BULLETIN OF MARINE SCIENCE, 37(1): 364–376, 1985

EPIFAUNAL SETTLEMENT, THE PROCESSES OF COMMUNITY DEVELOPMENT AND SUCCESSION OVER TWO YEARS ON AN ARTIFICIAL REEF IN THE NEW YORK BIGHT

P. M. J. Woodhead and M. E. Jacobson

ABSTRACT

An experimental reef of 16,000 solid blocks (500 tons) of synthetic, cementitious materials was established, at depth of 20 m in the New York Bight in 1980. The reef covers an area of 1,230 m^2 and has a profile of 70 to 130 cm. Measurements of epifaunal settlement and growth on test bricks retrieved from the reef site allowed the processes of community development and seasonal succession to be followed in detail over 2 years.

Test bricks were made from a concrete, and from two coal waste materials (fixated mixtures of fly ash and FGD scrubber sludge) from two modern power stations. The bricks were compared for their suitability as substrates for colonization by organisms characteristic of reefs. Comparative settlement and growth of communities on the different bricks are described in terms of species richness, abundance and the surface area of brick covered. Altogether 36 species of attached epibenthic organisms were recorded colonizing the bricks. About the same number of species occurred on all bricks, and although several dominant species settled year-round, seasonality played a role in structuring colonization patterns; a few animals (*Balanus crenatus, Zirfaea crispata, Polydora socialis*) had associations with a particular type of material.

There were differences in settlement and in the rate of community development between the two coal wastes and the concrete. Concrete tended to be overgrown more quickly than either coal waste. Differences between communities persisted after 2 years in the sea; nevertheless, coal waste bricks appeared suitable substrates for development and growth of epifaunal communities.

In September 1980 an experimental artificial reef was built in the New York Bight at a depth of 20 m about 3 km south of the Altair lighthouse on Fire Island, N.Y. The reef was constructed with some 15,000 solid blocks, formed and cured from the stabilized combustion wastes produced by two coal-fired power stations (Parker et al., 1982; 1985). The blocks of coal wastes were tested for their suitability as new resources for reef construction, and as substrates for settlement of communities of organisms characteristic of hard bottoms in the region. The reef of blocks lies on an open sand bottom, it is 77 m × 14 to 18 m, the highest elevation is about 1.4 m, most of the reef being 0.7 to 1.2 m; the area covered is approximately 1,230 m^2 (Parker et al., 1982).

As part of a multidisciplinary investigation of the interactions of the coal waste reef with the marine environment (Parker et al., 1981; 1982; 1985; Woodhead et al., 1982; Woodhead and Jacobson, 1985; Woodhead and Parker, 1985). We have made a 2-year study of colonization and succession in the communities of encrusting epifauna settling and growing on the test blocks. For comparison, we measured epifaunal colonization on concrete blocks of the same size placed in the sea at the same time as the test blocks of wastes. The study has yielded information on both seasonal and yearly variations in settlement on subtidal hard substrates, as well as testing the suitability of the coal waste materials for reef construction.

An earlier paper (Woodhead and Jacobson, 1985) reported initial findings on the settlement by epibenthos on coal wastes. This paper follows changes in community development on bricks of coal wastes throughout 2 years in the sea, to

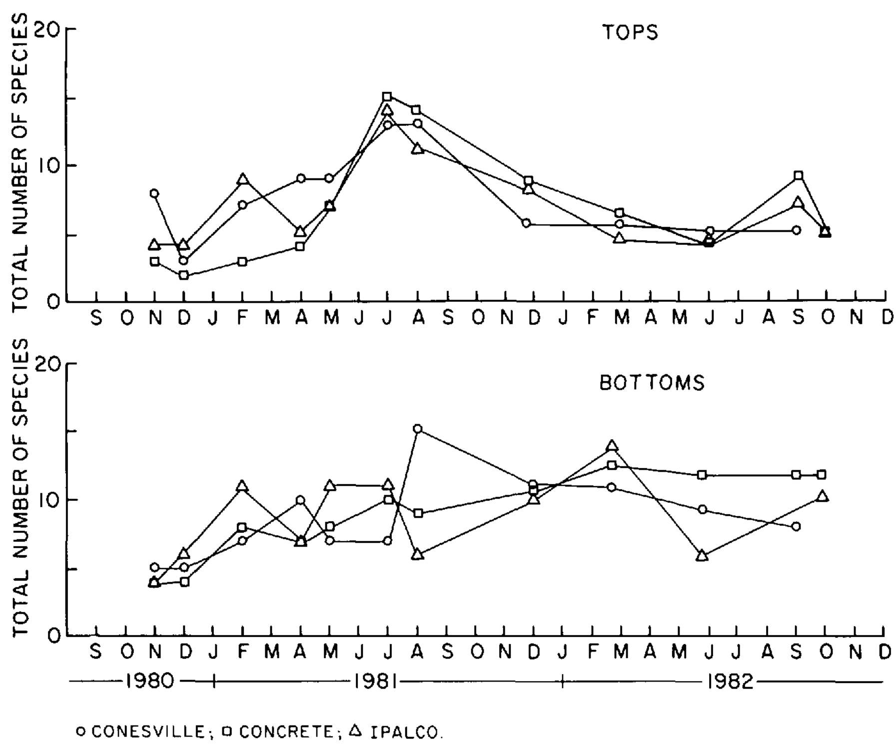

Figure 1. Number of species counted on the test bricks.

completion of the study. We compare the results of our experiments with data from other reports of biological colonization of coal wastes in the sea (Bamber, 1978; 1983; Roethel, 1981; Roethel et al., 1983). The results are of general interest because rather few studies have described marine epifaunal communities, and their changes over years at these depths (20 m).

Materials and Methods

Coal combustion wastes, fly ash and flue gas desulfurization (FGD) scrubber sludge mixed with 3% lime, were consolidated into bricks, 10 × 10 × 12 cm and cured to hardness. The coal wastes were from two modern coal fired power stations, at Petersburg, Indiana (Indiana Power and Lighting Company) and Conesville, Ohio (Columbus and Southern Ohio Electric Company); the waste materials from the first plant have been designated IPALCO, from the second designated Conesville in this paper. The fly ash and FGD sludge were combined in different ratios in each material, Conesville 3:1 fly ash to sludge, IPALCO 1.5:1. Physical and chemical properties of these materials and their interactions in the sea have been described in detail (Parker et al., 1981; 1982; Woodhead and Duedall, 1980; Woodhead et al., 1984).

Epifaunal community development was studied by exposing test bricks of concrete and of coal wastes in the sea for increasingly long periods, to follow biological colonization through 2 years. The bricks, 10 × 10 × 12 cm, were set out at the seabed on testing tables in racks of PVC plastic, which each held a set of four test bricks of the same material. The open racks allowed exposure of both the top and bottom surfaces to settlement and colonization by epibenthic organisms, and provided two sets of measurements of community development.

The experiment began in October 1980, subsequently, one rack each of the two coal wastes and a rack of concrete bricks were retrieved by divers in November and December 1980, in February, April, May, July, August and December 1981, and March, June, September and October 1982. Bricks retrieved were fixed with buffered formalin, then preserved in 70% ethanol. In the laboratory the bricks were examined microscopically to identify species which had settled, to count individuals, and

Table 1. Presence of species in epibenthic community on tops of test bricks, 1980–1982 (○ = present on bricks, ● = dominant)

Species	1980		1981						1982			
	Nov	Dec	Feb	Apr	May	Jul	Aug	Dec	Mar	Jun	Oct	Dec
Protozoa												
Folliculinid sp.									○		○	
Peritrichid sp.	○	○	○	●	○	○	●	○				○
Zoothamnium sp.			○		○			○				
Colenterata												
Metridium senile									○	○		○
Clytia hemisphaerica	○	○			○	○	○		○		○	●
Stylactis sp.												○
Halecium halecium						○	●			○		○
Obelia dichotoma	○		○	○	●	○						
Sertularia cupressina												
Tubularia crocea									○		○	
Athecate hydroid				○	○					○		
Astrangia danae												○
Anemone unident.										○		
Bryozoa												
Aetea sp.							●	●			●	●
Bugula turrita							○	○			○	○
Bowerbankia gracilis					○							
Callopora aurita					○		○	○	○		○	○
Cribulina punctata			○	○	○	○		○				○
Electra crustulenta				○		○	○					
Electra hastingsae			○	○	○	●	●		○			○
Electra pilosa												
Membranipora tenuis					○							
Schizoporella unicornis								○	○			○
Mollusca												
Anomia aculeata												
Anomia simplex		○	○	○		○	○	○				
Mytilus edulis	○	○	●	●	●	●	○	○	●	●	○	○
Onchidoris sp.					○	○	○					○
Zirfaea crispata			○	○	○		○	○	○	○	○	○
Acanthodoris pilosa					○	○						
Eubranchus exiguus					○	○						
Spisula solidissima	○											
Nudibranch eggs										○		
Annelida												
Harmothoe extenuata						○						
Phyllodoce arenae		○					○			○		
Polydora socialis	●	○	●	●	○	○	○	○	○			
Syllis sp.						○						
Nereis grayi						○						
Sabellaria vulgaris						○				○		
Arthropoda												
Balanus crenatus	○	○	○	●	●	●	●	○	○	○	○	○
Caprella linearis				○	○							
Harpacticoid copepod		○										
Edotea triloba		○										
Tunicata												
Amaroucium sp.			○	○	○							
Molgula manhattensis									○			
Porifera												
Haliclona loosanoffi											○	○
Scypha sp.									○			

Table 2. Presence of species in epibenthic community on bottoms of test bricks, 1980–1982 (○ = present on bricks, ● = dominant)

	1980		1981						1982			
Species	Nov	Dec	Feb	Apr	May	Jul	Aug	Dec	Mar	Jun	Oct	Dec
Protozoa												
Folliculinid sp.						○	●	○	○	●	○	○
Peritrichid sp.	○	●	●	●	●	●	○	●	○		○	○
Zoothamnium sp.						○			○			
Colenterata												
Metridium senile	○					○				○		
Clytia hemisphaerica	○	○	○			●	○		●		○	
Stylactis sp.											○	○
Halecium halecium						○	○			○		○
Obelia dichotoma	○		○	○		○						
Sertularia cupressina					○							
Tubularia crocea									○			
Athecate hydroid							○					
Astrangia danae												
Anemone unident.										○		
Bryozoa												
Aetea sp.								○				○
Bugula turrita		○				○	○	●		○	○	●
Bowerbankia gracilis					○	○						
Callopora aurita						○		○	○	●	●	○
Cribulina punctata			○	○	○	○	○	○				
Electra crustulenta												
Electra hastingsae				○	○	●	○	○	○	○		○
Electra pilosa												
Membranipora tenuis									○			
Schizoporella unicornis								○	○	○	●	●
Mollusca												
Anomia aculeata												
Anomia simplex		○	○	○		○	○	○				
Mytilus edulis	○	○	○	○	●	●	●	○	●	●		○
Onchidoris sp.					○	○	○					○
Zirfaea crispata			○	○	○		○	○	○	○	○	○
Acanthodoris pilosa					○	○						
Eubranchus exiguus					○	○						
Spisula solidissima	○											
Nudibranch eggs										○		
Annelida												
Harmothoe extenuata						○						
Phyllodoce arenae		○					○			○		
Polydora socialis	●	●	○	●	●	○	○	○	○			
Syllis sp.						○						
Nereis grayi						○				○		
Sabellaria vulgaris								○	○		○	○
Arthropoda												
Balanus crenatus	○	●	○	●	●	●	●	○	○	●	○	○
Caprella linearis				○	○							
Harpacticoid copepod		○										
Edotea triloba		○										
Tunicata												
Amaroucium sp.			○	○	○							
Molgula manhattensis									○			

Table 2. Continued

Species	1980		1981						1982			
	Nov	Dec	Feb	Apr	May	Jul	Aug	Dec	Mar	Jun	Oct	Dec
Echinodermata												
Asterias forbesi									●			
Porifera												
Haliclona loosanoffi											○	○
Scypha sp.									○			

to measure area covered by the developing community. Area coverage was measured by placing a sheet of plexiglass, marked with one hundred points, 2 cm above the brick surface to be studied. The presence or absence of an organism below each point was recorded, with its' identity. Only the basal area of canopy species was counted, points where species grew on top of the remains or skeletons of other species were counted for the upper species only. Both the top and bottom surfaces of exposed bricks were measured, for two independent assessments of colonization.

Data Analysis.—Epibenthic colonization and community development on the bricks was measured as: (1) number of species retained on brick surfaces, (2) abundance, or the extent of area covered, and (3) the similarities and differences between developing communities.

Data consisted of species presence (or absence) and species abundance (as percent of surface area of brick measured) and was analyzed by ANOVA and by cluster analysis. The Bray-Curtis similarity coefficient, used for cluster analysis, is an index which responds to both species number and relative abundance (Clifford and Stephenson, 1975). The numerical taxonomy system of multivariate statistical programs was used to generate dendrograms (Rohlf et al., 1981).

Results

Number of Species Settled.—During the first year of brick exposure in the sea, community richness on the upper surfaces of bricks increased fairly steadily from 8 species on Conesville bricks, 4 on IPALCO, and 3 on concrete in November after only 1 month, to 13 on Conesville, 14 on IPALCO, and 15 on concrete in July 1981. During that period, the communities on brick undersurfaces increased in number of species from 5 on Conesville, 4 on IPALCO, and 4 on concrete in November 1980, to 7 on Conesville, 11 on IPALCO, and 10 on concrete by July 1981. The increase in species richness was by both new settlement and the maintenance of established species. During the first year, neither tops nor bottoms of the coal wastes, nor of the concrete, showed consistent predominance in the number of sessile species which settled (Fig. 1). In the second year the numbers of species changed in a different pattern, also the community richness on the brick tops changed differently from that on bottoms. Species growing on the tops of IPALCO and concrete brick declined in number from summer 1981 until May 1982; the species declined in number on all blocks to only three on IPALCO and concrete and six on Conesville bricks. During the summer of 1982 species increased in number on concrete and IPALCO blocks. The decrease in species during 1982 principally reflected on intense settlement of blue mussels and barnacles which smothered the pre-existing communities attached to the blocks.

On the bottoms of bricks, community richness was similar (10–12 species) on all materials in December 1981 and showed much less change than on brick tops. The IPALCO community on brick bottoms fell to a minimum of 6 species in May but rose again to 10 species by October. The bottom community on Conesville bricks declined slowly in species diversity throughout 1982. During 1982,

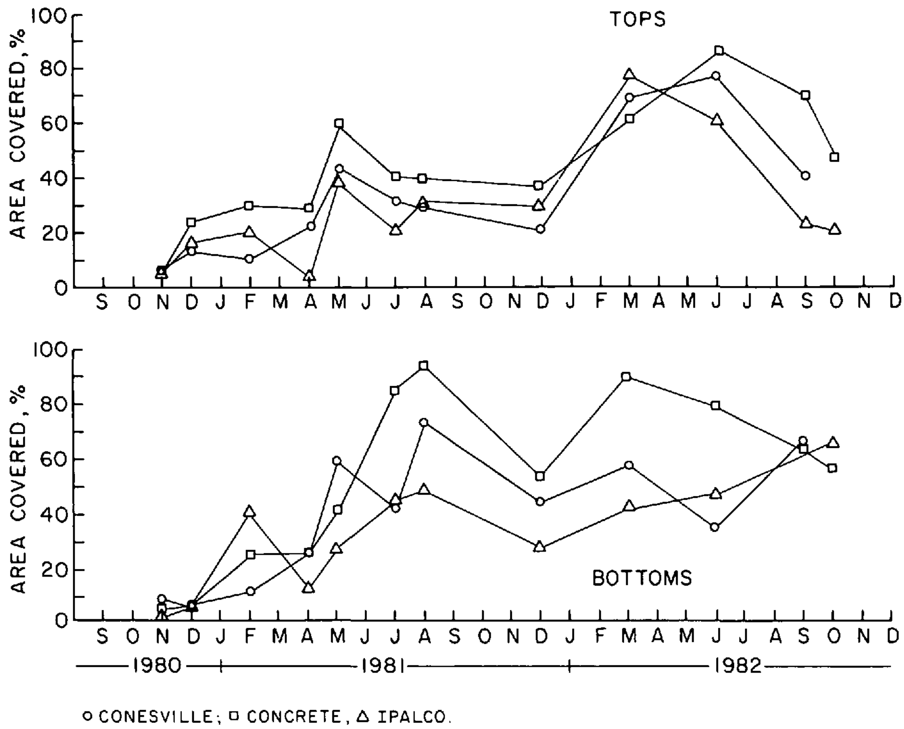

Figure 2. Percent surface area covered on bricks.

the bottoms of concrete bricks carried 12 or 13 species with no change to the end of the study in October.

Although community richness in species was similar for all three brick-types, there were some differences between the composition of the communities growing on the tops and bottoms of the test bricks. From July 1981 until September 1982, folliculinids were significantly ($P < 0.01$) more abundant on the brick bottoms; peritrichs also predominated on the majority of brick bottoms from May and July 1981. Blue mussels, *M. edulis,* were more numerous on tops ($P < 0.01$), generally two to three times greater on brick tops than on bottoms from February 1981 onward. An encrusting bryozoan, *Schizoporella,* grew predominantly on bottoms; coelenterates, *Obelia dichotoma* and *Tubularia crocea,* were present on the tops of all materials but were almost absent from the bottoms.

Temporal Change.—Changes occurred in the species composing the epifaunal communities at different times of the year (Tables 1 and 2). Organisms which were only found during the summer included the hydroid, *Halicium halicium,* the polychaete, *Nereis grayi,* and the nudibranchs, *Eubranchus exiguus* and *Acanthodoris pilosa*; during the summer, nudibranchs spawned and attached their eggs to the blocks. The dominant branching bryozoan, *Bugula turrita,* settled in summer and persisted until the winter. Species settling in the fall and living through the winter included the tube worm, *Sabellaria vulgaris,* the bryozoans, *Schizoporella unicornis* and *Aetae* sp., the mollusc, *Anomia aculeata,* and the sponge, *Haliclona loosanoffi.*

A group of invertebrates that persisted throughout the year (or settled sporad-

Table 3. Percent of live cover on colonization bricks in the ocean October 1980 to September 1982

	IPALCO		Concrete		Conesville	
	$\bar{x}$	±SD	$\bar{x}$	±SD	$\bar{x}$	±SD
Tops						
1980						
November	2	1.15	5	2.87	6	3.16
December	16	6.83	24	14.7	13	3.11
1981						
February	20	9.85	33	7.57	10	3.46
April	4	1.73	29	9.33	22	12.3
May	39	15.6	60	6.85	43	9.11
July	20	13.5	40	9.33	30	8.06
August	31	14.3	41	5.67	28	8.60
December	30	5.12	35	8.70	26	6.98
1982						
March	78	7.79	59	23.0	72	8.50
June	66	11.4	80	4.55	82	10.2
September	22	7.78	70	3.95	40	12.0
October	21	7.78	51	8.38		
Bottoms						
1980						
November	2	0.96	4	4.69	7	4.11
December	6	3.83	5	3.30	6	5.26
1981						
February	40	7.94	24	10.6	16	3.78
April	11	1.26	24	11.3	25	4.11
May	26	8.37	38	11.5	58	6.29
July	44	9.03	84	3.11	42	15.9
August	47	10.3	93	1.89	70	15.7
December	34	5.90	46	8.23	43	10.61
1982						
March	40	11.6	89	7.93	59	12.25
June	41	2.94	78	17.8	33	4.04
September			65	13.5	63	9.70
October	65	0.70	53	5.56		

ically at all seasons) included the blue mussel, *Mytilus edulis,* the barnacle, *Balanus crenatus,* the boring clam, *Zirfaea crispata,* the tube worm, *Polydora socialis,* and folliculinid and peritrich protozoans. Other persistent organisms were the bryozoans, *Callopora punctata, Cribulina punctata, Electra crustulenta, E. hastingsae,* and *Membranipora tenuis.* Persistent coelenterates included *Clytia hemisphaerica, Obelia dichotoma,* and the anemone, *Metridium senile.*

Area Colonized.—The area colonized on all brick surfaces tended to increase with longer exposures in the sea during the first year (Fig. 2). By August 1981, after 10 months the average surface area covered by organisms on the brick bottoms was 93% for concrete, 70% for Conesville, and 47% for IPALCO; the area colonized on the brick tops was 41% on concrete, 28% on Conesville, 31% on IPALCO (Table 3). The increase area cover was not steady through the first year, there was little growth in the communities during winter 1980–1981 and settlement of new organisms was sparse. There was also some winter losses of previously settled colonies.

Table 4.

Welsh step-up test for significance of difference on cover on bricks (C=Conesville; I=IPALCO; K=Concrete)

Low cover			High cover		Lowest vs. highest		
C	. . ns . .	I	—*—	K	*	1981	Feb Top
I	——	C	. . ns . .	K	*		Apr Top
I	. . ns . .	C	. . ns . .	K	*		Apr Bottom
I	. . ns . .	C	—*—	K	*		May Top
I	. . ns . .	K	—*—	C	*		May Bottom
I	. . ns . .	K	—*—	C	*		Jul Bottom
I	—*—	C	—*—	K	*		Aug Bottom
I	—*—	C	—*—	K	*	1982	Mar Bottom
I	—*—	C	. . ns . .	K	*		Jun Top
C	. . ns . .	I	—*—	K	*		Jun Bottom
I	. . ns . .	C	—*—	K	*		Oct Top

* Significant difference ($p < 0.05$)
ns No significant differences.

During the second year in the sea, the area of brick bottoms covered by colonizers had decreased from the summer maxima by December 1981. During the winter period 1981–1982, blocks did not loose colonizers, then colonized areas gradually increased again through the summer of 1982.

On brick tops area of colonization changed little during the fall of 1981, but all of the brick tops had increased cover by March 1982; the average surface area colonized being greatest on IPALCO (78%) and Conesville (72%), compared to concrete (59%). For both tops and bottoms, these increases in colonization were principally due to a massive settlement of mussels, *M. edulis* and barnacles.

The data for percent area covered on the test bricks of the different materials were subjected to an analysis of variance. During the 2 years of exposure, significant differences in percent cover were found between community growth on brick materials for the tops in February and April 1981 and June and October 1982. On bottom surfaces, significant differences in cover were found for May, June and July 1981 and for May and June, 1982. In such cases, with significant differences in cover, the data were subjected to a "Welsch Step-Up procedure" (Sokal

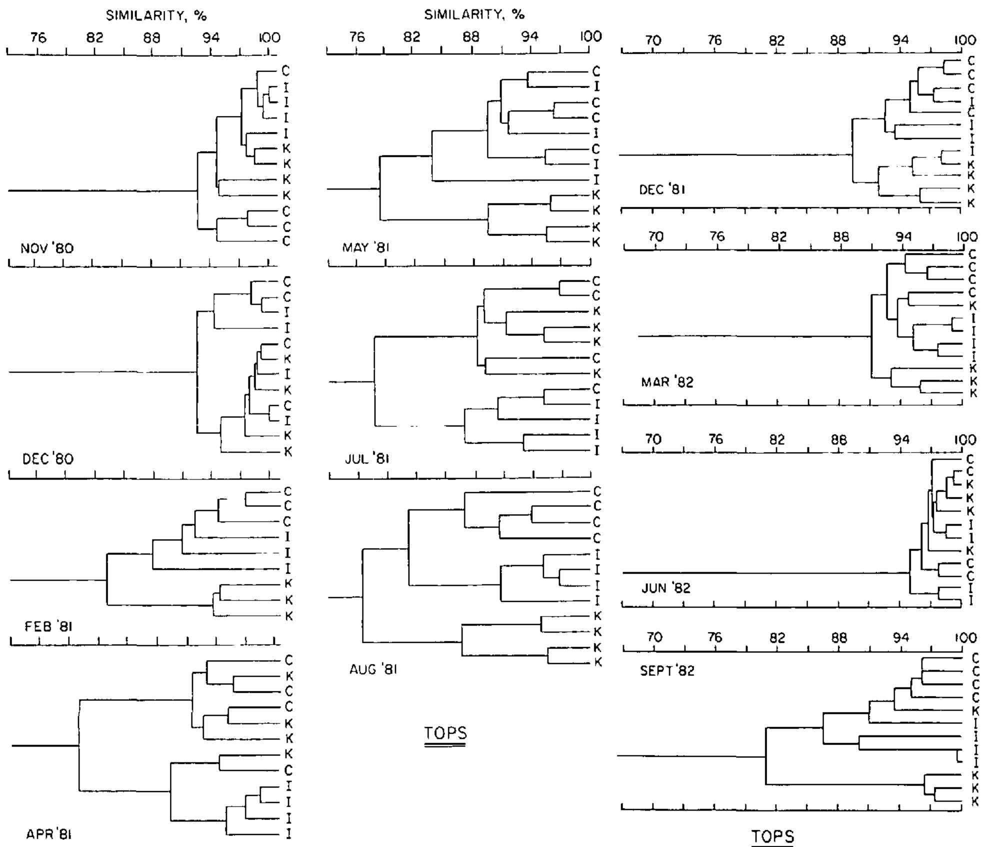

Figure 3. Dendrograms for similarity between communities on the tops of the three brick types. K = concrete; C = Conesville; I = IPALCO.

and Rohlf, 1981) (Table 4) to determine which brick types were most similar to each other in cover. In summary, 11 sets of data for brick surface area covered by organisms had significant differences for communities on two or more brick materials. Concrete had the highest percent surface cover in nine cases and IPALCO had the lowest percent surface cover also in nine cases (although not in the same nine as the concrete). In all 11 sets, concrete carried more cover than IPALCO, and, in nine of the cases, this difference was significant ($P < 0.01$). In eight cases, there was significantly greater coverage on concrete than on Conesville bricks. In six cases, the two coal wastes had significantly different amounts of cover; there being no differences in the remaining five.

Cluster Analysis.—To compare the similarity of the colonization processes on the different bricks, the community data were assessed by cluster analysis; the Bray-Curtis coefficient was the index of similarity used. For these analyses, the data sets from the tops and from brick bottoms were treated separately, providing two independent measures for comparison. The results are illustrated in two series of similarity dendrograms (Figs. 3 and 4) which present changes in the communities on brick tops and bottoms. Dendrogram clusters are influenced by the species found on blocks and by the abundance of these organisms, similar community groups cluster in proximity to each other on dendrograms.

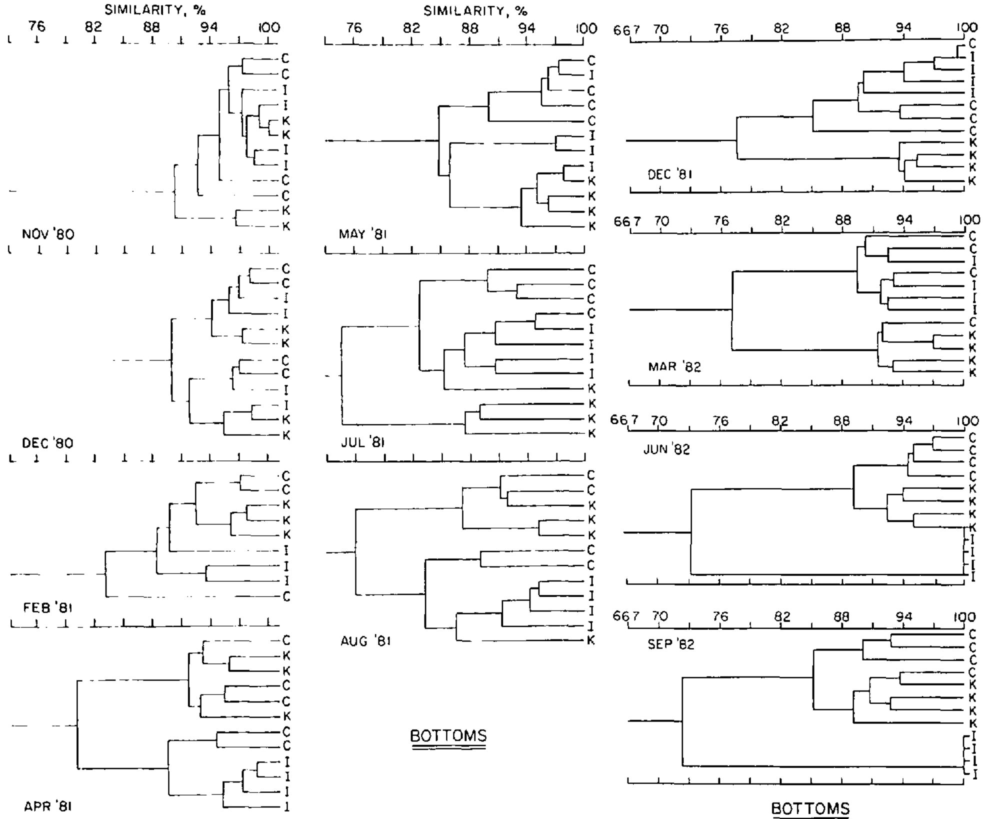

Figure 4. Dendrograms for similarity between communities on the bottoms of the three brick types: K = concrete; C = Conesville; I = IPALCO.

During the early months of exposure in the sea, great similarity was seen in the sessile communities which settled on the bricks. As the time spent in the sea increased and colonization progressed, the communities growing on the bricks became increasingly dissimilar. While these communities became more dissimilar for each brick material, communities growing on blocks of the *same* material remained similar (i.e., clustered together). This can be seen generally for both tops and bottoms in Figures 3 and 4.

In August 1981, at the end of 1 year in the sea, the communities on the tops of each of the three brick materials were clustered quite separately. Communities on the bottoms of bricks were not completely separated; only the IPALCO bottoms formed a separate cluster. This pattern of increasing differentiation and dissimilarity of the communities established during the first year, was reversed during most of the second year in the sea (October 1981–October 1982). Increased similarity developed strongly in the communities growing on brick tops. By March 1982, the separation of the communities by brick type was still maintained but similarity had increased, as indicated by the shortening of the limbs of the dendrogram. Similarity was greatest in June 1982 when the dendrogram limbs were very short, all of the communities being 97% similar or greater. These increases in similarity in March and June were due to a very heavy set of juvenile mussels which covered the surfaces and blanketed many of the organisms on the block tops. At the end of the summer in September, dissimilarity and differentiation between the communities on brick tops had been re-established leading to discrete clustering of communities according to brick materials again.

The communities on brick bottoms did not show such large increases in similarity as on brick tops, but the changes in the same direction occurred at the same time (Figs. 3 and 4). The communities on brick bottoms achieved greatest differentiation and lowest similarity in July–August 1981. Similarity increased in the communities on bottoms in March and June 1982, although the communities growing on concrete remained differentiated from the communities on coal waste. Communities on the bottoms of bricks retrieved in September and in October 1982 showed some increase in dissimilarity and differentiation once again, as was found on tops.

Discussion

During 2 years a total of 36 species of attached epibenthos and 13 errant species were recorded in the communities on the bricks of coal wastes and of concrete. Most species occurred on all three types of material. Coal waste blocks appeared to provide surfaces suitable for settlement and growth of the many sessile and encrusting organisms. A few animals were strongly associated with a particular material. Barnacles, *Balanus crenatus,* were significantly more abundant ($P < 0.01$) on tops of concrete bricks than on the coal waste bricks in April, May and July 1982. The tube worm, *Polydora socialis,* and the burrowing clam, *Zirfaea crispata,* were associated only with the bricks of coal wastes.

Colonization followed similar patterns on all three brick-types both in the numbers of species present and the amount of surface area covered. During the first year in the sea, there was a trend of increasing surface area covered with time, which was most marked on the brick bottoms. Simultaneously, the number of species in the community increased. In the second year, communities were quite different. Change was greatest on brick tops, the number of species decreased on all three brick-types, from the summer maxima of 1981, to only three to five species in June 1982. The initial decrease in species in fall-winter of 1981 was due to the seasonal cycle of change, but the low diversity in March and June 1982 was caused by catastrophic settlement of barnacles and mussels, which overgrew all of the blocks. Community growth in area took place at similar rates on all three materials, almost total cover on brick tops occurred in March and June 1982 when the heavy settlement of barnacles and mussels occurred. However, greater differences were found between materials in area of bottoms covered; concrete bricks had wider areas covered than coal waste bricks.

Similarities between the communities growing on the bricks were analyzed using the Bray-Curtis index in cluster analysis. During the first year early similarity was found between communities on all bricks. But with increasing time in the sea, dissimilarities arose and differentiation of the communities took place on bricks according to the different materials. During the second year, however, the processes of community differentiation according to brick material were reversed. Differentiation decreased for all communities between August and December 1981 due to seasonal changes in communities, especially due to the growth of a dominant bryozoan, *Bugula turrita* on all surfaces. The similarity between all communities increased further in March and June 1982, especially on brick tops, caused by the catastrophic settlement of barnacles, *B. crenatus,* and mussels, *M. edulis.* Colonization measurements taken in September and October 1982, and showed that community differentiation according to brick material was again being re-established, following reductions of the dense overgrowths of barnacles and mussels.

There are few reports concerning the biological communities inhabiting coal waste materials, exceptions of particular interest to us, are the investigation of coal waste blocks in a shallow embayment of Long Island Sound, New York (Roethel et al., 1983), and the report of Bamber (1983) on the fauna inhabiting aggregates of fly ash formed on the seabed off Northumberland, U.K., in the North Sea. The fauna inhabiting aggregates of fly ash in the North Sea is probably closer to that reported here, both communities were growing in deeper water, below the euphotic zone, and algae were absent. The ash aggregates were inhabited by two boring clams, *Zirphaea crispata* and *Hiatella arctica,* and a diverse encrusting fauna, altogether 28 species were found living on the aggregates. Bamber's North Sea fauna includes four species common in the fauna associated with our coal-waste bricks; nine genera of invertebrates occur in the two faunal assemblages. The fauna growing on coal waste blocks at 6 m, in Long Island Sound (Roethel, 1981; Roethel et al., 1983) consisted of 29 species, five of which are found on our bricks; 11 genera of invertebrates occur on the sets of coal waste blocks in both environments. Boring pholad clams, *Zirfaea crispata,* were characteristic of all three assemblages associated with coal wastes. We have found specimens of *Z. crispata* of 3 years old in coal waste blocks, but Bamber (1983) reported clams of this species which were 7 years old in North Sea aggregates. He suggests that such long residence indicates that the waste material is not toxic, this conclusion receives support from elemental analyses of the tissues of *Z. crispata* (Roethel 1981; Roethel et al., 1983), which showed no accumulation of potentially toxic trace elements. Bamber (1983) also noted selective settlement on fly ash by cyphonautes larvae of bryozoans, we have also found selective settlement on coal wastes by invertebrate larvae when given a choice between coal waste or concrete as substrates.

CONCLUSIONS

Data assembled over 2 years on the settlement, growth, and differentiation of the epifaunal communities on the bricks of coal wastes and of concrete indicates that the succession of community changes were similar on all materials. The same assemblage of species was found on all bricks with only one or two important exceptions (*Z. crispata* and *P. socialis* on coal wastes). Changes in the number of species also increased and decreased in all communities at the same time. The size of the communities, measured as surface area overgrown, all followed similar cycles of increase and decrease, although from June 1981 to June 1982, concrete bricks were more densely colonized than were the coal wastes.

The correspondence between these communities, their specific components, and their responses to change over time indicates a parallel in behavior of the epifauna colonizing the bricks of all types. The principal difference for concrete appears to be that community growth and cover occurred more rapidly, at least on the bottoms of bricks, than was found on coal wastes. Overall, the data demonstrated that the stabilized coal waste materials are suitable substrates for settlement of epifaunal invertebrates typical of reefs and rocky bottom in the inshore waters of the northeast.

ACKNOWLEDGMENTS

Our thanks to J. Parker for directing and assisting with the collections at sea. We are grateful to D. Caulder, L. Harris, P. Morgan, and M. Myers for identifications of selected invertebrates, and M.

Myers for helping to set up the cluster analysis. We thank V. Abolins, and M. A. Lau for their careful assistance in the preparation of this manuscript. The study was supported by grants from a number of agencies and managed by the New York State Energy Research and Development Authority; other contributing agencies were the Power Authority of the State of New York, Electric Power Research Institute, U.S. Department of Energy and U.S. Environmental Protection Agency.

Literature Cited

Bamber, R. N. 1978. The effects of dumped pulverized fly ash on the benthic fauna of the Northumberland Coast. Ph.D. Thesis, University of Newcastle-on-Tyne. 150 pp.

———. 1983. Pozzolanic aggregates of fly ash in the sea. Mar. Biol. 77: 151–154.

Boesch, D. F. 1977. Application of numerical classification in ecological investigations of water pollution. EPA-600/3-77-033, March 1977. Corvallis Environmental Research Laboratory Office of Research and Development, U.S. EPA, Corvallis, OR 97330. 114 pp.

Clifford, H. T. and W. Stephenson. 1975. An introduction to numerical classification. Academic Press, New York. 229 pp.

Parker, J. H., P. M. J. Woodhead, and I. W. Duedall. 1981. Coal waste artificial reef program, Phase 3, Vol. 2: Comprehensive report. EPRI CS-2009 Project 1341-1 Interim Rept., November 1981. 302 pp.

———, ———, ——— and H. R. Carleton. 1982. Ocean disposal and construction with stabilized coal waste blocks. Pages 287–299 *in* International Conf. on Coal Fired Power Plants and the Aquatic Environment, Copenhagen. 16–18 August 1982.

———, ———, ———, J. Colussi, R. G. Hilton and L. E. Pfeiffenberger. 1985. Coal-waste blocks for artificial reef establishment: a large-scale experiment. Pages 537–556 *in* I. W. Duedall, D. R. Kester, P. K. Park and B. H. Ketchum, eds. Wastes in the ocean, Vol. 4: Energy wastes in the ocean. John Wiley and Sons, New York.

Roethel, F. J. 1981. The interactions of stabilized power plant coal wastes with the marine environment. Ph.D. Thesis, State University of New York at Stony Brook. 349 pp.

———, I. W. Duedall and P. M. J. Woodhead. 1983. Coal waste artificial reef program: the Conscience Bay report. Electric Power Res. Inst., Res. Project 1341-1. 295 pp.

Rohlf, J. F., J. Kishpaugh and D. Kirk. 1981. Numerical taxonomy system of multivariate statistical programs. Dept. of Ecology and Evolution, SUNY at Stony Brook. 104 pp.

Sokal, R. R. and F. J. Rohlf. 1981. Biometry. W. H. Freeman and Company, San Francisco. 776 pp.

Woodhead, P. M. J. and M. E. Jacobson. 1985. Biological colonization of a coal-waste artificial reef. Pages 597–612 *in* I. W. Duedall, D. R. Kester, P. K. Park and B. H. Ketchum, eds. Wastes in the ocean, Vol. 4: Energy wastes in the ocean. John Wiley and Sons, New York.

——— and J. H. Parker. 1985. Biological compatibility of a coal-waste block reef in the ocean. Pages 559–572 *in* I. W. Duedall, D. R. Kester, P. K. Park and B. H. Ketchum, eds. Wastes in the ocean, Vol. 4: Energy wastes in the ocean. John Wiley and Sons, New York.

———, I. W. Duedall and N. F. Lansing. 1980. Coal waste artificial reef program, Phase 1. Electric Power Res. Inst., EPRI FP-1252 Res. Project 1341-2. Interim Rept. 83 pp.

———, J. H. Parker and I. W. Duedall. 1982. The coal waste artificial reef program (C-WARP): Investigations of an important new resource potential for fishing reef construction. Marine Fish. Rev. 44(6/7): 16–23.

———, ———, H. R. Carleton and I. W. Duedall. 1984. Coal-waste artificial reef program, Phase 4B. Electric Power Res. Inst., EPRI CS-3726 Res. Project 1341-1 Interim Rept. 268 pp.

Date Accepted: March 19, 1985.

Address: *Marine Sciences Research Center, State University of New York, Stony Brook, New York 11794.*