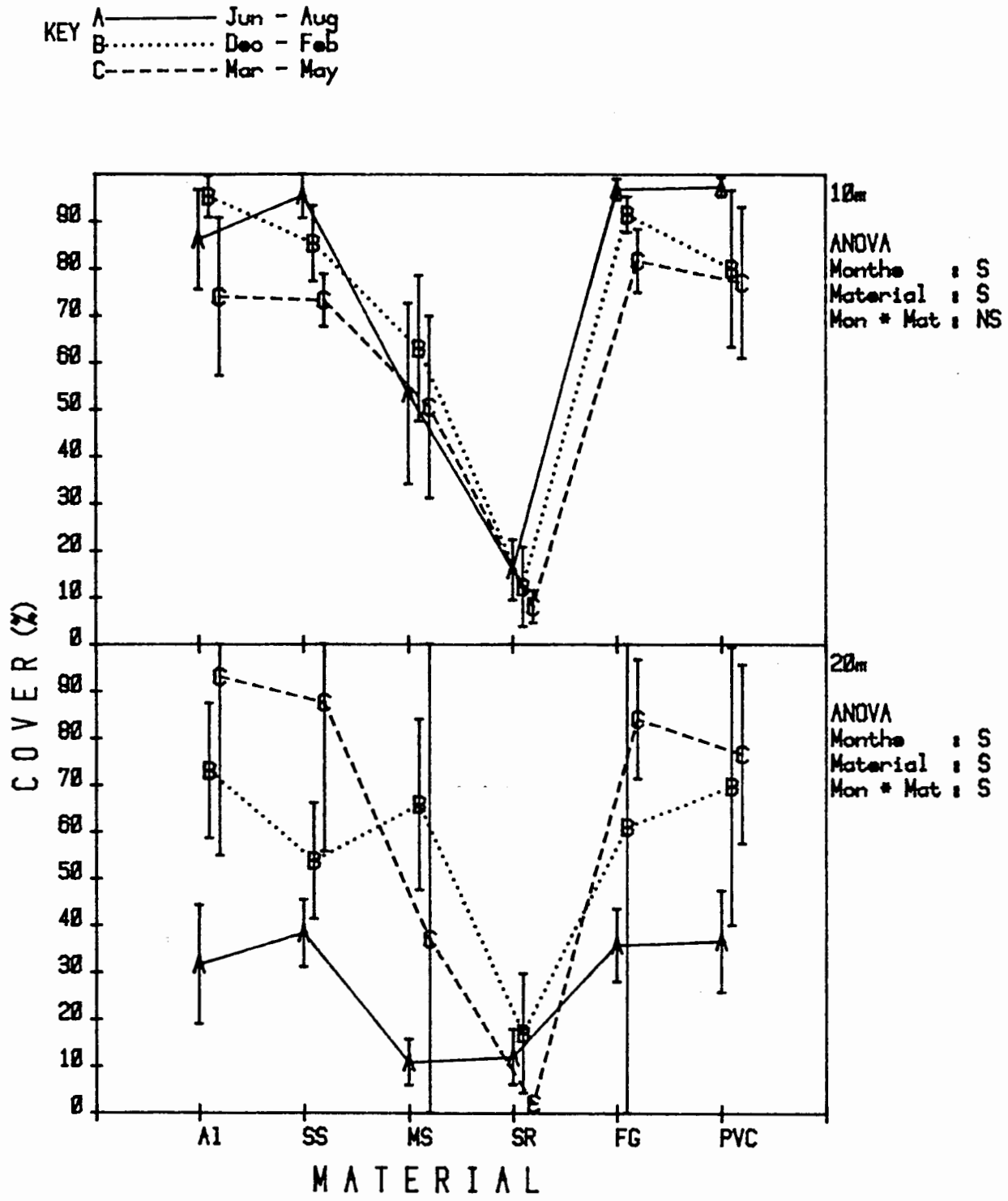


Fig 2222c: Interaction plots of substrate material vs. months of 3-month exposure for percent plate cover (±95% C.L.). Significance in the ANOVA was tested at the .5% level. (S = significant ; NS = not significant)

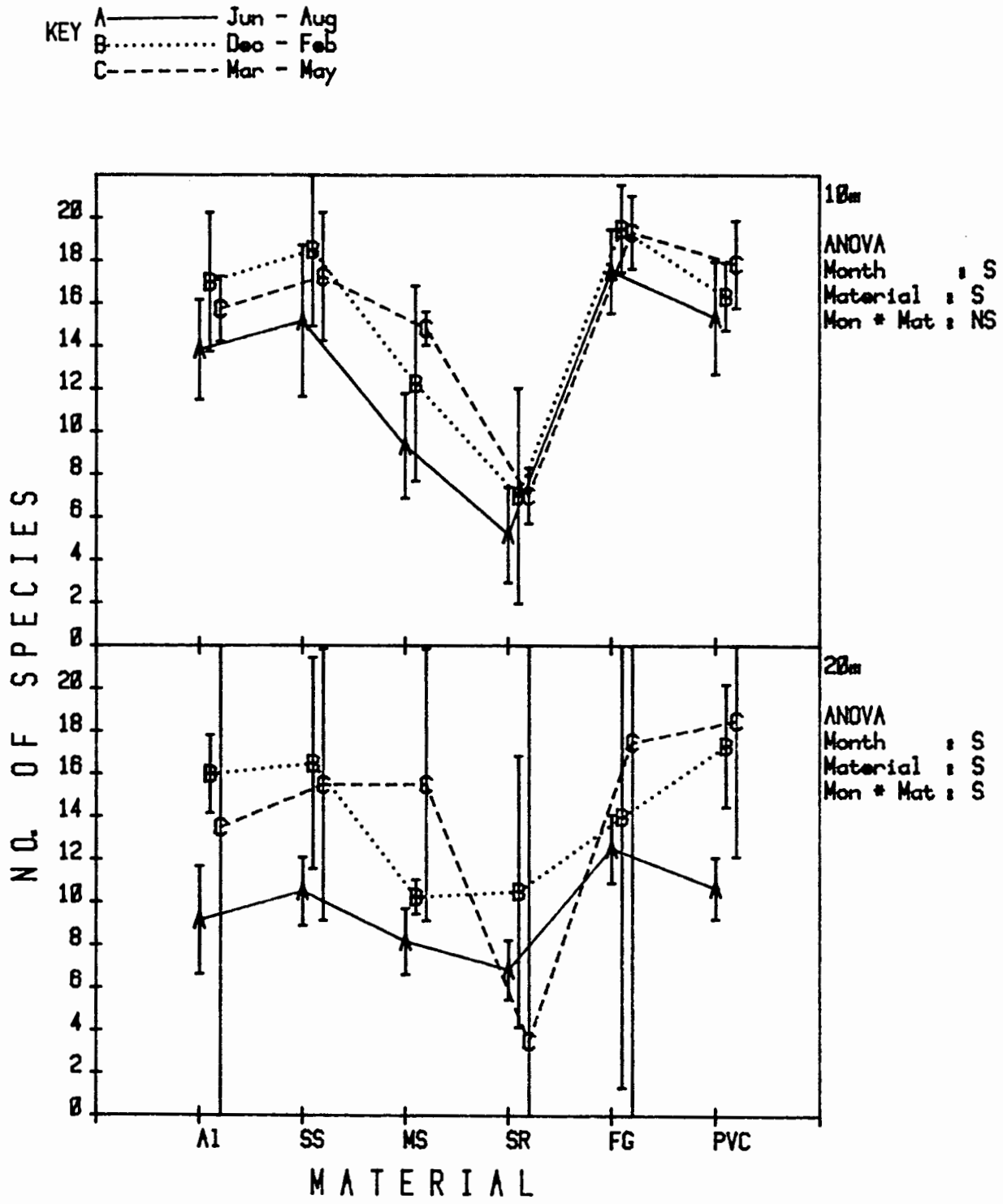
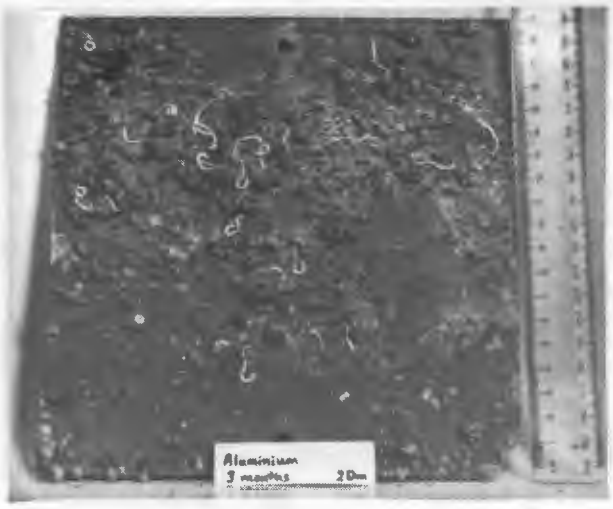
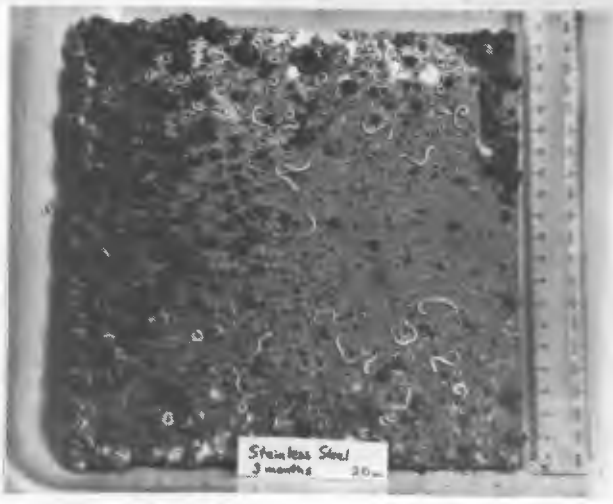


Fig 2222d: Interaction plots of substrate material vs. months of 3-month exposure for species diversity of sedentary organisms (±95% C.L.). Significance in the ANOVA was tested at the .5% level. (S = significant ; NS = not significant)





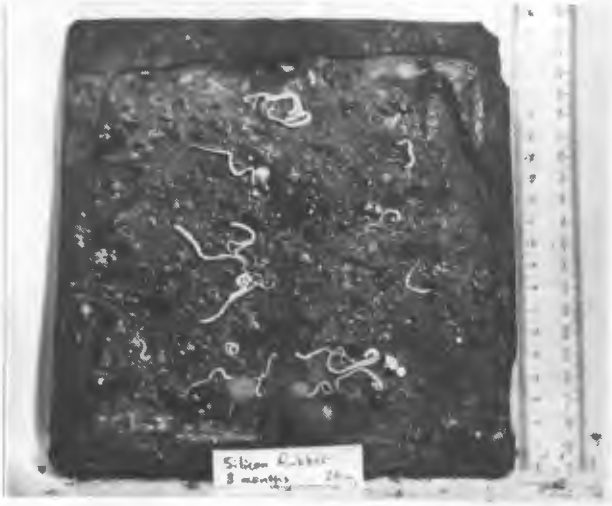


Plate 2.2.2a : Exposure at 20m for 3 months during June - August 1979.

(f) June to August at Site 1 - Plate 2.2.2.a

After exposing the panels for the three winter months, some panel surface is still left unoccupied. Barnacles, mostly Balanus amphitrite, were very numerous (500-800/dm^2), but generally still small, except for B.maxillaris. Numerous serpulids, Hydroides elegans (100-300/dm^2), not so common during other exposure periods, can be seen on all materials but mild steel. Occasionally patches of encrusting bryozoa, especially Membranipora sp., could expand over the surface and over previously settled organisms (see lower left corner FG and central PVC). Some Choromytilus spat settled on the barnacles, but were too small to be seen here. Clusters of feather-like stalks of the hydrozoan, Plumularia sp. (see FG), and networks of Campanularia integra were frequent. Note the damaged barnacles on the right edge of the PVC plate. This was possibly the effect of grazing by fish.

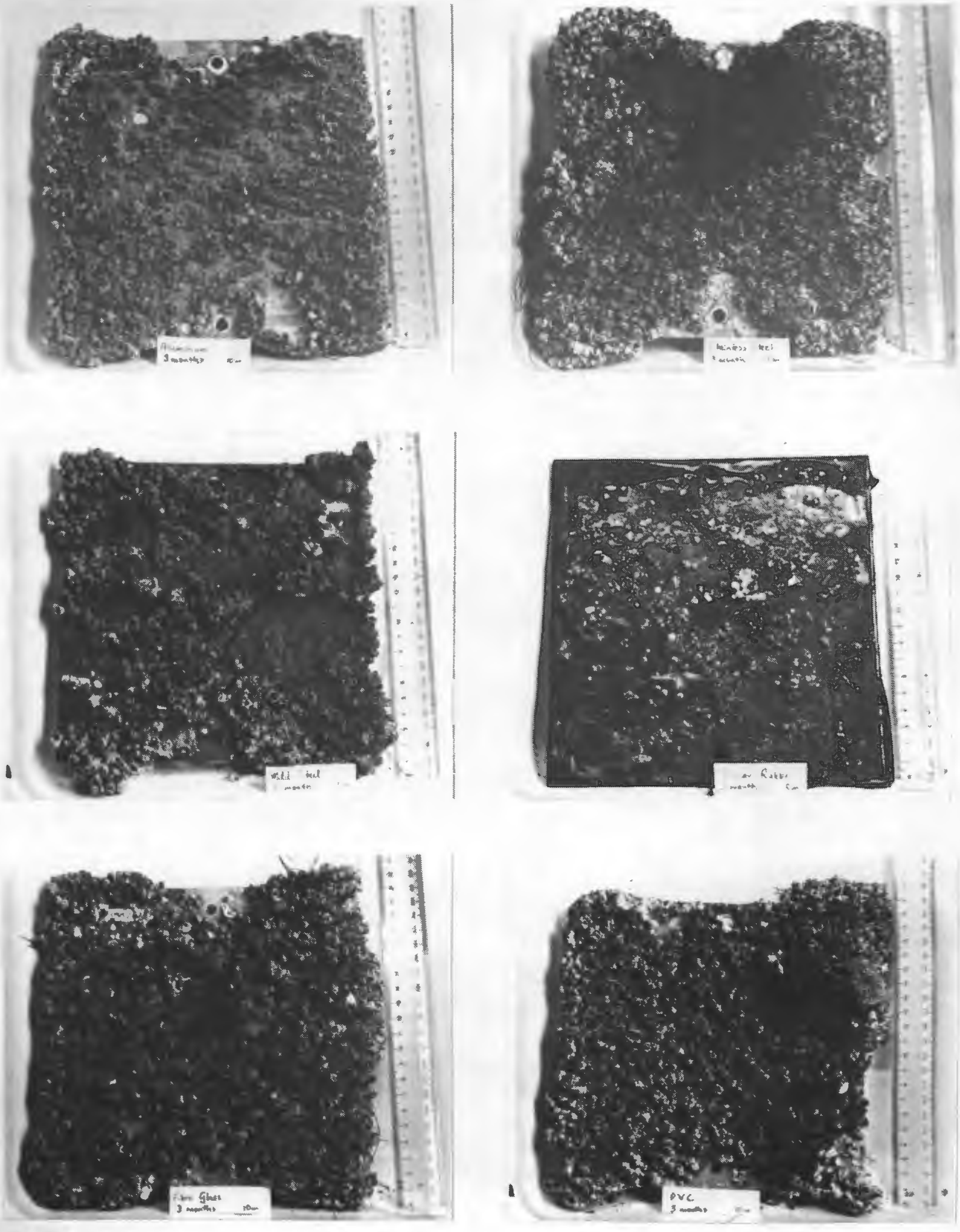
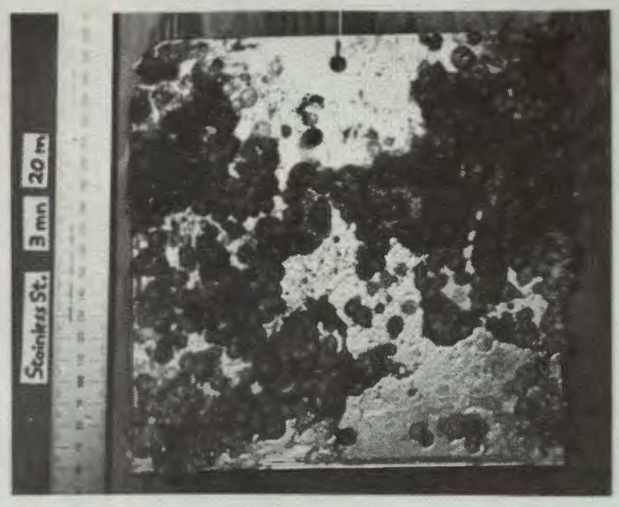
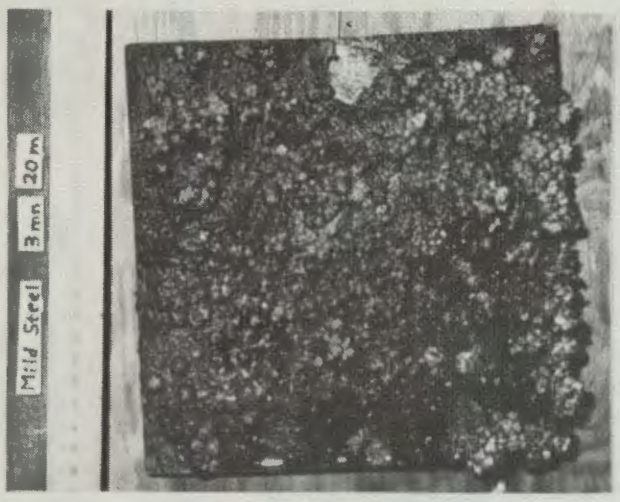


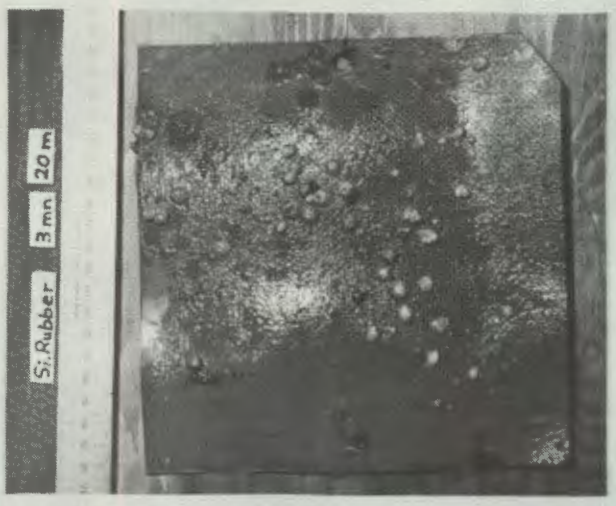
Plate 2.2.2b : Exposure at 10m for 3 months during June - August 1979.

(g) June to August at Site 2 - Plate 2.2.2.b

At 10m depth, in contrast to 20m depth, barnacles settled so abundantly (usually about 1000/dm^2) and were relatively large, that they overgrew each other, especially on stainless steel, fibre glass and PVC. On aluminium panels, individuals appeared to be smaller. Corroded mild steel presented an unstable substratum from which pieces would occasionally fall off, clearing previously colonized areas. Although many barnacles settled on silicon rubber, it is evident from the photograph that most of these were very small. Once they grow bigger, they probably fall off. Many spat of black mussel, Choromytilus meridionales (200-600/dm^2), were seen attached to barnacle shells during this period. Serpulids and hydrozoa were relatively sparse at Site 2, but encrusting bryozoa, Membranipora sp. and Watersipora subovoidea, and filamentous bryozoa, Bugula neritina, were common. Incrustations of compound ascidians were noted, on one aluminium, one stainless steel and one mild steel panel but could cover 20-90% of a panel side.







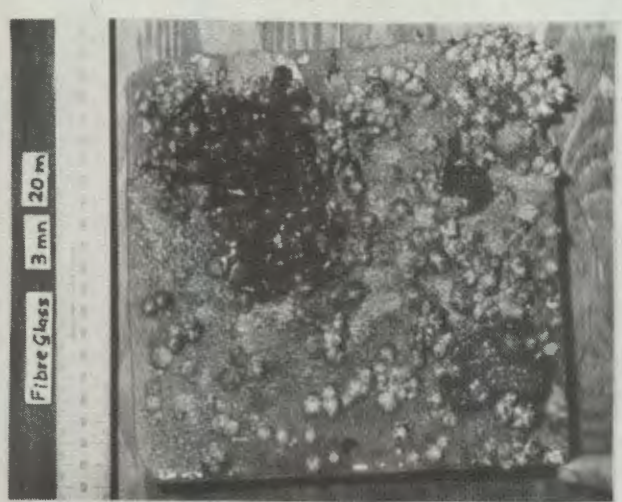


Plate 2.2.2c : Exposure at 20m for 3 months during December 1979 - February 1980.

(h) Decemoer to February at Site 1 - Plate 2.2.2.c

During December to February at Site 1, the surface was dominated by barnacles (about 500/dm^2), largely Balanus trigonus besides B.amphitrite. Tunicates, Pyura sp (see AL) and Diplosoma sp. (see SS & FG), were fairly common, but small. Networks of very fine filamentous bryozoa, Aetea sp.?, and hydrozoa, Campanularia, integra, sometimes overgrew the barnacles and small bivalves Choromytilus Saxicava, Anomia and Tellimya were frequent between the barnacles. Silicon rubber was relatively bare, its surface sometimes being used for egg deposit by invertebrates (darker patches).

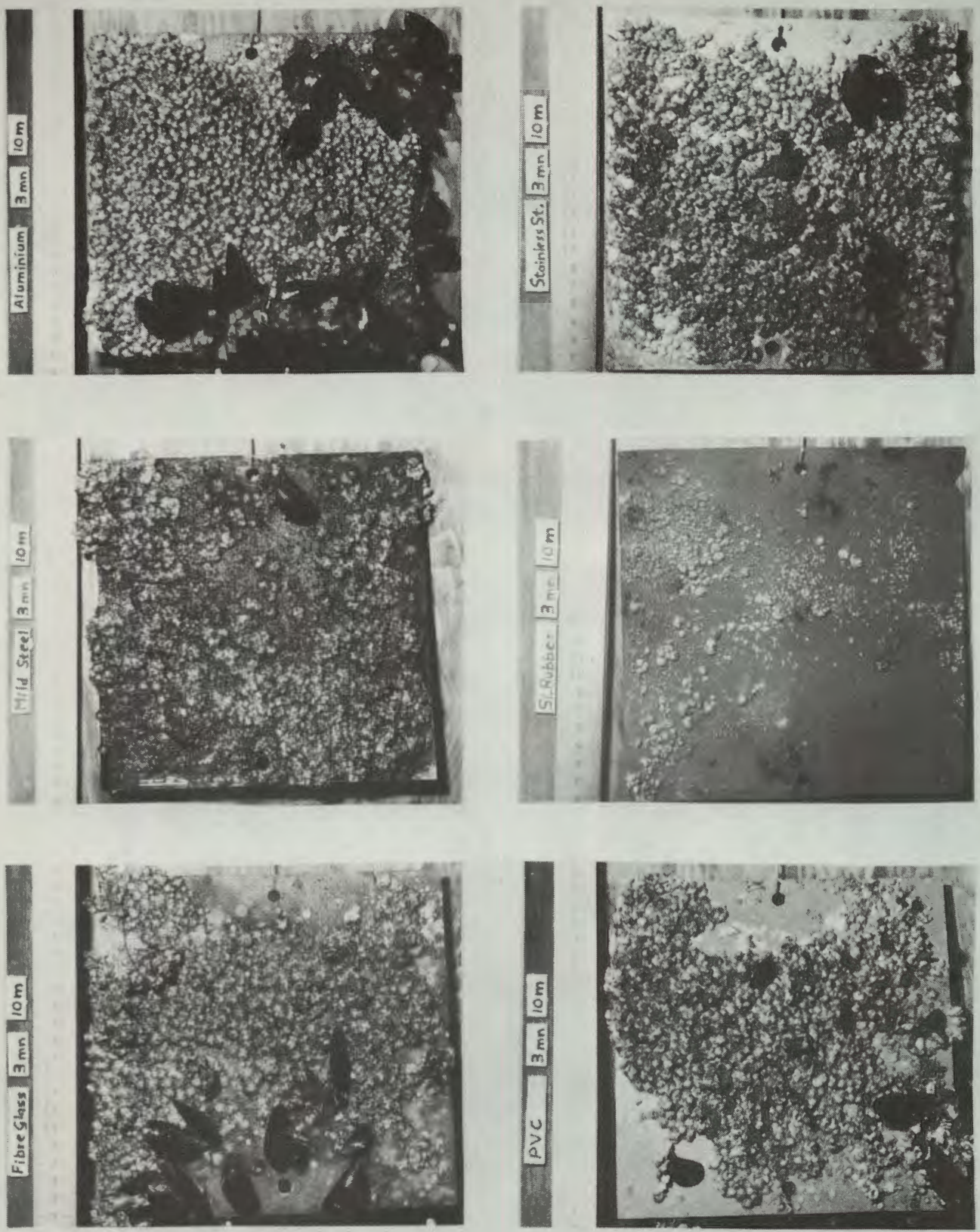


Plate 2.2.2d : Exposure at 10m for 3 months during December 1979 - February 1980.

(i) December to February at Site 2 - Plate 2.2.2.d

If the black mussels, which encroached onto these plates from more mature adjacent areas, are ignored, then the two barnacle species, Balanus trigonus and B.amphitrite, dominated almost exclusively (500-1300/dm^2), although filamentous bryozoa, Bugula neritina, were not uncommon and small colonies of Diplosoma sp. were recorded on some panels (see SS). As in previous months, mild steel had patchy coverage, while silicon rubber, although bearing many small barnacles and Campanularia, was almost bare.

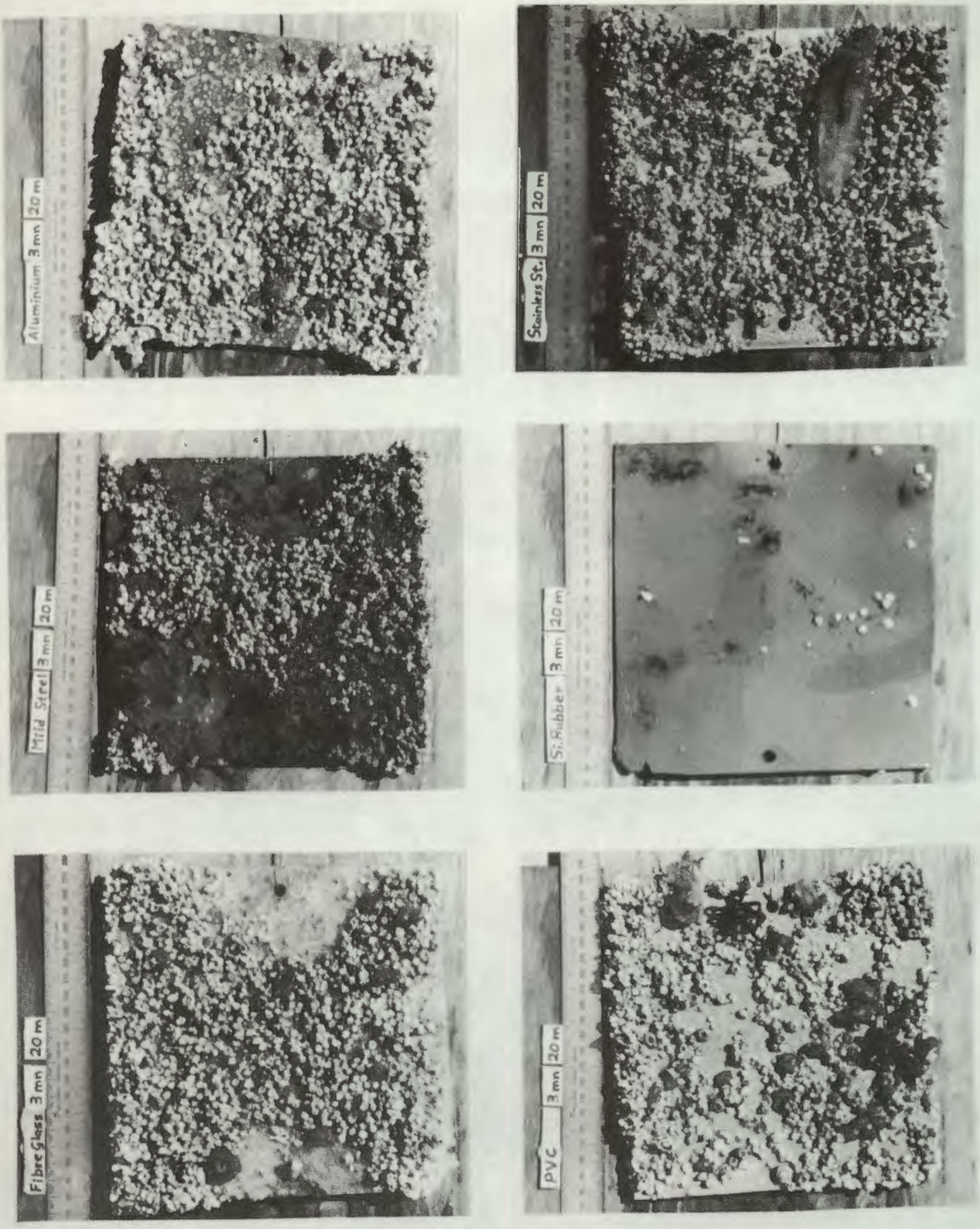


Plate 2.2.2e : Exposure at 20m for 3 months during March - May 1980.

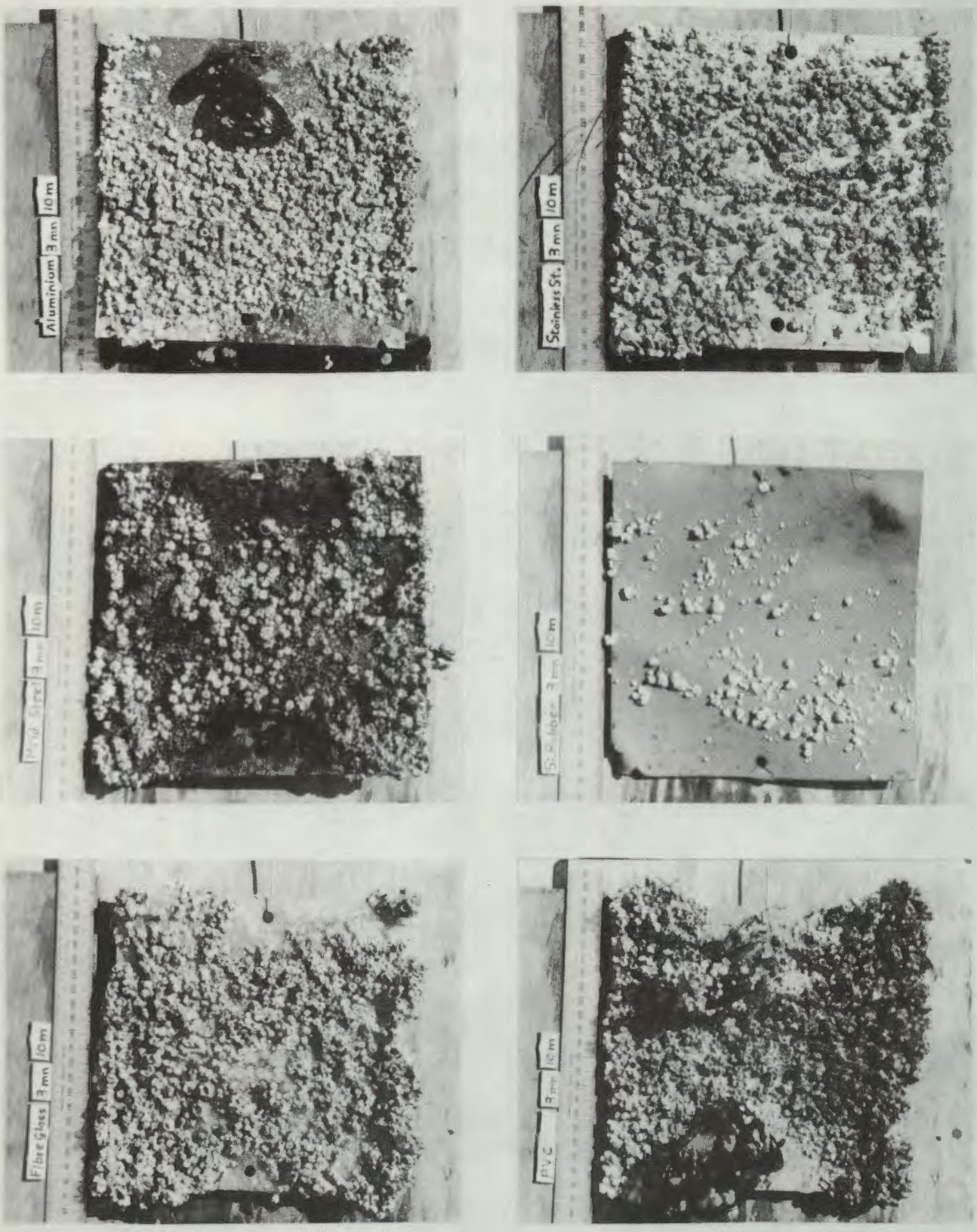


Plate 2.2.2f : Exposure at 10m for 3 months during March - May 1980.

(k) March to May at Site 1 & 2 - Plate 2.2.2e & f

The difference between the fouling communities on plates exposed at Site 1 and 2 was perhaps least obvious during March to May, although more tunicates, Pyura sp and Ciona intestinalis (see AL, SS, FG & PVC) settled at the former and more filamentous bryozoa, Bugula neritina (see PVC & MS) at the latter. The main fouling organisms, barnacles (500-2000/dm^2), mostly Balanus amphitrite and few B.trigonus, were of similar size and in similar numbers at both sites, accounting for the similarity in appearance. Between the barnacles, many small animals such as serpulids, Hydroides elegans and Spirorbis sp., and small bivalves, Choromytilus meridionales, Anomia sp., Saxicava arctica, Tapes sp., Chlamys tinctus and Tellimya rotunda, occurred. As before, the colonization on silicon rubber was sparse, while mild steel panels had many bare patches where the fouling had become detached. Many barnacles appeared to be damaged on some plates. This damage, presumably caused by carnivorous fish, can be seen clearly on fibre glass and aluminium plates at both sites and on PVC, Site 2. The large black mussels on Site 2 plates should be ignored because they had encroached from adjacent areas.

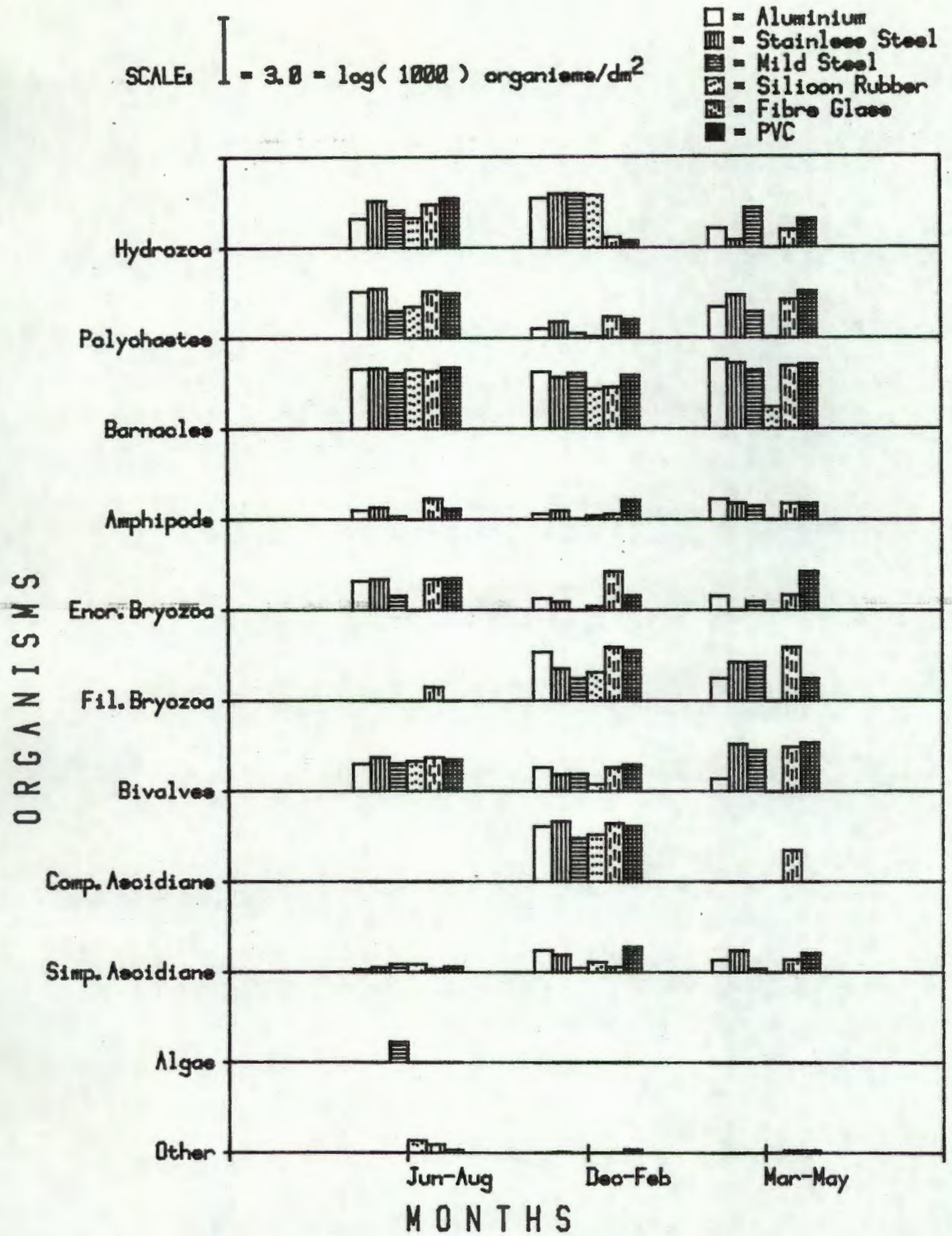


Fig 2222e : Number of organisms (log[X+1]) that settled on panels exposed for 3 months during different seasons at Site 1 (20m). Each group of plots shows data from different substrate materials : left to right Al, SS, MS, SR, FG & PVC.

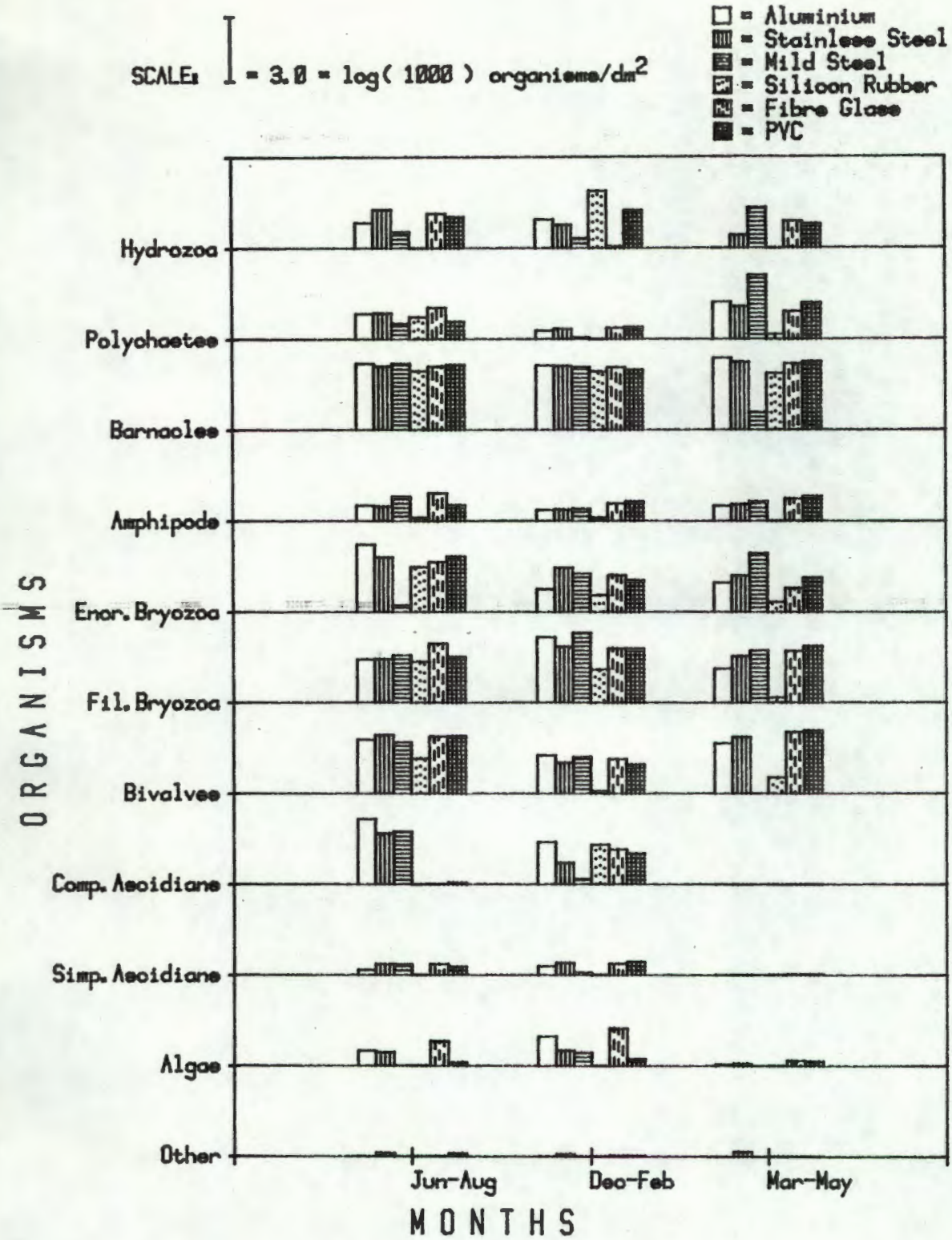


Fig 2222f : Number of organisms (log[X+1]) that settled on panels exposed for 3 months during different seasons at Site 2 (10m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

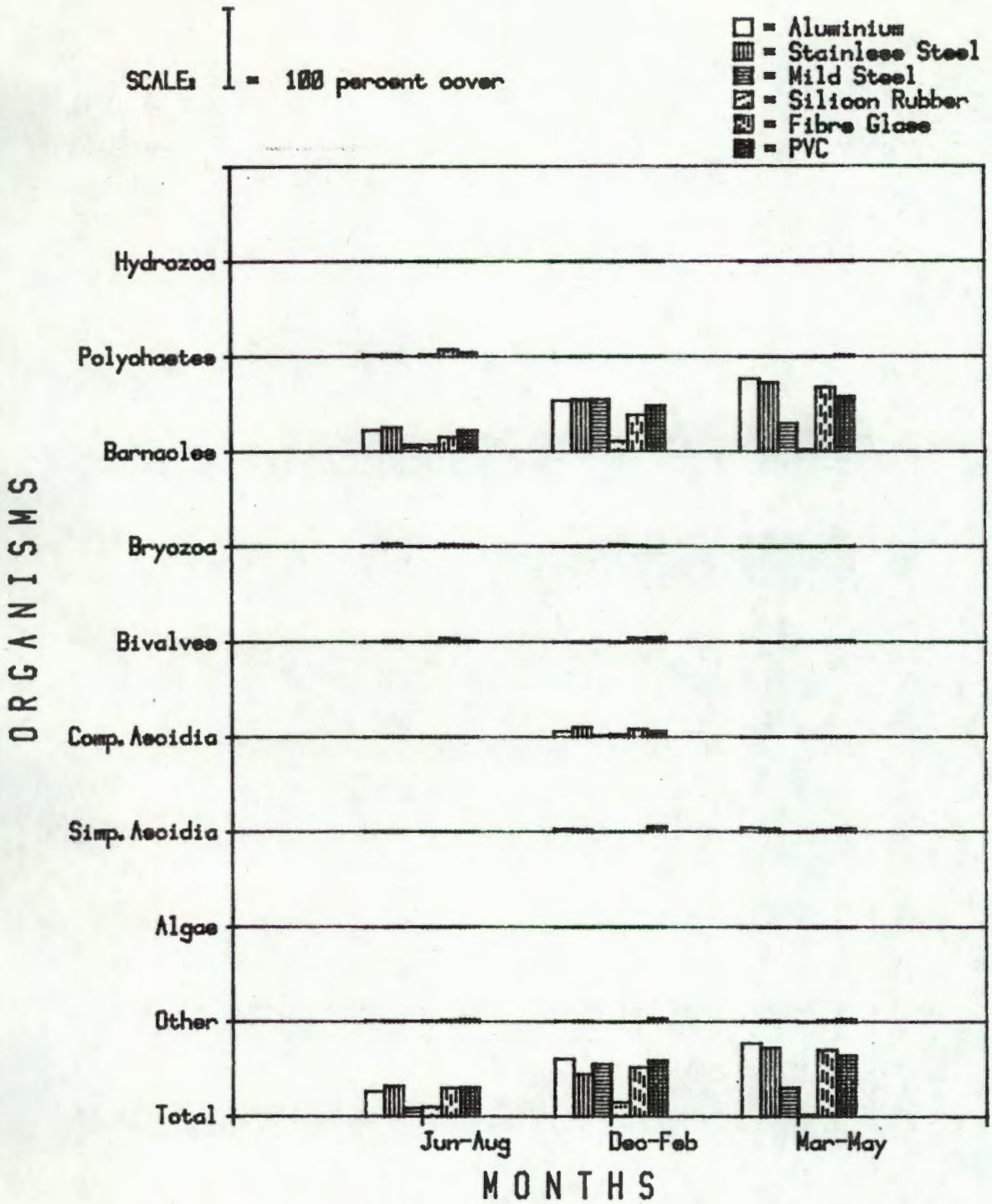


Fig 2222g : Percent cover by fouling organisms of panels exposed for 3 months at Site 1 (20m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

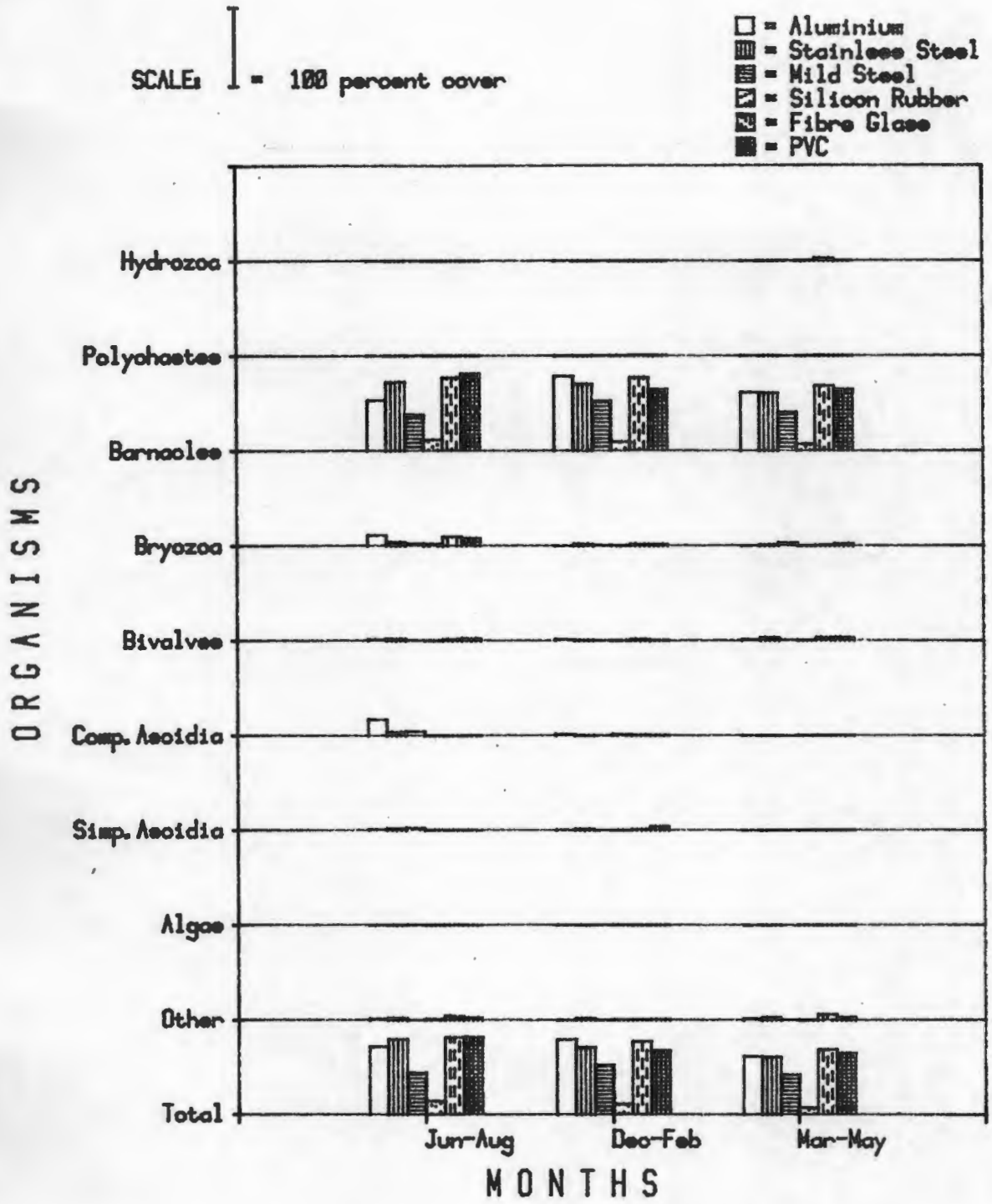


Fig 2222h : Percent cover by fouling organisms of panels exposed for 3 months at Site 2 (10m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

2.2.2.3. Seasonal effects

In temperate latitudes, the major seasonal trend is usually a drop in the degree of fouling during winter when the water temperature is low (Allen & Wood, 1950; Calder & Brehmer, 1967; Day, 1977; De Palma, 1976; Kawahara, 1965; Kawahara et al, 1979; Maloney, 1958; Russ, 1977; Schoener et al, 1978; Weiss, 1948). According to the water temperature record in False Bay (figure 2.1.1.1.), the winter condition lasted from May to mid-September. However, the actual increase already occurred in August, with the highest rate of fouling recorded in September and October. In the period of the initial increase in fouling, August to September, none of the measured environmental characteristics differed much from the winter conditions, June to July (Figure 2.1.1.a-b). The north-west wind storms, which prevailed in winter, began to subside in August. It is thus possible that, in Simonsbay, the offseason was primarily influenced by adverse weather conditions, and secondarily by temperature-dependant factors. Thus, Balanus amphitrite, Choromytilus meridionales, Hydroides elegans and Ectocarpus sp. may be weather-dependant, while Diplosoma spp., Pyura sp., Ciona intestinals, Bugula neritina and encrusting bryozoa appear to be mainly influenced by temperature regimes. Day (1977) noted that, although some species off Australia showed obvious temperature-dependance, other species were not influenced by the seasonal temperature fluctuations, and that these included most of the species that finally dominate the community.

The general seasonal occurrence of organisms is summarized in table 2.2.2.3a. The peak settling period of B.amphitrite is in August to October, with a secondary peak around April, while B.trigonus settled mainly during December to March. Numerous Choromytilus spat and Hydroides settled in early spring, August and September, at 10m and 20m respectively, the latter species having a secondary peak in autumn. Bugula and Diplosoma settled throughout spring and summer, but simple ascidians, mainly Pyura, settled during summer and early autumn. Algae seemed to occur throughout the year, but colonial diatoms, Licmophora flabellata, have a peak in winter (possibly because of less competition from more "aggressive" foulers) and brown algae, Ectocarpus and Colpomenia, settle most numerously in spring. (The sampling procedure was, however, not consistent, because algae occurred in the early stages of fouling, one-month, which was monitored only between June and November.)

Table 2.2.2.3a: Summary of the seasonal occurrence of organisms.

SEASON	OCCURRENCE	10m	20m
June-July	Abundant	-	-
	Numerous	B.amphitrite, Licmophora	-
	Frequent	Ectocarpus, Hydrozoa	B.amphitrite, Hydrozoa
August - October	Abundant	B.amphitrite	B.amphitrite
	Numerous	Ectocarpus, Colpomenia Choromytilus, Bugula	Hydroides, Campanularia
	Frequent	Diplosoma, B.maxillaris Encrusting Bryozoa	Diplosoma, Choromytilus B.maxillaris
November - February	Abundant	B.trigonus	B.trigonus
	Numerous	B.amphitrite, Bugula	B.amphitrite, Diplosoma Campanularia
	Frequent	Choromytilus, Ectocarpus Diplosoma	Pyura, Aetea
March - May	Abundant	B.amphitrite	B.amphitrite
	Numerous	B.trigonus, Hydroides Bugula	B.trigonus, Hydroides
	Frequent	Choromytilus	Choromytilus, Aetea Pyura

Table 2.2.2.3a: Summary of the seasonal occurrence of organisms.

SEASON	OCCURRENCE	10m	20m
June-July	Abundant	-	-
	Numerous	B.amphitrite, Licmophora	-
	Frequent	Ectocarpus, Hydrozoa	B.amphitrite, Hydrozoa
August - October	Abundant	B.amphitrite	B.amphitrite
	Numerous	Ectocarpus, Colpomenia Choromytilus, Bugula	Hydroides, Campanularia
	Frequent	Diplosoma, B.maxillaris Encrusting Bryozoa	Diplosoma, Choromytilus B.maxillaris
November - February	Abundant	B.trigonus	B.trigonus
	Numerous	B.amphitrite, Bugula	B.amphitrite, Diplosoma Campanularia
	Frequent	Choromytilus, Ectocarpus Diplosoma	Pyura, Aetea
March - May	Abundant	B.amphitrite	B.amphitrite
	Numerous	B.trigonus, Hydroides Bugula	B.trigonus, Hydroides
	Frequent	Choromytilus	Choromytilus, Aetea Pyura

2.2.3. Duration of exposure

The cumulative fouling record, starting in June 1979 and ending a year later, was examined in terms of the increase in weight, volume and panel cover, and changes in the fouling community. Since the fouling on one-month panels in winter, June and July, was much less than in other months (section 2.2.2.) and because the records of variables were less comprehensive for the one-month exposure periods June, July and August, the data chosen for comparison with longer periods was of September. All other samples compared in this section were immersed in June and recovered after progressively longer periods.

The system for comparing the exposure periods is similar as that used in section 2.2.2., namely:-

(i) Substratum materials and duration of exposure are compared on interaction plots for wet weight, volume, percent cover and number of species.

(ii) The data of abundance and cover of organisms from the very early stages upto a year, is summarized. The sequence of fouling development is discussed.

2.2.3.1. Cumulative fouling record

a) Weight - figure 2.2.3.1.a

The weight remains constant for the first three months of exposure at Site 1. After nine months it was, however, much higher on all materials, except SR, where it was still very low after 12 months. After 12 months, when only one sample of each material was available, the weight was extremely variable, ranging from 30g/dm^2 on PVC to 670g/dm^2 on SS. At Site 2 the materials were similar to each other, except SR, which remained very low throughout. The weight increased 2 to 3-fold from one month to three months with a further 3 to 6-fold increase from three months to nine, after which the weight did not appear to increase further.

b) Volume - figure 2.2.3.1.b

Since the trends for volume appeared to be so similar to those described for weight, the results of volume are not interpreted seperately.

c) Cover - figure 2.2.3.1.c

At both sites, SR remained relatively bare throughout (less than 30%). The cover of other materials, except MS, increased significantly from one month (5-25%) to three months (30-40%) at Site 1. After nine months and longer most surface area (more than 70%) was covered on all materials. At Site 2, the increase of cover was very rapid. After one month, PVC (70%) differed markedly from other materials (5-25%). After a three-month period, most of the plates, except MS (55%), were almost totally covered. Surface cover was complete on all materials after nine and twelve months.

d) Mean Species Diversity - figure 2.2.3.1.d

Except on SR, more species were present on all materials exposed for nine months and longer (16 - 21) at Site 1 than on those exposed for three months (11), the latter having a similar number of species as after one month. Initially more species would settle on PVC, FG and SS (13) than on AL and MS (8), but after longer exposure periods the differences between all these materials were minimal. At Site 2 there was a sharp increase in the number of species on AL, SS, FG and PVC plates from one month (8) to three months (16), thereafter remaining roughly constant. After three and nine months, MS (10) was lower than other materials, but, after 12 months, it had the same number of species as other materials (16).

e) General

On SR plates there were no significant changes in weight, volume, cover and species diversity at both depths during all exposure periods. On other materials immersed at Site 1, the weight and volume values were very low in the first three months and the number of species did not change, but the plate cover increased slightly. More species were present after 9 and 12 months, the plates were almost completely covered and the weight and volume values were very high, although variable after 12 months. At Site 2, the fouling

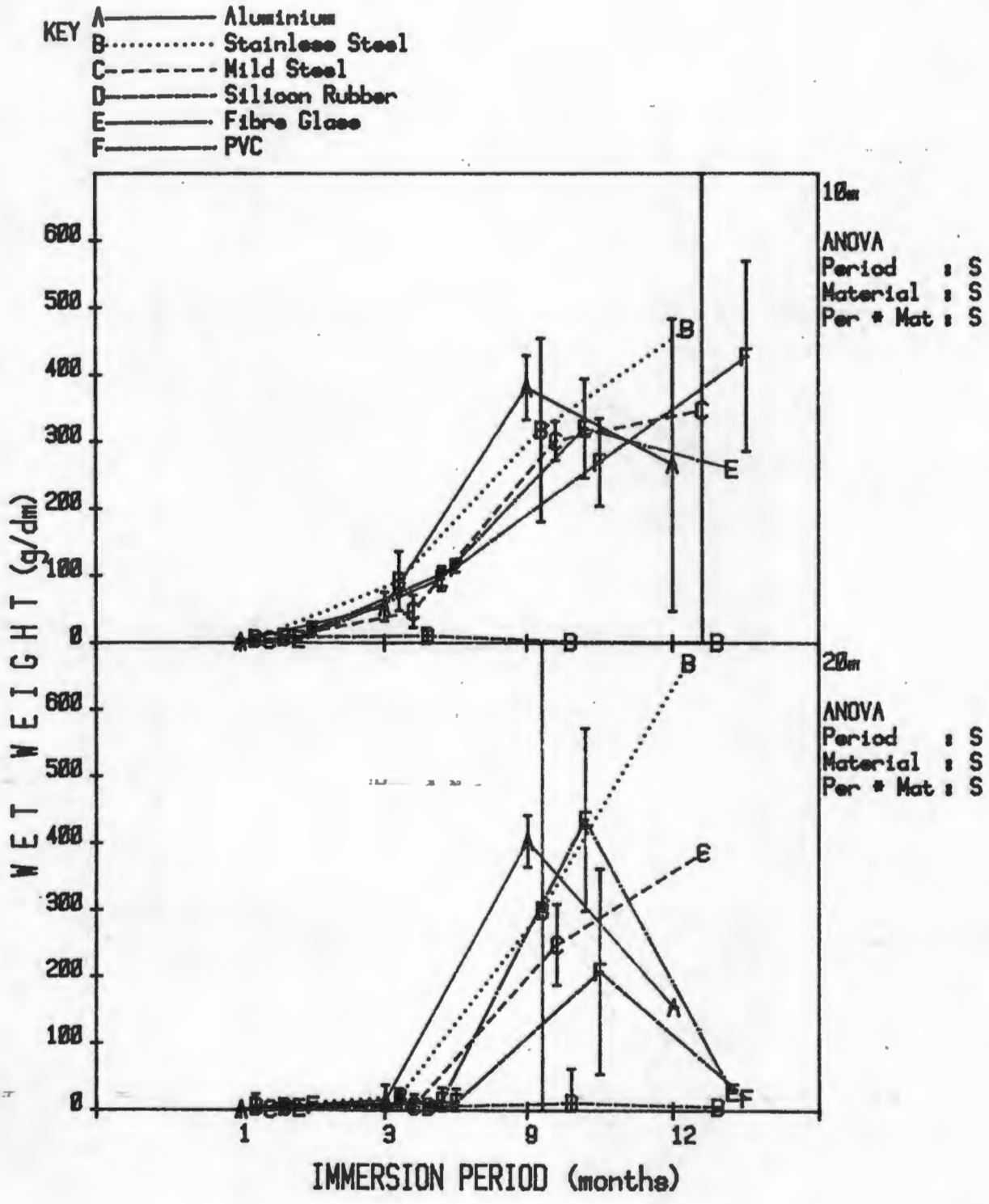


Fig 2231a: Interaction plots of immersion period vs. substrate material for wet weight (±95% C.L.). Significance in the ANOVA was tested at the .5% level. (S = significant ; NS = not significant)

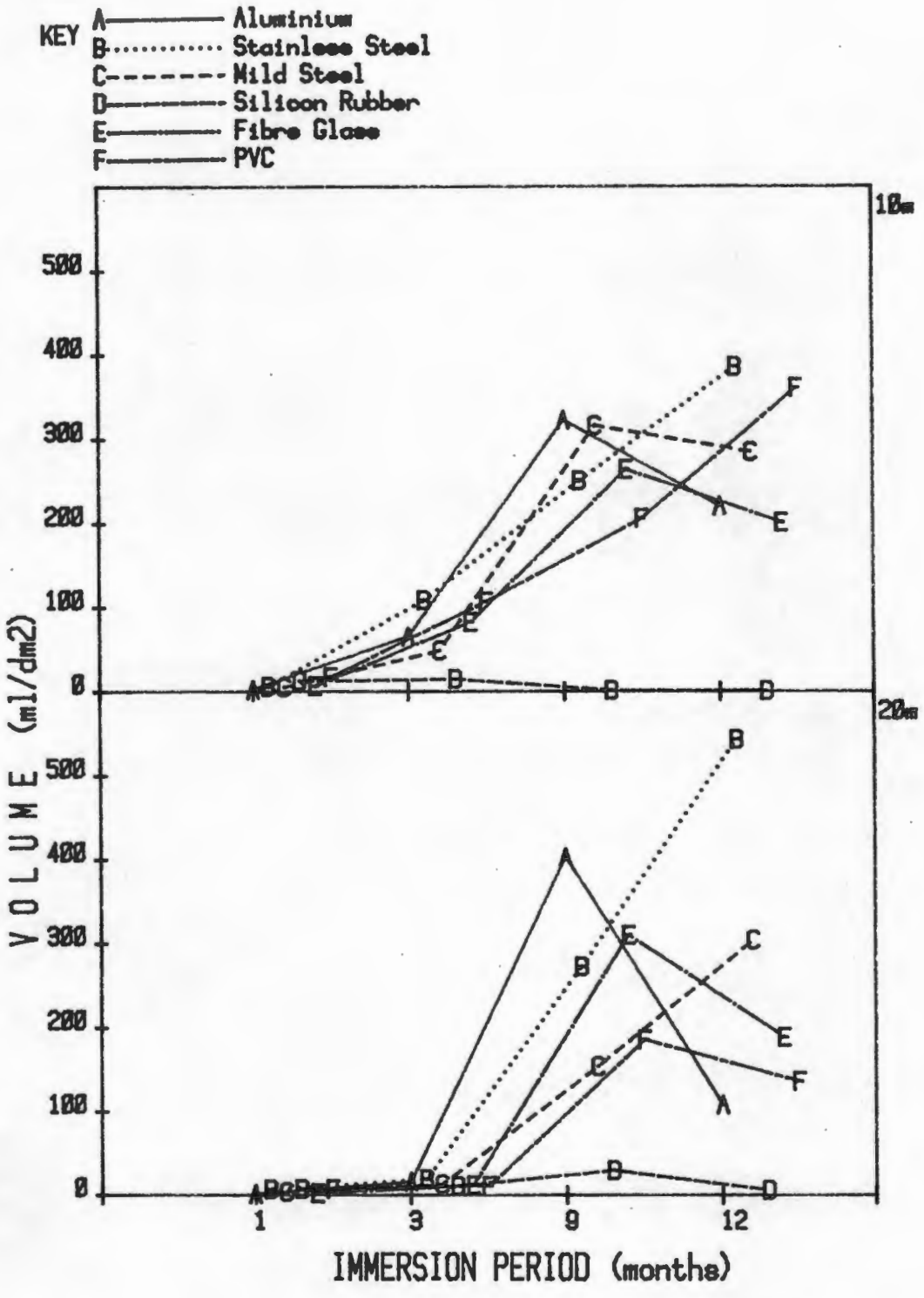


Fig 2231b: Interaction plots of immersion period vs. substrate material for volume of fouling organisms.

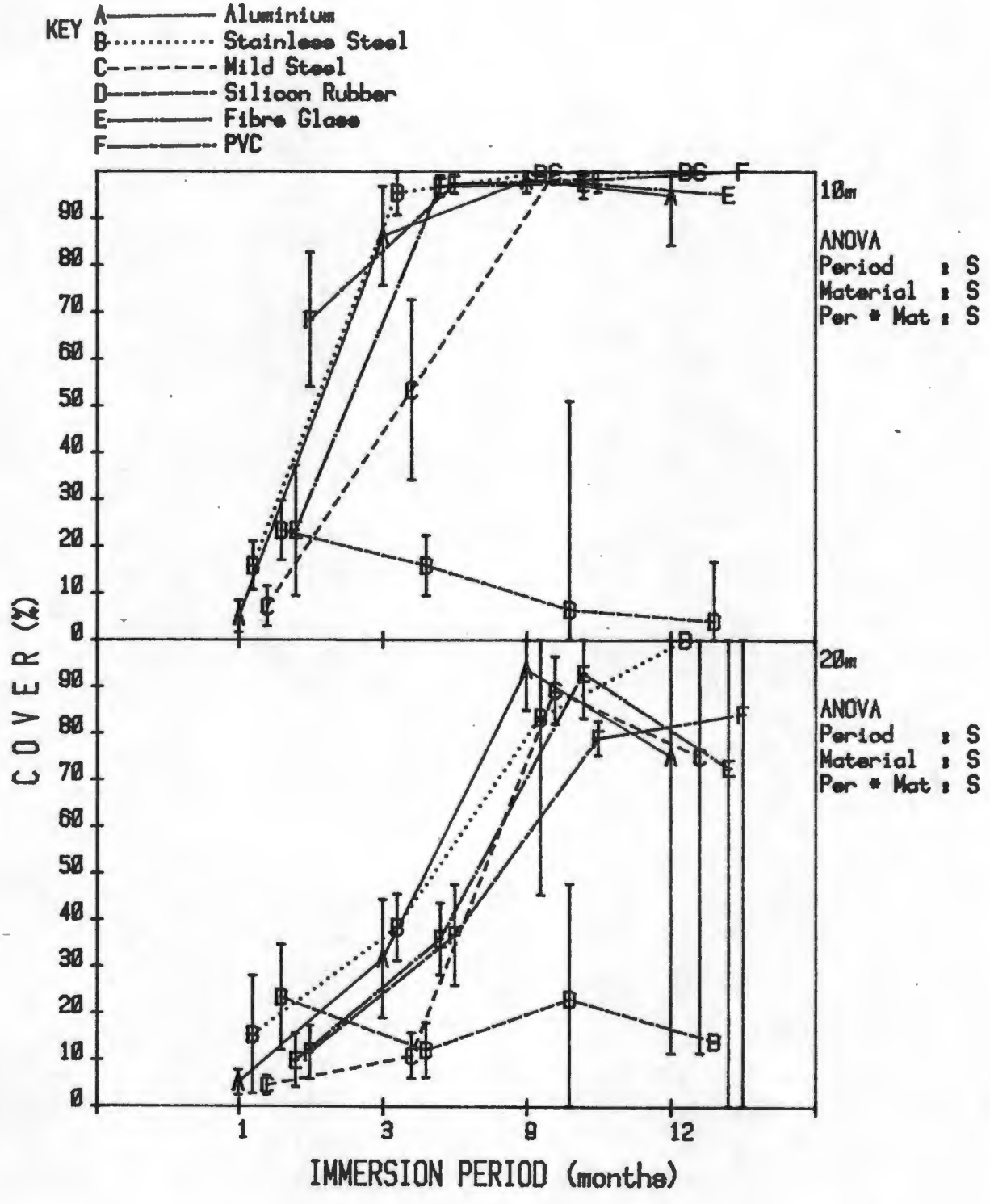


Fig 2231c: Interaction plots of immersion period vs. material of percent plate cover (± 95% C.L.).
Significance in the ANOVA was tested at the .5% level.
(S = significant ; NS = not significant)

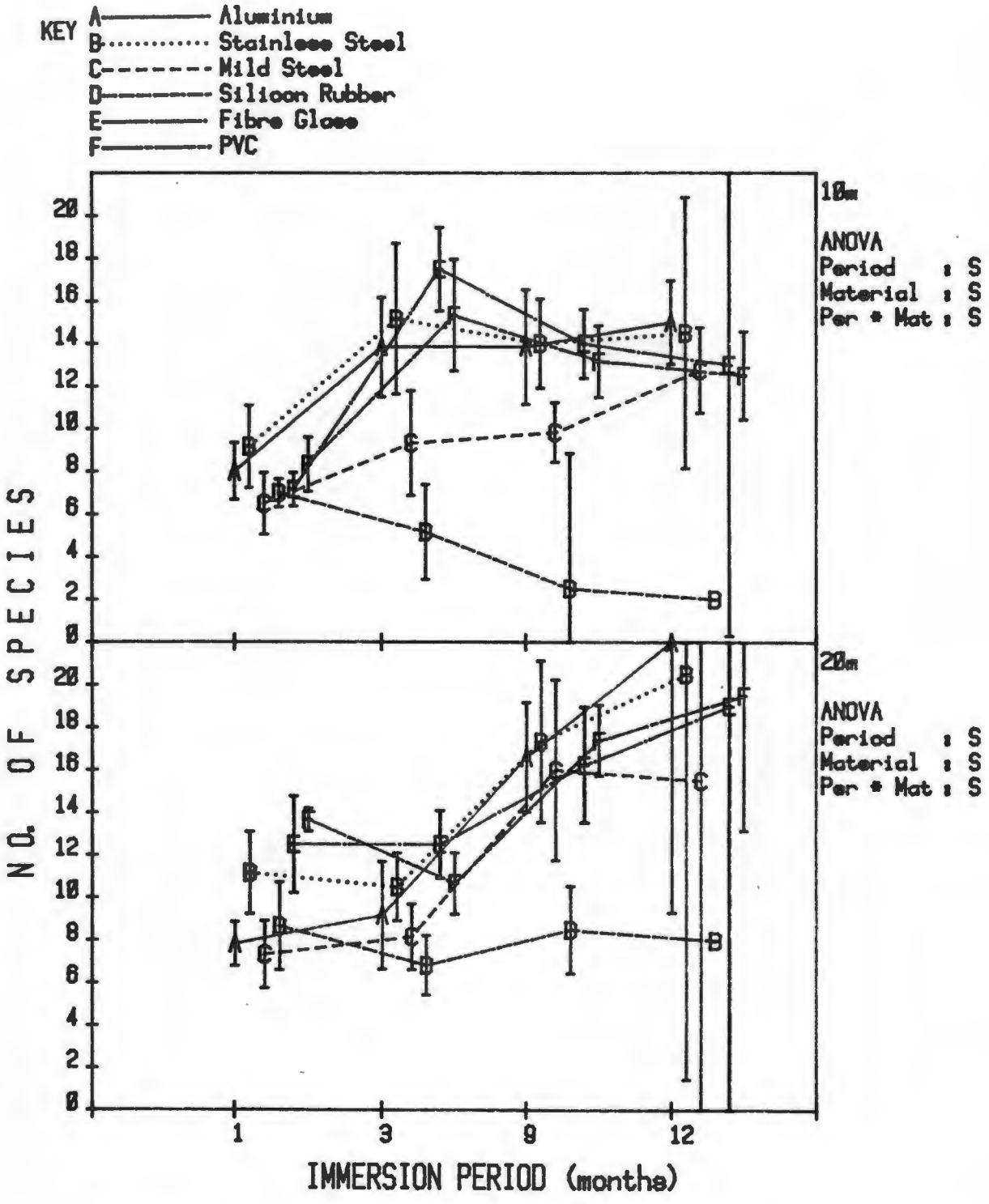


Fig 2231d: Interaction plots of immersion period vs. material for species diversity of sedentary organisms (±95% C.L.). Significance in the ANOVA was tested at the .5% level. (S = significant ; NS = not significant)

increased rapidly so that the plates were almost completely covered after three months. The main increase in weight and volume occurred after this period due to a substantial thickening of the fouling layer. The numbers of species per plate increased in the first three months and remained relatively constant thereafter.

f) Cumulative Species Diversity - figure 2.2.3.1.e&f

The more surface area is sampled, the larger the total number of species is expected to be until a sample size is reached when the occurrence of a 'new' species is rare. The minimum size of this area depends on whether conditions are limiting to the fouling community and depending on the number of potential fouling species (the 'species pool') (Day, 1977; Schoener, 1974; Schoener et al, 1978).

To test this for the present data, the cumulative number of species on replicate samples was plotted (figure 2.2.3.1.e&f). When analyzing the samples, new species were sometimes still encountered on the sixth replicate, especially on AL, SS, FG and PVC at Site 2. This would suggest that the number of potential fouling species was greater than the number represented on the panels. Since those species, that were not sampled on six replicates, were probably rare, or avoided settling on the test panels, the analysis of more than six replicates would not have made the results much more comprehensive. (Note: Although the larvae of some colonial organisms may be relatively rare, a developing colony may soon comprise numerous individuals, which bud off by asexual reproduction; Jackson, 1977.)

The fact that few species were recorded on SR, especially after long periods of exposure, and on MS after short periods, may be explained in two ways: (i) Settling organisms avoided becoming attached to the substratum i.e. either they were repelled from the surface or they failed to metamorphose because of the lack of releasing stimuli (Crisp, 1976); (ii) Species extinction rate was high, counteracting the immigration of species at a low equilibrium level (MacArthur-Wilson model; Schoener, 1974; Schoener et al, 1978) i.e. Once the organisms had settled, their longevity was limited by

unfavourable conditions - in some species more than in others. (This is the case with most toxic anti-fouling measures; Crisp, 1976.)

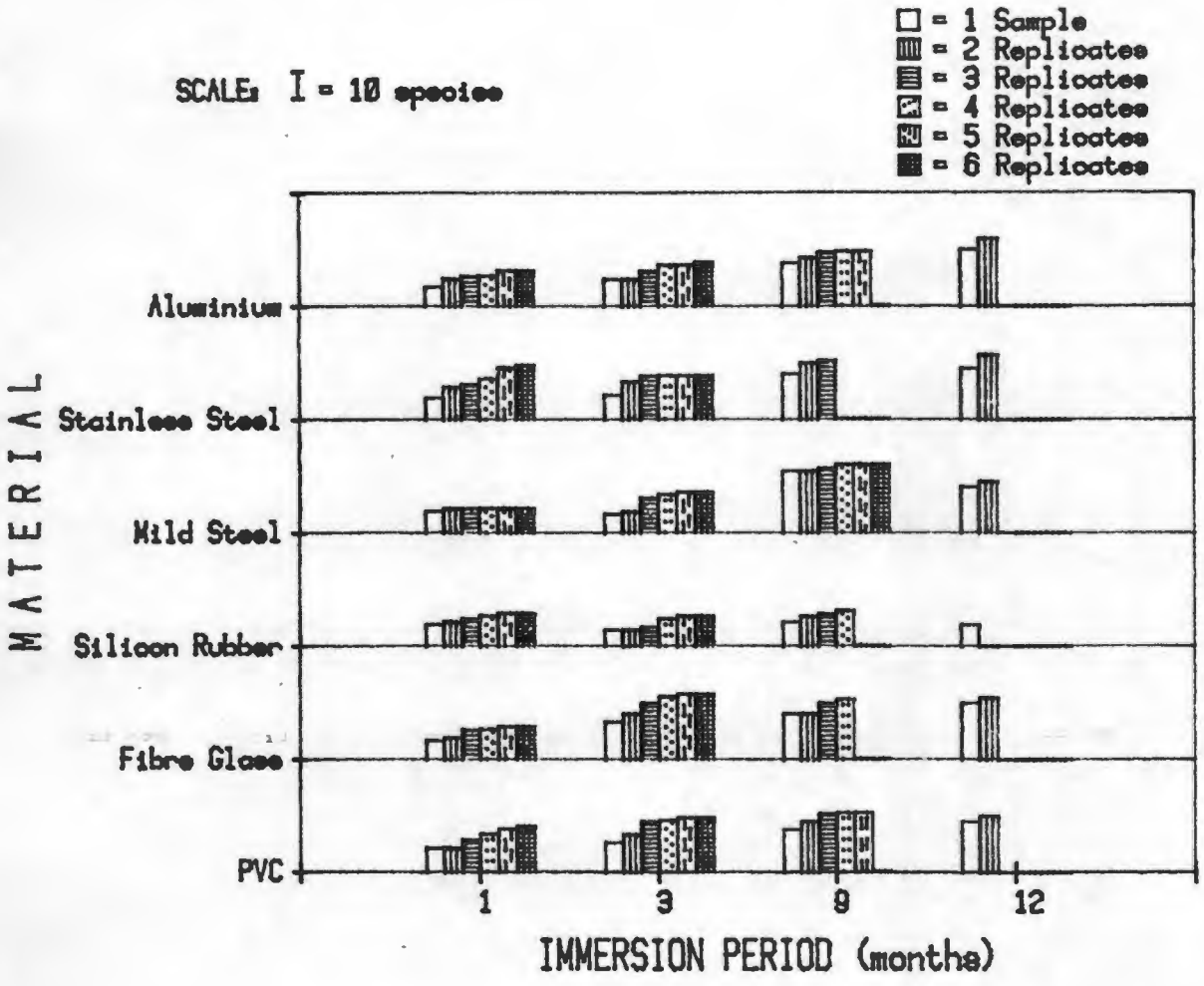


Fig 2231e : Number of sessile species on replicate panels of different materials, exposed for various periods of time at Site 1. Each group of plots shows the cumulative total number of species on replicate panels.

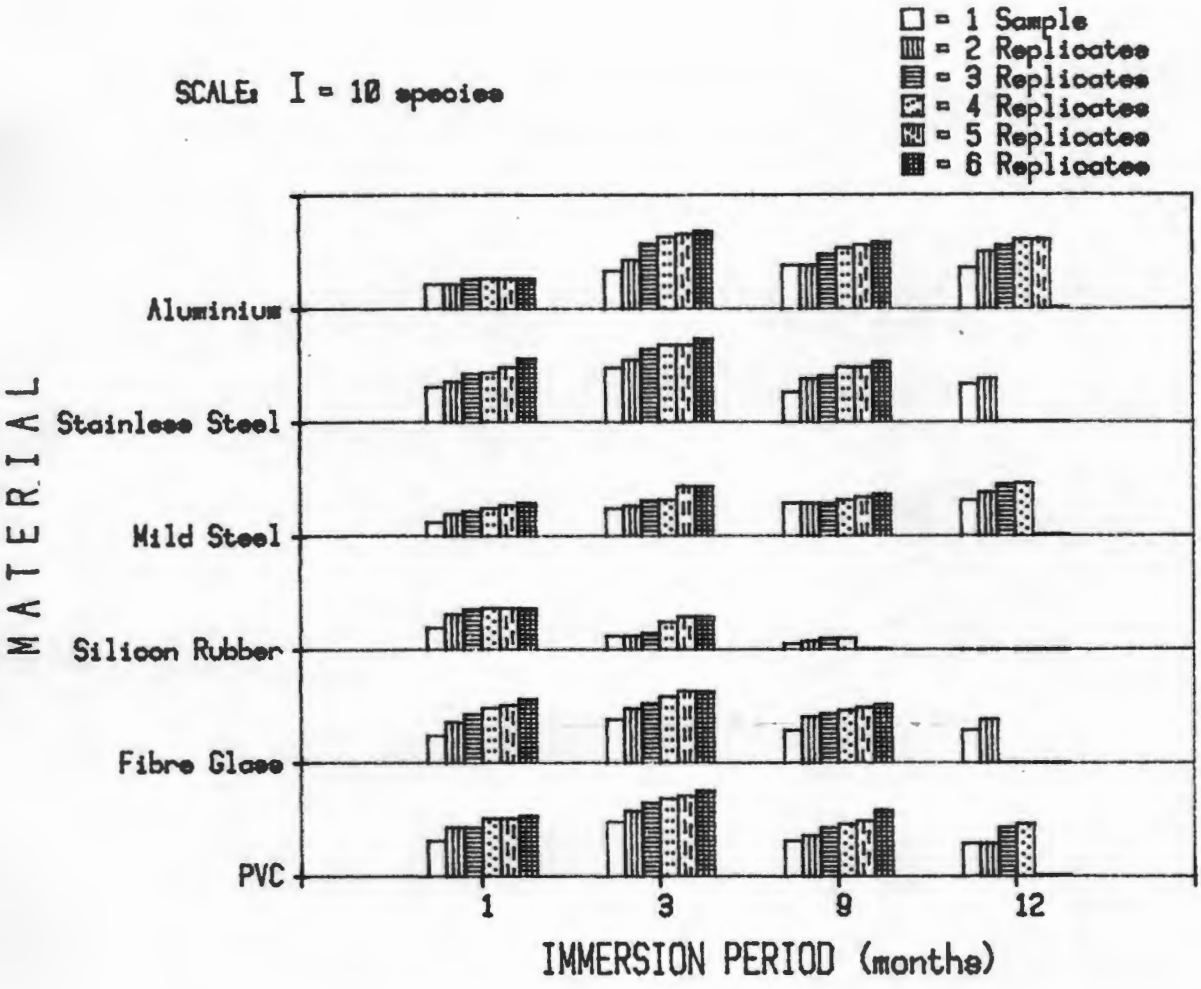


Fig 2231f : Number of sessile species on replicate panels of different materials, exposed for various periods of time at Site 2. Each group of plots shows the cumulative total number of species on replicate panels.

2.2.3.2. Sequence of Fouling Development

In 1979, de Chalain studied the first stages of the fouling sequence in Simonsbay on the same six substratum materials as used in the present study. His results, which will be examined alongside the observations on the development of the macrofouling community in this study, showed that the general fouling sequence was: molecular adsorption, bacteria, diatoms, protozoa, fungus, "pioneer" macro-organisms, "secondary" macro-organisms.

A similar sequence, whose components are not necessarily in a clear-cut temporal sequence, has been identified by other authors (Crisp, 1976; Cundell and Mitchell, 1977; Liberatore et al, 1972; Meadows and Campbell, 1972; Mitchell et al 1972, 1976 and 1977; Russ, 1977; Skerman, 1956; Wood, 1950; Zobell and Allen, 1935). Some of these authors and numerous others have proposed that the early stages of fouling, the primary film, may influence the settling behaviour of invertebrate larvae (Daniel, 1955; O'Neill and Wilcox, 1967; Horbund and Freiberger, 1970). The primary film could have a preconditioning effect on the settlement of macro-organisms, either by having "chemical releasing agents" that induce settlement (Müller, 1973; Neumann, 1979) or by modifying the physical properties of the surface to promote adhesion (Zobell, 1939). Although it has been demonstrated that serpulid (Crisp and Ryland, 1960; Daniel, 1955; Meadows and Williams, 1963; Wilson, 1955), barnacle (Daniel, 1955; Liberatore et al, 1970), hydrozoa (Müller, 1973) and bryozoa (Crisp and Ryland, 1960; Miller et al, 1948) larvae settle more readily in the presence of primary film constituents than without, Crisp (1976) insists that this is a preference and not a precondition and that settling larvae also respond to numerous factors other than those involving the primary film. However, when encountering a surface, larvae first come into contact with the primary film. It is conceivable that this could influence their settlement response.

In the present context, the sequence of fouling development on panels after various periods of immersion should not be regarded as a series of discrete stages, but as an increasingly more complex process. Because the details of the community constituents were variable they are described only in broad terms with emphasis on the dominant species.

Note:- Experiments with various durations of exposure were carried out at different times of the year and are not in a chronological sequence. Russ (1977) noted that there can be a seasonal variation in the degree of microfouling but that the sequence remains similar. All descriptions of microfouling presented in this section are according to de Chalain (1979), who carried out his study in various months between January and November 1979. The short-term records of macrofouling (less than a month) were carried out in March to April 1980 (figure 2.2.3.2.a), the one-month records between June and November 1979 and all other experiments between June 1979 and May 1980 (figure 2.2.3.2.b-e).

a) 1 Day

A population of bacteria began to proliferate a few hours after immersion and developed a thin mucopolysaccharide layer within a day, more so on metals than on plastics. Already after one day the first macro-organisms had settled. On 18 PVC plates (total area $9dm^2$), four barnacles and two polyps of Campanularia integra (one colony) were recorded.

The attachment of the macro organisms at such an early stage could mean either: (i) that their settlement response was independant of the primary film characteristics, (ii) that these barnacle and hydrozoan species responded to the early appearance of bacteria, or (iii) that their establishment was an "artifact" (a term used by de Chalain for cases where an organism that settles when its "threshold stimulus", for releasing the settlement response, falls after a lengthy unsuccessful exploratory phase so that it becomes attached on a less favourable site; Crisp, 1976). Liberatore et al (1972) found that barnacle settlement was promoted by the primary film, but that barnacles did settle on cleaned surfaces. Similar observations were made for Bugula by Miller et al (1948; see below). In temperate and subtropical latitudes of the United States, Balanus eburneus, settles in large numbers during the first 24 hours. Pomerat and Reiner (1942) recorded the first few settled cyprids already after 6 hours, and an average of 40 barnacles/dm^2 after a day. Phelps (1941) sometimes found more than 20/dm^2 after the first day. During peak settlement periods Weiss (1944) recorded a maximum of 320/2days and usually between 1-4/dm^2/day cyprids and metamorphosed barnacles. Under high settlement conditions, organisms seem to settle less discriminately (Weiss, 1944) probably as a result of competition for attachment sites.

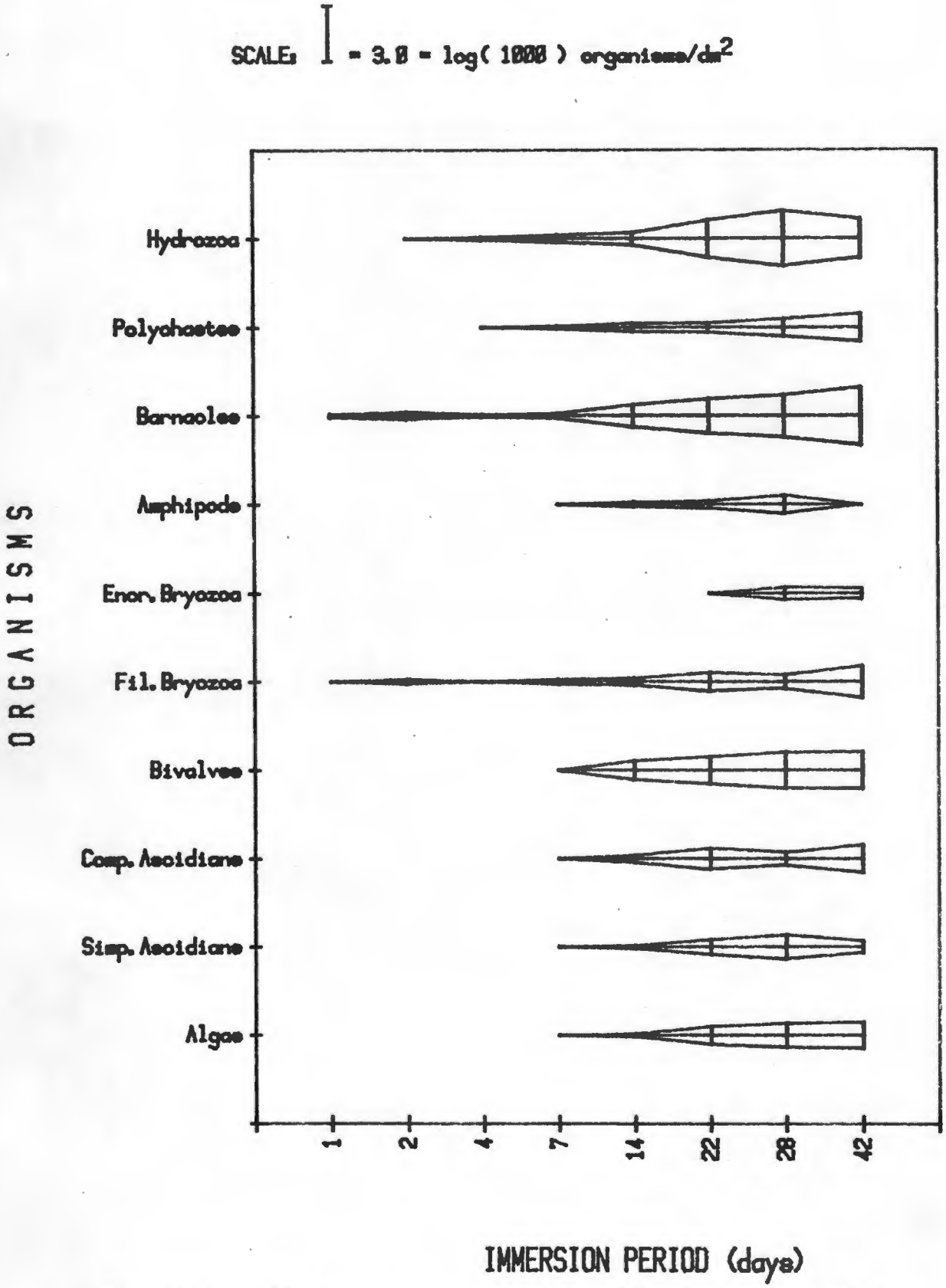


Fig 2232a : Number of organisms (log[X+1]) that settled on PVC plates (5x5 cm) exposed at Site 3 (10m) for various periods of time during March 1980.

b) 2 Days

A thin meshwork of bacterial mucopolysaccharides had spread over much of the surface; diatoms and coccoliths began to appear. Besides four barnacles, two colonies of Bugula sp. (one zooid each) were seen on the plates (total area $3dm^2$).

c) 7 Days

An extensive bacterial population had become established, forming thick patches of mucopolysaccharide. Diatoms had become numerous and a few protozoa and algal spores were seen. Mild steel had corroded to form a layer of flaky loose rust. More species of macro organisms had appeared: a few barnacles, a single zooid of Menipea sp., one Spirorbis sp individual and two colonies of Tubularia sp.? (per $3dm^2$ PVC).

d) 14 Days

The fouling community had become more complex at the micro and the macro level. Besides the increasing abundance of bacteria, the diatoms, algal spores, protozoa and fungi had proliferated (the latter were only seen under low magnification by this author - no mention was made of fungi at this stage by de Chalain). A variety of macro organisms had settled on 18 PVC plates exposed during March and April at 10m. These were mainly Balanus sp. ($75/dm^2$), saddle oysters, Anomia sp. ($8/dm^2$) and mussel spat (probably Choromytilus meridionales; $10/dm^2$), but also included: hydrozoa, Tubularia sp., Campanularia integra, Obelia dichotoma, serpulids, Spirorbis sp. and Hydroides elegans, bryozoa, Bugula sp., Menipea sp. and Watersipora sp., colonies of compound ascidians, Diplosoma spp., simple ascidians (possibly Ciona intestinalis), brown algae, Colpomenia sp., red algae, Ceramium sp. and tubiculous amphipods, Erictnonius brasiliensis. All of these "pioneer species" (Loucks, 1970) were attached directly to the substratum (or, possibly, to the overlying primary film) i.e. they did not use other macro-organisms for shelter or attachment. The development of this pioneer community was very similar to that described by Allen & Wood (1950) in Australia for the same duration of exposure.

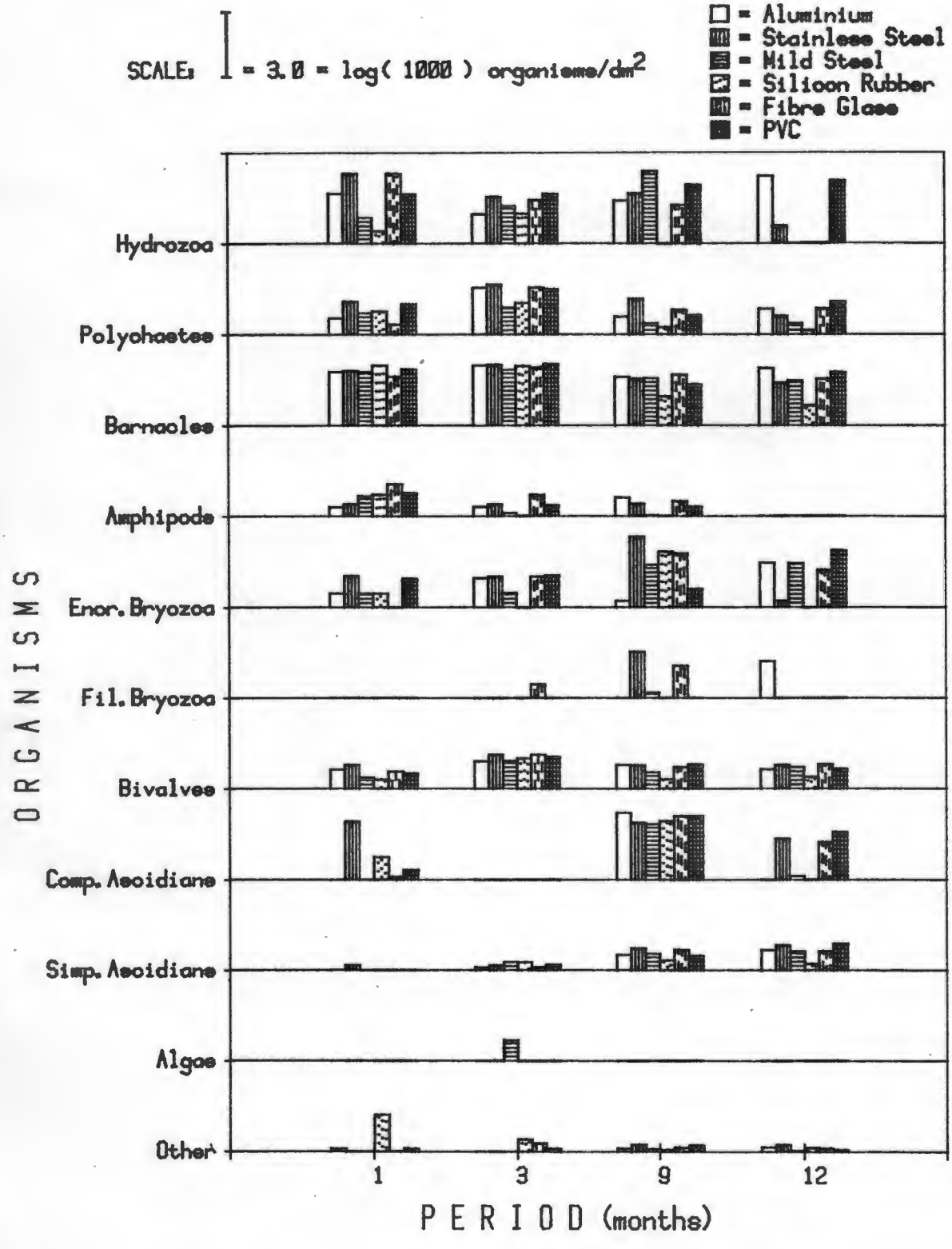


Fig 2232b : Number of organisms (log[X+1]) that settled on panels exposed for various periods of time at Site 1 (20m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

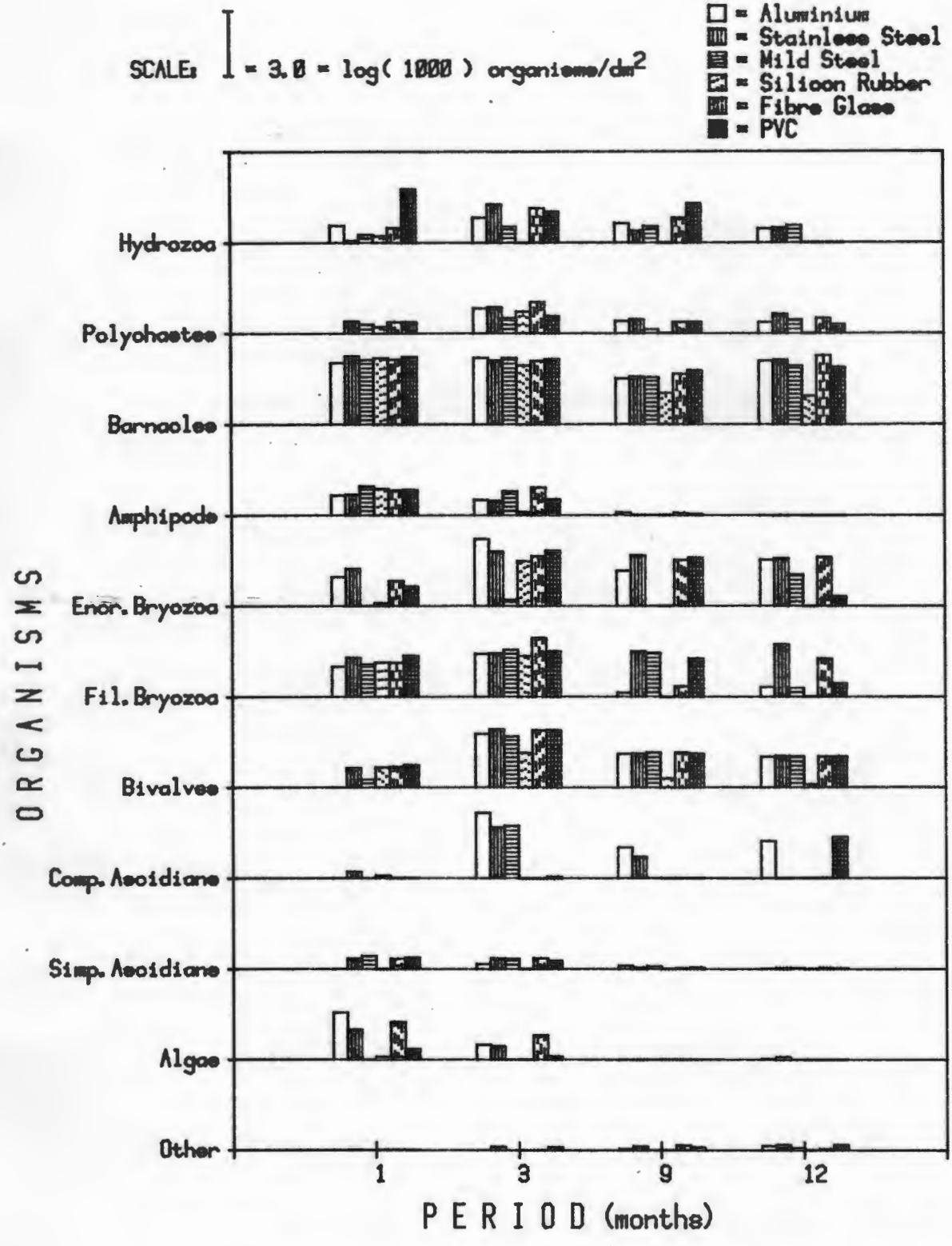


Fig 2232c : Number of organisms (log[X+1]) that settled on panels exposed for various periods of time at Site 2 (10m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

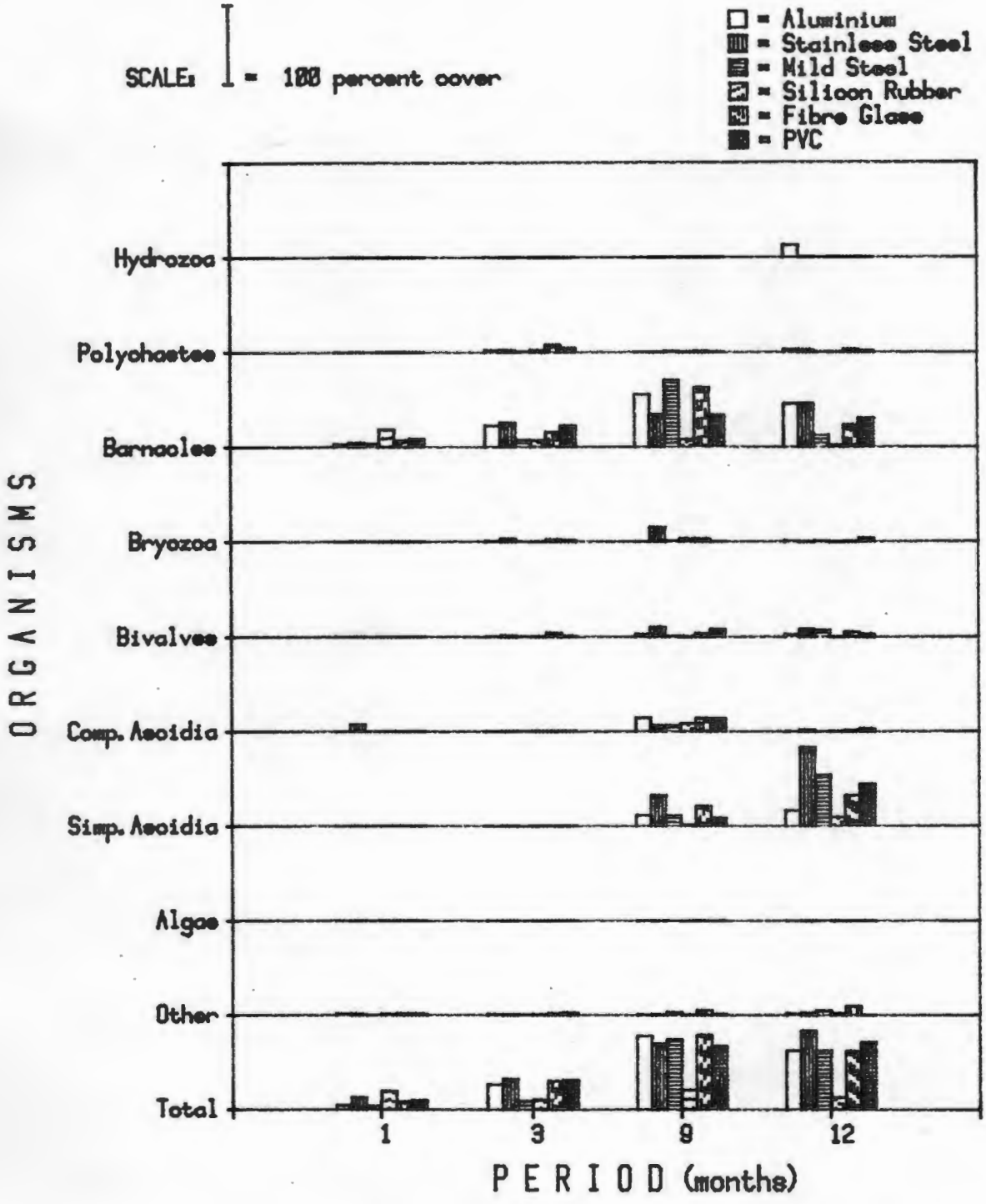


Fig 2232d : Percent cover by fouling organisms of panels exposed for various periods of time at Site 1 (20m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

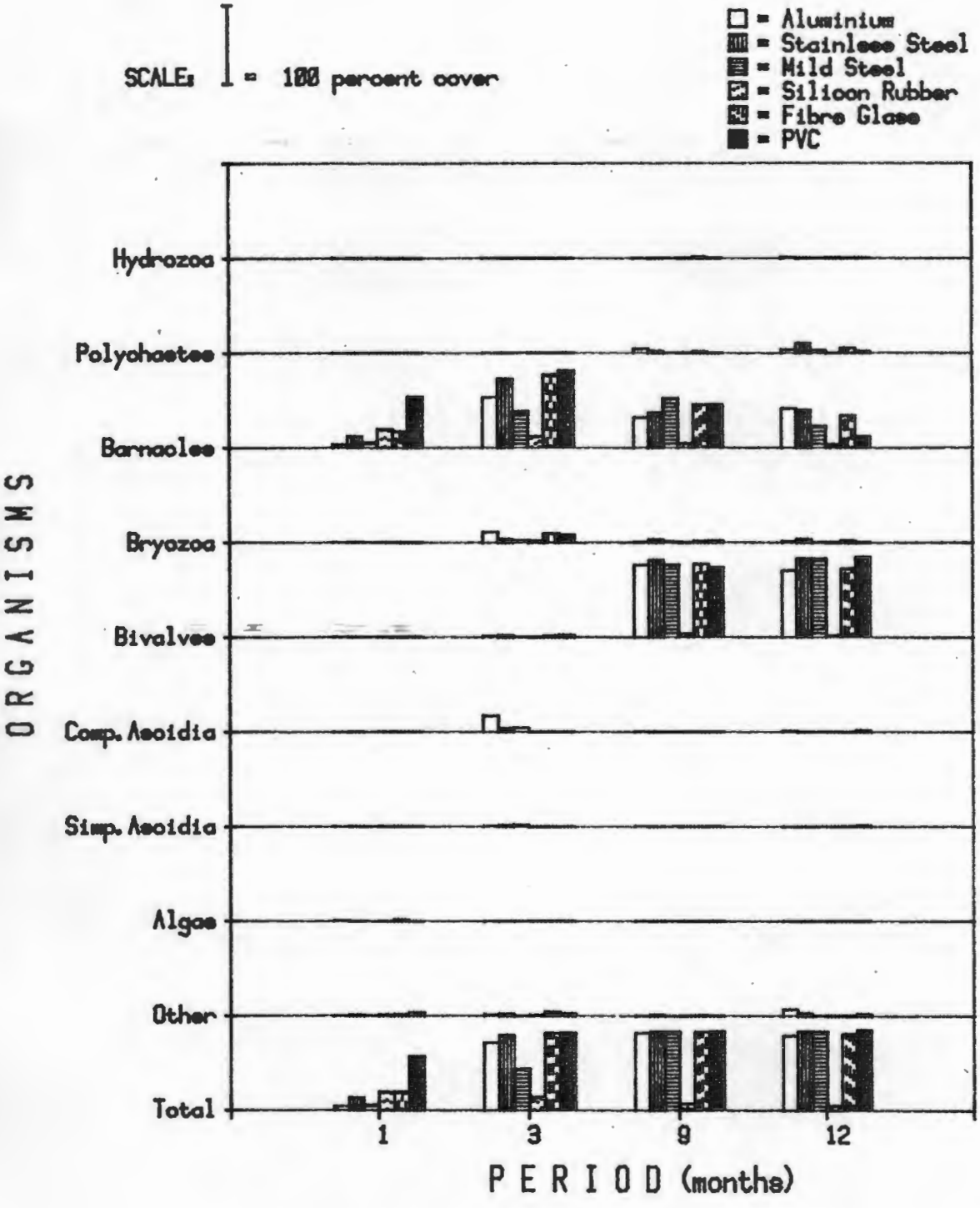


Fig 2232e : Percent cover by fouling organisms of panels exposed for various periods of time at Site 2 (10m). Each group of plots shows data from different substrate materials : left to right, Al, SS, MS, SR, FG & PVC.

e) 22 Days

Bacterial mucopolysaccharides, diatoms, protozoa and fungi had formed a thick layer which was clearly visible to the naked eye. The mild steel surfaces were covered with floccular corrosion products with less microfoulers than the other materials. Few new species of macro-organisms were recorded, the increase in fouling being in degree rather than nature. Balanus (100/dm^2), Campanularia (about 70 zooids/dm^2), Anomia (10/dm^2) and mussel spat (15/dm^2) were fairly common, and most of the species listed in (d) were represented. New species include: Eudendrium sp., Aetea sp.? and Membranipora sp.

f) 1 Month

The primary film, comprising an abundance of bacteria with slime, a wide variety of diatoms, protozoa, fungi, blue-green algae and organic debris, covered all surfaces. Macrofoulers were abundant and included a large number of species, except during the winter months June and July. New organisms, that were first recorded after a month include: algae, mainly Ectocarpus sp., bivalves, Saxicava arctica and Tapes sp., more species of encrusting bryozoa and of tubiculous amphipods, and the hydrozoans, Plumulariidae and Sertulariidae. The communities that developed on AL, SS, FG and PVC were broadly similar, but differed between sites mainly because few algae and bryozoa were recorded at 20m. Algae and encrusting bryozoa avoided MS and SR, but barnacles were abundant on all materials, more so at 10m (3000/dm^2) than at 20m (2000/dm^2). PVC was most heavily fouled and MS least.

g) 3 Months

A visible layer of slime bound the accumulated debris and fine sediments onto the surfaces, sometimes forming sheaths around algal filaments or hydrozoan stalks. On mild steel, a thick, almost black layer, possibly comprising complexes of ferrous oxide with extracellular products of bacteria (see de Chalain, 1979), covered a layer of brown flaky rust.

SR was no more fouled than at the one-month stage, but most of the surface area of other materials was covered by macrofoulers, many of them settling on top of resident individuals (plate 2.2.2.a-f). The fouling of the other materials was broadly similar at each depth, except of MS, on which loose flakes of rust sometimes sloughed off. Barnacles were very abundant, occurring in multiple layers. However, different species of barnacles would dominate in different times of the year: Balanus amphitrite between June and November, B.trigonus between December and May. Numerous mussel spat, Choromytilus meridionales, had settled on top of previous settlers at this stage. This may indicate that the spat preferred a prefouled surface, although they also settled at an earlier stage (see above), when they were directly attached to the substratum . In view of the future development of fouling, it should be pointed out that, although Choromytilus spat were numerous at both sites, they seldom grew large at 20m, suggesting that their mortalities were higher. Few algae were present. It seems that the algal species occurring at 10m required open patches, where they could attach directly to the substratum (see Scheer, 1945). Overcrowding by invertebrates would thus explain their drop in numbers and the near-absence of Ectocarus and Colpomenia. (One species of red algae, Agardhinula sp.?, which was recorded here, attached only to the stem of the hydrozoan, Sertularella arbuscula).

Most of the other invertebrates, recorded at earlier stages, were more abundant after three months. Occasionally, some of them occupied a considerable amount of space e.g. colonial tunicates, Diplosoma spp., bryozoa, Bugula neritina or serpulids, Hydroides elegans. The presence at 20m of a few simple ascidians, mainly Pyura sp. and Ciona sp., is significant, because their potential as servere foulers is high. New species that become established in the community, usually occurring on top or sheltering among other organisms, included: sea anemone, Anthothoe stimpsoni and sometimes Bunodosoma capensis, polychaetes, Megalomma quadrioculatum and Nicolea macrobranchia, encrusting bryozoa, Chaperia sp., bivalves, Aulacomya sp., Chlamys tinctus and Tellimya rotunda and simple ascidians, Pyura sp., Microcosmus sp., Molgula sp., Styela sp. and Ascidia sydneiensis.

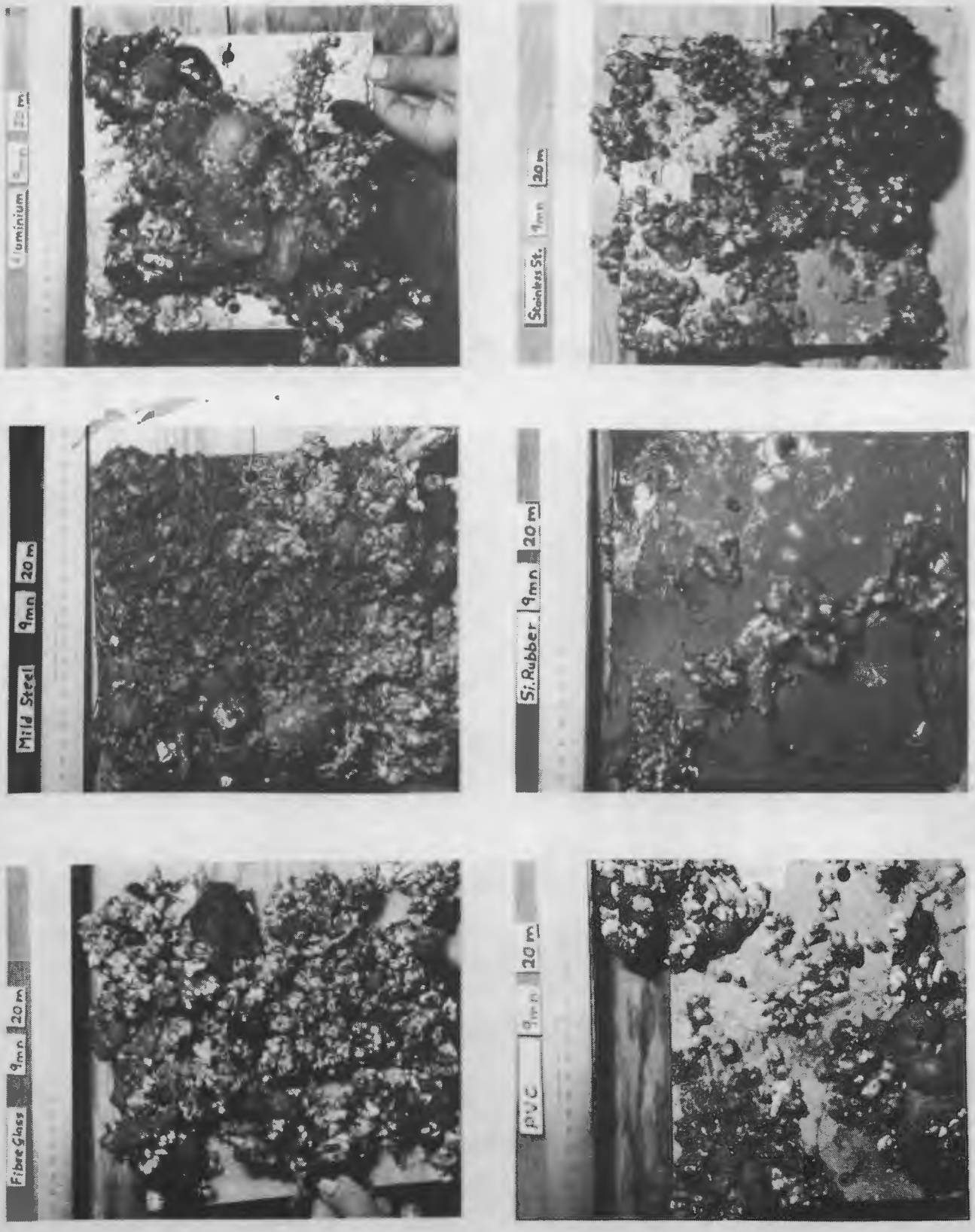


Plate 2.3.1a : Exposure at 20m for 9 months during June 1979 - February 1980.

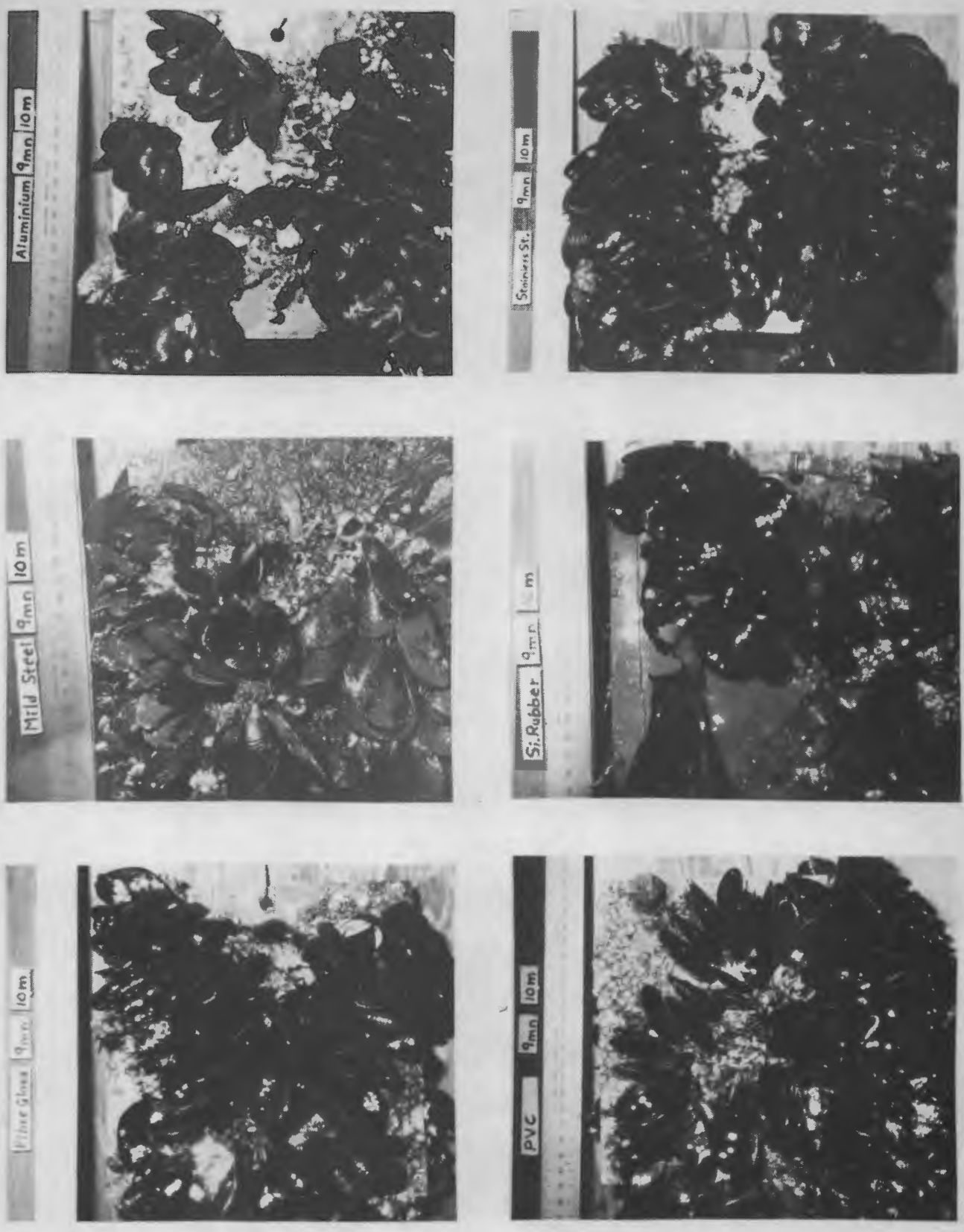


Plate 2.3.1b : Exposure at 10m for 9 months during June 1979 - February 1980.

Plate 2.3.1c : Exposure at 20m for 12 months during June 1978 - May 1979.

h) 9 Months

Because the nature of fouling was so grossly different at the two sites, the community at each is described separately.

At 20m depth (plate 2.3.1.a), much of the space on all plates, except silicon rubber, was occupied by large tunicates, mainly Pyura sp. Large individuals of Balanus maxillaris and smaller B.trigonus and some B.amphitrite dominated the areas around the tunicates. Many small organisms used the crevices in this thick layer as shelter. Colonial organisms, such as bryozoa, compound ascidians (see MS and FG) and hydrozoa (see PVC and AL) sometimes overgrew the barnacles. Lumps of fouling could sometimes fall off to reexpose the surface (see PVC). Silicon rubber was almost devoid of macrofoulers, although the partly exposed underlying mild steel was colonized. This pattern of development was predictable from the three-month period, December to February, when the main constituents were similar to those noted here, the difference being one of degree rather than nature.

At 10m depth (plate 2.3.1.b), large individuals of Choromytilus meridionales occupied almost all of the available space on panels of all materials except silicon rubber. Open patches were mainly colonized by Balanus trigonus, but mussel shells by B.amphitrite, while the earlier barnacle community was smothered. The mussel shells provided substratum for encrusting bryozoa and shelter for terebellids, Nicolea macrobranchia. Hydrozoa and filamentous bryozoa sometimes grew on top of the barnacles. The few remaining patches of SR that had not peeled off were almost unoccupied.

i) 12 Months

At 20m (plate 2.3.1.c), the numbers of B.amphitrite and B.trigonus seemed to be limited due to smothering by Pyura and Ascidia and due to grazing (see FG and AL). Over-enthusiastic fishermen account for damage to some of the larger Pyura specimen (see MS). In places where tunicates did not dominate, a mixed barnacle community could exist, with hydrozoa, Sertularella (see AL) or Campanularia, sea anemones, Anthothoe, encrusting bryozoa, Chaperia and others.

At 10m (plate 2.3.1.d), the Choromytilus - Balanus community resembled that of 9 months, except that new settlements of Balanus amphitrite covered most of the mussel shells.

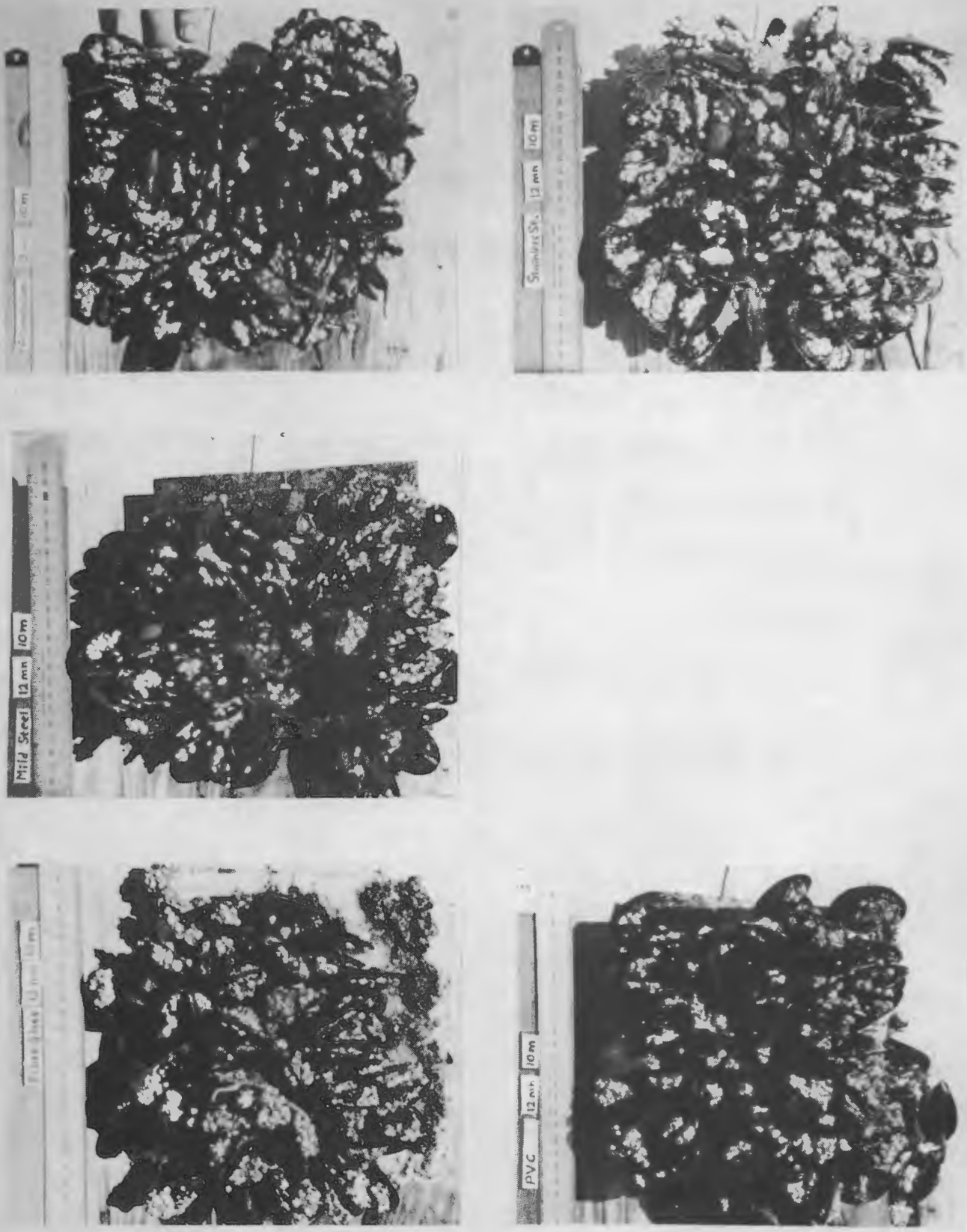


Plate 2.3.1d : Exposure at 10m for 12 months during June 1979 - May 1980.

Thin layers of SR had peeled off the MS bases. At both depths these were almost bare except for very few barnacles and saddle oysters, Anomia sp. At each depth, the five other materials resembled each other. Even MS was almost completely covered and fouled as heavily as other materials, unlike as after 3 months.

2.2.4. Depth of immersion

To evaluate the fouling conditions at the various depths, the following system is adopted:-

(i) Data of weight, volume, cover and species diversity at each depth is presented on interaction plots. Although this data has been presented elsewhere (section 2.2.3.) it is here arranged in such a way as to assist quantitative comparison of the depths.

(ii) The major fouling constituents found in this study are compared to the fouling described in ealier years at the upper depths.

2.2.4.1. Degree of fouling

a) Weight - figure 2.2.4.1.a
After one month, the weight of fouling on plastics was higher at 10m than at 20m. Very little fouling was recorded on all SR panels exposed for longer than a month, but other materials were more fouled at 10m than 20m after 3 months, but this difference was only significant for FG and PVC. For longer exposure periods the weight of all panels did not differ significantly with depth, except that the weight on FG and PVC at 20m was very low after 12 months (some of the fouling had dropped off).

b) Volume - figure 2.2.4.1.b
The trends for mean volume were similar to those described for weight.

c) Cover - figure 2.2.4.1.c
The mean cover for each material was about twice as high at Site 2 than at Site 1, although this was not significant for AL and SS. After three months, the cover of AL, SS, FG and PVC was again much higher at Site 2 (80%) than at Site 1 (60%). In later periods, plate cover was almost complete at both depths, except on SR.

d) Species diversity - figure 2.2.4.1.d

More species were identified on all materials after one month at Site 2 than at Site 1. After three months this was again the case, but the difference was only significant for FG. The opposite was true after 9 and 12 months i.e. species diversity was higher at Site 1 than 2, but only significantly so for MS and PVC, 9 months.

e) General

In terms of weight, volume, cover and species diversity, the following differences in depth were recorded: During the first three months, fouling was higher at 10m than at 20m; After 9 months and longer, the weight, volume and cover values did not differ at the two sites, but non-significantly more species were recorded at Site 1. At both depths, all values for SR were low after longer than one month.

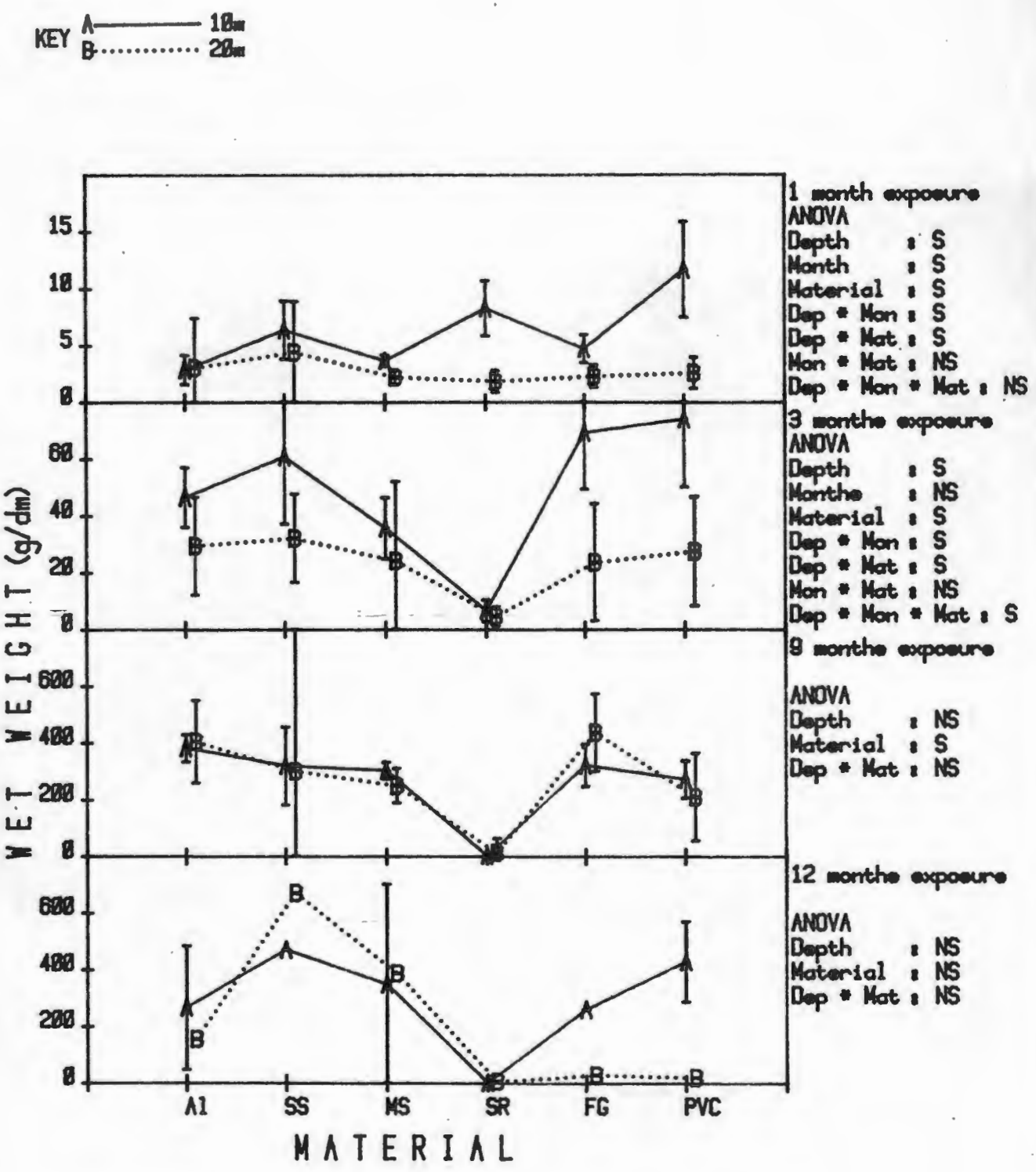


Fig 2241a: Interaction plots of substrate material vs. depth of immersion for wet weight (±95% C.L.). Significance in ANOVA was tested at the .5% level. (S = significant ; NS = not significant)

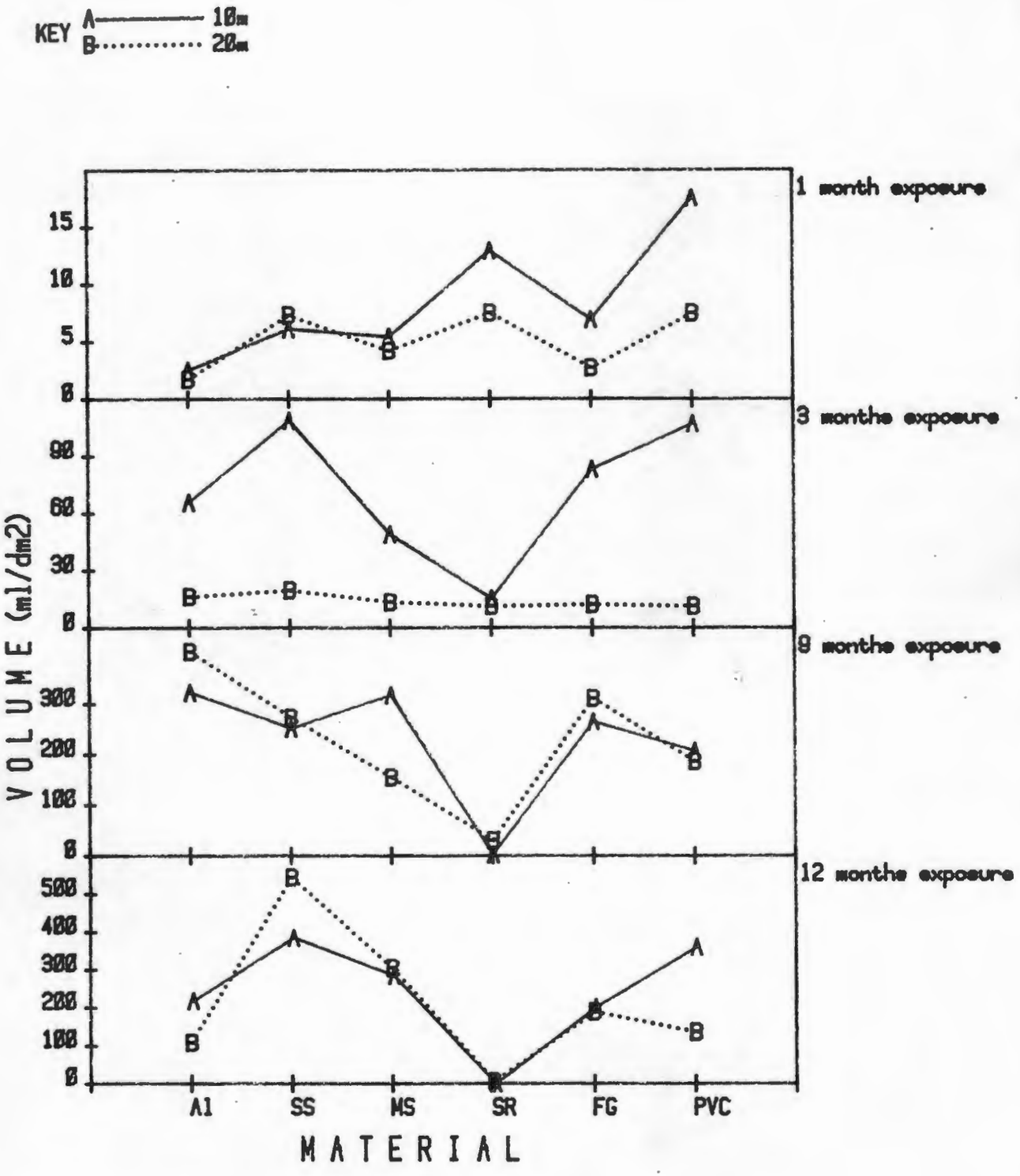


Fig 2241b: Interaction plot of substrate material vs. depth of immersion for volume of fouling organisms. Values represent means for 3 plates.

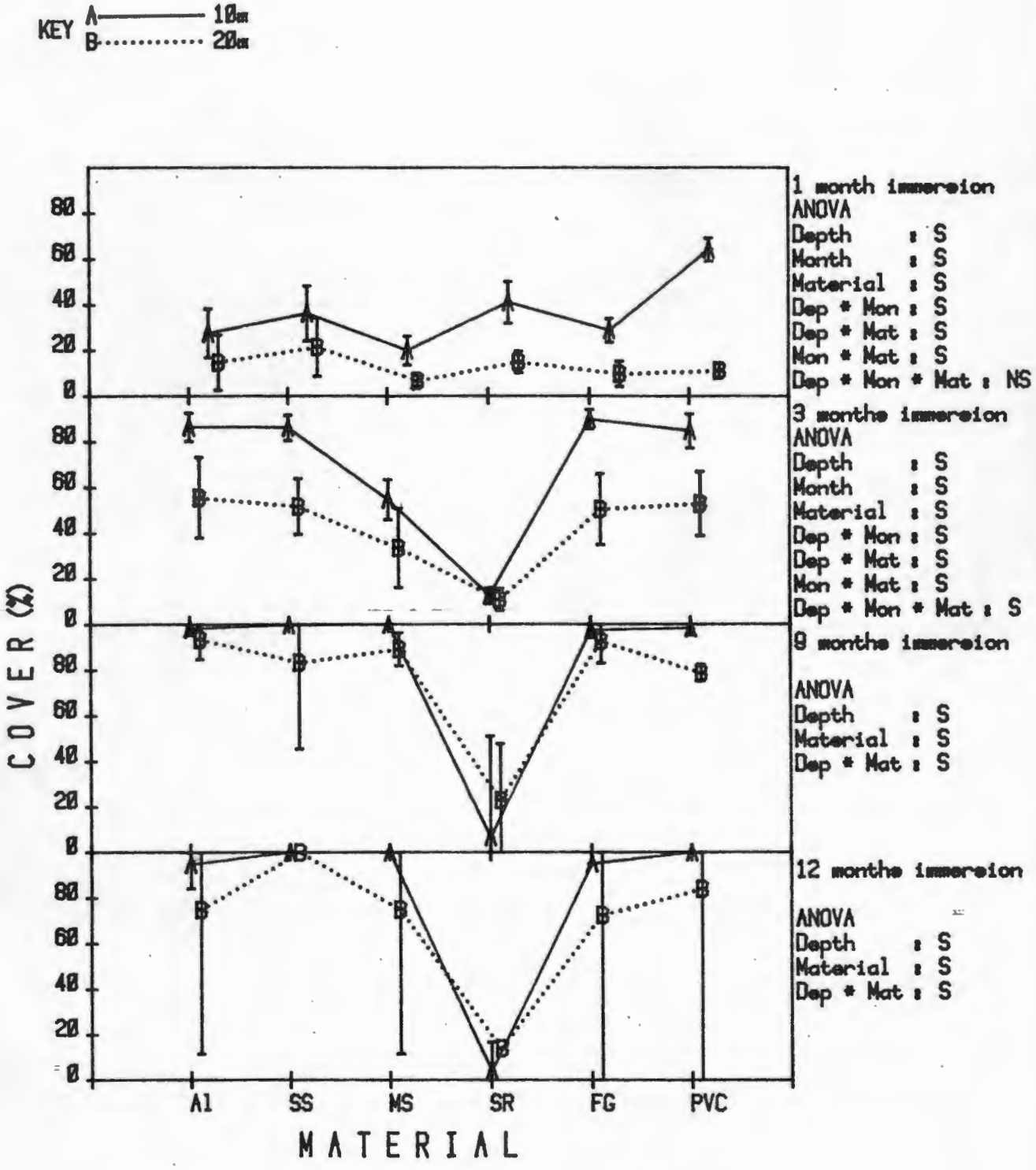


Fig 2241c: Interaction plots of substrate material vs. depth of immersion of percent plate cover (±95% C.L.). Significance in the ANOVA was tested at the .5% level. (S= significant ; NS = not significant)

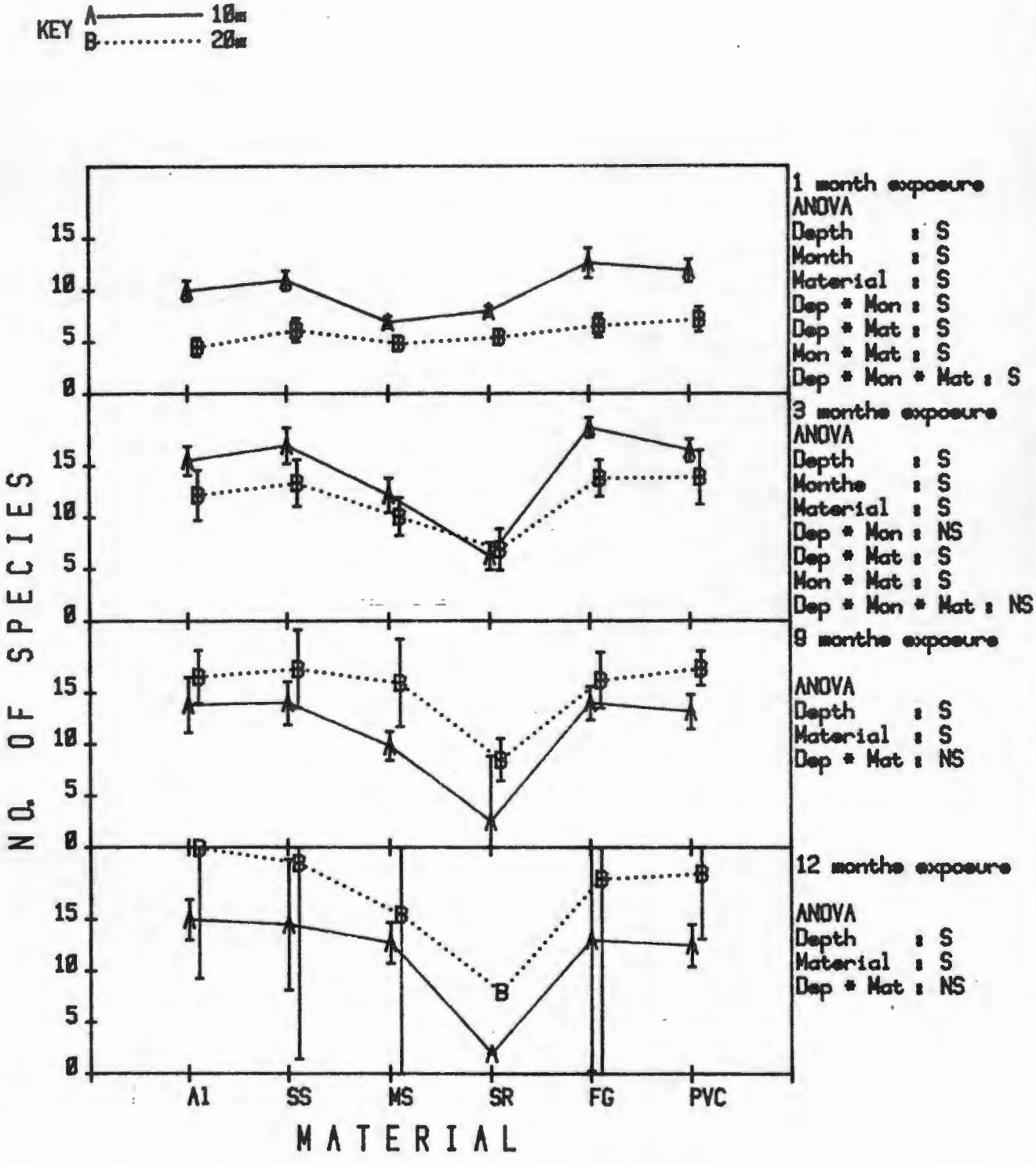


Fig 2241d: Interaction plots of substrate material vs. depth of immersion for species diversity of sedentary organisms (± C.L.). Significance in the ANOVA was tested at the .5% level. (S = significant ; NS = not significant)

2.2.4.2. Vertical distribution of organisms

During 1969 and 1971, McClurg and Day, respectively, carried out fouling experiments in Simonsbay at 0-2m depths. Their sites were located within 1km of Site 2, and their results are compared to the present experiments. Many authors have documented major annual changes, which might invalidate such a comparison as attempted here (Millard, 1952; Sutherland and Karlson, 1977). However, as Schoener et al (1978) have emphasized, although annual variations are present, these are less than the regional differences. Insofar as the seasonal trends in the abundance of barnacles, bryozoa and compound ascidia, recorded in this study, were also found in earlier years at lesser depths, it appears that the data should be comparable. Because of this uncertainty about annual conditions, differences should be interpreted with caution.

It was found in earlier sections (2.2.1.-3) that the nature and degree of fouling depended to some extent on substratum material. For this reason only the "passive" plastics, namely FG and PVC, are included in this comparison with neoprene, prespex and alkyd enamel. The abundance estimates of organisms were made by various authors (McClurg, 1969; Day, 1972; this study) and may not have been consistent (e.g. such arbitrary terms as "common" and "numerous" are subjective, depending on circumstances). Therefore, in examining table 2.2.4.2.a, only the general trends in relative abundance should be interpreted.

Strong seasonal trends prevailed at all depths. Less organisms settled during winter, although the length of the "offseason" is variable, only three to four months with barnacles, bryozoa and algae, but possibly longer for ascidians and mussels. In comparing the data from different depths, emphasis is laid on the peak settlement periods occurring between September to April. The distribution of organisms is described

as follows (table 2.2.4.2.a):

(i) Barnacles are the most important organisms in the initial phases of fouling (one month) at all depths, 0 to 20m. They are less abundant at the waterline, but attain peak numbers in the upper 10m, and are slightly less abundant, although still numerous at 20m depth. Among the four barnacle species identified in the various studies, Balanus trigonus, which was usually most numerous, and B.maxillaris, occurred at all depths, but B.algicola was recorded only in the top 1m and B.amphitrite only at 10m and 20m. In the present study at 10m and 20m, the peak settlement periods of B.amphitrite and B.trigonus were to some extent temporally seperated (the latter species was numerically more abundant than the former only on three-month plates between December and May), whereas at 2m and above, B.trigonus dominated throughout.

(ii) The most striking differences at various depths seem to be the abundance and species constitution of algae. The green algae, Enteromorpha sp. and Ulva sp. and red algae, Streblocladia, were recorded only at 0-2m depths, where they could be abundant. Small red algae, mainly Polysiphonia sp. and Ceramium sp., were common in the top two metres, but scarce at 10m. The small brown algae, Ectocarpus sp. and Colpomenia sp., were only identified at 10m, where they were common. Algae were absent at 20m. De Palma (1976) states that the average compensation depth for most algae in temporal latitudes is 10-11m.

(iii) The filamentous bryozoa, Bugula neritina, was fairly common upto a depth of 10m, whereas encrusting bryozoa, mainly Membranipora sp. and Watersipora sp., were only recorded at 10m and 20m.

(iv) Compound ascidians were present to fairly common at all depths.

(v) Serpulids, Hydroides elegans, were apparently suoject to considerable annual functuations. They were common in the upper 1m during March 1969, but were not recorded during 1971. In 1979, they reached peak abundance at 10m and especially 20m during August and September, but were present throughout the study period June 1979 to May 1980.

(vi) Hydrozoa were common at 20m and fairly common at 10m, but less numerous in the upper levels.

(vii) Mussels, which were numerous at 10m depth and fairly common at 20m, where they were identified as Choromytilus meridionales, were also encountered at 0m and 1m depths by McClurg, who had tentatively identified them as Perna perna. However, Day reports that no mussel spat settled during 1971, except when plates were exposed for three months or longer after April. It therefore appears that, although mussels occasionally settled elsewhere, conditions for their settlement and development were optimal at 10m depth.

The nature of the long-term development of the fouling community depended to a large extent on the season (see section 2.2.2.). The dominant community components (listed in order of importance), that were recorded on plastic substrata during 1969, 1971, 1979 and 1980 (and the increase in weight of fouling), are summarized as follows (table 2.2.4.2.b):-

(i) The type of community that may finally develop at the waterline can only be guessed at from McClurg's (1969) report. It is likely that large algae Enteromorpha sp. and Ulva sp. would dominate during summer and that barnacles would be common between them.

(ii) At 0,3m below the surface a Balanus - Bugula - Ulva (50g/dm^2) community developed after three months, followed by a Balanus - Bugula (55/dm^2) community at 5 months and a Balanus - Ciona - Ascidia (180g/dm^2) community after 9 months. Finally, after 11 months, a mixed community of Balanus - Algae - Simple Ascidians - Compound Ascidians (300g/dm^2) had developed. Balanus trigonus was dominant throughout, but the algae and ascidians were apparently seasonal. Day pointed out that the abundance of Bugula neritina could be of importance for later stages, notably Ciona, which may attach to it.

(iii) At 1m depth, the principal components were Balanus - Bugula (60g/dm^2) after three months, and Balanus - Ciona (130g/dm^2) after five months.

(iv) The long-term development of fouling was not investigated at 2m depth.

(v) In the present study, it was shown that at 10m, Balanus dominated with Bugula and other bryozoa being important after three months (100g/dm^2). The principal components after 9 (300g/dm^2) and 12 months (400g/dm^2) were Choromytilus - Balanus.

(vi) After three months at 20m, Balanus dominated (30g/dm^2), with Hydroides being important in spring. A mixed community of Balanus - Pyura - Diplosoma had developed after 9 months (200-450g/dm^2). This was followed by Pyura - Balanus dominance after 12 months (50-600g/dm^2).

Table 2.2.4.2.a: Relative abundance of fouling organisms on panels exposed for 1 month at various depths in Simonsbay. Abundance estimates may not be consistent between the authors, but show the general relative importance of the organisms. They are as follows: 1-present, 2-fairly common, 3-common, 4-very common, 5-abundant.

Depth	Year	Substratum	Source	Organism	Month										
					Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0m	1969	Grey Neoprene	McClurg 1969 Table 1	Hydrozoa		1	2	2	2	-	1				
				Serpulids		2	-	-	-	-	-				
				Barnacles		3	2	1	1	1	1				
				Bryozoa		2	2	2	-	-	-				
				Mussels		2	-	-	2	2	-				
				Comp.Ascidia		1	1	-	-	-	-				
				Algae		5	2	1	1	1	2				
0,3m	1971	Perspex	Day 1972 Fig4&5	Hydrozoa	-	-	-	-	-	-	-	1	-	1	1
				Barnacles	5	5	4	3	1	1	2	4	3	4	4
				Bryozoa	2	1	2	1	1	-	1	1	1	3	4
				Comp.Ascidia	1	-	1	-	1	1	2	2	2	3	3
				Algae	3	2	1	1	-	1	1	4	5	5	4
1m	1969	Grey Neoprene	McClurg 1969 Table 2	Hydrozoa		1	-	1	2	-	1				
				Serpulids		2	2	-	-	1	-				
				Barnacles		5	4	4	3	3	3				
				Bryozoa		1	2	3	1	1	-				
				Mussels		2	-	-	2	2	2				
				Comp.Ascidia		3	1	-	1	1	3				
				Algae		5	1	1	1	-	2				
2m	1971	Grey Alkyd Enamel	Day 1972 Fig. 6	Hydrozoa					-	-	-	-	2	1	
				Barnacles					1	1	2	1	3	5	
				Bryozoa					-	-	-	-	1	3	
				Comp.Ascidia					-	-	-	3	-	1	
				Algae					1	2	2	3	5	4	
10m	1980	Fibre Glass + PVC	This study	Hydrozoa					1	1	2	2	1	1	
				Serpulids					1	1	1	1	1	1	
				Barnacles					3	3	4	4	5	5	
				Bryozoa					1	1	1	2	3	3	
				Mussels					1	1	2	2	3	2	
				Comp.Ascidia					-	-	-	1	2	3	
				Algae					2	2	2	2	2	3	
20m	1980	Fibre Glass + PVC	This study	Hydrozoa					1	2	1	3	2	1	
				Serpulids					1	1	2	2	1	1	
				Barnacles					2	2	3	4	4	4	
				Bryozoa					1	1	1	1	1	1	
				Mussels					1	1	1	1	2	1	
				Comp.Ascidia					-	-	-	2	2	3	
				Algae					-	-	-	-	-	-	

Table 2.2.4.2.b: Summary of the dominant community components (in their order of importance) on plastic substrata immersed at various depths. The first line at each depth is a list of the major organisms in the first 3 months of community development; the second line shows the later stages (6-12 months). The presence of algae, Ciona, Diplosoma and Hydroides was a seasonal phenonemon. (Ulva, Enteromorpha and Streblocladia are algae, which were not recorded in the present investigation.)

Depth	Dominant organisms
Surface	Ulva - Enteromorpha - B.trigonus - B.algicola
0,3m	B.trigonus - Bugula - Ulva - Streblocladia to B.trigonus - Ulva - Streblocladia - Ciona - Diplosoma
1m	B.trigonus - Bugula to B.trigonus - Ciona
10m	B.amphitrite - B.trigonus - mixed bryozoa - Choromytilus to Choromytilus - B.trigonus - B.amphitrite
20m	B.amphitrite - B.trigonus - Hydroides - Diplosoma - Campanularia to Pyura - B.maxillaris - B.trigonus + B.amphitrite

2.2.5. The Fouling Community

Panels of the type used in this experiment can be considered to be planar marine islands on which the primary resource is space (Jackson, 1977; Schoener, 1974). The longer such panels are exposed to the sea, the more individuals and more species should occur on them until the main resource, space, is "used up". Because, as Osman (1977) has pointed out, most fouling invertebrates feed at only one trophic level (suspended particles), the interactive and successional processes are of necessity complex. Odum (1969) outlined processes of "classical" ecological succession where early community constituents modified the physical environment to enable other organisms to settle, develop and perhaps replace earlier forms. This would be a uni-directional progression ending in a stable climax community the nature of which should be predictable by environmental characteristics like climate (Clements, 1936). There are two features that are characteristic of a community with a stable climax (according to Sutherland and Karlson, 1977): (i) Irrespective of the initial fouling development, individual plates should bear close resemblance to each other after some time; (ii) Once the community has reached a climax, its structure should remain essentially unchanged for a long time.

However, it has been conclusively demonstrated that such a classical succession terminating in a stable climax, is an exception rather than the rule in temperate and subtropical fouling communities (Harger and Tustin, 1973; Jackson, 1977; Millard, 1952; Osman, 1977; Sutherland, 1974, 1978; Sutherland and Karlson, 1977) and that at any given time the nature of the community is unpredictable and highly variable on replicate samples. Succession is not uni-directional because the resident community may enhance or impede subsequent developments. Because most organisms are short-lived they are soon replaced by others, while the offspring of the former would settle elsewhere. The development of a community should thus be an ongoing process which is influenced by numerous changing stochastic events (Sanders, 1968), primarily:- (i) the physical environment, (ii) availability of space for colonization, (iii) larval recruitment (usually with seasonal abundance peaks), (iv) biotic interactions (competition and factors that promote or inhibit settlement) and (v) mortalities (overgrowth, predation, senescence, physical disturbance). The status of all these events at a given place and time is what Day (1977) termed "patch history" (Osman, 1977).

Working with a coral ecosystem, Maguire and Porter (1977) found that in the early stages of colonization, species compete by settling in large numbers. The predominant settlers then have an advantage in competition for space and overgrowth, which governs the later stages of community development. Such a condition can on occasion end with one species monopolizing space (Osman, 1977), but Connell (1976) noted that such monopolies should usually be avoided by reciprocal interactions and the resistance of some species, who escape being dominated. Especially in temperate latitudes, where the climate changes seasonally, the diversity should be high, because different species may thrive during different environmental conditions so that the interactive relationships change (Connell, 1978; Yodzis, 1976). Loucks (1970) would describe this as a stationary process, which is dynamically stable, or, as he put it (for forest community; pg.23): "the changes that take place are in fact part of a characteristic series of transient phenonema, which collectively make up the 'stable system' capable of repeating itself every time a perturbation starts the sequence over". That this idea of "cyclical progression" should be applicable to space-limited fouling communities is supported by the data of Harger and Tustin (1973) as well as the conclusions of Osman (1977) after two and a half years work on a temporal epifaunal community. Finally, it should be noted that Schoener et al, (1978) concluded that stability in a marine community seldom ensues in the first year of development so that the interpretations made for the present study are limited.

Three questions will be pursued in this section:-

(i) What were the major patterns of community development observed in Simonsbay?

(ii) Why did a Choromytilus - Balanus community finally develop on all plates at 10m and Pyura - Balanus at 20m?

(iii) How does the fouling in Simonsbay compare with other regions?

It is recognized that the limited scope of the present study is too narrow to provide conclusive answers to these questions. The evidence accumulated in this year's study is arranged in a convenient way to enable suggestions to be made. Furthermore, since the fouling of six different materials was analyzed, only the "passive materials" (non-corrosive and not severely limiting to organisms i.e. AL, SS, FG & PVC) are included in the present discussion.

(a) Patterns of Community Development

The most dominant organisms on all plates after 9 and 12 months were Choromytilus at 10m and Pyura at 20m. However, the makeup of other community constituents could vary considerably. Most of the other important organisms were short-lived, their abundance apparently being a seasonal phenonemon, especially Balanus amphitrite and B.trigonus, Campanularia integra, Hydroides elegans, Bugula neritina, Membranipora spp. & Watersipora sp., Anomia sp., Ericthonius brasiliensis, Diplosoma spp. and Ciona intestinalis. All of these were also members of the "pioneer community" and seem to have the ability to settle in the early and late stages of community development. Other organisms appeared, at least to some extent, to depend on the earlier development. These include Sertularella arbuscula, Anthothoe stimpsoni, Sabellidae, Terebellidae, Cnaperia sp., Tellimya rotunda, Saxicava arctica, Aulacomya sp. and Agardhinula sp. which either settled on top of other organisms or seemed to rely on shelter provided by others. No true causal succession was observed, because these "secondary organisms" were not important community constituents (in terms of space competition). The case of Choromytilus meridionales, which is discussed further below, deserves special mention. Most mussel spat were attached to larger barnacle shells, sometimes forming a fringe around the shell opening, although this phenonemon appears to be a preference rather than a prerequisite, because some spat were attached directly to the substratum. Choromytilus is therefore considered here as a "secondary" colonizer, depending on Balanus for substratum. It therefore appears to be the only case of causal succession (partial), eventually smothering the barnacles.

The role of predation can only be guessed at. Obvious effects of heavy grazing were only evident with the barnacles. However, areas cleared by grazing were rapidly recolonized by barnacles. Predators of Choromytilus, namely Octopus granulatus, Jasus lalandii and Marthasterias glacialis and possibly others, were recorded on the frames, but did not appear to limit Choromytilus. In the present study, the possible role of colonial ascidians, Diplosoma spp., is poorly understood. Russ (1980) found that predation by fish

prevented colonial ascidians from monopolizing space in an Australian epifaunal community. If this situation was also true for Simonsbay, it is possible that predation on Diplosoma spp. would have enabled Choromytilus to establish dominance at 10m. It is not known how predation could have influenced other species.

At 10m, a Balanus - Ectocarpus and mixed pioneer community, was followed by the elimination of Ectocarpus, which was apparently dependant on primary space (directly on the substratum), the settlement of numerous Choromytilus spat and the growth of bryozoa and ascidian colonies. The main competition for space between barnacles, mussels and colonial ascidians gave way to near-monopoly by mussels, followed by a heavy settlement of barnacles on top of the mussels. It is possible that this secondary barnacle growth may eventually smother the mussels, or that this accumulated layer could get too heavy so that it drops off and the fouling cycle repeat itself.

At 20m, development is considerably slower than at 10m in the initial stages. Early Balanus dominance, with interspersed hydrozoa, is followed by Diplosoma spp. and Hydroides elegans and hydrozoa, but still dominated by Balanus. A few simple ascidians appear at this stage. These, mainly Pyura, but also Asidia sp. and Microcosmus sp., grew persistently and finally displaced some of the earlier forms, which still coexisted between the ascidians. The final degree of fouling at 20m seems to be limited by the adhesion to the substrata. In the case of plactics, fibre glass and PVC, a stage is reached before one year, when much of this fouling becomes detached under its own bulk and the colonization cycle can repeat itself. Pyura appears to have better ability to adhere to metal surfaces and it is possible that space may eventually be monopolized by the persistent ascidian community on these materials.

(b) Choromytilus dominance at 10m and Pyura at 20m.

The following factors should be considered in trying to explain why mussels and ascidians dominated so consistently at either depth:-

(i) The depth range of Choromytilus and Pyura spans from the waterline to well beyond 20m (Day, Field and Penrith, 1970). Independant factors of depth, per se, do not suffice to explain the observed results.

(ii) In the months of peak settlement of mussel spat, August to October, nutrient levels and temperature were similar at both sites.

(iii) In earlier months, mussel spat, although fairly common at 20m, settled mainly at 10m. Furthermore, it appeared that very few mussels grew large at 20m.

(iv) Although Ciona intestinalis did not appear to differ with depth, very few Pyura settled at 10m, even on plates where Choromytilus did not dominate.

(v) Most Choromytilus spat preferred attaching to barnacle shells (see above). Dayton (1971) and Millard (1952) report that Mytilus also seemed to require secondary space on top of previous settlers. Another factor, which may influence the abundance of mussel spat is the abundance of Hydroides elegans. Kazihara (1964) found that this serpulid checked the development of a Mytilus community. As was suggested above, it is possible that Diplosoma spp. have an adverse effect on mussel spat (clogging shell openings). At 20m depth, fouling by barnacles was considerably slower than at 10m, in growth and numbers. During the peak spatting season, there would thus have been less of the preferred substratum at 20m. Furthermore, the greater numbers of Hydroides and Diplosoma could have had an additional depressing effect on spat numbers.

(vi) The abundance of fungi was not quantified in this study, but from a subjective assessment, fungi appeared to proliferate at 20m, whereas they were less abundant at 10m (fig. 4.2.1.). Leung Tack Kit (1976) explained the repulsion of simple ascidians from certain surfaces by the abundance of fungi on these surfaces. Since such a phenonemon would repel ascidians from 20m but not 10m, which does not tally with observed results, such a mechanism cannot explain the

dominance of ascidians at 20m.

The evidence presented in these considerations is insufficient to confirm the observed trends. A more comprehensive study, initiating year-long exposures at different times of the year, would be necessary to provide more answers. An examination of the epifaunal community on the rocks of Phoenix Reef, which runs from Roman Rock towards the shore past Phoenix Bouy to the inshore Demolition Range, east of the Naval Dockyard (Chart 1.2.1.1), would be a valuable comparison to the present study.

(c) Comparison with other regions

In many temperate regions, barnacles dominate after a month, with algae above their "compensation depth", followed by filamentous bryozoa (usually Bugula) or various other organisms depending on season. Apart from simple ascidians and mussels, serpulids or hydrozoa can become established and either dominate, co-dominate with barnacles, or form mixed barnacle communities (no clear dominance by any species, but barnacles abundant). The constituents of the final community usually vary with season, depending on the longevity of resident species and the availability of settling recruits. Fouling in Simonsbay is broadly compatable to that in the following regions: Table Bay (Millard, 1952); Australia (Allen & Wood, 1950; Russ, 1977; Russ, 1980); Northern Atlantic (Calder & Brehmer, 1967; De Palma, 1969 & 1976; Efird, 1976; Maloney, 1958; Schoener et al, 1978); Northern Pacific (Iwaki et al, 1977; Kawahara, 1961, 1962 & 1969; Kawahara et al, 1960, 1979; Tarasov, 1961; Schoener et al, 1978).

2.2.6. Substratum materials

In an attempt to predict differences in the fouling susceptibility of various materials, Zachary et al (1978) found that the succession of microfouling was similar on all materials, but slower on less attractive surfaces. de Chalain (1979) found that the initial rate of bacterial colonization was similar on AL, SS, FG & PVC, but slower on MS, where corrosion products seemed to have a "self-sterilizing effect". On SR, the rate of bacterial colonization was highest, in spite of its smooth surface. These results should be remembered when comparing the macrofouling on the materials.

(a) Aluminium

This material has been classified by Efird (1976) as a "passive metal", because early after immersion a grey layer of aluminium oxide coats its surface, slowing down further oxidation. This layer presents a relatively stable and slightly rough substratum to foulers. Algae, Ectocarpus, appeared to favour aluminium in the initial stages of colonization, although the difference to other materials was not significant. The relatively low surface energy of this metal and its slightly rough surface favoured the tight adhesion of a heavy fouling layer. The present observations agree with Efird (1976) and La Que (1978) that, in general, the fouling of aluminium differed little from that of other inert, non-toxic, high-energy surfaces.

(b) Stainless Steel

The marine grade 316L stainless steel had high chrome and nickel contents. Even after a year of exposure, its surface was smooth, shiny and essentially unaltered. The susceptability to fouling was similar to aluminium. On the long run, this chemically inert alloy developed the heaviest layer of fouling, which adhered tightly to its surface, as previously evidenced by Long (1974).

(c) Mild Steel

Efird (1976) noted that the early stages of fouling on MS, easily slough off, but that later stages are attached more firmly, the underlying layer of rust being thin. Initially, while much of the metal surface is still bare, places that are covered by organisms become galvanic cells. This promotes pitting below the organisms, which finally slough off (La Que, 1969). However, when the increase in fouling is so rapid that it soon covers all of the metal surface, this galvanic cell action recedes and corrosion slows down. The macrofouling community can adhere more firmly and provides a measure of protection to the metal (Lebedev, 1978). This was the situation on MS after 9 and 12 months in the present study. For longer exposure periods it is predicted that, if some fouling drops off under its own weight, complete sloughing off may result and the process repeat itself.

(d) Silicon Rubber

The characteristics and susceptibility to fouling of silicon rubber differs markedly from those of other materials. Apart from having a low-energy (non-wettable) smooth surface, it is chemically inert and of a flexible (rubbery) nature. Its red colour might be partly responsible for the near-absence of algae (see appendix section 4.1.1), but other characteristics are expected to be of much greater consequence. Eiben (1978), Müller et al (1976) and Loeb (1978) found that many organisms with hydrophobic surfaces were attracted to hydrophobic substrata because of their mutual tendency to reduce the surface area in contact with water. Thus, in this investigation, many individuals attached in the initial stages, but they failed to remain attached because, as Baier et al (1968) pointed out, bioadhesion is reduced on low-energy surfaces. Thus, in the degree of fouling, silicon rubber did not differ much from other materials after a month, but did not develop further beyond that stage. Balanus amphitrite, Hydroides elegans, Campanularia integra, Anomia sp. and Diplosoma spp. appeared to have the highest degree of tolerance to these conditions.

This characteristic is not unique to silicon rubber. Griffith and Bultman (1980) noted that Teflon, polytetrafluoroethylene, presents a very low-energy surface from which foulers readily become detached. Recently new forms of Teflon have been applied as paints and are being tested. They also recognized the potential value of the characteristics of silicon rubber: "The ability of fouling organisms to adhere to a surface depends in part upon the physical nature of the material as well as its surface chemical properties, and the silicones allow the production of relatively soft, anti-adhesive surfaces which apparently are more effective in the marine environment than the fluoropolymers. However, they are not as durable, and it is necessary to combine the best properties of the fluoroepoxies or fluoropolyethanes, Teflon, and certain silicones in order to produce the most effective compositions in overall terms." Such combinations are as yet, chemically, not possible.

(e) Fibre Glass

This material permitted the rapid accumulation of colonizers, not unlike aluminium and stainless steel. Minute spionid polychaetes appeared to have the ability to burrow into its surface. This did not result in any extensive damage during the time period of the experiment. This polychaete is not abundant, but it is possible that, in the long run, it could facilitate local surface deterioration where other foulers are not attached.

(f) PVC

Settlement and growth rate was initially higher on this plastic than on any other material. However, after 3 months it resembled that of other "passive" materials. Although simple ascidians grow to large size on PVC surfaces, their ability to adhere seems to be poorer than on metals. Thus, as on fibre glass, some fouling had sloughed off before retrieval after a year. The surface of PVC is apparently unchanged after a year of exposure.

It appears that the relative initial colonization rates of various materials can be predicted from the degree of microfouling. Zachary et al (1978) suggested that this was so because the settling of larvae may depend on the primary film. The present results did not negate this, but it is equally probable that the same physical properties of the surfaces responsible for differences in microfouling, also influenced the macrofouling.

3. SUMMARY AND CONCLUSION

3.1. Conclusion

The principal aims of this study were to characterize fouling conditions in Simonsbay upto a depth of 20m and to assess the susceptability of six substratum materials to fouling. This is complementary to the work done by de Chalain on the microfouling community during 1979. The following conclusions can be made:-

(a) The occurrence of settling organisms was a seasonal phenonemon. A mid-winter offseason was followed by an increase in the colonization rate, when the storms subsided in spring, and a further increase in species numbers and individuals during early summer, coinciding with a rise in temperature at all depths. During this peak period the initial community mainly comprised Balanus amphitrite at both depths with numerous small algae, Ectocarpus sp., bryozoa, Bugula neritina and mussel spat, Choromytilus meridionales at 10m and serpulids, Hydroides elegans, and hydrozoa, Campanularia integra at 20m. In mid-summer, Balanus trigonus dominated at all depths, 0-20m, but in autumn, when the colonization rate dropped again, Balanus amphitrite reached a secondary peak before the temperature dropped and winter conditions ensued. The potential value of the offseason for carrying out maritime activities with minimum fouling, is offset by the concurrence of winter storms in Simonsbay.

(b) The development of the fouling community differed with depth. The initial stages were slower at 20m, developing from a Balanus - dominated community to Balanus - Hydroides followed by a more complex situation with Diplosoma and Campanularia. Finally, Pyura dominated, sometimes growing so bulky that it sloughed off. At 10m, numerous mussel spat that settled during the early Balanus - Bugula stage, grew to appreciable size in half a year. Later, secondary settlement of Balanus on Choromytilus further increased the bulk of the layer. The consistent development of Pyura-dominated communities at 20m and Choromytilus at 10m could be due to differences in the development of the pioneer communities at these depths.

(c) The biological interactions that may have influenced the colonization sequence differed with stages of development. True cases of causal succession were not observed, but Choromytilus spat seemed to attach preferrentially to Balanus, which they later smothered. Although the primary film may have played an important role for some species, it did not appear to be a prerequisite to Balanus sp., Bugula neritina and Campanularia integra, which settled in the earliest stages of fouling. This conclusion is, however, an oversimplification and requires further investigation. | Some macro organisms relied on pioneer species for attachment or shelter. | These include sabellid and terebellid polychaetes, some bivalves, encrusting bryozoa, some hydrozoa, actinaria and red algae. Possible negative interactions were of Hydroides to the settlement of mussel spat, of Diplosoma to the development of Choromytilus and of Ectocarpus to the colonization of barnacles. The manipulation of such biological interactions, to prevent the development of bulky foulers, could be an effective antifouling technique.

(d) In comparing the fouling of different non-toxic substrata, hydrophobicity and degree of surface stability appeared to be more important than colour, light reflectance or surface texture. Some species showed slight preferences for certain colours or grades of roughness, but none had consistent preferences among aluminium, stainless steel, fibre glass and PVC. The fouling was similar on these four substrata and differed markedly from that of silicon rubber and mild steel. The latter was highly corrosive and "self-sterilizing" in the early stages, but heavy fouling provided a degree of protection to further corrosion in later stages, when the community on mild steel was similar to those on the passive materials. Silicon rubber had a hydrophobic surface, which initially attracted organisms, but counteracted bioadhesion, thereby preventing heavy fouling. The possibility of using silicon rubber as a protective mantel of underwater instruments should be considered.

(e) The results of this report should be a stepping stone to future work. Now that the general nature of fouling at a macro and micro-level is known upto a depth of 20m, further studies might concentrate on broad regional differences and on examining the particular interactions outlined in this report and by de Chalain (1979). The various materials may be valuable for specific underwater uses: Stainless Steel because it remains inert after a long exposure period; Mild steel because of its self-sterilizing effect; Silicon rubber because it prevents heavy fouling.

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3.3. References

Allen, F.E. & E.J.F. Wood (1950)
Investigation on Underwater Fouling II : The Biology of Fouling in Australia : Results of a Year's Research.
Journal of Marine and Freshwater Research 1

Aoki, K. and Wada, K. (1978)
Durability of protective Coatings under Flow and/or Stagnant Conditions of Sea-Water.
CRIEPI REPORT
Energy and Environmental Laboratory

Atkins, G.R. (1970)
Winds and Current Patterns in False Bay.
Trans. roy. Soc. SAfr. 39(1) : 139-148

Atkins, G.R. (1970)
Thermal Structure and Salinity of False Bay.
Trans. roy. Soc. S. Africa 39(1) : 117-128

Baker, J.R.J. & L.V. Evans (1973)
The ship fouling alga Ectocarpus
I. Ultrastructure and cytochemistry of plurilocular reproductive stages
Protoplasma 77 : 1-13

Baier, R.E., Shafrin, E.G. & W.A. Zisman (1968)
Adhesion : Mechanisms that assistor or impede it.
Science 162 : 1360-1368

Calder, D.R. & Brehmer, M.L. (1967)
Seasonal Occurrence of Epifauna on Test Panels in Hampton Roads, Virginia
Int. J. Oceanal. & limnol. 1(3) : 149-164

Christie, A.O. & Evans, L.V. (1975)
A new look at Marine Fouling Part I
Shipping World and Shipbuilder. October 1975

Christie, A.O. & L.V. Evans & M. Shaw (1970)
Studies on the ship. fouling alga enteromorpha : II. The effect of certain enzymes on the adhesion of zoospores
Annals of Botany 34(135) : 467-482

Clements, F.E. (1936)
Nature and structure of the climax
Journal of Ecology 24 : 252-284

Cliff, G. (1979)
The contribution of phytoplankton, bacteria and detritus to a rocky shore ecosystem
University of Cape Town, M.Sc. Thesis

Clitheroe and Evans (1975)
A new look at Marine fouling : Part III
Shipping World and Shipbuilder. December 1975

Connell, J.H. (1976)
Competitive Interactions and the Species Diversity of Corals
In: Mackie GO, Coelenterate Ecology and Behaviour; Plenum Press, NY & London.

Connell, J.H. (1978)
Diversity in Tropical Rain forests and Coral Reefs
Science. 199: pp.1302-1310

Costello, J.A. (1969)
The Corrosion of Metals by Micro-organisms : A literature survey
International Biodeterioration Bulletin 5(3) : 101-118

Cram, D.L. (1970)
A suggested origin for the cold surface water in central False Bay
Trans. roy. Soc. S.Afr. 39(1) : 129-137

Crisp, D.J. (1965)
The ecology of marine fouling
in: Ecology and the Industrial Society : 5th Symposium of the British Ecological Society. Ap.13-16 (1964)

Crisp, D.J. (1974)
Factors Influencing the Settlement of Marine Invertebrate Larvae
In: P.T. Grant and A.M. Mackie (Ed.)
Chemoreception in Marine Organisms
Academic Press, London, NY and San Francisco

Crisp, D.J. (1976)
Settlement responses in marine organisms
In: R.C. Newell (Ed.) Adaptations to Environment
Butterworths, London-Boston : pp.83-124

Crisp, D.J. and P.S. Meadows (1962)
The chemical basis of gregariousness in cirripedes.
Proc. roy. Soc. B. 156 : 500-20

Crisp, D.J. and J.S. Ryland (1960)
Influence of Filming and of Surface Texture on the Settlement of Marine Organisms
Nature 185 : 119

Cundell, A.M. & R. Mitchell (1977)
Microbial Succession on a Wooden Surface Exposed to the Sea.
Int. Biodeterior. Bull. 13(3) : 67-73

Daniel, A. (1955)
The Primary Film as a Factor in Settlement of Marine Foulers
J. Madras Univ. B25(2) : 189-200

Day, J.H. (1967)
A Monograph on the Polychaeta of Southern Africa. Part 2 : Sedentaria.
Trustees of the British Museum (Natural History) London.

Day, J.H. (1970)
The Biology of False Bay, South Africa
Trans. roy. Soc. S.Afr. 39(1) : 211-211

Day, J.H. (1974)
A Guide to Marine Life on South African Shores
A.A. Balkema. Cape Town.

Day, J.H., Field, J.G. & Penrith, M.J. (1970)
The Benthic Fauna and Fishes of False Bay, South Africa.
Trans. roy. Soc. S.Afr. 39(1) : 1-108

Day, R. (1972)
Fouling and Fouling Conditions in Simonstown.
Unpublished Report to DTS Corrosion Section,
South African Navy

Day, R. (1977)
Ecology of settling organisms
Ph.D. Thesis, University of Sydney

Dayton, P.K. (1971)
Competition, disturbance and community organization: the provision and subsequent utilization of space in a rocky intertidal community.
Ecological Monographs 4 : 351-389

de Chalain, T.M.B. (1979)
An investigation into aspects of biological fouling on selected artificial substrata, at sub-littoral depths in Simonsbay.
M.Sc. Thesis, University of Cape Town

De Palma (1969)
A Study of Deep Ocean Fouling: Straits of Florida and Tongue of the Ocean 1961 to 1968.
Informal Report No. 69-22
Naval Oceanographic Office, Washington D.C. 20390

De Palma, J.R. (1972)
Fearless Fouling Forecasting
Proceedings - 3rd International Congress of Marine Corrosion and Fouling.
Gaithersburg. M.D. : 865-879

De Palma, J.R. (1976)
Final Report on Marine Biofouling Studies at Admiralty Inlet, Washington.
NOO Reference Publication 12
Naval Oceanographic Office, Washington DC, 20373

De Palma, J.R. (1974)
An Annotated Bibliography of Marine Biofouling for Scientists and Engineers.
Technical Note TN3423-01-74
Naval Oceanographic Office, Washington D.C. 20373

De Palma, J.R. (1978)
Macrofouling: Its Effect on OTEC Components
In: Gray RH (Ed.)
Proceedings of the Ocean Thermal Energy Conversion (OTEC) Biofouling and Corrosion Symposium : 185-9

Efird, K.D. (1976)
The Inter-Relation of Corrosion and Fouling for Metals in Sea Water.
Materials Performance : 15(4) : 16-25

Eiben, R. (1976)
Einflusz von Benetzungsspannung und Ionen auf die Substratbesiedelung und das Einsetzen der Metamorphose bei Bryozoenlarven (Bowerbankia gracilis)
Mar Biol 37 : 249-54

Fava, J.A. & Thomas, D.L. (1978)
Use of Chlorine to Control OTEC Biofouling
Ocean Engng 5 : 269-288

Field, J.G. (1970)
The Use of Numerical Methods to Determine Benthic Distribution Patterns from Dredgings in False Bay
Trans roy Soc S Afr 39(1) : 183-200

Field, J.G. (1971)
A numerical analysis of changes in the soft-bottom Fauna along a transect across False Bay, South Africa
J. exp. mar. Biol. Ecol. 7 : 215-253

Field, J.G. & McFarlane, G. (1968)
Numerical Methods in Marine Ecology 1. A Quantitative Similarity Analysis of Rocky Shore Samples in False Bay, South Africa.
Zoologica Africana 3(2) : 119-137

Freiberger, A, Cologer, C.P., Liguori, V.R. & Nigrelli, R.F. (1969)
Some New Approaches to the Study of Barnacles
Ocean Engng 1(4) : 469-474

Goodbody, I (1961)
Inhibition of the Development of a Marine Sessile Community
Nature 190 : 282-3

Graham, J.W., Stock, J. & Benson, P.H. (1977)
Further studies on the use of heat treatment to control biofouling in seawater cooling systems
Oceans '77, Conference Record Los Angeles, Vol.1 : 23A

Griffith, J.R. & Bultman, J.D. (1980)
Fouling Release Coatings
Naval Engineers Journal, April 1980

Griffiths, C.L. (1976)
Guide to the benthic marine amphipods of Southern Africa.
SA Museum, Cape Town

Harger, J.R.E. & Tustin, K. (1973)
Succession and stability in biological communities Part 1 : Diversity
Int. J. Environment. Studies 5 : 117-130

Harger, J.R.E. & Tustin, K. (1973)
Succession and stability in biological communities Part 2 : Organization
Int. J. Environment. Studies 5 : 183-192

Harlin, M.M. and J.M. Lindberg (1977)
Selection of Substratum by Seaweeds: Optimal Surface Relief
Mar. Biol. 40 : 33-40

Heathfield, P.E.H. (1970)
An Electrolytic System for Controlling Corrosion and Marine Growth
Underwater Sci.Technol.J.2(3) : 168-173

Horbund, H.M. & A. Freiberger (1970)
Slime films and their role in marine fouling : A Review.
Ocean Engng. 1(6) : 631-634

Houghton, D.R. (1970)
Marine Anti-Fouling
Underwater Science and Technology Journal 2(2) : 100-4

Houghton, D.R. (1978)
Marine Fouling and Offshore Structures
Oceanology International 78
Section B : 41-42

Hurlbert, S.H. (1971)
The Non-Concept of Species Diversity : A Critique and Alternative Parameters.
Ecology 52 : 577-586

Iwaki, T., Hibino, K. & Kawahara, T. (1977)
Seasonal Changes in the Initial Development of Fouling Communities in Matoya Bay
Bulletin of the Faculty of Fisheries, Mie University 4(1) : 11-29

Jackson, J.B.C. (1977)
Competition on Marine Hard Substrata : The adaptive significance of solitary and colonial strategies
The American Naturalist 3(980) : 743-767

Kamenskaya, O.E. (1977)
Amphipods as fouling organisms of hydrotechnical structures in the sea of Japan (Russian with English abstract)
Marine Biology (Vladivostok) 5 : 70-75

Kawahara, T. (1961)
Regional Differences in the Composition of Fouling Communities in Ago Bay
Report Faculty of Fisheries, Prefectural University of Mie 4(1) : 65-80

Kawanara, T. (1962)
Studies on the Marine Fouling Communities I. Development of a fouling community.
Report on Faculty of Fisheries, Prefectural University of Mie 4(2) : 27-41

Kawahara, T. (1963)
Studies on the Marine Fouling Communities II. Differences in the Development of the Test Block Communities with Reference to the Chronological Differences in their Initiation.
Report of Faculty of Fisheries, Prefectural University of Mie 4(3) : 391-418

Kawahara, T. (1965)
Studies on the Marine Fouling Communties III. Seasonal Changes in the Initial Development of Test Block Communities.
Report on Faculty of Fisheries, Prefectural Univ. of Mie 5(2) : 319-364

Kawahara, T. (1969)
Studies on the Marine Fouling Communities IV. Differences in the Constitution of Fouling Communities According to Localities.
a. Nagasaki Harbor.
Report of Faculty of Fisheries, Prefectural University of Mie 6(3) : 109-125

Kawahara, T. & H. Iizima (1960)
On the Constitution of Marine Fouling Communities at Various Depths in Ago Bay
Report of Faculty of Fisheries, Prefectural University of Mie 3(3) : 582-594

Kawanara, T., T. Iwaki, K. Hibino & Y. Sugimura (1979)
Fouling communities in Yokkaichi Harbor
Publications Amakusa Marine Biological Laboratory, Kyushu University 5(1) : 19-30

Kazihara, T. (1964)
Ecological studies of marine fouling animals
Deep Sea Research 13(2) : 333-5 (Abstract)

Knight-Jones, D.E.W. & Crisp, D.J. (1953)
Gregariousness in barnacles in relation to the fouling of ships and to anti-fouling research
Nature 171 (4364) : 1109-1110

La Que F.L. (1969)
Deterioration of Metals in an Ocean Environment
Ocean Engng 1(2) 1299-312

La Que F. (1978)
OTEC Component Materials Typical for Survival at Sea
Sea Technology 19(2)

Lebedev E.M. (1978)
Fouling, Biocorrosion and Biodeterioration in Sea and Fresh Water
in: O.A. Scarlato & A.N. Golikov: Regularities of Distribution and Ecology of Coastal Marine Biocenosis. USSR Academy of Sciences, Leningrad

Leung Tack Kit, D. (1975)
Etude qualitative et quantitative des salissures biologique de plaques experimentales immergees en pleine eau : 5 - Les Ascidies.
Tethys 7 (2-3) : 223-234

Liberatore, G.L., E.J. Dyckman, J.A. Montermarano & J.A. Cohn (1972)
Antislime Coatings. Part II - Preconditioning Value of Slime for Barnacle Attachment
Naval Ship Research and Development Center : 28-288. Annapolis, Md.
(NTIS Abstract)

Loeb, G.I. (1978)
The Settlement of fouling organisms on hydrophobic surfaces
U.S. Naval Research Laboratories Progress Reports, 1978 : 1-9

Loeb, G.I. & R.A. Neihof (1974)
Marine Conditioning Films
Applied Chemistry and Protein Interfaces : 319-335,
U.S. Naval Research Laboratories

Long, E.R. (1974)
Marine Fouling Studies off OAHU, HAWAII
The Veliger 17 (1) : 23-39.

Loucks, O.L. (1970)
Evolution of diversity, efficiency, and community stability.
American Zoologist 10 : 17-25

Maguire, L.A. & J.W. Porter (1977)
A spatial model of growth and competition stategies in coral communities.
Ecological modelling 3 (4) : 249-271

Maloney, W.E. (1958)
A Study of the Types, Seasons of Attachment, and Growth of Fouling Organisms in the Approaches to Norfolk, Virginia.
Technical Report TR-47
US Navy Hydrographic Office, Washington DC

Marshall, K.C., R. Stout and R. Mitchell (1971)
Mechanism of the initial events in the sorption of Marine Bacteria to Surfaces
Journal of General Microbiology 68 : 337-348

Mc Clurg, T.P. (1969)
An assessment of fouling conditions in Simonstown waters.
Zoology Hons. Report, University of Cape Town

Meadows, P.S. & J.I. Campbell (1972)
Habitat Selection by Aquatic Invertebrates
Adv. Mar Biol 10 : 271-282

Meadows, P.S. & G.B. Williams (1963)
Settlement of Spirorbis borealis Daudin Larvae on Surfaces bearing Films of Micro-organisms
Nature 198(4880) : 610-1

Millard, N. (1951)
Observations and experiments on fouling organisms in Table Bay Harbour, South Africa
Trans. roy. Soc. S. Afr. 33(4) : 415-445

Millard, N.A.H. (1975)
Monograph on the hydroida of Southern Africa.
Ann. S. Afr. Mus.: 68 : 1-513

Miller, M.A., J.C. Rapean & W.F. Whedon (1948)
The role of slime film in the attachment of fouling organisms
Biological Bulletin of Woods Hole 94(2) : 143-157

Mills, E.L. (1969)
The Community Concept in some Marine Communities : A Review
Journal of the Fisheries Research Board of Canada 26 : 1415-28

Mitchell, R., Cundell, A.M., Boyle, P.J. & Sleeter, T.D. (1977)
The role of microorganisms in marine fouling and boring processes.
Technical Report No. 3
Division of Engineering and Applied Physics Harvard University. Cambridge, Massachusetts

Mortlock, A.M. (1969)
One approach to the barnacle problem
J.R.N.S.S. 24(5) : 260-270

Müller, W.A. (1973)
Metamorphose - Induktion bei Planulalarven. I. Der bakterielle Induktor.
Wilh. Roux' Arch. 173 : 107-121

Müller W.A. & Bucnal, G. (1973)
Metamorphose - Induktion bei Planulalarven. II. Induktion durch monovalente Kationen.
Wilh. Roux' Arch. 173 : 122-135

Müller, W.A., Wieker, F. & Eiben, R. (1976)
Larval Adhesion, Releasing Stimuli and Metamorphosis
In: Mackie, G.O., Coelenterate Ecology and Behaviour. Plenum Press, New York and London.

Muraoka, J.S. (1971)
Deep ocean biodeterioration of materials
Ocean Industry 6(2) : 21-23

Neihof, R. & G. Loeb (1974)
Dissolved organic matter in seawater and the electric charge of immersed surfaces.
Journal of Marine Research 32 : 5-12

Neumann, R. (1979)
Bacterial Induction of Settlement and Metamorphosis in the Planula Larva of Cassiopea andromeda (Cnidaria: Scyphozoa, Rhizostomea)
Marine Ecology - Progress Series 1 : 21-28

Odum, E.P. (1969)
The Strategy of Ecosystem Development
Science 164 : 262-270

O'Neill, T.B. & G. Wilcox (1967)
The Formulation of a 'Primary Film' on Materials Submerged in Sea Water at Port Hueneme, California.
Naval Civil Engineering Lab - Technical Note - 894, Port Hueneme, California
(NTIS Abstract)

Osman, R.W. (1977)
The Estaolishment and Development of a Marine Epifaunal Community
Ecol. Monogr. 47 : 37-63

Phelps, A. (1941)
Observations on Reactions of Barnacle Larvae and Growth of Metamorphosed forms at Beaufort, North Carolina. June - September 1941
Progress Report of Woods Hole Oceanographic Research Institute to Bureau of Ships, United States Navy : Paper 7

Pomerat, C.M. & Reiner, E.R. (1942)
The Influence of Surface Angle and of Light to the Attachment of Barnacles and other Sedentary Organisms
Biological Bulletin of Woods Hole 82(1) 14-25

Ralph, R. & K. Goodman (1979)
Foul Play beneath the waves
New Scientist 82 (1160) : 1018-1022

Rastetter E.B. & W.J. Cooke (1979)
Responses of Marine Fouling Communities to Sewage Abatement in Kaneohe Bay, Oahu, Hawaii
Mar Biol 53 : 271-80

Reason, R.E. (1970)
The Measurement of Surface Texture
Macmillan and Co Ltd, Bristol

Russ, G.R. (1977)
A Comparison of the Marine Fouling Occurring at the two principal Australian Naval Dockyards
Report No. MRL-R-688, Australian Dept of Defence, Materials Research Laboratories

Russ, G.R. (1980)
Effects of Predation by Fishes, Competition, and Structural Complexity of the Substratum on the Establishment of a Marine Epifaunal Community
J. exp. mar. Biol. Ecol. 42 : 55-69

Sanders, H.L. (1968)
Marine Benthic Diversity : A Comparative Study
Amer. Natur. 102 : 243-282

Saroyan, J.R. (1969)
Coatings and Encapsulants - Preservers in the Sea
Ocean Engng. 1 : 435-456

Scheer, B.T. (1945)
The Development of Marine Fouling Communities
Biol. Bull, Woods. Hole 89 : 103-121

Schoener, A. (1974)
Colonization Curves for Planar Marine Islands
Ecology 55 : 818-827

Schoener, A, E.R. Long & J.R. De Palma (1978)
Geographic Variation in Artificial Island Colonization Curves.
Ecology 59(2) : 367-382

Shapiro, S.S. & M.B. Wilk (1965)
Biometrika 52 : 191

Simons, R.H. (1976)
Seaweeds of Southern Africa: Guide-lines for their study and identification.
Fish. Bull, S. Afr. 7 : 1-100

Skerman, T.M. (1956)
The Nature and Development of Primary Films on surfaces submerged in the sea
New Zealand Journal of Science and Technology (July 1956)

Springer, P.C. (1977)
Ocean Thermal Energy Conversion Heat Exchanger Biofouling - Strategies of Control
Ocean '77 Conference Record, MTS-IEEE Washington DC : 41D

Stubbings, H.G. (1961)
Fouling and Anti Fouling
Research 14 : 309-314

Sutherland, J.P. (1974)
Multiple Stable Points in Natural Communities
Amer Natur 108(964) : 859-873

Sutherland, J.R. (1978)
Life Histories and the Dynamics of Fouling Communities.
In: OA Scarlato and AN Golikov: Regularities of Distribution and Ecology of Coastal Marine Biocenosis. USSR Academy of Sciences, Leningrad.

Sutherland, J.P. & R.H. Karlson (1977)
Development and stability of the fouling community at Beaufort. North Carolina
Ecological Monographs 47(4) pp.425-446

Tarasov, N.I. (1961)
On Marine Fouling
Zoologichesky Zhurnal 40(4) : 477-489 Moscow

Thomas, T.R. (1979)
Surface roughness measurement: alternatives to the stylus.
Metrology and Inspection, March 1979 : 0-13

Thorson, G. (1964)
Light as an ecological factor in the dispersal and settlement of larvae of marine bottom inverteorates
Ophelia 1(1) : 167-208

United States Naval Institute (1952)
Marine Fouling and its prevention
Woods Hole Oceanographic Research Institute.

Visscher, J.P. & R.H. Luce (1928)
Reactions of the Cyprid Larvae of Barnacles to Light with Special Reference to Spectral Colours
Biological Bulletin of Woods Hole 54(4) : 336-350

Walton-Smith, F.G. (1941)
Effect of illumination and depth on the attachment and growth of fouling organisms on stationary surfaces
Progress Report of Woods Hole Oceanographic Institute to Bureau of Ships, United States Navy : Paper 17

Weiss, C.M. (C.1944)
Progress report on settling and metamorphosis of barnacle larvae on painted surfaces at Beaufort, N.C.
Progress Report of Woods Hole to Bureau of Ships, United States Navy : Paper 8 (1&2)

Weiss, C.M. (1948)
The Seasonal Occurrence of Sedentary Marine Organisms in Biscayne Bay, Florida
Ecology 29(2) : 153-172

Wilson, D.P. (1955)
The Role of Micro-organisms in the Settlement of Ophelia bicornis Savigny
J Mar biol Ass UK 34 : 531-43

Wood, E.J.F. (1950)
Investigations on underwater fouling. I. The role of bacteria in the early stages of fouling
Australian Journal of Marine and Freshwater Research Vol(1)

Yodzis, P. (1976)
Species richness and stability of space limited communities
Nature 264 : 540-541

Yull Rhee, G. (1978)
Effects of N : P atomic ratios and nitrate limitation on algae growth, cell composition and nitrate uptake
Limnology and Oceanography 23(1) : 10-25

Zachary, A., M.E. Taylor, F.E. Scott and R.R. Colwell (1978)
A Method for Rapid Evaluation of Materials for Susceptibility to Marine Biofouling
Int. Biodeterior. Bull 14(4) : 111-118

Zobell, C.E. (1939)
The role of bacteria in the fouling of submerged surfaces.
Biological Bulletin, Mar. Biol. Lab., Woods Hole 67(2) : 302

Zobell C.E. & E.C. Allen (1935)
The significance of marine bacteria in the fouling of submerged surfaces
Jour. Bacteriol. 29 : 239-251

7. APPENDIX

4.1.1 Colour and surface texture experiment

In an effort to differentiate between the effects that substratum colour and roughness might have had when comparing the six materials, a four-week experiment was designed to test these characteristics in isolation.

PVC plates of various colours, white, grey, red, blue and green, were cut into 5 x 5cm plates and treated to bring them to three grades of roughness:-

(a) Glossy - mirror finish (CLA=0,03-0,07)
(b) Dull - rubbing with waterpaper (CLA=1,00-1,32)
(c) Rough - scratching with coarse sandpaper (CLA=6,97-9,50).

The reflectance of six primary light colours from these plates was measured, the results being presented on fig. 2.1.2.1.a top. This range of colours and roughness, covered the whole range of these characteristics for the six materials used in the main experiments.

Eight replicates (total area 4 dm^2) of each colour and each roughness grade and of the standard light-grey PVC (used in the main experiment), were mounted randomly on 8 frames and immersed at 10m depth at Site 3 for four weeks. After retrieval, the plates were stored in formalin, until they were examined under a dissecting microscope (12,5X) to identify and count all individuals. Organisms, that settled on the edges or at the holes drilled into the plates, were ignored, because these were the areas of inconsistent roughness.

The results, which are summarized for each group of organisms, are presented in figure 4.1.1.1. During the experimental period, April 1980, settlement of organisms at Site 3 was somewhat reduced compared to previous months (at Site 1,2&3). For example, barnacles, which were usually common in all months, scarcely numbered $10/dm^2$, whereas only a month earlier their numbers were well above $100/dm^2$ for a similar four-week period at the same site (see fig. 2.2.3.2a). In spite of this drawback, the following points should be noted in examining the data:-

(i) None of the groups of organisms were absent from any of the roughness grades. Also, no marked differences were apparent in numbers that settled generally on plates of each grade, although glossy plates may have had less individuals, especially hydrozoa, Campanularia integra and Obelia, and apparently less encrusting bryozoa, Watersipora sp. and Membranipora sp., simple ascidians (not identified) and algae, mainly colonial diatoms Licmophora flabellata. Mussel spat, Choromytilus meridionales and Saxicava arctica, and serpulids, Hydroides elegans and Spirorbis sp., which were fairly common on all plates, did not seem to have any obvious preference for roughness grades. Subjective tests indicated that most organisms were not firmly cemented to the smooth surfaces and easily became detached.

(ii) None of the groups of organisms were absent from any of the colours. However, it appears that more or less individuals of some groups settled on one colour than on another. These were: more tubiculous amphipods on white, less Bugula neritina on blue and red, less simple ascidians on white and less colonial diatoms, Licmophora flabellata, and algae, Ectocarpus sp., on red.

(iii) Since settling organisms may respond to a multitude of environmental stimuli (Crisp, 1976), it is conceivable that the interaction of colour and roughness might enhance or diminish the "affinity" of organisms to a surface. e.g. Species A will not settle on colour X, unless the surface is rough.

Although this approach is oversimplistic, it can be used, perhaps, to indicate whether any interaction took place. In that case, colonial diatoms avoided red plates, except when these were rough; fine filamentous bryozoa, Aetea sp. ?, were only recorded on a single red glossy plate; encrusting bryozoa, Watersipora sp., only settled on white plates if these were not glossy; less barnacles settled on white and green glossy plates than on others; hydrozoa, Campanularia integra, were only common on blue rough plates. Since none of these differences appeared to be consistent, their significance is not clearly understood.

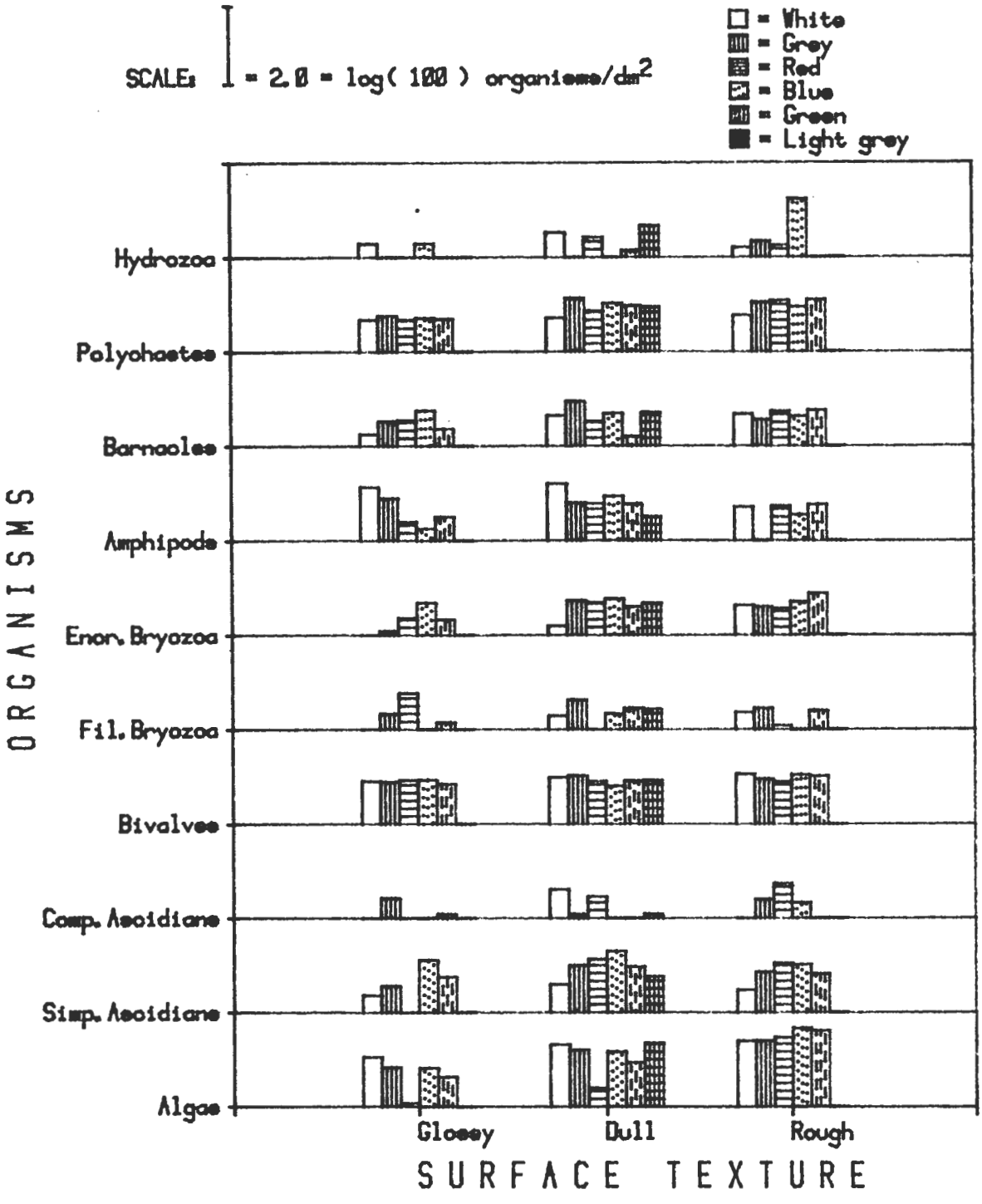


Fig 4111 : Number of organisms (log[X+1]) that settled on coloured PVC plates (5x5 cm) of various surface textures. Plates were exposed for 4 weeks at Site 3 (10m). Each group of plots shows data of different coloured plates: left to right, white, grey, red, blue & green and standard light grey in column 6, dull.

4.1.2. Abundance Estimates

Table 4.1.2 : The general relative abundance of benthic organisms in the fouling community during different months and exposure periods. Abundance estimates, based on frequency and size, are as follows:- 1-present, 2-fairly common, 3-common, 4-very common, 5-abundant.

Depth	20m											10m										
Exposure period (months)	1	1	1	1	1	1	3	3	3	9	12	1	1	1	1	1	1	3	3	3	9	12
Month	Jun	Jul	Aug	Sep	Oct	Nov	Jun Aug	Dec Feb	Mar May	Jun Feb	Jun May	Jun	Jul	Aug	Sep	Oct	Nov	Jun Aug	Dec Feb	Mar May	Jun Feb	Jun May
HYDROZOA																						
Sertulariidae	1	2	-	-	-	-	1	-	1	2	3	1	1	-	-	-	-	1	1	1	1	-
Turbulariidae	1	1	1	1	1	-	-	-	-	-	-	1	1	-	1	1	-	1	1	1	-	-
Plumulariidae	1	-	-	-	-	1	1	1	1	-	-	-	1	1	1	1	1	2	1	1	2	1
Campanulariidae	-	-	-	3	2	1	2	3	1	2	3	-	1	2	2	-	1	1	2	-	-	1
Other	2	2	2	1	1	1	1	-	1	1	-	2	1	1	1	1	1	1	-	1	-	-
POLYCHAETES: ERRANTIA																						
Aphroditidae	-	-	-	-	-	1	-	-	-	1	2	-	-	-	-	1	1	1	1	1	2	2
Nereidae	-	-	-	1	-	1	1	1	1	2	1	-	-	-	1	1	1	1	1	1	1	2
Other	-	-	-	1	1	1	1	-	1	1	-	-	-	-	1	1	1	1	1	1	-	-
POLYCHAETES: SEDENTARIA																						
Sabellidae	1	-	-	1	-	1	1	1	1	1	1	-	1	-	1	1	-	1	-	-	1	1
Terebellidae	-	-	-	1	1	1	-	1	1	1	2	-	-	-	-	-	1	1	1	1	2	3
Serpulidae	1	1	2	2	1	1	3	1	2	2	2	1	1	1	1	1	1	1	1	2	1	1
Other	-	-	-	1	1	1	-	1	-	1	1	-	-	-	1	1	1	-	-	1	-	1
ARTHROPODA: CIRRIPENDIA																						
Balanus amphitrite	2	2	3	3	3	3	4	3	4	2	1	3	3	4	4	5	4	5	3	4	1	3
Balanus maxillaris	-	-	1	2	2	1	2	1	2	3	3	-	-	2	2	2	1	2	1	1	2	2
Balanus trigonus	-	-	-	1	-	-	-	3	2	3	3	-	-	-	-	-	2	-	4	2	3	1
ARTHROPODA: ISOPODA																						
Cirolana obtusispina	-	-	-	1	1	1	-	1	1	2	1	-	-	-	1	1	1	1	1	2	2	1
Cymodacae comans	-	-	-	1	-	1	-	1	1	1	1	-	-	-	-	-	1	-	1	-	1	1
ARTHROPODA: AMPHIPODA																						
Tube-forming	1	1	1	1	1	2	1	1	1	1	-	1	1	2	2	1	1	1	1	2	1	-
Paramoera capensis	-	-	1	1	1	1	1	1	1	2	1	-	1	1	3	3	2	4	1	3	3	2
Caprella circur	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1	1	1	1	1	-	-	-
Other	-	-	-	1	1	1	1	1	1	1	1	-	-	-	1	1	1	1	1	1	1	1
OTHER ARTHROPODA																						
Plagusia chabrus	-	-	-	1	1	1	-	1	1	2	2	-	-	-	-	-	1	1	1	2	3	3
Jasus lalandii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	-
Tanystylum brevipes	-	-	-	1	-	-	-	-	-	-	1	-	-	-	-	-	1	-	1	-	1	1
Other																						
BRYOZOA																						
Membranipora spp.	-	1	-	1	1	1	1	1	1	2	1	1	-	1	1	1	1	1	1	1	1	1
Watersipora sp.	1	1	-	1	1	1	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1
Menipea spp.	-	-	-	-	-	-	-	1	1	1	-	-	-	-	1	1	1	1	1	1	1	1
Bugula spp.	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	2	2	2	1	3	1	1
Aetea sp. (?)	-	-	-	-	-	1	-	2	2	-	1	-	-	-	-	1	1	-	3	2	-	-
Other	1	1	1	-	1	1	1	-	-	1	1	-	1	-	1	1	-	1	1	1	-	-
MOLLUSCA: PELECYPODA																						
Choromytilus meridionales	1	1	1	1	1	1	2	1	2	1	2	1	1	2	1	2	1	3	2	3	5	5
Anomia sp.	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	2
Aulacomya sp.	-	-	-	-	-	1	-	1	-	1	2	-	-	-	-	-	1	-	1	1	1	1
Other	-	-	-	1	1	1	-	1	2	1	1	-	-	-	1	1	1	1	1	3	1	1

Depth	20m											10m										
Exposure period (months)	1	1	1	1	1	1	3	3	3	9	12	1	1	1	1	1	1	3	3	3	9	12
Month	Jun	Jul	Aug	Sep	Oct	Nov	Jun Aug	Dec Feb	Mar May	Jun Feb	Jun May	Jun	Jul	Aug	Sep	Oct	Nov	Jun Aug	Dec Feb	Mar May	Jun Feb	Jun May
OTHER MOLLUSCA																						
Nudibranchs	-	-	-	1	1	1	1	-	-	-	-	-	-	-	1	1	1	1	-	1	-	1
Gastropoda	-	-	-	1	-	1	-	-	-	-	-	1	-	-	1	-	1	-	-	1	1	-
Cephalopoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
ECHINODERM																						
Crinoidea	-	-	-	1	2	1	1	1	1	1	2	1	1	-	2	3	2	1	1	1	1	1
Echinoidea	-	-	-	1	-	2	-	-	1	1	1	-	-	1	1	1	1	1	2	1	2	1
Asteroidea	-	-	-	-	-	1	-	-	-	1	1	-	-	-	-	-	-	-	1	1	1	1
Ophiuroidea	-	-	-	1	1	2	1	2	2	2	2	1	1	1	1	-	-	1	1	1	1	1
Holothuroidea	-	-	-	-	1	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-	1	1
ASCIDIACEA: Compound																						
Diplosoma macdonaldi	-	-	-	2	3	3	-	2	1	1	1	-	-	-	-	2	2	1	1	-	1	1
Diplosoma listeriamum	-	-	-	1	1	2	-	2	1	2	-	-	-	-	1	2	3	2	1	-	1	1
ASCIDIACEA: Simple																						
Pyura sp.	-	-	-	-	-	1	1	2	2	4	5	-	-	-	-	-	1	1	1	1	1	-
Ciona intestinalis	-	1	-	1	1	2	1	1	1	2	1	-	-	-	1	1	1	1	1	-	1	-
Microcosmus sp.	-	-	-	-	-	-	-	1	1	2	1	-	-	-	-	-	-	-	1	-	-	-
Ascidia sp.	-	-	-	-	-	-	-	1	1	1	3	-	-	-	-	-	-	-	1	1	-	1
Styela costata	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	1
ALGAE																						
Colpomenia sinuosa	-	-	-	-	-	-	1	-	-	-	-	2	1	2	-	1	3	1	2	1	-	-
Ectocarpus sp.	-	-	-	-	1	-	-	-	-	-	-	2	3	2	2	2	3	-	1	1	-	-
Other green & brown	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	1	1	1	-	-
Agardhinula (?)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	1	1	-	1
Other red	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1	1	1	1	1	1	-	1
OTHER ORGANISMS																						
Platyhelminthes	-	-	-	1	-	-	-	1	1	1	1	-	-	-	1	-	1	1	-	1	1	1
Porifera	1	-	-	1	1	-	1	-	1	-	-	-	-	1	-	-	-	-	-	-	-	-
Actiniaria	-	-	-	1	1	1	1	1	1	1	2	-	-	-	1	1	1	1	1	-	2	2
Sipunculida	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	1	-	-	-	-	-	1
Nemertea	-	-	-	-	1	1	-	-	1	-	-	-	-	1	-	1	1	1	-	1	-	1
Eggstrings	-	1	1	1	1	1	1	1	1	1	1	-	-	1	1	1	1	1	1	1	1	1
PRIMARY FILM	1	1	2	1	1	2	3	3	2	3	3	2	1	1	2	1	3	3	4	3	4	5
FUNGUS	1	2	2	1	1	2	2	3	2	2	-	-	1	-	-	-	1	-	-	2	-	-

4.1.3. Dendrograms of Cluster Analysis Results

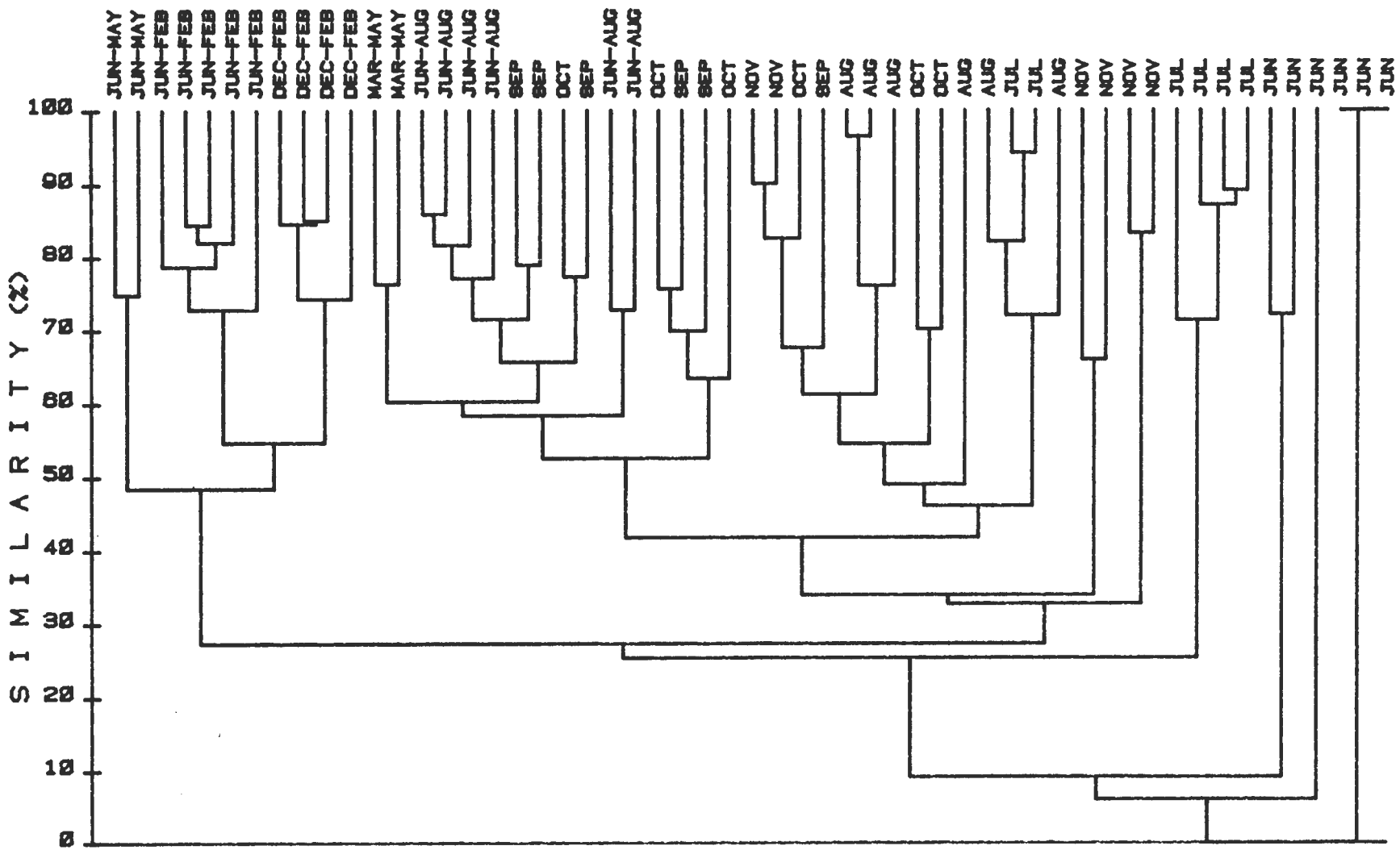


Fig 4131a : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Aluminium plates were exposed at Site 1 (20m) during different months for various periods of time.

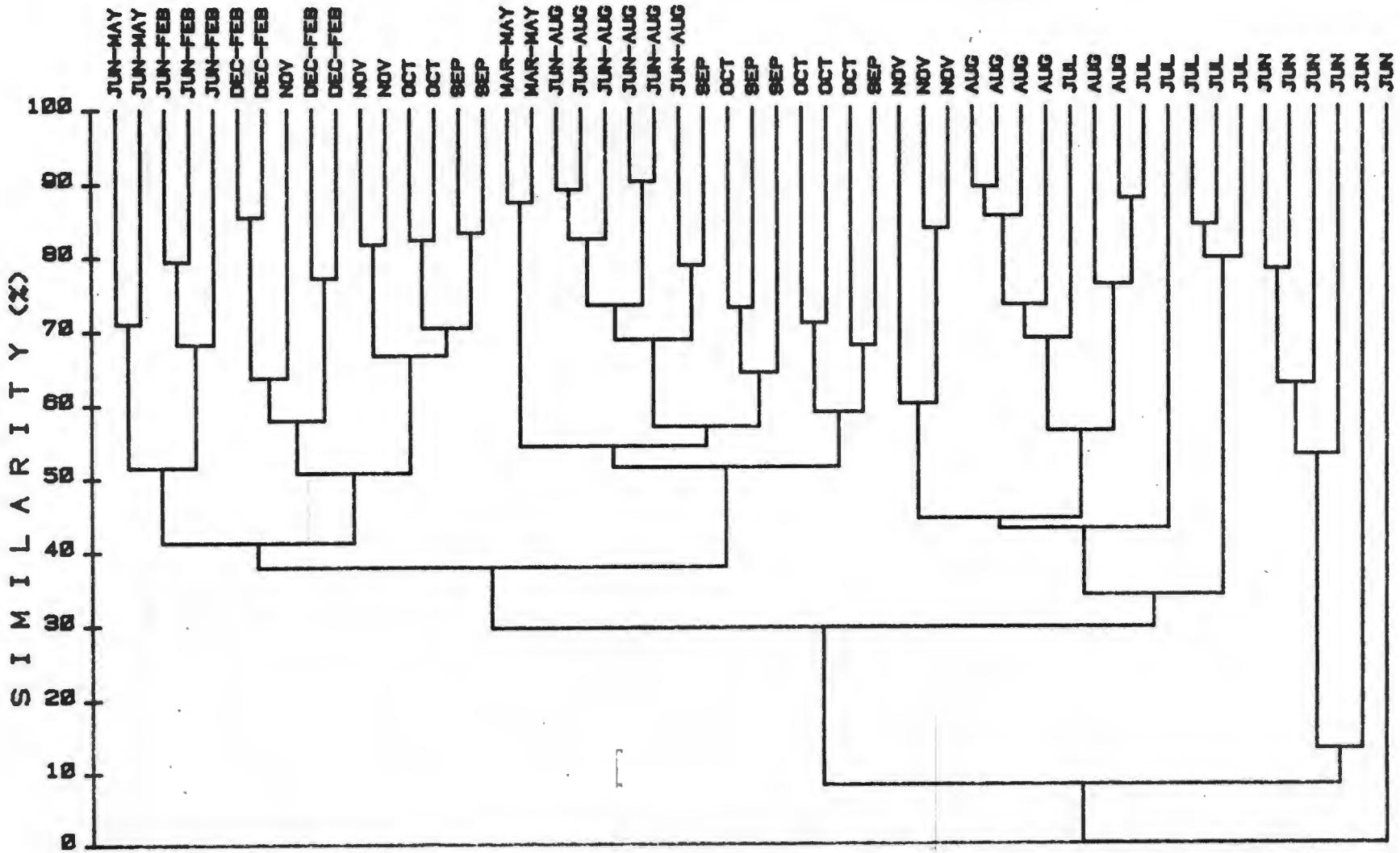


Fig 4131b : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Stainless steel plates were exposed at Site 1 (20m) during different months for various periods of time.

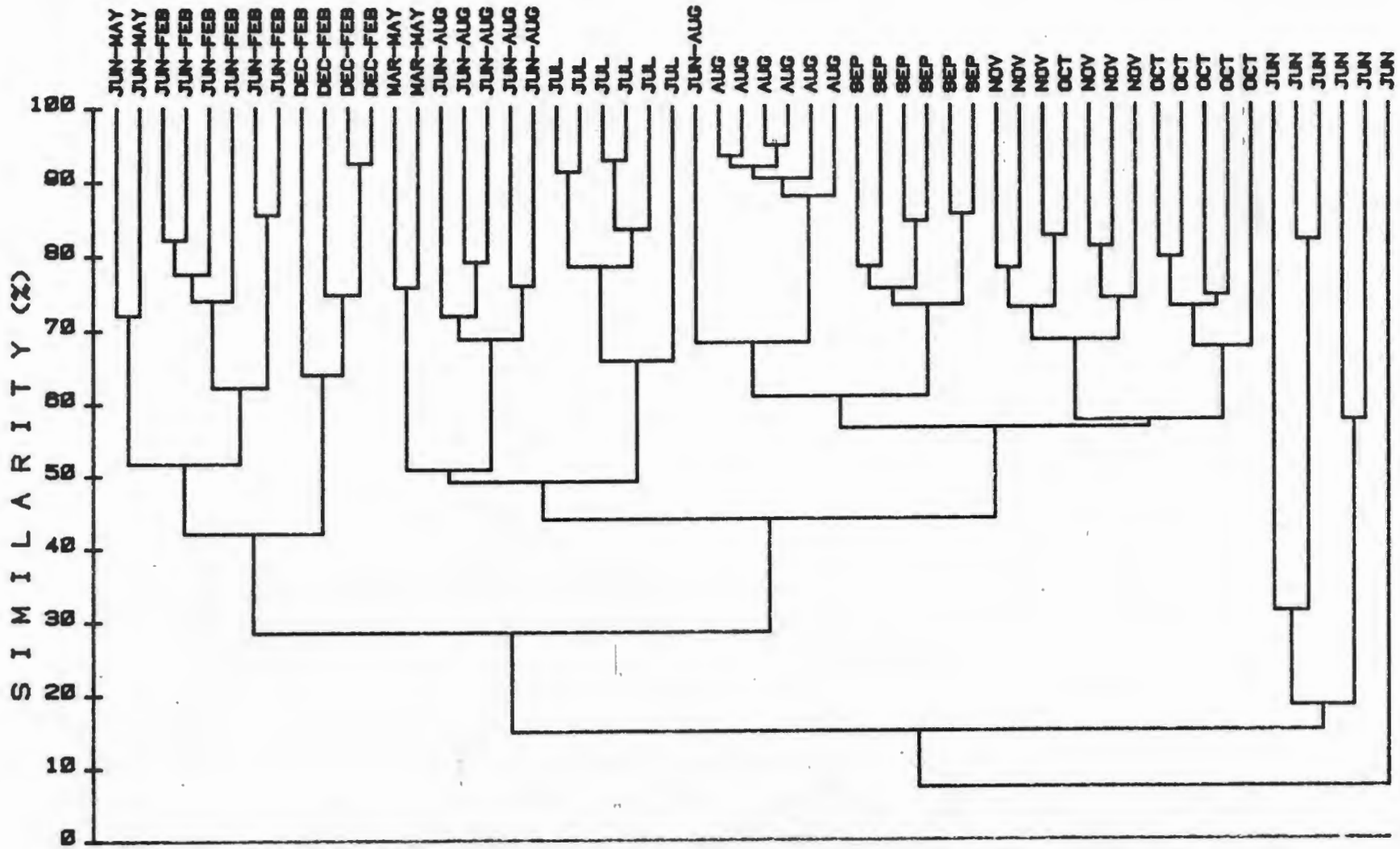


Fig 4131c : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Mild steel plates were exposed at Site 1 (20m) during different months for various periods of time.

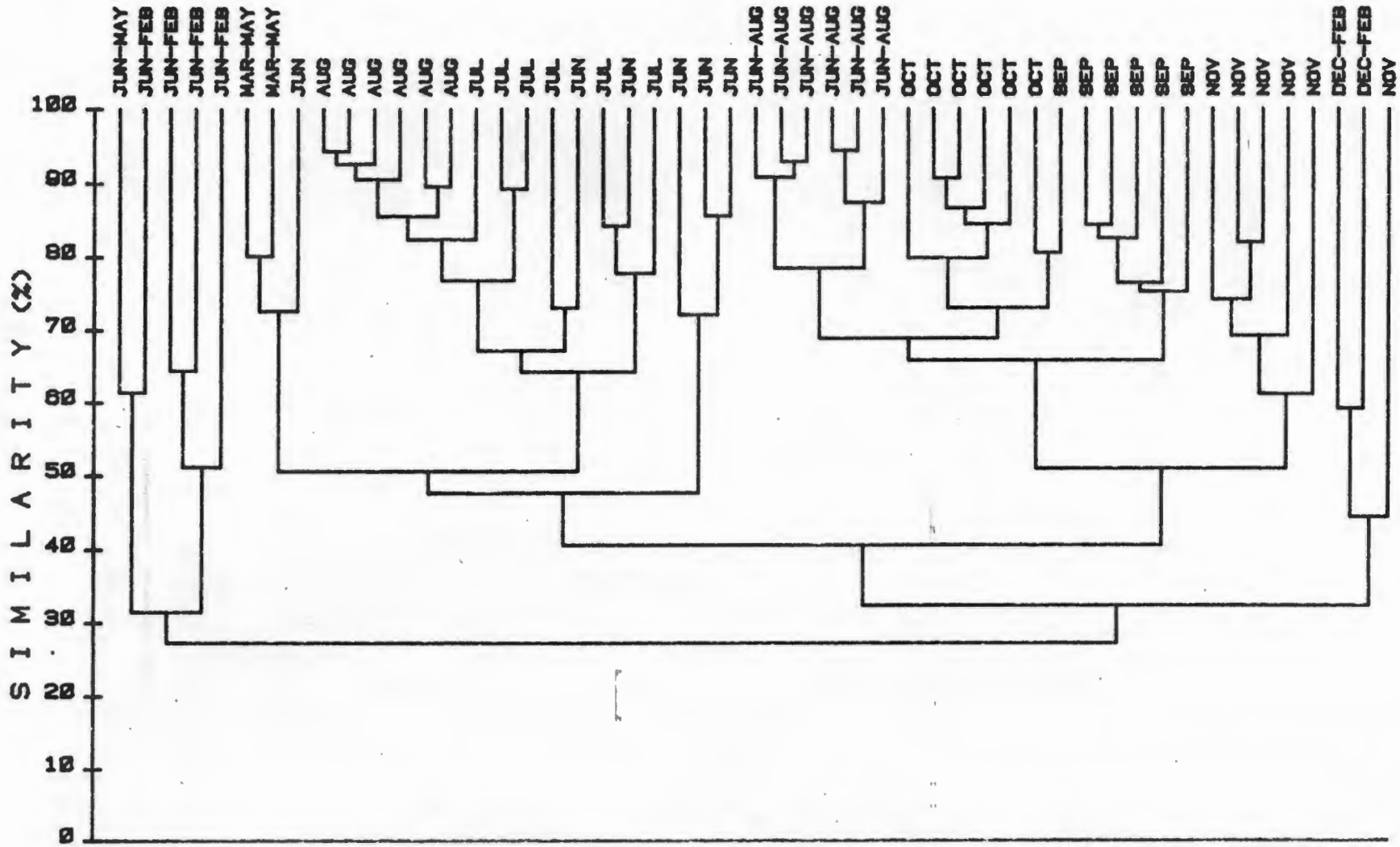


Fig 4131d : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Silicon rubber plates were exposed at Site 1 (20m) during different months for various periods of time.

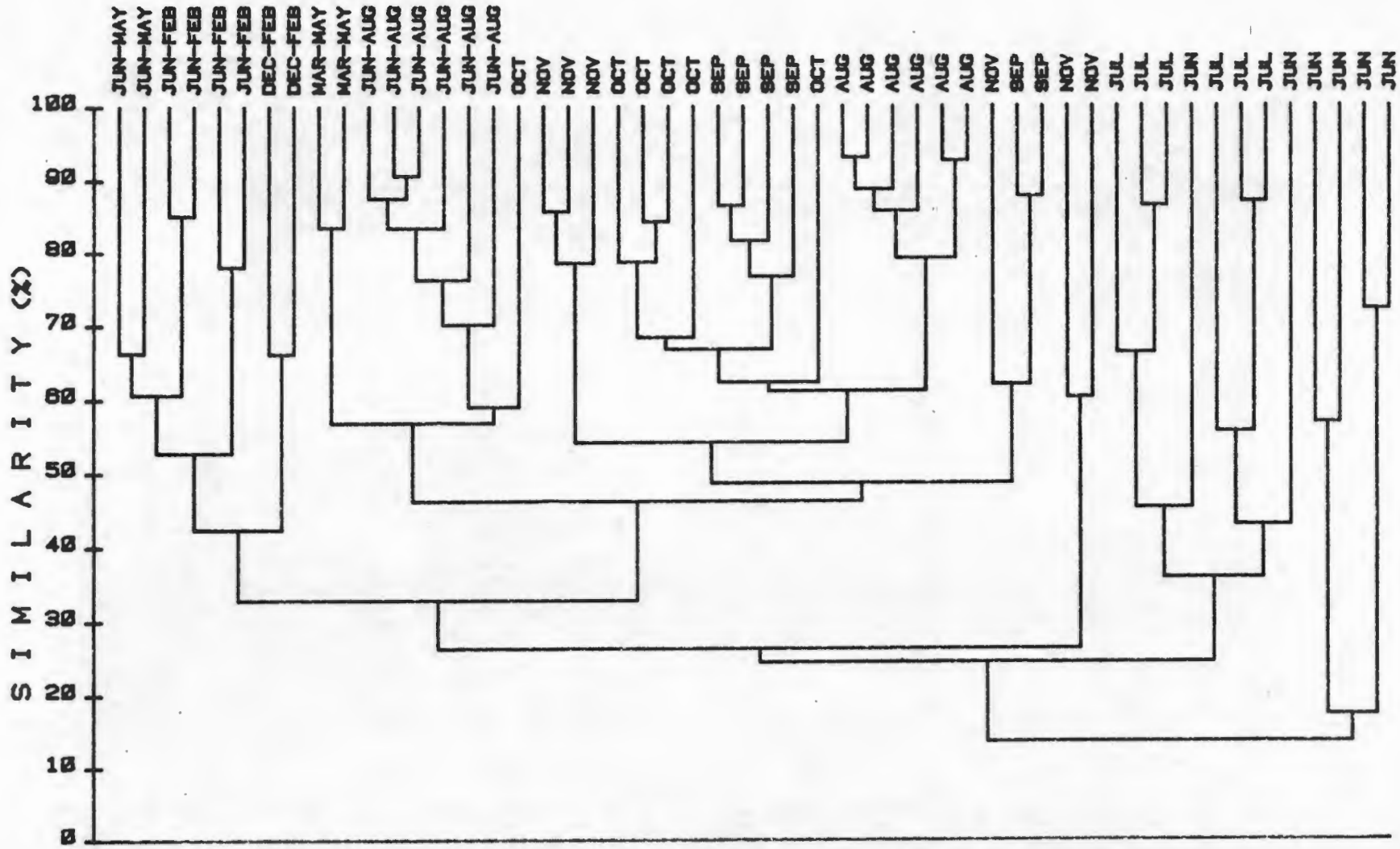


Fig 4131e : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Fibre glass plates were exposed at Site 1 (20m) during different months for various periods of time.

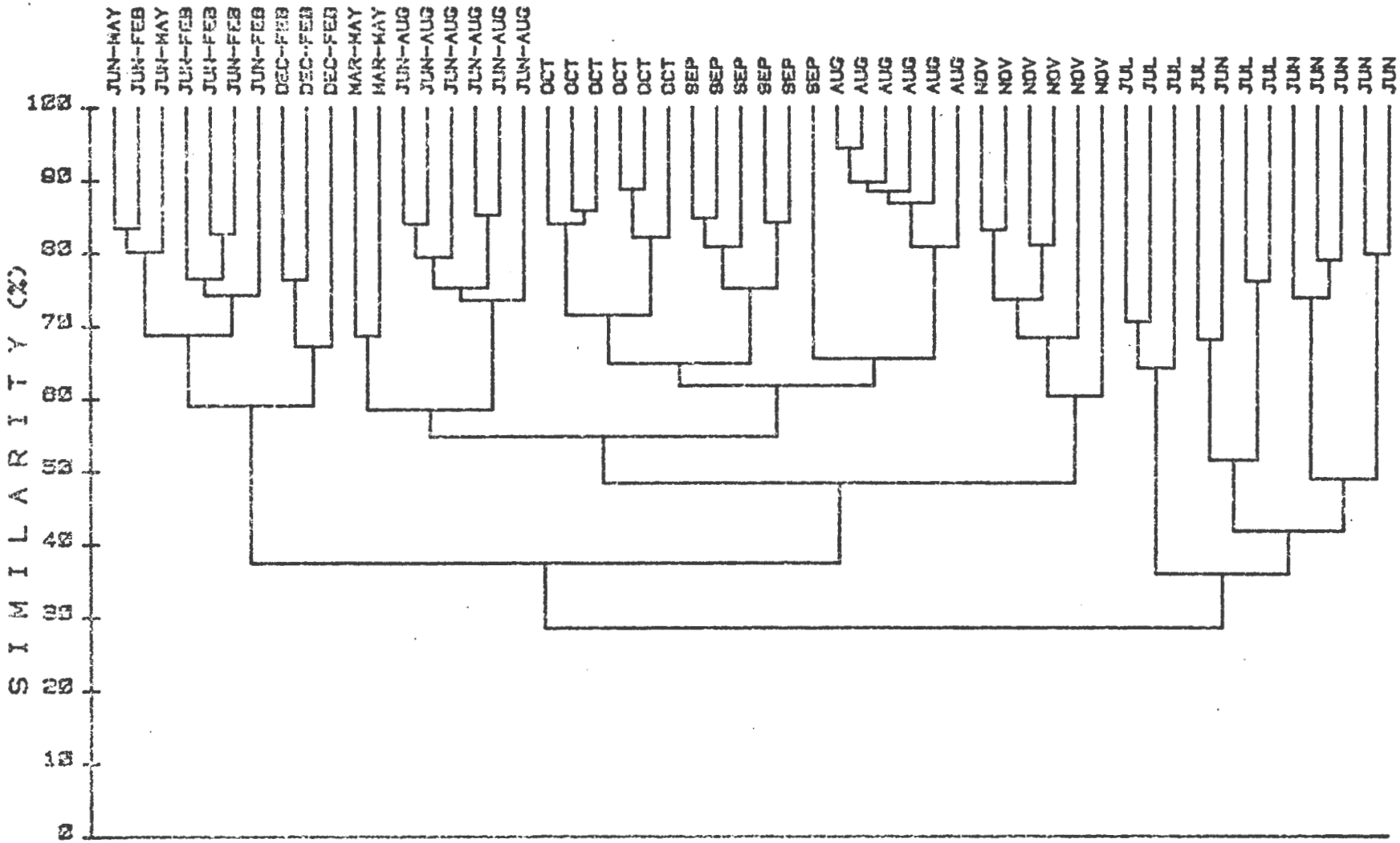


Fig 4131f : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. P.V.C. plates were exposed at Site 1 (20m) during different months for various periods of time.

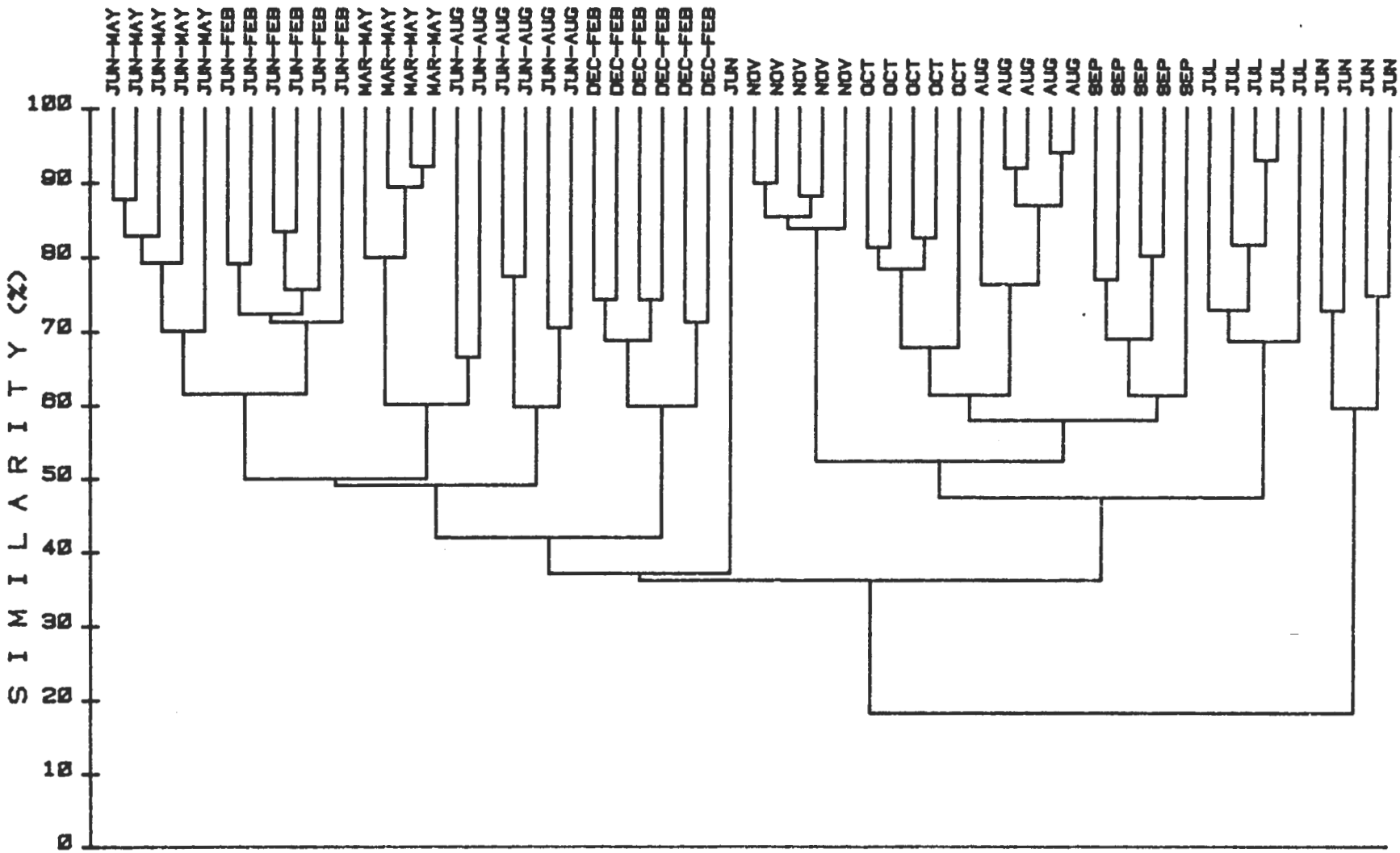


Fig 4131g : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Aluminium plates were exposed at Site 2 (10m) during different months for various periods of time.

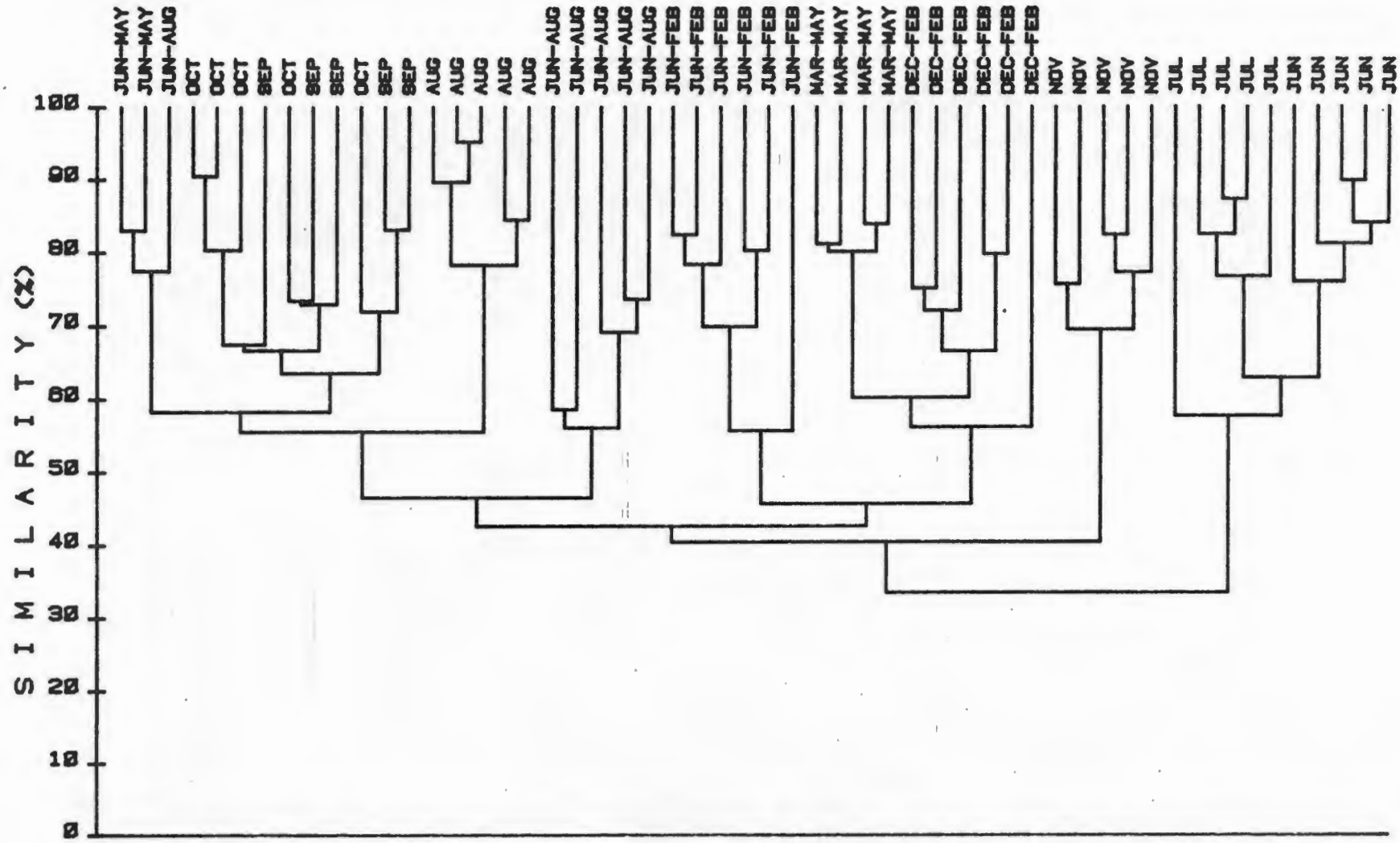


Fig 4131h : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowsi coefficient. Stainless steel plates were exposed at Site 2 (10m) during different months for various periods of time.

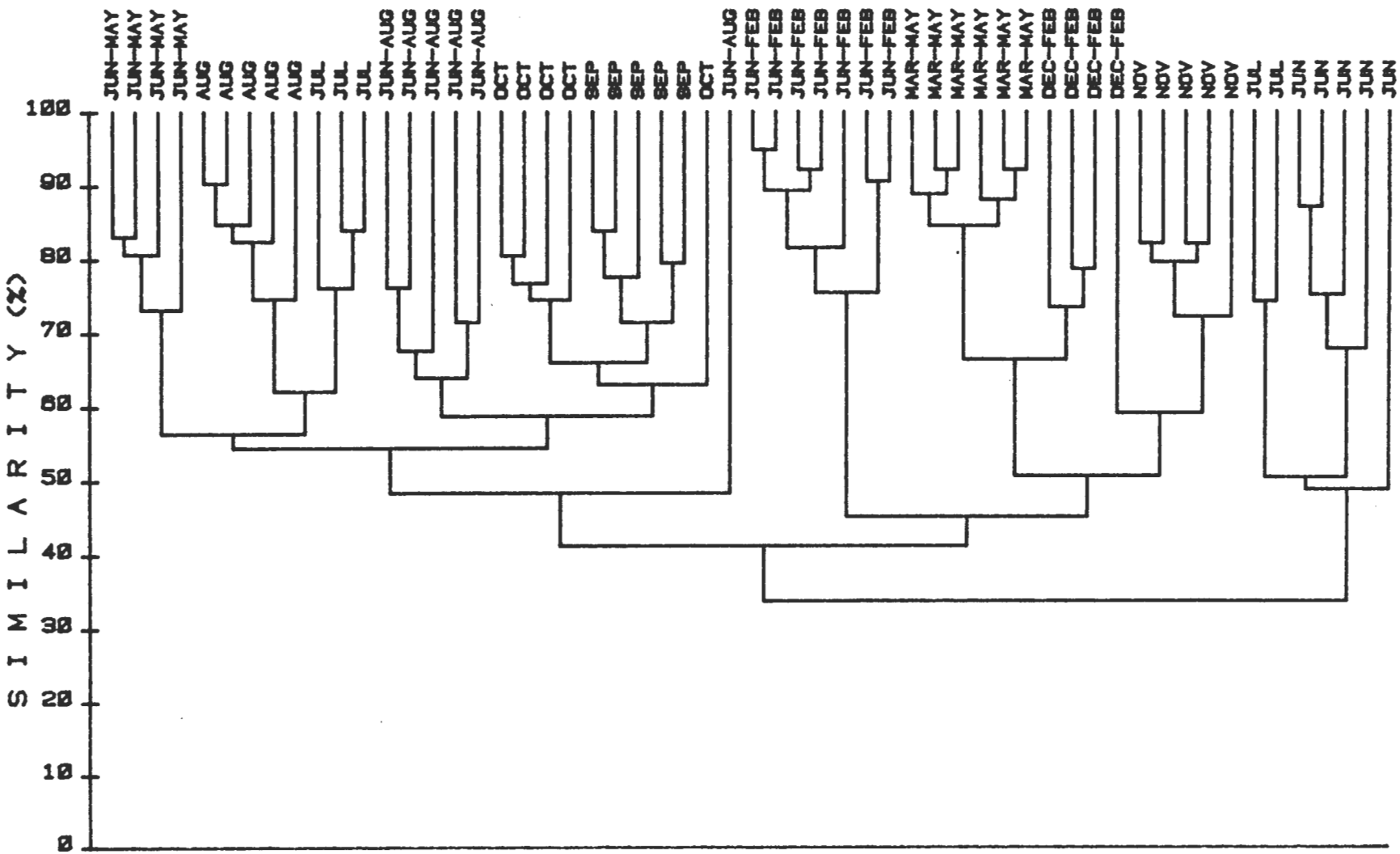


Fig 4131i : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Mild steel plates were exposed at Site 2 (10m) during different months for various periods of time.

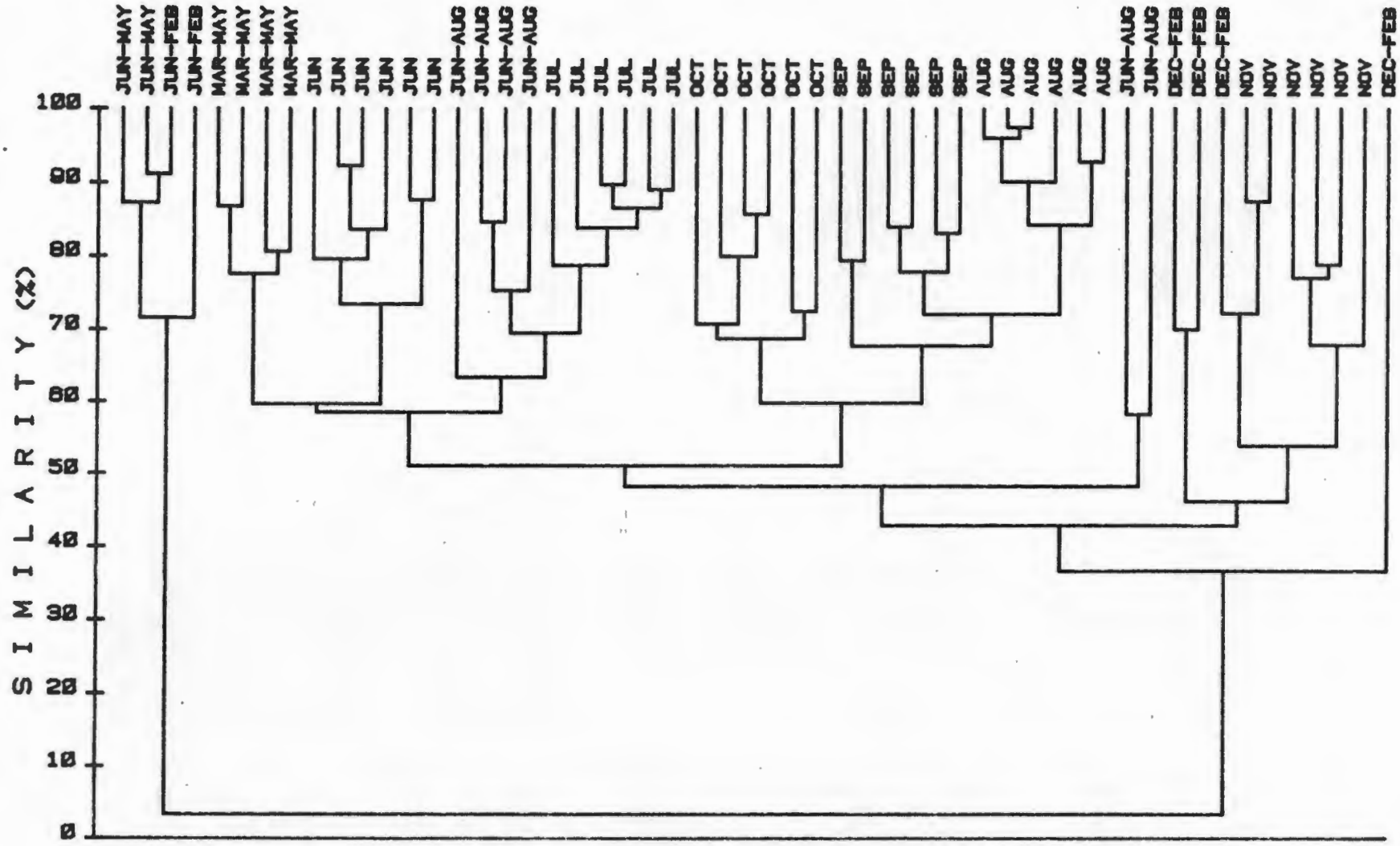


Fig 4131k : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Silicon rubber plates were exposed at Site 2 (10m) during different months for various periods of time.

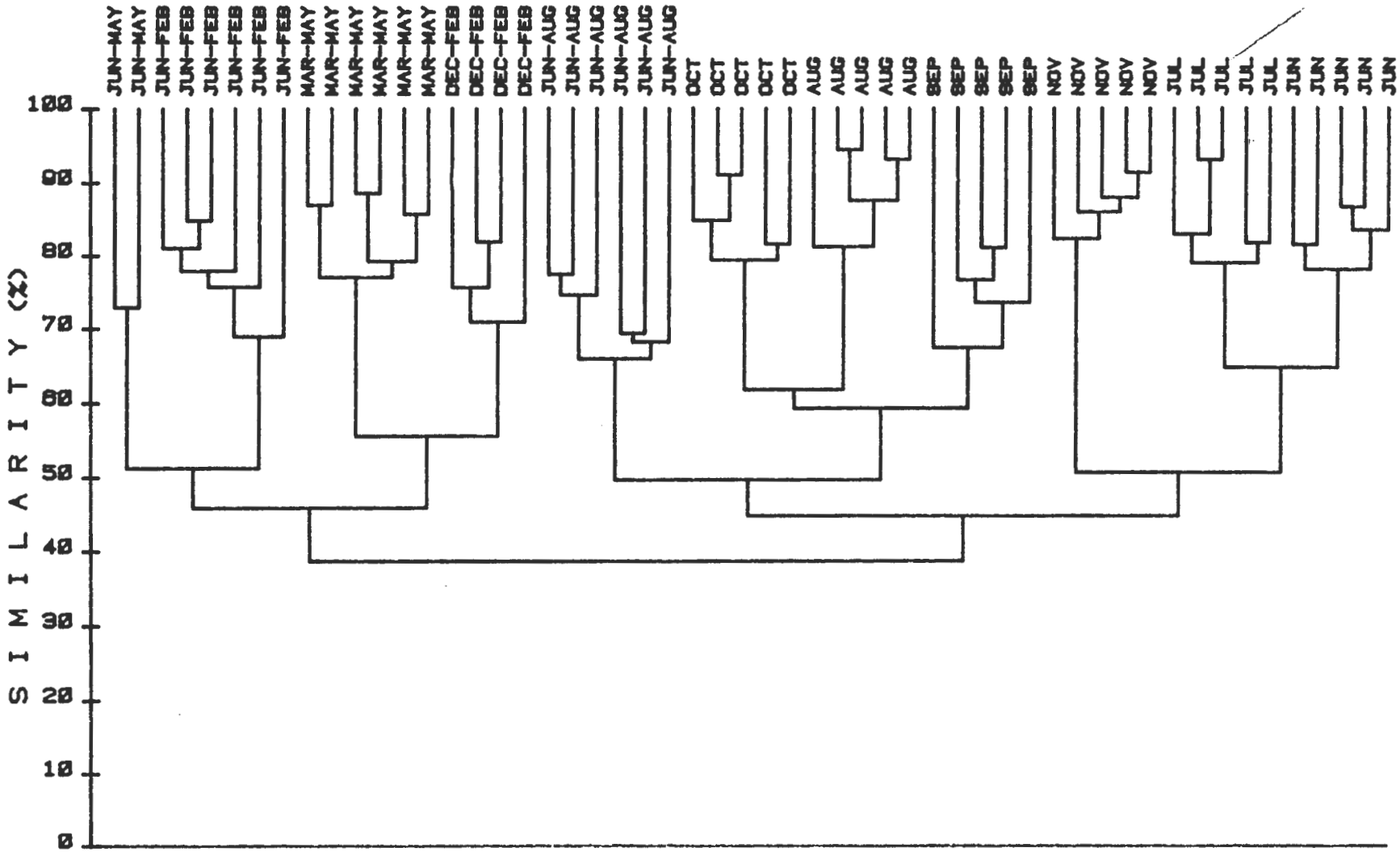


Fig 41311 : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Fibre glass plates were exposed at Site 2 (10m) during different months for various periods of time.

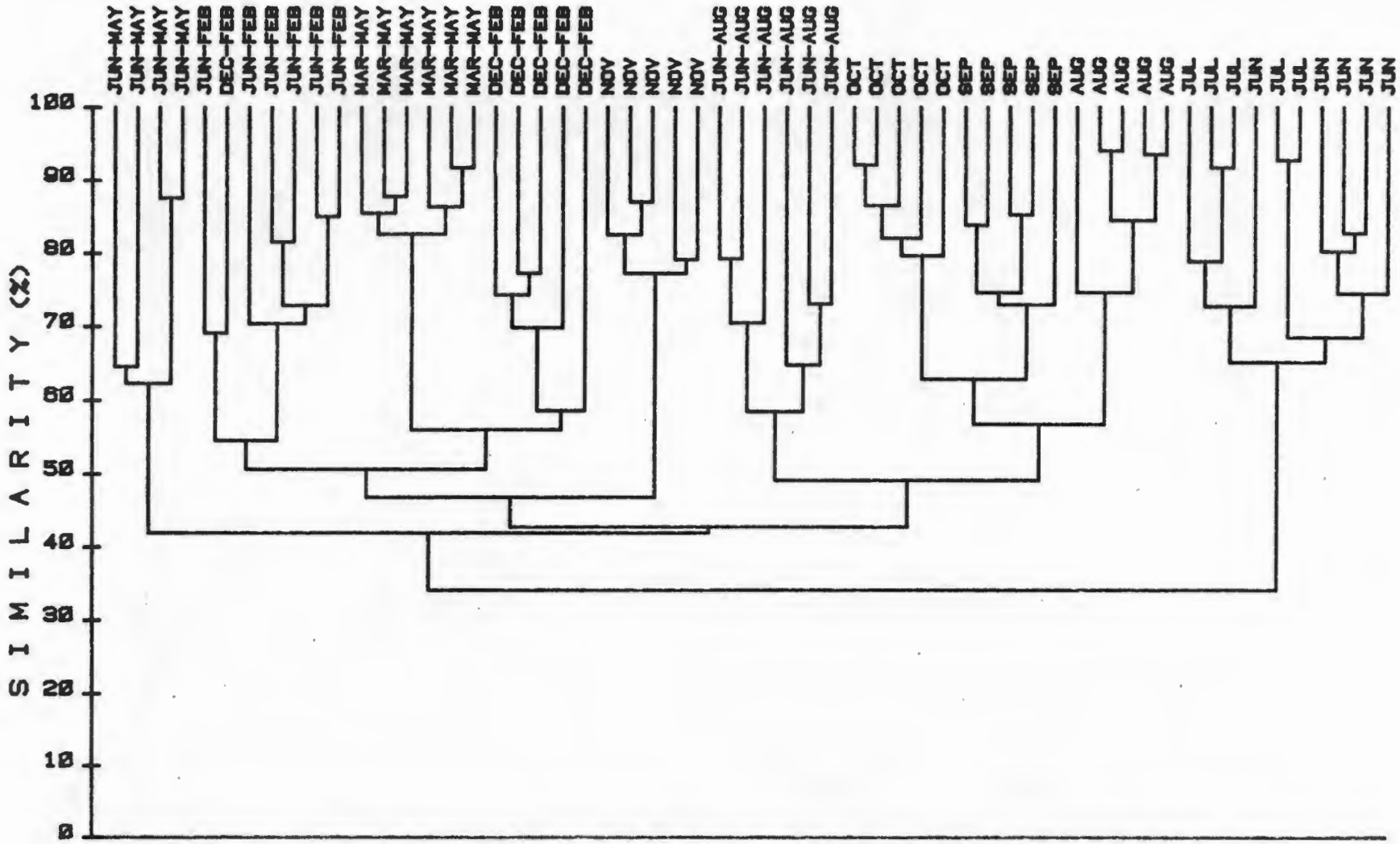


Fig 4131m : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. P.V.C. plates were exposed at Site 2 (10m) during different months for various periods of time.

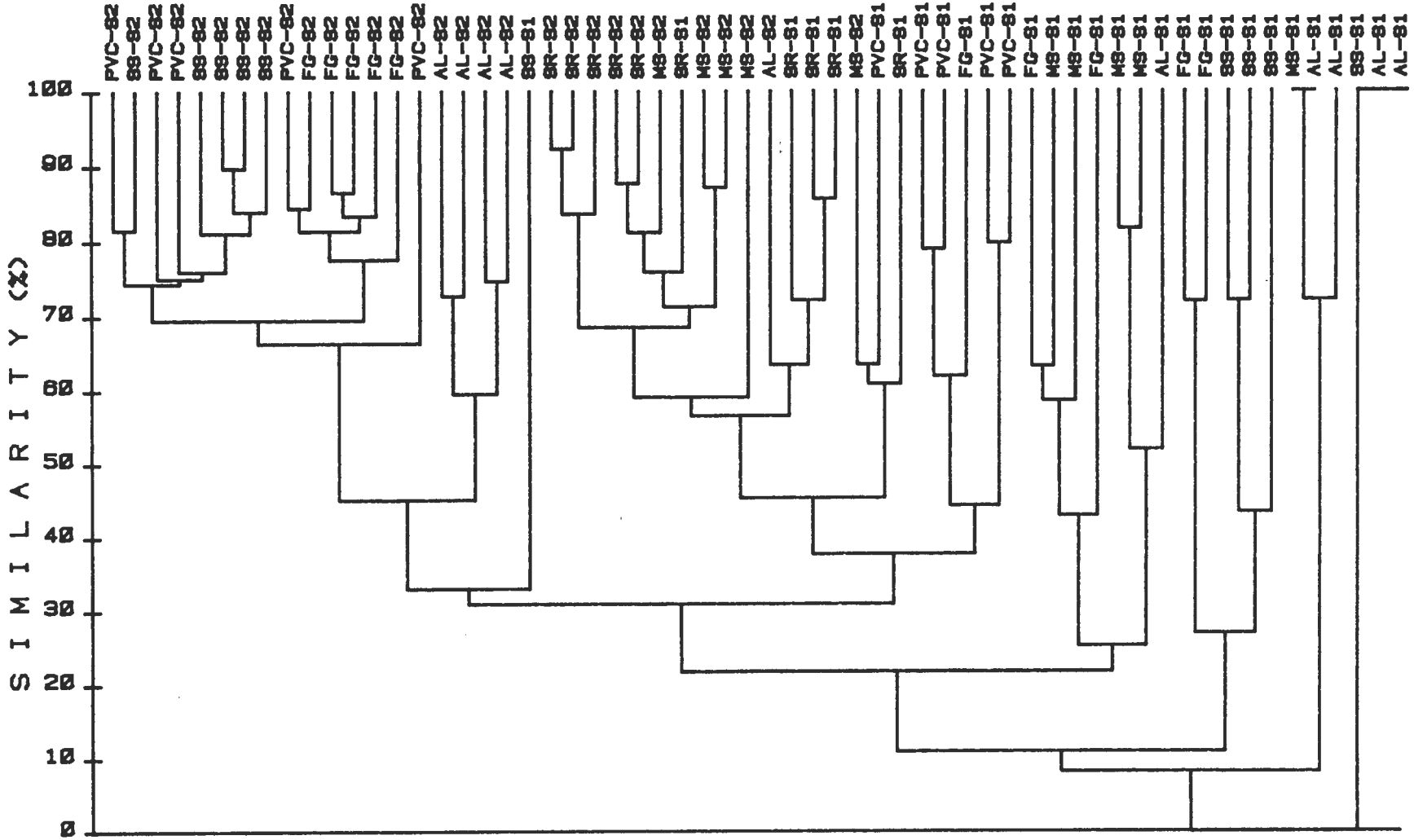


Fig 4132a : Dendrogram showing similarity counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) during June 1979.

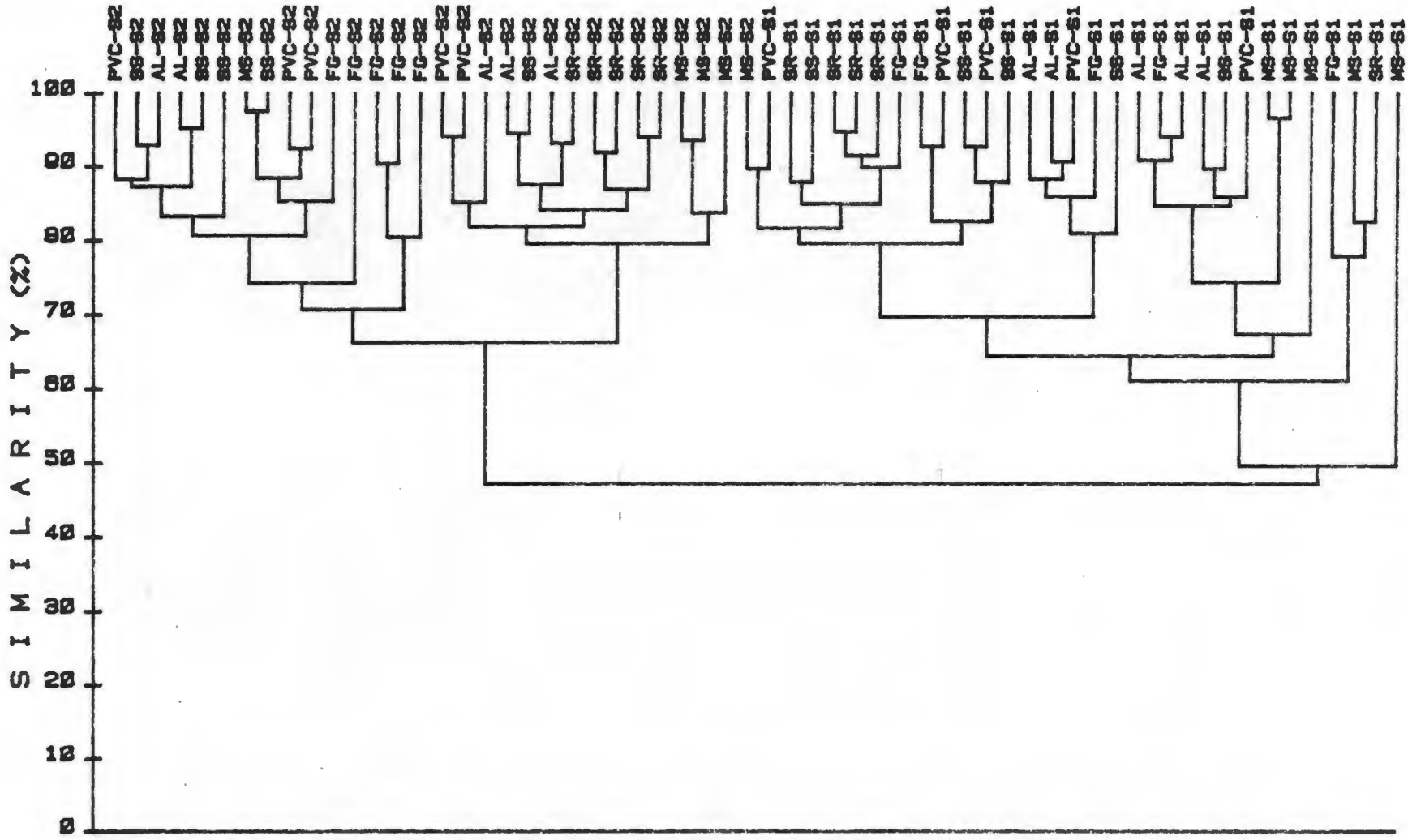


Fig 4132b : Dendrogram showing similarity counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) during July 1979.

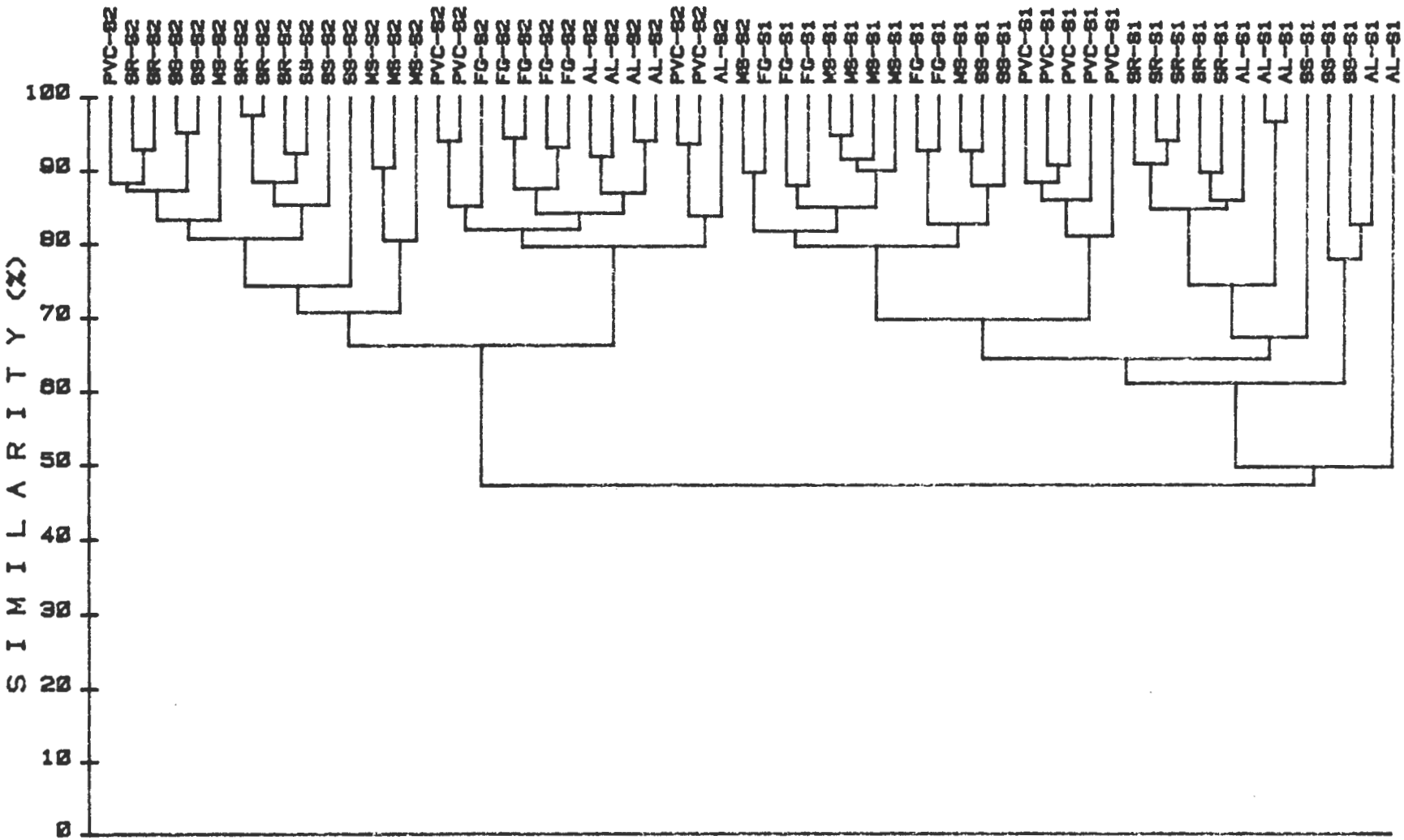


Fig 4132c : Dendrogram showing similarity counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) during August 1979.

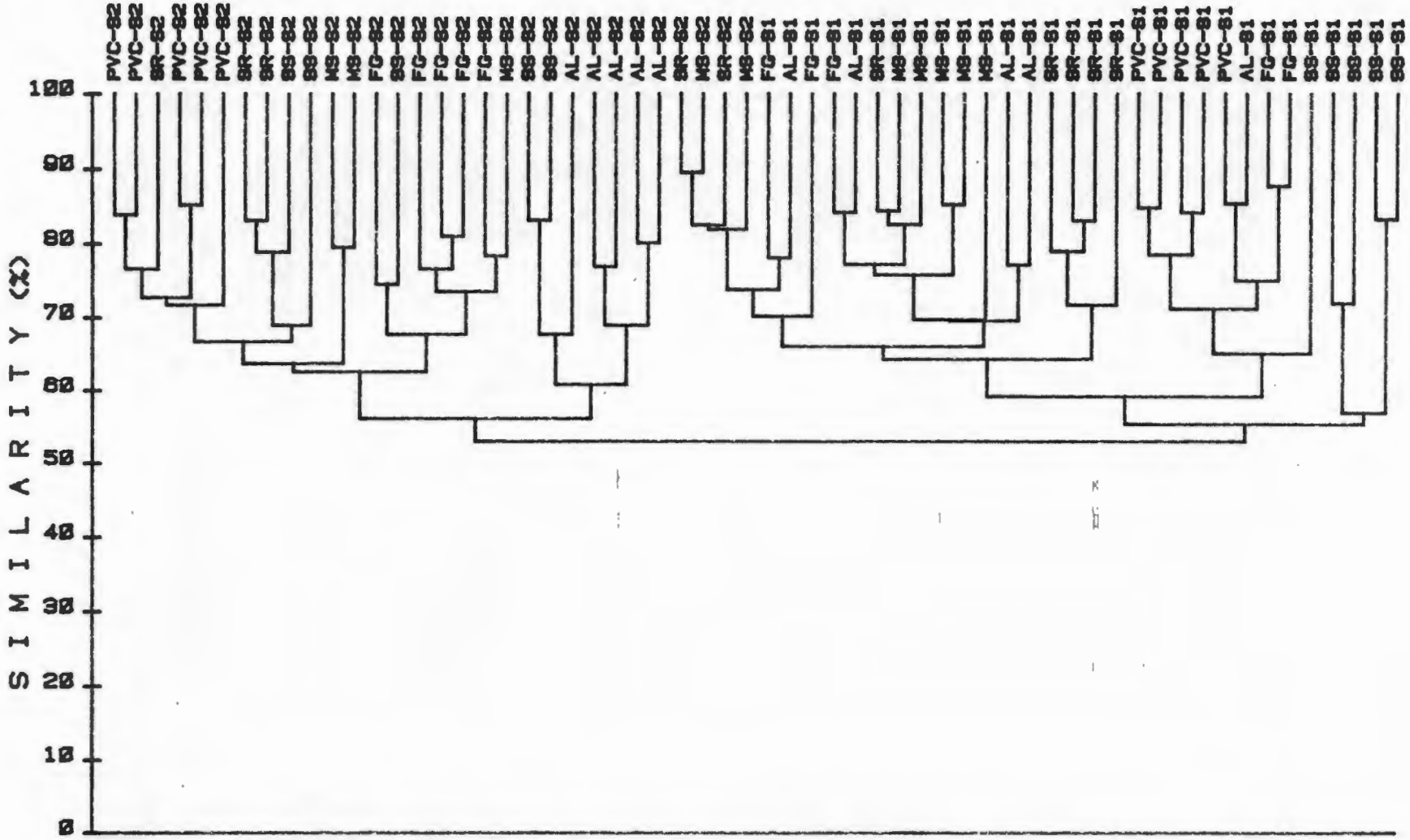


Fig 4132d : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) during September 1979.

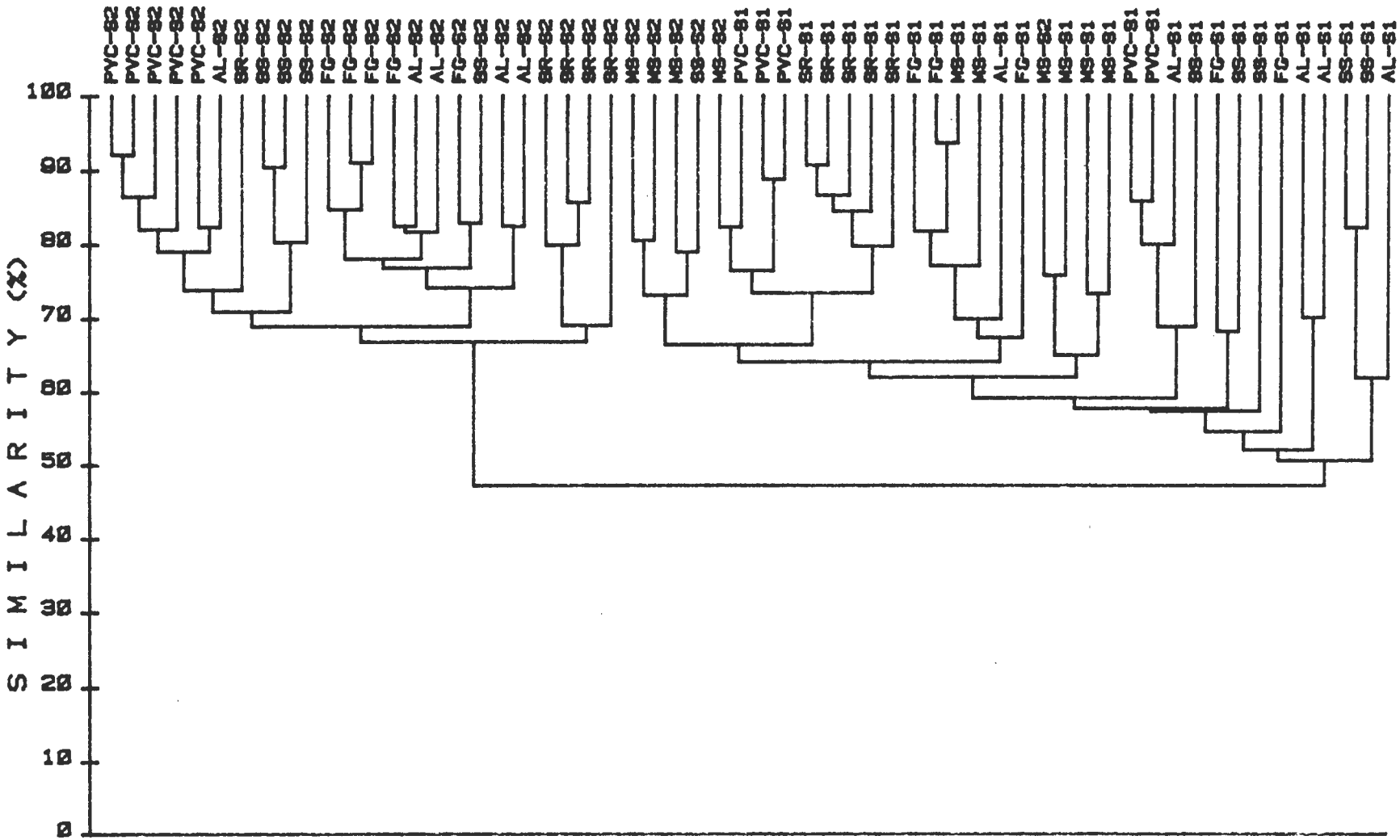


Fig 4132e : Dendrogram showing similarity counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) during October 1979.

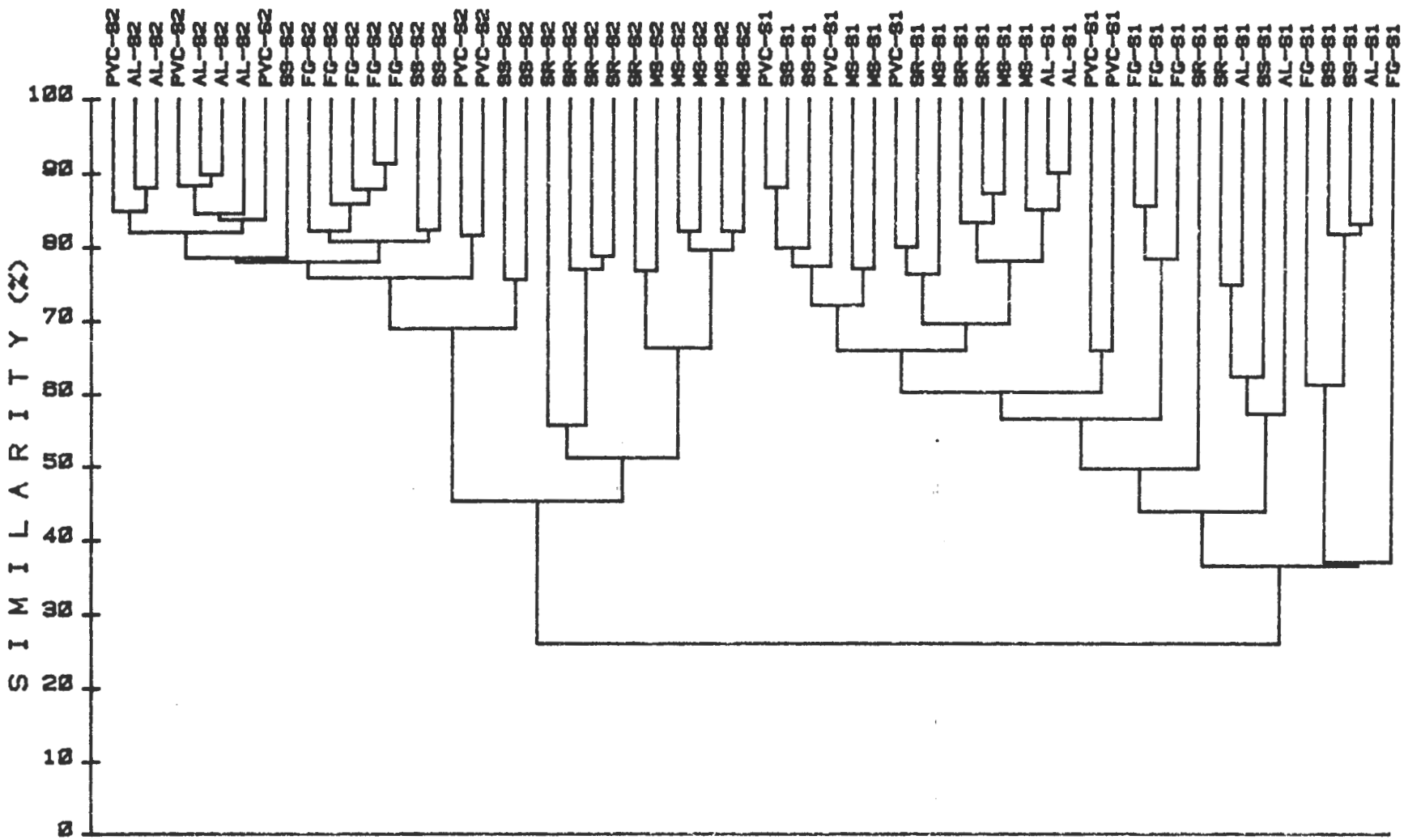


Fig 4132f : Dendrogram showing similarity counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) during November 1979.

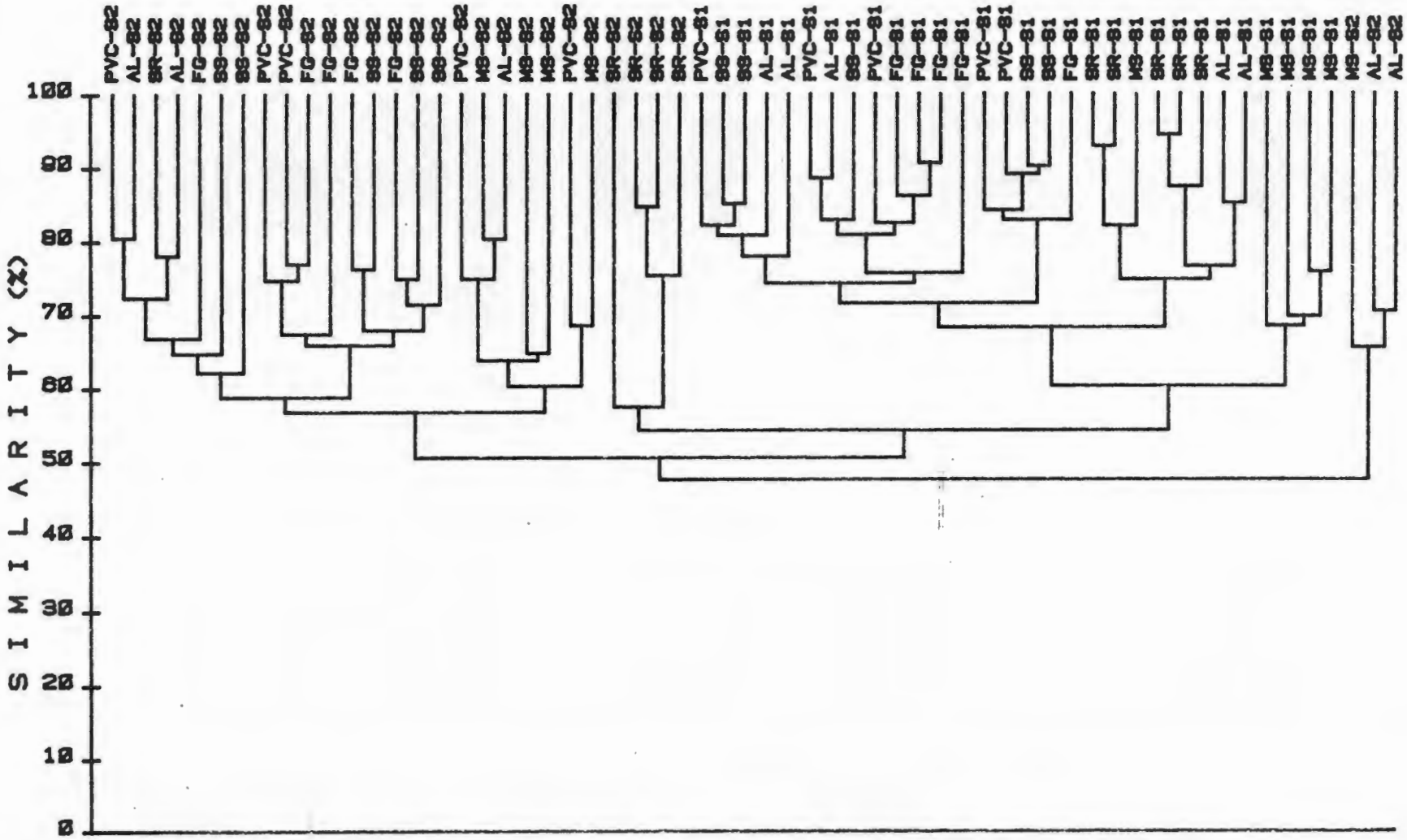


Fig 4132g : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) between June and August 1979.

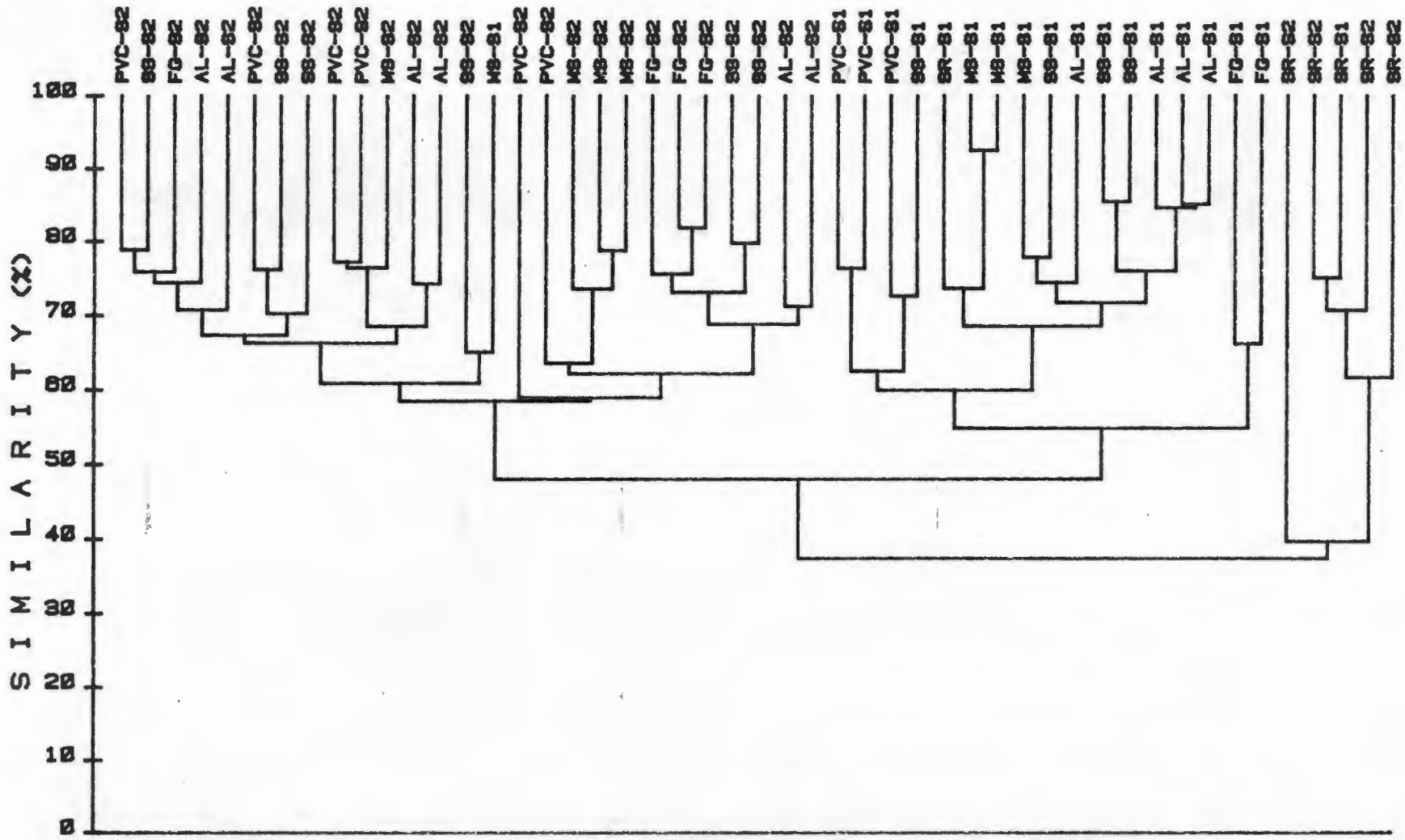


Fig 4132h : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) between December 1979 and February 1980.

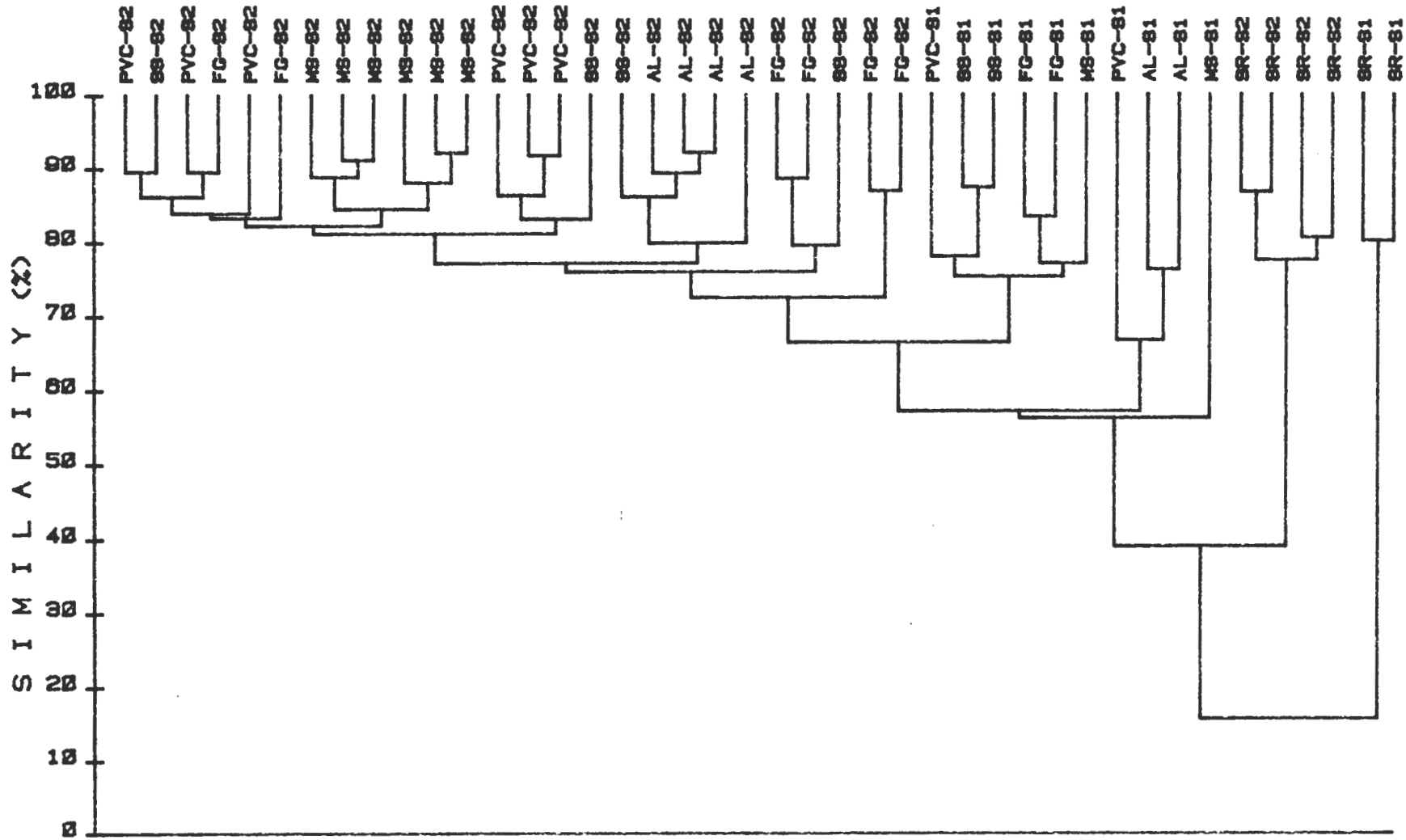


Fig 4132i : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) between March and May 1980.

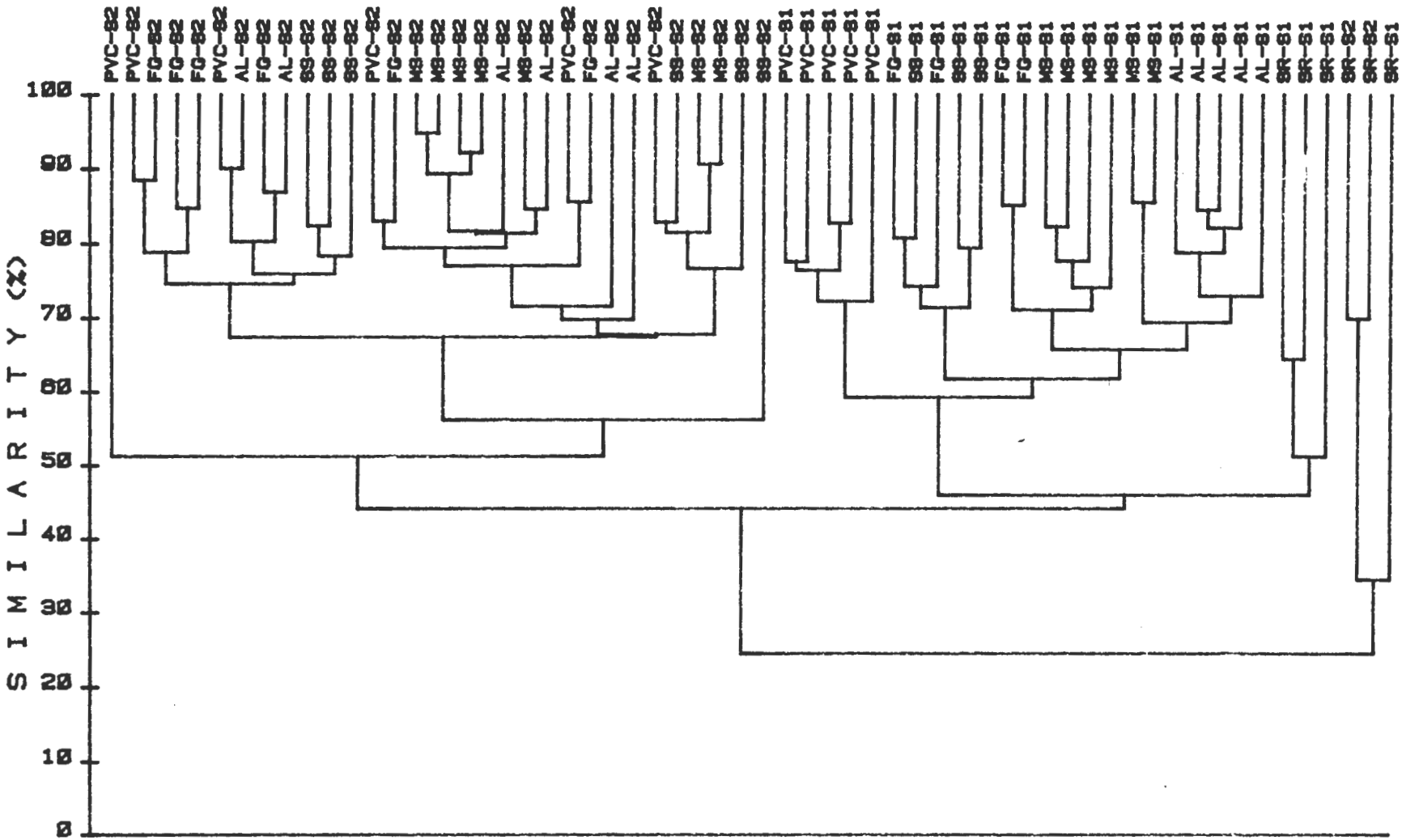


Fig 4132k : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) between June 1979 and February 1980.

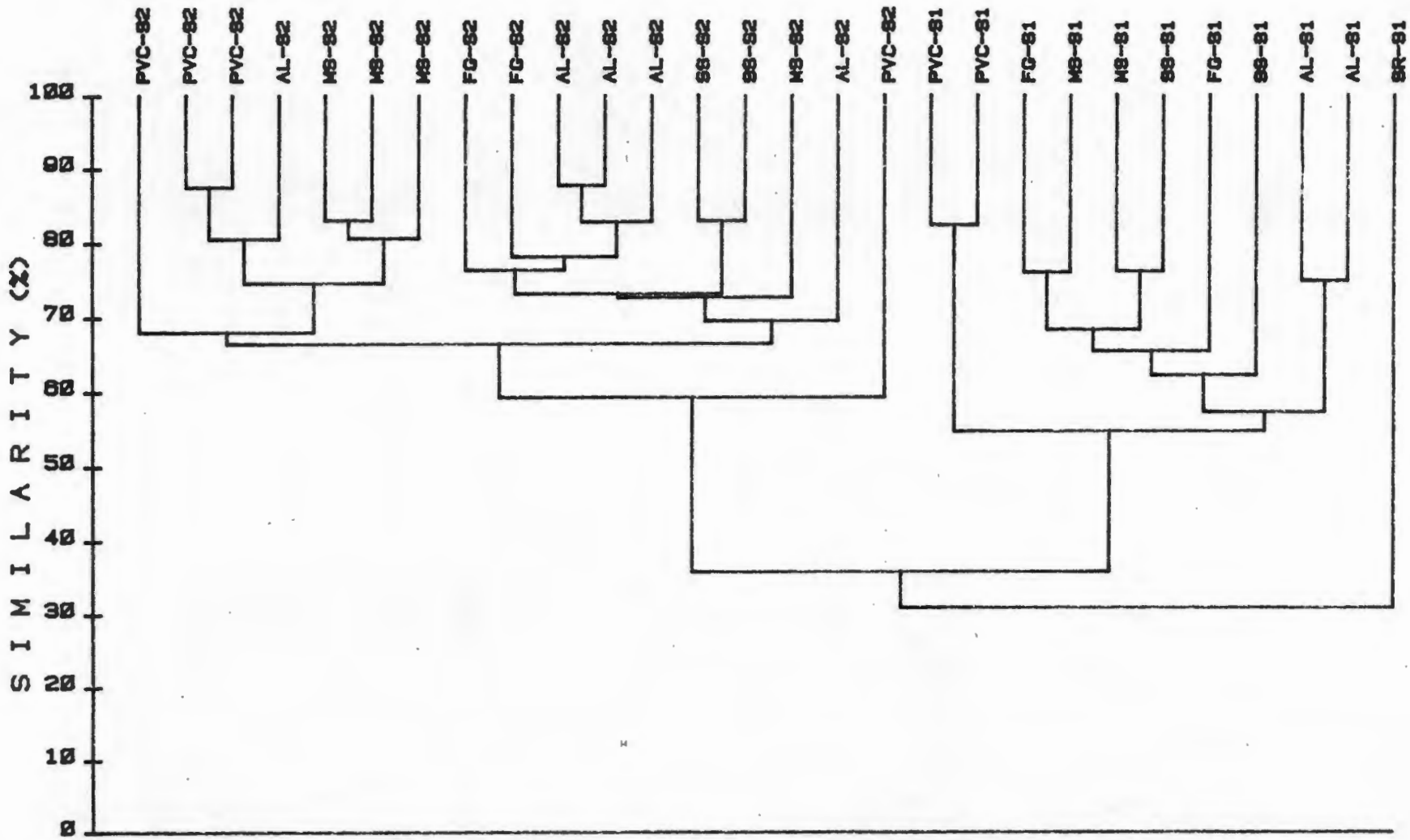


Fig 41321 : Dendrogram showing similarity of counts of sessile organisms as given by the Czekanowski coefficient. Plates of various materials (AL, SS, MS, SR, FG & PVC) were exposed at Site 1 (S1) and Site 2 (S2) between June 1979 and May 1980.

4.1.4 Correspondence Analysis

A new statistical technique, which to the author's knowledge has not been applied to biological data, was applied to the data from this study to test its applicability.

In the correspondence model, the rows (subjects) and columns (objects) of the data matrix are presumed to be vectors in two seperate multidimensional matrices. The analysis consists of finding the respective subspaces (of lower dimension), which optimally contain the two clouds of points. This enables the user to find contrasts between subjects and objects, which are given in rank order along the principal axes.

The simultaneous display of subjects and objects on the same graph, enables the interpretation of differences between subjects (e.g. substratum materials), the relative participation of each object (e.g. species) in the dispersion and the correspondence between subjects and objects (Greenacre, 1978)

Correspondence analysis was applied in the present study to show which organisms are characteristic for the samples in comparison. The computer program used was developed by N.Tabet in France and modified by Greenacre (1978). The Eigenvalues, or moments of inertia, give an indication of the degree of participation of points along the vectors. Thus, on figure 4.1.4.1.a 10m, the dispersion of points along the vertical direction represents 48 percent of the actual dispersion and the dispersion along the horizontal direction represents a further 29 percent. This means that analysis of results along the first axis is of greater importance than along the second axis (in this case horizontal). Altogether, figure 4.1.4.1a 10 m explains 77% of the dispersion, while figure 4.1.4.1.a 20m explains 84%.

In general, the results agree with findings by other techniques. After all exposure periods, SR was unlike the other materials, while MS appeared to be different for the one and three month periods. Compound ascidia usually contrasted strongly with other species, although no particular material was drawn towards its point in space i.e. compund ascidia did not appear to be characteristic to any particular material.

It is noteworthy that algae, encrusting bryozoa, filamentous bryozoa, hydrozoa and tubiculous amphipods would sometimes be in contrast to a relatively close group of points representing barnacles, mussels, polychaetes and simple ascidians after various exposure periods. These results may indicate that proflieration of colonial or soft-bodied foulers, especially compound ascidia, tended to exclude other organisms.

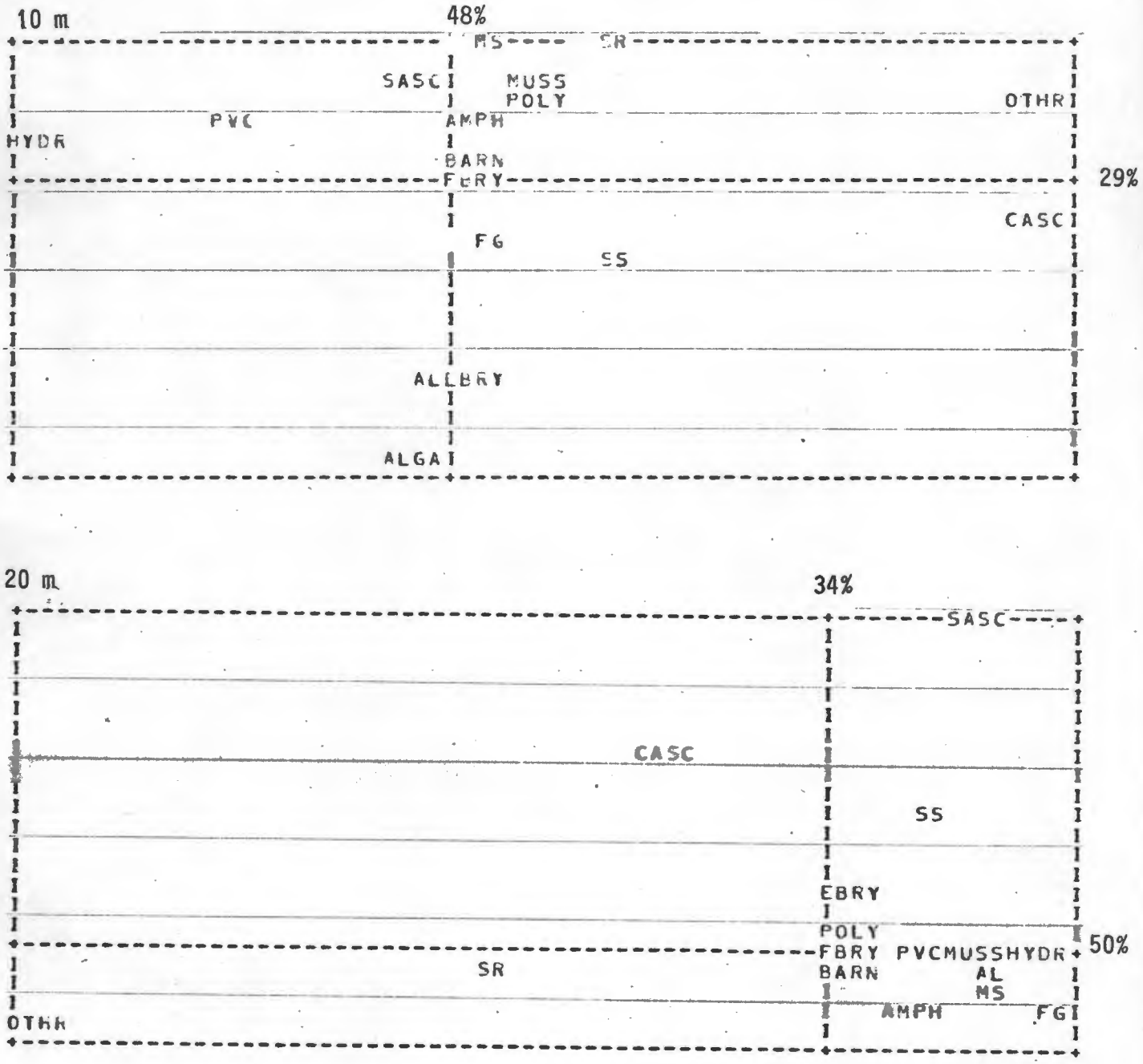


Fig 4.1.4.1a Dispersion of materials, and organisms along the principal axes. Panels were exposed for 1 month at 10m and 20m. Percentage figures are derived from Eigen values and indicate the degree of participation of points along each vector.

Subjects: AL, SS, MS, SR, FG & PVC (six materials)

Objects: HYDR (hydrozoa), POLY (polychaetes), BARN (barnacles), AHPH (amphip), EBRY (encrusting bryozoa), FBRY (filamentous bryozoa), MUSS (mussels), CASC (compound ascidians), SASC (simple ascidians), ALGA (algae), OTHR (other).

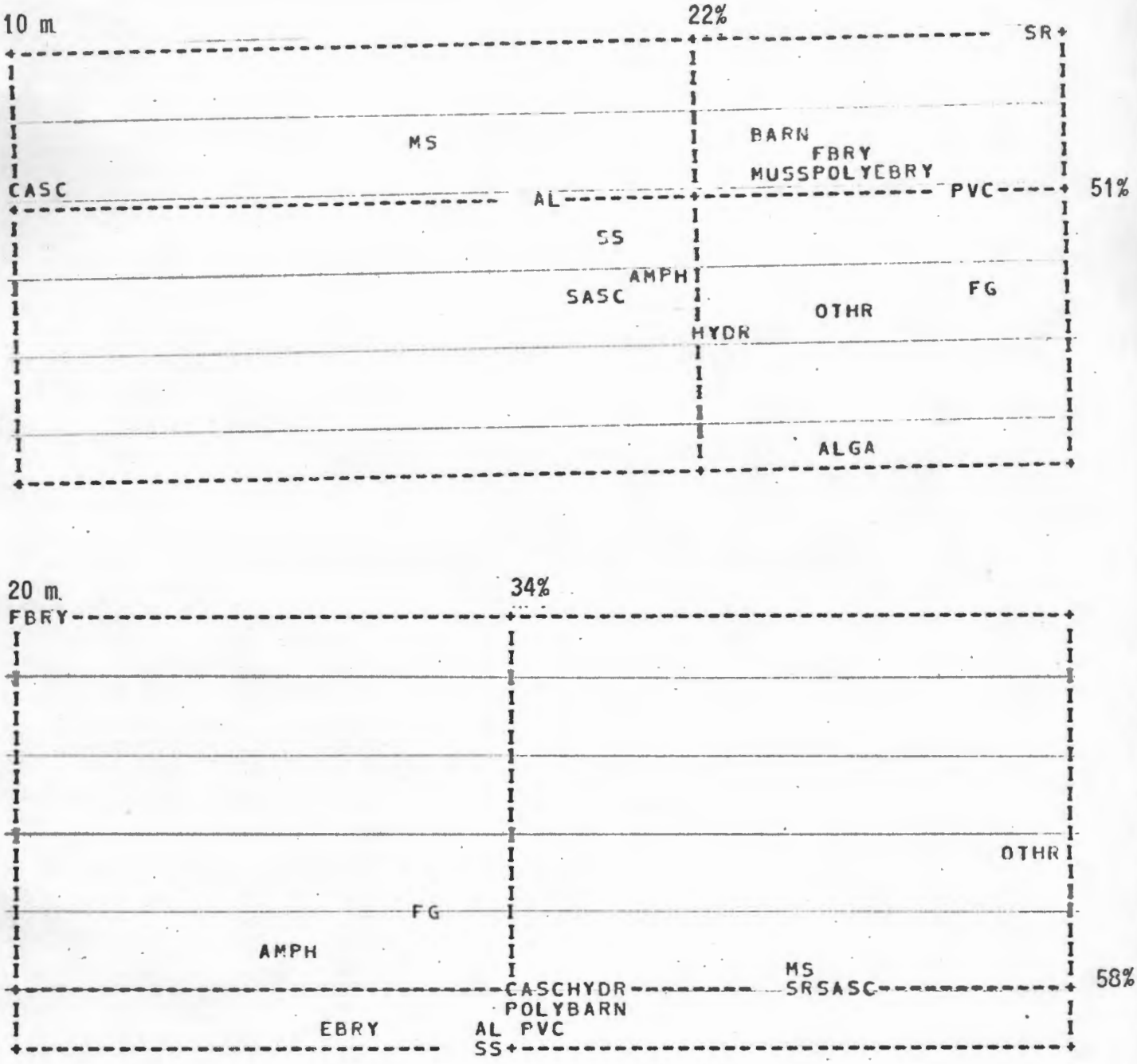


Fig. 4.1.4.1b Dispersion of materials and organisms after 3 months' exposure.

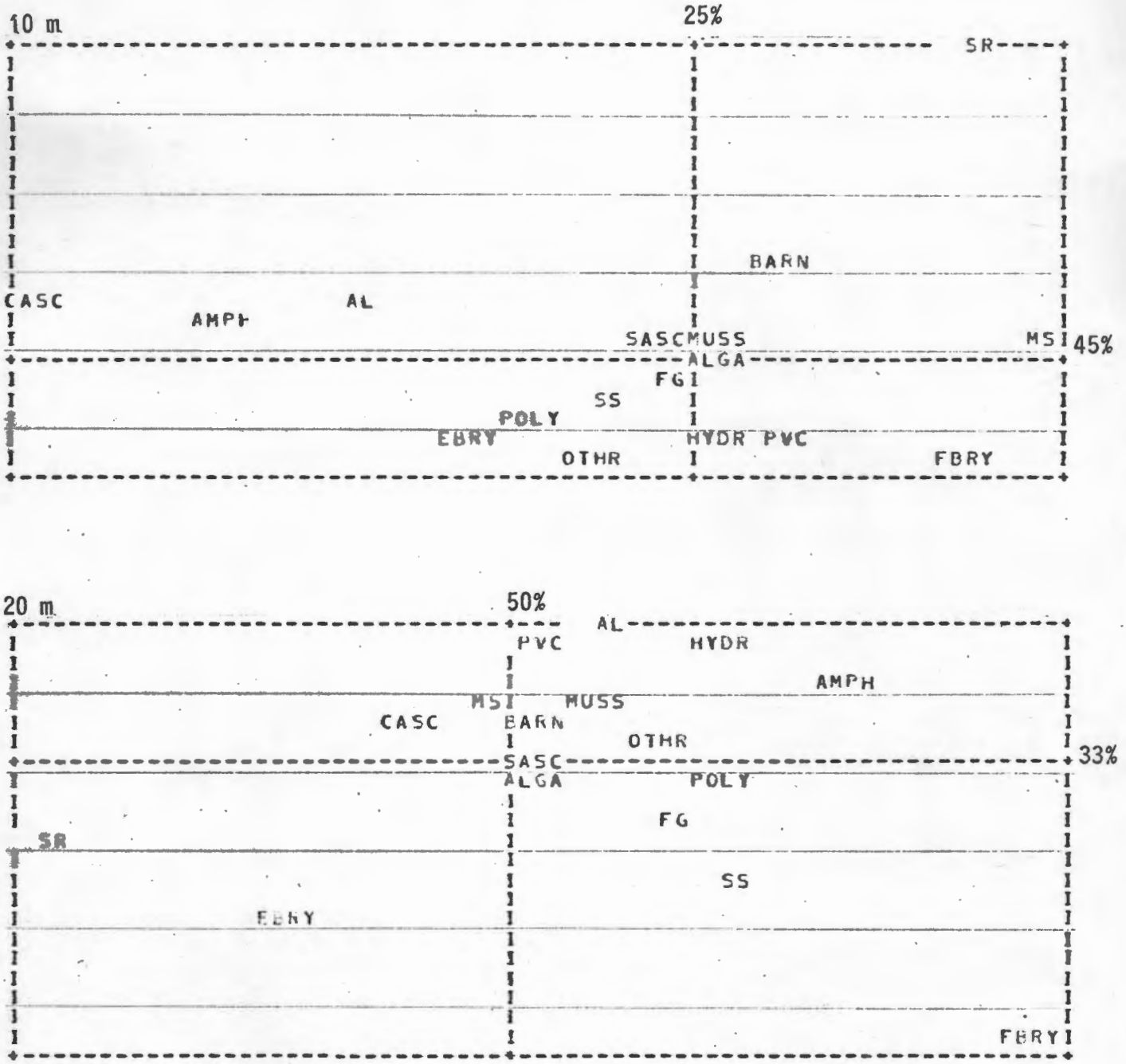


Fig. 4.1.4.1c Dispersion of materials and organisms after 9 months' exposure.

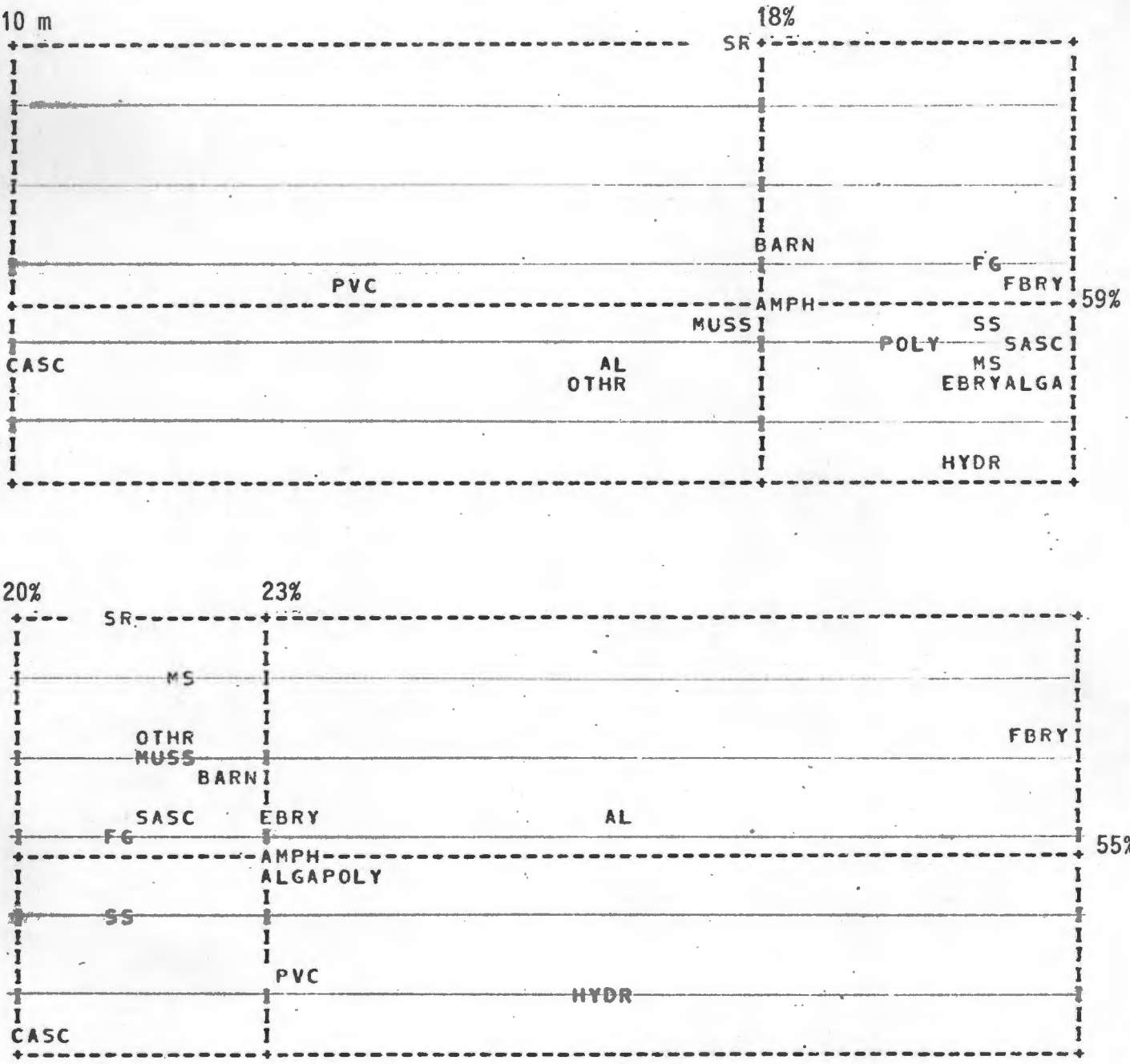


Fig.4.1.4.1d Dispersion of materials and organisms after 12 months' exposure.

4.2. Recommendations for further study

4.2.1. A survey on the specific effects of biofouling on local maritime and naval activities should be carried out in colloboration with the navy. A report on cost-effective aspects of fouling and anti-fouling burdends should ensure motivation for naval support to carry out further fouling and anti-fouling research.

4.2.2. By monitoring the fouling on a small scale (perhaps expose a few platese every 3 months), the annual trends of conditions can be determined. That would also serve as monitor of environmental quality in the harbour region.

4.2.3. By manipulating the fouling by the primary film (e.g. elimination, using antibiotics, or proliferation, using enrichments), attempt to evaluate its effects on macrofoulers and the potential of using such techniques for antifouling.

4.2.4. Carry out biological experiments, in the laboratory or field, to determine the nature of interaction between:

a) primary film to hydrozoa
b) hydrozoa to barnacles
c) algae and colonial diatoms to barnacles
d) serpulids to mussels
e) colonial ascidians (when not predator - limited) to mussels, barnacles and simple ascidians.

The former organisms are less severe (bulky) foulers. Selective disruption of certain community components may encourage the growth of other less severe components and prevent recolonization by the latter.

4.2.5. Determine how the foul-resistant properties of silicon rubber can be used in wider applications. It may be necessary to combine this material with more durable materials. This should be evaluated, chemically. Define the physical surface properties more precisely so that an antiadhesive can be produced.

D. PART II: EFFECTS OF PRIMARY FILM FORMATION ON THE SETTLEMENT OF MACROFOULING ORGANISMS.

1. PROJECT OUTLINE

1.1. INTRODUCTION

As soon as a non-reactive solid is immersed in the sea, inorganic, organic and biotic matter accumulates on its surface. This process, collectively known as fouling, is primarily a result of physical and chemical properties of the solid-liquid interface, but subsequently involves biological events and interactions. It is thought that a sequence of cause-effect procedures results in the increasing diversity of accumulated matter (see below).

The early stages of fouling were first intensively studied during the 1930's and 1940's at the Woods Hole Oceanographic Institute, Massachusetts, (Renn & Johnston, 1940; Ketchum & Davidson, 1941; Phelps, 1941; Waksman & Weiss, 1941; Weiss & Ketchum, 1941; U.S.Naval Institute, 1952) and by Zobell and his colleagues at the Scripps Institute of Oceanography, California (Zobell & Allen, 1935; Zobell, 1939, 1943). They identified the various components in the fouling process and were instrumental in refining toxic antifouling paints.

During the late 1940's upto the early 1970's, some evidence was found that adsorbed organic molecules, bacteria and a mucoid slime layer and other microbes, collectively known as primary film, could play an important role in fouling. It was recognized that the film somehow appeared to play an integral part in colonization processes of invertebrates (Miller et al, 1948; Wood, 1950; Knight-Jones, 1951; Daniel, 1955; Skerman, 1956; Crisp & Ryland, 1961; Meadows & Williams, 1963; Horbund & Freiberger, 1970; Corpe, 1970). However, the main emphasis during this period was on the physico-chemical factors and the nature of macrofouling

(see Part I).

Recently the emphasis has shifted to a biological approach to research in antifouling techniques that could provide more efficient, species-specific and permanent methods of control (O'Neill & Wilcox, 1971; Marshall et al, 1971; Liberatore et al, 1972; Mitchell & Young, 1972). The impetus of this approach grew notably with the advent of electron microscopy (Jones et al, 1969; Fletcher & Floodgate, 1973; Mitchell et al, 1977; Cundell & Mitchell, 1977; Paul et al, 1977; Zachary et al, 1978; de Chalain, 1979; Marszalek et al, 1979; Dempsey, 1981). Biochemical and biophysical aspects of interfaces and their influence on organisms are, as yet, poorly understood. In the last decade, a number of workers have investigated various characteristics of interfaces, relevant to research in fouling (Baier, 1970; Yongue & Cairns, 1971; Neihof & Loeb, 1972; Müller, 1973; Loeb & Neihof, 1974; Dexter et al, 1975; Eiben, 1976; Müller et al, 1976; Neumann, 1979; Fletcher & Loeb, 1979; de Chalain, 1979; Marshall, 1980).

Some of the early fouling events and interactions that have been identified can be illustrated using a hypothetical example, as follows. Upon immersing an inert material into the sea, dissolved molecules are attracted to or repelled from the substratum surface by electrostatic forces and surface energy (degree of wettability). Some molecules are thus adsorbed onto the substratum (Neihof & Loeb, 1972). Adsorbed organics are important in many biological adhesion systems (Baier, 1970), because they change surface characteristics, such as hydrophobicity (Dexter et al, 1975; de Chalain, 1979), electronegativity (Loeb & Neihof, 1974) and chemical nature. It has been shown that compounds, such as carbohydrates, calcium or magnesium ions (Marshall, 1971;

Müller & Buchal, 1973) and proteins (Crisp & Meadows, 1962; Meadows, 1971; Cook, Tosteson, Marshall & Baier, unpublished, in Dempsey, 1981) are instrumental in the binding of organisms to the surface.

Bacteria are attracted to the surface by electrostatic and hydrophobic interactions (Fletcher & Loeb, 1979) and are loosely held by the balance of van der Waal's attraction and ionic repulsion (Marshall et al, 1971). The first bacteria to appear, the primary periphytes, are rod-shaped or coccoid chemoorganotrophic gram-negative pseudomonads that account for most of attached marine bacteria (Corpe, 1970; Sieburth, 1979). These produce an acidic mucopolysaccharide of fibrous reticular nature, which irreversibly binds them to the surface (Fletcher & Floodgate, 1973). The heterotrophic secondary periphytes that appear later come in a variety of stalked, budding and filamentous shapes that usually attach by a polar end (Meadows, 1971; Marshall & Cruickshank, 1973; Marshall, 1980; Dempsey, 1981). As bacteria proliferate, they produce so much mucilage material that a thickening layer soon covers much of the surface and imbeds many of the bacteria (Jones et al, 1969; de Chalain, 1979).

The appearance of diatoms, fungus and cyanophytes (blue-green algae) can occur at any stage before (Wood, 1950; Skerman, 1956; O'Neill & Wilcox, 1971; Paul et al, 1977) or after the proliferation of bacteria (the usual case; O'Neill & Wilcox, 1971; de Chalain, 1979). This initial layer of bacteria, fungi and non-motile small diatoms is in intimate contact with the substratum, or its cover of adsorbed organics, and is tightly

enmeshed in a mucilage layer of bacterial and possibly diatomaceous origin (de Chalain, 1979), transforming the surface into a micro-habitat (Marszalek et al, 1979).

This first tier of microfouling, as Marszalek et al (1979) termed it, usually precedes the development of a second tier, which consists of large motile diatoms, microalgae, filamentous fungi, debris, flagellates and protozoa. The proliferation of these microbes completes the formation of the primary film to a dynamic climax after about one month (de Chalain, 1979). The situation at this stage has been aptly summarized by Paul et al (1977), when they stated that the primary film structurally modifies surfaces into "ecologically more complex systems capable of supporting a diverse array of species".

Sedentary invertebrates may settle at any time after substratum exposure, but are usually only present in significant numbers after primary film formation. The latter phenonemon has led investigators to believe that the primary film could enhance colonization by invertebrates (Zobell & Allen, 1935; Miller et al, 1948; Knight-Jones, 1951; Daniel, 1955; Crisp & Ryland, 1961; Meadows & Williams, 1963; Horbund & Freiberger, 1970; Mitchell & Young, 1972; Liberatore et al, 1972; Mitchell et al, 1977; Cundell & Mitchell, 1977). Little is known about how the primary film could be of importance to settling larvae, but since it became clear that surface characteristics appeared to influence larvae in their pre-attachment exploratory phase, it was conceivable that a coat of microfouling on the substratum should affect the larvae (Crisp, 1976). Apart from altering the surface chemistry, wettability, colour and texture, a number of other interaction mechanisms have been proposed:

a) The mucilage network could facilitate adhesion by trapping or binding appendages or acting as a holdfast (Zobell, 1939; Knight-Jones, 1951; Dempsey, 1981).

b) Primary film components could serve as a food source to settling organisms (Zobell, 1939; O'Neill & Wilcox, 1971; Liberatore et al, 1971). However, there are reasons to believe that this is not the case. Gabbott (1976) and Lucas et al (1979) demonstrated that barnacles and bivalves do not feed during the settlement phase but live on stored lipid energy reserves. Barnacles are structurally incapable of feeding after metamorphosing to the cyprid stage until about four days after metamorphosis into adults, when they become filter-feeders (Rainbow & Walker, 1977).

c) Yongue & Cairns (1971) found that the pH in the primary film micro-habitat could differ by more than 3 units from that of surrounding water, and acted as a pH buffer. It is noteworthy that this would be important to hard-shelled animals, because calcium carbonate deposition is pH-dependant.

d) The mucilage layer can concentrate certain organic molecules that are settlement inducers e.g. proteins originating from conspecific barnacles (Barnes, 1970; Liberatore et al, 1971) or compounds originating from natural host algae of serpulids (Crisp & Williams, 1960; Williams, 1964).

e) Bacteria could be a prerequisite to metamorphosis. Müller et al (1976) and Neumann (1979) found that certain sessile live bacteria triggered metamorphosis in settling scyphozoan planulae.

A simple approach to investigate the interdependance of various components of a system is to study two identical systems, one with all components present, the other with a component removed or reduced. Another method, specifically applicable to biological communities, is to enhance a component in one system but not the other. These techniques have been used in studies of marine benthic communities and have, for instance, provided valuable information on the role of sand-inhabiting microorganisms to tube-dwelling invertebrates (Wilson, 1955; Meadows, 1964; Gray, 1966).

Since the likely importance of the primary film was first recognized by Zobell (1939), a number of investigators have used such techniques to test the role of the film to macrofouling invertebrates in laboratory experiments, but few workers have used microbial enrichments in field studies (Zobell & Allen, 1935; Wood, 1950; Daniel, 1955). Microbial reduction has only recently been considered for field studies, but the techniques still need to be refined (Mitchell et al, 1977).

In the present investigation, the intention is to test some techniques of specific microbial reduction in the field, to compare them with enrichment procedures and to study their effects on the settlement of invertebrates.

A preliminary six-week experiment was conducted to test whether fouling can be retarded on surfaces that are exposed to the sea if these are immersed in antibiotics daily for short periods of time. The feasibility of using various non-toxic inhibitors, mixed with paint, to retard specific primary film components was tested in short-term field experiments. The best of these methods were finally applied in a four-week experiment which

included inhibition and enrichment procedures in seperate tests. The various experiments are described and discussed seperately, but finally, their outcome is examined alongside concepts of community succession in the early stages of marine fouling.

Note: a) In the present context, distinction should be made between the following terms:

i) sea= the natural marine environment at subtidal levels; natural seawater

seawater = water which has been removed from the test locality for the purpose of laboratory experiments.

ii) primary film = an accumulation of adsorbed compounds, attached microorganisms, their secretions, and trapped debris on substrata.

microfouling = events involved in the development of a primary film.

macrofouling = events involving the attachment of invertebrates and algae.

iii) surface = any interface between two media.

substratum = artificial solid surface which accumulates marine fouling.

b) Abbreviations are used for the various substrata. These are explained for each respective experiment. A complete list of abbreviations is given on the back flap for purposes of cross-reference.

c) In comparing data from different tests, the substrata are sometimes directly referred to e.g."SP differed from IV" actually means that the biological fouling of the SP substratum differed from that of the IV substratum.

1.2. MATERIALS and METHODS

1.2.1. Test Sites

Experiments were carried out at the two principal dockyards in the Cape Peninsula (chart.1.2.1.): Table Bay Harbour (33°55'S; 18°25'E) and the South African Naval Harbour, Simonstown (34°11'S; 18°26'E). The work in Simonsbay was carried out during March and April, 1980, at 10m depth on the seaward side of the harbour wall. The Table Bay site was in a side-arm of the main seawater intake channel of the Salt River Power Station (ESCOM), Paarden Eiland. Experiments were carried out during February to May, 1981, at a depth of 2-3m.

1.2.2. Substratum Materials

Polyvinylchloride (PVC) surfaces were treated in various ways, either by dipping into solutions or by painting. The following chemicals and paint were used:

a) Paint: Intervinux VF series finish, a vinyl/acrylic paint (colour dark brown; supplied by International Marine Coatings).

b) Antibiotic: Streptomycin sulphate B.P.

c) Antibiotic: Sodium benzylpenicillin Crystapen

d) Benzoic Acid

e) Tannic Acid

f) Herbicide: Diuron;
3-(3,4-Dichloro-phenyl)-1,1-di-methyl urea.

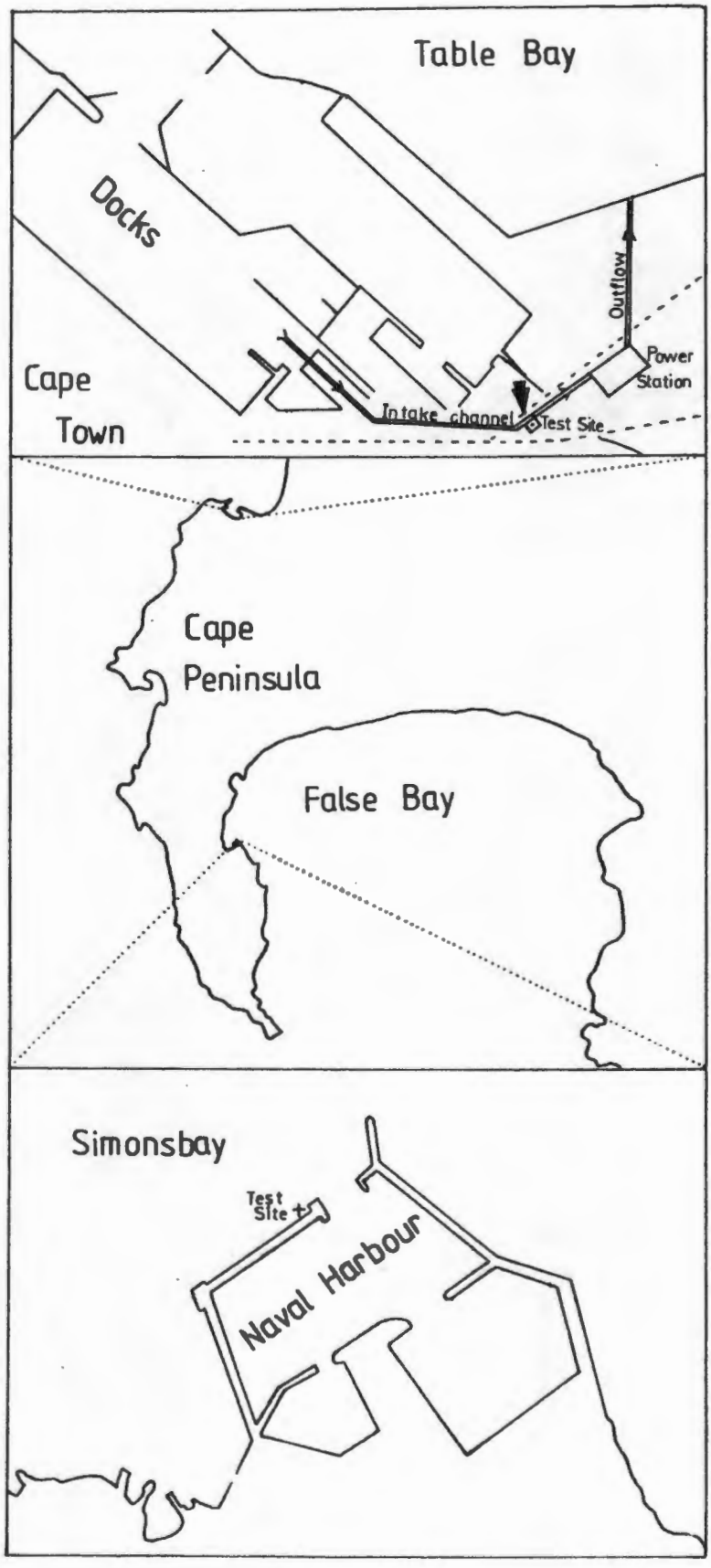


Chart 121: Location of test sites.

1.2.3. Exposure Racks

Nine frames (20x30cm) were constructed of PVC piping. Upto 16 small panels (5x5cm) and upto 4 large panels (14x26cm) could be secured to each frame. The small plates were rigidly suspended between the rungs of the frames with fishing line. Nylon nuts and bolts were used to secure the large plates to the outside edges of the frames (fig.1.2.1.).

The exposure racks were weighed down with 1-5kg metal blocks and were suspended upright in the sea with nylon rope, which was secured to overhanging structures (fig.1.2.1.). The frames were free to turn about their axis. The panels were mounted asymmetrically to act as flukes which would keep the frames uniformly orientated to water currents.

1.2.4. Experimental Procedure

The methods and materials used for the various experiments are outlined in the relevant sub-sections (section 2).

1.2.5. Scanning Electron Microscopy

Samples were prepared for viewing by a S180 Cambridge Stereoscan unit at the University of Cape Town by fixation, staining, dehydration, drying and coating. Immediately upon removing samples from the test locality, discs of 2,5cm diameter (area $5cm^2$) were cut from them and fixed in 2% gluteraldehyde in artificial seawater. After 3 hours they were stained in 0,5% Osmiun tetroxide for half an hour. Dehydration was accomplished by 15 minute exposures through an ethanol series from 30% to 100%.

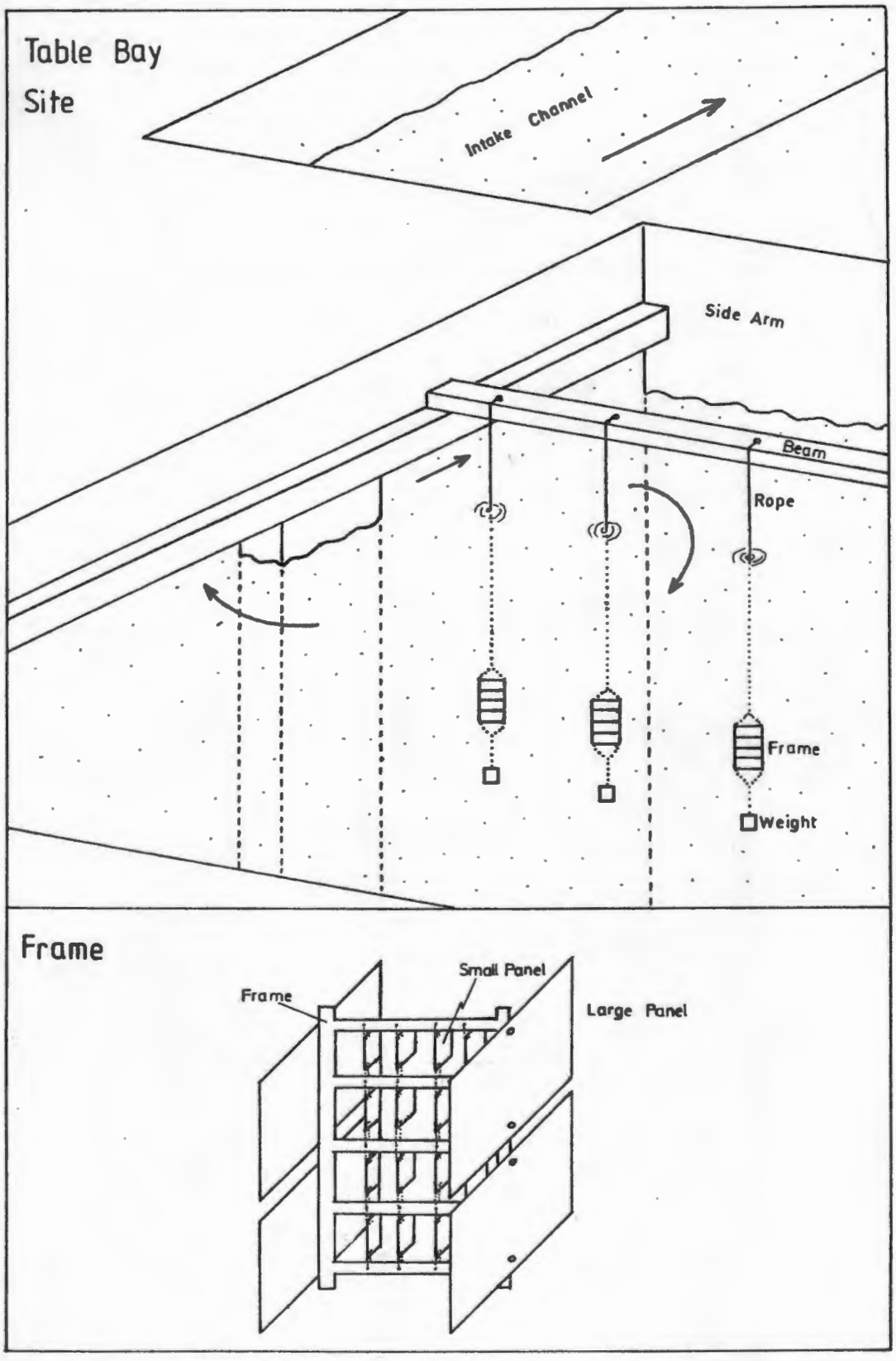


Fig 121: Diagrammatic view of the test site (top) and a full set of panels (bottom).

The samples were stored overnight in absolute alcohol and dried in a Polaron Critical Point Drier unit with liquid carbon dioxide for three hours. The dry samples were stuck to SEM stubs with silver paint and coated with gold/palladium in a Balzers Vacuum Coater. All SEM work was done at an accelerating voltage of 20kV at magnifications of upto 10000 times.

A qualitative elemental analysis of Intervinux paint was carried out with a KEVEX International Energy Dispersive X-Ray analyzer. A polished graphite disc was dipped into paint and allowed to dry. It was viewed under SEM and subjected to a standardless EDS analysis, which indicated the approximate ratio of elements heavier than carbon.

Analysis of the microcommunity was subjective, involving: a) a superficial scan of much of the area to gain an impression of the stage of development; b) the identification of the various components; c) relative abundance estimates of the components; d) counts of bacteria from a number of "representative" areas (qualitative assessment, top layer of bacteria only); e) the taking of photomicrographs. Because the quality of assessment was dependant on the thoroughness of examination, each sample was scanned for at least 30 minutes and, depending on its complexity, upto two hours. Unfortunately no workable and statistically valid method of quantification has been developed for studies of this nature to give a more objective determination.

A positive identification of microbes was usually not possible by these pictorial means, but many of the organisms resembled those illustrated elsewhere (Sieburth, 1979; but also Mitchell et al, 1977; de Chalain, 1979; Marszalek et al, 1979; Dempsey, 1981) and these were used as a guide to their possible

identity. Furthermore, some identifications were confirmed or rectified by Prof.R.N.Pienaar, Botany Department, University of Natal, Pietermaritzburg.

2. EXPERIMENTS

2.1. PRELIMINARY STUDY

2.1.1. Introduction

During March and April, 1980, an experiment was carried out in Simonsbay to evaluate the feasibility of using antibiotics to disrupt the natural microbial community and study the effect on colonization by macrofoulers.

A previously used technique of countering film development in laboratory cultures involved scraping it off (Knight-Jones, 1951; Horbund & Freiberger, 1971; Liberatore et al, 1971). Mechanical disruption is here considered unsatisfactory because frequent removal does not inhibit new growth of primary film and provides no information on the relative importance of its various components. Furthermore, it would be difficult to impose selective disruption of the primary film in open-system experiments, such as the sea, without interfering with settled macroorganisms. The use of non-toxic inhibitors of selected primary film components would be more acceptable.

Antibiotics have been used previously to inhibit microbial activity in seawater. Neumann (1979) used 0,13% streptomycin and 0,1% penicillin to prevent bacteria from proliferating in laboratory water. Schleyer (1981) found that a mixture of 0,4% penicillin, 0,2% streptomycin and 0,08% chloramphenicol reduced microbial activity in seawater to less than 50% of its normal activity. For the present experiment, the dosage of 0,2% streptomycin and 0,12% penicillin was slightly higher than that used by Neumann (1979), because test panels were exposed to

antibiotics intermittently for relatively short periods of time only.

2.1.2. Materials & Methods

For the present experiment, nine frames, each containing 16 small plates (25cm^2), were used. After mounting, the plates were cleaned by washing with Teepol, rinsing, drying and wiping with cotton dipped in 70% ethanol. Three frames (AB) were immersed for one hour in a bucket containing 20 litres filtered seawater (30um mesh), to which 2,4g sodium benzylpenicillin (0,12%) and 4g streptomycin sulphate (0,2%) antibiotics had been added. All nine frames were then submerged at the experimental site. At daily intervals, the three AB frames were reimmersed in the bucket of antibiotic seawater for one hour before being returned to the sea. The antibiotic water, which was renewed weekly, was kept at ambient sea temperature and was aerated before use by vigorous stirring. To test the possible effect of daily manipulation on the development of the fouling community, another three frames were simultaneously immersed for one hour in a bucket containing fresh filtered seawater. The remaining three frames were left undisturbed, except for occasions of plate removal.

Using an ocular microscope, the settled and metamorphosed macroorganisms were identified and counted on six plates, which were removed at random from each of the three treatments after one day, 2,4,7,14,28 and 42 days. The primary film was not analyzed, but its abundance was crudely estimated by visual examination. The current speed and water temperature were measured at 15 minute intervals with an Anderaa current meter deployed at the test site.

2.1.3. Results & Discussion

The test site, which had already been used in previous studies (de Chalain, 1979; Part I, this report), was located on the seaward side partly under hollow caissons of the Simonstown harbour wall. A well-developed macrofouling community covered the nearby concrete walls (5-10m from experimental setup). In a superficial examination it appeared that the subtidal community was mixed, the conspicuous sedentary organisms being large Balanus maxillaris and Pyura, but also sea anemones (Bunudosoma and Anthothoe), ascidians (Ciona intestinalis), mussels (Choromytilus meridionales) and hydrozoa (Tubularia), inter alia. At the experimental depth of 10m, the water was usually calm (<0,1m/sec) and the temperature range small (14,6-16,8°C).

Aspects of primary film development at that site had been examined about a year earlier by de Chalain (1979). Because no detailed analysis of the primary film was conducted in the present investigation, it would be appropriate to examine some of de Chalain's findings here. Working with a number of different substratum materials, de Chalain found that microfouling on passive (inert) metals and plastics, including PVC, was convergent and fairly similar after a few days of exposure. Chlorophyll levels indicated that small plate size (1,2cm^2) appeared to favour the proliferation of diatoms or microalgae, compared to larger plates (5,9cm^2 and 25cm^2).

By scanning electon microscopy, de Chalain saw numerous rod-shaped and coccoid bacteria after a day of plate exposure. After two days, a fine network of mucoid threads was spreading, binding numerous rod bacteria. The first few diatoms had attached by day 2 and had grown numerous by day 7, when extensive

bacteria-mucoid patches were noted. de Chalain found that flagellates and algal spores were fairly common on day 14 and bacteria and diatoms abundant. After 3 weeks, these primary film components had increased further and a week later comprised a thickening mucoid layer, many types of diatoms, organic debris, cyanophytes (blue-green algae), flagellates and some other protozoa, but, rather surprisingly, no fungi were reported.

In the present study, scanning electron microscopy showed that, although bacteria were common on SW after one day, they were not present on AB (Cook, pers.comm.). After 7 days a thin greenish film could be clearly seen on SW and CON by ocular microscope, but on AB only after 14 days. Fine filaments, that appeared to be fungal hyphae, were common on all plates after 14 days. From this crude visual evaluation it is concluded that the antibiotic treatment was somewhat effective in retarding microfouling upto 7 days.

The macrofouling community that had developed after 6 weeks in this experiment was mixed Balanus or Balanus-Obelia with Choromytilus, Anomia and Bugula, inter alia (table 2.1.3.). The number of individuals that were counted after a month (580,5/dm^2) was considerably lower than the numbers recorded on one-month PVC panels that had been exposed at 10m depth at a nearby locality (1km away) three months earlier (5452/dm^2; see Part I), but were higher than during the previous winter, May to August (403/dm^2).

Since fungi were apparently common in this study, but were not identified by de Chalain (1979) a year earlier, it is possible that other primary film constituents were different as well. Although de Chalain had not quantified macrofouling and was working with very small (1,2cm^2) panels, which might have

influenced the settlement of invertebrates, he noted that the first hydrozoa and barnacles were seen after 14 days and were common after 28 days. In the present study, a few barnacles (Balanus) and hydrozoa (Campanularia) had settled already after the first day (0,7 individuals/dm^2; N=$9dm^2$), joined by a bryozoan (Bugula) and compound ascidian (Diplosoma) on the second day (1,6 individuals/dm^2) and serpulids (Spirorbis) hydrozoa (Tubularia), a simple ascidian and bryozoan (Menipea) by the seventh day (4,7 individual/dm^2). After 14 days at least 16 species had settled and barnacles were common (25,2 barnacles/dm^2). Seasonal affects alone would not explain these apparent differences in fouling between this and de Chalain's studies, because his work encompassed a number of experiments throughout the year (1979). It is possible that differences in plate size or annual variation could have played a role. Furthermore, it should be noted that since harbour construction was only completed in early 1979, the walls at the test site were still relatively bare during 1979, when de Chalain's work was carried out, but had developed a rich fouling community by March 1980, when the present experiment was conducted. It is possible that this difference in the degree of community development in the proximity of the test site may have influenced the results.

If the degree of microfouling affected macrofouling, a significantly different number of invertebrates should have been present on AB than on SW and CON. If the daily disturbance caused by experimental manipulation was deleterious, AB and SW would be less fouled than CON. The results presented on figure 2.1.3. show that there was little difference between the three treatments. The six replicate samples were often so dissimilar that the

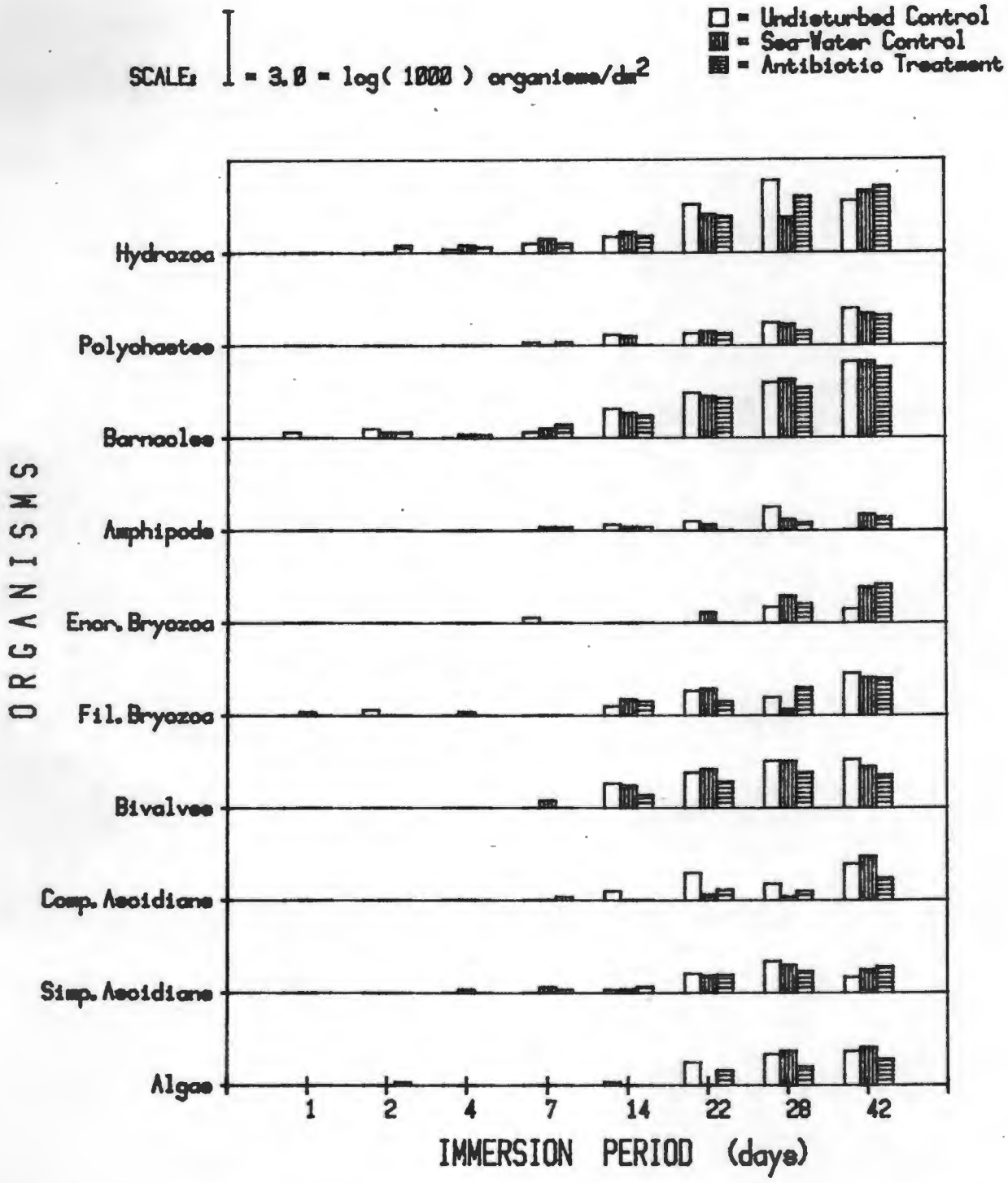


Fig 2.1.3. : Number of organisms (log[X+1]) that settled on PVC plates (5x5 cm) exposed in Simonsbay for various periods of time. Each group of three plots shows data for different treatments: left to right, a) Control (undisturbed), b) Sea-water Control & c) Anti-biotics Treatment.

application of the Student-t test seldom showed significant differences ($P<0,05$) between treatments. After 14,22,28 and 42 days, only slightly less barnacles, mussels and serpulids had colonized AB than SW and CON panels, although none of these differences were significant. The mean abundance of other organisms, especially hydrozoa, bryozoa, compound ascidia and colonial diatoms did not show consistent trends between treatments.

This preliminary experiment demonstrated that the colonization rate of macroorganisms did not appear to be very sensitive to differences in the degree of microfouling. Invertebrates settled very early on plates in all treatments and increased in numbers equally on panels where microfouling was retarded as on panels where it was not. However, these results are inconclusive because the primary film was not quantified nor qualified.

Table 2.1.3.

List of organisms attached to PVC plates exposed for 6 weeks or less at 10m depth in Simonsbay during March and April, 1980. Similar species were sometimes difficult to distinguish because of their small size. Therefore, organisms were only identified to genus level.

Class	Genus
Hydrozoa	Obelia, Campanularia, Tubularia also: Eudendrium, Sertularella
Actiniaria	Anthothoe
Polychaeta	Hydroides, Spirorbis
Cirripedia	Balanus
Peracarida (tube amphipods)	Ericthonius also: Jassa, Corophium
Bryozoa	Bugula also: Menipea, Aetea, Membranipora, Watersipora
Pelecypoda	Choromytilus, Anomia also: Saxicava
Ascidia	Ciona, Diplosoma
Algae	Ectocarpus, Colpomenia also: Dictyota, Polysiphonia
Diatoms	Licmophora

2.2. FEASIBILITY STUDIES

2.2.1. Introduction

In the preliminary experiment (section 2.1.) the method, dosage and periodicity of antibiotic application was carried out without proper knowledge of its effectiveness. It is felt that binding microbial repellants to the surfaces with paint matrix would enhance their effectiveness without undue disruption of the experimental setup.

The antibiotic activity of penicillin, which is specific against gram-negative and gram-positive bacteria (Umezawa, 1967), involves its binding to the cell wall where it blocks mucoplysaccharide synthesis (Woodruff & Miller, 1963). Streptomycin is also effective against gram-negative, gram-positive, mole- and mycobacteria (Umezawa, 1967). Its activity causes the cell membrane to become permeable to a number of compounds, resulting in the loss of nucleotides, amino acids and potassium ions and inside the cell, nucleic acid and protein synthesis are inhibited (Woodruff & Miller, 1963). Since it can be assumed that these antibiotics are specific against bacteria only, they are applicable in the present context.

In recent studies done for the U.S.Navy (Young & Mitchell, 1973; Chet et al, 1975; Mitchell et al, 1975, 1977) it was demonstrated that tannic acid and benzoic acid repelled marine bacteria from surfaces and prevented the appearance of microalgae and wood borers. Apart from this effect of repulsion, tannic acid also inhibits bacterial decarboxylation of amino acids (Clark, 1963). Benzoate inhibits bacterial fatty acid oxidation by complexing with coenzyme-A (Scholefield, 1963). Mitchell and

coworkers consider these properties of tannic acid and benzoic acid promising, although their effect on macroorganisms *per se* (apart from algae) has not been tested. Because of the previous interest in these compounds, it was decided to include them in the present tests.

Some workers have indicated that diatoms and microalgae, rather than bacteria, could be the precursors to macroorganism colonization (Wood, 1950; Daniel, 1955; Meadow & Williams, 1963; Chet *et al*, 1975; Mitchell *et al*, 1975). On panels used in a different experiment (Part I) it was observed that barnacles and serpulids were attached away from large patches of diatom colonies, suggesting that diatoms may compete for surface space with invertebrates, in agreement with Rastetter & Cooke (1979). A selective herbicide would be needed to investigate these possible roles of diatoms in fouling.

Diuron, or 3-(3,4-Dichloro-phenyl)-1,1-di-methyl urea (DCMU), is a powerful inhibitor of photooxidation reactions that involve the evolution of oxygen. Chlorophyll, when excited, donates an electron to an electron acceptor and in turn accepts an electron from an hydroxyl ion. Diuron blocks this electron transfer from the hydroxyl ion and thus selectively blocks plant growth (Losada & Arnon, 1963). Since this property of diuron appears to be ideal for testing the possible role of diatoms in fouling, it was included in the present experiments.

2.2.2. Materials & Methods

A neutral vinyl-acrylic paint, Intervinux (IV; elemental analysis on table 2.2.1.), used in marine applications, was used as control surface and as vehicle for the various compounds.

Penicillin and streptomycin (SP), tannic acid (TA), benzoic acid (BA) and diuron (DU) were added at various concentrations (1g/l, 10g/l, 20g/l & 50g/l; 0,1-5%) and each concentration applied to four 25cm^2 PVC panels, while another eight were left unpainted. The freshly painted dry surfaces were assumed to be clean and sterile, but the unpainted panels were cleaned with soap and 70% ethanol. No precautions were taken to prevent possible contamination when plates were immersed through the air-sea interface, although DiSalvo (1973) warned against such practice.

Examination by SEM after 3-day exposure periods in Table Bay would indicate optimal pigment concentration for effectiveness and paint stability and enable the choice of optimal pigment concentration.

2.2.3. Results & Discussion

The microfouling of IV looked similar to that on unpainted PVC panels. It was therefore assumed that the Intervinux surface was inert and neutral in seawater with similar fouling properties as PVC (see de Chalain, 1979).

Already at low concentrations of tannic acid (<1%) the paint surface developed blisters and became unstable. Benzoic acid was not very effective against bacteria, even at 5% concentration, and was excluded from further experiments. This was possibly because of its good miscibility with the paint and, hence, slow leaching rate.

Penicillin and streptomycin were difficult to mix with the paint as they would not dissolve in it. At 1-2% concentration, the paint surface appeared to be stable, with very small pores,

presumably caused by antibiotic leaching. This concentration drastically reduced the number of attached bateria and was used in further tests. The effectiveness of diuron against diatoms could not be tested in a 3-day period, because diatoms had not appeared on the control panels during this period. Because the surface was stable at 1-2% concentration, but uneven at 5%, the former concentration was adopted as optimal dosage.

To test the long-term efficacy of the pigments, three sets of 16 plates were painted either with empty matrix Intervinux (IV), or 2% diuron (DU) or a mixture of 2% streptomycin, 1,2% penicillin and 1% tannic acid (SPT). The panels were exposed for 28 days and examined by light and electron microscopes.

The SPT surface was rough with blisters and numerous pores, but the DU and IV surfaces were smoother and stable. The primary film had reached a complex stage. In all cases, bacteria, diatoms, fungus and protozoa were represented, with fungus being dominant. On IV, bacteria and diatoms were abundant and protozoa common. Only few diatoms, but numerous bacteria, were seen on DU. Bacteria were common on SPT, but apparently less than on IV.

The number of hydrozoa, barnacles, tunicates, other invertebrates and total number of organisms counted on DU was less (but non-significant; $P>0,05$) than on IV (table 2.2.3.). Significantly more barnacles ($P<0,05$), less tunicates and nonsignificantly more hydrozoa ($P>0,05$) had settled on SPT than on IV. Although serpulids, Spirorbis, were common on IV, significantly less ($P<0,05$) were attached to DU and none to any of the SPT panels.

The tentative conclusions that can be drawn from these trials are that diuron was fairly effective against diatoms and slightly reduced macrofouling, especially by Spirorbis. The blistered rough surface of SPT can be attributed to tannic acid (see above). The proliferation of bacteria on SPT indicated that its strength had faded rapidly by leaching from the porous paint. The complete absence of Spirorbis from SPT could be a result of the rough surfaces, because Spirorbis may prefer smooth to rough surface, (Crisp & Ryland, 1960) or could be the result of the direct effect of SPT pigments on Spirorbis. Similarly the presence of more barnacles on SPT could be a response to surface texture (Crisp, 1976) or to differences in the microcommunity.

Table 2.2.2.

Standardless qualitative elemental analysis of Intervinux paint, using a KEVEX International Energy Dispersive X-Ray Analyzer. The vinyl-acrylic paint was based on chloride, tinidium and silicon oxides and contained much iron oxide, which was probably used for the red-brown pigmentation. It can be assumed that the paint substratum *per se* was not toxic to marine organisms.

Element	Weight %	Oxide formula	Oxide %
Al	0,45	Al2O3	0,84
Si	5,98	SiO2	12,79
P	2,27	P2O2	5,20
S	0,41	SO3	1,03
Cl	24,45	Cl	24,45
Ti	8,84	TiO2	14,75
Cr	1,48	Cr2O3	2,17
Fe	29,14	FeO	37,49
Sb	1,07	Sb2O3	1,28
O	25,91		

Table 2.2.3.

Number of invertebrates (±95% confidence limits) counted on different painted surfaces (0,5dm^2; N=14) immersed in Table Bay for 28 days.

	DU	IV	SPT
Total	48,6 (35-62)	122,5 (97-148)	96,9 (45-149)
Hydrozoa	35,6 (25-47)	72,5 (62- 83)	84,4 (32-136)
Serpulidae	3,7 (2- 5)	17,3 (15- 20)	0,0
Cirripedia	3,0 (1- 5)	3,1 (2- 4)	9,7 (7- 12)
Tunicata	2,9 (2- 4)	4,4 (2- 6)	0,6 (0- 1)
Other	3,4 (1- 6)	16,0 (2- 30)	2,3 (1- 4)

2.3. FINAL EXPERIMENT

2.3.1. ENVIRONMENTAL CONDITIONS

The water movement in the side-arm of the Table Bay seawater channel was influenced by the velocity of flow in the main channel, which could vary considerably. In general, there was a slow unidirectional eddy in the side-arm. Although current speed was not measured, it is estimated that even at maximum current speed in the channel, the eddy water did not exceed 0,5m/sec. During the 28-day experimental period in March and April, 1981, the water temperature was fairly constant around 12,3°C, ranging from 11,0°C to 13,6°C. The water, which originated in the Table Bay Docks, appeared to have a fairly high content of suspended debris and petroleum effluents. Superficial examination of the concrete walls in the channel and side-arm revealed that a rich Choromytilus community dominated the areas where water flow was fast, but that a mixed Ciona-Balanus-Anthothoe-Choromytilus community existed in areas of lesser flow.

2.3.2. PRIMARY FILM DEVELOPMENT

The problem of investigating the role of various components of the microfouling community was approached in two ways: a) enrichment and b) specific inhibition. The effects of specific microbial inhibitors on natural development has previously been examined by Mitchell et al (1977). Enrichment cultures, allowing some community components to become well established on surfaces in the laboratory before being introduced into the sea, have previously been used by Zobell & Allen (1935), Wood (1950) and Daniel (1955).

In this study, which was conducted in Table Bay during March and April, 1981, four sets of plates (N=16) were treated differently. A microcommunity was precultured in a 20 litre bucket of filtered seawater (30um mesh) for 10 days on one set (PC) painted with Intervinux. The water was kept in a cool sheltered place and was changed every two days to prevent stagnation. Other sets were painted with 2% diuron (DU), 1% streptomycin and 1% penicillin (SP) or with empty-matrix Intervinux (IV), but were kept sterile until all four sets were submerged in the sea. One small panel ($25cm^2$) was removed from each of the four sets after 1,3,7,14 and 28 days and a 5cm subsample prepared for S.E.M. examination.

The results are descriptive rather than qualitative. The bacterial counts, which are presented in the next section (fig.2.3.3a), are the means from a number of "representative" areas. Because the analysis would tend to focus on more highly populated areas, these numbers are perhaps artificially higher than the actual mean numbers. When comparing different methods,

de Chalain (1979) concluded that S.E.M. counts tend to yield higher numbers than other methods. The estimated relative abundance of microorganisms is summerized on a histogram (fig.2.3.2) to facilitate visual interpretation. The photomicrographs (plates 2.3.2a-f) are a selection on which the differences between sets and exposure periods is illustrated most clearly. It is difficult to give a representative picture in a few micrographs because of the heterogeneity of the primary film. Therefore the presentation of micrographs emphasizes the community development on IV (control) on a number of frames and one or two frames from other sets are shown to illustrate some differences.

The system used to label the micrographs is as follows. The three figures below each picture are, from left to right, the type of substratum, the actual distance in μm between adjacent grid marks, and a sequence number referring to the micrograph position and the caption on the opposite page. The duration of exposure is indicated on the bottom of each plate, but deviations in exposure time, as for PC on plate 2.3.2a, are indicated in the caption. Items on the micrographs are sometimes labelled with a single letter, or their positions emphasized by arrows.

In the captions, a short outline of general conditions on a substratum, not necessarily seen on the micrographs, is sometimes given for better perspective. The identification of organisms was tentative and sometimes not attempted beyond class level. Some classifications were confirmed by Prof.R.N.Pienaar, but where the identity could not be established, a likely explanation is given. A detailed classification of microorganisms was considered of secondary importance to the characterization of the stages of primary film development.

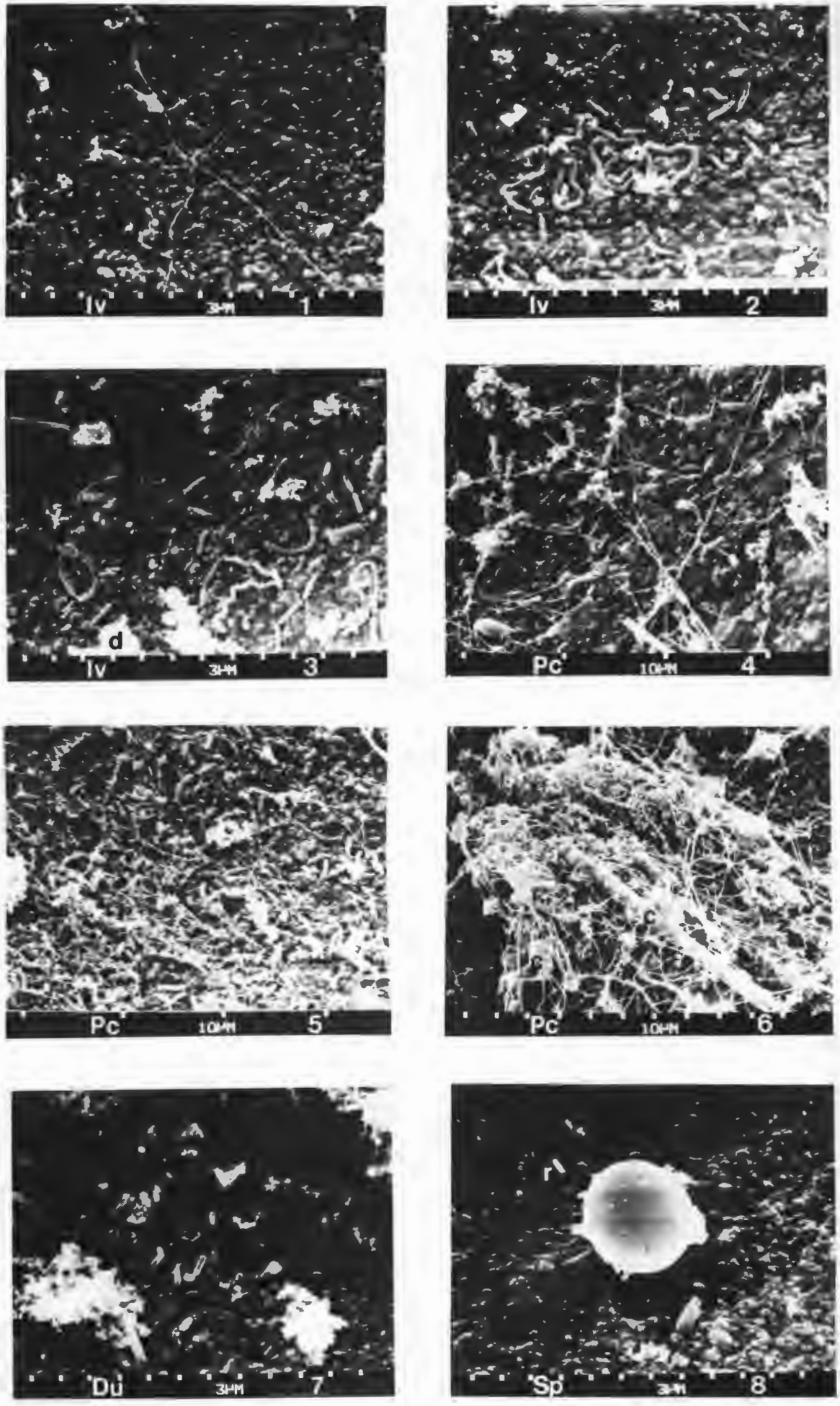


Plate 2.3.2.a -1 day

Plate 2.3.2.a - 1 day

Control: Primary periphytes, mainly rods, were fairly common and proliferated by division. A few fine threads, coming from bacteria, began to spread over the surface.

Frame 1: IV (1800X)
A prosthecate bacterium (centre), bound by long threads. A typical number of solitary rods can be seen around it. Note the granular appearance of the "clean" paint surface.

Frame 2: IV (1800X)
A group of actively dividing rods. Such clusters were frequently encountered and should give an idea of the proliferation rate of bacteria at this stage.

Frame 3: IV (1800X)
Division (arrowed) in long strings of rod bacteria (left and lower right). Long spiral bacteria can be seen at the lower centre. Debris (d), the light floccular material, occurred in loose patches on all surfaces.

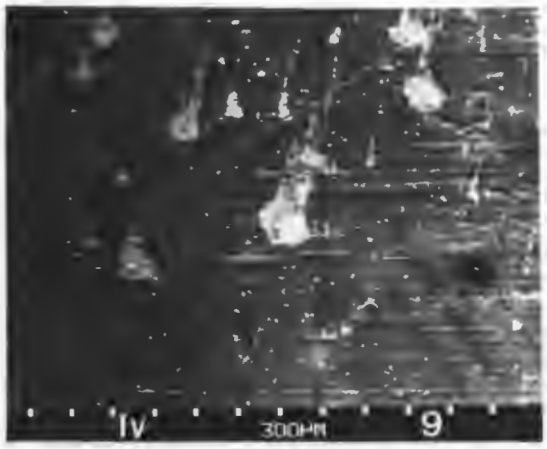
Frame 4: PC (1800X) day 0 ; 10-day preculture
Rod bacteria in a network of mucopolysaccharide threads. Note the fine reticular appearance (especially top right) of an underlying mucilage layer to the right of an apparent border (dashed line; see frame 10). Before immersion in the sea, the precultured surfaces already had a well-developed mucilage layer, in contrast with the "clean" surfaces underlying the bacteria on IV.

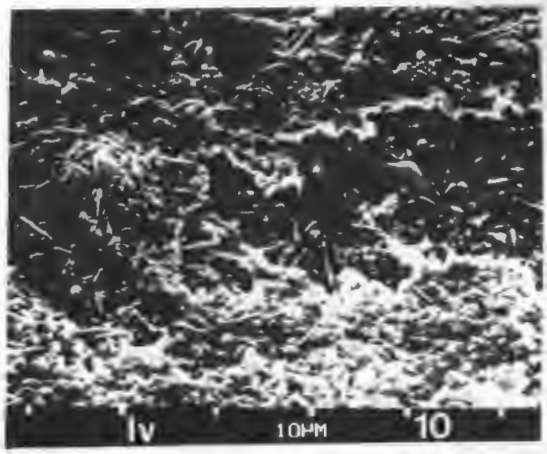
Frame 5: PC (1800X)
Numerous rods under a criss-cross of fine threads. After a day in the sea, bacteria were common on precultured surfaces and producing a network of mucopolysaccharide.

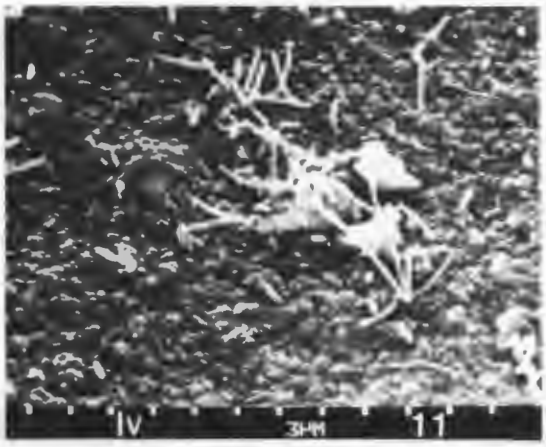
Frame 6: PC (600X)
A conglomeration of threads shows how the network appears to trap particles and enmesh centric diatoms, such as these Skeletonema (c).

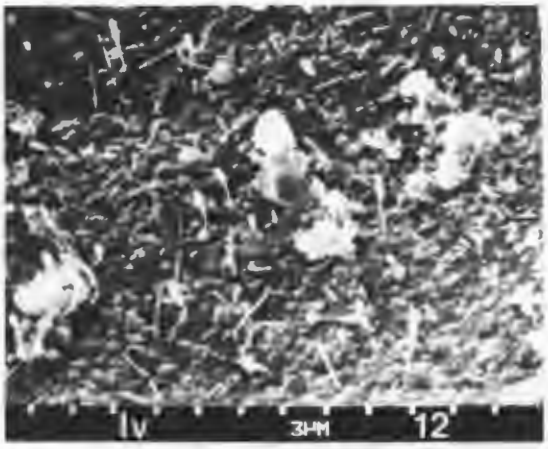
Frame 7: DU (1800X)
The number of rods, solitary or in small groups, was similar as on IV. A few fine threads seem to emerge from a single source (centre), perhaps a prosthecate bacterium such as in frame 1.

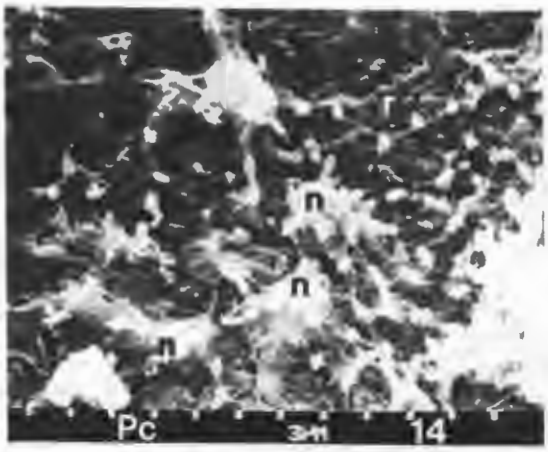
Frame 8: SP (1800X)
An algal spore (?) and a single rod bacterium on an almost barren surface. Very few bacteria occurred on the antibiotic surface.

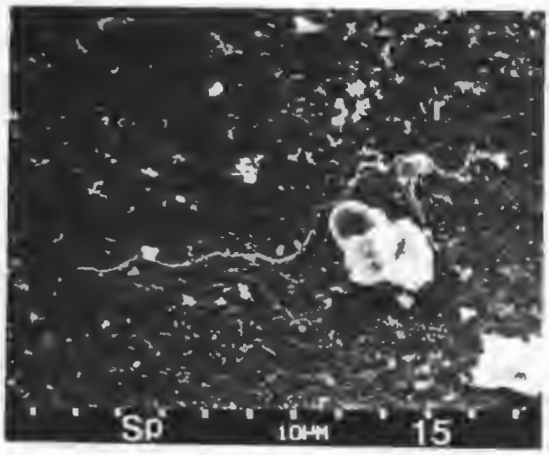












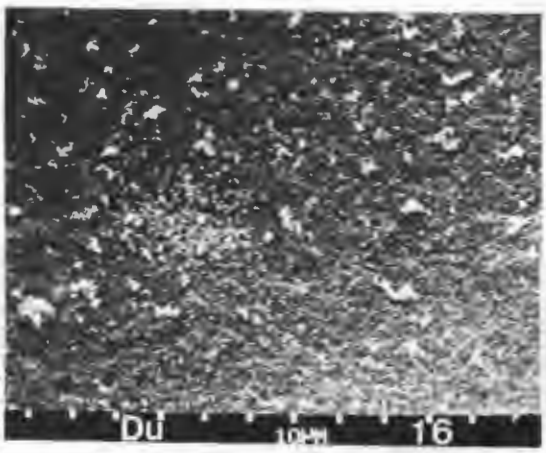


Plate 2.3.2.b - 3 days

Plate 2.3.2.b - 3 days

Control: Colonies of bacteria were growing large with an underlying mucilage layer spreading within its borders. The diversity of bacteria was increasing and a few secondary periphytes had attached.

Frame 9: IV (180X)
The light patches seen in this overview are bacteria colonies. A section of the centre colony can be seen enlarged in frame 10.

Frame 10: IV (1200X)
The edge of a colony of rods. The area of lighter background appears to be an underlying organic mucilage layer, presumably of bacterial origin. Such layers spread and soon cover much of the surface.

Frame 11: IV (1800X)
An aggregation of polarly attached filamentous bacteria. It appears as if the debris (centre) acts as focal point for this aggregation.

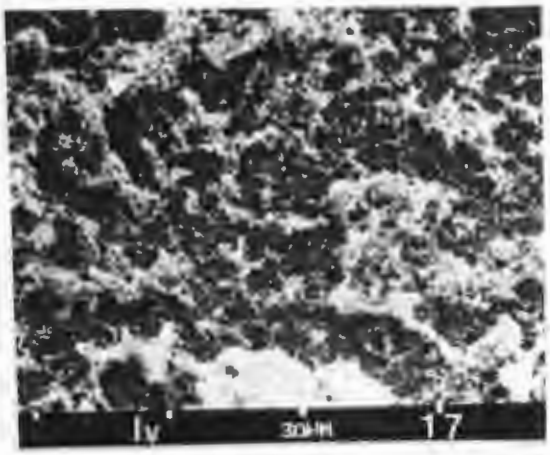
Frame 12: IV (1800X)
Upright stalked bacteria, similar to Caulobacter, are scattered among prosthecate long and short rods. Such numbers of rods as seen here were typical for areas outside the borders of colonies.

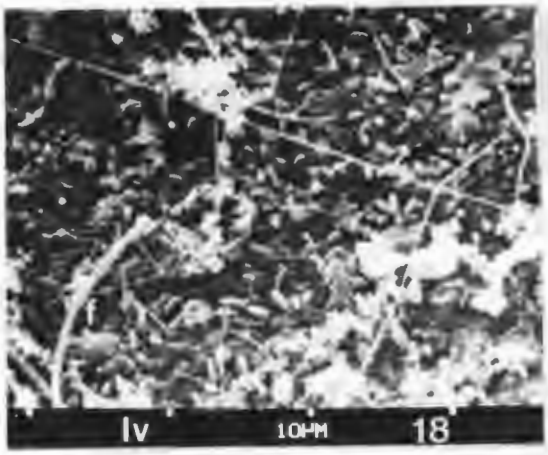
Frame 13: PC (1800X)
Filaments, possibly bacteria or fungal hyphae, were fairly common. These should not be confused with the fine mucopolysaccharide threads (m). Numerous coccoid and small rod bacteria are attached onto what appears to be an incomplete mucilage layer (not covering the bare underlying surface at top left). Although not shown here, a number of diatoms and choanoflagellates had colonized this substratum.

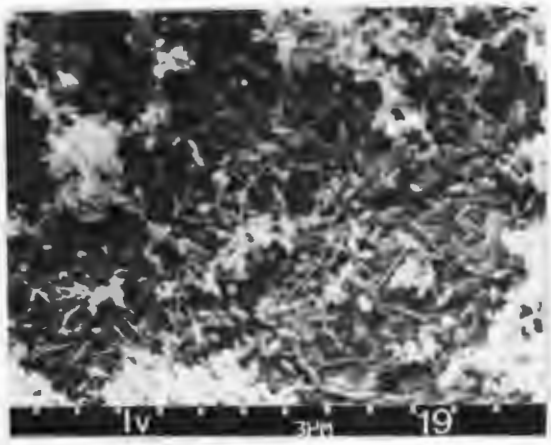
Frame 14: PC (1800X)
Very fine reticular threads emerge from bacteria and irreversibly bind them to the surface. The extensive fine network (n) illustrates how this bacterial product thickens and partially imbeds the bacteria. Another way how bacteria could become irreversibly bound to surfaces is to be covered by the mucilage layer as seen here with a group of small rods (r).

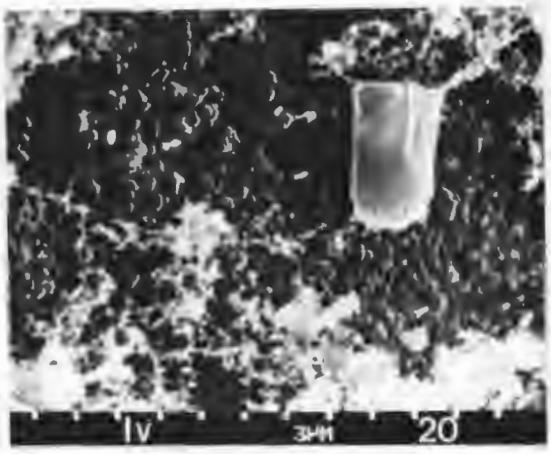
Frame 15: SP (600X)
An unidentified undulating filament growing on an almost barren surface. Note the few solitary rods (r), indicating that the antibiotics did not prevent bacterial activity completely, although they reduced it.

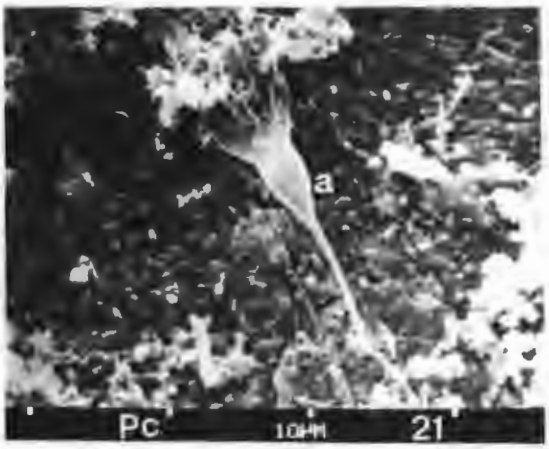
Frame 16: DU (600X)
A small colony of rods. The stage of bacteria proliferation and mucilage growth was less advanced than on IV, but secondary periphytes were also seen (elsewhere) on DU.

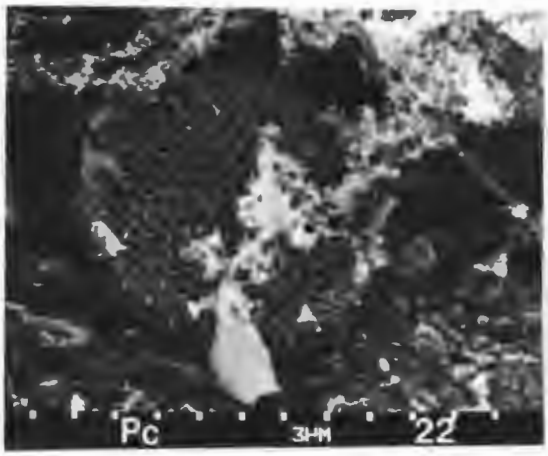


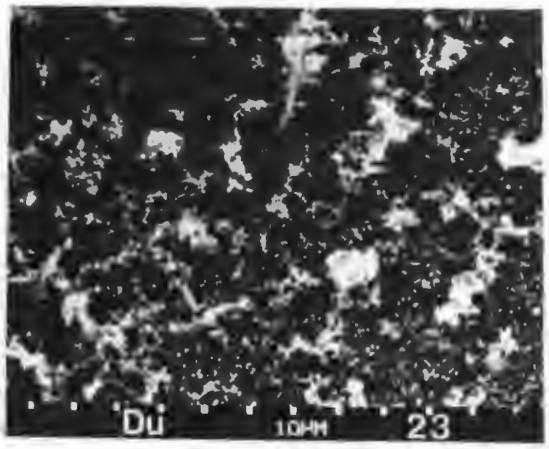












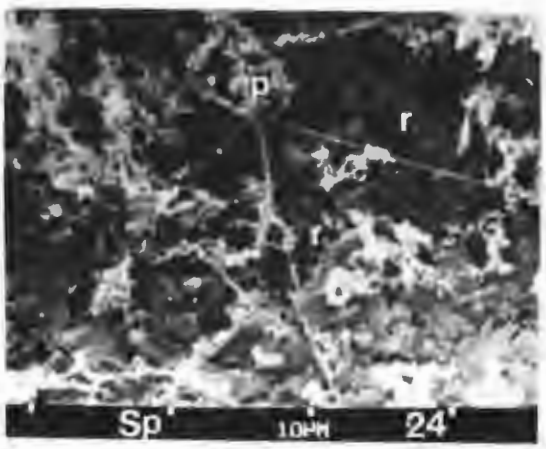


Plate 2.3.2.c - 7days

Plate 2.3.2.c - 7 days

Control: Bacteria and their products were abundant, but a large quantity of debris was bound on top and between them. The first diatoms and fungal mycelia were seen.

Frame 17: IV (600X)
Organic debris covered much of the surface with an extensive network of mucoplysaccharide threaded between and through it. Rod bacteria dominated the surface between the debris.

Frame 18: IV (1800X)
The number of long and short rods seen here was typical for this exposure period. Secondary periphytes (seen elsewhere) were common on IV. Several fungi, such as this coelomycete filament (f), were growing.

Frame 19: IV (1800X)
A network of polysaccharide threads, such as seen here, may account for the large quantity of debris trapped on the surface. Bacteria were proliferating as is illustrated by the string of dividing rods (s).

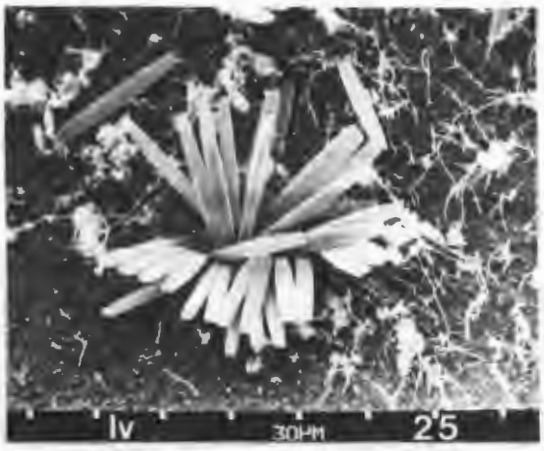
Frame 20: IV (1800X)
A diatom, probably part of a Skeletonema, attached to debris by its outside corners. A number of other pennate and centric diatoms occurred elsewhere on the surface.

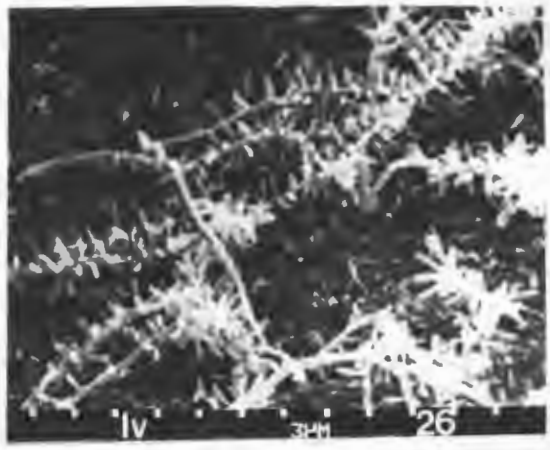
Frame 21: PC (1800X)
The main difference between IV and PC was that choanoflagellates, such as this Acanthoeopsis (a), were common on PC, but absent on IV. Note the ring of fine threads around the base of the flagellate, possibly indicating that these protozoa could also contribute to the extensive network of threads.

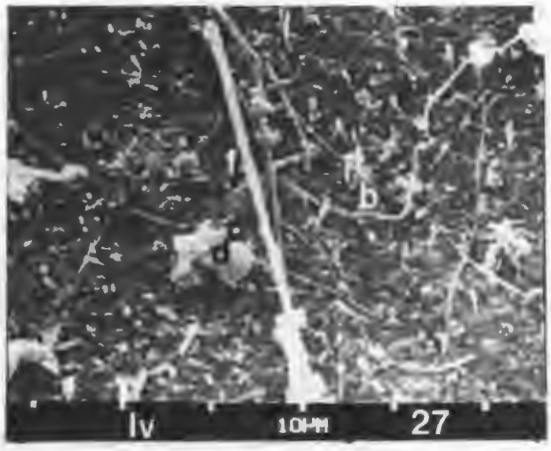
Frame 22: PC (1800X)
A centric diatom, an example of various types of diatoms on PC.

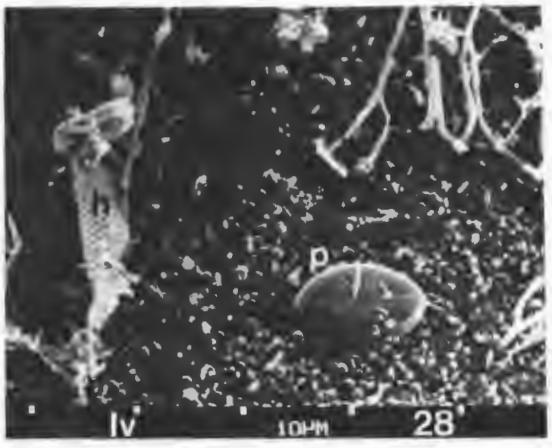
Frame 23: DU (600X)
In terms of number of bacteria, this surface closely resembled IV, but diatoms were absent on DU.

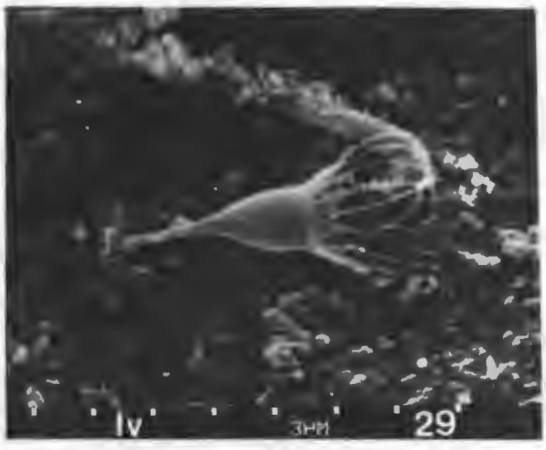
Frame 24: SP (1800X)
A prosthecate bacterium (p), a number of rods (r) in the background, and a growing mucilage layer indicate that bacteria were beginning to influence the surface in places. In spite of this, bacteria numbers were still relatively low.

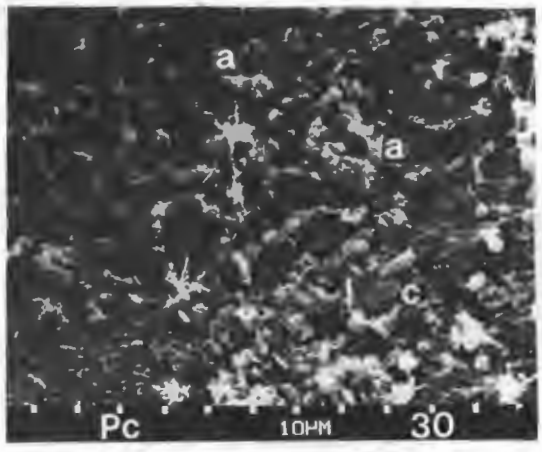


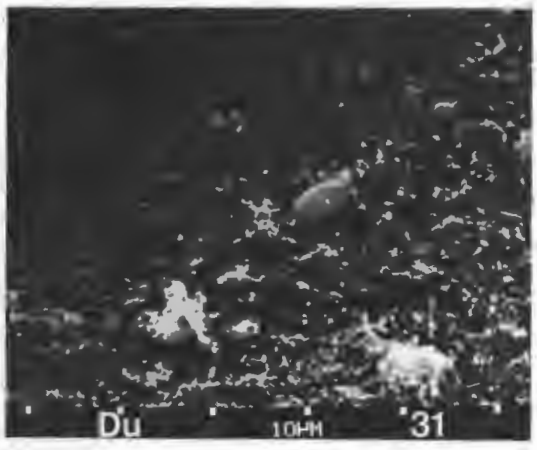












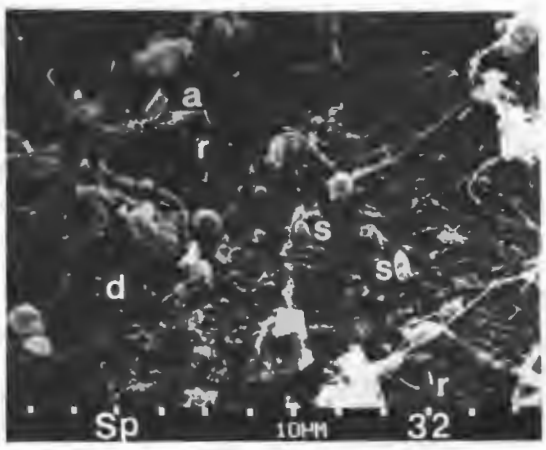


Plate 2.3.2.d - 14 days

Plate 2.3.2.d - 14 days

Control: The first tier of primary and secondary periphytes and small diatoms was well advanced and second tier organisms, large diatoms, fungal mycelia and flagellates, were becoming important.

Frame 25: IV (300X)
This typical view shows a group of large Naviculoid diatoms with a fungal mycelium around it, standing above an understorey of bacteria.

Frame 26: IV (1800X)
Secondary periphytes, stalked and filamentous bacteria, were numerous and sometimes, as in this view, occurred in high densities. It looks as if aggregations of stalked bacteria, similar to Caulobacter, were growing on filamentous bacteria. Other stalked bacteria were attached directly to the substratum in the background.

Frame 27: IV (1200X)
A fungus hypha (f) growing over bacterial filaments (b). Stalked bacteria are scattered among rods that still dominated numerically. Sometimes bacteria could be seen associated with debris (d).

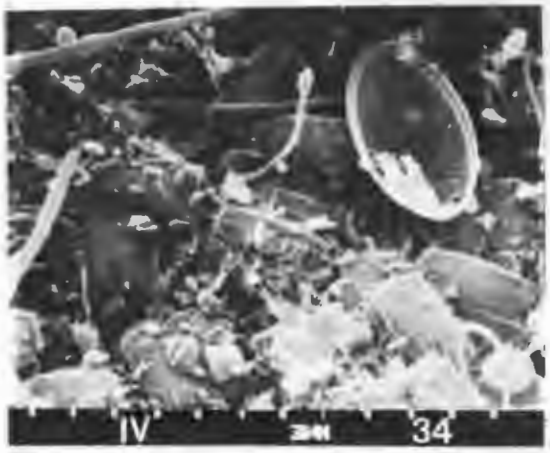
Frame 28: IV (1200X)
A typical view of first tier fouling with numerous rods around a prostrate small pennate diatom (p) and a number of filamentous and stalked bacteria in the vicinity. The honeycomb structure (h) is probably a fragment of a centric diatom.

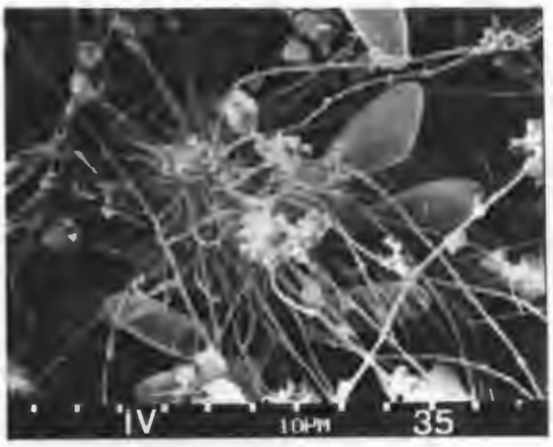
Frame 29: IV (1800X)
Choanoflagellates, such as this Acanthoeopsis, were common. The filament in the background is probably the base of a fungal hypha.

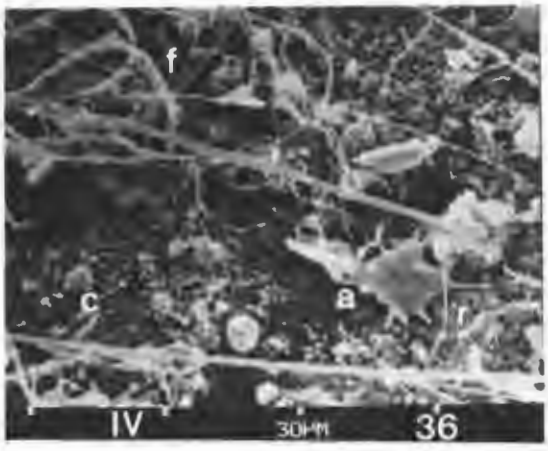
Frame 30: PC (600X)
The precultured surface did not appear to be much different from IV, but the underlying mucilage layer looked more complex. Besides the numerous rods aggregated around the debris in the centre, two acanthoecan flagellates (a) and a section of a centric diatom (c) can be seen.

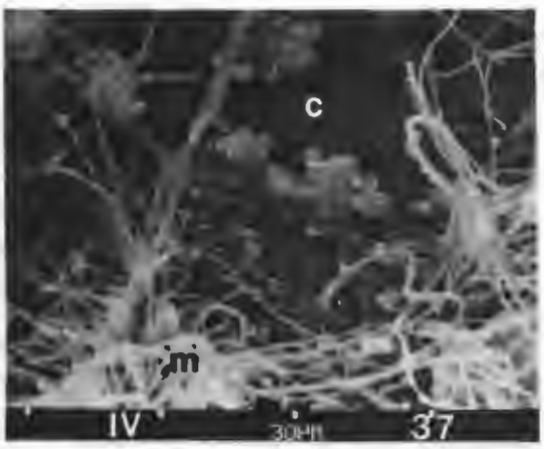
Frame 31: DU (1200X)
The notable difference of DU from IV was that diatoms were nearly absent. Bacteria were abundant and second tier constituents, such as this choanoflagellate, Salpingoeca, and fungi (not shown here) were common.

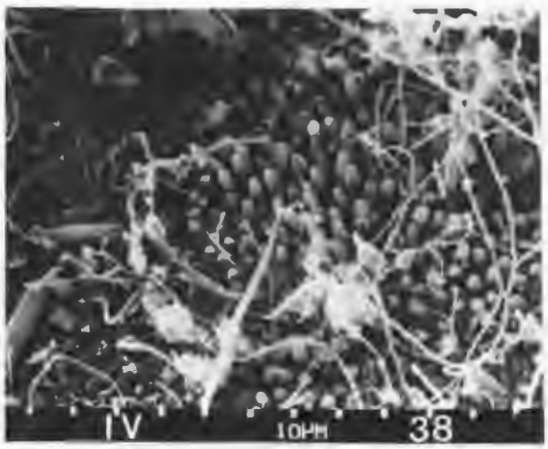
Frame 32: SP (600X)
This overview shows that, although rods (r) were still scarce, salpingoecan (s) and acanthoecan (a) flagellates, filamentous bacteria and small diatoms (d) had colonized the surface.

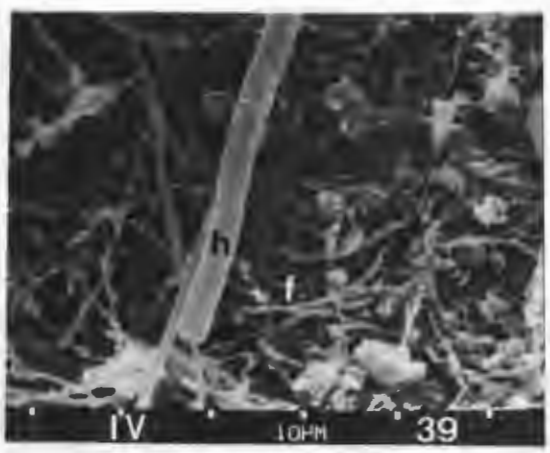












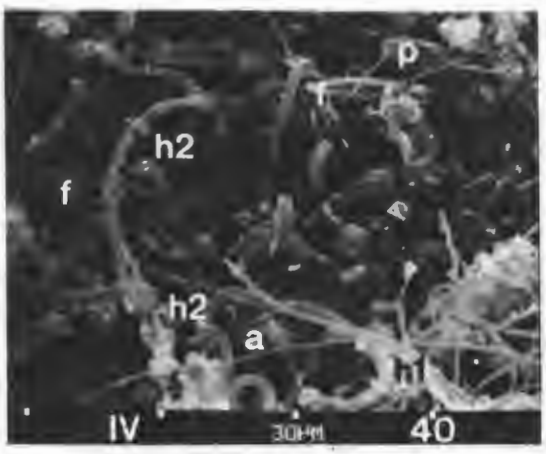


Plate 2.3.2.e - 28 days

Plate 2.3.2.e - 28 days

Control: The first tier had formed a thick and almost continuous, firmly bound layer over most of the surface. Proliferating second tier constituents, like large diatoms and fungi, overgrew much of the first tier and protozoa were common. This stage is near the completion of primary film formation.

Frame 33: IV (180X)
Large diatoms, mainly Licmophora, and fungus mycelia dominated the space above a layer of small prostrate pennate and centric diatoms, rod bacteria and cyanophytes.

Frame 34: IV (1800X)
The advanced stage of first tier fouling is well illustrated here. Diatoms, Cocconeis, were stacked close together and were bound by the thick mucilage network. Numerous bacteria were imbedded in and grew on top of this layer.

Frame 35: IV (600X)
Fungal hyphae arise from a common body, probably a fruiting body, which is surrounded by large diatoms, Licmophora.

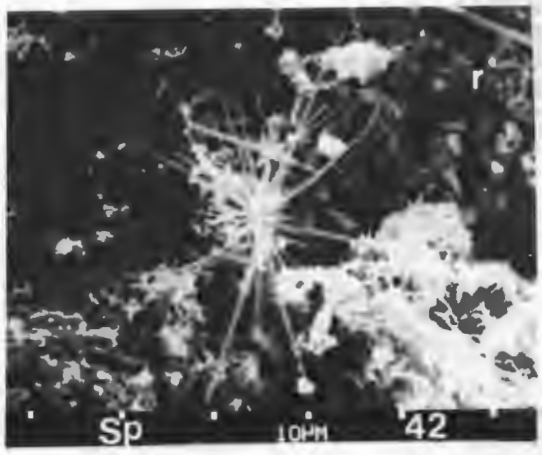
Frame 36: IV (600X)
Protozoa, especially flagellates, but also other forms, such as this amoeba (a) and ciliates (some examples are shown in frames41&46-48), were common. Note the "dirty" appearance of the uneven surface in the background, with groups of cyanophytes (c), rods (r) and filamentous bacteria growing on it.

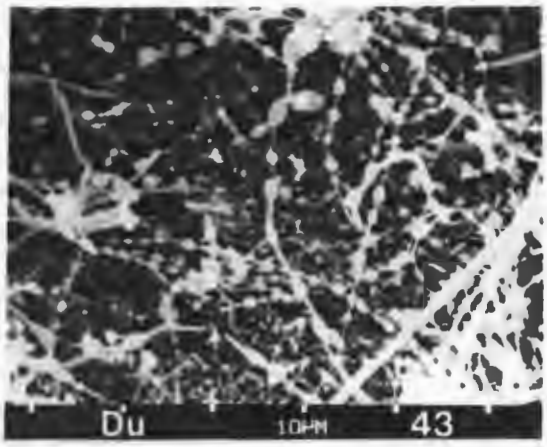
Frame 37: IV (600X)
Unicellular cocci, possibly cyanophytes (c), were of considerable importance and patches, such as this, were fairly common. It is interesting to note that the surface around cyanophytes appeared to be free of heterotrophic bacteria and mucilage, as is illustrated in this example. Fungus mycelia (m) were abundant and the most important primary film constituent after a month.

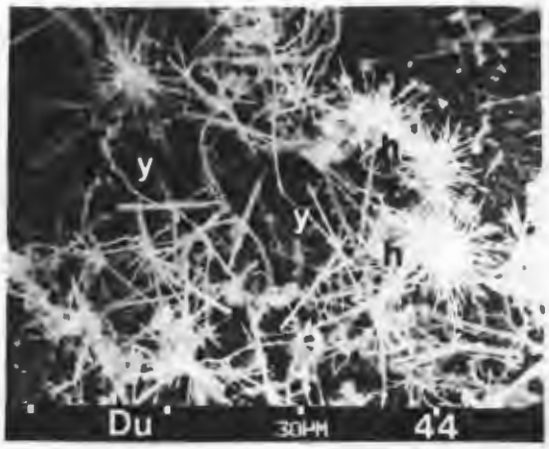
Frame 38: IV (600X)
A cluster of what are possibly microalgal zoospores in early stages of growth. Note the complexity of the surface in the background.

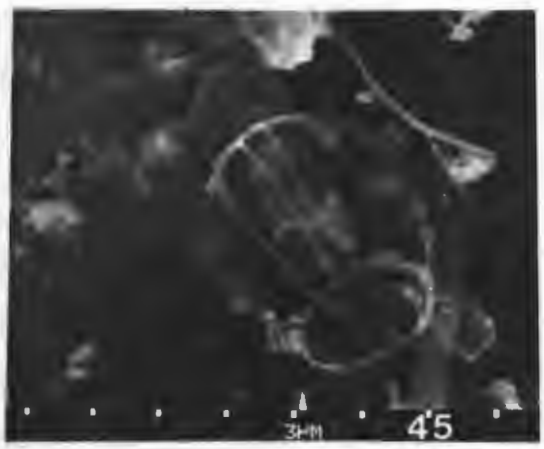
Frame 39: IV (1200X)
A multi-storey layer of filamentous bacteria (f), with short rods between them, growing below the end of an upright fungal hypha (h).

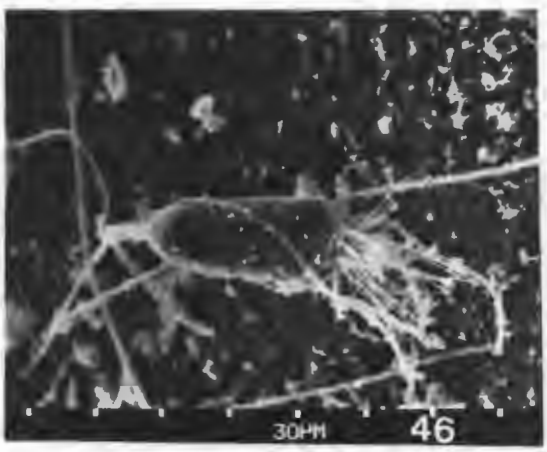
Frame 40: IV (600X)
This micrograph illustrates the different types of filaments that occurred. The larger types were probably fungal hyphae, which could vary in thickness (h1 & h2). The fine filaments (f) were probably heterotrophic or phototrophic bacteria. Two pennate diatoms (p) and an acanthoecan flagellate (a) can be seen. Note the uneven complex surface in the background with numerous rods growing on it.

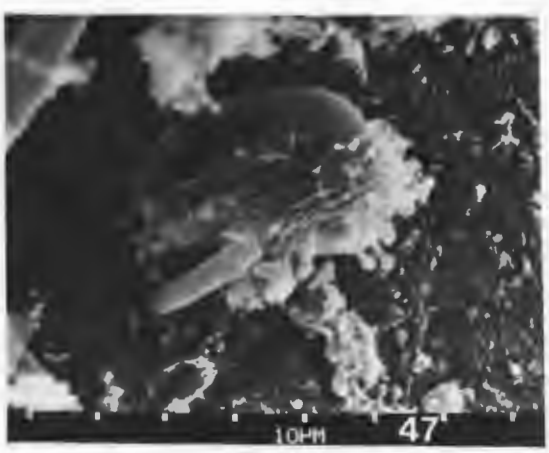












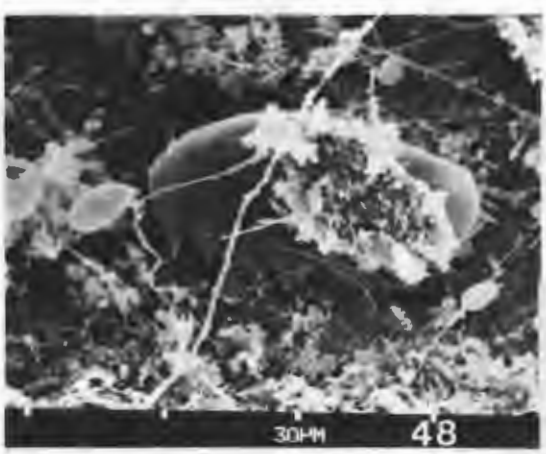


Plate 2.3.2.f - 28 days

Plate 2.3.2.f - 28 days

Frame 41: PC (600X)
A loricate peritrich, resembling the European ciliate, Cothurnia, is surrounded by a number of yeast pseudomycelia (y), cyanophytes (larger coccoid forms that are scattered about), rods, filamentous bacteria and debris. Yeasts were occasionally encountered already in the earlier stages of fouling an all surfaces and were fairly common after 28 days. In general, PC closely resembled IV after this exposure period.

Frame 42: SP (1200X)
An unidentified organism attached at the edge of a patch of collapsed paint. It is possible that the leaching of antibiotics leaves the paint matrix with hollow regions, which collapse. Although rods (r) were appreciably more numerous than after shorter exposure periods, they were still less abundant than on other surfaces by a factor of five to ten.

Frame 43: DU (1200X)
Strings of yeast pseudomycelia (?) and fungal hyphae stand above an understorey of rod and cocci bacteria. It is interesting to note that on DU, where diatoms were nearly absent, other forms, especially fungus, but also yeasts, appeared to be of greater importance than on other surfaces. Yeast pseudomycelia were numerous on DU, but only fairly common on IV. Bacteria numbers were higher on DU than on other surfaces.

Frame 44: DU (600X)
Conglomerations of straight filaments (h; identity unknown) stand among a fungal mycelium. Note a number of yeast pseudomycelia (y) in the background.

Frame 45: General (3000X)
An acanthoecan choanoflagellate, Stephanoeca. This was the earliest type of flagellate to appear on surfaces and was first seen on PC on day 3, occurring occasionally thereafter.

Frame 46: General (300X)
A side-view of a suctorian, similar to the Madagascan Acineta. This stalked protozoan appears to be gregarious, because it was either absent or fairly common on surfaces.

Frame 47: General (900X)
Another small stalked suctorian. Other types of suctorians included a large type (400um tall), similar to the mid-Atlantic Ephelota.

Frame 48: General (600X)
An example of a number of types of heterotrichous ciliates seen. Protozoa probably play an important role as grazers in the mature primary film.

The results of the S.E.M. analysis are summarized on fig 2.3.2 and bacteria counts are presented on fig 2.3.3a (next sub-section). A resumé is given below.

On the control surfaces, IV, bacteria assumed early dominance and were abundant after 3 days ($1,6x10^5/mm^2$). Fungi and diatoms appeared after 7 and flagellates after 14 days. A slight decline in bacteria numbers was evident after 28 days ($9,0x10^4/mm^2$) with the appearance of protozoa and the dominance of space by fungus and diatoms.

The pattern was similar, but earlier, on PC. At the onset of the experiment, bacteria were common ($1,7x10^4/mm^2$) and a day later diatoms and fungus were present. The early appearance of flagellates after 3 and other protozoa after 7 days is a good indication that the community development remained more advanced than on IV until day 28, when PC resembled IV.

The application of antibiotics was effective in retarding the general development of microfouling. On SP only few bacteria ($2,8x10^2/mm^2$) were present on day 3 and even on day 28, their numbers ($1,0x10^4/mm^2$) were still considerably less than on IV ($9,0x10^4/mm^2$). The first diatoms and fungi on SP were seen only on day 14, but fungi were dominant on day 28, as they were on all other sets.

Diuron was effective against diatoms and only few were present after 14 and 28 days. It did not appear to be detrimental to other community components, except perhaps cyanophytes, and on day 28, bacteria ($2,1x10^5/mm^2$) and fungus were very abundant.

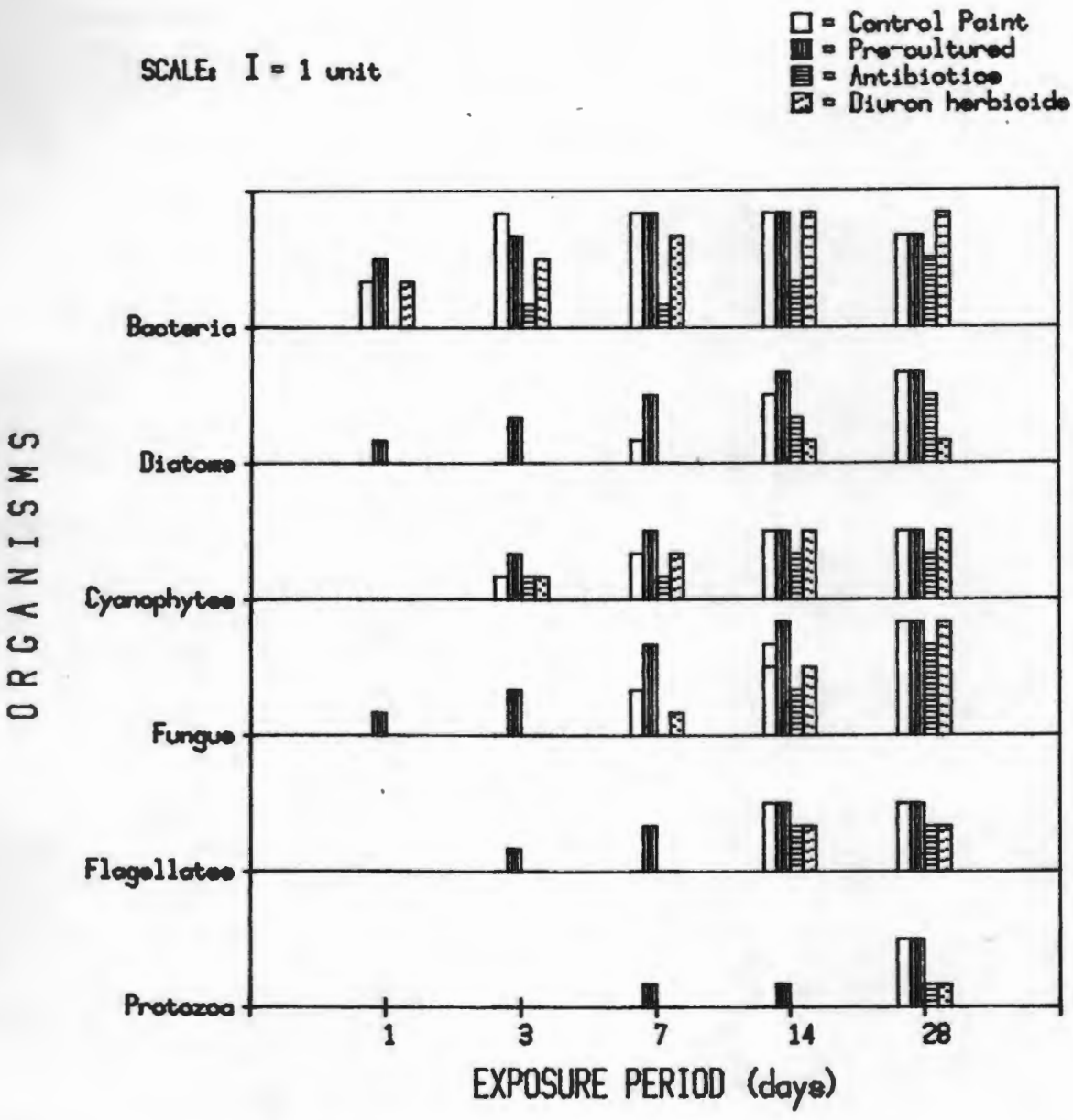


Fig232: Estimated relative abundance of microorganisms on different surfaces exposed for various periods in Table Bay waters. Relative abundance was expressed in five units: 1=present; 2=fairly common; 3=common; 4=numerous; 5=abundant.

The general succession pattern of microorganisms, bacteria proliferation preceding diatoms, followed by fungi, protozoa, large diatoms and microalgae, was similar to the patterns of microfouling recorded by numerous other authors, but appeared to proceed more slowly than in some of these studies (Zobell & Allen, 1935; Wood, 1950; Skerman, 1956; Corpe, 1970; O'Neill & Wilcox, 1971; Mitchell & Young, 1972; Zachary et al, 1978; Marszalek et al, 1979).

The present results from Table Bay are in general agreement with observations of microfouling in Simonsbay conducted two years earlier by de Chalain (1979), but for major differences in the abundance of fungi and quantities of debris. Fungi are usually the primary colonizers of decaying plant matter (Paul et al, 1977). It is possible that, in this experiment, the quantity of debris on all surfaces at day 7, resulting from the fairly high concentration of harbour effluents in the water, sufficiently altered the surface characteristics to simulate natural substrata, and thus attract fungus. The objection against the suggestion that abnormally high detritus levels were solely responsible for fungus proliferation is based on personal observations of PVC panels exposed for a month in cleaner water of Simonsbay (see section 2.1) and at 10m depth off Melkbosstrand, just north of Table Bay. Numerous fine filaments, that appeared to be fungal hyphae (similar to the specimen shown on frame 25, plate 2.3.2d), were seen by ocular microscope, indicating that fungal proliferation on artificial substrata may be a more widespread phenonemon in local waters. Despite these differences, it should be noted that the overall pattern of microfouling in this study was similar to that seen by de Chalain (1979; see section 2.1). It is thus concluded that primary film development was normal.

2.3.3. SETTLEMENT OF MACROORGANISMS

The response of invertebrates to the retarded, normal or advanced primary film was tested simultaneously to the examination of microfouling. The four large panels (400cm^2) in a set were either painted with Intervinux only (IV), or with diuron (DU), or streptomycin and penicillin (SP), or were pre-cultured in seawater (PC). All metamorphosed macroorganisms were counted on two sample areas of 1dm^2 on each side of a panel (16 samples to each set). After inspection on day 1,3,7,14 and 28, each panel was again secured to its frame and reimmersed at its site.

The total number of invertebrates (fig.2.3.3a) increased about 200-fold on all panels from the first day of immersion (1-13/dm^2) upto day 28 (392-1215/dm^2). This increase was similar on all sets, although significantly less ($P<0,05$) individuals were counted on SP than on IV and PC after 1, 7 and 28 days and less on DU after 3 and 14 days.

The results are more meaningful when treating the various classes seperately (fig.2.3.3b). Only relatively few species were encountered (table 2.3.3) compared to earlier studies carried out in False Bay (section 2.1). Spirorbis dominated numerically from the first day onwards (1-11/dm^2; $x=3,1-6,0$/dm^2) and were common after 28 days (196-422/dm^2; $x=264,1-357,1$/dm^2). Upto day 7, slightly less Spirorbis (significant; $P<0,05$) were found on SP and DU than on PC, but their numbers were similar on all sets after 14 and 28 days. Very few hydrozoa, simple ascidians, barnacles and bivalves had settled by day 14, but by day 28 their numbers had increased. Significantly less hydroids ($P<0,05$) were encountered on SP than on PC. Also, slightly less Ciona and Choromytilus ($P<0,05$) were attached to SP than to IV.

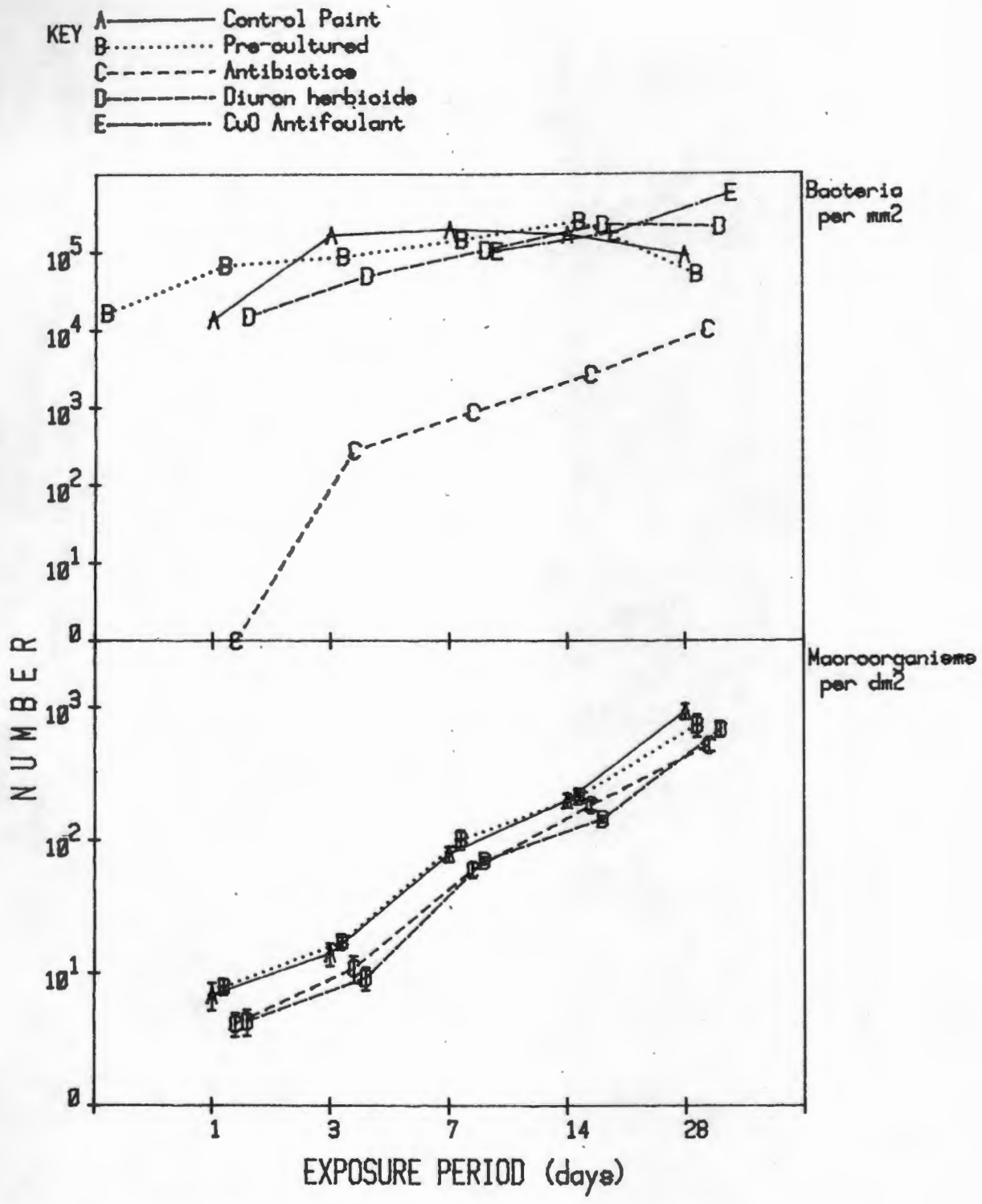


Fig 233a: Total number (log[X+1], ±95% confidence limits) of bacteria and macroorganisms on different painted surfaces after various exposure periods in Table Bay waters. Macroorganisms were counted on 16 replicate areas of 1dm^2. Bacteria numbers were estimated by viewing the surfaces by S.E.M.

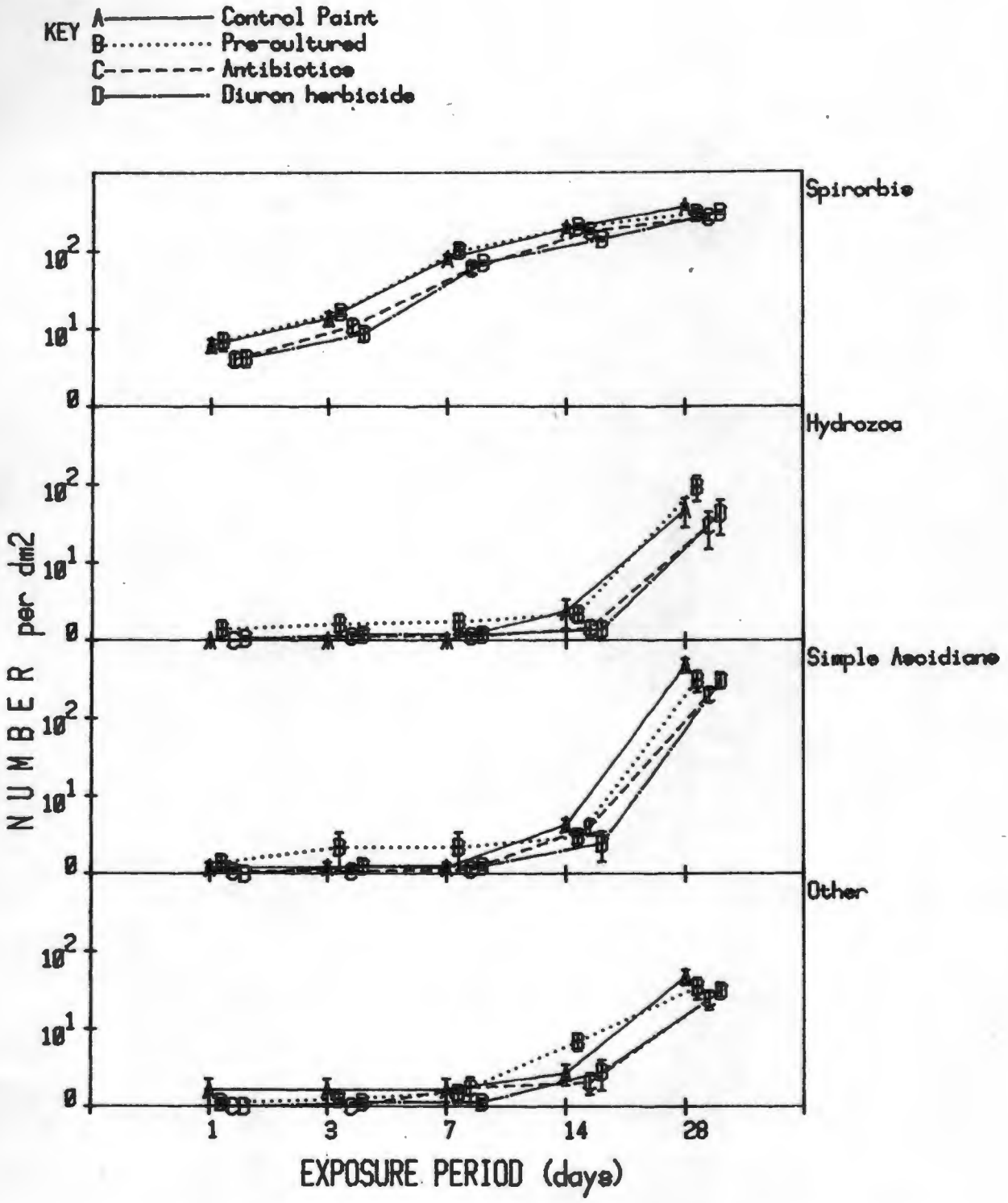


Fig233b: Number of animals (log[X+1], ±95% confidence limits) that were counted on different painted surfaces (N=16) exposed to Table Bay waters for various periods of time.

In general, the number of each species was fairly similar on all sets, but SP appeared to have marginally less organisms than PC or IV. It is noteworthy that the abundance of organisms other than Spirorbis was similar on DU and IV. This indicates that diatoms apparently played no important role in the settlement of their larvae.

The pattern of numerical increase of macroorganisms was similar to that observed in other investigations. That is, an initial period in which a few organisms settle, soon followed by a period of exponential increase (Daniel, 1955; O'Neill & Wilcox, 1971; Mitchell & Young, 1972; Cundell & Mitchell, 1977). These authors interpreted such a pattern as implying that a "mature" primary film (with most of the major constituents present) had to develop before macroorganisms could settle. If this were the case in this study, the differences between SP and IV and PC should have been considerably larger than observed, unless settling larvae responded only to the presence of certain primary film constituents rather than to their quantity.

Table 2.3.3:

List of organisms attached to painted surfaces immersed for 4 weeks or less at 2-3m depth in Table Bay during March and April, 1981. Growth was slow and the small individuals were difficult to identify positively. The surrouding mature community was used as a guide to some classifications to genus level e.g.mussel spat were classified as Choromytilus from the numerous mussels found closeby.

Class	Genus
Hydrozoa	Obelia, Tubularia
Actiniaria	Anthothoe
Polychaeta	Spirorbis also: Hydroides
Cirripedia	Balanus
Peracarida	Amphipoda (tubiculous)
Bryozoa	Bugula, also: encrusting bryozoa
Pelecypoda	Choromytilus, Anomia
Tunicata	Ciona, also: compound ascidia

3. GENERAL DISCUSSION

It is generally assumed that miroorganisms play an important role in fouling. Some of the evidence used for this by previous authors will be examined in this section before comparing the advent of macrofouling in various field studies. Finally, an attempt will be made to relate the early development of fouling communities to specific environmental factors.

Studies by previous authors range from the straightforward approach of primary film enrichment or prevention to more refined biochemical techniques. It was found that:-

a) In laboratory experiments, barnacles, such as Balanus (Daniel, 1955; Horbund & Freiberger, 1971; Liberatore et al, 1972), the hydrozoan, Tubularia (Pyefinch & Downing, 1949), and the serpulids, Spirorbis and Hydroides (Knight-Jones, 1951; Daniel, 1955; Crisp & Ryland, 1960; Meadows & Williams, 1963) preferred filmed to clean surfaces when given the choice. The contents of diatoms, microalgae or algal extracts in the film were important in the attraction of Spirorbis (Williams, 1964) and bryozoans (Miller et al, 1948; Crisp & Ryland, 1960; Crisp & Williams, 1960) to a filmed surface.

b) In laboratory tests, where organisms were not given a choice of substrata, Balanus (Daniel, 1955), Spirorbis (Knight-Jones, 1951) and oyster larvae, Crassostrea (Mitchell & Young, 1972), took much longer to settle and metamorphose on clean than on filmed substrata (Knight-Jones, 1951; Daniel, 1955; Mitchell & Young, 1972).

c) Sterile sand was found to be much less attractive than filmed sand to the settlement and growth of sand tube-dwellers,

the polychaetes, Ophelia (Wilson,1955) and Protodrilus (Gray, 1966), and the amphipod, Corophium (Meadows, 1964). The active agent, which was only effective on contact, was the bacterial film and not the bacteria per se (Meadows, 1964; Gray, 1966). Summing up the approach of these and other workers, Meadows & Campbell (1972) noted that a key discovery was that the repertoire of microbes occurring in sands appeared to be involved in the species-specific recognition by tube-dwellers of their natural sands.

d) By applying bacterial repellants (tannic acid and benzoic acid) to surfaces, Mitchell et al (1977) found that the colonization by micro- and macroorganisms was reduced. However, possible direct effects of these chemicals on macroorganisms have not been tested.

e) Bacteria-originated chemicals were found to be important in inducing metamorphosis of planulae and bryozoan larvae. Planulae of the scyphozoan, Cassiopea, only fully metamorphosed when in contact with certain live sessile bacteria, the mechanism involving suppression of an inhibiting factor in the planulae (Müller et al, 1976; Neumann, 1979). A lipid was isolated from bacteria which stimulated active Na^+/K^+ ATPase transport across cell membranes, necessary for the metamorphosis of the hydroid, Hydractinia, and the bryozoan, Bowerbankia (Müller, 1973; Müller & Buchal, 1973; Eiben, 1976; Müller et al, 1976). Although factors involved in the settlement and metamorphosis of other invertebrates are possibly much more complex (Crisp, 1976), this promising biochemical approach used by Müller and coworkers could be found applicable to fouling organisms such as barnacels, bivalves and serpulids, inter alia.

Another line of evidence, frequently cited, is that macroorganisms only settle once a mature primary film has become established, although only few field studies have actually demonstrated this (Wood, 1950; Daniel, 1955; O'Neill & Wilcox, 1971; Michell & Young, 1972; Cundell & Mitchell, 1977). Daniel (1955) interpreted his observations in a field study, where he found an average of 5 cyprids/dm^2 on test panels after one day, as follows: "Considering the numbers which settled later, it must be assumed that even the larvae of the most successful foulers, Balanus amphitrite and Hydroides norvegica, failed to settle for the first two days of immersion". To date, such opinions have persisted (see Horbund & Freiberger, 1971; Zachary et al, 1978), although evidence to the contrary has been presented.

Where conditions are not limiting, colonial and gregarious fouling organisms increase exponentially in numbers (Knight-Jones & Crisp, 1953; Jackson, 1977). The advent of the first colonizers on a surface is thus of considerable importance for the subsequent appearance of numerous conspecifics. In the present investigation, metamorphosed Balanus (0,7/dm^2/day) and Spirorbis (5,1/dm^2/day) were encountered on the first day of plate exposure. Such results are not without precedent. Previous counts of metamorphosed Balanus on the first day range from 1/dm^2 (Weiss, 1944), through 2,4/dm^2 (Zobell & Allen, 1935), 4/dm^2 (Skerman, 1956), 20/dm^2 (Phelps, 1941) and 40/dm^2 (Pomerat & Reiner, 1942) to a maximum of 87/dm^2 (Phelps, 1941). In this study and others it was shown that microfouling was still at an early phase of bacteria proliferation after one day. Unless the early settlers responded to the presence (not the quantity) of sessile bacteria per se, it should be concluded that biotic microfouling was not required for initial colonization.

The results of previous studies conducted in the field showed that in the first weeks of panel exposure, more macroorganisms attached to pre-cultured surfaces than to initially sterile surfaces (Zobell & Allen, 1935; Wood, 1950; Daniel, 1955). In the present study, the differences in colonization rate of panels on which bacteria proliferation was retarded, or diatom development was inhibited, or microfouling was normal, or primary film had been pre-cultured, were marginal and are regarded as of little significance.

It may be of interest to consider why fouling organisms sometimes settle irrespective of the degree or nature of the primary film while at other times they do not. Since the various studies were carried out at different localities and at different times of the year, differences in species repertoire may have influenced the findings. This does not explain why such contradictions in response are found even within a genus, for example, Balanus or Spirorbis.

O'Neill & Wilcox (1971) reported a study in which two seperate simultaneous field experiments yielded different conclusions. They examined fouling events at two sites, situated a few kilometers apart, over a period of nine weeks. One site was near pylons bearing a rich community and the other was along a wharf bearing few macroorganisms. O'Neill & Wilcox found that barnacles and algae appeared on the first day of panel exposure at the site close to the rich community and that these and other organisms were common within a few days. At the other site, the first hydrozoans, bryozoans, polychaetes and barnacles only appeared after 16 days in spite of heavier microfouling.

O'Neill & Wilcox (1971) concluded that "the early appearance of barnacle larvae at Site A [close to the established community] indicates that a primary film is not necessary for attachment..... The advanced stages of fouling already present at Site A negate somewhat the importance of the primary film..... The lack of a rich biotic community at Site B necessitates a primary film and could account for the orderly succession of organisms."

Experimental fouling sites in coastal environments can be classified into two types: a) Type A: Close to a rich established macrocommunity; b) Type B: Not close to such a community. The patterns of early succession can be grouped according to the following criteria: a) Pattern 1: An orderly sequential succession with microorganisms preceding macroorganisms; b) Pattern 2: a less structured series of events. O'Neill & Wilcox (1971) had found Pattern 2 at a Type A site and Pattern 1 at a Type B site.

From early 1979 to 1980, the Simonsbay site used by de Chalain (1979) and in this study, had changed from a Type B to a Type A site (i.e. a rich fouling community had developed on the harbour walls a year after its construction). It is interesting to note that de Chelain (1979) reported Pattern 1 at the Type B site, wheras Pattern 2 was observed at the Type A site during the present investigation.

It is not clear in what way the distance from a mature community could affect the fouling events. It may be best to approach this question by considering the factors by which a mature community could influence the colonization rate in its vicinity. These factors would be lesser or absent at some distance away.

The further one gets from a source of larvae, the less larvae one would expect to find, depending on the duration of their dispersal phase and the prevalent water currents. It has been indicated that very high concentrations of larvae can lead to "indiscriminate" settlement, which would cause deviations from an orderly succession pattern (Knight-Jones, 1951). Larval concentrations were not measured at the two Type A sites used in the present study, but it is felt that the degree of panel colonization over a month would be unusually high at very dense larval concentrations. The overall monthly colonization rates were low (580/dm^2/month in Simonsbay; 930/dm^2/month in Table Bay) compared to figures obtained in other experiments (5452/dm^2/month in Simonsbay, Part I; more than 1290/dm^2/month off Melkbosstrand, personal observations). Therefore, the early colonization of panels should not be attributed to abnormal concentrations of larvae.

Another factor that could be related to the distance from a mature community is the concentration of specific organic compounds produced by members of the community. Some of these compounds may be adsorbed onto surfaces and could promote or deter colonization. That such chemicals could exist has been suggested by Goodbody (1961), who found that colonization was inhibited close to a mature sponge-anemone-ophiuran community. The existence of other surface-active molecules that attract settlers has been demonstrated in laboratory experiments (Crisp & Williams, 1960; Crisp & Meadows, 1962; Williams, 1964). If sedentary invertebrates primarily respond to such chemical factors in nature, members of a mature community would be capable of influencing colonization on bare substrata in their vicinity. The concentration of these compounds would be lower at some distance from its source where

secondary characteristics of the primary film, for instance, its ability to concentrate the specific chemicals, would influence colonization. The evolutionary advantage of such a postulated mechanism would lie in the ability of larvae to recognize the proximity of an established community as a potentially suitable habitat (Crisp, 1976) or as an unsuitable locality where competition would be unfavourable.

It is suggested that factors related to the distance from a mature community could have a greater influence on colonization than the development of a primary film. This could explain the discrepancy of conclusions drawn in different studies, but since authors have seldom documented the presence or absence of already established communities in the vicinity of their study sites, this suggestion remains to be tested.

4. SUMMARY & CONCLUSION

4.1. CONCLUSION

Techniques of enriching or retarding primary film development were tested in this study and used to evaluate the importance of microfouling to settling invertebrates. The following conclusions can be made:-

a) The use of surface-bound chemicals is more effective than are intermittent treatments with chemicals in solution in inhibiting primary film development. At 1% concentration in paint, penicillin and streptomycin reduced bacteria proliferation by more than 90%, which retarded the general development of primary film, but only marginally reduced the settlement rate of invertebrates. Herbicide application, 2% diuron in paint, inhibited diatoms, but apart from increasing fungal proliferation, had no marked effect on other colonizers. Advancing the primary film development by 10-day pre-culturing did not increase the initial settlement rate of macroorganisms.

b) In general, primary film development on control panels in Table Bay followed the normal sequence of bacteria, mucilage network, diatoms, fungus and protozoa colonization, the rate of development being similar as that in other studies conducted in local waters. An early stage of first tier fouling, dominated by bacteria and their products, was later overgrown by a second tier in which large diatoms and fungus dominated.

c) Spirorbis and Balanus settled on the first day and were common after a few days of panel exposure. The colonization rate of other species was slower, but none of the macroorganisms showed marked preferences for surfaces with retarded or advanced primary films. This indicates that primary film development played no fundamental role in the settlement response of invertebrates in this study. Changes in surface characteristics caused by the primary film are considered to be of secondary importance to other factors.

d) It is postulated that the settlement rate of invertebrate foulers is sensitive to factors related to their distance from an established community. The proximity of rich communities at the present study sites would negate the importance of a primary film. Conversely, it it possible that microfouling would be of greater importance to macrofouling at sites some distance away from established communities.

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4.3. REFERENCES

Baier R.E. (1970) Surface Properties Influencing Biological Adhesion. In: R.S.Manly (Ed.) Adhesion in Biological Systems. Academic Press, N.Y., London.

Baier R.E., E.G.Shafrin & W.A.Zisman (1968) Adhesion: Mechanisms that assist or impede it. Science 162:1360-8

Barnes H. (1970) A Review of some Factors Affecting Settlement and Adhesion in the Cyprid of Common Barnacles. In: R.S.Manly (Ed.) Adhesion in Biological Systems. Academic Press, N.Y., London.

Chet I., P.Asketh & R.Mitchell (1975) Repulsion of Bacteria from Marine Surfaces. Appl.Microbiol.30:1043-5

Clark W.G. (1963) Inhibition of Amino Acid Decarboxylases. In: R.M.Hochster & J.H.Quastel (Eds.) Metabolic Inhibitors Vol 1:316-82

Corpe W.A. (1970) Attachment of Marine Bacteria to Solid Surfaces. In: R.S.Manly (Ed.) Adhesion in Biological Systems. Academic Press, N.Y., London.

Crisp D.J. (1976) Settlement responses in marine organisms. In: R.C.Newell (Ed.) Adaptations to Environment. Butterworths, London, Boston. pp83-124

Crisp D.J. & P.S.Meadows (1962) The chemical basis of gregariousness in cirripedes. Proc.roy.Soc.B.156:500-20

Crisp D.J. & J.S.Ryland (1960) Influence of Filming and of Surface Texture on the Settlement of Marine Organisms. Nature 185:119

Crisp D.J. & G.B.Williams (1960) Effect of Extracts from Fucoids in promoting Settlement of Epiphytic Polyzoa. Nature 188:1206-7

Cundell A.M. & R.Mitchell (1977) Microbial Succession on a Wooden Surface Exposed to the Sea. Int.Biodeterior.Bull.13(3):67-73

Daniel A. (1955) The Primary Film as a Factor in Settlement of Marine Foulers. J.Madras Univ.B.25(2):189-200

de Chalain T.M.B. (1979) An Investigation into Aspects of Biological Fouling on Selected Artificial Substrates, at Sub-littoral Depths in Simonsbay. M.Sc.Thesis, University of Cape Town.

Dempsey M.J. (1981) Marine Bacterial Fouling: A Scanning Electron Microscope Study. Mar.Biol.61(4):305-15

Dexter S.C., J.D.Sullivan, J.Williams & S.W.Watson (1975) Influence of Substrate Wettability on the Attachment of Marine Bacteria to Various Surfaces. Appl.Microbiol.30(2):298-308

DiSalvo L. (1973) Contamination of surfaces by bacterial neustron. Limnol.Oceanogr.18:165-8

Eiben R. (1976) Einflusz von Benetzungsspannung und Ionen auf die Substratbesiedelung und das Einsetzen der Metamorphose bei Bryozoenlarven (Bowerbankia gracilis). Mar.Biol.37:249-54

Fletcher M. & G.D.Floodgate (1973) An Electron-microscopic Demonstration of an Acidic Polysaccaride Involved in the Adhesion of a Marine Bacterium to Solid Surfaces. J.Gen.Microbiol.74:325-34

Fletcher M. & G.I.Loeb (1979) Influence of Substratum Characteristics on the Attachment of a Marine Pseudomonad to Solid Surfaces. Appl.Envirl.Microbiol.37(1):67-72

Gabbott P.A. (1976) Energy Metabolism. In: B.L.Bayne (Ed.) Marine Mussels, Internat.Biol.Programme 10:293-355 Cambridge University Press, Britain.

Gadd G.M. & A.J.Griffiths (1978) Microorganisms and heavy metal toxicity. Microb.Ecol.4:303-17

Geesey G.G., W.T.Richardson, H.G.Yeomans, J.T.Irvin & J.W.Costerton (1977) Microscopic examination of natural, sessile bacterial populations from an alpine stream. Canadian Journal of Microbiology 23:1733-6

Goodbody I. (1961) Inhibition of the Development of a Marine Sessile Community. Nature 190:282-3

Gray J.S. (1966) The attractive factor of intertidal sands to Protodrilus symbioticus. J.mar.biol.Ass.UK.46:627-45

Horbund H.M. & A.Freiberger (1970) Slime films and their role in marine fouling: A Review. Ocean Engng.1(6):631-4

Jackson J.B.C. (1977) Competition on Marine Hard Substrata: The Adaptive Significance of Solitary and Colonial Strategies. Amer.Natur.3(980):743-67

Jones H.C., I.L.Roth & W.M.Sanders (1969) Electron Microscopic study of a slime layer. Jour.Bact.99(1):316-25

Ketchum B.H. & M.W.Davidson (1941) The Copper Content of Slime Films. Progress Report, Woods Hole Oceanographic Institute report to the US Navy Bureau of Ships.

Knight-Jones E.W. (1951) Gregariousness and some other Aspects of the Setting Behaviour of Spirorbis. J.mar.biol.Ass.UK.30:201-222

Knight-Jones E.W. & D.J.Crisp (1953) Gregariousness in barnacles in relation to the fouling of ships and to anti-fouling research. Nature 171(4364):1109-10

Liberatore G.L., E.J.Dyckman, J.A.Montemarano & M.L.Cohn (1972) Antislime Coatings. Part II: Preconditioning value of slime for barnacle attachment. Report 3597 Naval Ship Research and Development Center, Bethesda, Maryland.

Loeb G.I. (1978) The settlement of fouling organisms on hydrophobic surfaces. Progress Report, US Naval Research Laboratories.

Loeb G.I. & R.A.Neihof (1974) Marine Conditioning Films. Progress Report, US Naval Reasearch Laboratories.

Losada M & D.I.Arnon (1963) Selective Inhibitors of Photosynthesis. In: R.M.Hochster & J.H.Quastel (Eds.) Metabolic Inhibitors Vol.2:

Lucas M.I., G.Walker, D.L.Holland & D.J.Crisp (1979) An Energy Budget for the Free-Swimming and Metamorphosing Larvae of Balanus balanoides (Crustacea:Cirripedia) Mar.Biol.55:221-9

Marshall K.C. (1980) Microorganisms and Interfaces. Bioscience 30(4):246-9

Marshall K.C. & R.H.Cruickshank (1973) Cell Surface Hydrophobicity and the Orientation of Certain Bacteria at Interfaces. Arch.Mikrobiol.91:29-40

Marshall K.C., R.Stout & R.Mitchell (1971) Mechanisms of the initial events in the sorption of marine bacteria to surfaces. J.Gen.Microbiol.68:337-348

Marszalek D.S., S.M.Gerchakov & L.R.Udey (1979) Influence of Substrate Composition on Marine Microfouling. Appl.Envirl.Microbiol.38(5):987-95

Meadows P.S. (1964) Experiments on Substrate Selection by Corophium Species: Films and Bacteria on Sand Particles. J.Exp.Biol.41:499-511

Meadows P.S. (1971) The Attachment of Bacteria to Solid Surfaces. Arch.Mirkrobiol.75:374-81

Meadows P.S. & J.I.Campbell (1972) Habitat Selection by Aquatic Invertebrates. Adv.mar.Biol.10:271-82

Meadows P.S. & G.B.Williams (1963) Settlement of Spirorbis borealis Daudin Larvae on Surfaces bearing Films of Microorganisms. Nature 198(4880):610-1

Miller M.A., J.C.Rapean & W.F.Whedon (1948) The role of slime film in the attachment of fouling organisms. Biol.Bull.Woods Hole 94(2):143-57

Mitchell R., I.Chet & P.Asketh (1975) Negative Chemotaxis: A New Approach to Marine Fouling Control. Technical Report 1, Division of Engineering and Applied Physics, Harvard University, Cambridge, Massachusetts.

Mitchell R., A.M.Cundell, P.J.Boyle & T.D.Sleeter (1977) The role of microorganisms in marine fouling and boring processes. Technical Report 3, Division of Engineering and Applied Physics, Harvard University, Cambridge, Massachusetts.

Mitchell R. & L.Young (1972) The role of microorganisms in marine fouling. Technical Report 3, Division of Engineering and Applied Physics, Harvard University, Cambridge, Massachusetts.

Müller W.A. (1973) Metamorphose-Induktion bei Planulalarven I. Der bakterielle Induktor. Wilh.Roux'Arch.173:107-21

Müller W.A. & G.Buchal (1973) Metamorphose-Induktion bei Planulalarven. II. Induktion durch monovalente Kationen. Wilh.Roux'Arch.173:122-35

Müller W.A., F.Wieker & R.Eiben (1976) Larval Adhesion, Releasing Stimuli and Metamorphosis. In:G.O.Mackie (Ed.) Coelenterate Ecology and Behaviour.
Plenum Press, N.Y., London.

Neihof R. & G.Loeb (1974) Dissolved organic matter in seawater and the electric charge of immersed surfaces. J.Mar.Res.32:5-12

Neumann R. (1979) Bacterial Induction of Settlement and Metamorphosis in the Planula Larva of Cassiopea andromeda (Cnidaria: Scyphozoa, Rhizostomea). Mar.Ecol.Progr.Ser.I:21-8

O'Neill T.B. & G.L.Wilcox (1971) The Formation of a "Primary Film" on Materials Submerged in the Sea at Port Hueneme, California. Pac.Sci.25:1-12

Paul R.W., D.L.Kuhn, J.L.Plafkin, J.Cairns & J.G.Croxdale (1977) Evaluation of Natural and Artificial Substrate Colonization by Scanning Electron Microscopy. Trans.Amer.Micros.Soc.96:506-19

Phelps A. (1941) Observations on Reactions of Barnacle Larvae and Growth of Metamorphosed Forms at Beaufort, North Carolina, June-September 1941. Paper 7, Progress Report of Woods Hole Oceanographic Research Institute to US Navy Bureau of Ships.

Pomerat C.M. & E.R.Reiner (1942) The Influence of Surface Angle and of Light on the Attachment of Barnacles and other Sedentary Organisms. Biol.Bull.Woods Hole 82:14-25

Rainbow P.S. & G.Walker (1977) The Functional Morphology and Development of the Alimentary Tract of Larval and Juvenile Barnacles. Mar.Biol.42:337-49

Rastetter E.B. & W.J.Cooke (1979) Responses of Marine Fouling Communities to Sewage Abatement in Kaneohe Bay, Oahu, Hawaii. Mar.Biol.53:271-80

Renn C.E. (1964) The Bacteriology of Interfaces. In: H.Heukelekion & N.C.Dondero (Eds.) Principles and Applications in Aquatic Microbiology. John Wiley & Sons Inc, N.Y., London, Sydney.

Renn C.E. & D.B.Johnston (1940) Effects of bacterial decomposition of matrix materials upon leaching rates of antifouling paints. Paper 6, Report of the Woods Hole Oceanographic Institute to the US Navy Bureau of Ships.

Schleyer M.H.(1981) Microorganisms and Detritus in the Water Column of a Subtidal Reef of Natal. Mar.Ecol.Prog.Ser.4:307-20

Scholefield P.G. (1963) Fatty Acids and Their Analogues. In: R.M.Hochster & J.H.Quastel (Eds.) Metabolic Inhibitors Vol.1:154-73

Sieburth J.McN. (1979) Sea Microbes. Oxford Univ.Press,NY.

Skerman T.M. (1956) The Nature and Development of Primary Films on Surfaces Submerged in the Sea. New Zealand Journal of Science & Technology, July 1956.

Umezawa H. (1967) Index of antibiotics from actinomycetes. University of Tokyo Press, Tokyo.

United States Naval Institute (1952) Marine Fouling and its Prevention. Woods Hole Oceanographic Research Inst.

Waksman S.A. & C.M.Weiss (1941) The Biology and Chemistry of the Silme Film: The Microbiology of the Slime Film. Paper 2, Progress Report of the Woods Hole Oceanographic Research Institute to the US Navy Bureau of Ships.

Weiss C.M. (1944) Settling and Metamorphosis of Barnacle Larvae on Painted Surfaces at Beaufort N.C. Paper 8, Progress Report of the Woods Hole Oceanographic Research Institute to the US Navy Bureau of Ships.

Weiss C.M. & B.H.Ketchum (1941) The Accumulation of Copper by Slime Films formed on Non-toxic Surfaces. Paper 6, Report of Woods Hole Oceanographic Institute to the US Navy Bureau of Ships.

Wilson D.P. (1955) The Role of Micro-organisms in the Settlement of Ophelia bicornis, Savigny. J.mar.biol.Ass.UK.34:531-43.

Wood E.J.F. (1950) Investigations on Underwater Fouling. I. The role of bacteria in the early stages of fouling. Australian Journal of Marine & Freshwater Research 1:84-91

Woodruff H.B. & I.M.Miller (1963) Antibiotics. In: R.M.Hochster & J.H.Quastel (Eds.) Metabolic Inhibitors Vol.2: 23-52

Yongue W.H. & J.Cairns (1971) Micro-Habitat pH Differences from those of the Surrounding Water. Hydrobiologia 38: 453-61

Young L. & R.Mitchell (1973) Negative Chemotaxis of Marine Bacteria to Toxic Chemicals. Appl.Microbiol.25(6):972-5

Zachary A., M.E.Taylor, F.E.Scott & R.R.Colwell (1978) A Method for Rapid Evaluation of Materials for Susceptibility to Marine Biofouling. Int.Biodeterior.Bull.14:111-8

Zobell C.E. (1939) The role of bacteria in the fouling of submerged surfaces. Biol.Bull.Woods Hole 67(2):302

Zobell C.E. (1943) The effect of solid surfaces upon bacterial activity. Jour.Bacteriol. 46:39-50

Zobell C.E. & E.C.Allen (1935) The significance of marine bacteria in the fouling of submerged surfaces. Jour.Bacteriol.29:239-51

5. APPENDIX

5.1. A LOOK AT FOULING ON ANTIFOULING PAINTS

5.1.1. Introduction

Present antifouling measures used for ships employ toxic paints or provide unstable substrata. They are specially designed to prevent the growth of invertebrates and algae, and are usually effective in this for a limited period of time (seldom exceeding three years; Dempsey, 1981).

Marine bacteria can respond to unfavourable substances by negative chemotaxis: Randomly change direction in response to an unfavourable stimulus, with the nett result that they remove themselves from a lethal or potentially lethal region (Young & Mitchell, 1973). In this way many types of bacteria appear to be capable of avoiding attachment to toxic antifouling surfaces (Mitchell et al, 1975).

It has been known for some time that some marine bacteria, notably gram-negative rod bacteria, are resistant to heavy metals and attach in large numbers (Ketchum & Davidson, 1941; Gadd & Griffiths, 1978; Marszalek et al, 1979; Dempsey, 1981). In fact, bacteria may play an integral part in the leaching of these chemicals by degrading the paint or by binding the chemicals in their mucilage layer (Renn & Johnstone, 1941; Ketchum & Davidson, 1941). This can increase the antifouling effectiveness if the film becomes toxic (Weiss & Ketchum, 1941) or decrease its effectiveness by shielding the toxic surfaces with a mucilage layer (Miller et al, 1948; Geesey et al, 1977), chemical complexing or detoxification (Gadd & Griffiths, 1978).

The purpose of the present experiment was to examine microfouling on a number of antifouling paints commonly used in South Africa.

5.1.2. Material & Methods

The following paints were tested:-

a) Chlorinated rubber (CR), Interspeed BLA 200 extra, with organotin/copper-oxide;

b) Vinyl copper (VC), Interspeed BJA 600 super, with copper oxide;

c) Cold plastic (CP), Interclene BCA 500 extra, with rosin-phenolic oil base and Cu/Zn oxides.

d) Self-polishing copolymer (SPC), Intersmooth BFA series SPC, with organotin/zinc-oxide.

A number of coats of paint were applied to PVC panels (5x5cm). These were tied to frames and submerged at a depth of 2-3m in Table Bay. The experiment was carried out during March, 1981, simultaneously and at the same site (but downstream) as the main experiment (section 2.3.). Samples were removed from each set after 7, 14 and 28 days and prepared for scanning electron microscope (SEM) examination (see section 1.2.7.).

5.1.3. Results & Discussion

The paint surfaces were viewed under scanning electron microscope and compared to surfaces, which had been painted with non-toxic vinyl-acrylic Intervinux (IV), used in the main experiment (section 2.3.2.).

Two of the paints (VC & CP) were unsuitable for the standard dehydration process. VC produced copious amounts of greenish material which dissolved in alcohol. CP chapped and cracked into small fragments and partially disintegrated. It is likely that the appearance of VC and CP surfaces was altered and any microorganisms, that might have been present, destroyed. Some material was also lost off the unstable SPC surface during the dehydration process and it is possible that this could have affected its appearance.

The micrographs presented on plate 4.1.3. concentrate on chlorinated rubber, because of its rich bacterial community. By standardless element analysis (KEVEX; see section 1.2.7.) it was found that chlorinated rubber was composed of 84.6% copper oxide. In spite of this high content of the heavy metal, it was found that bacteria proliferated on CR and were five to ten-fold as numerous after 28 days as on control surfaces, IV (see fig.2.3.3.a). The unusually high abundance of rod bacteria attained was perhaps possible because of the absence of space competitors, like diatoms, and the lack of grazers, like protozoa. Only few, perhaps only one type of rod bacteria were seen, indicating that copper oxide/organotin tolerance was limited. Dempsey (1981) also found that only a few types of gram-negative bacteria were tolerant to copper oxide/organotin antifoulants, but that these could become very numerous. It should be noted that

despite this rich bacterial growth, the short-term antifouling efficiency against macroorganisms was not affected. A better understanding could be gained if leaching rate before and after exposure were measured.

SPC was nearly devoid of bacteria. Besides toxicity, the effectiveness of SPC against fouling is based on the unstable properties of its surface, which literally wears off. Any bacteria that may attach are soon carried off with the dislodged surface material. This desirable property of SPC, however, gives it only a limited lifetime, depending on its thickness.

5.1.4. Conclusion

Chlorinated rubber does not prevent the development of a rich bacterial fouling community, but the number of resistant types is limited. In the long run this bacterial proliferation could affect the durability of the paint.

Self-polishing copolymers prevent biological fouling of all forms because of their unstable surfaces.

5.1.5. Acknowledgements

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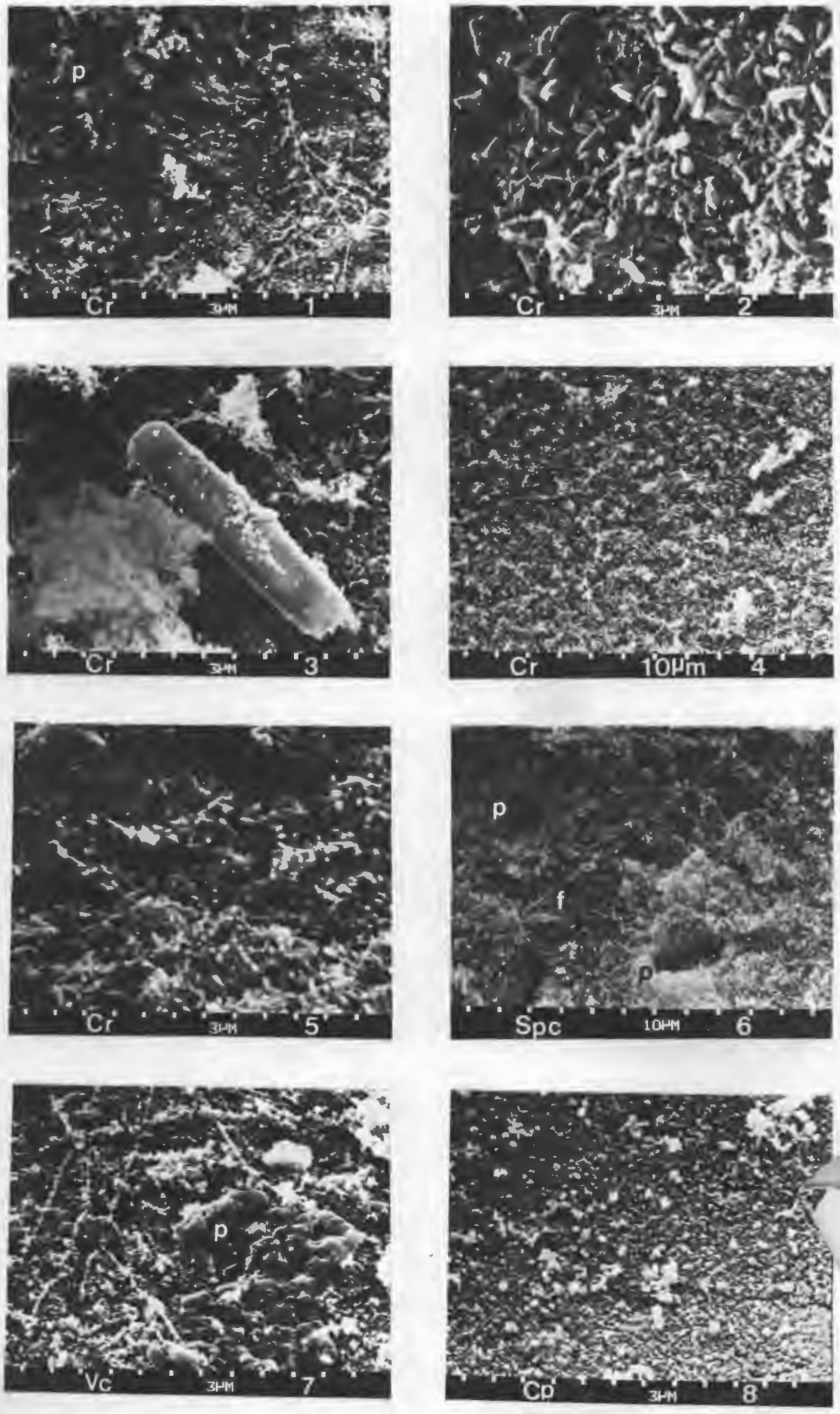

Plate 5.1.3. - Antifouling Paints

Plate 5.1.3. - Antifouling Paints

Frame 1: Chlorinated Rubber, 7days (1800X)
Numerous rod bacteria ($1,0x10^5/mm^2$) on a grainy uneven surface were entwined in a spreading network of mucopolysaccharide threads. The hole is probably a pore (p) caused by leaching.

Frame 2: Chlorinated Rubber, 14days (3000X)
Bacteria were abundant ($1,8x10^5/mm^2$) and had produced a thick network of threads, which covered the whole surface and even blocked the pores.

Frame 3: Chlorinated Rubber, 14days (1800X)
This pennate diatom (only one seen), like the debris next to it, may have become attached to the surface passively. Copper oxide is probably toxic to it, preventing its further growth.

Frame 4 & 5: Chlorinated Rubber, 28days (600X, 1800X)
Bacteria had reached such high numbers (about $6x10^5/mm^2$ on top surface) that they were stacked on top of each other in a thick layer.

Frame 6: Self Polishing Copolymer, 14days (600X)
The woolly appearance of this paint indicates how unsuitable this surface is for attachment. The soft top layer erodes away to leave the surface sterile. This view shows one filament (f), which could be a bacterium, and two leaching pores (p).

Frame 7: Vinyl Copper, 14days (1800X)
Dark material, probably the greenish deposit mentioned in the text, appears to emerge from a pore (p). This surface looks barren besides the floccular material arranged in the background.

Frame 8: Cold Plastic, 14days (1800X)
Numerous small globules covered this surface to give it a very granular appearance. This sample was spoilt by the dehydration process.

5.2. DATA OF FINAL EXPERIMENT

TYPE	Day 1	Day 3	Day 7	Day 14	Day 28
	Spirorbis/dm²				
IV	5,1+1,2	12,7+2,8	77,6+10,4	191,9+23,1	357,1+29,2
PC	6,0+1,9	15,4+1,7	99,8+16,8	203,8+16,6	296,5+40,5
SP	3,1+0,8	9,8+2,4	58,3+ 8,0	178,3+15,0	264,1+25,6
DU	3,2+1,0	7,6+1,8	69,2+ 4,2	140,4+ 7,9	303,4+15,7
	Hydrozoa/dm²				
IV	0,0	0,0	0,0	1,4+ 1,0	46,4+19,2
PC	0,4+0,4	0,6+0,5	0,8+0,4	1,2+ 0,5	93,4+33,5
SP	0,0	0,1+0,2	0,2+0,2	0,4+ 0,3	28,6+14,8
DU	0,1+0,1	0,2+0,2	0,2+0,2	0,4+ 0,4	41,5+20,2
	Ascidians/dm²				
IV	0,1+0,1	0,2+0,2	0,2+0,3	3,2+ 0,8	479,1+95,6
PC	0,4+0,3	1,2+1,8	1,2+1,8	2,0+ 0,7	307,9+93,7
SP	0,1+0,1	0,1+0,1	0,1+0,2	3,0+ 0,9	197,5+37,3
DU	0,0	0,2+0,2	0,2+0,1	1,4+ 1,0	303,6+64,7
	Other/dm²				
IV	0,6+1,2	0,6+1,2	0,6+1,2	1,6+ 0,8	46,8+10,6
PC	0,1+0,2	0,2+0,2	0,5+0,4	6,0+ 1,7	34,1+10,8
SP	0,0	0,0	0,8+0,6	1,1+ 0,6	23,5+ 6,7
DU	0,0	0,1+0,3	0,1+0,2	1,8+ 1,2	30,4+ 5,7
	Total/dm²				
IV	5,8+1,6	13,0+2,8	78,1+10,5	198,3+23,8	929,4+124,0
PC	6,9+1,1	16,2+1,7	100,9+16,8	212,9+16,7	731,9+142,0
SP	3,1+0,8	9,9+2,5	59,3+ 8,0	182,9+15,0	514,0+ 55,1
DU	3,3+1,0	8,2+1,8	69,4+ 4,1	143,9+ 7,9	681,4+ 86,7
	Bacteria/mm²				
IV	13550	164335	194110	165524	90291
PC	67847	89133	144565	250245	52301
SP	3	279	880	2697	10156
DU	15045	50256	106206	224722	209577

ABBREVIATIONS

PART I

Site 1 - 20m; 1,5km offshore, Simonsbay
Site 2 - 10m; 0,5km offshore, Simonsbay
Site 3 - 10m; at the harbour wall, Simonstown
AL - Aluminium
SS - Stainless Steel
MS - Mild Steel
SR - Silicon Rubber
FG - Fibre Glass
PVC - Polyvinylchloride

PART II

Preliminary Study

AB - Antibiotic treatment
SW - Seawater dip control
CON - Undisturbed control

Feasibility Study

SPT - Streptomycin, penicillin & tannic acid antibiotics
DU - Diuron herbicide
IV - Control; Intervinux paint

Final Experiment

SP - Streptomycin & penicillin antibiotics
DU - Diuron herbicide
PC - Primary film pre-culture before experiment
IV - Intervinux control