Chapter 16

DIATOM COMMUNITIES ON STEEL PROTECTED FROM CORROSION IN SEAWATER

R.G.J.EDYVEAN. DEPARTMENT OF METALLURGY
UNIVERSITY OF SHEFFIELD, SHEFFIELD U.K. S1 3JD.

16.1 INTRODUCTION

There is a large body of work comparing micro-algal settlement (especially diatoms) on different substrata in freshwater (Blinn et al.,1980; Moore, 1976; Brown, 1976), however, only recently has this quantitative and qualitative work been extended to marine habitats (Neushul et.al.,1976; Santelices et.al.,1981; Edyvean et.al.,1985). The development of oil and gas production in the seas around Britain has led to a renewed interest in the effects of marine fouling of steel structures in seawater, especially the influence of microfouling upon subsequent macrofouling, and in the relationship between fouling organisms and the corrosion of steel (Houghton, 1978; Ralph & Troake, 1980; Terry & Edyvean, 1984).

A surface placed in the sea immediately undergoes complex physical and chemical interactions, resulting in dissolved organic material being absorbed/adsorbed onto the surface and changing the electrostatic and other characteristics of the substratum (Loeb & Neihof, 1977). Following these interactions, bacteria, diatoms and other microorganisms begin to colonise the substratum (Floodgate, 1971; Cuba & Blake, 1983). Diatoms usually comprise the greatest percentage of microalgal colonisation and can be present in large numbers within a few days of immersion (Cuba & Blake, 1983). This colonisation, known as the primary film, can considerably influence the physical and chemical conditions at the surface (Terry & Edyvean, 1984; Edyvean, 1984) and may influence macrofouling settlement and development, by chemical, nutrient (Young & Mitchell, 1973) or surface tension changes (Fletcher et al., 1984).

The methods used to protect steel structures from corrosion in seawater are barrier paints, cathodic protection, or a combination of both. Anti-corrosion barrier paint systems are usually coal-tar epoxy coatings used in conjunction with cathodic protection. Cathodic protection counteracts the normal electrochemical corrosion reaction by forcing the steel to become cathodic with respect to a sacrificial or inert anode. Sacrificial anodes are pieces of metal, such as Magnesium, Aluminium or Zinc alloys which, when in electrical connection with the structure, will corrode in preference to the steel. Inert anodes are used with a DC electrical current which is driven through the structure in the opposite direction to the normal corrosion current. The relative surface area and distance between the anode and the structure to be protected is dependant on the properties of the electrolyte (the seawater). Protection will cease if the electrolyte is removed (eg. by a receding tide) as the electrochemical circuit is broken. Both systems generate a high pH at the metal surface caused by the reduction of oxygen to form hydroxyl ions (the cathodic reaction) and since the solubility of most inorganic compounds, especially calcium and magnesium carbonates, decreases with increasing pH, calcareous deposits ("scale") will form on the protected steel. This scale is insoluble at normal seawater pH and can be an aid to corrosion prevention.

Many offshore oil and gas platforms in the North Sea are protected by a combination of coal-tar epoxy paints and zinc sacrificial anodes. This presents three possible substrata for colonisation by marine fouling organisms, a calcareous scale formed on cathodically protected steel, a painted steel surface, and a combination of the two systems in which calcareous scale fills any cracks in the paint. The study presented here assesses diatom settlement on these surfaces together with Perspex as a control at two sites, one continuously submerged and the other in the intertidal zone.

Fig. 16.1. Site of substrata exposure.

16.2 MATERIALS AND METHODS

16.2.1 Preparation of substrata

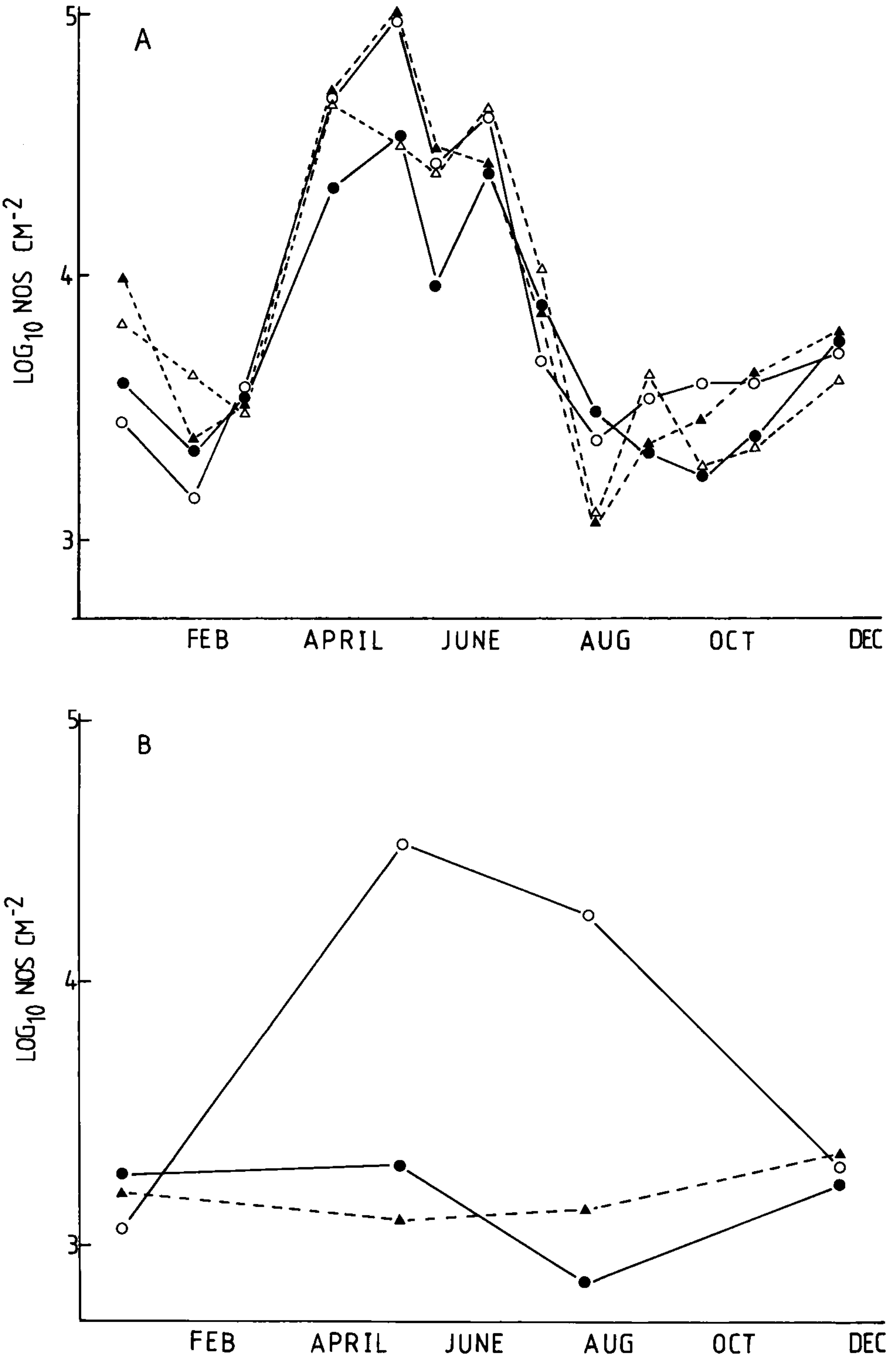
Perspex and steel substrata were cut to a standard size (8cm.x 2.5cm.x 0.3cm) with 1cm. holes drilled at one end for suspending on racks or mounting onto exposure panels. The steel, to BS 4360/43A specification was abraded to bright metal and protected from corrosion by: (a) connection to Zinc sacrificial anodes, (b) coating with an epoxy coal tar paint, or (c) protected by a combination of both systems. When used, anodes were positioned in such a way as to ensure even protection (even current density) over all steel specimens. All substrata were cleaned before use by immersion in concentrated surfactant (Decon 90) for ten minutes, washed in hot running water, rinsed in two changes of absolute ethanol, air dried and stored in a desiccator until required.

16.2.2 Exposure sites

Substrata were exposed at two sites: On racks in 50 cm. deep continuously flowing seawater tanks at the Dove Marine Laboratory, Cullercoats, Tyne and Wear (Grid Ref. NZ366717) or bolted to Perspex panels fixed to rocks in the intertidal zone at St.Mary's Island (Grid Ref. NZ353755). Both sites are on the north-east coast of England (Fig.16.1). Substrata were exposed for sequential 25 day periods between June 1980 and January 1982, for the continuously submerged site, and for four 25 day periods during 1981 at the intertidal site. These were the 25 days ending 8th. January, 19th. May, 3rd. August and 10th. December 1981.

16.2.3 Assesment of settlement

Total algal counts were made throughout 1981 at both sites. Community composition was assessed for each exposure period between June 1980 and June 1981 for the submerged substrata and throughout 1981 for the intertidally exposed substrata. Microalgal settlement was assessed quantitatively by using the direct count on membrane filter method of Jones (1979) and qualitatively using scanning electron microscopy. Replicate plates of the four substrata (three at the intertidal site), were removed at each sample date and stored in 0.45µm membrane-filtered seawater containing Lugol's iodine. Algae were removed from each plate with a small nylon bristle brush into known quantities of membrane filtered seawater containing Lugol's iodine. The resulting suspensions were diluted as necessary, and three replicate 5 ml. samples passed through 13 mm. diameter 0.45µm Millipore filters. The filters were placed on microscope slides, air dried and cleared with cedarwood oil. Algal counts and identification were made for 50 fields of view at X400 using a Vickers M17 microscope and the number of organisms on the original substratum calculated. Sub samples were washed in a 20% solution of ethanol containing 2% surfactant, filtered onto 0.2µm pore size "Nucleopore" polycarbonate filters, air dried,



A
5
4
3
LOG10 NOS CM-2
FEB
APRIL
JUNE
AUG
OCT
DEC
B
5
4
3
LOG10 NOS CM-2
FEB
APRIL
JUNE
AUG
OCT
DEC

gold coated and the algae identified using a JEOL JSM 1 Scanning Electron Microscope. Diatoms were identified to genera, and to species whenever possible, and all individuals were counted whether solitary or colonial. Other unicellular algae (green, blue-green and algal spores) were counted as individuals while each piece of a filamentous alga or macroalgal germling was counted as one unit.

16.3 RESULTS

16.3.1 Total microalgal counts

Microalgal communities developed to a greater or lesser extent on all substrata, depending on the time of year, but no macrofouling was found during the 25 day exposure periods. Colonisation was rapid at both sites with a layering process taking place, in which the initial colonising species are overgrown by different species. It was noticed that while colonisation tended to be uniform on the continuously submerged substrata, colonisation was more clumped and patchy on the intertidally exposed substrata.

Total numbers of microalgae present on the continuously submerged substrata are shown in Figure.16.2 (A). Counts were highest (98,400 per sq.cm.) for the 25 day period prior to the 16th.May 1981 on cathodically protected painted steel. The lowest value of 1,200 per sq.cm. was for the 25 days prior to the 14th.August 1981 on the same substratum. There were typical seasonal fluctuations in microalgae on all substrata, with peaks in the late spring and late autumn. Counts of microalgae on the intertidally exposed substrata are shown in Figure 16.2 (B). Counts were highest (41,800 per sq.cm.) for the 25 day period prior to the 19th. May 1981 on Perspex and lowest (817 per sq.cm.) for the 25 day period prior to 3rd. August 1981 on cathodically protected steel. On these intertidal substrata, seasonal fluctuations were only found on perspex.

The counts were analysed to determine any significance in the differences between substrata (One way analysis of variance on pairs of substrata, Sokal and Rohlf, 1969). On the continuously submerged substrata, cathodically protected steel had significantly lower levels of algae than the other substrata ($P<0.001$ for perspex, $P<0.02$ for cathodically protected painted steel and $P<0.1$ for painted steel) but there were no significant differences between the other substrata. At the intertidally exposed site algal numbers were significantly greater on Perspex than the other substrata during the summer months ($P<0.001$) but not when compared over all exposure periods, nor were there any significant differences between the other substrata.

Fig.16.2. (Opposite). Microalgal numbers on substrata exposed during 1981, (A).continuously submerged and (B) exposed intertidally. ○———○ Perspex. △- - - - -△ Painted steel. ▲- - - - -▲ Cathodically protected painted steel. ●———● Cathodically protected steel.

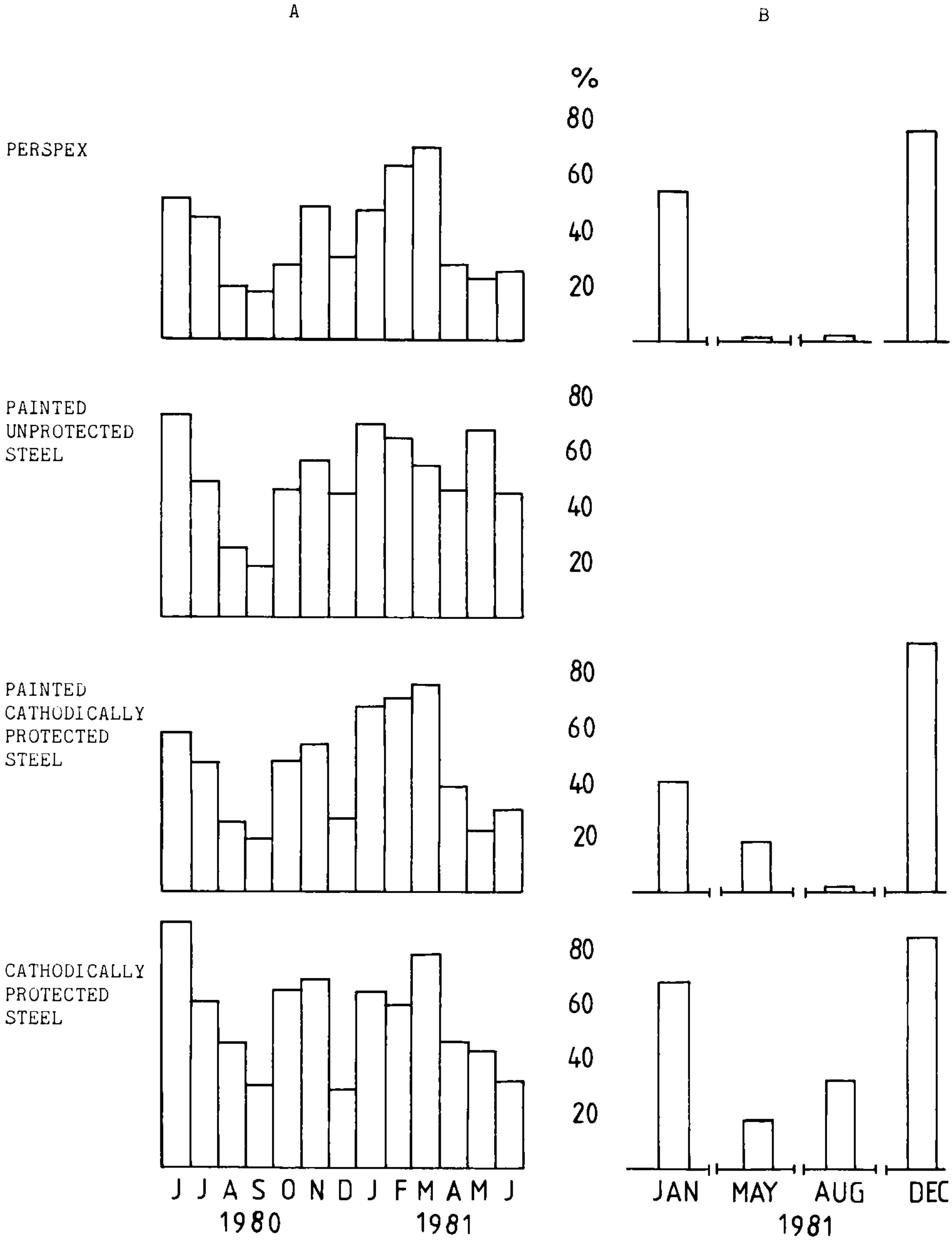


Fig. 16.3. Relative seasonal abundance of non-diatom algae as a percentage of total microalgal colonization on substrata A) Continuously submerged and B) exposed intertidally.

16.3.2 Community composition

The proportion of the communities made up of diatoms and other microalgae averaged over all exposure periods are given in Table 16.1.

TABLE 16.1

Average percentage of microalgal groups on A. Continuously submerged substrata and B. Intertidally exposed substrata. PX = Perspex, PU = Painted steel, PP = Cathodically protected painted steel, CS = Cathodically protected steel.

	PX	PU	PP	CS
A				
DIATOMS	64.4	53.7	56.3	46.4
OTHER UNICELLULAR ALGAE	34.9	44.9	42.4	52.2
MULTICELLULAR ALGAE	0.7	1.4	1.3	1.4
B				
DIATOMS	66.8	-	51.0	49.2
OTHER UNICELLULAR ALGAE	28.6	-	36.6	44.1
MULTICELLULAR ALGAE	4.6	-	12.4	6.7

At both sites diatoms are in greatest abundance on Perspex and least abundant on cathodically protected steel, making up between 46% and 67% of the total algal communities. There is, however, considerable seasonal variation, with other algae (unicellular green and blue-green algae, algal spores and filamentous green and red algae which may or may not have been actively attaching to the substrata) making up very high proportions of the communities at certain times of the year, especially on the intertidally exposed substrata (Figure 16.3).

The average composition of diatom communities is shown in Table 16.2 for the continuously submerged substrata and in Table 16.3 for the intertidally exposed substrata. 18 genera of diatoms were found, 17 on the submerged substrata and 11 on the intertidally exposed substrata. 10 were common to both sites, but only 6 averaged more than 5% on any of the substrata communities.

The most prominent diatoms were *Navicula* spp. (particularly *N. grevillei* (Agardh) Cleve found both as individuals and in colonial chains) which averaged between 55% and 67% of the diatom total on the continuously submerged substrata and between 80% and 86% of diatoms on the intertidally exposed substrata. Other diatoms which formed 5% or more of diatom communities are *Campylodiscus fastuosus* Ehrenb., *Paralia sulcata* (Ehrenb.) Cleve. and *Cylindrotheca closterium* (Ehrenb.) Reiman and Lewin on continuously submerged substrata and *Cocconeis*

TABLE 16.2

Average percentage composition of diatom communities on continuously submerged substrata. PX = Perspex, PU = Painted steel, PP = Cathodically protected painted steel, CS = Cathodically protected steel. * = Planktonic according to Hendey (1974).

	PX	PU	PP	CS
Navicula spp.	54.953	62.106	59.244	66.847
Cocconeis spp	3.097	2.561	3.499	3.991
Melosira spp.	0.943	1.139	0.944	0.777
Campylodiscus fastuosus	2.323	4.698	4.923	4.549
Diploneis sp.	1.190	1.038	1.078	1.143
Paralia sulcata	4.788	6.087	4.507	4.873
Actinoptychus senarius.*	0.071	0.233	0.263	0.593
Pleurosigma spp.	0.808	1.391	0.699	1.311
Cylindrotheca closterium	24.002	12.843	18.173	9.393
Biddulphia regia.*	0.036	0.208	0.033	0.033
Amphora spp.	0.915	1.074	0.747	0.838
Nitzschia spp.	1.038	2.508	2.513	2.051
Amphiprora alata	0.049	0.029	0	0
Achnanthes spp.	0.987	0.466	0.828	0.131
Licmophora sp.	0	0	0	0
Rhizosolenia sp.*	0	0.029	0	0.065
Chaetóceros sp.*	0.345	0.600	0.130	0
Unknown	4.455	2.990	2.419	3.406

spp., Melosira spp. and Achnanthes spp. on the intertidally exposed substrata. Some diatoms showed distinct site preferences. Both Cylindrotheca closterium and Campylodiscus fastuosus were almost entirely restricted to the continuously submerged substrata where they occurred in quite high numbers. Other less abundant diatoms such as Amphora spp., Nitzschia spp., Amphiprora alata Kutz, Rhizosolenia sp., and Chaetoceros sp. were also restricted to the continuously submerged substrata.

Some diatoms show seasonal peaks in abundance (Figs. 16.4 and 16.5). Navicula spp. are more dominant in the summer as are Cylindrotheca closterium and Campylodiscus fastuosus (Fig. 16.4). Cocconeis spp., Paralia sulcata and Melosira spp. show winter peaks at both sites (Fig 16.4 and 16.5).

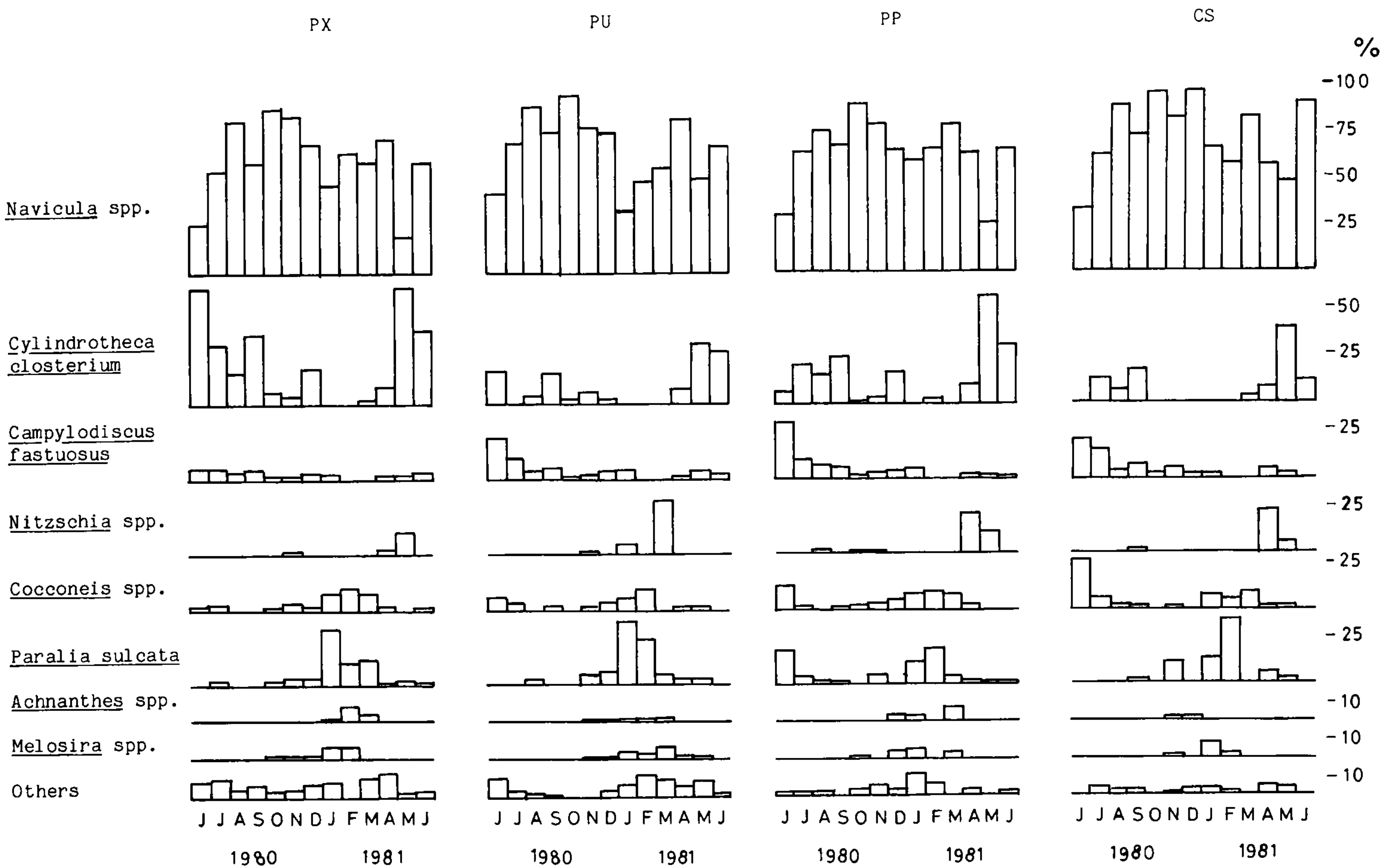
Some species show a substratum preference; On the continuously submerged

TABLE 16.3

Average percentage composition of diatom communities on intertidally exposed substrata. PX = Perspex, PP = Cathodically protected painted steel, CS = Cathodically protected steel. * = Planktonic according to Hendey (1974).

	PX	PP	CS
Navicula spp.	86.120	79.689	80.034
Cocconeis spp	3.450	6.591	4.315
Melosira spp.	0.704	7.869	3.659
Campylodiscus fastuosus	0	0.769	0
Diploneis sp.	0	1.274	0
Paralia sulcata	3.378	0.769	4.762
Actinoptychus senarius.*	0.674	0.385	0
Pleurosigma spp.	0	1.154	2.381
Cylindrotheca closterium	0	0	0
Biddulphia regia.*	0	0.253	0
Amphora spp.	0	0	0
Nitzschia spp.	0	0	0
Amphiprora alata	0	0	0
Achnanthes spp.	5.634	1.247	4.849
Licmophora sp.	0.038	0	0
Rhizosolenia sp.*	0	0	0
Chaetoceros sp.*	0	0	0
Unknown	0	0	0

substrata Campylodiscus fastuosus comprises a high proportion of the diatoms on all substrata except perspex to the 20% significance level overall (P<0.2), but with greater differences at certain times of the year. Nitzschia sp. is also more abundant on substrata other than perspex, but these differences are not significant. Cylindrotheca closterium however, is more abundant on perspex than the other substrata (P<0.05 for cathodically protected steel, P<0.2 for painted steel, not significant for cathodically protected painted steel). Cylindrotheca closterium is also more abundant on cathodically protected painted steel than on cathodically protected steel (P<0.02). On intertidally exposed substrata both Paralia sulcata and Achnanthes spp. are lower in abundance on cathodically protected painted steel than on the other substrata while Cocconeis spp. and Melosira spp. are highest on this substratum. Several diatoms were only found on cathodically protected painted steel, these were Biddulphia regia (Schultze) Ostenfeld., Diploneis sp., and Campylodiscus fastuosus.


PX
PU
PP
CS
%
100
75
50
25
Navicula spp.
50
25
Cylindrotheca closterium
25
Campylodiscus fastuosus
25
Nitzschia spp.
25
Cocconeis spp.
25
Paralia sulcata
10
Achnanthes spp.
10
Melosira spp.
10
Others
J J A S O N D J F M A M J
1980
1981

16.5 DISCUSSION

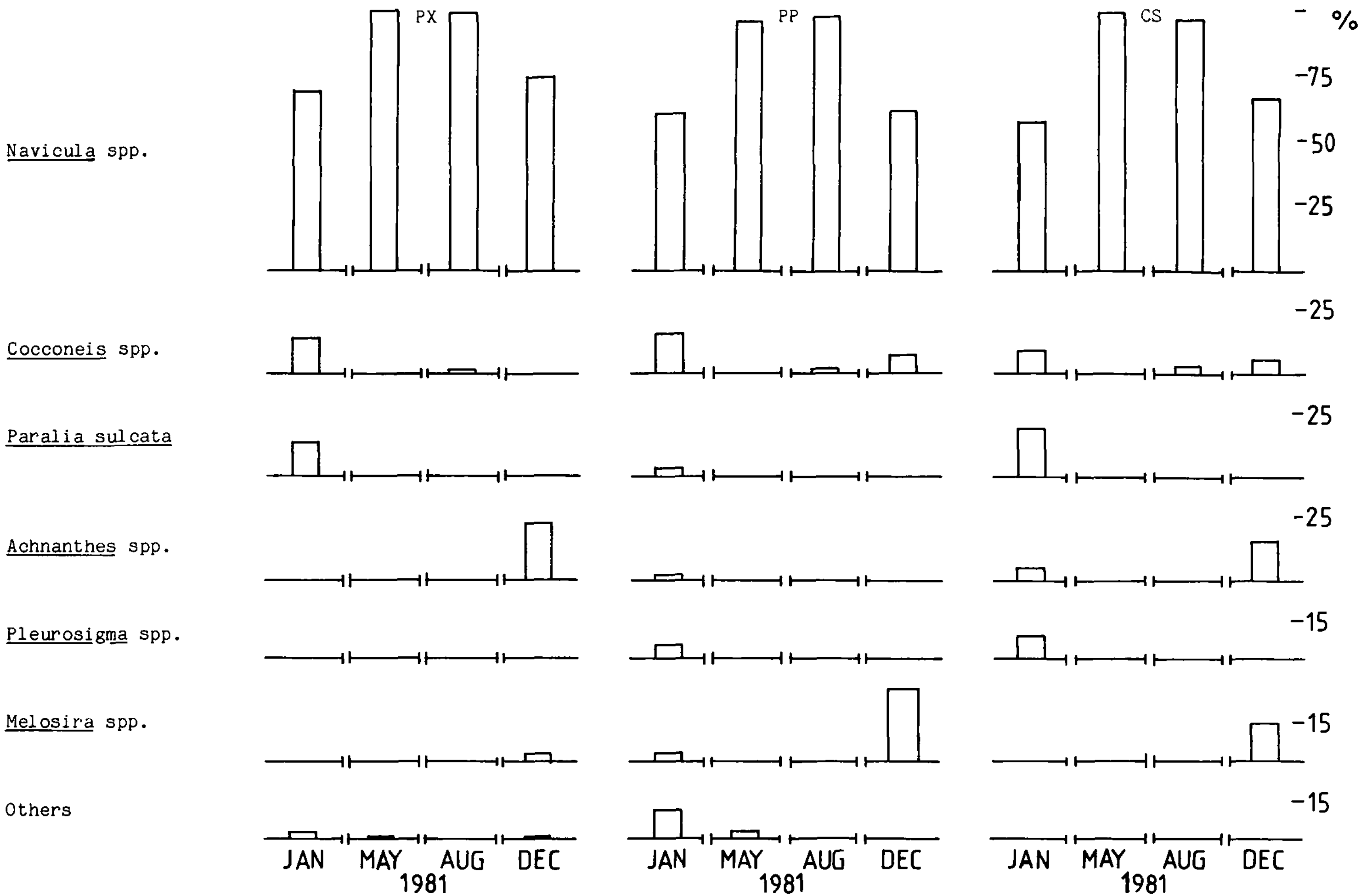
16.5.1 Microalgal counts

Microalgal colonisation varies considerably with season. The lowest counts being 817 algae per sq. cm. and the greatest 98,400 algae per sq. cm. The results for the continuously submerged substrata show the typical seasonal fluctuation in numbers expected of temperate microalgal communities with a spring/summer "bloom" (Fig.16.2A). However, at the intertidal site, these seasonal differences were found only on perspex (Fig.16.2B). The cathodically protected and cathodically protected painted steels did not show any seasonal increases, and there was even a tendancy to decrease in numbers over the summer. These differences may be due to the electrochemistry of cathodically protected steel, whether painted or not, where alternating immersion and exposure will affect the performance of the cathodic protection. Electrical conductivity is lost when the substrata are uncovered by the receding tide and this will result in large changes in pH, electrical charge and other chemical reactions at the surfaces. The chemical changes that occur on cathodically protected steel may explain the significantly lower colonisation on continuously submerged cathodically protected steel than on other continuously submerged substrata, especially perspex ($P<0.001$). High pH values and precipitating calcium carbonate create unfavourable conditions for algal settlement and trap initially settling algae (Edyvean, 1984). This will affect both recruitment and reproduction.

16.5.2 Diatom communities

Diatoms are the main constituents of the microalgal communities, averaging just over 50% of total algae. At both sites diatoms were least abundant on cathodically protected steel and most abundant on perspex. This may reflect a greater ability of diatoms to actively choose a substratum. Diatoms are widely reported as the dominant first algal colonisers, both on natural (Scheer,1945, Santelices et.al.1981,) and artificial substrata (Neushul et al.(1976), however the numbers and role of other algae tends to be overlooked in early colonisation studies. Despite the general preponderance of diatoms at both sites, other unicellular algae, algal spores and microscopic multicellular algae formed a very high proportion of the communities at certain times of the year (Fig. 16.3). These increases tended to occur during the winter months when total colonisation is low. An exception to this was for the continuously submerged substrata in mid summer (June) 1980. Again this may have coincided with a drop in total colonisation which is often encountered in mid summer, separating spring and autumn "blooms" (There was no marked mid summer fall in total

Fig. 16.4. (Opposite) Relative abundance of diatoms on continuously submerged substrata. PX = perspex, PU = painted steel, PP = cathodically protected painted steel, CS = cathodically protected steel.


PX
PP
CS
%
-75
-50
-25
-25
-25
-25
-15
-15
-15
Navicula spp.
Cocconeis spp.
Paralia sulcata
Achnanthes spp.
Pleurosigma spp.
Melosira spp.
Others
JAN MAY AUG DEC
1981
JAN MAY AUG DEC
1981
JAN MAY AUG DEC
1981

colonisation in 1981).

A total of 18 diatom taxa were found at both sites, however only seven groups (Navicula spp. Cylindrotheca closterium, Cocconeis spp., Melosira spp., Campylodiscus fastuosus, Paralia sulcata and Achnanthes spp.) make any significant contribution to the communities, and these are almostly completely dominated by Navicula spp.. The diversity is lower for the intertidal site than for the continuously submerged substrata with higher levels of Navicula spp. (Tables 16.2 and 16.3). Most of the diatoms show some seasonal preference (Figs.16.4 and 16.5), Cylindrotheca closterium is most prominent during the summer months reaching 62.5% of diatoms (49.6% of total algae) in the 25 days to 16th May 1981 on continuously submerged perspex. Campylodiscus fastuosus is also most prominent in the summer while Cocconeis spp., Nitzschia spp., Paralia sulcata, Achnanthes spp. Pleurosigma spp. and Melosira spp. tend to be more prominent during the winter.

The number of taxa found in this work is considerably lower than for diatom communities reported from freshwater and salt marsh environments (Sullivan, 1977; Czarnecki, 1979). However, Sullivan (1977) found that the number of diatom taxa decreases as salinity increases and in the marine environment, Callow (1984) has found 15 genera of diatoms on non-toxic panels exposed at San Fransisco, of which 5 genera were dominant. Similar results were found for Japan and Australia, while on the south coast of England two species of Navicula dominated non-toxic surfaces (Callow, 1984).

There appears to be little difference in diatom community composition between the substrata, due largely to the dominance of Navicula spp. This is in agreement with the findings of Edyvean and Moss (1986) and other authors (Tuchman and Blinn, 1979., Blinn et.al.,1980., Sullivan, 1975) who have used a Similarity Index to compare diatom communities and found high correlations between various non-toxic substrata. Both Wetzel & Westlake (1969) and Neushul et al.(1976) point out that there can be large differences in the numbers of organisms on different substrata, but species composition is often similar.

Although the communities are very similar overall, some diatom species do show site and substratum preferences. Campylodiscus fastuosus and Cylindrotheca closterium are two species which show both. They are virtually absent on the intertidally exposed substrata but reach high levels on the continuously submerged substrata. Cylindrotheca closterium shows a marked preference for perspex than the other substrata while Campylodiscus fastuosus is lowest on perspex. Such substratum preferences indicate either an active choice by some diatoms species, or that the physical and chemical conditions of the substrata

Fig. 16.5. (Opposite) Relative abundance of diatoms on substrata exposed intertidally. PX = perspex, PU = painted steel, PP = cathodically protected painted steel, CS = cathodically protected steel.

encourage or discourage settlement or entrapment of certain species. Cylindrotheca closterium forms closely adherent colonies and seems to favour smooth substrata such as perspex while Campylodiscus fastuosus does not appear to actively attach to a substratum, but becomes enmeshed on rough surfaces, such as are found on cathodically protected steel. While selective community development on toxic surfaces is well known, (Daniel and Chamberlain, 1981), any substratum preference shown by individual species on non-toxic surfaces are due to more subtle environmental influences, such as topography, surface charge, surface tension or nutrient availability. In the 25 day exposure periods used in this work, microalgae and other organisms will not only settle onto the substrata from the water but also reproduce insitu. These will produce copious amounts of mucilage, trapping other organisms, as well as dying and being washed off. Once an initial colonisation has established new species will settle and develop on top of earlier ones. Such a layering process was observed in this work and it serves to rapidly diminish any differences between the substrata, producing a surface more physically and chemically suitable for colonisation by other organisms (Bishop et al.,1974; Neushul et al.,1976; Paul et al.,1977; Blinn et al.,1980). It is likely that on the substrata used in this work any differences in the numbers of algae or choice of substratum by individual species would disappear with longer immersion periods.

16.6 CONCLUSIONS

(i) The differences in numbers of algae found at both sites are mainly those between cathodically protected steel and the other substrata, particularly perspex, for the continuously submerged substrata and between perspex and the other substrata at the intertidal site. This reinforces the conclusion that differences in substratum stability affects colonisation. The differences shown by perspex reinforce previous findings that extrapolation of data from perspex and glass to other substrata may be misleading (Edyvean et al. 1985).

(ii) There are no overall differences in community structure between the substrata, and it is unlikely that there will be any differences in influence on subsequent fouling.

(iii) Species of Navicula dominate the communities at both sites.

(iv) Some species, notably Cylindrotheca closterium and Campylodiscus fastuosus show marked site, substratum and seasonal preferences.

(v) Species diversity is less on these artificial substrata in seawater than for reports of artificial and natural substrata in freshwater.

ACKNOWLEDGEMENTS

This work was carried out during the tenure of an SERC CASE award, sponsored by British Petroleum, at Newcastle University. The author would like to thank

Dr.B.L.Moss for her help and support during the work. R.G.J.E. is the holder of the Sorby Research Fellowship of the Royal Society at Sheffield University.

REFERENCES

Bishop, J.H., Silva, S.R. and Sliva, V.M., 1974. A study of microfouling on antifouling coatings using electron microscopy. Journal of the Oil and Colour Chemists Association, 57: 30-35.

Blinn, D.W., Fredericksen, A. and Korte, V., 1980. Colonisation rates and community structure of diatoms on three different rock substrata in a lotic system. British Phycological Journal, 15: 303-310.

Brown, H.D., 1976. A comparison of the attached algal communities of a natural and an artificial substrate. Journal of Phycology, 12: 301-306.

Callow, M.E., 1984. A world-wide survey of fouling on non-toxic and three antifouling paint surfaces. Proceedings of the.6th International Congress on Marine Corrosion and Fouling, Athens. 325-346.

Cuba, T.R. and Blake, N.J., 1983. The initial development of a marine fouling assemblage on a natural substrate in a subtropical estuary. Botanica Marina, 26: 259-264.

Czarnecki, D.B., 1979. Epipelic and epilithic diatom assemblages in Montezuma well National Monument, Arizona. Journal of Phycology,15: 346-352.

Daniel, G.F. and Chamberlain, A.H.L., 1981. Copper immobilization in Fouling Diatoms. Botanica Marina,24: 185-191.

Edyvean, R.G.J., 1984. Interactions between microfouling and the calcareous deposit formed on cathodically protected steel in seawater. Proceedings of the 6th. International congress on marine corrosion and fouling, Athens. 469-483.

Edyvean, R.G.J., Rands, G.A. and Moss, B.L., 1985. A comparison of diatom colonisation on natural and artificial substrata in seawater. Estuarine, Coastal and Shelf Science,20: 233-238.

Edyvean, R.G.J. and Moss, B.L., 1986. Microalgal communities on protected steel substrata in seawater. Estuarine, Coastal and Shelf Science (in press).

Fletcher, R.L., Baier, R.E. and Formalik, M.S., 1984. The influence of surface energy on spore development in some common marine fouling algae. Proceedings of the 6th. International congress on marine corrosion and fouling, Athens. 129-144.

Floodgate, G.D., 1971. Primary fouling by bacteria. In: Jones, E.B.G. and Eltringham, S.K.(eds) Marine Borers, Fungi and Fouling organisms of wood. Organisation de Cooperation et de Development Economiques, 117-123.

Hendey, N.I., 1974. A revised checklist of British marine diatoms. Journal of the Marine Biological Association, 54: 277-300.

Houghton, D.R., 1978. Marine fouling and offshore structures. Ocean Management, 4: 347-352.

Jones, J.G., 1979. A guide to methods for estimating microbial numbers and biomass in fresh water. Freshwater Biological Association Scientific Publication 39,112pp.

Loeb, G.I. and Neihof, R.A., 1977. Adsorption of an organic film at the platinum-seawater interface. Journal of Marine Research, 35: 283-291.

Moore, J.W., 1976. Seasonal succession of algae in rivers 1. Examples from the Avon, a large slow-flowing river. Journal of Phycology, 12: 342-349.

Neushul, M., Foster, M.S., Coon, D.A., Woessner, J.W. and Harger, B.W.W., 1976. An in situ study of recruitment, growth and survival of subtidal marine algae. Techniques and preliminary results. Journal of Phycology, 12: 397-408.

Paul, R.W., Kuhn, D.L., Plafkin, J.L., Cairns, J. and Croxdale, J.G., 1977. Evaluation of natural and artificial substrate colonization by scanning electron microscopy. Transactions of the American Microscopical Society, 96: 506-519.

Ralph, R. and Troake, R.P., 1980. Marine growth on North Sea oil and gas platforms. Paper OTC 3860. In: Proceedings of the 12th Annual Offshore Technology Conference, Houston,Texas, Vol.4.49-52.

Santelices, B., Montalva, S. and Oliger, P., 1981. Competitive algal community organisation in exposed intertidal habitats from central Chile. Marine Ecology Progress Series, 6: 267-276.
Scheer, B.T., 1945. The development of marine fouling communities. Biological Bulletin, 89: 103-121.
Sokal, R.R. and Rohlf, F.J., 1969. Biometry, the Principles and practice of Statistics in Biological Research. W.H.Freeman, San Fransisco, 776 pp.
Sullivan, M.J., 1975. Diatom communities from a Delaware saltmarsh. Journal of Phycology, 11: 384-390.
Sullivan, M.J., 1977. Edaphic diatom communities associated with Spartina alterniflora and S.patens in New Jersey. Hydrobiologia, 52: 207-211.
Terry, L.A. and Edyvean, R.G.J., 1984. Influences of microalgae on the corrosion of structural steel. In: Lewis, J.R. and Mercer, A.D. Corrosion and Marine Growth on Offshore Structures. Ellis Horwood ltd. Chichester. 38-45.
Tuchman, M. and Blinn, D.W., 1979. Comparison of attached algal communities on natural and artificial substrata along a thermal gradient. British Phycological Journal, 14: 243-254.
Wetzel, R.G. and Westlake, D.F., 1969. Periphyton. In: Vollenweider, R.A. (ed). A manual on methods for primary production in aquatic environments. IPB Handbook No.12, Blackwell Scientific Publishers, Oxford. 33-40.
Young, L.Y. and Mitchell, R., 1973. The role of microorganisms in marine fouling. International Biodeterioration Bulletin, 9: 105-109.