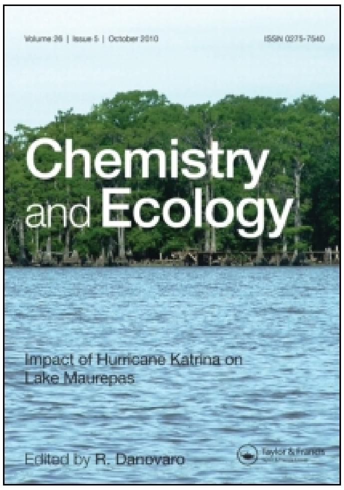

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K. J. Collins[a]; A. C. Jensen[a]; A. P. M. Lockwood[a]
[a] Department of Oceanography, University of Southampton, Southampton, U.K.

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STABILITY OF A COAL WASTE ARTIFICIAL REEF

K.J. COLLINS, A.C. JENSEN and A.P.M. LOCKWOOD

Department of Oceanography, University of Southampton, Southampton, SO9 5NH, U.K.

(26 July 1991)

The feasibility of using U.K. coal-fired power station waste materials for artificial reef production is being examined. In June, 1989, an experimental artificial reef was constructed in Poole Bay, off the central south coast of the U.K., using three different mixtures of pulverised fuel ash (PFA), flue gas desulphurisation (FGD) gypsum and slurry, stabilized with cement and formed into blocks. Fifty tonnes of 40 × 20 × 20 cm blocks were formed into eight conical reef units replicating three different PFA/gypsum mixtures and one concrete control. The reef structure is 10m below chart datum on a flat sandy sea-bed.

Combustion of coal concentrates the heavy metal content in the resultant ash. The purpose of stabilization of the ash as blocks is twofold: to immobilize heavy metals (or other components) and to provide hard substratum for the attachment of organisms. To examine the effectiveness of this stabilization and hence the environmental compatibility of the block materials, heavy metal (Cd, Cr, Cu, Pb, Mn, Ni, Zn) content of the blocks has been monitored routinely over two years, to determine leaching rates. Sectional profiles indicate partial replacement of calcium content by magnesium. Associated with this there has also been some redistribution of heavy metals. Only in the case of cadmium has there been a detectable loss from the surface of blocks. Chromium and manganese concentrations appear to have increased. The metal content of the reef epibiota (including ascidians, *Ascidia mentula*; hydroids, *Halecium* spp.; bryozoans, *Bugula* spp. and red algae) growing on the ash blocks has been compared to that of epibiota attached to the concrete controls and surrounding sea-bed. To date no evidence of excess bioaccumulation of metals has been detected.

The physical integrity of the ash reef blocks has been maintained. There is evidence that the blocks are increasing in compressive strength.

An indication of the fishery enhancement potential of the experimental structure is given by the presence of eight commercially fished species (crustaceans and molluscs) including lobsters (*Homarus gammarus*).

KEY WORDS: Pf ash, artificial reef, trace metals, colonization, marine fauna

INTRODUCTION

Artificial reefs have been constructed around the world to enhance fisheries. The Japanese have invested millions of dollars in reefs made of concrete, steel and plastics, to promote their inshore fishing and aquaculture industry (Thierry, 1988). The United States has also built large numbers of reefs to support sport fishing by creating sites more accessible for charter boats than previous fishing sites on naturally occurring reefs. These reefs have usually been constructed from scrap materials such as building rubble and scuttled ships. Groups are also examining cement stabilized coal waste (Woodhead *et al.*, 1985, 1986), oil ash (Metz and Trefry, 1988; Nelson *et al.*, 1988) and incinerator ashes as potential reef materials.

The possibility of using coal fired power station wastes (Pulverised Fuel Ash (PFA) and Flue Ash Desulphurisation (FGD) gypsum) for reef construction is now being explored in the U.K. Three different compositions as shown in Table 1. were made up in 40 × 20 × 20 cm blocks at a commercial block-making plant.

An experimental structure was deployed in Poole Bay, off the central south coast

Table 1 Composition of the 3 reef block mixtures (% mass)

	Mix 1	*Mix 2*	*Mix 3*
PFA	40	50	40
gypsum	20	10	17.5
FGD sludge	–	–	2.5
cement	10	10	10
gravel	30	30	30

of England, in June 1989. The reef consists of 50 tonnes of blocks formed into 8 units each 1m high by 4m across. The preliminary studies, licensing and deployment have been described by Collins *et al.*, (1990a, 1990b).

PHYSICAL CONDITIONS

The reef lies on a flat, sandy sea-bed (10m below chart datum) 3km distant from natural rocky outcrops. Tidal currents were measured with a recording current meter moored 2m off the bottom, in the centre of the reef site. Velocities reached 0.75ms^{-1} on spring tides. The principal tool for studying the reef has been SCUBA diving which, weather pemitting, has taken place throughout the year. Underwater visibility ranges from less than 1m over the winter period to 5m in summer.

The reef licence (issued by MAFF) includes a requirement to monitor the stability of the reef structure arising from a concern that stray blocks could interfere with trawling and dredging. Whilst the site is sheltered from the prevailing south-west winds it is exposed to the south-east. Both the 1989/90 and 90/91 winters provided wind strengths which, theoretically, could have produced wave heights in Poole Bay exceeding 6m, so some block movement was expected during these periods. Actual movement was limited. Toppled blocks had travelled no more than 2m. An indication of overall stability is given by the fact that marked photographic monitoring blocks on each reef could all be identified after the winter of 90/91. The imposition of the reef structure on a sedimentary substratum has the potential to cause some changes in the sea-bed topography. Steel pegs driven into the sea-bed to anchor the reef grid lines between the reef units have provided a datum against which such variations might be measured. Minor sediment accumulation has occurred against and between the basal blocks of the reefs but nowhere has exceeded an incremental height of 100mm. Much of the accretion appears to be due to the initial presence of *Crepidula* shells which subsequently trapped muddy silts. The overall pattern suggests that these mollusc shells have been driven across the sea-bed during the south easterly storms and have accumulated on the exposed sides of the reef units and also to the north on the lee side of the reef units. The fine silty component of the accumulated sediment has subsequently been colonised by burrowing organisms.

There has been no visible deterioration in ash block integrity. Only those moved by the storms have shown some abrasion. Initial block compression strength was low (<2N mm^{-2}). Blocks tested after 21 months immersion ranged from 0.5 to 5.9N mm^{-2}. The lower values were from cracked blocks. Parallel trials by the Building Research Establishment, with a range of ash mixes in sea water, have indicated that the blocks increase in compression strength with time. The results of studies in the U.S.A. with stabilised coal-ash products suggest long term stability (Carleton and Muratore, 1985, Labotka *et al.*, 1985).

CHEMICAL STUDIES

Routine chemical analyses for heavy metals of the reef blocks and encrusting organisms have been undertaken.

Blocks have been sampled by divers removing a corner (of 8cm side) from a block with a hammer and chisel from each reef unit. Such corner samples contain a high proportion of surface material. The samples were dried in an oven at 90°C for several days to constant weight and then the epifauna was scraped off. The block, inside a polythene bag, was crushed with a hammer and then passed through a 500μm sieve, effectively removing the gravel fraction.

A variety of epifauna was removed by divers from each reef unit and stored, frozen, in numbered polythene bags. Prior to analysis the samples were thawed and sorted into taxonomic groups. Any adhering reef block material was removed by scraping/brushing and finally rinsing the organisms in a small amount of distilled water. The sorted sub-samples were placed in plastic weighing boats and dried in the same way as the block samples.

Methods similar to those recommended by MAFF (Harper *et al.*, 1989) were used to determine heavy metal content. Samples have been routinely analyzed for cadmium, chromium, copper, lead, manganese and zinc. Samples were digested in concentrated nitric acid before flame atomic absorbtion spectrophotometry using a Pye Unicam SP9 AAS. BDH "Spectrosol" standards were used. One blank was included for every 10 samples. All block samples were analysed alongside pre-deployment samples for reference and standard deviation of determinations was within ± 1%, although the reproducibility of sampling due to the non-uniformity of block material increased this to ± 5%.

Block Composition

Corner samples from reef blocks have been taken regularly to give an indication of changes in the metal concentrations of the surface layer. Figure 1a. shows the pooled results for all PFA/gypsum blocks over the first 18 months since installation of the reefs. An alternative, more detailed, presentation of this data is given in Figure 1b. A least squares regression line drawn through the data for each element indicates the overall trend in the surface concentrations. Only calcium and cadmium show evidence of leaching. In contrast, there appears to be uptake of a number of elements; magnesium, manganese, chromium, copper and zinc.

The analysis of corner samples from blocks gives a limited amount of information about chemical processes happening within the blocks. Therefore a block raised from the reef in November, 1990, was coarsely sectioned to enable examination of the concentration profile of metals within the block. Analyses confirmed surface elevation of some metal concentrations and indicated the depth to which this enhancement had taken place (about 4cm). In March, 1991, (21 months immersion) blocks were raised from reefs of each of the 3 PFA/gypsum mixtures. A rectangular "core" was cut from the centre section of each block and this in turn was manually sectioned at 0.5cm intervals with a hammer and chisel. The levels of various heavy metals, calcium and magnesium were examined. The profiles for 9 elements for one block (mix 1) are given in Figure 2. Very similar profiles were found for the other two mixes.

Most striking is the massive loss of calcium from the surface, an effect which extends inwards to about 5cm. In contrast, magnesium levels appear to have been enhanced. To test whether there has been direct replacement of calcium by magnesium, the molar concentrations of the two elements are plotted together in Figure 3. The total molar concentration approximates to a constant level throughout each block section suggesting that 1:1 exchange of calcium ions from the blocks with magnesium ions from sea water may be occurring. This replacement causes a decrease in the mass of the affected block material which would contribute to an apparent elevation of metal concentrations. This reduction, however, is in the order of 3% loss at the surface, calculated from values given in Table 2, less than the reproducibility of sampling.

The profiles of heavy metals with depth in the block (Figure 3) show similar trends to that observed over time (Figure 1a); loss of cadmium and uptake of the other heavy metals (Pb, Zn, Cu, Ni, Cr & Mn). The outer active zone appears to extend from the surface to about 5cm depth. One method of summarizing these data was to fit a linear regression line to the 0–5cm depth data using the statistical software Statgraphics (STSC, Inc. U.S.A.). The Y axis intercept of the regression line gives a calculated surface concentration (Table 2) and thus an indication of the magnitude of leaching/uptake. In many cases, the correlation coefficient is high (<0.9), showing

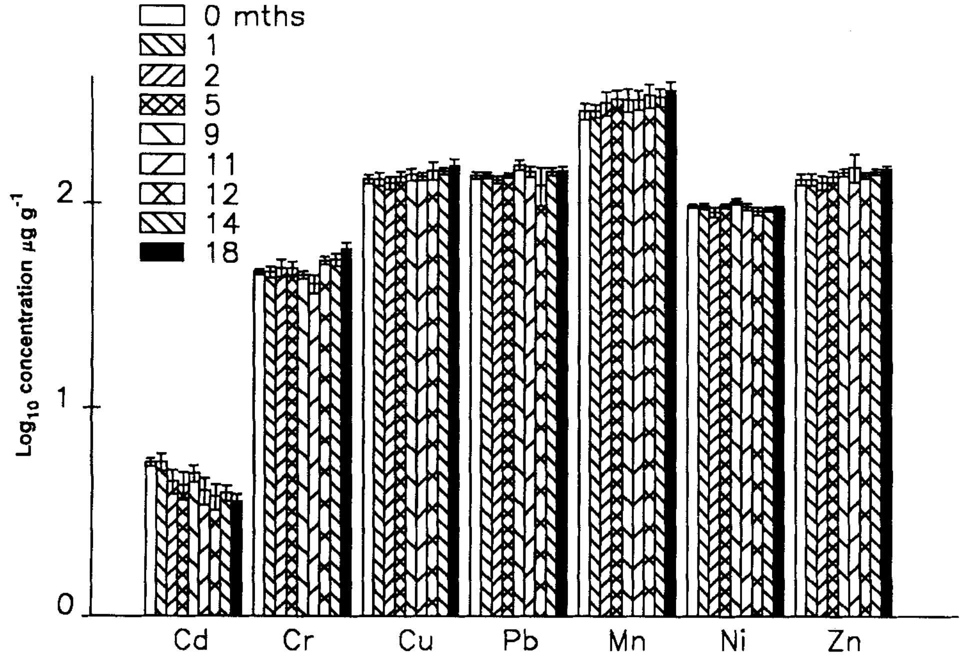

Figure 1a Average values of surface metal concentration (showing standard deviation) for the three PFA/ gypsum mixtures over a 21 month period underwater.

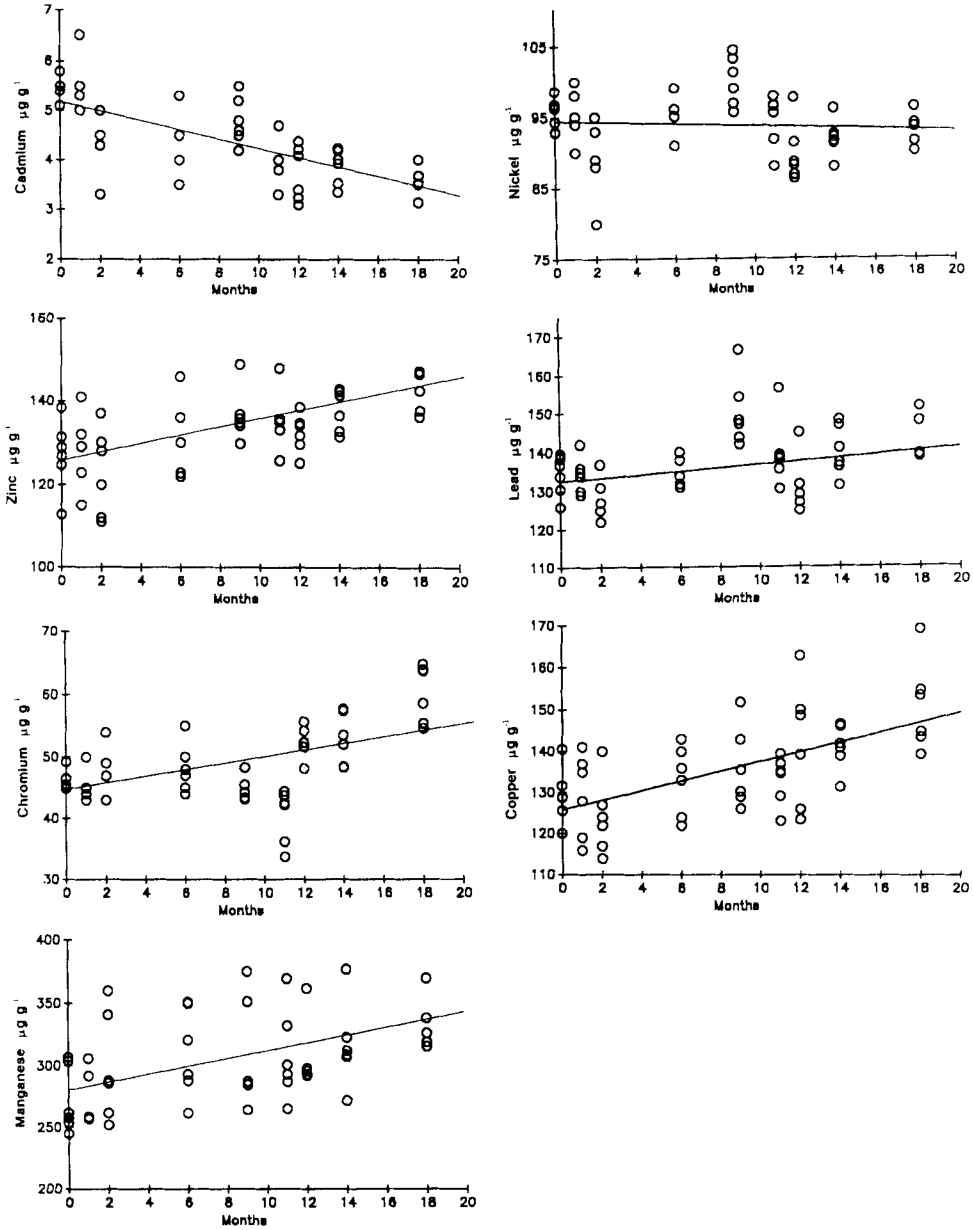

Figure 1b Plot of surface metal concentration of blocks from each of the 6 PFA/gypsum reef units for an 18 month period underwater.

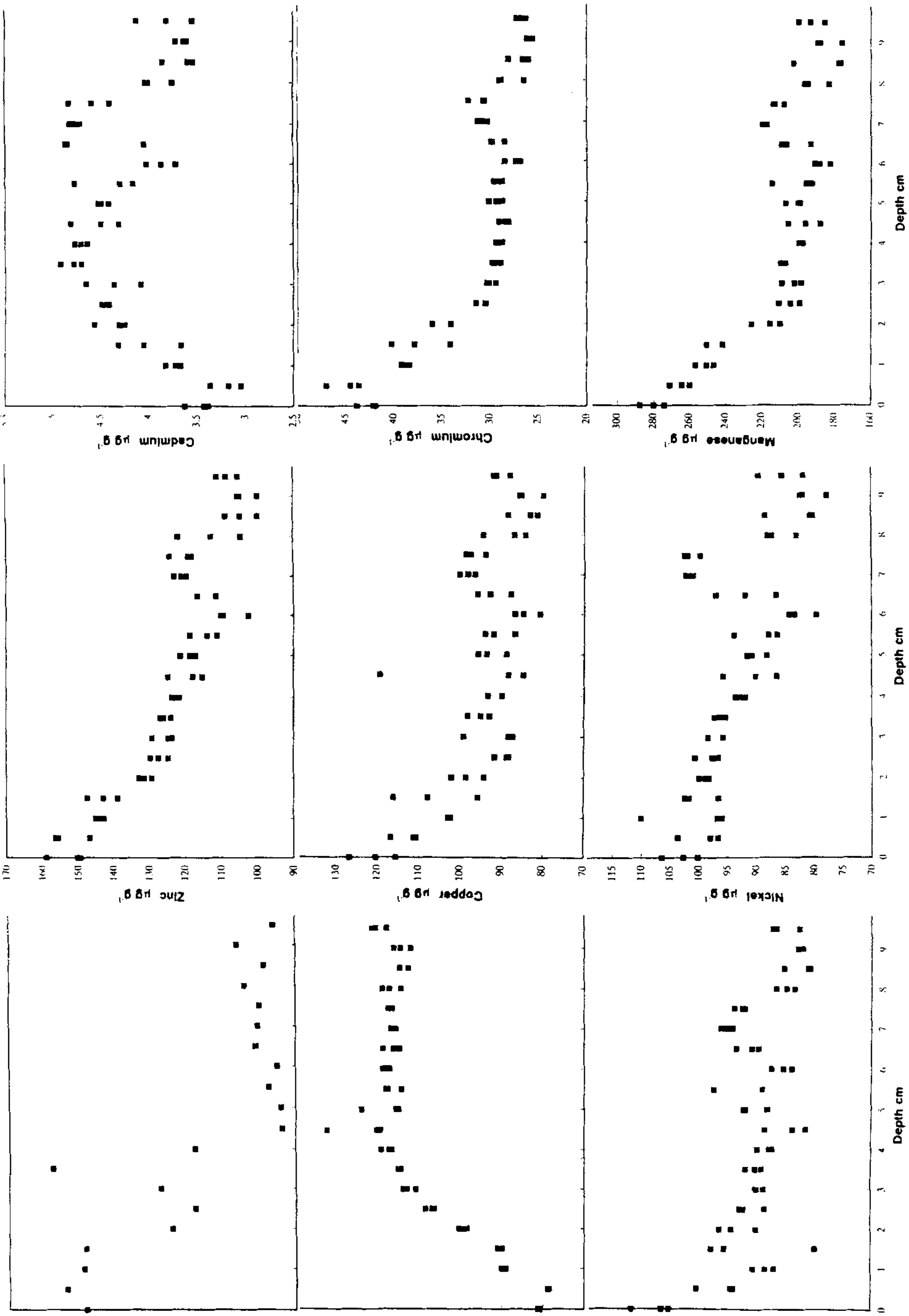

Figure 2 Depth profiles of metal concentration in a PFA/gypsum reef block (mix 1) immersed for 21 months.

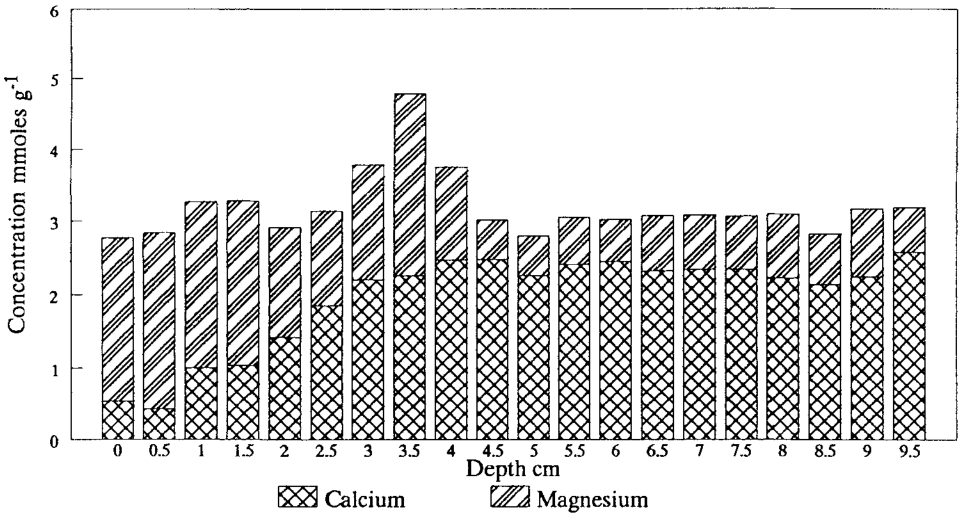

Figure 3 Depth profile of calcium plus magnesium concentration (mmoles g^{-1}) in a PFA/gypsum reef block (mix 3) immersed for 21 months.

Table 2 Analysis of reef block section profiles showing: initial (pre-deployment) metal ion concentration, average inner zone (5–10cm depth) concentration, results of linear regression analysis on outer zone (0–5cm depth) concentration intercept (=calculated surface concentration), and correlation coefficient.

mix	*Cd* *ug/g*	*Cr* *ug/g*	*Cu* *ug/g*	*Mn* *ug/g*	*Ni* *ug/g*	*Pb* *ug/g*	*Zn* *ug/g*	*Mg* *mg/g*	*Ca* *mg/g*
1 initial	4.70	29.95	105.24	221.73	99.78	118.29	126.55	4.76	102.04
inner	4.17	28.51	90.17	197.81	89.13	115.47	112.52	5.66	93.72
intercept	3.43	43.20	113.20	270.40	103.10	130.90	152.80	58.71	15.30
correlation coeff.	0.87	−0.93	−0.67	−0.93	−0.72	−0.66	−0.94	−0.68	0.98
2 initial	4.17	35.84	116.79	216.57	101.17	122.69	130.17	4.91	81.15
inner	3.73	34.12	99.52	199.42	90.06	111.99	126.52	6.02	59.75
intercept	3.38	53.70	123.90	267.80	107.90	137.70	154.60	60.32	7.76
correlation coeff.	0.78	−0.91	−0.71	−0.87	−0.39	−0.76	−0.80	−0.96	0.96
3 initial	4.07	30.54	118.88	238.47	98.75	124.57	113.63	5.40	90.31
inner	3.69	31.20	108.08	258.36	93.21	120.41	112.31	18.17	47.95
intercept	2.97	43.50	126.80	308.80	103.00	137.50	58.71	12.20	
correlation coeff.	0.64	−0.79	−0.80	−0.82	−0.76	−0.80	−0.79	−0.40	0.89
1 intercept/inner	0.73	1.44	1.07	1.22	1.03	1.11	1.21	12.32	0.15
2 intercept/inner	0.81	1.50	1.06	1.24	1.07	1.12	1.19	12.28	0.10
3 intercept/inner	0.73	1.42	1.07	1.29	1.04	1.10	1.10	10.87	0.14
average (NSC)	0.76	1.46	1.07	1.25	1.05	1.11	1.16	11.82	0.13

these processes to be significant. Comparison of inner (5–10cm) values and initial (pre-deployment) values for the blocks suggest that the core of the blocks has remained largely unaffected. In order to directly compare the changes, the surface intercepts have been divided by the initial element concentration for each block mixture. These values appear to be very similar for the 3 different block mixtures, suggesting similar rates of interaction with sea water.

The average values for the surface intercept divided by the initial concentration (giving the Normalised Surface Concentration, NSC) at the bottom of Table 2 give an indication of the overall level of leaching/uptake for the different elements. A value of 1.00 would indicate no change. Thus for calcium (NSC = 0.13) 87% has been lost at the surface. Similarly 24% of cadmium (NSC = 0.76) has been lost at the surface. The high uptake of magnesium (NSC = 11.82 ≡ 1182% elevation) can largely be explained as direct replacement of calcium. However, the elevated surface levels of heavy metals is surprising, particularly of chromium (NSC = 1.46 ≡ 46% elevation), manganese (NSC = 1.46 ≡ 46% elevation), manganese (NSC = 1.25 ≡ 25% elevation) and zinc (NSC = 1.16 ≡ 16% elevation). These values are in excess of the expected apparent elevation due to mass loss arising from calcium/magnesium exchange (~3%).

To test whether these elevated surface concentrations are a result of uptake from sea water or simply due to migration from the core of the blocks, an approximation to a mass balance is given in Figure 4. Average outer (0–5cm depth) and inner/core (5–10cm depth) concentrations are compared to the pre-deployment value. Large changes in calcium and magnesium are confirmed as external exhange. Similarly the net loss of cadmium is evident. Results from some of the heavy metals (nickel, copper, lead and possibly zinc) indicate no net external exchange; elevated outer levels are matched by depressed core values suggesting the possibility of migration. However, in the case of chromium (all 3 mixes) and manganese (only mix 3) there are greater outer block concentrations than can be explained simply by depletion of the block core. This confirms the impression that there has been significant uptake of these latter metals from the water column.

The loss of calcium, largely due to the solution of gypsum, has been reported (Roethel and Oakley, 1985) from early work with coal waste/FGD sludge blocks during the initial stages of the American Coal Waste Artificial Reef Programme (CWARP). Replacement of calcium by magnesium in the same materials was noted by Labotka *et al.* (1985).

The average calculated loss of cadmium from the outer surface of the PFA/gypsum blocks after 21 months was estimated to be 24% (Table 2). This loss decreased inwards to an unaffected core deeper than 5cm. This left some 90% of the metal still bound up within the block. Additionally, the levels of this metal are relatively low (~5 $\mu g\ g^{-1}$), similar to those found in the concrete controls (~3 $\mu g\ g^{-1}$).

Van der Sloot *et al.* (1985) examined the leaching of coal-ash and coal-ash products, and demonstrated considerably reduced availability of metals from stabilized products. Arsenic and chromium leachates were found to be 15% and 5%, respectively, of the total available from crushed block product. Diffusivity models have been proposed for coal ash blocks based on laboratory and field measurements of exposed blocks. The metal concentration profiles from a coal waste block from the CWARP experiment, exposed for 1.5 years, showed no significant uptake or loss of iron, cobalt, chromium or vanadium, a slight loss of antimony, zinc and copper and, due to large variation, no clear pattern for arsenic and cadmium. Molybdenum and lead were identified as being significantly lost from the surface layer. Some uptake of manganese was found, also noted by Roethel and Oakley (1985).

The mineralogical changes which take place within the PFA/gypsum/cement blocks are complex (Labotka *et al.*, 1985) and include formation of:

etteringite (formed from reaction of gypsum, cement, PFA and sea water)
calcium silicate hydrate (formed from reaction of sea water, cement and PFA)

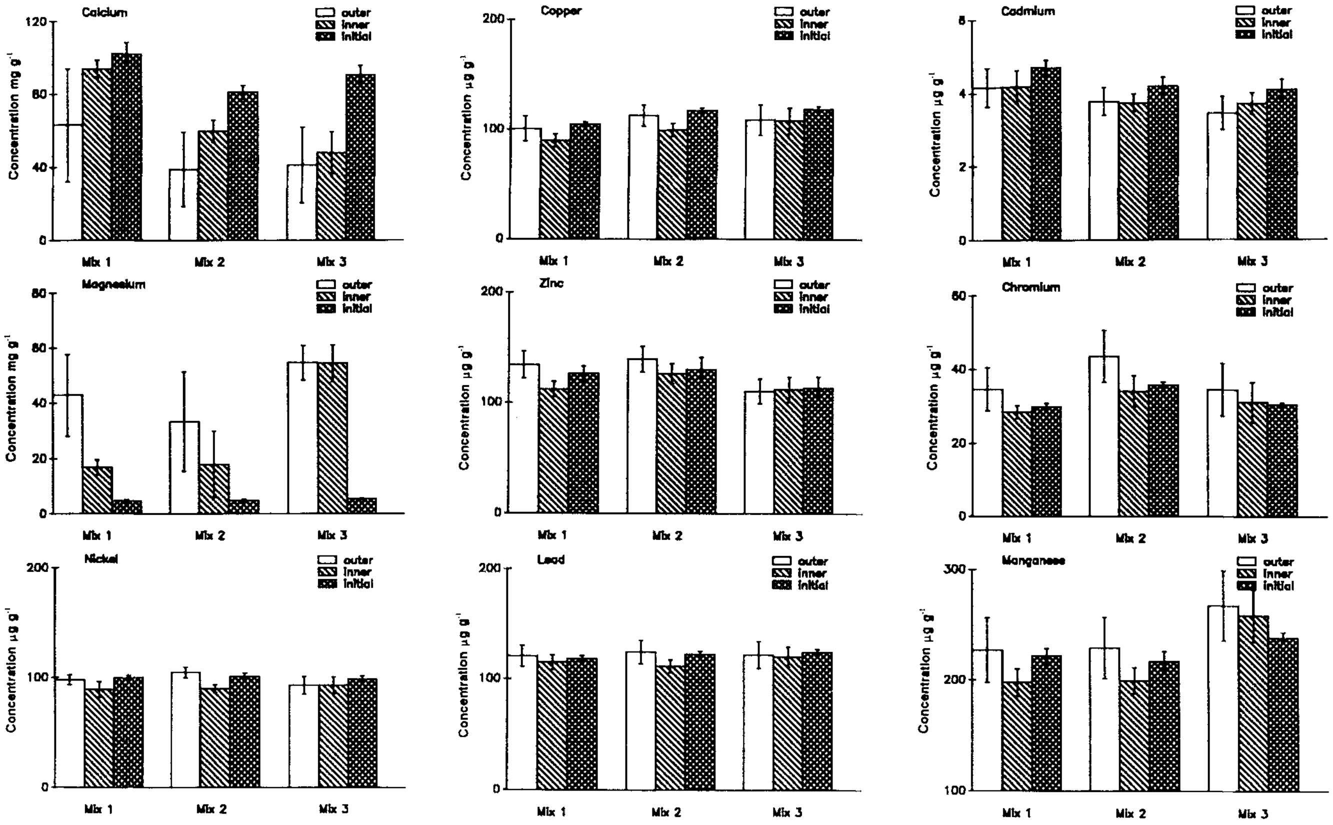

Figure 4 Average metal concentrations (showing standard deviation) for the inner (0–5cm) and outer (5–10cm) compared to the initial, pre-deployment value; for blocks of the 3 different PFA/gypsum mixtures.

The reactions are complex and there is the possibility for the formation of zeolite type matrices in which ion exchanges can occur.

Block Epibiota

Epifauna and algae from the surface of the blocks have been routinely analysed for heavy metals to determine if there has been any excess uptake relative to that of organisms growing on control surfaces; concrete and sea-bed stones. The pooled results of some 2000 analyses from samples taken up to November, 1990, are shown in Figure 5a. No epibiota grouping from a particular ash mixture stands out from the rest. This is evidence consistent with the absence of epibiotic uptake of excess metals. These results were similar across a range of phyla. Figure 5b plots the average value for different epibiotic groups growing on the PFA/ash mixtures against the average value for that group growing on concrete or sea-bed stones. Any bias of data points above or below the 1:1 line would suggest that elevated or lowered metal concentrations are present in one of the epibiotic groups. Indeed, one of the sponge results falls markedly below the 1:1 line, suggesting higher values on the control surfaces than on the ash blocks. This may be partly explained by the fact that the reef sponges were very small and had a short residence time compared to those on stones which were generally older and could have accumulated metals over a longer period. With this in mind, it is interesting to examine the ascidian results which were largely from *Ascidia mentula* samples. This was a pioneering species and continues to flourish on the underside of blocks and in crevices. Specimens are large and many are likely to be of a similar age to the reef. If there was significant release of metals, this

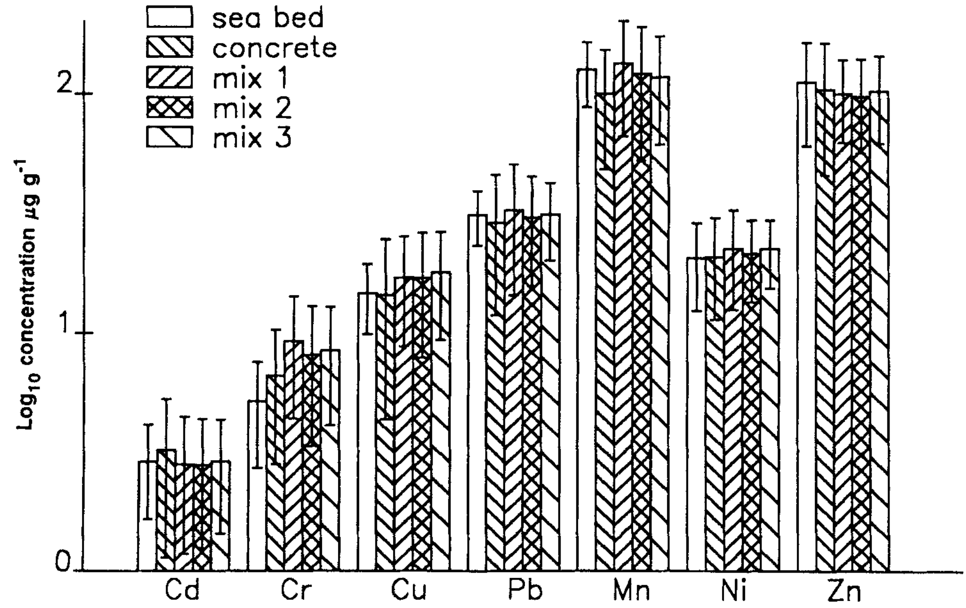

Figure 5a Comparison of average metal concentrations (with standard deviation) in epibiota on the 3 different PFA/gypsum block types compared with those on the concrete controls and local sea-bed.

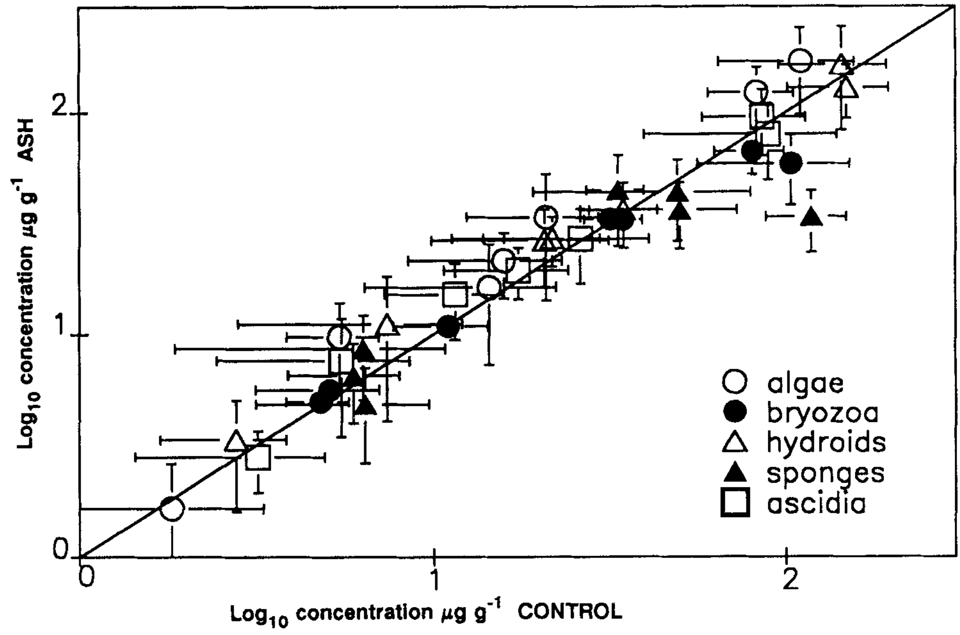

Figure 5b Graph of average metal (Cd, Cr, Cu, Pb, Mn, Ni, Zn) concentration (with standard deviation) of different epibiotic groups growing on PFA/gypsum blocks plotted against the same group growing on control surfaces. The x = y line is also plotted to aid comparison.

species, a filter feeder, would be well placed to indicate this. There is no evidence of significant (within 1 standard deviation) excess metal levels in this or any other group.

Given the minimal leaching described above, it would be surprising to find significant elevation of ash block epifauna metal concentrations at this stage in the programme. Similarly, workers on the CWARP study (Woodhead *et al.*, 1985, Woodhead, Parker and Duedall, 1986) found no evidence for trace metal transfer from coal-waste block to epifauna.

BIOLOGICAL STUDIES

The principal method used for following the colonisation of the reef has been direct observation by divers supported by sampling and photography (still and video). Marked blocks on each reef unit have been photographed routinely to give quantitative data on coverage by different organisms and hence allow comparison between block mixes. Sea-bed core samples, for infaunal and granulometric analysis, have been collected along a transect from the reef complex.

Block Colonisation

Within one month of the installation (June, 1989) small ascidians, *Ascidiella aspersa* and *Ascidia mentula,* had settled as well as the serpulid worms, *Pomatoceros triqueter*. A month later, the ascidians were larger and more recognizable, more serpulid worms had settled and fine red algae began to appear on horizontal surfaces. In September, 1989, three months into the project, there was red algal cover on horizontal surfaces and *Pomatoceros* numbers had continued to increase. A fine growth of hydroids (*Kirchenpaueria* sp. and *Sertularella* sp.) began to appear on vertical surfaces. Small patches of didemnids and encrusting bryozoans also became apparent. A month later (October, 1989), this growth on vertical surfaces had become more extensive and now included erect bryozoa (*Vesicularia spinosa*). With the onset of winter (November), algae declined. The initial numbers of ascidians were not maintained. Encrusting bryozoans continued to develop and barnacles had settled.

By April 1990, a continuous turf had begun to form. This included *Bugula* spp., which was overgrowing the initial settlement of *Pomatoceros*. Didemnids and colonial ascidians were no longer evident. One year after installation a deep turf of hydroids and bryozoans covered horizontal and vertical surfaces. Amongst this were found sponges (*Scypha ciliata*), larger bryozoans (*Halecium halecinum*), a few didemnids and some red algae. The peak of hydroid growth, in particular *Tubularia* sp., occurred at this time (June, 1990). By July, foliose algae had begun to grow, areas of encrusting bryozoans were increasing and growth of an erect bryozoan (*Bugula* spp.) had thickened the turf. Barnacles had continued to grow and were being grazed (discussed later).

Many other species, particularly mobile fauna, took advantage of the developing block surface habitat for shelter and food.

Fish

Natural structures in the sea, such as reefs, are recognised as areas which attract fish. Workers have taken advantage of this fact. The behaviour of shoals of saithe (*Pollachius virens*) around a natural reef has been described by Wyche (1984). Potts and McGuigan (1986) have examined the distribution of post larval fish associated with inshore reefs. Similarly artificial features (Bohnsack and Sutherland, 1985) provide food, shelter from predators and from tidal currents, or even simply a point of reference. This was demonstrated during the underwater archaeological excavation of the "Mary Rose"; the area of exposed timbers was progressively colonised by shoaling fish, crabs, lobsters and epifaunal species (Collins and Mallinson, 1984).

Pouting (*Trisopterus luscus*) have been present on the reef from its inception and are the most significant fish in terms of biomass and numbers. Post larval shoals collected around the markers used for reef installation and remained around the reef units, increasing in size through the following months. Most of the larger fish disappeared over winter. The pattern was repeated in 1990, with the few remaining large specimens present early in the year, being replaced by post larvae. A distinct pattern of behaviour related to tidal currents has been observed. During peak flow the shoals swim close to the reef units, below the tops and predominantly in the lee of reefs, demonstrating the use of the reef structure as a means of conserving energy. As tidal velocity decreases the shoals spread outward and upward. In 1989 shoals of between 100 and 200 fish were associated with each unit. In 1990, the numbers were greater with estimates of up to 1000 around a reef unit.

The typical territorial fish associated with U.K. inshore reefs is the wrasse (*Labrus* spp.). Within the first month after deployment corkwing wrasse (*L. melops*) appeared on the reef, followed by lesser numbers of ballan (*L. maculatus*) and goldsinny wrasse (*Crenilabrus melops*). In June, 1990, male corkwing wrasse were found to be building nests on all reef units, behaviour well documented on natural reefs (Potts, 1985). Nests were constructed from seaweeds compacted between reef blocks. Individuals were seen and filmed collecting drift seaweeds from the water column and placing them in the nest structures.

During the summer of 1990 a shoal of 40 red mullet (*Mullus surmuletus*) was closely associated with the reef complex.

Crustacea

Crabs (*Cancer pagurus*) and lobsters (*Homarus gammarus*) appeared within three weeks of reef deposition and subsequently have been observed routinely. In order to estimate the reef population and residence time a tagging programme was started in 1990 (Collins *et al.*, 1991; Collins and Jensen, 1991), initially using claw, T-bar and streamer tags. Animals were captured in parlour pots set by each of the 8 reef units. The pots were normally fished for two days each week through the summer. Caught animals were measured, tagged and returned to the reef of capture. A number of lobsters were caught repeatedly giving an indication of total population (estimated at 16–24) and movement between reef units. Two of the lobsters on the reef have been observed in a "berried" condition. Acoustic tags (78kHz) were also used to track 2 lobsters intensively over a two month period. The two lobsters stayed on the reef site throughout this period, both moving between units, and were still present some 11 months later. In contrast, a movement of some animals off reef has been confirmed with recaptures several kilometres distant.

Edible crabs (*Cancer pagurus*) were also routinely observed on the reef and a small number were caught in the pots and tagged with Petersen tags. Individual spider crabs (*Maja squinado*), were also present through the summer months, whilst in July, 1990, some 50 moults from an aggregation were found near one of the reef units.

Other Commercial Species

Cuttlefish (*Sepia officinalis*) have been observed feeding on the velvet swimming crabs (*Liocarcinus puber*); both are local commercial species. Oysters (*Ostrea edulis*) have settled on the reef.

CONCLUSIONS

Subsequent to deployment the blocks have remained intact and show little sign of attrition or fracture. The reef units as a whole have withstood severe winter storms with minimal block movement.

Heavy metal (Cd, Cr, Cu, Pb, Mn, Ni, Zn) content of the blocks has been monitored routinely over two years, to determine leaching rates. Sectional profiles indicate replacement of calcium by magnesium. Associated with this there has been some redistribution of heavy metals. Only cadmium has shown detectable loss. Chromium and manganese appear to have been taken up. The metal content of the epibiota (including ascidians, *Ascidia mentula*; hydroids, *Halecium* spp.; bryozoans, *Bugula* spp. and red algae) on the ash blocks is being compared to that on the concrete controls and surrounding sea-bed. No evidence of excess bioaccumulation of metals has been detected.

Biological colonisation of the reef has been rapid and currently the reef-associated species list contains some 200 species of fauna and flora. The surfaces of the blocks are showing a subjective increase in species diversity and number. No gross difference has been observed in the colonisation of the different reef types.

The presence of eight locally important, commercial species (lobsters, edible crabs, spider crabs, swimming crabs, whelks, oysters, red mullet and cuttlefish) demonstrates the fishery potential of this type of structure.

One of the major concerns regarding artificial reefs is that they attract members of the existing natural population without contributing to overall numbers, and so enhance exploitation (Bohnsack and Sutherland, 1985). The lobsters on the Poole Bay reef have certainly come from existing reefs, but the addition of new sites would allow for expansion of the natural population where there is habitat limitation at present. The reef is already providing new food sources through browsing of the epibiota and predation of mobile species.

This study has demonstrated a potential use for stabilized waste materials and the fishery potential of inshore structures in the U.K. New coastal structures such as harbour walls, coastal defences or offshore islands could be designed to incorporate a variety of habitats and niches for fishery enhancement and aquaculture.

Acknowledgements

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