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Responses of Macrobenthos Colonizing Estuarine Sediments Contaminated with Drilling Mud Containing Diesel Oil

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Drilling muds are used in offshore exploration for gas and oil to bring up drill cuttings, to maintain hydrostatic pressure, to cool and lubricate the bit, and to seal the well. Large amounts are discharged and deposited in the marine environment during drilling. In addition, as many as 30 ingredients may be used in a single well to control fluid properties or for specific drilling conditions (Neff, 1982). Because drilling muds differ greatly in composition and in toxicity to aquatic organisms, different types need to be studied to assess their environmental impact and to determine if particular additives change the toxicity of generic muds.

Acute toxicities and sublethal effects were determined in several investigations for 11 types of drilling muds obtained from offshore drilling sites in the Gulf of Mexico, which the Petroleum Equipment Suppliers Association supplied to the Environmental Protection Agency. All were used muds that had been recycled during drilling. Those containing the highest amounts of No. 2 diesel fuel oil were the most acutely toxic to mysids (*Mysidopsis bahia*), grass shrimp (*Palaemonetes pugio*), quahog clams (*Mercenaria mercenaria*), and sand dollars (*Echinarachnius parma*) and elicited the greatest sublethal responses in corals (*Acropora cervicornis*) (National Research Council, 1983; Duke and Parrish, 1984). A lignosulfonate mud containing 9.43 mg diesel/g of mud was the most toxic, followed by a lime mud containing 3.98 mg diesel/g (wet weight, solid phase).

The present study was initiated to determine the impact of the lime mud with its diesel oil component on field colonization by macrobenthos. This field study follows similar work on lignosulfonate drilling muds conducted earlier in our laboratory. In these studies, community structure of benthic communities was affected by drilling mud in the sediment (Tagatz et al., 1978) or in the water (Tagatz et al., 1982). Review of information shows that the biological effects of drilling mud discharges are confined primarily to the benthic environment (National Research Council, 1983).

MATERIALS AND METHODS

We compared communities that developed in clean sediment, sediment containing lime drilling mud, and sediment containing barite[1] (barium sulfate). Barite, a clay weighting-agent and primary constituent of drilling muds, was tested separately to distinguish between effects due to barite and to drilling mud. In previous laboratory experiments, barite affected recruitment in benthos; its impact was attributed primarily to differences in sediment structure (particle size) between control sediment and barite-contaminated sediment (Cantelmo et al., 1979; Tagatz and Tobia, 1978). American Petroleum Institute (1981) has established standards of specific gravity, pore size, and alkalinity for barite to ensure consistency in oil well drilling.

The sample of lime mud, collected from a depth of 17,195 feet (5,241 m), had a pH of 11.5, and a fluid weight of 18.1 pounds per gallon (2.2 kg/l). Solid content by volume was 40% and liquid content was 3% oil and 57% water. Lime muds are made up of barite, bentonite, caustic soda, lignite, lignosulfonate, lime, and soda ash/sodium bicarbonate and are able to carry larger concentrations of clay solids at lower viscosities than other types of mud. Diesel oil is a common drilling mud additive; as much as 2 to 4 percent is added to improve lubricity (National Research Council, 1983). The lime mud was analyzed for diesel oil (3.98 mg/g wet weight) at New England Aquarium (1984) and for metal content (35.1% Ba, dry weight, highest of 10 elements), aliphatic fraction concentrations (resolved, 1,260 mg/l; unresolved, 5,970 mg/l) and aromatic fraction concentrations (resolved, 230 mg/l; unresolved, 445 mg/l) at Science Applications, Inc. (1983). Detailed results of these analyses can be found in the references cited above.

SCUBA divers placed 20 sediment-filled boxes, in four groups of five, in 3 m of water in Santa Rosa Sound adjacent to our laboratory. The boxes, 32 cm X 32 cm X 6 cm deep, constructed of acrylic plastic, were positioned in the substratum so that their surfaces were level with the surrounding sand.

Each group of the test containers consisted of a control box filled with only 6-cm clean sand and four boxes filled with 4 cm of clean sand with a 2-cm overlay of mixtures of sand with barite or drilling mud. Mixture ratios (blended by hand) consisted of 1:10 or 1:3 barite to sand and 1:10 or 1:3 drilling mud to sand. Sand (82% of particles were 0.36 to 0.71 mm) was dredged more than 6 months previously from Santa Rosa Sound. After 8 weeks of colonization, June 20 to August 15, 1983, field communities (covered with acrylic plastic and then transferred to the laboratory) were harvested. Animals retained by a 1-mm mesh sieve were preserved, identified, and counted.

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[1] IMCO BAR, IMCO Services, Houston, Texas. Mention of trade names does not constitute endorsement by EPA.

Salinity and temperature of Santa Rosa Sound water, recorded continuously at our laboratory, averaged 23.5°/oo (15.0 to 31.5°/oo) and 27.5° C (25.0 to 30.0° C) during the 8-week period.

Various comparisons and biological indices were applied to our data. One-way analysis of variance and Duncan's Multiple Range post hoc analysis (Winer, 1971) were used to compare numbers of individuals and species in control and contaminated boxes by taxon ($\alpha = 0.05$). The Shannon-Weaver (1963) index ($\log_{10}$) was calculated to assess species diversity, an integrated measure of richness and evenness. Simpson's (1949) index was used as a comparative measure of dominance; degree of dominance by the more abundant species determines the evenness of distribution of individuals among species. The Bray-Curtis dissimilarity index (Swartz et al., 1976) was used to document spatial-temporal faunal heterogeneity between the control and contaminated boxes. Index values range from 1, when the collections have no species in common, to 0, when all species are common and of equal relative abundance.

RESULTS AND DISCUSSION

A total of 1081 animals representing 63 species of 10 phyla was collected from field-colonized boxes (Table 1). No erosion was evident as all boxes retained their sand and barite. Mollusca, Annelida, Chordata, and Arthropoda, in decreasing order of abundance, were the dominant phyla. The average numbers of animals and species in test boxes containing both ratios of mud to sand were significantly less than those in control boxes (Table 2). Only 24 and 32 species occurred in the 1:3 and 1:10 mud mixtures, respectively, compared with 43 species in the control. Mollusks, particularly gastropods, and annelids were significantly affected. Although individuals and species were fewer in barite mixtures than in the control, only species effect for combined phyla in 1:3 barite was significant (Table 2).

The lime drilling mud caused effects on community structure beyond beyond those caused by its barite component. For all phyla combined, both number of individuals and number of species in 1:3 mud mixtures differed significantly from those in the barite mixtures. In addition, a significant difference in number of species was detected between the 1:10 mud mixtures and the 1:10 barite mixtures.

Species diversity, species dominance, and dissimilarity indices changed markedly only in communities exposed to 1:3 mud mixtures. Shannon-Weaver diversity in 1:3 mud (0.20) was substantially less than that in other communities (control was 1.29, 1:10 barite was 1.25, 1:3 barite was 1.19, and 1:10 mud was 1.21). Simpson's index of dominance was relatively low in the 1:3 mud communities (0.62), but very similar in the other mixtures and the control (0.90-0.92). Relative abundance of individual species for all treatments differed little from the control, as reflected by low Bray-Curtis dissimilarity indices; however, communities in

Table 1. Number of animals in field-colonized benthic communities collected from control boxes and from boxes contaminated by barite or drilling mud for 8 weeks. Replicates were pooled.

Taxon	Control	Barite:Sand		Mud:Sand	
		1:10	1:3	1:10	1:3
MOLLUSCA					
Pelecypoda					
Anomalocardia auberiana	54	58	54	44	29
Crassostrea virginica	33	29	29	22	15
Laevicardium mortoni	26	17	19	20	12
Brachidontes exustus	1	1	1	0	1
Tellina sp.	1	1	0	0	0
Abra aequalis	0	0	1	0	0
Musculus lateralis	0	1	0	0	0
Total pelecypods	115	107	104	86	57
Gastropoda					
Crepidula maculosa	31	19	21	16	16
Acteocina canaliculata	16	11	13	6	2
Mitrella lunata	9	13	5	8	3
Diastoma varium	11	8	9	4	1
Persicula sp.	6	5	8	5	6
Nassarius vibex	8	4	2	6	2
Marginella apicina	5	4	1	4	3
Crepidula plana	4	1	0	0	1
Mangelia stellata	1	1	0	1	0
Polinices duplicatus	1	1	0	0	1
Terebra protexta	0	0	0	1	1
Olivella mutica	0	1	0	0	0
Total gastropods	92	68	59	51	36
Total mollusks	207	175	163	137	93
ANNELIDA					
Axiothella mucosa	10	10	4	8	0
Poecilochaetus johnsoni	3	4	3	5	0
Neanthes succinea	3	3	4	4	0
Laeonereis culveri	5	5	1	1	0
Scolelepis sp.	1	1	3	3	0
Hydroides dianthus	1	2	1	0	3
Heteromastus filiformis	2	3	1	0	0
Mesochaetopterus taylori	1	1	2	2	0
Polydora sp.	1	2	1	0	2
Notomastus latericeus	2	0	1	1	0
Glycera americana	0	1	1	1	0
Haploscoloplos robustus	2	0	1	0	0
Loimia virdis	0	2	1	0	0
Prionospio heterobranchia	0	2	1	0	0

Table 1. continued.

Taxon	Control	Barite:Sand 1:10	Barite:Sand 1:3	Mud:Sand 1:10	Mud:Sand 1:3
Cistenides gouldii	0	0	0	2	0
Sabellidae unident. sp.	2	0	0	0	0
Aricidea fragilis	0	0	1	0	0
Capitellides jonesi	0	0	0	1	0
Dasybranchus lunulatus	1	0	0	0	0
Diopatra cuprea	0	0	1	0	0
Lepidonotus sp.	0	1	0	0	0
Lumbrineris sp.	0	0	1	0	0
Malacoceros sp.	1	0	0	0	0
Phyllodoce sp.	1	0	0	0	0
Platynereis dumerilii	0	0	0	1	0
Sabella micropthalma	1	0	0	0	0
Total annelids	37	37	28	29	5
CHORDATA					
Branchiostoma caribaeum	21	25	15	17	5
ARTHROPODA					
Acanthohaustorius sp.	11	7	1	0	0
Tanaidacea (fam. Apseudidae)	3	5	3	2	0
Grandidierella bonnieroides	6	1	0	3	2
Pagurus annulipes	2	2	3	3	1
Bowmaniella sp.	1	1	0	2	1
Heterocrypta granulata	1	0	0	0	1
Oxyurostylis smithi	0	0	1	0	1
Trachypenaeus sp.	0	0	0	1	1
Pinnixa chaetopterana	0	0	1	0	0
Upogebia affinis	0	0	0	0	1
Total arthropods	24	16	9	11	8
PHORONIDA					
Phoronis architecta	3	3	3	0	0
COELENTERATA					
Actiniaria unident. sp.	1	0	1	0	0
ECHINODERMATA					
Hemipholis elongata	0	0	0	1	0
Leptosynapta inhaerens	1	0	0	0	0
HEMICHORDATA unident. sp.	0	0	1	1	0
RHYNCHOCOELA unident. sp.	1	1	0	0	0
SIPUNCULA					
Phascolion strombi	1	0	0	1	0

Table 1. continued.

Taxon	Control	Barite:Sand 1:10	Barite:Sand 1:3	Mud:Sand 1:10	Mud:Sand 1:3
ALL PHYLA					
Individuals	296	257	220	197	111
Species	43	38	38	32	24

1:3 mud were most dissimilar. Indices calculated by comparing the control with 1:10 barite, 1:3 barite, 1:10 mud, and 1:3 mud were 0.17, 0.20, 0.20, and 0.31, respectively. Species number and density were more sensitive and reliable indicators of stress than the biological indices employed since they indicated effects of barite or lime mud at both 1:10 and 1:3 mixtures.

Results of this field study corroborate some of our laboratory studies on the effects of barite or mud/sand mixtures on benthic communities (Tagatz and Tobia, 1978; Tagatz et al., 1978). Some differences also occurred, probably because dominant species and depth of barite or mud/sand mixtures in test boxes differed. Numbers of annelids were affected by drilling mud in both studies, but mollusks only in the field study. In field and laboratory barite studies, gastropods, but not pelecypods, were affected; annelids were affected only in the laboratory study. Gastropods probably were more vulnerable to barite in sediments than were pelecypods since their feeding is associated with sediments; pelecypods primarily utilize the water column.

Although various components of drilling mud, such as some bactericides and surfactants, are toxic to aquatic organisms (Sprague and Logan, 1979), the substantial amount of diesel oil in the lime mud we tested probably was the primary contributor to mortality or larval avoidance. Capuzzo and Derby (1982) tested five drilling muds to determine their effects on developmental stages of the American lobster (*Homarus americanus*). Their results indicated that it is primarily the chemical and not the physical features of drilling muds that caused the detrimental effects and that muds with a diesel oil component $\leq$ 4% were more toxic than those without this component. Also Conklin et al., (1983) found that diesel oil, as a component, contributed significantly to the toxicity of drilling muds (0.13 to 5.53 mg/g). They reported that the 96-hour toxicity of 18 muds (taken from various depths from an exploratory well) to grass shrimp, *Palaemonetes pugio*, increased as the concentration of the oil increased. Other experiments have shown that diesel oil is toxic to benthic communities. Low chronic additions of No.2 fuel oil to the water column (190 and 90 ppb) caused significant decline in the numbers of macrofauna and meiofauna in experimental tanks compared with controls (Grassle et al.,

Table 2. Average number of animals and average number of species per box collected from field-colonized boxes. Standard error in parentheses.

Taxon	Control	Barite:Sand 1:10	Barite:Sand 1:3	Mud:Sand 1:10	Mud:Sand 1:3
Mollusks	41.4 (3.6)	35.0 (7.0)	32.6 (3.2)	27.4 (5.2)	18.6* (1.6)
	10.2 (0.9)	10.2 (0.4)	8.0 (0.9)	7.8 (0.9)	7.4* (0.6)
Pelecypods	23.0 (3.5)	21.4 (6.4)	20.8 (1.9)	17.2 (4.6)	11.4 (1.3)
Gastropods	18.4 (3.2)	13.6 (1.2)	11.8* (2.1)	10.2* (1.2)	7.2* (0.7)
Annelids	7.4 (0.7)	7.4 (0.9)	5.6 (0.7)	5.8 (1.2)	1.0* (0.4)
	5.6 (0.7)	5.0 (0.4)	5.2 (0.5)	4.0 (0.7)	1.0* (0.4)
Chordates	4.2 (0.9)	5.0 (1.3)	3.0 (1.4)	3.4 (1.4)	1.0 (0.3)
	1.0 (0.0)	1.0 (0.0)	0.8 (0.2)	0.8 (0.2)	0.8 (0.2)
Arthropods	4.8 (0.8)	3.2 (1.2)	1.8 (0.7)	2.2 (0.4)	1.6 (0.7)
	3.2 (0.4)	2.0 (0.6)	1.4 (0.5)	1.6 (0.2)	1.4 (0.5)
Other phyla	1.4 (0.2)	0.8 (0.4)	1.0 (0.3)	0.6 (0.2)	0
	1.4 (0.2)	0.6 (0.2)	1.0 (0.3)	0.6 (0.2)	0
All phyla	59.2 (4.8)	51.4 (7.3)	44.0 (3.5)	39.4* (6.5)	22.2* (1.7)
	21.4 (1.7)	18.8 (1.3)	16.4* (0.9)	14.8* (1.4)	10.6* (0.5)

*Significantly different from control ($\alpha = 0.05$)

1981; Oviatt et al., 1982). Many benthic animals feed on suspended matter or bottom sediments that may contain oil. Studies reported by Lee (1976) have shown uptake of petroleum hydrocarbons from sediments by bivalves, decapods, and polychaetes; the latter two groups are able to metabolize them. Available information indicates that any diesel oil additive needs to be considered in the environmental impact of aquatic disposal of drilling muds.

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