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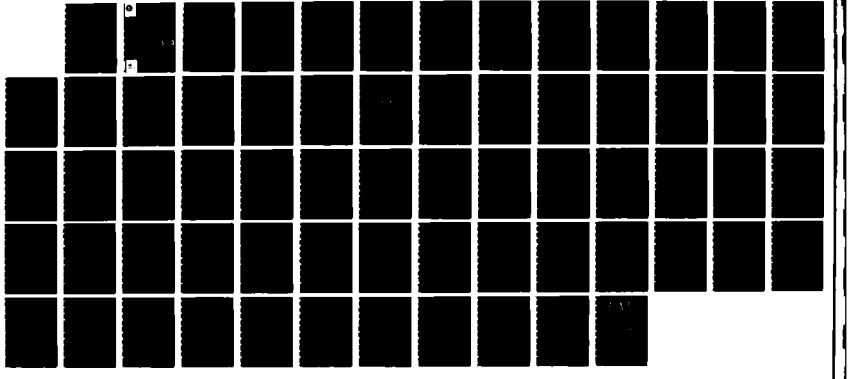

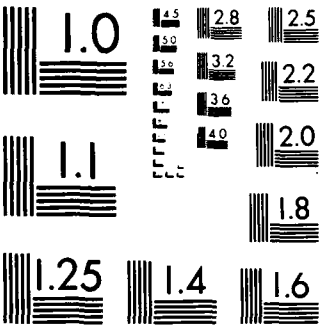

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TECHNICAL REPORT D-87-3

THE ASSESSMENT OF BLACK ROCK HARBOR DREDGED MATERIAL IMPACTS ON LABORATORY POPULATION RESPONSES

by

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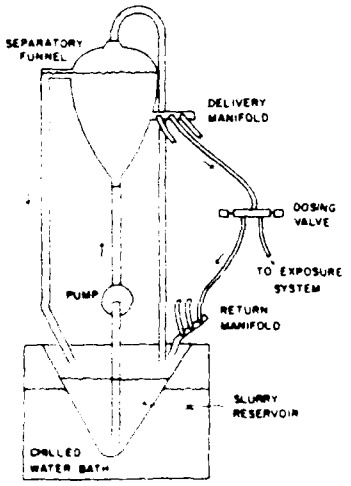

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Studies were conducted to determine the applicability of using population responses to assess the impact of dredged material. Laboratory methods were successfully developed to continuously expose *Ampelisca abdita* and *Mysidopsis bahia* to bedded and suspended sediments throughout their life cycle. Biological effects, including survival, individual growth, reproduction, and intrinsic rate of population growth, were measured over a range of exposures to Black Rock Harbor dredged material (BRH).

Short-term effects (96-hr LC50) were observed at BRH suspended sediment concentrations of 262 mg/l and 80 mg/l for *M. bahia* and *A. abdita*, respectively, while the 10-day LC50 for *A. abdita* was 10.5 mg BRH/l. Thus, *A. abdita* was three times more sensitive to the acute effects of BRH sediment than *M. bahia*. Acute toxicity in *A. abdita* was strongly time dependent with 10-day exposures showing an eightfold increase in toxicity compared to the 4-day toxicity data. This may be the result of *A. abdita*'s more intimate contact with the

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contaminated sediments. The concentrations of BRH suspended sediments causing effects on growth, reproduction, and population growth to *M. bahia* were 25, 18, and 8 mg/l, respectively. *Ampelisca abdita* growth and reproduction were impaired at 2.2 mg/l, and population growth was affected at 1.1 mg/l.

This study demonstrates that chronic responses are the best predictors of environmental impacts. The use of population responses is of particular value since populations are the level of biological organization of concern. The application of demographic techniques to life cycle toxicity tests provides an ecological framework for interpreting the significance of chronic toxicity data.

PREFACE

This report describes work performed by the US Environmental Protection Agency (USEPA), Environmental Research Laboratory, Narragansett, R. I. (ERLN), as part of the Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal Alternatives Program (Field Verification Program (FVP)). The FVP was sponsored by the Office, Chief of Engineers (OCE), US Army, and was assigned to the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The objective of this interagency program was to field verify existing test methodologies for predicting the environmental consequences of dredged material disposal under aquatic, intertidal, and upland conditions. The aquatic portion of the FVP was conducted by ERLN, with the intertidal and upland portions conducted by WES.

The principal investigators for this aquatic study and the authors of this report were Dr. John H. Gentile and Ms. Suzanne M. Lussier of ERLN and Dr. K. John Scott and Ms. Michele S. Redmond of Science Applications International Corporation (SAIC). Technical support was provided by Ms. Ann Kuhn and Mr. John Sewall of SAIC. The authors wish to thank Dr. Wayne R. Munns, SAIC, for his incisive and timely reviews of this document, and Ms. Joan E. Seites, Computer Sciences Corporation, for manuscript preparation and word processing support.

The USEPA Technical Director for the FVP was Dr. Gentile; the Technical Coordinators were Dr. Gerald Pesch and Mr. Walter R. Galloway.

The study was conducted under the direct WES management of Drs. Thomas M. Dillon and Richard K. Peddicord and under the general management of Dr. C. Richard Lee, Chief, Contaminant Mobility and Criteria Group; Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division; and Dr. John Harrison, Chief, Environmental Laboratory. The Environmental Effects of Dredging Programs Manager was Dr. Robert M. Engler, with Mr. Robert L. Lazor, FVP Coordinator. Dr. Thomas D. Wright was the WES Technical Coordinator for the FVP reports. This report was edited by Mses. Jamie W. Leach and Jessica S. Ruff of the WES Information Products Division.

The OCE Technical Monitors were Drs. John Hall, Robert J. Pierce, and William L. Klesch. The Water Resources Support Center Technical Monitor was Mr. Charles W. Hummer.

COL Dwayne G. Lee, CE, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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Part I: INTRODUCTION

Background

1. The Marine Protection, Research, and Sanctuaries Act (Public Law 92-532) was passed by Congress in 1972. This law states that it is the policy of the United States to regulate disposal of all types of materials into ocean waters and to prevent or strictly limit disposal of any material which would adversely affect human health, welfare, the marine environment, or ecological systems. The implementation of this law, through the issuance of permits as defined in the final regulations and criteria, is shared jointly by the US Environmental Protection Agency (USEPA) and the US Army Corps of Engineers (CE).

2. In 1977, the CE and the USEPA prepared technical guidance for the implementation of the final ocean dumping regulations in the form of a manual entitled "The Ecological Evaluation of Proposed Discharge of Dredged Material Into Ocean Waters" (USEPA/CE 1977). This manual specified which test procedures were to be followed in collecting information to be used in making a disposal decision. Among the procedures were those for: (a) chemically characterizing the proposed dredged material; (b) determining the acute toxicity of liquid, suspended particulate, and solid phases; (c) estimating the potential contaminant bioaccumulation; and (d) describing the initial mixing during disposal. These methods have been used for determining the suitability of dredged material for open-water disposal. The procedures in this manual represented the technical state of the art at that time and were never intended to be inflexible methodologies. The recommended test methods were chosen to provide technical information that was consistent with the criteria specified in the regulations. However, use of the manual in the permit process has identified conceptual and technical limitations with the recommended test methods (Gentile and Scott 1986).

3. To meet this critical need, the Interagency Field Verification of Testing and Predictive Methodologies for Dredged Material Disposal

Alternatives Program or the Field Verification Program (FVP) was authorized in 1982. This 6-year program was sponsored by the Office, Chief of Engineers, and was assigned to the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss. The objective of this interagency program was to field verify existing test methodologies for predicting the environmental consequences of dredged material disposal under aquatic, intertidal, and upland conditions. The aquatic portion of the FVP was conducted by the USEPA Environmental Research Laboratory, Narragansett, R. I. (ERLN). The intertidal and upland portions, conducted by WES, are reported in separate documentation.

4. The USEPA ERLN was responsible for conducting research on the aquatic option for disposal of dredged material. There were three research objectives for this portion of the program. The first was to demonstrate the applicability of existing test methods to detect and measure effects of dredged material, and to determine the degree of variability and reproducibility inherent in the testing procedure. This phase of the program (Laboratory Documentation) is complete, and the results are published in a series of technical reports. This information provides insight into how the various methods function, their sources of variability, their respective and relative sensitivities to the specific dredged material being tested, and the degree of confidence that can be placed in the data derived from the application of the methods.

5. The second objective was to field verify the laboratory responses by measuring the same response under both laboratory and field exposures. A basic and often implicit assumption is that the results derived from laboratory toxicity test methods are directly applicable in the field. While this assumption is intuitive, there are no supporting data from studies on complex wastes in the marine environment. The study reported herein offers a unique opportunity to test this basic assumption.

6. The third objective was to determine the degree of correlation of tissue residues resulting from bioaccumulation of dredged material contaminants with biological responses from laboratory and field exposure to dredged material. However, this study was not designed to address cause-effect relationships, and the multicontaminant nature of the dredged material precludes any such assumptions.

Project Description

7. The aquatic disposal portion of the FVP was a site- and waste-specific case study that applied the concepts and principles of risk assessment. The disposal site for the FVP was an historical site known as the Central Long Island Sound (CLIS) disposal site (1.8 by 3.7 km) located approximately 15 km southeast of New Haven, Conn. (Figure 1). The sedimentology at the disposal and reference sites is primarily silt-clay, with a mean grain size of 0.013 mm. Thermal stratification occurs from April to September and during this period bottom salinity is slightly higher than that of the surface. Tidal currents typically dominate the near-bottom water in an east-west direction. The net bottom drift is to the northwest at 0.5 cm/sec. Suspended sediment concentrations average 10 mg/l, with storm-induced values to 30 mg/l. The baseline community data revealed a homogeneous, mature infaunal community dominated by the polychaete *Nephtys incisa* and the bivalve molluscs *Nucula proxima* and *Yoldia limatula*.

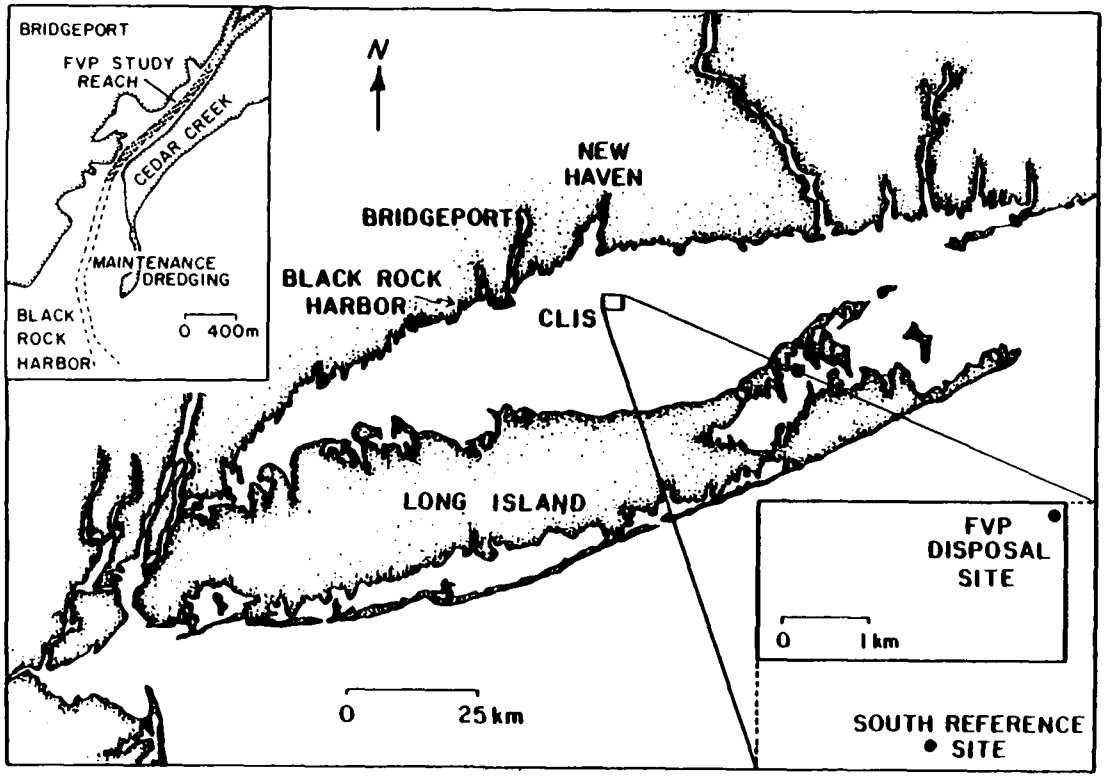

Figure 1. Central Long Island Sound disposal site and Black Rock Harbor dredge site

8. The FVP disposal site was selected within the CLIS so as to minimize contamination from other sources, including relict disposal operations or ongoing disposal activities occurring during the study period. This was necessary to ensure a point source of contamination. The uniformity of physical, chemical, and biological properties of the disposal site prior to disposal allowed detection of changes in these properties due to the disposal of the dredged material. Finally, the stations used to study the biological effects in this study were selected along the primary axis of current flow to represent a gradient of potential exposure for the biota (Figure 2).

9. The spatial scale of this study was near-field and limited to the immediate vicinity of the disposal site. A primary assumption was that the mound of dredged material constitutes a point source of contamination. The temporal scale for the study was 4 years, which included a year of predisposal data collection to define seasonal patterns in the physical, chemical, and biological variables and 3 years of postdisposal data collection to address the objectives of the program and to evaluate the long-term impacts of the disposal operation on the surrounding benthic communities.

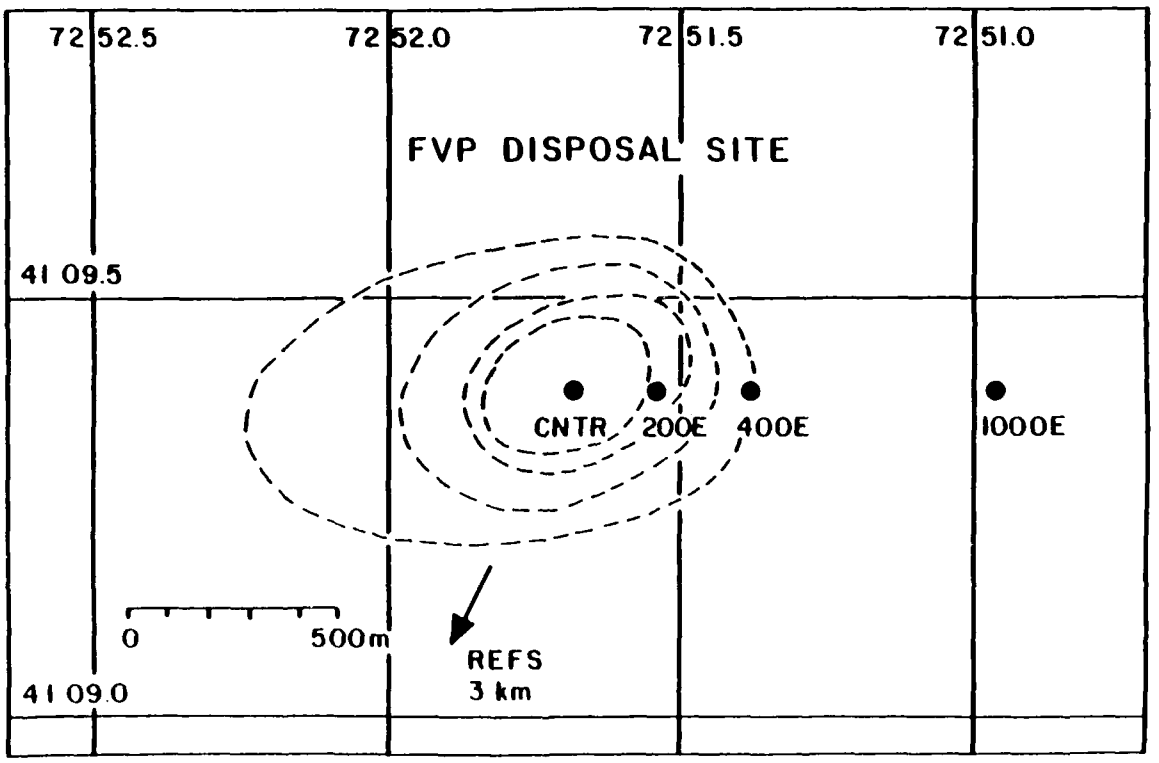

Figure 2. FVP sampling stations

10. The dredging site was Black Rock Harbor (BRH), located in Bridgeport, Conn., where maintenance dredging provided a channel 46 m wide and 5.2 m deep at mean low water (Figure 1). Approximately 55,000 m^3 of material were dredged during April and May 1983 and disposed in 20 m of water in the northeastern corner of the CLIS disposal site.

11. The dredged material from Black Rock Harbor contained substantial concentrations of both organic and inorganic contaminants (Rogerson, Schimmel, and Hoffman 1985). Polychlorinated biphenyls were present in the dredged material at a concentration of 6,300 ng/g, and polynuclear aromatic hydrocarbons (PAHs) with molecular weights between 128 and 302 were present at concentrations ranging from 17 to 9,100 ng/g, respectively. Alkyl homologs of the PAHs were also present in the dredged material at concentrations between 110 and 13,000 ng/g. Inorganic contaminants of toxicological importance present in the dredged material include copper (2,900 ug/g), chromium (1,480 ug/g), zinc (1,200 ug/g), lead (380 ug/g), nickel (140 ug/g), cadmium (24 ug/g), and mercury (1.7 ug/g).

Project Scope

12. The FVP was unique among marine research studies for several reasons. The program objectives were directly focused on addressing specific limitations in the methodologies and interpretive framework of the current regulatory process. Among the program strengths were: the development and evaluation of a suite of biological endpoints that used the same material; the biological tests represented different levels of biological organization; the tests were conducted under both laboratory and field exposure conditions; tissue residues were examined concurrently with measurements of biological effects; the duration of the study was adequate to evaluate the use of community responses as a benchmark against which other biological responses could be compared; and the project was a site- and waste-specific case study for the application and evaluation of the components of a risk assessment, including the development of methodologies for predicting and measuring field exposures in the water column and benthic compartments. Limitations of this study were: only one dredged material was evaluated, which constrained certain types of comparisons; the size of the study put limits on the extent to which any given objective could be examined; and the resources allocated to determine field

exposures were insufficient. The latter was particularly important because the laboratory-field comparisons and the risk assessment process both required accurate predictions of environmental exposures.

Population Responses

13. The regulation of potential pollutants in aquatic environments is generally based upon toxicological information involving the quantification of a biological response with a pollutant concentration for some finite period of exposure. Traditionally, decisions have been made utilizing acute toxicity data where the exposure period is 96 hr and the measured biological response is lethality (Sprague 1976). It is well recognized that this type of information, while useful, is insufficient to identify acceptable toxicant concentrations that do not adversely affect growth and reproduction (Mount 1968; Sprague 1971, 1976). This limitation has been addressed by the development of chronic toxicity tests designed to assess pollutant effects on survival, growth, and reproduction over long periods of exposure, often an entire life cycle. Unfortunately, these chronic exposures are measured at the individual organism level of biological organization and are not coupled in a predictive manner to population responses (Rand 1980, Hansen and Garton 1982).

14. The National Research Council's report Testing for the Effects of Chemicals on Ecosystems (1981) recommends that appropriate and relevant decisions regarding the release of potentially toxic chemicals into the environment be based upon a hierarchy of biological tests, with those at the level of populations and communities being particularly crucial to such an assessment. The Field Verification Program specifically addresses this need by employing a hierarchy of biological tests including methods for estimating the intrinsic rate of population growth.

15. The intrinsic rate of population growth, r, integrates age-specific survivorship and all facets of reproduction including age at reproductive maturity, number of offspring per brood, frequency of reproduction, and reproductive longevity. Using life tables to calculate this demographic parameter, the growth rate and reproductive potential of a population under both contaminant and environmental stress can be determined. The life histories of *Mysidopsis bahia* and *Ampelisca abdita* lend themselves to this type of analysis in that all aspects of the reproductive process can be readily discerned and

quantified. Finally, and most importantly, the use of a population statistic provides a biological and ecologically defensible basis for regulatory decisions.

PART II: MATERIALS AND METHODS

General Laboratory Methods

Sediment collection

16. Two sediment types were utilized to conduct laboratory tests for the field verification studies. The reference sediment (REF) was collected from the South Reference site in Long Island Sound (40°7.95'N and 72°52.7'W) by Smith-MacIntyre grab (0.1 m^2), press sieved through a 2-mm sieve and stored at 4° C until used. Prior to dredging, contaminated sediment was collected from Black Rock Harbor (41°9'N and 73°13'W) with a gravity box corer (0.1 m^2) to a depth of 1.21 m, thoroughly mixed, press sieved through a 2-mm sieve, and refrigerated (4° C) until used. Details of sediment collection and storage procedures may be found in Rogerson, Schimmel, and Hoffman (1985). In all experiments, sediments were allowed to reach test temperature and homogenized prior to use.

Suspended sediment dosing system

17. Laboratory studies required the construction of two identical sediment dosing systems to provide either BRH or REF material as suspended sediment simultaneously. Each dosing system (Figure 3) consisted of a

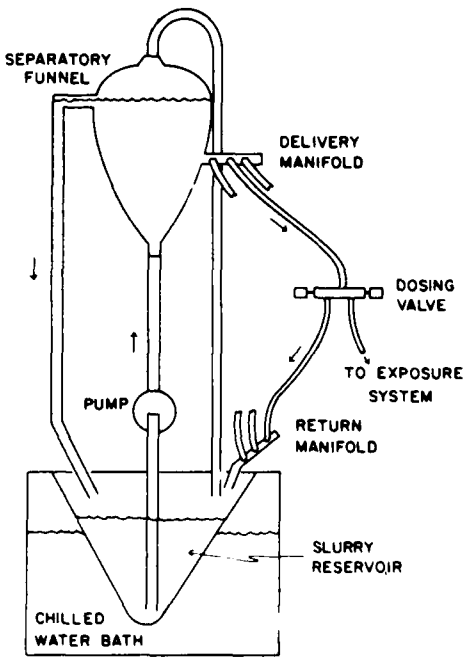

Figure 3. Composite dosing system

conical-shaped slurry reservoir placed in a chilled fiberglass chamber, a diaphragm pump, a 4-litre separatory funnel, and several return loops that directed the particulate slurry through dosing valves. The slurry reservoirs (40 cm diam by 55 cm high) contained 40 litres of slurry composed of 37.7 litres of filtered seawater and 2.3 litres of either BRH or REF sediment. The fiberglass chamber (94 cm by 61 cm by 79 cm high) was maintained between 4° and 10° C using an externally chilled water source to minimize microbial degradation during the test. Polypropylene pipes (3.8 cm diam) extended to the bottom of the reservoir cones and were connected to pumps (16- to 40-litre/min capacity) fitted with Teflon diaphragms. These pumps were used to circulate the slurry while minimizing abrasion which might produce changes in the physical properties (e.g., particle size) of the material.

18. The slurry was pumped up to separatory funnels and returned via an overflow to the reservoir through polypropylene pipes. The separatory funnel provided the constant head pressure needed to circulate the slurry through Teflon tubing to the dosing valves where the slurry was mixed with seawater to provide the desired concentrations for the toxicity tests. Narragansett Bay seawater filtered (to 15 microns) through sand filters was used.

Suspended sediment oxidation system

19. In order to have compatibility between environmental exposures and laboratory effects, it was necessary to consider the oxidation state of the sediments used in the laboratory studies. The field data collected by REMOTS (Scott et al. 1985) indicated oxidation of the surficial BRH sediments on the disposal mound. Since the most likely source of particulate contaminants in the water column was oxidized surficial sediment, it was decided that laboratory exposures would be conducted with REF and BRH sediments that had been oxidized in a consistent manner prior to introduction into the dosing system.

20. Two litres of sediment were transferred to an inverted polycarbonate carboy and diluted to 19 litres with filtered natural seawater at room temperature and aerated for 3 to 4 days (Figure 4). The contents were transferred to the composite dosing system reservoir and diluted to 38 litres with natural seawater. Chemical oxygen demand measurements indicated that this time period was sufficient to satisfy the immediate oxygen demand of the sediments.

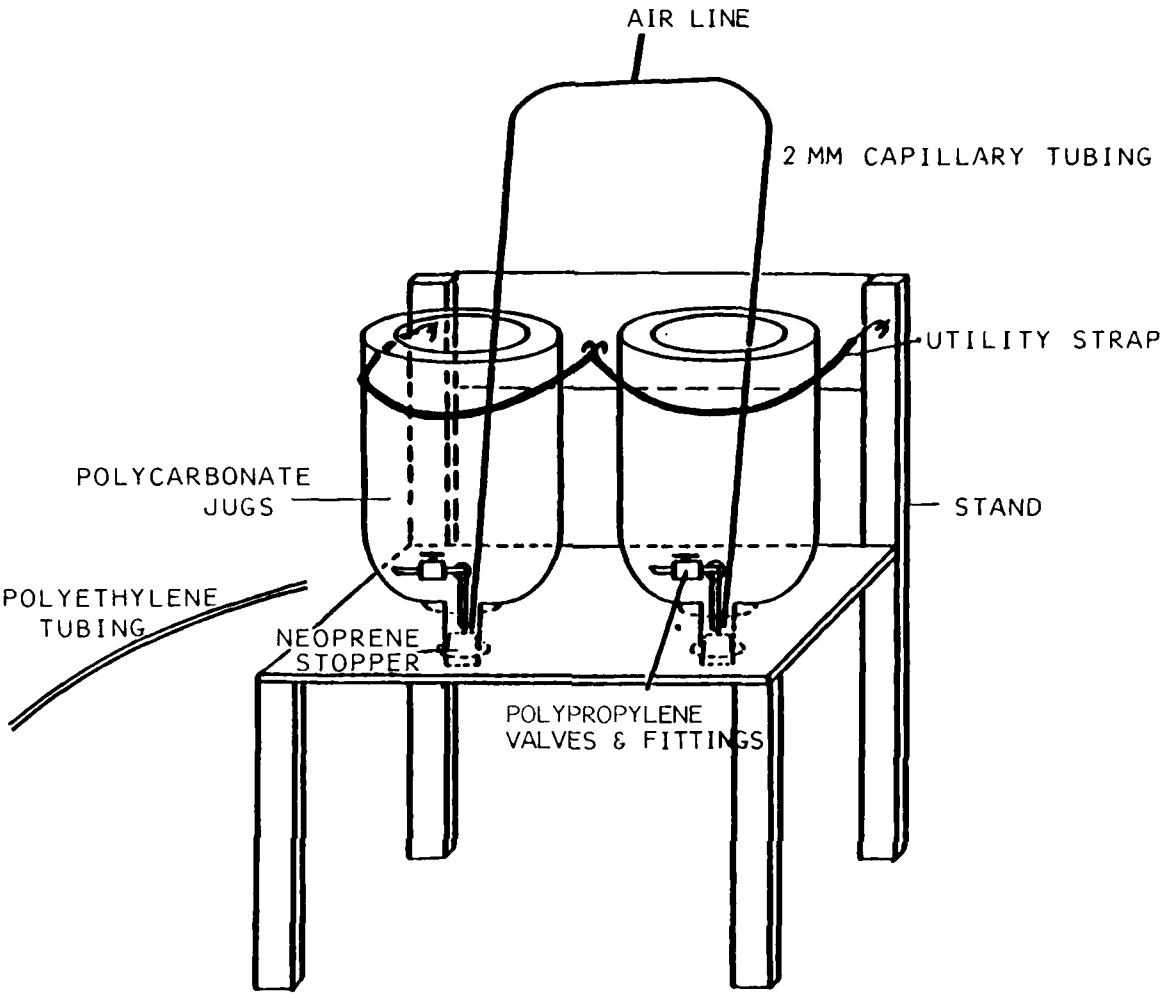

Figure 4. Suspended sediment oxidation system

Statistical analysis

21. Acute toxicity data were analyzed using probits, moving average, binomial, and graphical methods as appropriate (Stephan 1977). Analysis of variance was used to analyze survival, growth, and reproductive data from all tests. Significant treatment differences were identified from Dunnett's or Tukey-Kramer's pairwise comparison tests (Snedecor and Cochran 1980). In addition, reproductive data for *A. abdita* were evaluated by analysis of covariance to account for differences in female size.

Laboratory Exposure Methods

Rationale for laboratory exposures

22. The basic premise of the laboratory tests with *M. bahia* and *A. abdita* was that the exposures simulate the fringe areas of the BRH disposal mound. In this case, the fringe areas are 400 m and 1,000 m east of the mound center. Since suspended sediments are the primary route of exposure at these locations, the solid phase exposure was REF sediment. Suspended sediment levels for these exposures were estimated from the DAISY and acoustic profilometer deployments which measured suspended solids concentrations from 1 m above the bottom to the sediment-water interface (Munns et al. 1986). Since *M. bahia* is an epibenthic species and *A. abdita* builds tubes and feeds at the interface, the near-bottom data are of the most interest for both species. Field exposure data collected 1 m above the bottom indicate that suspended solids loads under background conditions are typically 10 mg/l. Profilometer estimates indicate that maximum suspended loads at the sediment-water interface could be 10 times those at 1 m. Laboratory exposures of 100 and 50 mg/l total suspended sediments were chosen for *M. bahia* and *A. abdita*, respectively, based on previous toxicity data (Gentile et al. 1985) and the above estimates of field exposure conditions.

23. In contrast to the earlier laboratory documentation and sediment characterization studies, the BRH and REF sediments were dosed in the oxidized state. Since population responses are long term in nature, off-mound exposure to dredged material would be affected, not by the disposal operation per se, but by the resuspension and transport of BRH sed[illegible]ff the mound over time. These resuspended sediments have been in pl[illegible]n the oxidized state, for some extended period of time, contributing to t[illegible]face bed load and, hence, to the exposure of organisms in the near field.

Exposure system design

24. *Mysidopsis bahia.* A suspended sediment proportional diluter was designed to mix small quantities of concentrated slurries of suspended marine sediments (10 to 20 g/l) from the sediment dosing system with seawater to produce two dilute sediment suspensions in the milligrams-per-litre range (Gentile et al. 1985). The diluter then combines the two different slurry types (e.g., REF and BRH sediment suspensions) proportionally to maintain the same concentration of total suspended particulates while producing different ratios

of the two sediments. It can also function with one sediment diluted with seawater to produce a range of suspended solids concentrations. The diluter delivers two replicates for each of five treatments and a seawater control (Figure 5).

25. The distribution chamber is partitioned into two cells and works by dividing the two volumes of suspension among a number of capillary tubes thereby delivering different volumes of each suspension to the five splitters depending upon the number of capillary tubes draining into them (Figure 6).

26. Each of the cells of the collection chamber drains its contents of a proportioned suspension into one of the five splitters. Each splitter contains two self-priming siphons, each of which delivers to the replicate animal exposure chambers.

27. In summary, the diluter system employed for quantitatively delivering suspended solids to the population tests consists of four tiered components. The first tier consists of the water cells, which measure a predetermined volume of seawater, and three-way valves, which deliver quantities of slurry from the sediment dosing system. The second tier consists of the mixing chambers, which combine the slurry and the seawater to produce the desired concentrations of suspended sediments. The third tier includes the distribution and collection chambers where the REF and BRH slurries are proportionally mixed to produce the five treatment concentrations. The fourth and final tier includes the splitters where each treatment concentration is divided into two replicates and delivered to the exposure chambers.

28. *Ampelisca abdita.* The composite dosing system (CDS) supplies suspensions of REF and BRH sediments as previously described (Figure 3). The appropriate amount of material is delivered to the amphipod dosing system via a three-way valve controlled by a microprocessor. For the oxidized BRH range-finding test, slurry was delivered to a mixing chamber (glass 4-litre reagent bottle) where it was initially diluted with seawater at a preset flow rate (right side of Figure 7). The diluted suspension then passes from the bottom of the bottle to a distribution chamber (17 cm diam by 9 cm high) fitted with a standpipe to maintain a constant water level. The suspension flows via a siphon, at a flow rate controlled by head pressure, to a collection funnel which distributes the material to the exposure system. Each collection funnel is fitted with an umbrella siphon which acts as a flow accelerator to rapidly mix materials collected in the funnels. For the acute test, the mixing and

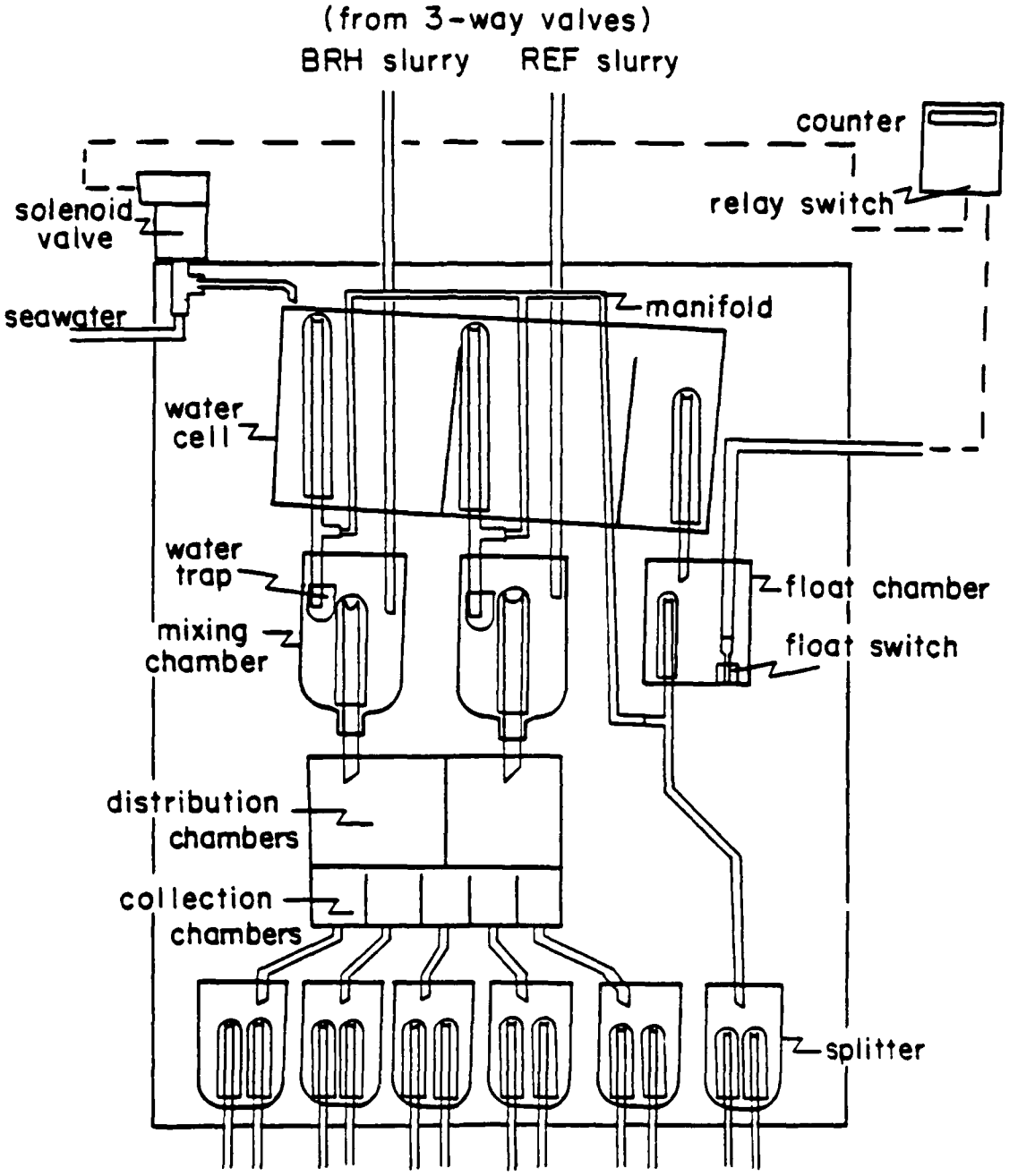

Figure 5. Suspended sediment proportional diluter for *M. bahia*

distribution chambers with siphons are set up in duplicate where one mixing chamber is dosed with the BRH sediment while the other is fed filtered seawater only.

29. To achieve a test concentration of 100 mg/l, where the distribution chamber concentration is 200 mg/l, the sediment distribution chamber siphon

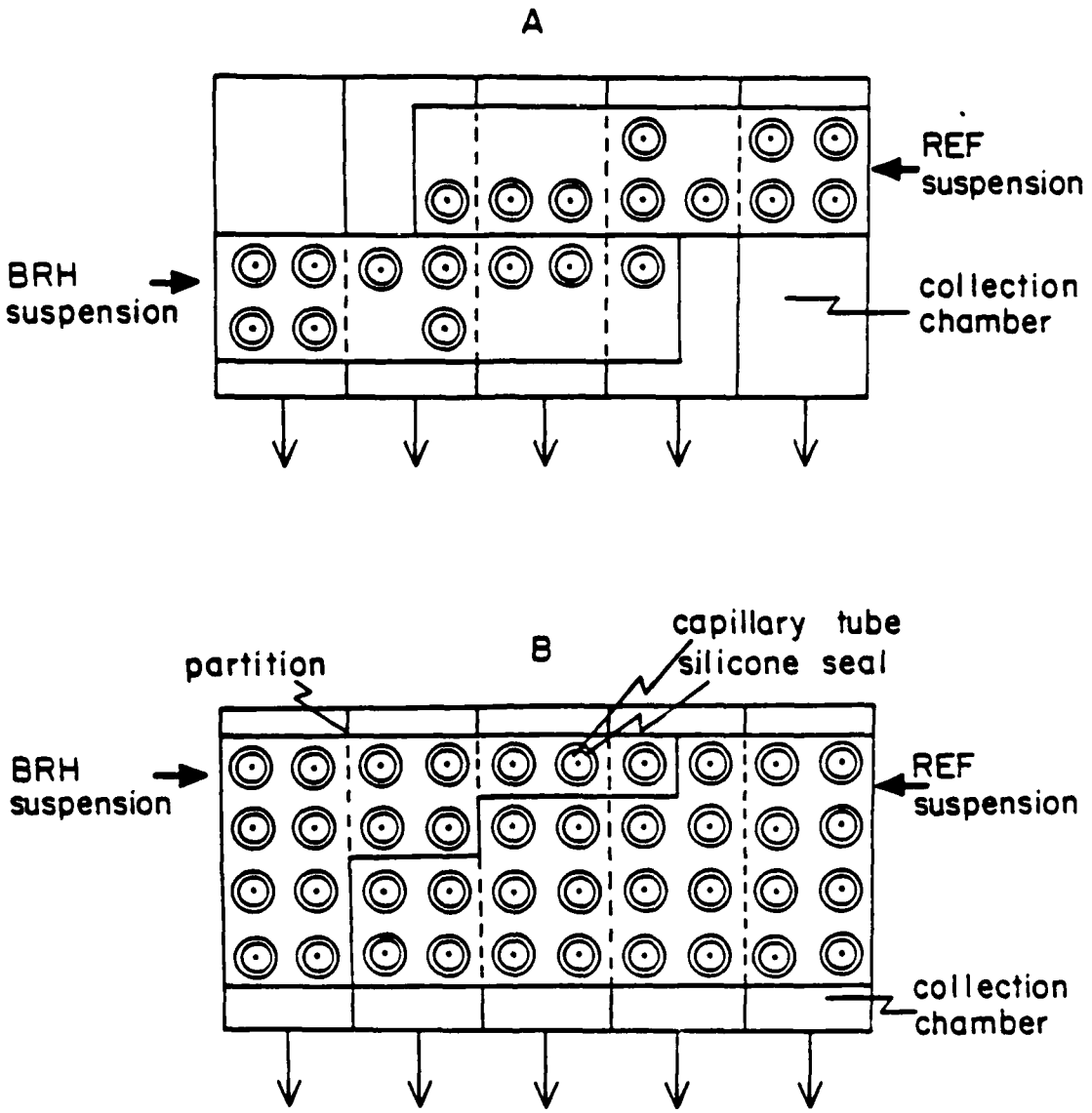

Figure 6. *Mysidopsis bahia* proportional diluter distribution chamber configuration

and the seawater distribution chamber would be set at equal flow rates, e.g., 40 ml/min each. Likewise, to achieve 50 mg/l of the test sediment, the seawater siphon flow rate would be three times the suspension flow rate, e.g., 60 ml/min seawater and 20 ml/min sediment suspension. For the 10-day short-term tests and the 56-day chronic tests, a constant suspended particulate density was desired, where BRH sediments were diluted with REF sediment instead of with seawater. To achieve this, REF sediment is dosed to one mixing chamber and BRH sediment to the other so that there is an equal particle

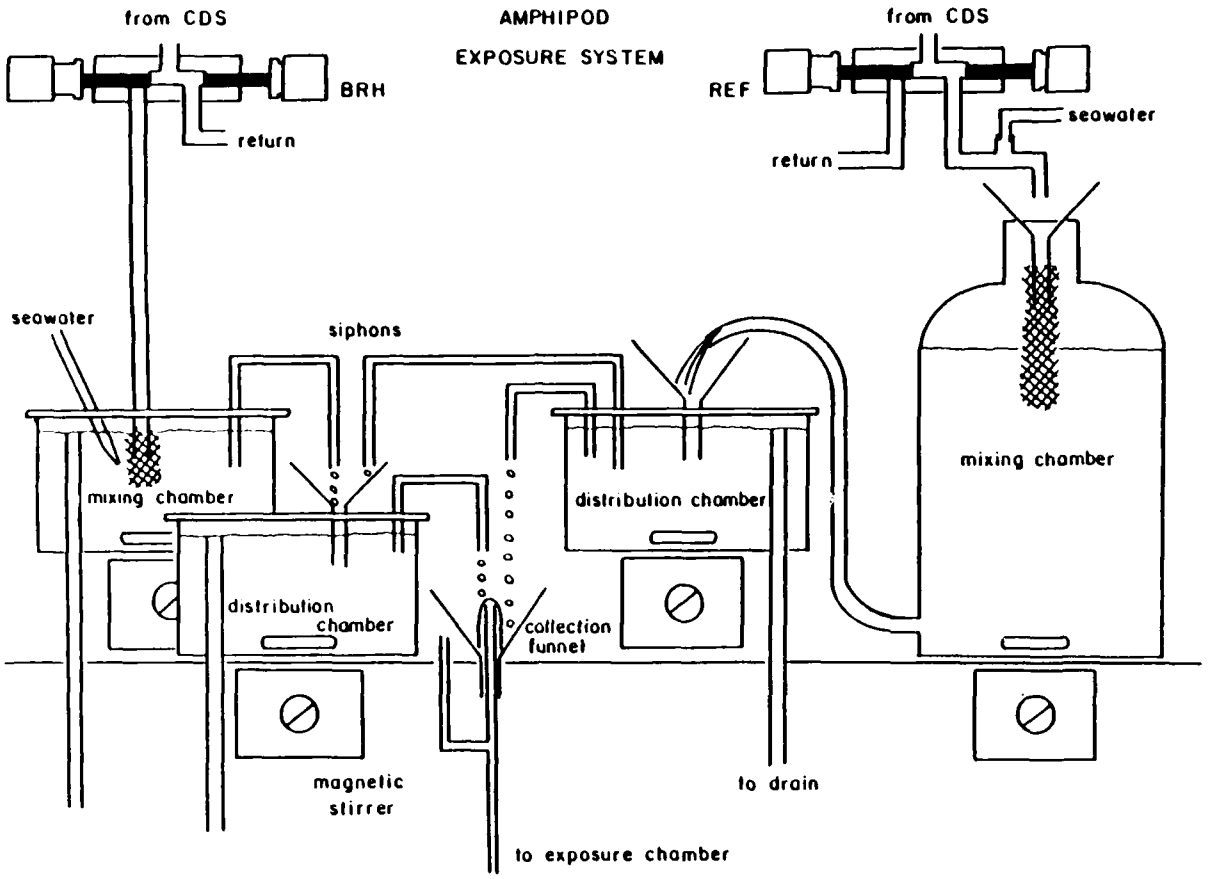

Figure 7. Suspended sediment dosing system for *A. abdita*

concentration in each distribution chamber. As for the seawater dilutions, equal siphon flow rates yield a 50-percent BRH concentration, a 3-to-1 REF-to-BRH flow rate yields a 25-percent BRH concentration, and so on.

30. The limiting factor of this dosing design is the minimum flow rate, 10 ml/min, that can readily be attained from the siphons. If each exposure chamber is to receive 20 ml/min, the total flow to the collection funnel is 40 ml/min or, for a 25-percent BRH concentration, 30 ml/min of REF sediment and 10 ml/min of BRH sediment. As was shown previously, toxicity levels were high at 25-percent BRH, so a modified design, as described in Gentile et al. (1985), was implemented (left side of Figure 7). The BRH concentration in the distribution chamber is set to 50 percent for the preliminary chronic test by feeding that chamber 50 ml/min of REF and 50 ml/min of BRH at equal particle densities. The BRH concentrations of 50, 25, and 12.5 percent are subsequently achieved as described above. For the 56-day chronic test, the BRH

concentration in the distribution chamber is set at 8-percent BRH by dosing that chamber 170 ml/min REF sediment and 15 ml/min BRH sediment. The BRH concentrations of 4 and 2 percent, respectively, are achieved, as above, by siphon adjustment.

31. The collection funnels feed the exposure chambers through a polypropylene tube fitted with a polypropylene tee with 5-mm outside diameter glass elbows to split the flow to two exposure chambers.

Exposure chamber design

32. *Mysidopsis bahia.* The exposure chamber for *M. bahia* is illustrated in Figure 8. Four glass cups are suspended in each of twelve crystallizing dishes (190 mm by 100 mm) by a small glass hanger glued to the top rim. To maintain the vertical position of each jar, a small drop of silicone sealant is placed near the bottom rim of each cup just under the hanger. Each treatment (six total) consists of two replicate crystallizing dishes; each replicate contains four observation cups for a total of eight per treatment.

33. Suspended sediment from the diluter flows through glass delivery tubes which empty into the center of each exposure chamber at the surface. Drainage from each chamber is accomplished by an enclosed umbrella siphon. When a chamber fills to about 1 cm from the top, the siphon is primed and drains about one third of the dish. This excursion of the water level ensures proper water circulation through the exposure cups. The enclosure around the umbrella siphon forces water to flow from the bottom of the water column. Inflow at the top and outflow from the bottom help eliminate potential vertical size partitioning of suspended particulates.

34. The twelve exposure chambers are held in position on a fiberglass grating in a temperature-controlled water bath by polyvinyl chloride (PVC) centering rings 3.2 cm high by 20.3 cm in diameter. These rings center the dishes over water-driven magnetic stirrers (embedded in the grating) which are used to spin 6.4-cm by 0.64-cm Teflon-coated stirring bars in the dishes to keep the sediment in suspension. The magnetic stirrers are driven by a manifold supplied with deionized water from the temperature control bath by Teel epoxy-magnetic submersible pumps (Model #1P681A). This also serves to circulate the bath to ensure uniform temperature.

35. The position of the dishes in the bath is randomized. Bath temperature is maintained with Teflon heat exchanging coils under microprocessor control. Microprocessor-controlled lighting is designed to simulate day/night

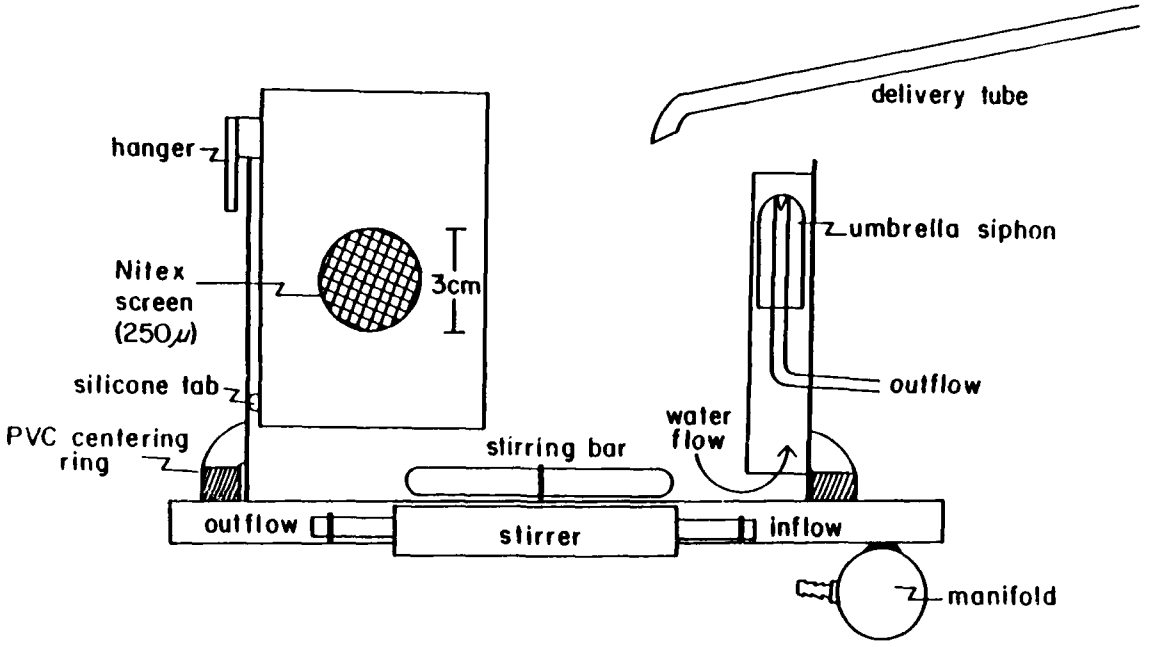

Figure 8. Exposure chamber design for *M. bahia*

cycles with the fluorescent lights growing gradually brighter at dawn and dimmer at dusk. The construction materials that contact the test solutions or the animals are glass, silicone rubber (to cement and seal), Nitex screen, and Teflon.

36. *Ampelisca abdita.* The exposure chambers for all suspended particulate tests are the chronic test chambers described in Gentile et al. (1985) (Figure 9). The chamber is a glass gallon jar filled with 0.75 litre of REF sediment (5 cm deep). The test suspension is fed to the gallon jar from the tee and maintained in suspension by aeration. The suspension is removed from the jar by a siphon which collects material from just above the sediment surface. The effluent enters a water trap with a screened standpipe that permits the monitoring of swimming activity and the presence of mating adults in the water column.

37. The flow rate to each gallon jar was 40 ml/min for the BRH range finding test and was reduced to 20 ml/min for the long-term tests in order to maximize the concentration of food supply. In the latter tests, the diatom *Phaeodactylum tricornutum* was cultured (Guillard and Ryther 1962) and delivered to each gallon jar at 1 ml/min using a Harvard peristaltic pump.

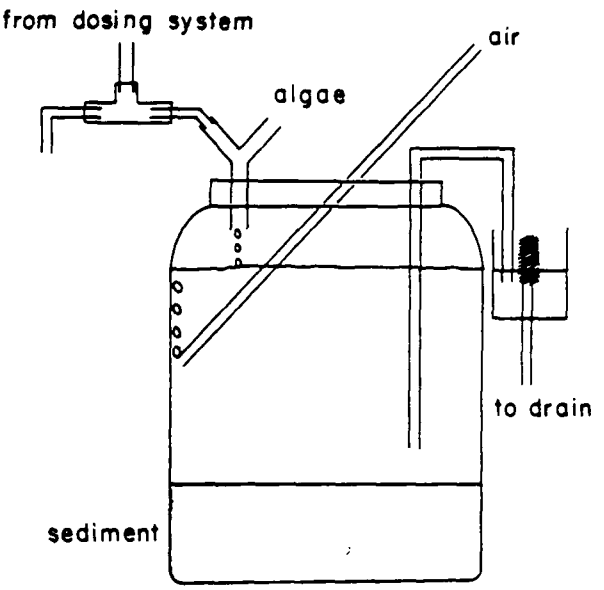

Figure 9. Exposure chamber design for *A. abdita*

Exposure system monitoring

38. *Mysidopsis bahia.* Bioassays were conducted at a temperature of 25° ± 2° C, salinity of 28 ± 2 ppt, and illumination of 1,000 lux on a 14-hr light:10-hr dark cycle. Dissolved oxygen, temperature, and salinity were measured daily with a Yellow Springs Instrument dissolved oxygen probe. Three times each week, suspended particulate concentrations from the control and exposure chambers were analyzed by dry weight determination conducted according to Standard Methods (American Public Health Association (APHA) 1976) with the following modifications: the filters were washed with a 50-ml aliquot of deionized water before sample filtration, and then with three 10-ml rinses of deionized water immediately after sample filtration to remove salt.

39. *Ampelisca abdita.* The total suspended solids concentration in the exposure system was monitored as total dry weight in milligrams per litre. One-hundred-millilitre samples were taken twice weekly from each gallon jar using a free-standing siphon to minimize disturbance. Suspended particulate concentrations from the control and exposure chambers were analyzed by dry weight determination conducted according to Standard Methods (APHA 1976), with the modifications described above. Temperature and salinity were measured daily. Exposure system flow rates were checked biweekly and adjusted when necessary. Photoperiod for all suspended phase tests was 14 hr light and 10 hr dark.

40. In experiments where the amphipods were fed, samples of the diatom culture used were taken regularly for dry weight determinations. An estimation of the numbers of cells fed was obtained through a previously determined relationship of dry weight to cells per millilitre.

Laboratory Effects Methods

Biology, collection, and culture

41. *Mysidopsis bahia.* *Mysidopsis bahia* is an epibenthic crustacean important in estuarine and marine food webs (Markle and Grant 1970). The life cycle of this species lends itself to population studies because the life cycle is short, being completed in 25 days at 25° C, and because the young are carried in a brood pouch, permitting the monitoring and quantification of reproductive processes.

42. *Mysidopsis bahia* was cultured in flow-through 76-litre glass aquaria continuously supplied with filtered (15 um) natural seawater at a salinity of 28 ± 2 ppt and temperature of 25° ± 2° C. A photoperiod of 14 hr light:10 hr dark was maintained by microprocessor which simulated dawn and dusk. Flow rates of 200 ml/min provided a 99-percent volume exchange every 24 hr. Subgravel filters with a 25.4-mm-deep dolomite substrate were used to provide aeration and a feeding current.

43. Cultures were fed continuously, ad libitum, with 24-hr posthatch *Artemia salina* (reference strain, Sorgeloos 1981) at a rate of 7×10^4 nauplii/day for each 76-litre culture.

44. *Ampelisca abdita.* *Ampelisca abdita* is a tube-dwelling amphipod which constructs a soft, upright, membranous tube, 3 to 4 cm long, in surface sediments. It ranges from Maine to Louisiana from the intertidal zone to depths of 60 m (Bousfield 1973). The amphipod is a particle feeder, ingesting either surface-deposited particles or particles in suspension. Fertilization occurs in the water column, and they brood their young after mating. After mating, the egg-bearing females return to the bottom and, after a brood period of approximately 2 weeks, young are released into the surrounding sediment. They are reproductively active at about 5 mm and grow to a maximum length of 7 to 9 mm (Mills 1967). Available information indicates that each female reproduces only once.

45. *Ampelisca* were collected from tidal flats in the Pettaquamscutt River, a small estuary flowing into Narragansett Bay, R. I. Bulk sediment containing the amphipods was immediately transported to the laboratory. The sediment was sieved through a 0.5-mm screen and the *Ampelisca* collected by flotation from the air-water interface. When collection temperatures were lower than the test temperature, amphipods were acclimated at 1° C/day up to 20° C. During acclimation, these animals were fed, ad libidum, laboratory-cultured *Phaeodactylum tricornutum*. At the initiation of a test, animals were sieved from the holding sediment, sorted by size, and randomly placed in 100-ml plastic beakers with seawater for subsequent distribution to the appropriate exposure chamber. Each beaker contained the desired number of amphipods per replicate.

Short-term responses

46. *Mysidopsis bahia.* Acute tests were initiated with 24- to 30-hr postrelease juvenile *M. bahia* which were randomly distributed into four exposure cups of five animals each in two replicate exposure chambers randomized among the exposure concentrations. Each cup received 24-hr posthatch reference *Artemia* daily and was removed and monitored daily for mortality.

47. In the first 96-hr flow-through test, juvenile *M. bahia* were exposed to a nominal suspended particulate concentration of 200 mg/l. Five treatments were chosen containing proportional mixtures of REF and BRH sediments ranging from 0-, 25-, 50-, 75-, to 100-percent BRH sediments. These mixtures result in 0, 9, 103, 113, and 183 mg/l of BRH sediment, respectively.

48. The second 96-hr flow-through acute test used a nominal suspended sediment concentration of 400 mg/l with the same percentages of BRH sediment as in the first test, yielding nominal BRH sediment concentrations of 0, 90, 159, 230, and 336 mg/l.

49. *Ampelisca abdita.* A 96-hr test was conducted with 200, 100, 50, and 25 mg/l of BRH suspended sediment and a seawater control. The solid phase treatment for all suspended phase tests described in this report was REF sediment. There were 25 subadult amphipods in each of two replicates per treatment. A definitive short-term test was run for 10 days at a constant particle load of 50 mg/l, with proportions of BRH suspended sediment of 50, 25, 12.5, and 0 percent. There were two replicates per treatment, each replicate containing 50 *Ampelisca*.

Long-term responses

50. *Mysidopsis bahia.* Two life-cycle tests (30 days) were conducted to assess the effects of suspended sediment exposures of mixtures of oxidized BRH and REF sediments on the survival, growth, and reproduction of *M. bahia*. The reproductive responses used were time to sexual maturity, time to appearance of embryos in brood sacs, and time to first brood release. Productivity was estimated from the number of young produced per available female reproductive day (AFRD), which corrects for different numbers of females and female mortality during the test. An additional response, the percent of females bearing eggs at day 12, was measured to provide an early indication of reproductive success.

51. Both long-term tests used nominal total suspended sediment concentrations of 100 mg/l with varying proportions of REF and BRH material. The solid phase component of these tests consisted of REF sediment. In the first test, the mixtures were 50-, 25-, and 0-percent BRH, resulting in calculated BRH concentrations of 53, 25, and 0 mg/l, respectively. The proportional mixtures in the second test were 25-, 12-, and 0-percent BRH, resulting in calculated BRH concentrations of 21, 10, and 0 mg/l, respectively. The concentrations of these two tests included a common replicate of 25-percent BRH, which provided additional data at a critical exposure concentration and allowed for comparison between the two assays.

52. Growth was determined by taking the dry weights and total lengths of individual test organisms at the start of the test and at three times during the course of the test (e.g., 4, 7, and 28 days).

53. Life tables were used to calculate age-specific survivorship for controls and treatments (Birch 1948). Starting with an initial number of newborn females, the percentage of this initial population alive at each age was calculated by sequentially subtracting the percentage of deaths occurring during that age interval. The fraction surviving at age x gives the probability that an average newborn will survive to that age (which is designated l_x).

54. Age-specific fecundity, m_x, is the number of female offspring produced by a female of age x during the next age period. Specifically, the types of data collected included the number of juveniles released per day and the number of surviving females.

55. Age-specific survivorship, l_x, and fecundity, m_x, were used to calculate, by successive approximation, the intrinsic rate of population growth, r, from the Euler equation (Euler 1970):

$$\Sigma\ l_x m_x\ e^{-rx} = 1 \qquad (3)$$

where

l_x = the probability of a female surviving to age x

m_x = the number of female offspring per female of age x produced during the interval x to x + 1

e = the natural logarithm

r = the intrinsic rate of population growth

x = the age class

56. *Ampelisca abdita.* A long-term (56-day) chronic test was conducted at a nominal total suspended solids concentration of 50 mg/l with BRH concentrations of 4 and 2 percent with REF sediment. Fifteen egg-bearing females were added to each of four replicates per treatment. The size and number of eggs of 30 females were determined prior to the start of the test. Two replicates were sieved after 28 days of exposure, and the remaining two replicates were harvested after 56 days of exposure.

57. The overflow water trap was checked daily, and the amphipods were enumerated and sexed when possible. Live *A. abdita* were returned to the exposure chambers. At the end of each test, all containers were sieved and the amphipods were enumerated. Any animals not accounted for (either removed earlier or recovered on sieving) were considered dead.

58. In addition, animals from the chronic test were sexed and then measured using a computerized digitizer and camera lucida. The data collected at the 28-day sampling of the chronic experiment included survival, mean size, and proportion of amphipods that were mature. In addition, the number of eggs held by each ovigerous female was enumerated and the developmental stage determined. These same data were collected at the termination of the test, as was the total number of young amphipods produced per chamber. When the number of young per chamber exceeded 100, these young were subsampled for size measurements using a Folsom plankton splitter, which randomly splits the sample in halves. A minimum sample size of 30 was arrived at by examining the size

variability found in previous tests and by determining the minimum sample size necessary to observe a treatment effect at the 5-percent probability level.

59. Life tables were generated as described above using empirical data on age-specific survivorship and productivity at days 28 and 56. Estimates of these parameters were made for two additional intervals, days 14 and 42, based on the female age structure and number of projected young per female.

PART III: RESULTS AND DISCUSSION

Laboratory Exposures

Mysidopsis bahia

60. The results of the definitive short-term tests are summarized in Table 1. The suspended solids concentrations for the first test ranged from

Table 1

Mysidopsis bahia Acute Toxicity and Suspended Sediment Concentrations ($\bar{x}$ ± SD) for Oxidized BRH Sediment Exposure

Treatment	Suspended Sediment Concentration mg/l	Calculated BRH Concentration mg/l	Percent Mortality (N = 20)*
	Experiment 1**		
REF control	206 ± 41	0	0
25% BRH	175 ± 48	44	5
50% BRH	205 ± 54	102	5
75% BRH	150 ± 19	112	5
100% BRH	183 ± 24	183	5
	Experiment 2†		
REF control	362 ± 73	0	0
25% BRH	361 ± 158	90	5
50% BRH	318 ± 126	159	5
75% BRH	308 ± 151	231	50
100% BRH	336 ± 28	336	78

* See para 67 for discussion.
** Experiment 1: LC50 > 183 mg/l.
† Experiment 2: LC50 = 262 mg/l.

150 to 206 mg/l with a mean of 184 ± 41 mg/l. The range for the second test was 308 to 362 mg/l with a mean of 337 ± 28 mg/l. Analysis of variance (ANOVA) detected no statistically significant differences ($P = 0.05$) in the total suspended sediment concentrations among the individual treatments within an experiment. Therefore, biological responses observed within an experiment could not be attributed to total suspended solids but rather to the

contaminants originating from the proportion of BRH sediment in each treatment.

61. Dissolved oxygen concentrations were within an acceptable range (7.0 to 7.1 mg/l) for all treatments in both experiments and were, in general, higher than those previously reported for tests conducted with unoxidized BRH sediment (Gentile et al. 1985). Temperature (25° ± 1° C) and salinity (30 ± 1 g/kg) were identical in both experiments.

62. The total suspended sediment concentrations selected for the chronic tests were 100 mg/l and were based upon field exposure data in combination with results from previous chronic tests with anaerobic sediments. The measured total suspended sediment concentrations ranged from 101 to 120 mg/litre with a mean of 109 ± 20 mg/l for Experiment 1. The range for Experiment 2 was 83 to 88 mg/l with a mean of 85 ± 12 mg/l (Table 2). The dissolved oxygen concentrations ranged from 7.4 to 7.5 mg/l in each of the experiments, and the salinity was constant at 30 ± 1 g/kg in both tests. The temperature in the first experiment was 27° ± 1° C and 25° ± 1° C in the second experiment.

Ampelisca abdita

63. Monitoring data for the 96-hr range-finding test with oxidized BRH sediments are shown in Table 3. The measured suspended sediment concentrations were close to the nominal concentrations for the lower treatments while the measured concentrations for the two highest treatments (100 and 200 mg/l) were somewhat lower than nominal levels. The variability of these estimates, as measured by the coefficient of variation, ranged from 5.2 to 28.2 percent. This variability is consistent with that previously reported for the 96-hr test with anaerobic BRH sediments (Gentile et al. 1985).

64. Table 4 shows measured suspended sediment concentrations for the 10-day short-term lethality test, where oxidized REF and BRH sediments were mixed in proportions of 50-, 25-, 12.5-, and 0-percent BRH sediments at a nominal suspended particulate density of 50 mg/l. The proportional mixes of BRH yielded mean nominal concentrations of 8 mg/l at 12.5-percent, 13 mg/l at 25-percent, and 22 mg/l at 50-percent BRH sediments. Variability estimates (coefficient of variation) were comparable with the 96-hr range-finding test, ranging from 6.3 to 25.2 percent of the mean values.

65. Based on the results of the short-term tests, which indicated that the oxidized BRH material may be more toxic than the anaerobic dredged

Table 2

Total Suspended Sediment ($\bar{x}$ ± SD) and Calculated BRH Suspended Sediment Concentrations for Chronic Tests with *M. bahia*

Treatment	Suspended Sediment* Concentration mg/l	Calculated BRH Concentration mg/l
	Experiment 1	
REF control	120 ± 15	0
25% BRH	101 ± 22	25
50% BRH	106 ± 20	53
	Experiment 2	
REF control	88 ± 14	0
12% BRH	83 ± 11	10
25% BRH	84 ± 11	21

* N = 10 for all measurements.

Table 3

Ampelisca abdita 96-hr Mortalities and Suspended Sediment Concentrations ($\bar{x}$ ± SD) for Oxidized BRH Sediment Exposures*

Nominal Concentration mg/l	Measured Concentration BRH, mg/l $\bar{x}$ ± SD (N)	Mortality %**
0	--	6
25	31 ± 9 (3)	26
50	51 ± 13 (3)	30
100	76 ± 4 (2)	48
200	167 ± 38 (3)	74

* LC50 = 80 mg/l (confidence interval = 64 to 106 mg/l). N for percent mortality = 50. Size of *A. abdita* ($\bar{x}$ ± SD), 6.40 ± 0.89 mm (N = 50).

** See paras 68-69 for discussion.

Table 4

Suspended Sediment Concentration and *Ampelisca* Mortality for a 10-Day Exposure to Oxidized BRH in a Suspended Phase Preliminary Chronic Test*

Treatment	Replicate Number	Total Suspended Sediment Concentration $\bar{x}$ ± SD (N)	Calculated BRH Concentration mg/l	Mortality %**
REF control	1	56 ± 4 (5)	0	0
	2	53 ± 3 (5)	0	2
12.5% BRH	1	61 ± 8 (5)	8	12
	2	59 ± 6 (5)	7	14
25% BRH	1	51 ± 5 (5)	13	70
	2	51 ± 8 (5)	13	74
50% BRH	1	41 ± 9 (5)	21	88
	2	44 ± 11 (5)	22	72

* The number of amphipods per replicate is 50. Initial mean size and SD = 4.74 ± 0.43 mm (N = 50).

** See paras 68-69 for discussion.

material and that chronic mortalities may be significant, treatment levels of 4-percent and 2-percent BRH were chosen for the long-term test at a constant suspended particulate load of 50 mg/l.

66. The particulate densities and the calculated amounts of BRH sediments for each treatment of the chronic tests are shown in Table 5. The measured particle concentrations ranged from 51 to 57 mg/l and showed very good repeatability over time with the coefficient of variation varying from 9.2 percent to 16.7 percent of the mean. The nominal proportions of BRH sediments yielded calculated BRH sediment concentrations of 1 mg/l at 2-percent and 2 mg/l at 4-percent BRH. The validity of these estimates depends on the presence of equal concentrations of each sediment type in the distribution chambers. Repeated dry weight measurements showed good agreement between the two chambers. Dry weight measurements of [illegible] during the test indicated [illegible] to [illegible] cells/day were supplied to each exposure chamber.

Table 5

Suspended Sediment Concentration ($\bar{x}$ ± SD) for 28- and 56-Day Exposures to Oxidized REF and BRH Sediments

Treatment	Exposure Duration days	Replicate Number	Total Suspended Sediment Concentration mg/l	N	Calculated BRH Concentration mg/l
REF control	28	2	57 ± 7	8	0
		3	57 ± 10	8	0
	56	1	54 ± 5	16	0
		4	53 ± 7	16	0
2% BRH	28	2	51 ± 6	8	1
		3	57 ± 7	8	1
	56	1	57 ± 8	16	1
		4	56 ± 6	16	1
4% BRH	28	2	57 ± 7	8	2
		3	56 ± 8	8	2
	56	1	56 ± 7	16	2
		4	53 ± 9	16	2

Laboratory Effects

Short-term responses

67. *Mysidopsis bahia.* There were no significant differences in mortalities observed among the treatments in the first experiment when the mean suspended sediment concentration was 183 mg/l (Table 1). Mortalities were less than 5 percent in all treatments, precluding the calculation of an LC50. In Experiment 2, where the mean total suspended solids concentration was 336 mg/l, the 96-hr LC50 was 262 mg/l BRH sediments (77.3-percent BRH) with a 95-percent confidence interval of 242 to 286 mg/l. LC50 values ranging from 290 to 410 mg BRH/l were reported from previous acute toxicity studies with

anaerobic BRH sediment (Gentile et al. 1985). These results indicate the similarity in the acute toxicity of oxidized and unoxidized BRH dredged material to *M. bahia*.

68. *Ampelisca abdita.* The percent mortality for the 96-hr short-term test ranged from 74 percent at 167-mg/l BRH to 26 percent at 25-mg/l BRH, producing an LC50 value of 80 mg/l with a 95-percent confidence interval from 64 to 106 mg/l (Table 3). This value is 10 mg/l lower than the LC50 with anaerobic BRH sediments; however, the 95-percent confidence intervals completely overlap those of the previous experiment (Gentile et al. 1985).

69. The mortalities for the 10-day exposures are shown in Table 4. There were mortalities at all BRH concentrations, producing a 10-day LC50, as a proportion of BRH, of 19.6 percent (95-percent confidence interval = 18.1 to 21.3 percent). If the BRH suspended sediment concentration is used, the LC50 is 10.5 mg/l (10.0 to 11.2 mg/l, 95-percent confidence interval) yielding a ratio of 7.6 for the 96-hr acute test versus the 10-day preliminary chronic. The threshold for the 10-day LC50 appears to lie between 7 and 12 mg/l BRH sediment. These data are consistent with anaerobic exposures for 18 days where the 25-percent BRH mixture (12.6 mg/l BRH sediment), the lowest BRH concentration tested, produced mortalities of 90 to 98 percent. The significantly higher mortalities for the 10-day exposure, as compared with the 4-day exposure, are most likely due to extended exposure duration. The mortality patterns suggest that under chronic test conditions, where food is provided, mortalities in long-term exposures could be significant, and caution must be exercised in choosing the exposure levels.

Long-term responses

70. *Mysidopsis bahia.* Replicate life-cycle tests were conducted to determine the effects of chronic exposure of oxidized BRH sediment on the survival, growth, and reproduction of *M. bahia*. Data on age-specific survivorship and fecundity were used to calculate the intrinsic rates of population growth, mean generation times, and multiplication rates per generation.

71. Growth, as measured by length and dry weight (Tables 6 and 7), was significantly reduced in animals exposed to BRH sediments only in Experiment 1, which had higher concentrations of BRH suspended solids than Experiment 2. There was excellent correspondence between length and weight in those treatments where significant differences occurred. Analysis of variance of the growth data (length and weight) in the second experiment indicated that

Table 6

Length ($\bar{x}$ ± SD) of *M. bahia* Chronically Exposed to BRH Suspended Sediment

Treatment (BRH Sediment)	Mean Length, mm		
	Day 4 (N = 10)	Day 7 (N = 10)	Day 28 (N = 10)
	Experiment 1		
REF control	2.80 ± 0.19	3.63 ± 0.26	6.34 ± 0.30
25% BRH (25 mg/l)	2.53 ± 0.32*	3.39 ± 0.41*	6.19 ± 0.34
50% BRH (53 mg/l)	2.54 ± 0.19*	3.13 ± 0.34*	5.83 ± 0.43
	Experiment 2		
REF control	2.95 ± 0.37	3.90 ± 0.33	6.30 ± 0.21
12% BRH (10 mg/l)	2.86 ± 0.28	3.91 ± 0.33	6.26 ± 0.46
25% BRH (21 mg/l)	2.76 ± 0.27	3.73 ± 0.21	6.19 ± 0.49

* Significantly different (ANOVA, Duncan's) from REF control (P = 0.05).
Length at Day 1 = 1.66 ± 0.12 mm (N = 30).

Table 7

Weight ($\bar{x}$ ± SD) of *M. bahia* Chronically Exposed to BRH Suspended Sediment

Treatment (BRH Sediment)	Dry Weight, mg		
	Day 4	Day 7	Day 28
	Experiment 1		
REF control	0.09 ± 0.02	0.17 ± 0.03	0.74 ± 0.12
25% BRH (25 mg/l)	0.07 ± 0.02*	0.13 ± 0.03*	0.70 ± 0.13
50% BRH (53 mg/l)	0.08 ± 0.02*	0.13 ± 0.04*	0.53 ± 0.11*
	Experiment 2		
REF control	0.12 ± 0.02	0.22 ± 0.04	0.78 ± 0.11
12% BRH (10 mg/l)	0.11 ± 0.02	0.24 ± 0.05	0.84 ± 0.19
25% BRH (21 mg/l)	0.11 ± 0.02	0.21 ± 0.03	0.78 ± 0.16

* Significantly different (ANOVA, Duncan's) from REF control (P = 0.05). Dry weight at Day 1 = 0.072 ± 0.011 mg (N = 15).

there were no statistically significant differences between treatments. This was the result of the lower BRH sediment concentrations observed in this experiment.

72. Growth (in millimetres) through Day 7 calculated for each treatment and plotted against exposure concentration is illustrated in Figure 10. The results indicate the control and 10-mg/l treatments to be identical but with a steep exposure-response gradient between 10 and 30 BRH mg/l.

73. The three measures of reproduction, quantified in the long-term chronic tests, were the times to sexual maturity and initial reproduction, and the number of young produced per AFRD (Table 8). The time to reach sexual maturity was 12 days in the REF controls in both experiments. The 1-day delay reported at 21 and 53 mg/l of BRH sediments is within the natural variability (12 to 14 days) of the species and cannot be considered a significant effect.

74. The percentage of females bearing eggs at Day 12 of the life cycle was affected by exposure to BRH sediments (Table 8). Analysis of variance of the arc sine transformed percentages indicated that there were significant treatment differences (P = 0.05). Pairwise comparisons (Duncan's Test) revealed that there were no differences between the REF control and the 10-mg/l BRH treatment but there was a significant reduction in the percentage of females with eggs in the 21-, 25-, and 53-mg/l BRH treatment compared with

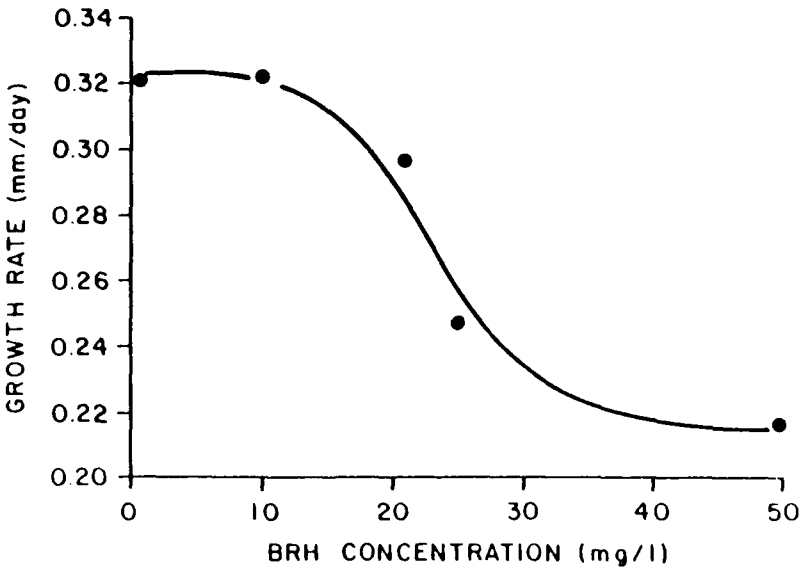

Figure 10. *Neodiaptomus bakeri* growth rate versus BRH suspended sediment concentration

Table 8

Reproductive Results for *M. bahia* Chronically Exposed to BRH Suspended Sediment

Treatment (BRH Sediment)	Sexual Maturity days	Females Bearing Eggs %	Initial Reproduction days	Young per AFRD
		Experiment 1		
REF control	12	83	17	0.22
25% BRH (25 mg/l)	12	30*	25	0.04*
50% BRH (53 mg/l)	13	22*	--	0.00*
		Experiment 2		
REF control	12	85	16	0.32
12% BRH (10 mg/l)	12	91	15	0.29
25% BRH (21 mg/l)	13	73*	16	0.10*

* Significantly different (ANOVA, Duncan's) from REF control (P = 0.05).

the REF control. These results proved to be a good predictor of productivity in that significant effects in the number of young per AFRD also occurred at 21-mg/l BRH treatment (Table 8).

75. The time to reach initial reproduction in the REF controls was 17 and 16 days, respectively, in Experiments 1 and 2 (Table 8). In Experiment 1, there was an 8-day delay in the 25-mg/l treatment and no reproduction observed in the 53-mg/l treatment. Thus, the time to initial reproduction increased with increasing concentrations of BRH sediment in the first experiment. This was not the case in the second experiment, indicating that the response threshold lies between 21 and 25 mg/l BRH sediments.

76. Productivity, estimated from the number of young per AFRD, in the REF sediment controls was 0.22 and 0.32 in Experiments 1 and 2, respectively. There was a decrease in productivity in both experiments with increasing concentrations of BRH sediments, such that reproduction was completely inhibited at the 53-mg/l concentration in Experiment 1. Analysis of variance showed significant reduction in the number of young produced at the 25- and 53-mg/l treatments in the first experiment, and at the 21-mg/l treatment in the second experiment. There was good reproducibility between the two experiments with significant reductions in reproduction being observed between 21 and 25 mg/l

of BRH sediment. In previous experiments with anaerobic sediment, productivity was significantly reduced at 43-mg/l BRH sediments indicating the oxidized dredged material to be twice as toxic to reproduction as the reduced material (Gentile et al. 1985).

77. The concurrence between the control growth rates, times to sexual maturation, initial reproduction, and the performance of the exposure systems between Experiments 1 and 2 permitted the combination and scaling of the young per AFRD data from the experiments (Figure 11). The results indicate a steep exposure-response curve producing an EC50 of 18 mg/l for oxidized BRH sediments, which is approximately one-half the value previously reported for anaerobic BRH sediments (Gentile et al. 1985).

78. Population response parameters were calculated from life tables (Appendix Tables A1 and A2) that utilize age-specific survival and fecundity data from the whole life-cycle long-term tests. The three response parameters examined are the intrinsic rate of population growth r , the net reproductive value or multiplication rate per generation, and the mean generation time.

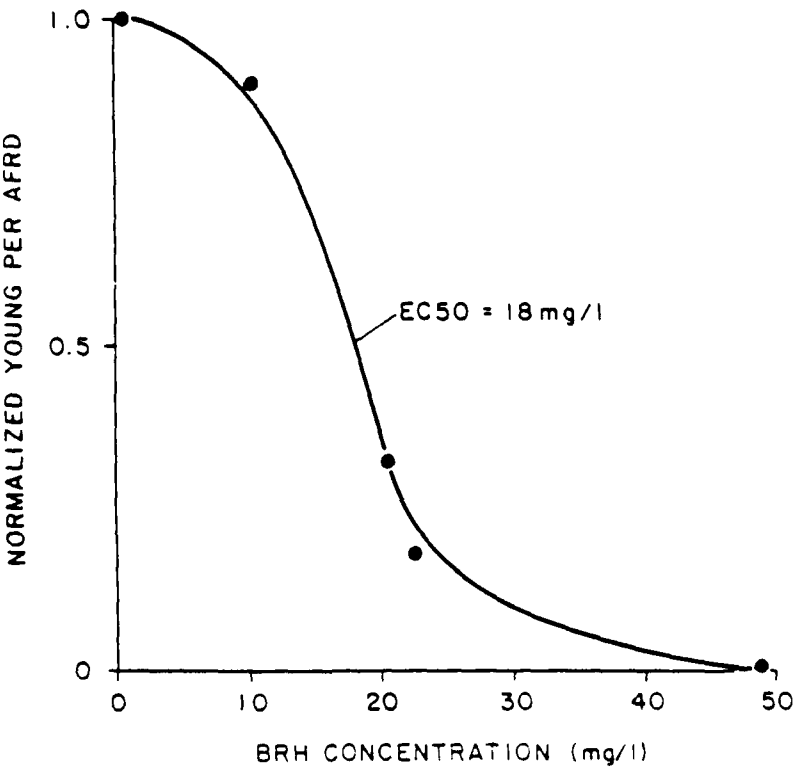

Figure 11. [illegible] young per AFRD versus BRH suspended sediment concentration

The patterns of these parameters, measured for *M. bahia* exposed to BRH sediments in Experiments 1 and 2, are summarized in Table 9.

79. There were differences in the absolute values between the two experiments for r measured for the REF sediment controls. Values for r that are positive represent populations whose birth rate exceeds the death rate and, consequently, are increasing in size. Values of r that are at or close to zero represent populations whose birth and death rates are balanced, resulting in maintenance of the population but with little resiliency to withstand additional stress. Strongly negative values for r are indicative of populations whose death rates greatly exceed the birth rates and ultimately will become extinct.

80. The REF controls in both experiments had positive r values, indicating that these populations were increasing in size. The slightly negative value of -0.003 observed in the 10-mg/l treatment concentration is indicative of a population that is slowly moving toward extinction. The strongly negative values calculated for the 25- and 21-mg/l treatments indicate that these populations are declining precipitously. The results of these experiments on oxidized BRH sediments indicate that the intrinsic rate of population growth

Table 9

Population Responses for Life-Cycle Tests with *M. bahia*

Treatment (BRH Sediment)	Intrinsic Rate of Growth	Multiplication Rate per Generation	Mean Generation Time days
	Experiment 1		
REF control	+ 0.004	1.107	22.84
25% BRH (25 mg/l)	- 0.050	0.273	26.11
50% BRH (53 mg/l)	- 0.100	0.0	--
	Experiment 2		
REF control	+ 0.019	1.481	20.55
12% BRH (10 mg/l)	- 0.003	0.942	18.10
25% BRH (21 mg/l)	- 0.023	0.661	17.10

is moderately affected at 10 mg/l and strongly affected at concentrations at or greater than 10 mg/l. Previous studies with anaerobic BRH sediments found that significant reductions in intrinsic rates of growth were detectable at and above 47 mg/l (Gentile et al. 1985). The relationship between the intrinsic rates of growth and BRH sediment exposure is illustrated in Figure 12. The results indicate that 8-mg/l BRH sediment will reduce the intrinsic rate of growth to zero, leaving the populations with no resiliency to adjust to additional stress.

81. The second population response parameter, multiplication rate per generation, decreased with increasing BRH sediment concentration in both experiments. The absolute values for the REF controls in both experiments were greater that 1.0, indicative of populations that are replacing themselves, while values of less than 1.0 characterized all the other treatments.

82. The multiplication rates per generation from the two experiments were scaled to the control value and plotted as a function of BRH sediment concentration in Figure 13. The results indicate that BRH sediment exposures greater than 10 mg/l reduce the multiplication rate per generation to less than 1.0, which will result in population extinction.

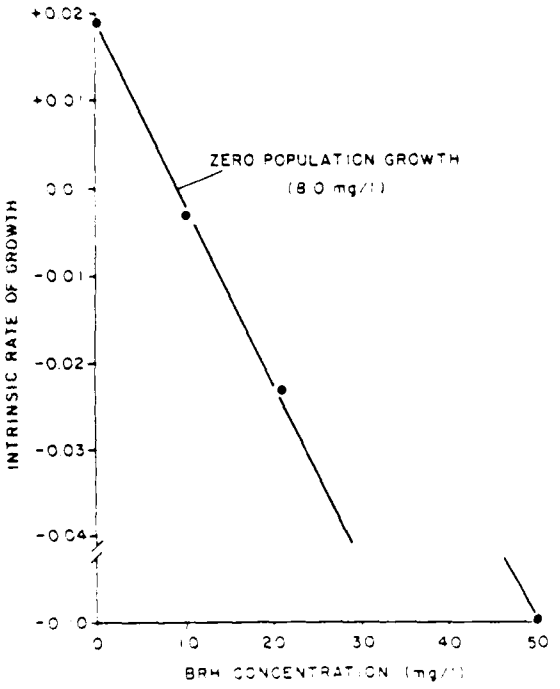

Figure 12. *Mysidopsis bahia* intrinsic rate of growth versus BRH suspended sediment concentration

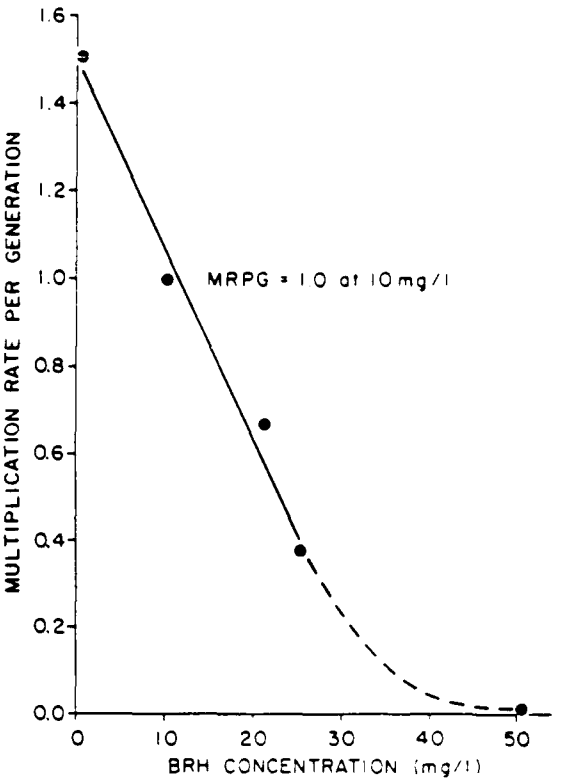

Figure 13. *Mysidopsis bahia* multiplication rate per generation versus BRH suspended sediment concentration

83. The mean generation times for the REF controls in the two experiments were 22.8 and 20.5, respectively, and differed by only 10 percent. However, the mean generation time increased by 20 percent in the 25-mg/l treatment and indefinitely at the 53-mg/l treatment in Experiment 1. There were no differences between the REF sediment control and the 10-mg/l treatment in the second experiment.

84. *Ampelisca abdita.* Results of the short-term tests indicated that the oxidized BRH material is slightly more toxic than the anaerobic dredged material and that chronic mortalities may be significant. Based on these results, the treatment levels for the long-term test were selected to be 4- and 2-percent BRH with a constant suspended particulate load of 50 mg/l.

85. *Ampelisca abdita* mortalities were estimated for the chronic test by comparing the number of amphipods harvested with the estimated number of initial young, assuming 100-percent survival of all eggs of ovigerous females introduced into the containers on Day 0. A random sample of 30 females from the original population of females at the start of the experiment had a mean egg number of 11.4 (SD = 4.98) yielding 171 young per container. The numbers of amphipods harvested on Days 28 and 56 are shown in Table 10. The predicted

Table 10

Estimated *Ampelisca* Adult Mortality in 28- and 56-Day Chronic Exposures to Oxidized BRH Suspended Sediment

Treatment (BRH Sediment)	Number of Ovigerous Females Introduced	Harvested/ Number Predicted	Estimated % Mortality
	Day 28		
REF control	28	304/320	5.0
2% BRH (1 mg/l)	28	332/320	0.0
4% BRH (2 mg/l)	29	285/331	13.9
	Day 56		
REF control	30	123/342	64.0
2% BRH (1 mg/l)	29	172/331	48 0
4% BRH (2 mg/l)	30	115/342	66.4

number of juveniles is adjusted to 160 for some containers because one ovigerous female died in each of those replicates on the first day. The 95-percent confidence limits are 9.5 to 13.3 eggs/female resulting in 266 to 372 offspring for 28 females, 276 to 386 young for 29 females, and 285 to 399 for 30 females.

86. For the 28-day exposure with pooled replicates there were no significant mortalities. Mortalities in the adult population at the 56-day harvest ranged from 48.0 to 66.4 percent; these are also not considered to be due to BRH sediment exposure. Alternatively, they represent a 6- to 8-week life span in laboratory populations with a significant contribution to the mortalities being males, who die subsequent to mating. Of the 72 mortalities observed in the overflow cups across all treatments, 76.4 percent were adult males. These results are consistent with those from tests with anaerobic BRH sediments where 56-day mortalities ranged from 22.6 to 72.6 percent (Gentile et al. 1985). Since the chronic tests were designed to limit lethal effects, the absence of significant mortality is not surprising.

87. *Ampelisca abdita* individuals can be sexed and classified into stages of sexual maturity based on morphological characteristics. Morphologically, adult males (M) are the most distinctive with a carinate urosome and elongated second antennae (Bousfield 1973). Males are specially adapted for

swimming, which facilitates mating in the water column. They do not molt again because they die after mating. Whether they mate with more than one female is unknown.

88. Female *A. abdita* can be divided into four progressively distinct groups. The earliest stage, after sexual differentiation, is here termed developing female (FDV). This stage is distinguished by the presence of a brood plate, oostegite, on the interior of each of the first five coxal appendages. As the female grows, the brood plate increases in size and eggs begin to develop in the oviduct, which is dorsal to the digestive tract, and which can be seen through the exoskeleton. This stage is termed developing egg female (FE). After a series of molts the brood plates develop long setae and the eggs are deposited through a gonopore into a fully developed brood pouch. This stage is termed ovigerous female (FOV). Presumably, mating occurs at this time. Since all eggs in a brood pouch are in the same stage of development, all eggs in the oviduct are assumed to be deposited at once. After releasing their young, the females do not immediately die but remain in the population for some undetermined time before death. These females may have eggs in the oviduct, but do not have eggs in the brood pouch, at the same time retaining the setose oostegites. This stage is termed spent females (FS).

89. There is one other group, termed undifferentiated (UD). These include juveniles and undifferentiated subadult females and males. In most cases where this group was encountered, the animals were larger than 4.0 mm. These animals are probably subadult males since females can be distinguished at a smaller size when the brood plates first develop.

90. The numbers of *Ampelisca* found in each of the categories described above are shown in Appendix Table B1, and percentages are shown in Table 11. At Day 28 the majority of the population in all treatments was composed of the undifferentiated group although there was a greater percentage in this group at 4-percent BRH. Differentiated females constituted less than 20 percent of the population at 4-percent BRH, whereas the other two treatments had at least 25 percent females. These data indicate that BRH exposure retarded development.

91. The length data are shown in Appendix Table B2 and Table 12. Analyses of variance of the lengths of developing females and the undifferentiated group at Day 28 indicate significant differences at $P < 0.05$. Duncan's

Table 11

Percent of *A. abdita* in Each Sex Category for 28- and 56-Day Exposures to Oxidized BRH Suspended Sediment

Treatment (BRH Sediment)	Replicate Number	Sex Category						Total No. Recovered
		UD	FDV	FE	FOV	FS	M	
				Day 28				
REF control	2	65.6	22.1	9.9	2.3	0	0	131
	3	73.4	20.2	2.9	3.5	0	0	173
2% BRH	2	62.6	31.6	3.2	2.6	0	0	155
(1 mg/l)	3	74.0	17.5	7.3	1.1	0	0	177
4% BRH	2	81.2	16.9	0.6	1.3	0	0	154
(2 mg/l)	3	80.2	15.3	0.0	3.8	0	0.8	131
				Day 56				
REF control	1	4.9	4.9	1.6	45.9	39.3	3.3	61
	4	11.3	3.2	1.6	30.6	22.6	30.6	62
2% BRH	1	25.4	14.1	16.9	16.9	14.1	12.7	71
(1 mg/l)	4	7.9	19.8	7.9	36.6	14.9	12.9	101
4% BRH	1	13.6	15.9	9.1	40.9	9.1	11.4	44
(2 mg/l)	4	15.5	8.4	4.2	39.4	14.1	18.3	71

multiple range test showed the 4-percent BRH treatment to be significantly smaller in each case. These results explain the presence of fewer mature females in the 4-percent treatment because the slower growth rate delayed maturation. The smaller size of the undifferentiated group also suggests that they grew slower. When all individuals were pooled, ANOVA showed that the 4-percent treatment was significantly smaller.

92. At the 56-day harvest, the percentage of the undifferentiated group had decreased to less than 25 percent of the total population, with most of the females having deposited eggs in the brood pouch, reaching full maturity. Although there is considerable variability between replicates, the REF control is characterized by a large number of spent females which had already released their broods (Tables B1 and 11). Again, the total mean size of the population is also smaller at that treatment.

Table 12

Mean Length (mm) of *A. abdita* for 28- and 56-Day Exposures to Oxidized BRH Suspended Sediment

Treatment (BRH Sediment)	Sex Category UD	FDV	FE	FOV	FS	M	Total
			Day 28				
REF control	3.77 *	4.07	4.62	6.59	-	-	4.06
2% BRH (1 mg/l)	3.77	4.11	5.03	6.98	-	-	4.05
4% BRH (2 mg/l)	3.21	3.78	4.41	6.44	-	-	3.56
			Day 56				
REF control	6.69	5.69	6.13	6.77	6.74	5.83	6.55
2% BRH (1 mg/l)	6.60	6.28	6.95	6.88	6.94	6.17	6.66
4% BRH (2 mg/l)	6.32	5.95	7.13	6.21	6.09	6.16	6.23

* Sizes connected by the same line are not significantly different from each other at $P < 0.05$.

93. Examination of the length data from the 56-day harvest, by ANOVA, shows that the ovigerous females and spent females were smaller in the 4-percent BRH treatment (Table 12). The smaller size of these females reflects the slower growth that would be predicted from the 28-day size data.

94. To summarize the population structure and growth data, there appears to be an adverse impact on growth, which, although small, does have an effect on maturation. The effect on maturation is more evident at 28 days than at 56 days. These patterns of effects are similar to those described in Gentile et al. (1985) using anaerobic BRH sediments where growth was impacted at 5 mg/l BRH. As will be shown below, the impact on growth may be symptomatic of more subtle effects of exposure to dredged material on egg production and juvenile survivability.

95. Fecundity, the number of eggs/female, in *A. abdita* is a function of female size, with larger females having larger broods (Mills 1967). Treatment effects were assessed using analysis of covariance (ANCOVA), with egg number as the dependent variable and female size as the covariate. Once the quantitative relationship between egg number and female size is determined, the

differences in egg number female can be analyzed by statistically adjusting the fecundity estimates based on the regression relationship.

97. The raw and size-adjusted fecundity estimates for the 56-day exposures are shown in Table 13. The number of eggs/female was significantly correlated with female size ($F = 13.83$, $P < 0.0003$), and there were significant treatment effects, with the fecundity of 4-percent BRH females being lowest. These data show that in the 4-percent BRH treatment, the ovigerous females were not only smaller (Table 13), and thus produced fewer eggs, but also had lower fecundities when compared with similar-sized animals in the other two treatments.

98. The effect of dredged material exposure on fecundity and growth is further borne out by examining the number of young produced (Table 14). There were over eight times the total number of young produced in the controls as compared with the 4-percent BRH treatment. Unexpectedly, however, the productivity of the 2-percent BRH treatment was also lowered, even though fecundity was equal to that of the controls. This indicates possible effects on either hatching success or juvenile survival, neither of which were directly measured in this experiment.

99. The mean sizes of these juveniles were analyzed by ANOVA which shows the controls to be significantly larger ($P < 0.05$) than the other two treatments. The control juveniles were either released sooner or are growing faster. In either case, the assumption is that, with continued exposure, they will mature and reproduce sooner than juveniles in the two BRH treatments.

Table 13

Mean Number of Eggs/Ovigerous Female (± Standard Error) for *A. abdita* Exposed to Oxidized BRH Suspended Sediment for 56 Days

Treatment (BRH sediment)	n	Raw $\bar{x}$ ± SE	Size Adjusted* $\bar{x}$ ± SE
BEF control	17	** 15.8 ± 1.06	15.4 ± 1.02
2% BRH (2 mg/l)	19	15.8 ± 1.23	15.0 ± 1.01
4% BRH (4 mg/l)	20	10.8 ± 0.78	12.0 ± 1.07

* Raw data for egg number were adjusted for female size using ANCOVA.

** Means connected by the same line are not significantly different from each other at $P = 0.05$.

Table 14

Total Number of Young Produced and the Mean Size for *A. diffixa* Populations Exposed to Oxidized BRH Suspended Sediment for 56 Days

Treatment (BRH Sediment)	Replicate Number	Total Young Produced	
		Number	x Size, mm
REF control	1	680	
	4	332	
		1,012	2.29
2% BRH (1 mg/l)	1	54	
	4	63	
		117	1.65*
4% BRH (2 mg/l)	1	27	
	4	95	
		122	1.72*

* Means are not significantly different from each other at $P < 0.05$.

These size data and the productivity results are the first evidence in this experiment of impacts at the 2-percent BRH level.

99. These results, in conjunction with the previously presented information on population structure and individual growth, support the conclusion that the impact of dredged material tends to be compounded with each generation. In this particular case, the exposed parental populations grew slower and exhibited delayed maturation. The mature females were not only smaller but also produced fewer eggs, resulting in fewer young in the next generation. Because these filial young hatch at a later date, time to first reproduction, as compared with control populations, is already adversely affected. The implications of effects on growth and time to first reproduction are that in temperate (seasonal) environments, survival of late brooders may be severely impacted by being out of synchrony with the normal water temperatures and food supplies that are necessary for naturally growing populations.

100. Population response parameters were calculated from life tables using age-specific survival and reproduction data (Appendix Table A3) from the long-term test. To construct the life tables, the test period was broken into 14-day intervals up to Day 56, and survival data were estimated for each age

interval by using the initial number of amphipods, those harvested at the interim sampling (Day 28), and those at the final sampling (Day 56). Survival was estimated for Days 14 and 42, assuming linear mortality between Days 0 and 28, and 28 to 56. Survival was assumed to be 0 after Day 70 because the experiment was terminated at Day 56 for logistical reasons. The reproductive data were estimated for the 29- to 42-day and 43- to 56-day intervals from the total number of young produced on Day 56. Estimates of young produced were made for the 29- to 40-day and 57- to 70-day intervals, which were derived from the number of reproductive females surviving and mean egg number at Days 28 and 56, respectively.

101. The population responses of intrinsic rate of growth, multiplication rate per generation, and generation time for the three treatments are shown in Table 15. There are large differences between the REF control and both BRH exposed treatments for r and multiplication rate per generation. For r, the 2- and 4-percent BRH treatments are very similar (0.008 and 0.010) and are approximately three times less than that of the control treatment (0.034). The multiplication rates for the two BRH treatments are also similar (1.5 and 1.7) and are at least one third less than the rate (5.1) in the control treatment.

102. The primary reason for the differences noted here is the much lower reproductive output of the two BRH treatments (Table 14), which is a function of delayed maturation, in combination with lower fecundities in those treatments. As discussed above, the smaller mean size of the progeny at the

Table 15

Population Responses for *A. abdita* Exposed to Oxidized BRH Suspended Sediment for 56 Days

Treatment (BRH Sediment)	Intrinsic Rate of Growth	Multiplication Rate per Generation	Mean Generation Time days
REF control	+ 0.034	5.1	48.6
2% BRH (1 mg/l)	+ 0.008	1.5	52.5
4% BRH (2 mg/l)	+ 0.010	1.7	53.3

56-day harvest would cause even later maturation of those individuals leading to the potential for negative r values and multiplication rates below 1.0.

103. The mean generation time of 48.6 days in the REF treatment is 4 to 5 days shorter than the two BRH-exposed treatments. These data are consistent with the faster individual growth rate of the controls and suggest that, after two generations, exposure to these low levels of BRH suspended sediments (1 and 2 mg/l) would cause an increase in the maturation time relative to control animals.

104. When compared with previous studies with anaerobic BRH sediments (Gentile et al. 1985), the patterns of the population responses are very similar. The 2.2-mg/l BRH anaerobic sediment/exposure produced an r of 0.009, a multiplication rate of 1.60, and a generation time of 51.6 days. These data are nearly identical to the responses reported here for aerobic BRH sediment exposures (0.010, 1.7, and 53.3, respectively).

PART IV: CONCLUSIONS

105. This research was designed to evaluate the use intrinsic rates of population growth for dredged material testing. The results are as follows:

a. The two species selected for testing, *A. abdita* and *M. bahia*, are readily collected, held, and cultured throughout their life cycle under laboratory conditions and are amenable to testing fine-grained sediments, in a variety of test systems, and under various exposure conditions.

b. Laboratory test methods were developed to continuously expose *A. abdita* and *M. bahia* to bedded and suspended sediments throughout their life cycle.

c. The biological responses included in this study--lethality, individual growth, reproduction, and intrinsic rate of population growth--were sensitive to the contaminants in BRH sediments and responded in a reproducible manner when exposures were similar.

d. The intrinsic rate of population growth was equal to or more sensitive than any of the other chronic responses evaluated.

e. The results from this study demonstrate the need for chronic test methods and biological responses, and the usefulness of population responses to assess potential ecological impact.

f. This study indicates that chronic responses are the best predictors of potential environmental impacts and that research needs to be conducted to increase the number of species that can be studied throughout their whole life cycle. The importance of introducing population-level analyses into our routine testing cannot be overstated. These responses are excellent indices of impact since our goal is to protect populations and not individuals. In addition, other chronic responses, such as individual growth, must be related to population responses to determine their significance. Finally, models have been developed to handle size-specific data in addition to age-specified data since, many times, the age of field organisms is not known.

g. Laboratory toxicity tests have been traditionally conducted using continuous exposure to contaminants. It would be quite useful to determine the significance of intermittent exposures on the biological endpoints, since such exposures often characterize field conditions.

h. There is a need to develop the methods for the testing of in place bedded sediments. These methods should initially include short-term tests using lethality and growth, which have been coupled to sexual maturation and intrinsic rate of growth. These tests could be supplemented with chronic tests and cohort analyses to determine population responses.

i. This study examined only one dredged material, and therefore does not provide comparative data for the species and responses. We would recommend that a minimum suite of responses and species be utilized in a comprehensive testing program to evaluate the methods and rationale presented here.

REFERENCES

American Public Health Association. 1976. Standard Methods for the Examination of Water and Wastewater, 14th ed., Washington, D.C.

Birch, L. C. 1948. "The Intrinsic Rate of Natural Increase of an Insect Population," Journal of Animal Ecology, Vol 17, pp 15-26.

Bousfield, E. L. 1973. Shallow Water Gammaridean Amphipoda of New England, Cornell University Press, Ithaca, N.Y.

Euler, L. 1970. "A General Investigation Into the Mortality and Multiplication of the Human Species," Theoretical Population Biology, Vol 1, pp 307-314.

Gentile, J. H., and Scott, K. J. 1986. "The Application of a Hazard Assessment Strategy to Sediment Testing: Issues and Case Study," Fate and Effects of Sediment-bound Chemicals in Aquatic Systems, K. L. Dickson, A. W. Maki, and W. Brungs, eds., SETAC Spec. Pub., pp 1-17.

Gentile, J. H., Scott, K. J., Lussier, S., and Redmond, M. S. 1985. "Applications of Population Responses for Evaluating the Effects of Dredged Material," Technical Report D-85-6, prepared by the US Environmental Protection Agency, Environmental Research Laboratory, Narragansett, R. I., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Guillard, R. R., and Ryther, J. H. 1962. "Studies on Marine Planktonic Diatoms. I. *Cyclotella nana* Hustedt and *Detonula confervacea* (Clere) Gran.," Canadian Journal of Microbiology, Vol 8, pp 229-239.

Hansen, S. R., and Garton, R. R. 1982. "Ability of Standard Toxicity Tests to Predict the Effects of the Insecticide Diflubenzuron on Laboratory Stream Communities," Canadian Journal of Fisheries and Aquatic Sciences, Vol 39, pp 1273-1288.

Markle, D. F., and Grant, G. C. 1970. "The Summer Food Habits of Young-of-the-Year Striped Bass in Three Virginia Rivers," Chesapeake Science, Vol 11, pp 50-54.

Mills, E. L. 1967. "The Biology of an Ampeliscid Amphipod Crustacean Sibling Species Pair," Journal of the Fisheries Research Board of Canada, Vol 24, pp 305-355.

Mount, D. I. 1968. "Chronic Toxicity of Copper to Fathead Minnows (*Pimephales promelas* Rafinesque)," Water Research, Vol 2, pp 215-233.

Munns, W. R., Jr., Paul, J. F., Bierman, V. J., Jr., Davis, W. R., Galloway, W. B., Hoffman, G. L., Rogerson, P. F., and Pruell, R. J. 1986. "Exposure Assessment Component of the Field Verification Program: Data Presentation and Synthesis," Contribution No. 751, US Environmental Protection Agency, Environmental Research Laboratory, Narragansett, R. I.

National Research Council. 1981. Testing for the Effects of Chemicals on Ecosystems, National Academy Press, Washington, D.C.

Rand, G. M. 1980. "Detection: Bioassay," Introduction to Environmental Toxicology, F. E. Guthrie and J. J. Perry, eds., Elsevier, Amsterdam, pp 390-403.

Rogerson, P. F., Schimmel, S. C., and Hoffman, G. L. 1985. "Chemical and Biological Characterization of Black Rock Harbor Dredged Material," Technical Report D-85-9, prepared by the US Environmental Protection Agency, Environmental Research Laboratory, Narragansett, R. I., for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Scott, K. J., Morton, R. W., Bohlen, F., Germano, J. D., Paquette, G. D., Rhoads, D. C., and Stewart, L. L. 1985. "Field Verification Program (FVP); Disposal Area Monitoring System (DAMOS) Summary of Program Results, 1981-1984," Vol 2, Part C-III, R. W. Morton, J. H. Parker, and W. B. Richmond, eds., DAMOS Contribution No. 46, pp 1-231.

Snedecor, G. W., and Cochran, W. G. 1980. Statistical Methods, 7th ed., The Iowa State University Press, Ames, Iowa.

Sorgeloos, P. 1981. "Availability of Reference Artemia Cysts," Aquaculture, Vol 23, pp 381-382.

Sprague, J. B. 1971. "Measurement of Pollutant Toxicity to Fish. III. Sublethal Effects and Safe Concentrations," Water Research, Vol 5, pp 245-266.

_____. 1976. "Current Status of Sublethal Tests of Pollutants on Aquatic Organisms," Journal of the Fisheries Research Board of Canada, Vol 33, pp 1988-2022.

Stephan, C. E. 1977. "Methods for Calculating LC50," Aquatic Toxicology and Hazard Evaluation, F. L. Mayer and J. L. Hamelink, eds., ASTM STP 634, pp 65-84.

US Environmental Protection Agency/US Army Corps of Engineers. 1977. "The Ecological Evaluation of Proposed Discharge of Dredged Material Into Ocean Waters; Implementation Manual for Section 103 of PL 92-532," Environmental Effects Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

APPENDIX A: LIFE TABLES FOR *MYSIDOPSIS BAHIA* and *AMPELISCA ABDITA*

Table A1

Life Tables for *M. bahia* Exposed to BRH Sediments in Experiment 1

Age, days	No. Females	l_x*	Female Young	m_x**
		REF Control		
1-16	28	1.000	0.0	0.000
17-18	28	1.000	3.0	0.107
19-20	25	0.893	6.0	0.240
21-22	20	0.714	4.0	0.200
23-24	20	0.714	0.0	0.000
25-26	14	0.500	13.0	0.964
27-28	13	0.464	4.0	0.346
		25% BRH (25 mg/1)		
1-16	33	1.000	0.0	0.000
7-18	33	1.000	0.0	0.000
19-20	29	0.879	0.0	0.000
21-22	27	0.818	0.0	0.000
23-24	27	0.818	0.0	0.000
25-26	23	0.697	4.0	0.174
27-28	21	0.636	5.0	0.238
		50% BRH (53 mg/1)		
1-16	23	1.000	0.0	0.000
17-18	23	1.000	0.0	0.000
19-20	23	1.000	0.0	0.000
21-22	22	0.956	0.0	0.000
23-24	22	0.956	0.0	0.000
25-26	18	0.782	0.0	0.000
27-28	16	0.695	0.0	0.000

* l_x = the probability of a female surviving to age x.
** m_x = female offspring per female per age interval.

Table A2

Life Tables for *M. bahia* Exposed to BRH Sediments in Experiment 2

Age, days	No. Females	l_x*	Female Young	m_x**
		REF Control		
1-14	27	1.000	0.0	0.000
15-16	27	1.000	4.0	0.167
17-18	25	0.926	10.0	0.400
19-20	22	0.815	2.0	0.091
21-22	18	0.667	12.0	0.639
23-24	18	0.667	2.0	0.111
25-26	14	0.519	6.0	0.393
27-28	13	0.481	4.0	0.346
		12% BRH (10 mg/l)		
1-14	26	1.000	0.0	0.000
15-16	26	1.000	11.0	0.404
17-18	21	0.808	7.0	0.357
19-20	19	0.731	1.0	0.026
21-22	17	0.654	1.0	0.029
23-24	17	0.654	1.0	0.088
25-26	16	0.615	2.0	0.125
27-28	13	0.500	2.0	0.154
		25% BRH (21 mg/l)		
1-14	28	1.000	0.0	0.000
15-16	28	1.000	2.0	0.071
17-18	24	0.857	12.0	0.479
19-20	23	0.821	2.0	0.087
21-22	21	0.750	2.0	0.119
23-24	21	0.750	1.0	0.024
25-26	17	0.607	0.0	0.000
27-28	15	0.536	0.0	0.000

* l_x = the probability of a female surviving to age x.
** m_x = female offspring per female per age interval.

Table A3

Life Tables for *A. abdita* Populations Exposed to BRH Sediments for 56 Days

Age, days	No. Females	l_x*	Female Young	m_x**
		REF Control		
1-14	86	1.000	0.0	0.000
15-28	65	0.756	0.0	0.000
29-42	45	0.523	11.5	0.256
43-56	45	0.523	239.0	5.311
57-70	27	0.314	185.5	6.870
71-84	0	0.000	0.0	0.000
		2% BRH (1.1 mg/l)		
1-14	83	1.000	0.0	0.000
15-28	73	0.880	0.0	0.000
29-42	62	0.747	11.0	0.177
43-56	62	0.747	18.5	0.298
57-70	50	0.602	96.5	1.930
71-84	0	0.000	0.0	0.000
		4% BRH (2.2 mg/l)		
1-14	86	1.000	0.0	0.000
15-28	83	0.965	0.0	0.000
29-42	83	0.965	9.5	0.114
43-56	80	0.930	21.0	0.262
57-70	71	0.826	119.5	1.683
71-84	0	0.000	0.0	0.000

* l_x = the probability of a female surviving to age x.
** m_x = female offspring per female per age interval.

APPENDIX B: BIOLOGICAL DATA FOR *AMPELISCA ABDITA*

Table B1

Number of *A. abdita* in Each Sex Category for 28- and 56-Day Exposures to Oxidized BRH Suspended Sediment

Treatment	Replicate Number	Sex Category UD	FDV	FE	FOV	FS	M	Total
			Day 28					
REF control	2	86	29	13	3	6	0	131
	3	127	35	5	6	4	0	173
2% BRH	2	97	49	5	4	4	0	155
	3	131	31	13	2	6	0	177
4% BRH	2	125	26	1	2	8	0	154
	3	105	20	0	5	8	1	131
			Day 56					
REF control	1	3	3	1	28	24	2	61
	4	7	2	1	19	14	19	62
2% BRH	1	18	10	12	12	10	9	71
	4	8	20	8	37	15	13	101
4% BRH	1	6	7	4	18	4	5	44
	4	11	6	3	28	10	13	71

* See paragraphs 87-89 of main text for designation of classes.

Table B2

Mean Length (mm) and Standard Deviation of *A. bahia* Exposed to Oxidized BRH Suspended Sediments for 28 and 56 Days in Chronic Test*

Treatment	Replicate Number	Ovigerous Female	Female With Eggs in Oviduct	Developing Female	Male	Undifferentiated	Juvenile
Day 28							
REF control	2	6.72 ± 0.33(3)	4.73 ± 0.27(13)	4.15 ± 0.54(27)	-	4.18 ± 0.72(82)	-
	3	6.53 ± 0.23(6)	4.35 ± 0.23(5)	4.00 ± 0.34(35)	-	3.50 ± 0.59(123)	-
	x	6.59 ± 0.26	4.62 ± 0.31	4.07 ± 0.44		3.77 ± 0.72	
1% BRH (1 mg/l)	2	6.88 ± 0.50(4)	5.21 ± 0.46(5)	4.06 ± 0.61(48)	-	3.53 ± 0.69(92)	-
	3	7.16 ± 0.29(2)	4.96 ± 0.35(13)	4.19 ± 0.52(31)	-	3.95 ± 0.75(135)	-
	x	6.98 ± 0.43	5.03 ± 0.39	4.11 ± 0.58		3.77 ± 0.76	
4% BRH (2 mg/l)	2	6.65 ± 1.17(2)	4.41 - (1)	3.74 ± 0.40(26)	-	3.21 ± 0.69(44)	-
	3	6.35 ± 0.24(5)	-	3.83 ± 0.41(20)	5.48 - (1)	3.21 ± 0.53(104)	-
	x	6.44 ± 0.54	4.41 -	3.78 ± 0.41	5.48 -	3.21 ± 0.62	
Day 56							
REF control	1	6.80 ± 0.56(28)	6.56 - (1)	5.28 ± 1.00(3)	6.39 ± 0.22(2)	6.34 ± 1.37(3)	2.22 ± 0.00(2)
	4	6.72 ± 0.65(19)	5.70 - (1)	6.32 ± 1.32(2)	5.77 ± 0.34(18)	6.84 ± 0.48(23)	2.56 ± 0.00(23)
	x	6.77 ± 0.59	6.13 ± 0.61	5.69 ± 1.12	5.83 ± 0.37	6.69 ± 0.79	2.29 ± 0.16
1% BRH (1 mg/l)	1	6.99 ± 1.05(12)	7.14 ± 0.55(12)	5.93 ± 1.09(10)	5.85 ± 0.41(9)	6.61 ± 0.92(18)	1.66 ± 0.11(53)
	4	6.84 ± 0.85(37)	6.66 ± 0.84(8)	6.46 ± 0.97(19)	6.40 ± 0.57(13)	6.58 ± 1.25(8)	1.64 ± 0.10(66)
	x	6.88 ± 0.90	6.95 ± 0.70	6.28 ± 1.03	6.17 ± 0.57	6.60 ± 1.04	1.65 ± 0.10
4% BRH (2 mg/l)	1	6.59 ± 0.84(18)	7.19 ± 0.55(4)	6.34 ± 0.84(7)	6.42 ± 0.44(5)	6.44 ± 1.14(6)	1.65 ± 0.05(27)
	4	5.97 ± 0.43(28)	7.05 ± 0.37(3)	5.50 ± 0.80(6)	6.06 ± 0.47(13)	6.26 ± 1.37(11)	1.74 ± 0.27(94)
	x	6.21 ± 0.69	7.13 ± 0.45	5.95 ± 0.90	6.16 ± 0.48	6.32 ± 1.26	1.72 ± 0.24

* N for each mean is in parentheses.

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