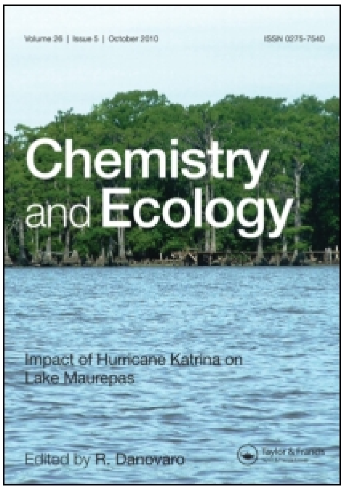


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# FISHERY ENHANCEMENT REEF BUILDING EXERCISE†

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The constructive use of coal-fired power station waste products for building artificial reefs is being explored for the first time in the U.K. At present, the practice of sea dumping of raw pulverised fuel ash (PFA) from coal combustion is under review and the use of consolidated PFA blocks offers a possible alternative. The planned fitting of flue gas desulphurisation (FGD) plant in the U.K. will additionally produce large quantities of gypsum. To test the environmental compatability of such materials in marine structures, an experimental reef has been constructed off the central south coast of the U.K. Fifty tonnes of blocks made from different combinations of PFA, gypsum, FGD waste water sludge, cement and gravel using standard concrete as the control material, were deployed. The site selected is remote from prominent sea bed features in an area of flat sand with limited species variety.

The preliminary studies leading to the licensing of this project included bioassay experiments with diatom cultures, field trials with test tiles and trace metal bioaccumulation studies. The stages of consultation and licensing of the project are outlined.

Colonisation of the reef has been rapid, initially by shoaling fish, particularly by bib (*Trisopterus luscus*) then, within the first month, by representatives of the commercial crab and lobster species typical of the local natural rocky coast. After three months the epifauna and flora were well established. At this stage some 80 species of flora and fauna have been identified in association with the reef with no differentiation in colonisation apparent between the PFA/gypsum mixtures and the concrete control. The number of species far exceeds that of PFA powder dumping grounds. Analyses for heavy metal ions in the reef blocks after 2 months immersion have not shown any significant difference from the original composition.



## INTRODUCTION

The aim of this project is to determine the feasibility of using coal waste products constructively in the marine environment. Much of the electricity in the U.K. is produced from coal combustion. Two coastal power stations (Blythe and Stella) currently dump pulverised fuel ash (PFA), or fly ash, into the sea. The effects of this have been described by Eagle *et al.* (1979) and Bamber (1984, 1989). The major impact of this is a smothering of the sea bed and subsequent infaunal mortality. Direct dumping of raw ash is currently under review for these plants and is unlikely to be a disposal option for other stations. In future, in line with an EEC directive to reduce sulphur emissions by 60% by 2003, some new U.K. coal-fired stations and larger existing stations will be fitted with flue gas desulphurisation (FGD) plant. One technique selected is the limestone/gypsum

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method; pulverised limestone slurry is sprayed through the furnace emission. The products of this process are gypsum and a smaller quantity of waste water sludge known as scrubber sludge. The initial output of gypsum is destined for the building industry. However, the quantities involved are large (800,000 tonnes PFA and 500,000 tonnes gypsum annually from a 2000 MW station) and are likely to exceed the requirements of commercial outlets, leaving a need to dispose of surplus PFA, gypsum and FGD scrubber sludge. The current exercise, the construction of artificial reefs using this material, is designed as a feasibility study. It will investigate the environmental acceptability of the use of these materials for reef construction. The project is funded by the Central Electricity Generating Board (CEGB), the U.K. national power industry, who are investigating this as one of several disposal options.

The construction of artificial reefs for fishery enhancement is well established in Japan and the U.S.A.. The use of stabilised coal waste products to construct reefs was pioneered by the Coal Waste Artificial Reef Program (CWARP) team in New York (Woodhead *et al.*, 1985,1986). Workers from this team are currently investigating a similar use for incineration ash (Roethel and Breslin, 1989). The use of oil ash for reef construction has been described by Metz and Trefry (1988, 1989) and Nelson *et al.* (1988).

Coal has a very variable composition related to source, so whilst the CWARP studies investigated coal utilised in the USA, specific chemical results cannot be automatically related to U.K. material. Similarly, local sources of limestone for the FGD process will yield different qualities of gypsum/FGD sludge. Additionally, there is no history of artificial reef deployment in the U.K. and we are aware only of one other experimental reef, in Scotland, constructed from natural stone. The current study, therefore, is also acting as a proving ground for the concept of building artificial reefs in the U.K., both politically and scientifically.

The U.K. is a signatory to the London and Oslo Conventions on dumping at sea, covered by the Food and Environment Protection Act 1985 (Part II, Deposits in the Sea) which requires the licensing of any deposit on the sea bed. The Ministry of Agriculture, Fisheries and Food (MAFF) is the designated authority and has licensed the reef project.



## PRELIMINARY STUDIES

Prior to seeking a licence to install the reef, three sets of preliminary experiment were undertaken:

1. the colonisation of test blocks suspended in the sea was observed.
2. the metal concentration in settling organisms was examined
3. diatom growth studies were undertaken in the presence of block extracts

(1) Preliminary studies were carried out with test tiles of cement stabilised PFA/gypsum/FGD sludge mixtures. These were suspended in Southampton Docks for 6 months and were rapidly colonised with typical marine epifauna, including ascidians (*Ascidiella aspersa* and *Ciona intestinalis*), tube worms, (*Pomatocerus triqueter*) and barnacles (*Balanus* spp.).

(2) The combustion of coal concentrates the heavy metal content in the ash.

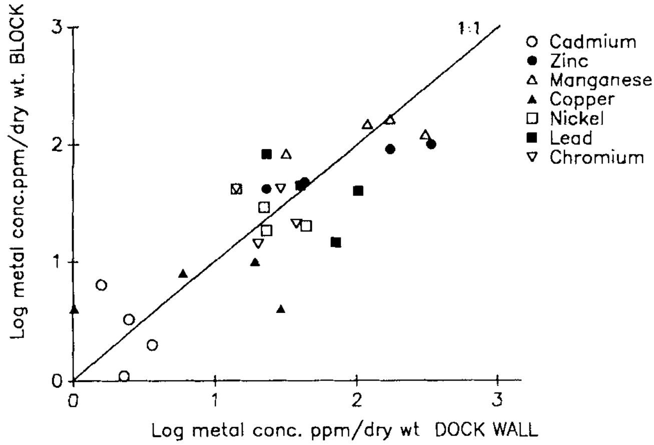


**Figure 1** Metal ion concentrations in epifaunal species from test PFA/gypsum tiles plotted against the concentration found in the same species growing on Southampton Dock wall.

Chemical analyses for copper, cadmium, chromium, lead, manganese, nickel and zinc were carried out with samples from the test blocks and encrusting organisms. The results of analyses of tile colonising species of ascidians, barnacles and tube worms for each of these elements were plotted against the results for control organisms growing on the dock wall nearby (Figure 1). There was no evidence to suggest bioaccumulation of metal ions by the block-encrusting organisms over and above that found in control animals. Additionally, the levels of arsenic, mercury and iron were measured in the test blocks.

(3) Diatom bioassay experiments were carried out with leachates from the test tiles, using methods similar to those described by Rose *et al.* (1985). To represent a worst case, tile material was ground to a powder, passed through a 500 $\mu$m sieve and shaken with sea water. The settled and filtered leachates were added to sea

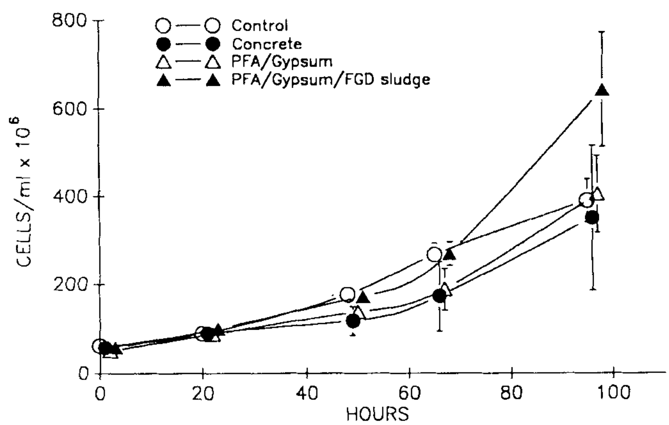


**Figure 2** Growth of the diatom *Phaeodactylum tricornutum* in sea water and leachates from test materials.

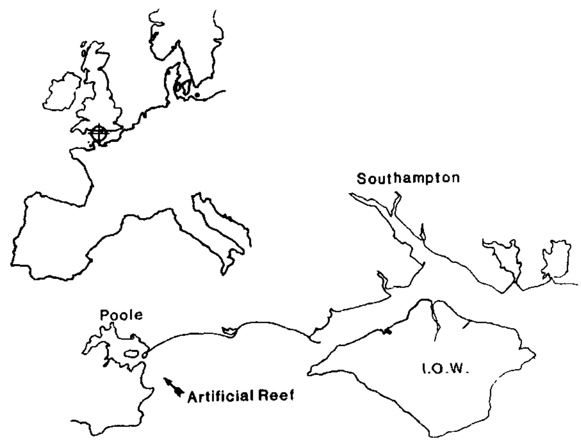


**Figure 3** Location of the artificial reef.



water along with standard algal culture medium, for growth studies using the diatom, *Phaeodactylum tricornutum*. Growth of three replicates was followed by cell counts over 4 days (Figure 2). Some initial depression of the cultures with added concrete and fly ash leachate mixture was noted, possibly due to the high pH of the cement, but these cultures subsequently caught up with the controls in untreated sea water. The test culture containing fly ash/desulphurisation sludge showed a higher growth rate than the control.

Western Poole Bay (Figure 3) was identified as a potential site for the reef systems, because: (1) it is protected from the prevailing SW winds, (2) initial wave height frequency analysis coupled with flume tests on trial blocks suggested that a reef situated below 10 m should not experience block displacement even in a "worst prediction" 10 year storm; (3) the area is easy to reach from Southampton. Exact positioning of the reef site was determined following discussion with local fishermen's associations and the MAFF fisheries officer.

Subsequent to this preliminary work a licence was granted by MAFF for the deposition of the reef. In addition to this licence, consents were gained from the Crown Estate Office, who administer the Crown's rights over the sea bed in U.K., and the Department of Transport who are concerned with navigation.

In parallel with the biological and chemical studies conducted by Southampton University, the physical properties of the reef materials are being studied by CEGB materials scientists and the Building Research Establishment (BRE).

## REEF DEPLOYMENT

Various mixes of PFA, gypsum, FGD sludge, cement and gravel were made up into blocks at a commercial plant. The different proportions of these materials in the three types of block selected for trial are shown in Figure 4. Gravel was added to aid mixing of the fine powdery materials and to increase the mass of the

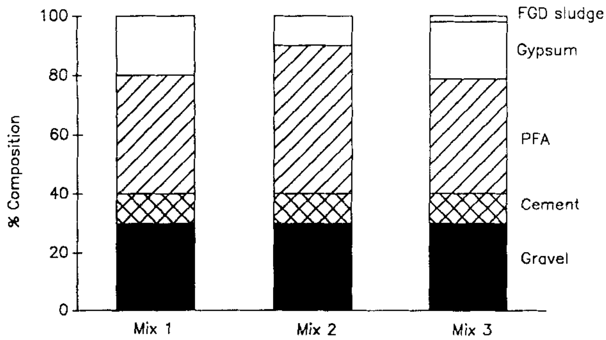


**Figure 4** Composition of the different mixtures used in the artificial reef experiment.

blocks. This, in turn, increased sea bed stability. The individual blocks each measure 20 × 20 × 40 cm and weigh approximately 32 kg.

The site selected for the reef system is 10 m below chart datum in water with a tidal range of 2 m. The sea bed is flat and sandy with natural reefs over 2 km distant. The site is immediately north of the exclusion zone of an historic wreck

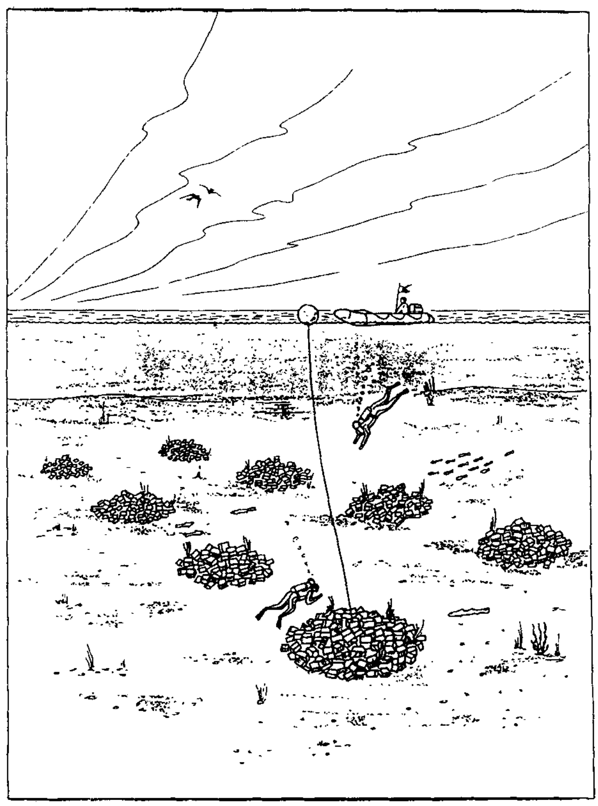

**Figure 5** Artist's impression of the artificial reef.

which is buried beneath the sea bed in an area not usually trawled by the local fishermen. The area was surveyed by divers and fished with commercial gear before reef installation. Sediment samples were taken for infauna, chemical and particle size analysis.

Prior to installation of the reefs, the diving team laid a 30 × 10 m rope grid on the sea bed, accurately positioning sinkers for marker buoys. The reef was constructed in mid-June 1989 using a dredger with crane to lower pallets of blocks to the sea bed. These blocks were then individually moved by divers to create 8 reef units with similar dimensions (Figure 5). Considerable effort was put into this phase to allow direct comparison of the units in terms of attractiveness to fish and crustaceans. Each completed reef unit consists of a conical pile of 6 tonnes of blocks 1 m high by 4 m diameter. Numerous different sized spaces (approximately 22% of reef volume) were left between blocks to provide habitat variety. There are 2 replicates of each of the three mixes and 2 concrete control reefs.

## INITIAL RESULTS

Shoals of post larval fish, bib (*Trisopterus luscus*) and pollack (*Pollachius pollachius*), were attracted to the site within hours of the deployment. The greatest surprise was to find lobsters (*Homarus gammarus*) in the reef after three weeks. Colonisation of the reef blocks has been monitored by monthly photography of vertical and horizontal surfaces of marked blocks on each reef. By July, there was an initial growth of erect hydroids (*Obelia* and *Kirchenpauria* spp.) and settlement by an ascidian (*Ascidiella aspersa*) on the vertical surfaces. This was followed in August by the tubeworm (*Pomatocerus triqueter*) with increasing coverage by hydroids and bryozoans (*Bugula plumosa*) and further ascidian species. Three months later (September 1989), a similar settlement of hydroids, bryozoa and tube worms with increasing dominance by red algae was found on horizontal surfaces. After the first three months the concrete blocks showed the greatest density of *Pomatocerus* tubes though with satisfactory settlement on the other mixtures. Conversely, the concrete and mixture 2 had the lowest algal coverage (Figure 6a, b).

An interesting colonisation mechanism was observed with the red alga, *Calleblepharis ciliata*. Drift specimens attached to the blocks by their stolons which continued to grow. On some vertical sheltered surfaces didemnids have achieved 100% cover. Within 2 months some 80 species of flora and fauna had been identified on the reef. Cluster analysis (Clustan, procedure heirarchy, method of Ward (Wishart, 1987)) of the presence/absence data for each reef mixture (Figure 7) shows no clear pattern or differentiation from control. Interestingly, the number of species already far exceeds that on the powder fly ash dumping grounds studied by Eagle *et al.* (1979) and Bamber (1984).

The CWARP study demonstrated the physical and chemical stability of stabilised coal waste material. Clearly it is too early to demonstrate this after only four months study. However, analyses for heavy metal ions using methods similar to those described by Harper *et al.* (1989), in surface samples from reef blocks which had been immersed for two months show no significant difference from the original material (Figure 8). Studies of test mixtures by BRE show an increasing strength after 3 months exposure to sea water.

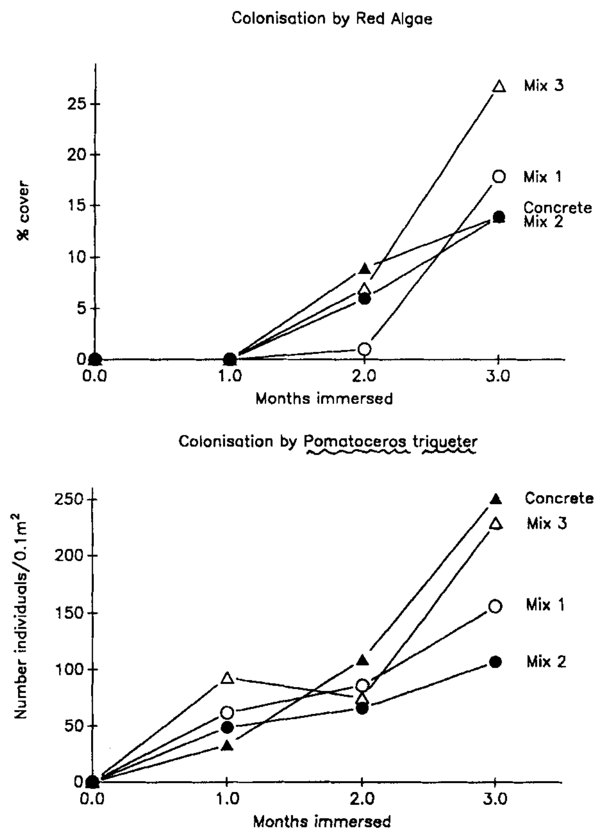


**Figure 6** Settlement of (a) red algae and (b) the tube worm (*Pomatocerus triqueter*) on the different reef types.

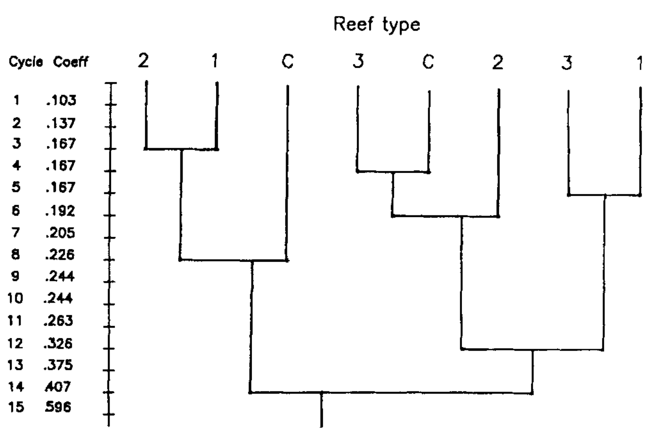


**Figure 7** Cluster analysis of the presence/absence data for flora and fauna species found the different reef units. (C = concrete control, 1 = Mix 1 etc.)

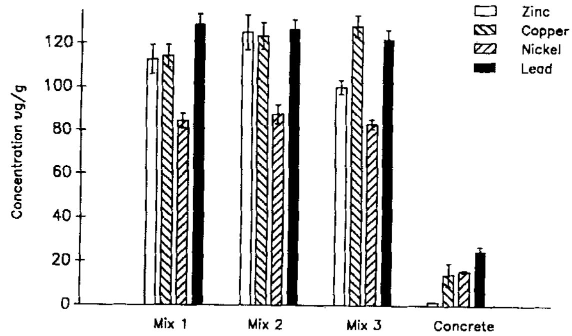


**Figure 8** Concentrations of heavy metal ions in the different reef block mixtures.

## COMPARISON WITH NATURAL REEFS

It is valuable to compare the artificial reefs to natural reefs in the area, although it is likely to be several years before a climax fauna and flora is achieved. At the artificial reef depth (10 m), sponges are an important component of the fauna of natural rocks on the South Coast; as yet, on the reefs they are only represented by the small sponge, *Scypha ciliatum.* Natural reefs attract shoals of fish and provide shelter for juveniles. A similar pattern is emerging with our reef. During the peak of tidal flow, shoals of over 100 bib (*Trisopterus luscus*) can be seen in the lee of each of the eight reef units. When the tide slackens the shoals disperse, presumably to feed on the surrounding sea bed.

One of the typical natural rocky coast territorial fish, the Corkwing wrasse (*Crenilabrus melops*), moved in within a month of deployment whilst other wrasse species (Ballan, Goldsinney and Cuckoo) now also occur, though in smaller numbers. These species seem to be well established and are observed regularly browsing on the reef block epifauna and flora. Tagging studies are planned to determine the reef specificity of these species. Studies of the sediment infauna will determine the extent of feeding by reef associated fish. Another species, typical of inshore rocks, which quickly established itself was the juvenile two-spot goby (*Gobiusculus flavescens*).

Along the south coast natural rocky outcrops are fished with pots for crabs and lobsters. The early occurrence of lobsters has been described above and they have been seen regularly since. Edible crabs (*Cancer pagurus*) and the swimming crab (*Liocarcinus puber*) are common. The reef block epiflora and fauna is developing to an extent sufficient to support small crab species such as *Macropodia* and *Hyas* spp.

## FUTURE WORK

There is considerable debate as to whether artificial reefs increase the sea bed productivity or simply attract existing stocks to a more easily exploited unit. The lack of data to determine this has been noted by Bohnsack and Sutherland

(1985). A related study will examine the energetics of the artificial reef to consider this question. The current study will continue until May 1991 with regular chemical analysis of the reef blocks and reef associated organisms to determine the rate of leaching of heavy metal ions and possible subsequent bioaccumulation. Assuming that the environmental acceptability of this material can be demonstrated, the building of full-scale reefs becomes a possibility. Construction may be driven by the demands of the fishing industry, sports fishermen, or coastal engineering schemes.

## *References*

Bamber, R. N. (1984). The benthos of a marine fly ash dumping ground. *J.mar.biol.Ass.UK.* **64,** 211–226.

Bamber, R. N. (1989). Colonisation and selection of fly ash substrates by marine invertebrates. Paper presented to the Eighth International Ocean Disposal Symposium, Dubrovnik, Yugoslavia, 9–13th October (In this volume.).

Bohnsack, J. A. and Sutherland, D. L. (1985). Artificial Reef Research: A review with recommendations for future priorities. *Bulletin of Marine Science,* **37**(1), 11–39.

Eagle, R. A., Hardiman, P. A., Norton, M. G., Nunny, R. S. and Rolfe, M. S. (1979). The field assessment of effects of dumping wastes at sea: 5. The disposal of solid wastes off the north-east coast of England. Fisheries Research Technical report No.51, MAFF Directorate of Fisheries Research, Lowestoft, 34pp.

Harper, D. J., Fileman, C. F., May, P. V. and Portmann, J. E. (1989). Aquatic Environmental Protection: Analytical Methods No.3, Methods of analysis for trace metals in marine and other samples. MAFF Directorate of Fisheries Research, Lowestoft. 38pp.

Metz, S. and Trefry, J. H. (1988). Trace metal considerations in experimental oil ash reefs. *Marine Pollution Bulletin* **19,** 11B, 633–636.

Metz, S. and Trefry, J. H. (1989). Stabilised oil ash reefs: A viable utilisation option based on chemical results. Paper presented to the Eighth International Ocean Disposal Symposium, Dubrovnik, Yugoslavia 9–13th October. (In this volume.)

Nelson, W. G., Navratil, P. M., Savercool, D. M. and Vose, F. E. (1988). Short term effects of stabilised oil ash reefs on the marine benthos. *Marine Pollution Bulletin,* **19,** 11B, 623–627.

Roethel, F. J. and Breslin, V. T. (1989). Marine utilisation of stabilised incineration residues. Paper presented to the Eighth International Ocean Disposal Symposium, Dubrovnik, Yugoslavia, 9–13th October. (In this volume.)

Rose, H., Woodhead, P. M. J. and O'Connors, H. B. (1985). Coal waste in the sea I: toxicity assays with cultures of a marine diatom. In *Wastes in the Ocean, Volume 4: Energy Wastes in the Ocean.* Duedall, I. W., Kester, D. R. and Park, P. K. (eds) pp 574–583.

Wishart, D. (1987). Clustan user manual. 4th edition. Computing Laboraratory, University of St. Andrews, 250 pp.

Woodhead, P. M. J., Parker, J. H., Carleton, H. R. and Duedall, I. W. (1985) Coal waste artificial program, Final Report, CS-3936, March 1985, EPRI, California

Woodhead, P. M. J., Parker, J. H. and Duedall, I. W. (1986). The use of by-products from coal combustion for artificial reef construction. In *Artificial Reefs—Marine and Freshwater Applications.* D'Itri, F. M. (ed.), Lewis Publications, Chelsea, Michigan, USA. pp 265–292.