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Linda C. Schaffner
Virginia Institute of Marine Science

Michele A. Horvath
Virginia Institute of Marine Science

Carl H. Hobbs III
Virginia Institute of Marine Science

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EFFECTS OF SAND-MINING ON BENTHIC COMMUNITIES AND RESOURCE VALUE:

THIMBLE SHOAL, LOWER CHESAPEAKE BAY

BY

LINDA C. SCHAFFNER, MICHELE A. HORVATH
AND C.H. HOBBS, III

VIRGINIA INSTITUTE OF MARINE SCIENCE
SCHOOL OF MARINE SCIENCE
COLLEGE OF WILLIAM AND MARY
GLOUCESTER POINT, VIRGINIA 23062

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EXECUTIVE SUMMARY

In August 1990 the City of Hampton placed approximately 276,000 cubic yards of sand from a designated borrow site on Thimble Shoal onto Buckroe Beach for beach restoration. The Buckroe reserve identified by Kimball et al. (1989) contains large quantities of beach quality material and is located less then 2.5 km offshore of Buckroe Beach. In early 1989 a small section (330 m by 240 m) located in 5 m of water was delineated and permitted for dredging. This project represents the first instance of permitted, sand-mining activities for beach nourishment in the lower bay. Although the impacts of the project on the benthic community were projected to be low (Kimball et al. 1989), the Commonwealth of Virginia retains an interest in the quality of state-owned bottomlands and, consequently, recognized the need to monitor the recovery of the site to provide information for modeling of similar projects in the future. This report summarizes results of monitoring activities and assesses the impacts on benthic (bottom) communities and resource value.

Monitoring of benthic resources in and around the mining pit was conducted from June 1990, just prior to dredging, until March 1994. The benthic monitoring activity had three main facets. Bottom profiling via acoustic techniques was used to document pit morphology, particularly to look for evidence of infilling. Macrobenthic communities were sampled to determine changes in community health and biotic integrity of the newly created pit habitat. Biotic integrity is defined as the ability of a habitat to support and maintain a balanced, integrated, adaptive community of organisms comparable to that of the natural habitat of the region (Karr and Dudley 1981). Finally, the potential impacts of mining on overwintering populations of the blue crab, *Callinectes sapidus*, were assessed using winter dredge surveys. Previous studies by Hobbs et al. (1982) and Kimball et al. (1989) determined that the potential for negative impacts of mining activities on other commercial resources, such as hard clams and fish, in the Thimble Shoal/Horseshoe Shoal regions was minimal.

The study revealed no significant negative impacts of the mining operation on benthic community health and positive effects on overwintering blue crab populations. The mining pit remained relatively intact during the study period. As a result of the increased depth of the pit, fine sediments collected and hydrodynamic reworking of the sediment was reduced, but there was no evidence of stagnation leading to oxygen limitation within the pit. The altered habitat of the pit supported a benthic community which was qualitatively and quantitatively different from the surrounding control area. However, the Benthic Index of Biotic Integrity indicates that the pit habitat is comparable to other healthy benthic habitats of the lower Chesapeake Bay.

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INTRODUCTION

In August 1990 the City of Hampton placed approximately 276,000 cubic yards of sand from a designated borrow site (the "Buckroe" site on Thimble Shoal, Figure 1) onto Buckroe Beach for beach restoration. The Buckroe reserve identified by Kimball et al. (1989) contains large quantities of beach quality material and is located less then 2.5 km offshore of Buckroe Beach. In early 1989 a small section (330 m by 240 m) located in 5 m of water was delineated and permitted for dredging. This project represents the first instance of permitted, sand-mining activities for beach nourishment in the lower bay. Although the impacts of the project on the benthic community were projected to be low (Kimball et al. 1989), the Commonwealth of Virginia retains an interest in the quality of state-owned bottomlands and, consequently, recognized the need to monitor the recovery of the site to provide information for modeling of similar projects in the future. This report summarizes results of monitoring activities and assesses the impacts on benthic (bottom) communities and resource value.

Benthic organisms often are used to monitor the effects of human activities in aquatic systems because they are relatively sedentary and are important living resources. They are an integral part of the Chesapeake Bay ecosystem. As major links in the estuarine food web, benthic organisms convert phytoplankton and detritus to forms more readily utilized by estuarine consumers such as fish and crabs. They also play a major role in the function of estuarine systems because they can have both direct and indirect effects on nutrient cycling and the degradation of organic matter (Diaz and Schaffner 1990, Weisburg et al. in press). Many commercially-important species such as the blue crab, *Callinectes sapidus*, and spot, *Leiostomus xanthurus*, utilize benthic invertebrates as a food source during some portion of their life history. Similarly, some commercially-valuable species such as the blue crab and the hard clam, *Mercenaria mercenaria*, utilize the benthic environment for habitat during all or a part of their life span.

Dredging and sand-mining activities disrupt benthic habitats by removing surface sediments and the resident organisms. These disturbances affect the value of benthic resources by altering the structure and function of resident benthic communities, the availability of bottom-dwelling invertebrates to predatory fishes and crabs and by disrupting populations of commercially important species. To assess the potential importance of sand mining activities at Thimble Shoal, pre-dredging investigations elucidated relative benthic resource value in terms of 1) abundance, composition and diversity of benthic organisms; 2) importance as habitat for hard clams and overwintering blue crabs; and 3) utilization by demersal fish predators. The results are summarized below.

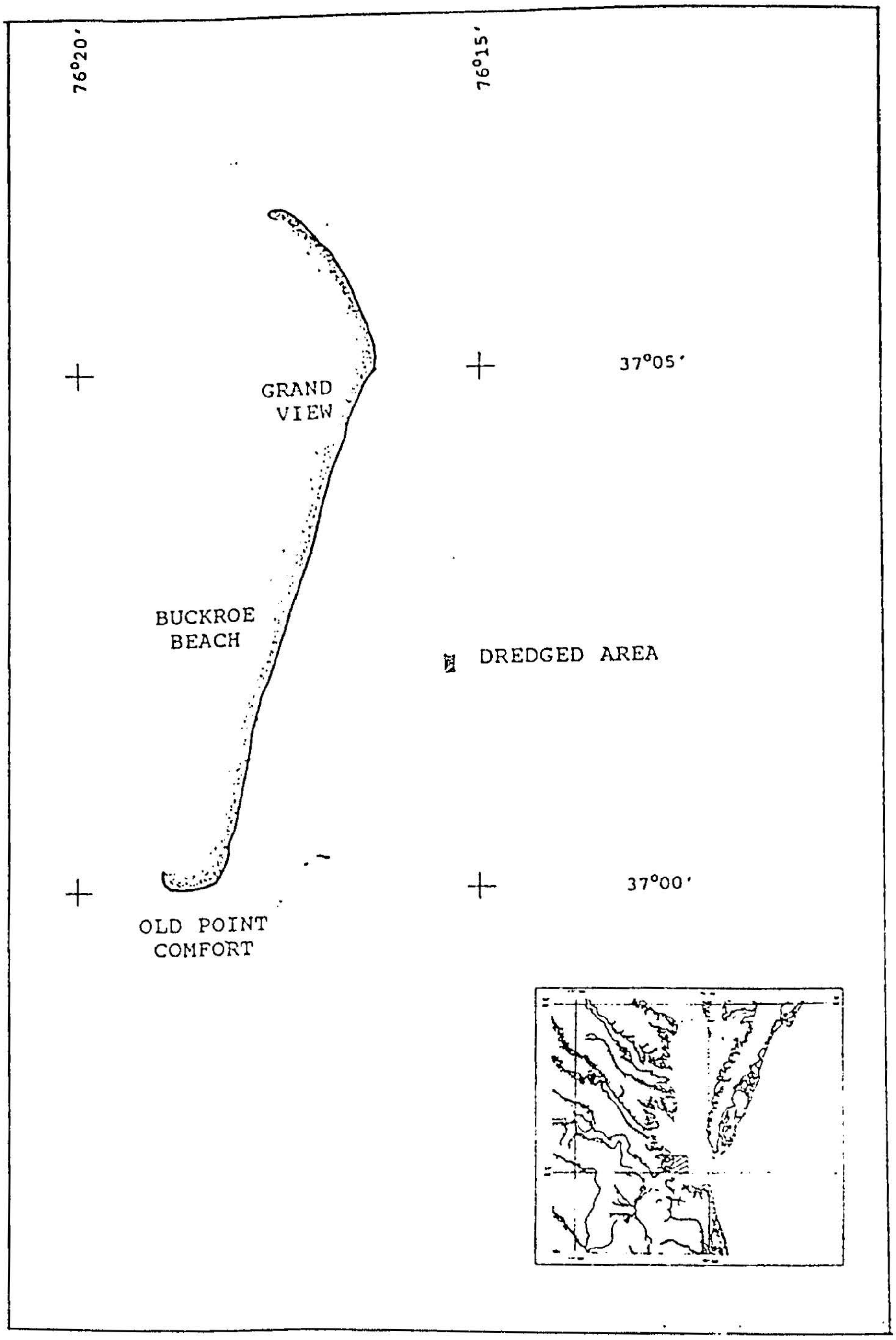


Figure 1. Location of the Buckroe sand-mining site on Thimble Shoal in lower Chesapeake Bay.

Background

Thimble Shoal is a shallow (< 9 m), sandy, polyhaline (> 20 ppt salinity) habitat dominated by a benthic community similar to that observed in other shoal areas of the lower Chesapeake Bay. The shoal originally was surveyed for sand and living resources by Hobbs et al. (1982, 1985). These authors found that the Horseshoe Bank-Thimble Shoal-Tail of the Horseshoe region of the lower bay had a large volume of sand suitable for beach replenishment, sparse to absent hard clam populations and low benthic resource value relative to other potential sand-mining areas in the lower bay. Hobbs et al. (1984) also surveyed commercial watermen at a meeting of the Virginia Working Watermen's Association to verify patterns of clam distribution and to determine preferred harvesting areas.

Kimball et al. (1989) further investigated three potential mining sites in the vicinity of Buckroe Beach. Their study included a more detailed assessment of sand quantity and quality, an evaluation of the utilization of the sites by overwintering blue crabs, *Callinectes sapidus*, and potential availability of food resources for other demersal predators such as fish. They found low densities of overwintering blue crabs for the region in general, a pattern consistent with results of a previous investigation of overwintering crab distribution patterns in the lower bay by Schaffner and Diaz (1988). Field observations of crab potting activities during the spring and early summer of 1988 suggested low usage of the study region by watermen. Conversations with working watermen from the Hampton, Newport News and Poquoson areas were used to verify patterns of crab harvesting activities in the region. A site, identified as the 'Buckroe' site, was recommended for mining based on the presence of sufficient volumes of beach-quality sand reserves, low overwintering crab densities, and relatively low benthic resource value.

OBJECTIVES

This study was designed to evaluate the impact of sand-mining on the benthic habitat integrity and benthic community resource value of the Buckroe sand reserve site on Thimble Shoal. The bathymetry and bottom characteristics of the site, pre- and post-dredging, provide information on morphology and bottom characteristics of the borrow site that may be related to the composition or abundance of living, benthic resources. Macrobenthic community composition and abundance patterns before and after dredging are used, along with a newly-developed **Benthic Index of Biotic Integrity** (B-IBI), to evaluate changes in the structure, function and resource value of dredged areas relative to controls. Overwintering blue crab abundances in dredged areas relative to controls are used to assess changes in habitat value for a commercially important species.

SAMPLING DESIGN AND METHODS

The overall sampling design included bathymetric and benthic faunal surveys of the borrow site and surrounding control areas performed pre-dredging, immediately following dredging, and at 1, 3, 6, 9, 15, 18, 25, 30, 36, 42, 48 and 54 months post-dredging (Table 1). Blue crab overwintering surveys were conducted during each winter following dredging, through February 1995.

Bathymetry and Bottom Characteristics

Bottom characteristics were mapped using an EG&G Model 960 Seafloor Mapping System (side scan sonar) until March of 1995 when the older system was replaced by the newer EG&G Model 260. In these systems, a 105kHz acoustic signal is transmitted in an arc variably set to scan a fixed distance on each side of the track line. The resulting record is a planimetric image of the seafloor corrected with respect to vessel speed. The intensity of the recorded signal is a representation of the character of the seafloor (Hobbs and Dame 1992). Dark areas on the record are the result of hard seafloors, coarse materials or areas of relief that reflect most of the acoustic signal. Light areas indicate soft or fine-grained sediments, or shadow zones behind areas of positive relief, and are the result of absorption of acoustic energy. Tracklines running across the dredged area provided a mosaic picture of the site on each sampling date. Bathymetric profiles were obtained using a Datasonics system at 3.5 and 200 kHz recorded on an EPC graphics plotter (through August 1993) or an Innerspace Model 448 depth sounder with digital recording (February 1994 through March 1995). Closely-spaced fix marks, positioned with a Delnorte positioning system or Magellan NAV 1000 Pro Global Positioning System (GPS) allowed spatial comparisons of bed features through time.

Benthic Resources

Benthic invertebrate abundance and potential availability to predators were determined using a combination of quantitative core sampling and photographic techniques. On each sampling date a total of 8 stations (4 within the pit, 4 in control areas outside of the pit) were occupied and positions fixed as described above. The small size of the borrow pit precluded randomization of the sampling design. The four stations were located within the northern, eastern, southern and western quadrants of the pit. Control stations were oriented similarly within 100 m of the perimeter of the pit. A Smith-MacIntyre grab was used to collect a benthic sample at each station. Two 10 cm diameter subcores were removed from each grab. The two cores were vertically-partitioned into depth intervals of 0-2, 2-5 and 5-10 cm, composited by depth interval, and fixed in 10% formalin. In the laboratory, samples were sieved on 500 um mesh screen and examined for resident organisms under a research grade microscope. Organisms were sorted to major taxa and

Table 1. Summary of sampling dates and data collected.

Cruise #	Date(s)	Bathymetric Survey	Macrobenthos and SPI	Crab Survey
1990				
01	6/13,14	X	X	
Dredging took place during August 1990				
02	8/23	X	X	
03	9/20,26	X	X	
04	11/19		X	
1991				
05	2/18,19	X	X	X
06	5/30	X	X	
07	11/20	X	X	
1992				
08	3/3,23	X	X	X
09	9/10	X	X	
1993				
10	2/3	X	X	X
11	8/11	X	X	
1994				
12	2/28, 3/1	X	X	X
13	8/24, 9/15	X	X	
1995				
14	2/28, 3/13	X	X	X

weighed (wet weight) for each depth interval. Subsequently, organisms were identified to the lowest possible taxonomic level.

Information on bottom sediment type and the distribution patterns of large, more sparsely distributed organisms dwelling on or just above the sediment surface, including blue crabs and fish, was obtained using a remotely deployed underwater camera system. The SPI (Surface and Profile Imaging) System developed at VIMS combines conventional surface photography and profile photography of the sediment-water interface. Information obtained from photographs includes sediment type, presence of bedforms, presence of biogenic features such as tubes, burrows and fecal pellets or mounds and presence of organisms. On each sampling cruise, the system was deployed for a maximum of 3 profile and 10 surface photographs at each station.

Overwintering crab distribution patterns were evaluated by dredging with a commercial crab dredge (2 m dredge width, 15 cm stretch mesh) towed by the *R/V Bay Eagle* at a controlled speed of 4.8 km h^{-1}. Eight 5 minute tows around the perimeter of the borrow pit and 4 tows within the pit were used to assess crab abundance patterns, proportions of live vs. dead crabs, and sex ratios.

Index of Biotic Integrity

To evaluate benthic community condition we used the Benthic Index of Biotic Integrity (B-IBI) developed for the Chesapeake Bay by Weisburg et al. (in press). Biotic integrity of a habitat is "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region (Karr and Dudley 1981). The original IBI was developed by Karr (1981) to incorporate information from the individual to ecosystem levels into a "single ecologically based index of the quality of a water resource". An IBI is based on a series of metrics which are assumed to correlate with biotic integrity. Each metric provides information about an attribute of the community at a sampling site. Multiple metrics (e.g. Shannon-Weiner diversity index, percent of pollution tolerant species, percent deposit feeders) are chosen to reflect a range of attributes of the community (e.g. species diversity, life history strategies of resident fauna, feeding guild measures). Metrics are chosen on the basis of their abilities to differentiate between known pollution-impacted and known healthy sites.

The B-IBI is a multimetric index which was developed independently for seven Chesapeake Bay habitats defined by salinity and substrate. The sample sites used in the calibration of the index were located throughout the Chesapeake Bay at subtidal depths exceeding 3 meters. We applied indices developed for polyhaline habitats for the control and mining pit sites following details presented in Weisburg et al. (in press). Briefly, threshold values were used to score metrics (Table 2) computed for each benthic macrofaunal sample collected during cruises 2, 9, 11 and 13.

Table 2. Metrics and scoring criteria for a Benthic Index of Biotic Integrity for polyhaline sand and mud habitats of Chesapeake Bay.

	Scoring Criteria		
Habitat	**5**	**3**	**1**
Polyhaline sand			
abundance (#/m^2)	3,000 - 5,000	1,500 - 3,000 or 5,000 - 8,000	< 1,500 or > 8,000
biomass (g dry/m^2)	5 - 20	1 - 5 or 20 - 50	< 1 or > 50
abundance of pollution-indicative taxa (%)	< 10	10 - 40	> 40
abundance of pollution-sensitive taxa (%)	> 50	25 - 50	< 25
abundance of deep-deposit feeders (%)	> 25	10 - 25	< 10
Shannon-Weiner diversity (bits/individual)	> 3.5	2.7 - 3.5	< 2.7

Table 2. (continued)

	Scoring Criteria		
Habitat	**5**	**3**	**1**
Polyhaline mud			
abundance (#/m^2)	1,500 - 3,000	1,000 - 1,500 or 3,000 - 8,000	< 1,000 or > 8,000
biomass (g dry/m^2)	3 - 10	0.5 - 3 or 10 - 30	< 0.5 or > 30
abundance of pollution-indicative taxa (%)	< 15	15 -50	> 50
abundance of pollution-sensitive taxa (%)	> 40	25 - 40	< 25
abundance of carnivore-omnivores (%)	> 40	25 - 40	< 25
Shannon-Weiner diversity (bits/individual)	> 3.3	2.4 - 3.4	< 2.4
taxa > 5 cm below the sediment-water interface (%)	> 40	10 - 40	< 10

We used only summer faunal collections to be consistent with the approach used for the original index development. The index was calculated by scoring each metric as 5, 3, or 1 depending on whether its value at a site approximated, deviated slightly from, or deviated greatly from the best reference sites used in development of the index. Metric scores were then averaged for each sample to obtain the sample B-IBI. The mean IBI was then computed for control and mining pit stations for each collection date.

RESULTS

Bathymetric Surveys

In the period June 1990 through March 1995 several bathymetric and side-scan sonar surveys of the Thimble Shoal Buckroe sand-mining area were performed (Table 3). Throughout the course of the project, specific survey methods and equipment were changed in order to improve the quality of the work in parallel with advances in technology. Unfortunately, the changes which yielded improved results for the bathymetry negated the ability to compare earlier with later surveys. Changes in the instrumentation used for the side-scan mapping did not affect the comparability of the data.

Comparisons of the bathymetry require two assumptions. The first assumption is that the pre-dredging bottom was smooth and that there was minimal relief in and around the dredged area. The second is that there has been no change in the elevation of the (smooth) bottom of the region surrounding the dredged area. Both assumptions are reasonable; the first conforming with pre-dredging data and the second follows as there is no evidence of erosion or deposition across the surrounding smooth bottom.

Because the surveys were performed with only two-dimensional control (x, y or east/west, north/south) the absolute elevation of the bottom with respect to some standard datum was not determined. Recorded water-depths are depths beneath the transponder without account for draft or stage of the tide. Given the assumption of a stable bottom, it is possible to compare the morphologies of the dredged pit at different times by adjusting the bathymetry to bring the unaltered bottom to a common elevation. This can be done by either a simple decrease of all depths in any one survey or through a more complex manipulation in the post-processing software.

In the field, data were collected by running survey lines across the dredged area. For the surveys that used the EPC graphics recorder, several "fix marks" were placed on the record and corresponding annotation on the positioning record. For the surveys using

Table 3. Bathymetric survey dates and types of instrumentation utilized.

Date	Depth	Side-scan	Navigation	Instrumentation
06/13/90	x		DelNorte	DataSonics
08/23/90	x	x	DelNorte	DataSonics
09/20/90	x		DelNorte	DataSonics
11/19/90		x	DelNorte	
02/18/91	x	x	DelNorte	DataSonics
05/30/91	x	x	DelNorte	DataSonics
11/20/91	x	x	DN & GPS	DataSonics
03/24/92	x	x	GPS	DataSonics
09/10/92	x	x	GPS	DataSonics
02/03/93	x	x	GPS	DataSonics
08/11/93	x		GPS	DataSonics
02/ /94	x		GPS	InnerSpace
05/ /94	x		GPS	InnerSpace
09/15/94	x		GPS	InnerSpace
03/13/95	x	x	GPS	InnerSpace

the Inner Space Depth Sounder, depth and position were recorded automatically and simultaneously on a portable computer.

The method of data reduction depended upon the nature of the original data set. In the case of those surveys that used the graphics recorder and fix marks, depths at the fix marks were measured as were depths at intermediate locations. The positions for the secondary depths were determined by interpolation. A much larger set of depths and positions were available from the more recent Inner Space surveys. The initial surveys used a locally configured DelNorte positioning system which provided positions in the state plane coordinates, North American Datum 1927 (NAD27). The surveys that used GPS reported positions in standard geographic coordinates (latitude and longitude) with reference to the North American Datum of 1983 (NAD83). Software obtained from NOAA (Corpscon) was used to convert the geographic coordinates to state plane and from NAD83 to NAD27.

Once the data were arrayed in x-y-z coordinates, the file was processed using Golden Software's *Surfer* program. In addition to preparing contour maps of the dredged area, the software also includes routines for calculating the volume between two surfaces. For the survey dates for which there was a sufficient data-density to allow such calculations, we estimated the volume in the following manner. One surface was the sea-floor as described by the survey data. We used the software to calculate the volume between this surface and a series of arbitrary, horizontal, plane surfaces. This first plane was selected as an elevation somewhat above the sea-floor. Each successive surface was an increment lower. As long as the difference in volumes between the two pairs of surfaces (sea-floor and arbitrary elevation) was constant, the arbitrary plane was still wholly in the water column. When the differences in volume decreased, the arbitral plane had intersected part of the sea-floor and the calculated volume represented the volume of the dredged pit.

Explained differently, an x-y plot of the volume between the volume of the two surfaces for successive lower, top, plane surfaces would have a constant slope until the plane surface and the sea-floor intersected, at which point the slope would decrease and the volume would be that of the dredged pit.

The volume of the dredged pit for those surveys for which there is sufficient data-density is shown in Figure 2. The volume data, however, should not be taken at face value and require some interpretation. The August 1993 value clearly is erroneous and should be discarded. Electronic problems (GPS off line?) significantly compromised several of the survey lines and left too few points for valid calculations. The surveys prior to August 1993 were performed with a graphics recorder and fix-mark positioning yielding a relatively small number of data-points when compared to the surveys made after August 1993 which used an electronically recording depth sounder and paired navigational system. It is unreasonable to compare the 2 data

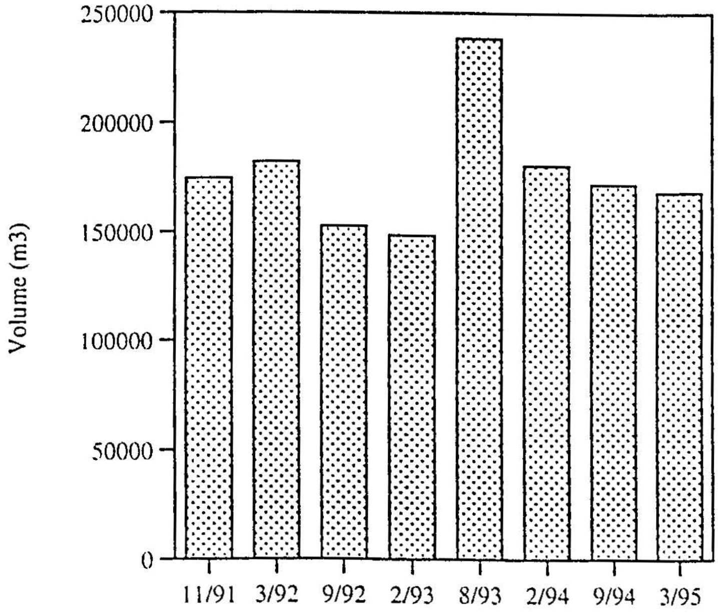


Figure 2. Volume of the dredged pit in cubic meters at the Buckroe mining pit, November 1991 through March 1995.

sets. For example, the data set for the November 1991 survey (Figures 3 and 4) contains 192 points whereas the data set for March 1995 contains over 4,400 points (Figures 5 and 6).

The validity, albeit at different levels of precision, of the bathymetry by the different methods is demonstrated in that each survey indicated the "mound" left in the mining site over a magnetic anomaly. (The anomaly was identified in a predredging Magnetometer survey performed by Tidewater Atlantic Research, Inc. on June 13, 1990.)

The best comparisons are among the final three surveys, February and September 1994 and March 1995. These surveys were performed with the best and same methods. The March 1995 volume is 93 percent of the February 1994 volume, indicating a minimal infilling of 7 percent (12,528 m^3 or 16,386 yd^3) in the period between surveys. This infilling may actually represent a change in morphology as indicated by comparison of the side-scan sonar images. The more recent images show a generally "smoother" bottom. Early images depicted some of the original dredge cutter-head scars while the more recent do not. This smoothing could be a function of either or both a slow filling of the pit and burial of the features and/or a redistribution of the sediments within the dredged site. The sonograms of the March 1995 survey (Figure 7) also indicate possible slumps of the pit wall. When considering the likelihood of slumping, it is necessary to consider the possibility that the slumped material expanded in volume as it lost consolidation, thus contributing to the apparent infilling of the site between February 1994 and March 1995. Overall, when we consider the trends over the duration of the study, we conclude that there has been minimal infilling of the pit, but some evidence of change in pit morphology.

Benthic Faunal Surveys

Fourteen benthic faunal surveys were completed. Station locations for quantitative core sampling and SPI camera system deployment are given in Table 4. Stations designated 5 - 8 were control stations prior to mining activities.

Abundance and Composition of Benthic Fauna

In both pre- and post-dredging collections, annelids were the numerical dominants in collections from the mining pit and control stations (Figure 8). Molluscs, crustaceans and other taxa (primarily Phoronida and Nemertinea) were less abundant. Molluscs dominated biomass at all stations prior to and immediately after dredging, but then were far less abundant at both control and mining pit stations (Figure 9). Molluscs and annelids comprised most of the biomass in subsequent collections, with crustaceans and other taxa being relatively unimportant.

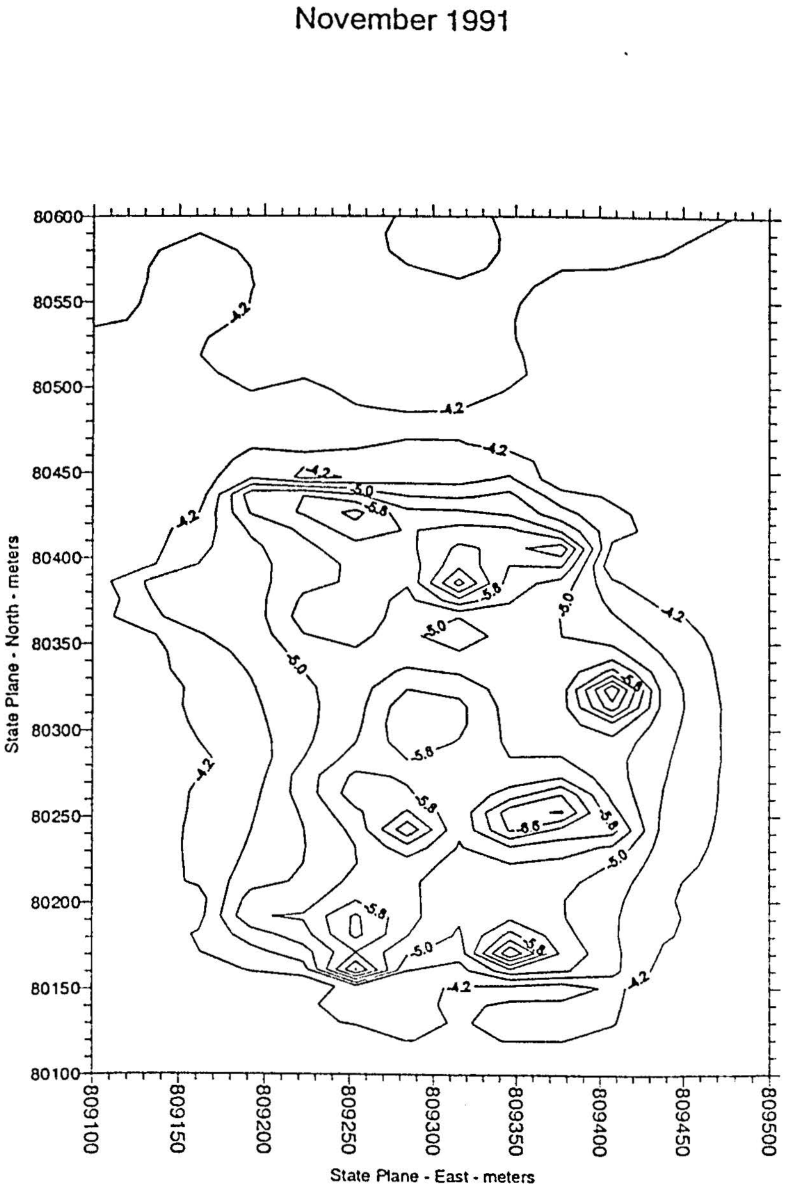


Figure 3. Contour map of the dredged area, November 1991. Depths are in meters, contour interval is 0.4 m.

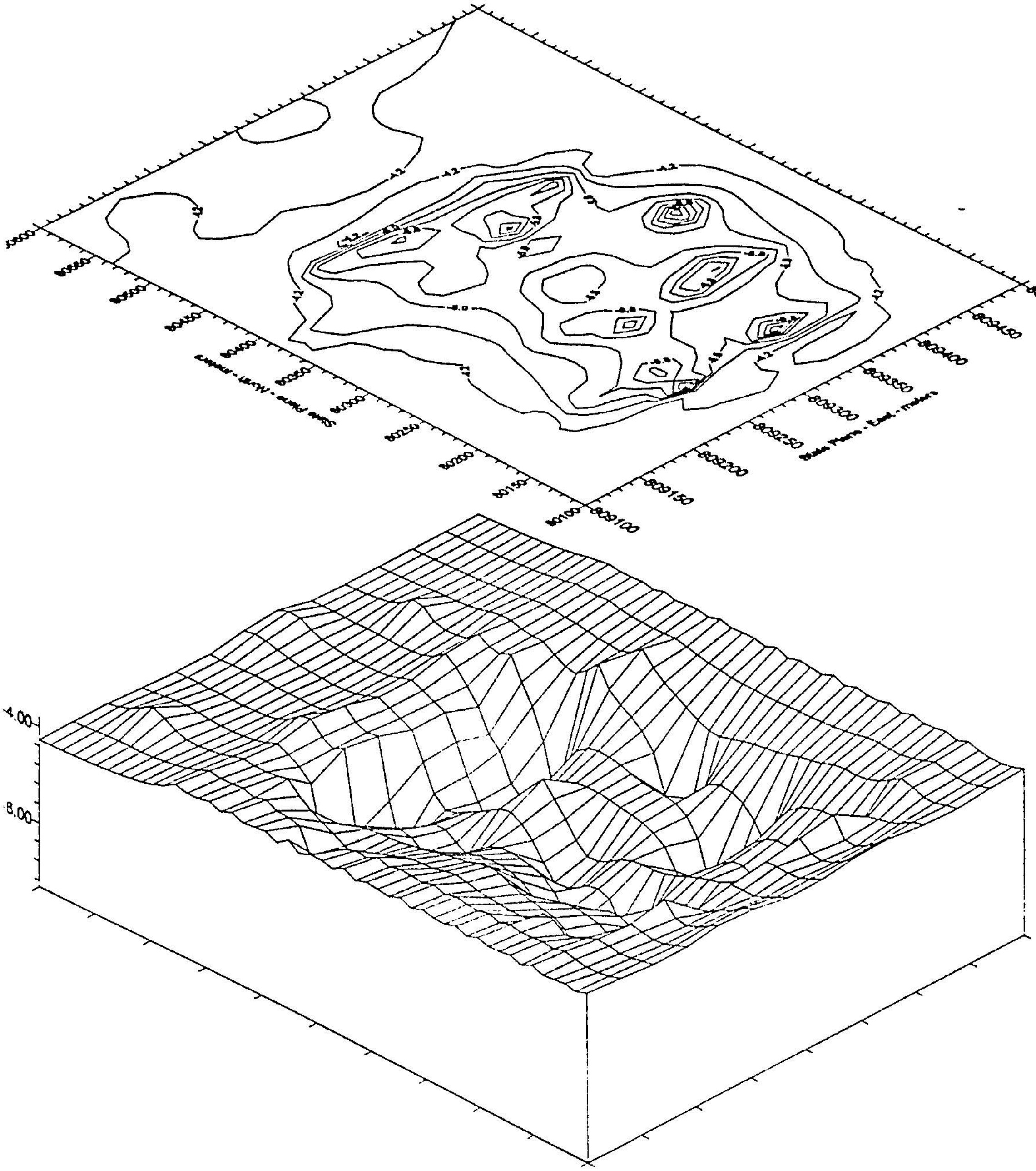
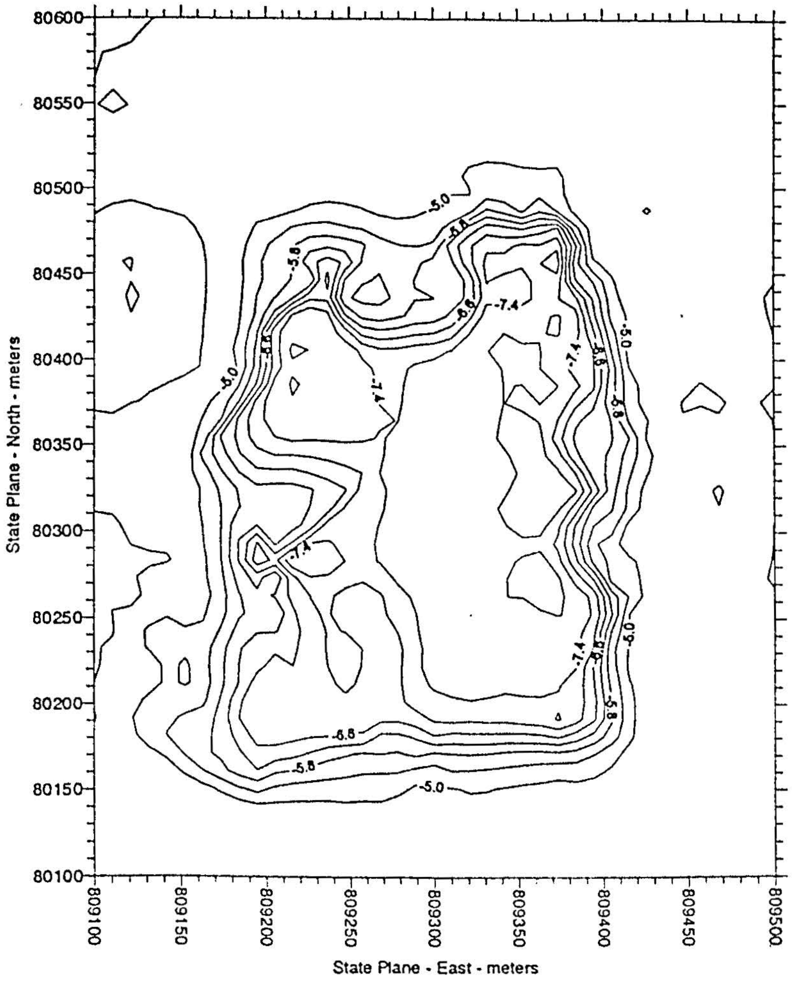


Figure 4. A perspective view of the map and of the surface depicted in Figure 3.

March 1995



Contour Interval: 0.4 m

Figure 5. Contour map of the dredge area, March 1995. Depths are in meters, contour interval is 0.4 m.

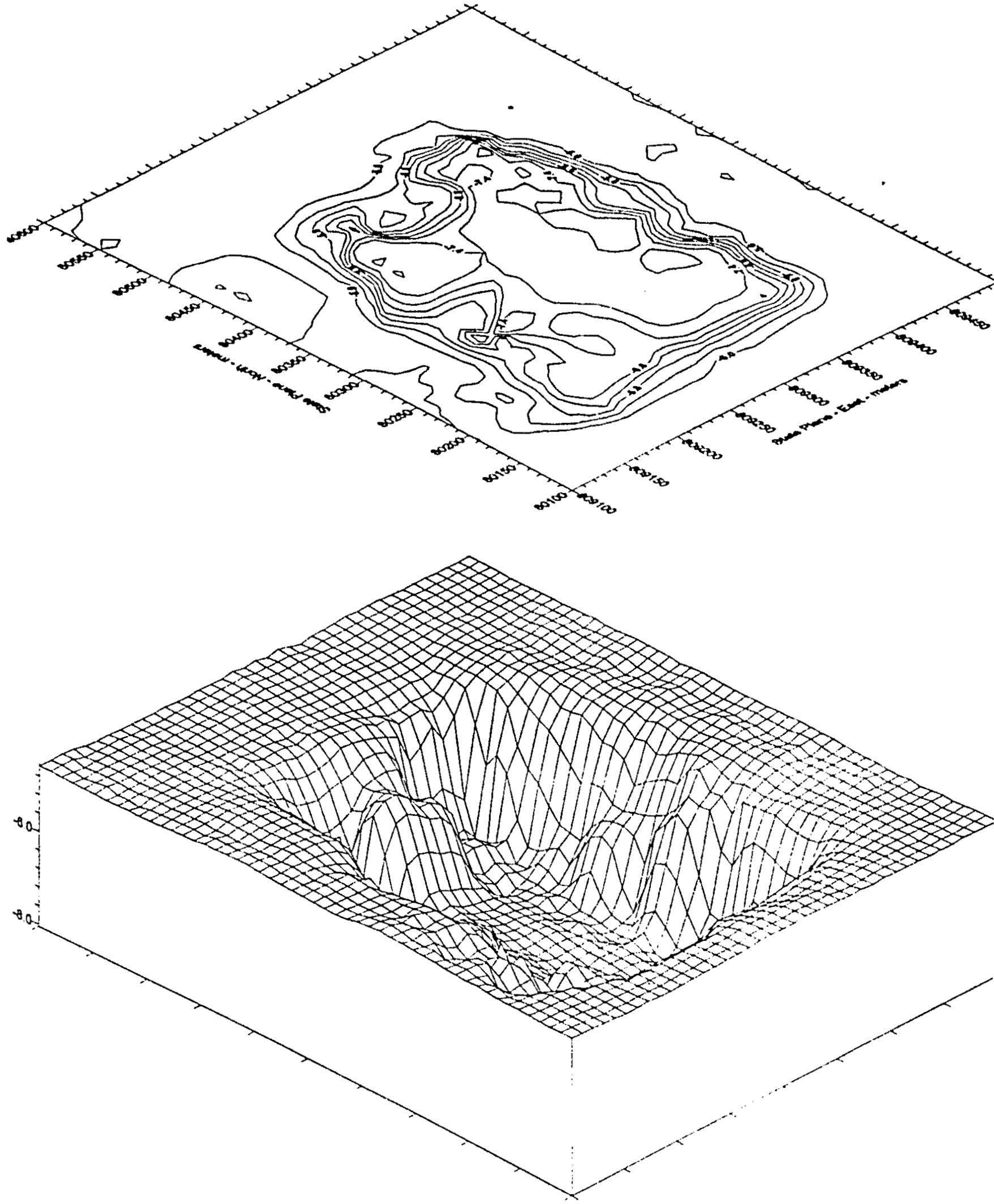


Figure 6. A perspective view of the map and of the surface depicted in Figure 5 .

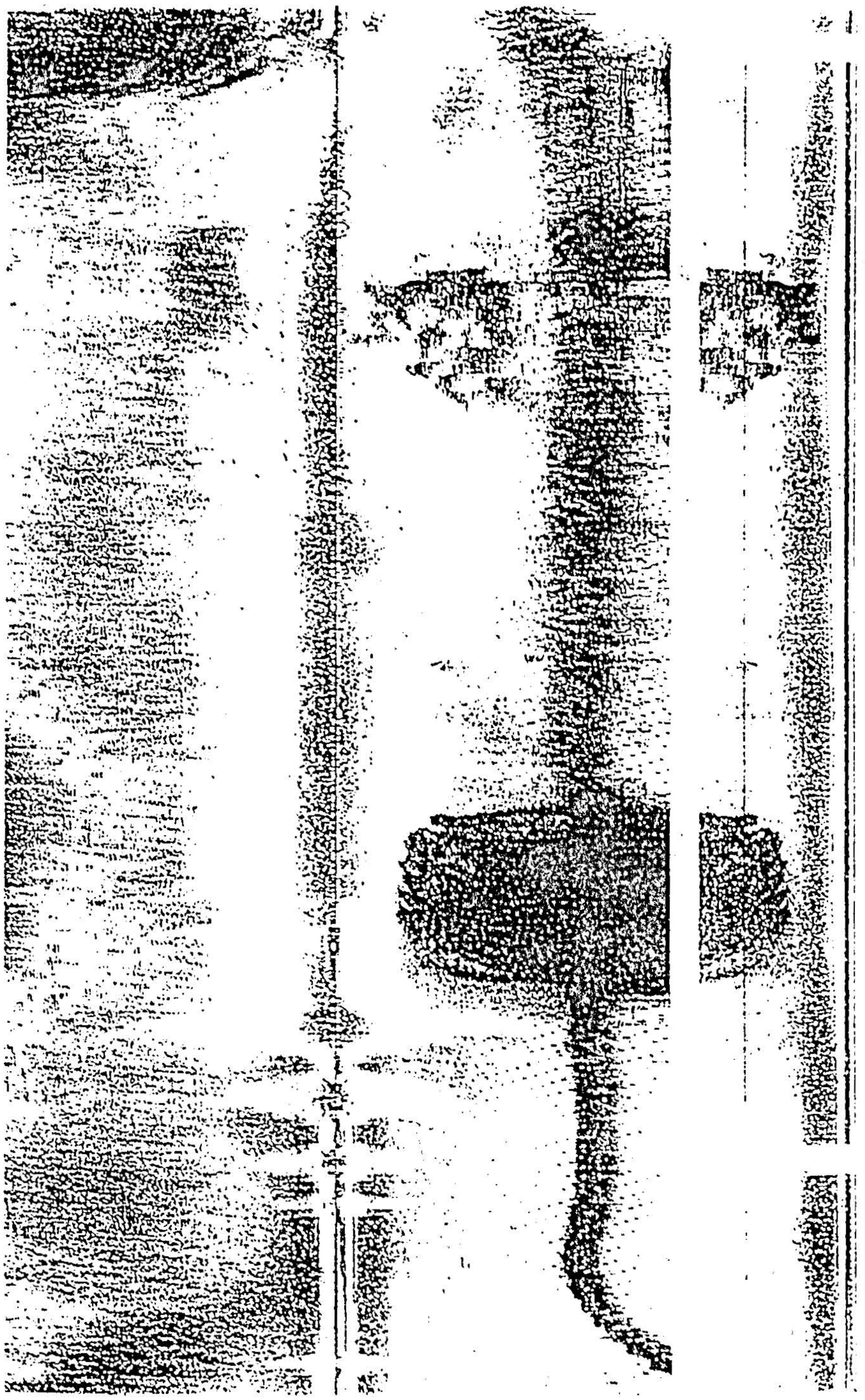


Figure 7. Sonogram produced by side-scan sonar survey of the mining pit in March 1995.

Table 4. Station locations for macrobenthos and SPI camera surveys. C - control, P - mining pit, N - north, S - south, E - east, W - west.

Station #	Area	Latitude (N) Deg. Min.	Longitude (W) Deg. Min.	Depth (m)
1	C-W	37 02.15	76 15.37	4.0 - 5.2
2	C-N	37 02.28	76 15.23	4.0 - 5.2
3	C-E	37 02.10	76 15.04	4.0 - 5.2
4	C-S	37 01.97	76 15.26	4.0 - 5.2
5	P-S	37 02.07	76 15.21	7.0 - 8.2
6	P-W	37 02.13	76 15.25	7.0 - 8.2
7	P-N	37 02.15	76 15.19	7.0 - 8.2
8	P-E	37 02.14	76 15.20	7.0 - 8.2

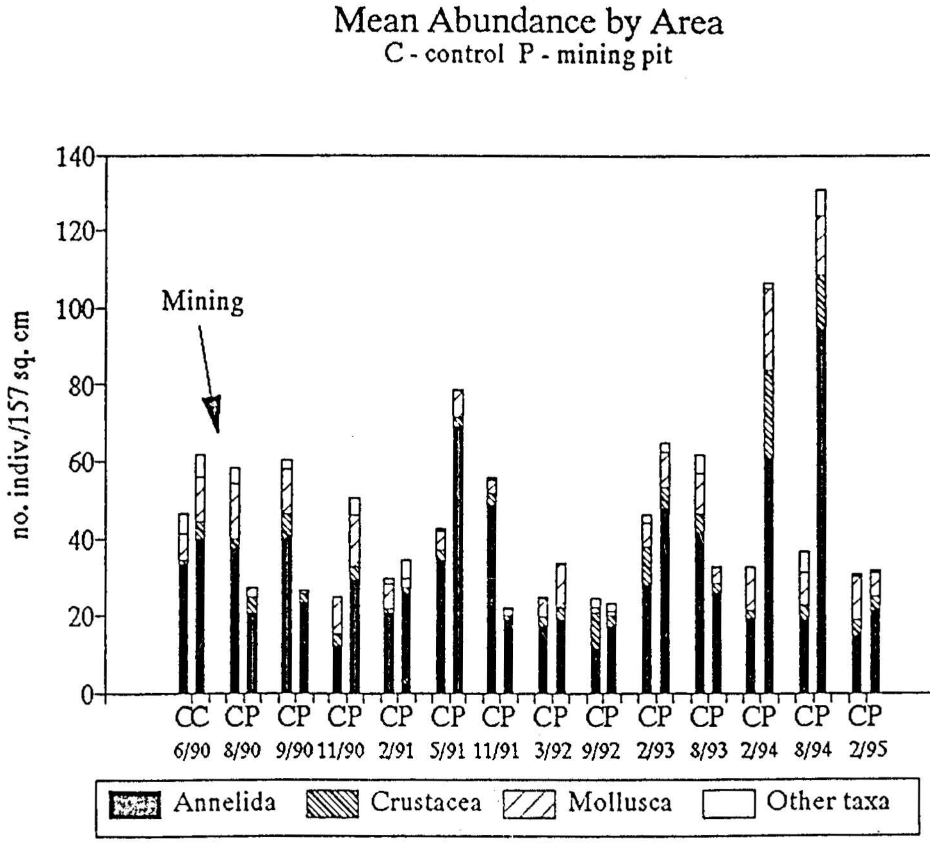


Figure 8. Abundance of macrobenthos in quantitative core samples by date of collection.

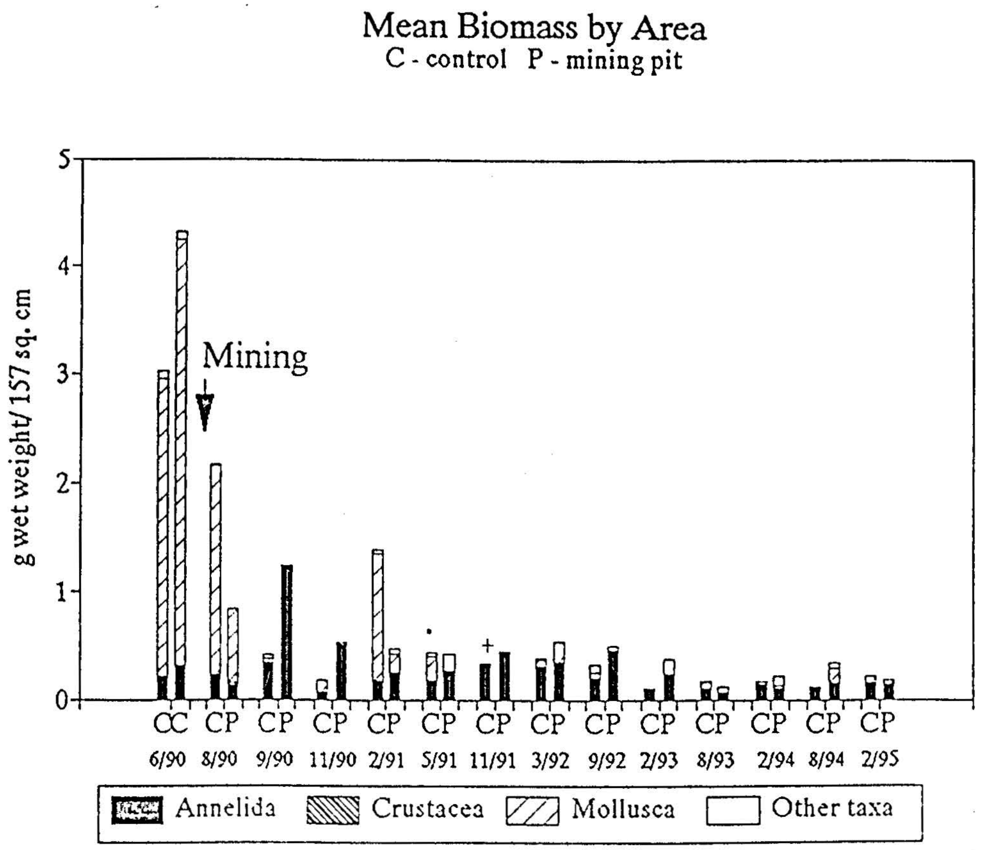


Figure 9. Biomass of macrobenthos in quantitative core samples by date of collection. * excludes a single large *Ensis directus*, + excludes a single large *Paranthus rapiformis*.

Two-way ANOVA for samples collected during the first project year (through May 1991) revealed significant differences among mean total faunal abundances (sq. root transformed) as a function of sampling date ($F = 3.06$, $p = 0.21$, d.f. = 5) and sampling date by site interactions ($F = 7.22$, $p < 0.001$, d.f. = 5). T-test comparisons of sites for each sampling date revealed significantly higher total faunal abundances at control stations relative to borrow pit stations immediately post-dredging ($t = 2.45$, $p = 0.05$, d.f. = 6) and 1 month post-dredging ($t = 3.9$, $p < 0.01$) and no significant differences on other sampling dates. We observed at least as much variability in abundance at each set of stations (i.e. control, pit) over time, as we did between sets of stations on a given date. For example, there is as much difference in faunal abundances within the pit from February 1994 to February 1995 as there is for the comparison between faunal abundance in the pit vs. control regions during February 1994.

Significant differences in mean total biomass for the first project year were related to sampling date alone ($F = 6.87$, $p < 0.001$, d.f. = 5); there were no significant effects of site or site by sampling date interactions. For both control and borrow pit stations, post hoc comparisons indicate that total biomass in pre-dredging collections was significantly greater ($0.001 < p < 0.43$) than that observed for all post-dredging collections (through May 1991). Biomass continued to decrease through the end of the study at both control and mining pit stations. These decreases were largely due to the absence of molluscs which had been abundant during the early cruises (primarily the razor clam *Ensis directus*).

Fauna Depth Distribution Patterns

Most of the organisms collected in quantitative benthic samples were found within the upper 5 cm of the sediment column (Figures 10 and 11). No clear trends in the depth distribution patterns of individuals or biomass were apparent relative to area of collection (control vs. mining pit).

Dominant Species

Prior to dredging (June 1990) the Thimble Shoals study region was dominated by the spionid polychaetes *Spiophanes bombyx*, *Scolelepis* sp., *Spio* sp., and paraonid polychaetes and the bivalve *Ensis directus* (Table 5). Subsequent to dredging the control area continued to be dominated by a similar suite of species. Also abundant until the end of the study were the small gastropod *Acteocina canaliculata* and the capitellid polychaete *Mediomastus ambiseta*.

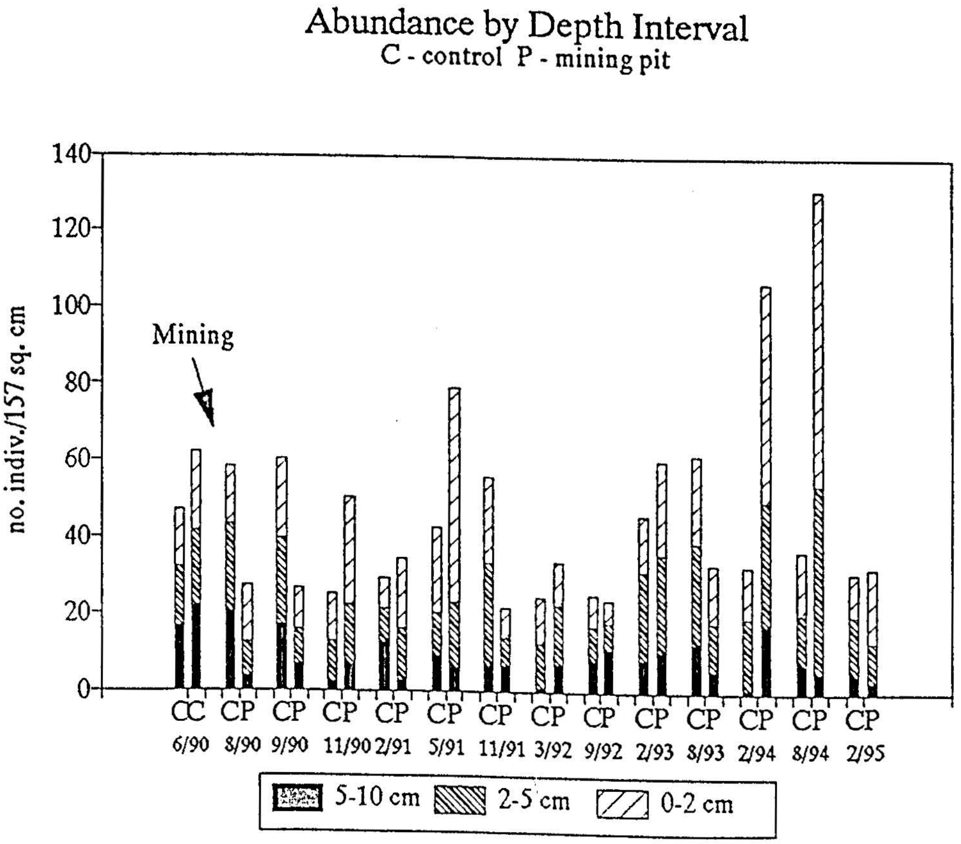


Figure 10. Depth distribution of macrobenthos in core samples by date of collection.

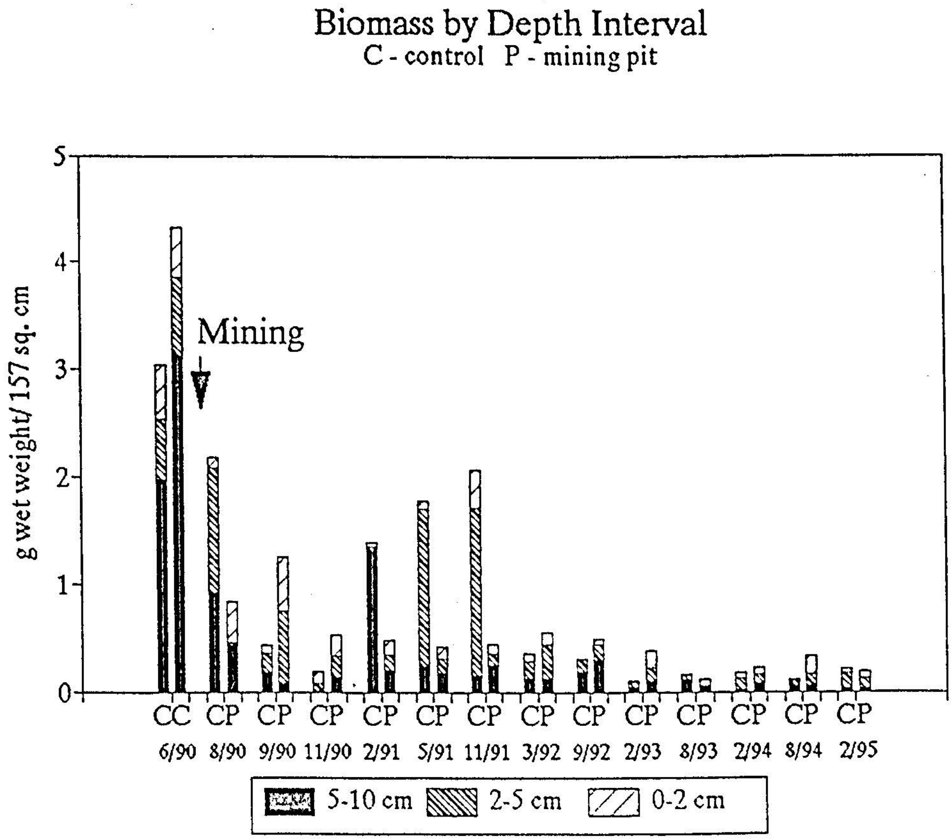


Figure 11. Depth distribution of biomass in quantitative core samples by date of collection.

Table 5. Dominant species in benthic core samples from control and mining pit areas, listed by date of collection. Taxa as follows: P = Polychaeta, B = Bivalvia, G = Gastropoda, A = Amphipoda, U = Urochordata. sd = standard deviation.

Date (Cruise #)	Area: **Control**	mean (sd)	**Mining Pit**	mean (sd)
6-14-90 (01)	*Spiophanes bombyx* (P)	13.0 (4.2)		
	Paranoidae (P)	8.5 (5.8)		
	Ensis directus (B)	4.3 (2.2)		
	Scolelpis sp. (P)	3.3 (3.3)		
	Phoronida	2.8 (2.5)		
	Spio sp. (P)	2.3 (2.1)		
8-23-90 (02)	*Acteocina canaliculata* (G)	13.5 (0.7)	*Paraprionospio pinnata* (P)	9.0 (5.7)
	Spiophanes bombyx (P)	11.0 (2.8)	*Mediomastus ambiseta* (P)	8.0 (11.3)
	Mediomastus ambiseta (P)	11.0 (2.8)	Paranoidae (P)	4.5 (6.4)
	Phoronida	4.5 (3.5)	*Spiophanes bombyx* (P)	2.5 (3.5)
	Tellina agilis (B)	3.5 (2.1)	*Rhepoxynius epistomus* (A)	2.0 (2.8)
	Paraonidae (P)	2.5 (0.7)	*Ampelisca* sp. (A)	1.0 (1.4)
9-20-90 (03)	*Acteocina canaliculata* (G)	12.0 (2.8)	*Paraprionospio pinnata* (P)	19.5 (7.1)
	Spiophanes bombyx (P)	11.0 (4.2)	*Glycinde solitaria* (P)	2.0 (2.8)
	Paraonidae (P)	6.5 (2.1)	*Diopatra cuprea* (P)	1.0 (1.4)
	Mediomastus ambiseta (P)	6.0 (1.4)	*Acteocina canaliculata* (G)	0.5 (0.7
	Rhepoxynius epistomus (A)	3.0 (1.4)	Pyramidellidae (G)	0.5 (0.7)
	Pyramidellidae (G)	2.0 (0.0)	*Nereis succinea* (P)	0.5 (0.7)
11-19-90 (04)	*Acteocina canaliculata* (G)	13.5 (7.8)	*Paraprionospio pinnata* (P)	23.5 (21.9)
	Spiophanes bombyx (P)	6.0 (2.8)	*Mediomastus ambiseta* (P)	12.0 (2.8)
	Spio sp. (P)	1.5 (0.7)	Bivalvia juveniles	10.0 (5.7)
	Eteone heteropoda (P)	1.0 (1.4)	Platyhelmithes	4.0 (4.2)
	Turbonillidae (G)	1.0 (1.4)	*Spiophanes bombyx* (P)	3.0 (1.4)
	Bivalvia juveniles	1.0 (1.4)	*Ampelisca* sp. (A)	1.5 (0.7)
	Rhepoxynius epistomus (A)	1.0 (1.4)		

Date (Cruise #)	Area: **Control**	mean (sd)	**Mining Pit**	mean (sd)
2-19-91 (05)	*Spiophanes bombyx* (P)	10.0 (0.0)	*Paraprionospio pinnata* (P)	21.0 (25.4)
	Acteocina canaliculata (G)	4.5 (7.1)	*Mediomastus ambiseta* (P)	6.5 (7.8)
	Mediomastus ambiseta (P)	1.5 (0.7)	*Streblospio benedicti* (P)	3.0 (4.2)
	Paraonidae (P)	1.0 (1.4)	Cirratulidae (P)	2.0 (2.8)
	Bivalvia juveniles	1.0 (1.4)	Nemertinea	1.5 (0.7)
	Spio sp. (P)	1.0 (0.0)	Bivalvia juveniles	1.0 (1.4)
	Magelona sp. (P)	1.0 (0.0)		
5-30-91 (06)	*Spiophanes bombyx* (P)	15.5 (7.8)	*Mediomastus ambiseta* (P)	24.5 (14.8)
	Streblospio benedicti (P)	5.0 (5.7)	*Streblospio benedicti* (P)	14.5 (13.4)
	Acteocina canaliculata (G)	3.5 (2.1)	Cirratulidae (P)	9.0 (7.1)
	Scolelepis sp. (P)	2.0 (0.0)	*Paraprionospio pinnata* (P)	5.5 (0.7)
	Cirratulidae (P)	1.5 (2.1)	Phyllodocidae (P)	4.5 (6.4)
	Ampelisca sp. (A)	1.2 (2.1)	*Glycinde solitaria* (P)	4.0 (1.4)
11-20-91 (07)	*Spiophanes bombyx* (P)	31.5 (14.9)	*Paraprionospio pinnata* (P)	7.0 (4.2)
	Paraonidae (P)	2.0 (0.0)	*Mediomastus ambiseta* (P)	4.5 (2.1)
	Rhepoxynius epistomus (A)	1.5 (2.1)	*Spio* sp. (P)	1.0 (0.0)
	Mediomastus ambiseta (P)	1.0 (0.0)	*Spiophanes bombyx* (P)	0.5 (0.7)
	Sabellaridae (P)	1.0 (1.4)	*Streblospio benedicti* (P)	0.5 (0.7)
	Tellinidae juveniles (B)	1.0 (1.4)	*Ampelisca* sp. (A)	0.5 (0.7)
3-3-92 (08)	*Spiophanes bombyx* (P)	25.0 (4.2)	*Spiophanes bombyx* (P)	19.0 (0.7)
	Mediomastus ambiseta (P)	2.5 (3.5)	*Mediomastus ambiseta* (P)	5.5 (3.5)
	Acteocina canaliculata (G)	2.5 (2.1)	*Tellina agilis* (B)	3.0 (1.4)
	Streblospio benedicti (P)	2.5 (2.1)	*Streblospio benedicti* (P)	2.5 (2.1)
	Spio sp. (P)	2.5 (0.7	*Ensis directus* (B)	1.5 (0.7)
	Tellina agilis (B)	2.0 (2.0)	*Mulinia lateralis* (B)	1.5 (0.7)

Date (Cruise #)	Area: **Control**	mean (sd)	**Mining Pit**	mean (sd)
9-10-92 (09)	*Spiophanes bombyx* (P)	5.8 (4.9)	*Paraprionospio pinnata* (P)	2.4 (1.7)
	Rhepoxynius epistomus (A)	5.3 (1.5)	*Glycera americana* (P)	1.6 (0.5)
	Ampelisca sp. (A)	3.0 (0.8)	*Spiophanes bombyx* (P)	1.6 (3.0)
	Amphioxus sp. (U)	2.0 (0.8)	Cirratulidae (P)	1.4 (1.5)
	Paraonidae (P)	1.3 (1.0)	*Mediomastus ambiseta* (P)	1.4 (2.2)
	Cirratulidae (P)	1.0 (0.8)	*Sigambra tentaculata* (P)	1.4 (2.2)
			Loimia meduas (P)	1.4 (2.6)
8-11-93 (11)	*Mediomastus ambiseta* (P)	16.0 (10.4)	*Mediomastus ambiseta* (P)	13.3 (8.7)
	Spiophanes bombyx (P)	13.5 (11.3)	*Acteocina canaliculata* (G)	4.0 (6.7)
	Acteocina canaliculata (G)	9.0 (1.6)	Cirratulidae (P)	3.0 (4.1)
	Glycinde solitaria (P)	3.5 (2.1)	*Ampelisca* sp. (A)	2.3 (1.0)
	Paraonidae (P)	3.5 (1.7)	Terebellidae (P)	1.5 (1.0)
	Ampelisca sp. (A)	3.3 (2.6)	*Spiophanes bombyx* (P)	1.5 (3.0)
8-25-94 (13)	Paronidae (P)	5.8 (2.5)	*Sabellaria vulagaris* (P)	28.0 (62.6)
	Acteocina canaliculata (G)	4.8 (3.0)	*Paraprionospio pinnata* (P)	17.4 (9.3)
	Spiophanes bombyx (P)	3.8 (2.1)	*Acteocina canaliculata* (G)	11.6 (10.4)
	Amphioxus sp. (U)	3.0 (2.9)	*Mediomastus ambiseta* (P)	11.0 (5.5)
	Mediomastus ambiseta (P)	3.0 (2.9)	*Streblospio benedicti* (P)	10.8 (13.6)
	Phoronida	2.0 (2.8)	Caprellidae (A)	9.8 (21.4)

Most of the species found abundantly within the control area were less abundant in the mining pit through the end of the study (Table 5). Collections from the pit through the November 1991 sampling were overwhelmingly dominated by the spionid polychaete *Paraprionospio pinnata*. Other dominants included *Mediomastus ambiseta* and the spionid *Streblospio benedicti*. Four of the species dominating collections from the mining pit in March 1992 were also dominants in control areas (i.e. the polychaetes *Spiophanes bombyx, Mediomastus ambiseta* and *Streblospio benedicti* and bivalve *Tellina agilis*). After March 1992, the dominant species included the polychaetes *Paraprionospio pinnata* and *Mediomastus ambiseta*, as well as the gastropod *Acteocina canaliculata*. During August 1994, the polychaete *Sabellaria vulgaris* was among the dominants recorded in the mining pit.

Camera Survey Results

Throughout the study, control stations were characterized by the presence of sand sediments (Tables 7 and 8, Appendices I and II). The dominant surface features were bedforms, shells of the bivalves *Ensis directus* and *Mulinia lateralis*, and small polychaete tubes (Figure 12). Tubes of the large infaunal polychaete *Diopatra cuprea* were infrequently observed. Small feeding pits were abundant in the study area prior to the onset of dredging (June 1990). Fecal mounds or coils, indicative of feeding activities of larger organisms, were common in photographs from November 1990, May 1991 and November 1991 (Figure 12).

Sediments within the mining pit consisted of layered mixtures of mud and sand throughout the duration of sampling (Table 6, Figure 13, Appendix I). Small bedforms were present on most sampling dates, but were less common in the pit than in the surrounding control area. Small mud clasts at the sediment surface were observed most commonly during the first few cruises following dredging (August, September and November 1990). The tubes of small, opportunistic species such as the polychaete *Paraprionospio pinnata* and amphipod *Ampelisca* sp. were common surface features in photographs from August 1990 through August 1994. Tube densities were highest in May 1991. Features such as feeding voids and animal burrows, indicative of subsurface sediment reworking by large infauna, were abundant later in the study. This suggests a successional shift in the community that was not apparent in other analyses. Surface and profile photographs show that the blue crab, *Callinectes sapidus*, was abundant in the mining pit (observed in 10-11% of photographs) during November 1990 (Figure 13). Crab tracks in the soft surface sediments were common on this date (Figure 13).

Table 6. Summary of features reported for SPI profile photographs from the Buckroe sand-mining site.

Area/Date	cruise	total no. of photos	percent of photographs with these features:										
			sand	mud	shell	bedforms	clasts	layered sediment	tubes	mounds or coils	voids	burrows	blue crabs
Control													
06/14/90	(01)	22	100	0	100	100	0	0	59	0	0	0	0
08/23/90	(02)	10	100	10	70	90	20	0	20	0	0	0	0
09/20/90	(03)	11	100	8	27	90	8	8	18	0	0	0	0
11/19/90	(04)	9	100	0	11	77	0	0	11	0	0	0	0
02/19/91	(05)	6	100	0	0	100	0	0	0	0	0	0	0
05/30/91	(06)	11	100	9	18	0	0	0	18	18	9	0	0
11/20/91	(07)	13	100	8	15	54	0	8	15	31	0	8	0
03/03/92	(08)	13	100	0	0	61	0	8	0	0	0	0	0
09/10/92	(09)	12	100	0	17	50	0	0	42	8	0	0	0
02/03/93	(10)	16	100	0	31	81	0	0	63	0	0	0	0
08/11/93	(11)	12	100	0	33	58	0	0	8	8	17	0	0
02/28/94	(12)	16	100	0	69	81	0	0	19	0	0	0	0
08/24/94	(13)	16	100	0	81	44	0	0	44	0	6	0	0
02/28/95	(14)	16	100	0	56	87	0	0	13	0	6	0	0
		median	100	0	29	79	0	0	18	0	0	0	0
		range	100	0-10	0-100	0-100	0-20	0-8	0-63	0-31	0-17	0-8	0

Table 6. continued

Area/Date	cruise	total no. of photos	percent of photographs with these features:										
			sand	mud	shell	bedforms	clasts	layered sediment	tubes	mounds or coils	voids	burrows	blue crabs
Mining Pit													
08/23/90	(02)	10	90	100	0	20	20	80	20	0	0	0	0
09/20/90	(03)	11	100	100	0	36	36	64	0	0	0	8	0
11/19/90	(04)	10	100	90	0	40	20	80	30	0	0	0	10
02/19/91	(05)	10	100	80	30	20	0	30	0	0	0	0	0
05/30/91	(06)	9	77	55	11	0	11	33	55	0	0	0	0
11/20/91	(07)	13	100	77	15	23	0	54	8	8	8	8	0
03/03/92	(08)	14	78	71	14	21	0	50	29	0	0	0	0
09/10/92	(09)	16	100	69	6	19	0	63	31	0	19	6	0
02/03/93	(10)	20	100	75	25	65	0	60	0	0	5	15	0
08/11/93	(11)	17	100	94	0	6	0	47	0	0	47	59	0
02/28/94	(12)	20	100	90	15	10	0	80	0	0	25	20	0
08/24/94	(13)	20	100	40	40	25	0	35	15	0	10	5	0
02/28/95	(14)	17	100	94	6	6	0	82	6	0	23	6	0
		median	100	80	11	20	0	60	8	0	8	6	0
		range	77-100	40-100	0-40	0-65	0-36	0-82	0-55	0-8	0-47	0-59	0-10

Table 7. Summary of features reported for SPI surface photographs from the Buckroe sand-mining site during 1990.

Area/Date	cruise	total no. of photos	percent of photographs with these features: bedforms	shell	tubes	feeding pits	mounds	tracks	blue crabs
Control									
06/14/90	(01)	58	91	93	98	29	3	0	0
09/20/90	(03)	27	96	100	100	11	0	4	0
11/19/90	(04)	37	97	92	92	3	5	3	0
Mining Pit									
09/20/90	(03)	4	0	0	25	50	0	0	0
11/19/90	(04)	35	71	49	80	0	6	49	11

Figure 12. Surface and profile photographs from control stations at Buckroe sand-mining site. (a) surface photograph from June 1990 showing bedforms, shell fragments, feeding pits (small circular depressions) and tubes of cf. spionid polychaetes or phoronids; (b) surface photograph from November 1990 with bedforms and shell of *Ensis directus*; (c) profile photograph from November 1990 showing bedforms; (d) profile photograph from November 1991 showing surface fecal coil - evidence of subsurface deposit feeding. Area of each photograph is approximately 15 x 20 cm.

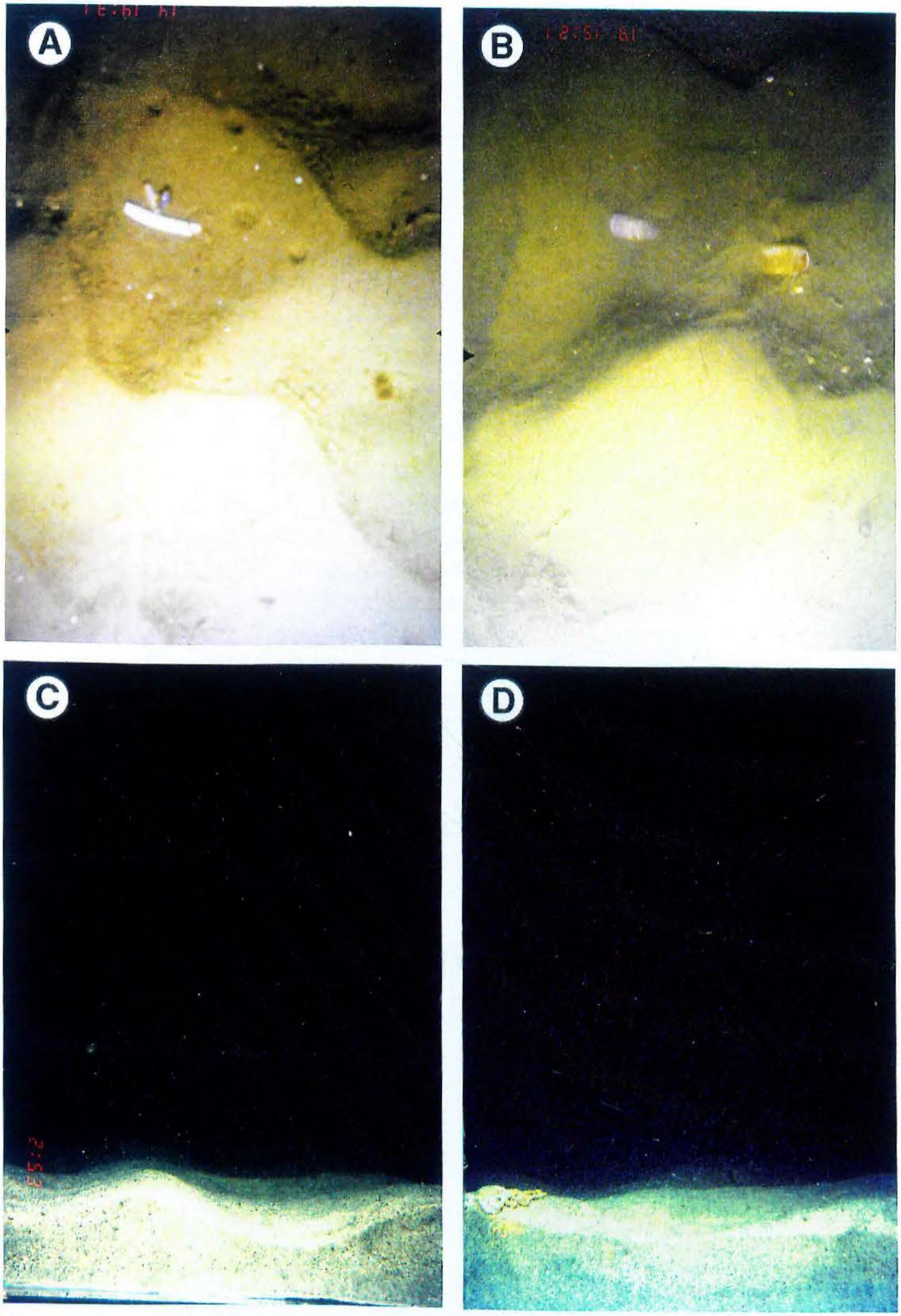


Figure 12

Figure 13. Surface and profile photographs from within the Buckroe sand mining pit. (a) Surface photograph from November 1990 showing small bedforms, tracks in the soft surface sediment and a buried blue crab *Callinectes sapidus* (red claw is visible); (b) profile photograph from March 1992 showing soft, muddy surface sediments and subsurface layering of mud and sand; (c) profile photograph from November 1990 showing a blue crab caught by the camera prism; (d) profile photograph from March 1995 showing sandy surface sediments and subsurface layering of mud and sand within the mining pit at the end of the study. Area of each photograph is approximately 15 x 20 cm.

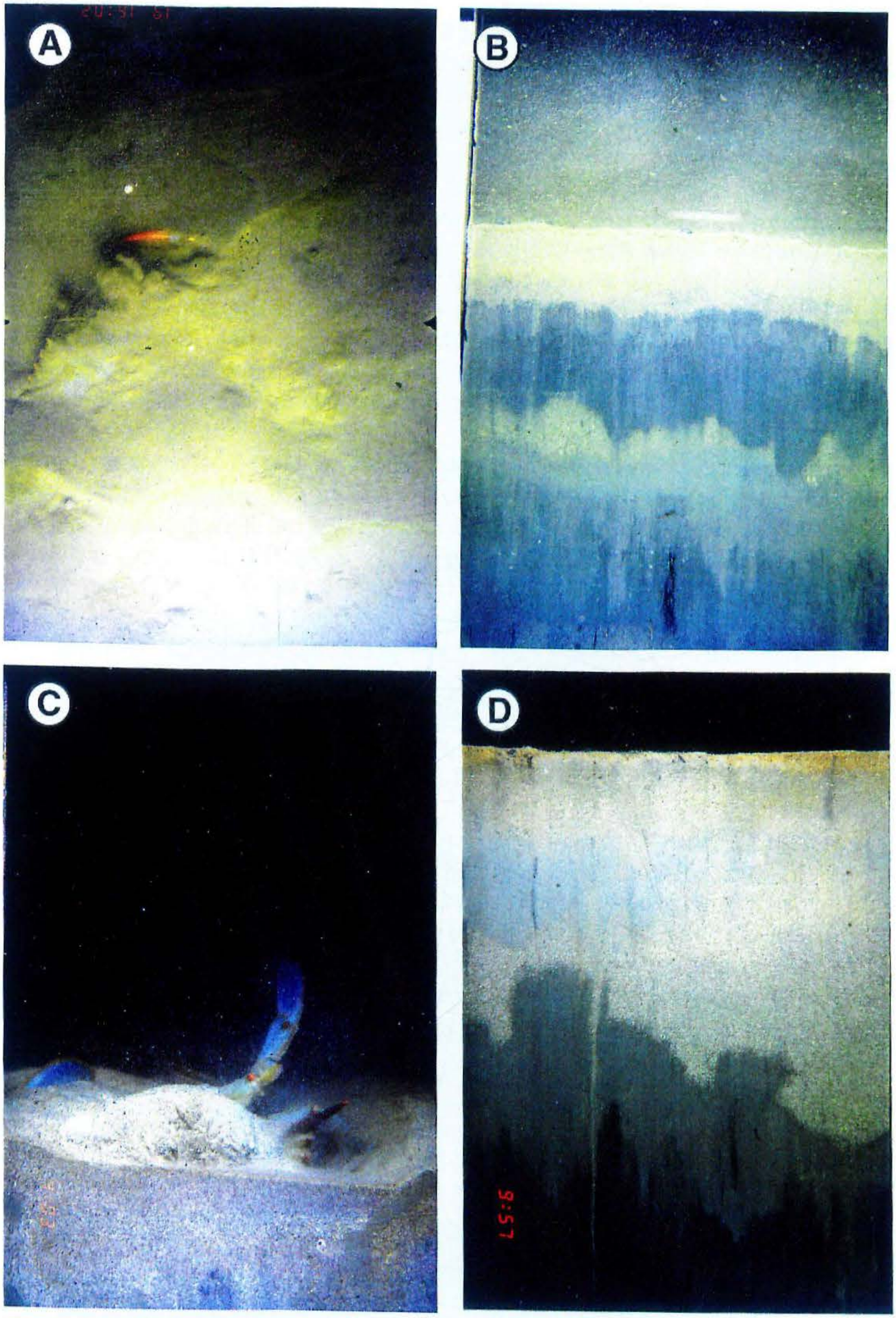


Figure 13

Benthic Index of Biotic Integrity (B-IBI)

The B-IBI scoring criteria for the polyhaline sand habitat were applied to collections from the control area - bottom sediments at these stations were nearly pure sand. For the mining pit collections, scoring criteria for both polyhaline sand and polyhaline mud habitats were applied for the following reasons. For B-IBI evaluations, sediments are considered to be within the mud category if they contain more than 40 % silt and clay (Weisburg et al. in press). The SPI analyses (Table 6 and 7, Appendices I and II) indicate a preponderance of muddy sediments at the surface in the mining pit during much of the study, but there was some spatial variability within the pit itself, sediment was often in distinct layers and sand was observed in the surficial layers towards the end of the study period (Figure 13). The calculated B-IBI values for the control and mining pit macrobenthic collections are shown in Figure 14 and it can be seen that there are only minor differences in the B-IBI values for the mining pit calculated with the two different sets of metrics.

Collections from cruise 2 (August 1990), the period immediately after dredging, show the greatest difference between control and mining pit B-IBI values. The mean value for the control site exceeds 4 while the mining pit, calculated by either set of criteria averages less than 3. B-IBI values calculated for the mining pit exceed the control region for cruises 9 and 11 (September 1992 and August 1993, respectively). For cruise 13 (August 1994), the B-IBI values calculated for the mining pit collections are slightly below 3. Collections on this date had high abundances of small surface-dwelling polychaetes, especially *Paraprionospio pinnata* and *Sabellaria vulgaris*, and as a result scored low for the abundance metric.

Crab Surveys

All crabs captured during the dredging surveys were adult females. In 1991, total crab densities were significantly higher in the pit relative to the control area ($t = 7.06$, $p < 0.001$, d.f. = 10). Although trends were similar in subsequent studies, differences were not significant. Both living and dead crabs were encountered in dredge tows from control and borrow pit areas (Figure 15). Dead crabs comprised a relatively high percentage of total crabs caught in 1991, particularly in the mining pit.

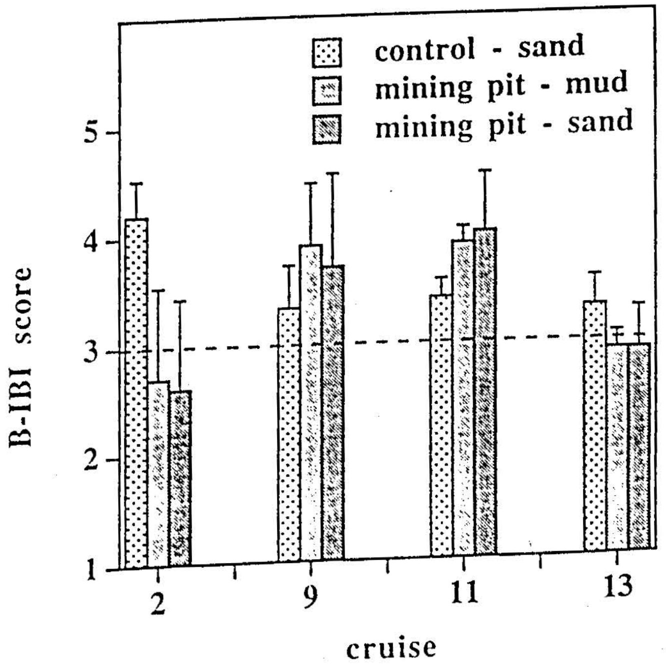


Figure 14. Benthic Index of Biotic Integrity values for control and mining pit habitats at the Buckroe sand-mining site.

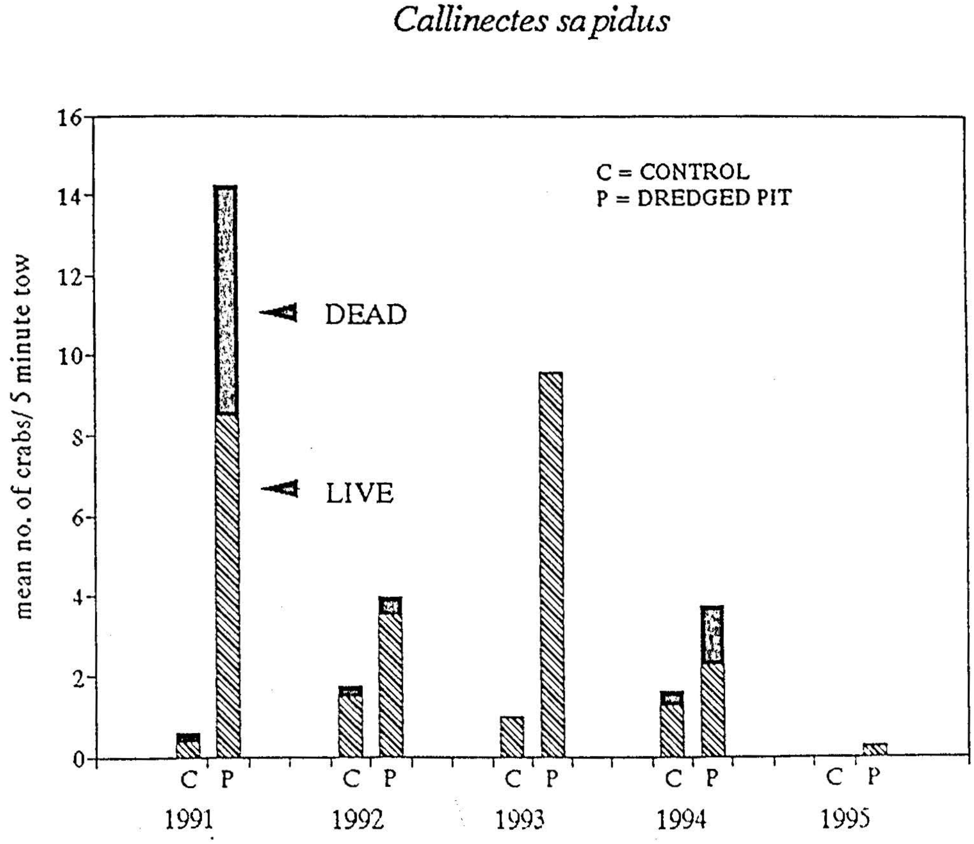


Figure 15. Abundance of overwintering blue crabs, *Callinectes sapidus*, at the Buckroe study site 1991 through 1994.

DISCUSSION

Sand-mining activities at the Buckroe site on Thimble Shoal produced a small pit with maximum overlying water depth increases of approximately 3 meters relative to the surrounding natural bottom. There is some indication that the pit volume may be decreasing, but overall the pit stability has been somewhat surprising given the expected levels of hydrodynamic activity in this region of the bay. Profile and surface photographic surveys show that sediments within the pit have, particularly during summer months, been finer than those in surrounding control areas, usually consisting of layered mixtures of sand and mud. The absence of bedforms in many photographs from within the pit during the summer months indicates that physical sediment reworking generally is lower than in the surrounding control area where bedforms were ubiquitous.

Water quality parameters were not monitored in the mining pit. Water stagnation and resultant decreases in water quality, potentially important factors influencing faunal recovery in mining pits (Boesch and Rackley 1974, Diaz and Boesch 1976), are unlikely given the hydrodynamic regime on Thimble Shoal (Wright et al. 1987, Linden 1991). We've seen no evidence in the faunal recovery dynamics of any water quality impacts in the pit relative to the surrounding control regions.

Faunal recolonization of the mining pit was rapid. Macrobenthic organisms were abundant within the pit on the first sampling date following cessation of dredging activities (i.e. less than 1 month later). Significant depressions in faunal abundances relative to control stations were observed only on the sampling dates immediately post-dredging and 1 month later. No significant differences in biomass were observed in pit collections relative to those from the control area. The within-sediment depth distributions of macrobenthos, an indication of availability to fish and crustacean predators, showed no changes that could be attributed to the dredging activity. The Benthic Index of Biotic Integrity suggests that there is little difference in the 'health' of the pit and control areas.

Macrobenthic community composition was strongly influenced by the dredging activity. The primary species dominating within the pit (i.e. the polychaete *Paraprionospio pinnata*) was rare in collections from control stations. *Paraprionospio pinnata* is an important component of benthic communities throughout the lower Chesapeake Bay at depths exceeding 5 meters (e.g. Boesch 1973, Schaffner 1990). Species dominating in collections from control stations (e.g. *Acteocina canaliculata, Spiophanes bombyx*) generally were rare or absent in the pit until March 1992. The significance of the observed shifts in community composition to benthic predators are unclear. In their previous study of this region, Kimball et al. (1989) found that fish predators collected in May 1988 had diets dominated by smaller fish or motile, epibenthic crustaceans. Similar patterns of prey utilization by demersal fish predators were observed during June 1989 in the deeper 'Tail of the Horseshoe' region of the bay mouth by Hobbs and Schaffner (1990). However, in the latter study some predators also consumed small benthic crustaceans, molluscs and annelids. It is interesting to note that *Paraprionospio pinnata* is an important food item in the diet of the spot *Leiostomus xanthurus* in the Chesapeake Bay (Pihl et al. 1992). Thus it seems unlikely that the resource value of the benthos in trophic support of fisheries was negatively impacted. At least one species, the spot, was potentially favored by changes in the benthic community composition.

Effects of previous sand-mining activities conducted in the lower bay-Hampton Roads region, for fill material for Newport News Shipyard and the construction of the second Hampton Roads bridge-tunnel, on benthic community structure were investigated by Boesch and Rackley (1974) and Diaz and Boesch (1976). These authors found negative impacts on community structure, but did not evaluate changes in resource value (e.g. they did not measure biomass or consider potential availability of benthos to predators). They further noted the high potential for sand excavation pits to act as traps for fine sediments and epifaunal species such as hydroid and bryozoans. The Buckroe sand-mining pit did act as a trap for fine sediment, but there was no evidence that the pit acted as a significant trap for epifaunal organisms such as hydroids.

Dredging surveys did show that densities of the blue crab were significantly enhanced in the pit relative to surrounding control areas during the first year following dredging. Comparisons of crab densities observed during this study with results of previous studies in lower Chesapeake Bay (Table 8) further demonstrate this enhancement.

In summary, it appears that this limited sand-mining activity on Thimble Shoal, an area of the lower Chesapeake Bay characterized by relatively low resource value (e.g. Kimball et al. 1989), did not have negative impacts on benthic resource value or biotic integrity. Conversely, some enhancement of benthic resource value, especially through the provision of habitat for the blue crab, *Callinectes sapidus*, was apparent during the post-dredging period. The effects of the pit on community composition and crab distribution were most apparent during the first 13 months following dredging. The 'pit effect' on benthic community composition has not diminished, largely because the pit has remained intact throughout the study period.

Table 8. A comparison of crab densities (no. of crabs/5 minutes of towing/4 feet of dredge width) at the study site during 1991 and 1992 with similarly collected data for other habitats in lower Chesapeake Bay.

Region	no. of tows	mean (sd)	range
Lower Chesapeake Bay			
Channel*	15	5.7 (6.7)	0-26
Basin*	43	9.1 (7.5)	0-34
Shoal*	36	1.8 (3.4)	0-13
Thimble Shoal			
January 1986**	10	2.3 (1.9)	0-16
February 1991			
Control	8	0.4 (0.5)	0-1
Pit	4	9.5 (3.8)	4-14
March 1992			
Control	4	1.2 (1.2)	0-3
Pit	4	2.7 (1.5)	1-5

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* from Schaffner and Diaz (1988)

** from Kimball et al. (1989)

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APPENDIX I

Thimble Shoal Sand-Mining Study SPI Analysis - Profile Photographs

Key:

Station (Sta., e.g. HP2-1): HP = study code, 2 = station, 1 = cruise

Stations 1 through 4 are controls
Stations 5 through 8 are within mining pit

D-max = maximum depth of penetration of prism
D-min = minimum depth of penetration of prism
R = roughness height [(D-max) - (D-min)]

Sediment types are:
S = sand, SH = shell; M = mud

Other features are:
B = bedforms
U = uneven or irregular surface
C = clasts
TF = less than 10 tubes
TS = ca. 10-20 tubes
DT = detritus or floc
FC = fecal coil
FP = fecal pellets
L = subsurface sediment layering
V = void

Sta.	Rep.	Time	D-max	D-min	R	Sed.	Surface	Subsurface	Other
Cruise 1 6-14-90									
HP1-1	A	1332	4.3	2.3	2.0	S,SH	B		
HP1-1	B	1333	3.0	2.1	0.9	S,SH	B		
HP1-1	C	1334	3.7	2.1	1.5	S,SH	B,TF		
HP2-1	A	1343	3.2	2.1	1.0	S,SH	B,TF		
HP2-1	B	1343	2.7	0.1	2.6	S,SH	B		
HP2-1	C	1345	2.7	1.7	1.0	S,SH	B,TF		phoronid type tubes
HP3-1	A	1352	3.4	1.6	1.8	S,SH	B		
HP3-1	B	1353	3.6	2.1	1.5	S,SH	B		
HP3-1	C	1353	1.7	1.2	0.5	S,SH	B		
HP4-1	A	1400	2.6	0.0	2.6	S,SH	B,TF		
HP4-1	B	1402	3.6	1.8	1.8	S,SH	B	?	
HP5-1	A	1408	3.6	1.4	2.2	S,SH	B,TF		
HP5-1	B	1409	3.6	0.0	3.6	S,SH	B,DT		Onuphid tube
HP5-1	C	1410	3.1	2.1	1.0	S,SH	B		
HP6-1	B	1419	4.5	0.9	3.7	S,SH	B,TF		spionids?
HP6-1	C	1419	3.7	1.7	2.0	S,SH	B,TF		spionids?
HP7-1	A	1426	2.2	1.3	0.9	S,SH	B,TF		spionids?
HP7-1	B	1428	2.6	1.3	1.3	S,SH	B,TF		spionids?
HP7-1	C	1428	3.2	1.5	1.6	S,SH	B,TF		spionids?
HP8-1	A	1436	2.9	1.6	1.3	S,SH	B,TF		spionids?
HP8-1	B	1437	4.9	2.1	2.7	S,SH	B,TF		
HP8-1	C	1438	3.0	0.9	2.1	S,SH	B		hydroid
Cruise 2 8-23-90									
HP1-2	A	N/A	3.0	1.7	1.3	S,SH	B,DT		
HP1-2	C		2.6	1.2	1.4	S,SH	B		
HP2-2	A		6.2	4.3	1.9	S,M	U,C		disturbed by dredging?
HP2-2	B		6.6	5.1	1.5	S	B,C		
HP3-2	A		1.7	0.0	1.7	S	B		
HP3-2	B		2.6	0.6	2.0	S,SH	B		onuphid tube w/ hydroid
HP3-2	C		3.4	1.9	1.5	S,SH	B		
HP4-2	A		4.0	1.3	2.7	S,SH	B,DT		
HP4-2	B		2.7	0.9	1.9	S,SH	B,TF		
HP4-2	C		2.6	1.0	1.5	S,SH	B,TF		
HP5-2	A		13.7	12.9	0.9	M,S		L	
HP5-2	B		14.6	13.9	0.7	M,S	U	L	
HP5-2	C		4.9	2.9	2.0	S,M	U,TF	L	mud layer at interface
HP6-2	A		7.5	6.3	1.2	S,M	U,B?,C	L	mud layer at interface
HP6-2	B		0.0	0.0	0.0				
HP6-2	C		4.3	2.3	2.0	M	U,C		
HP7-2	A		5.6	4.3	1.3	S,M	B,U		mud layer at interface
HP7-2	B		8.1	7.3	0.9	M,S	U,C	L	mud over sand
HP7-2	C		13.7	13.3	0.4	M,S	U	L	mud over sand, small burrow
HP8-2	A		16.3	15.4	0.9	S,M	TS	L	
HP8-2	B		0.0	0.0	0.0				
HP8-2	C		10.3	8.6	1.7	S,M	U	L	

Sta.	Rep.	Time	D-max	D-min	R	Sed.	Surface	Subsurface	Other
Cruise 3 9-20-90									
HP1-3	A	1509	3.2	1.7	1.5	S	B		
HP1-3	B	1510	5.1	3.3	1.9	S	B		
HP1-3	C	1515	2.3	0.9	1.5	S	B,TF		
HP1-3	D	1519	2.3	1.5	0.9	S	B		
HP2-3	A	1521	2.1	0.0	2.1	S	B		
HP2-3	C	1524	3.0	1.7	1.3	S,SH	B		
HP3-3	A	1531	2.6	1.9	0.7	S,SH	B		
HP3-3	B	1537	10.3	9.9	0.4	M,S	U,C	L	mud over sand
HP3-3	C	1539	4.8	3.4	1.4	S	B,TF		
HP4-3	A	1546	2.7	0.9	1.9	S,SH	B		
HP4-3	C	1551	2.8	1.1	1.7	S	B		
HP5-3	A	1557	14.6	12.3	2.3	M,S	U,C	L	mud over sand
HP5-3	B	1558	18.9	17.1	1.7	M,S	U,C	L	mud over sand
HP5-3	C	1600	5.6	3.9	1.7	S,M	B?		mud at interface
HP6-3	A	1605	9.8	9.0	0.8	S,M		L	thin subsurface mud layer
HP6-3	C	1608	9.2	7.7	1.5	S,M	B?	L	sand over mud
HP7-3	A	1612	8.5	6.9	1.6	S,M	B?		mud at interface
HP7-3	B	1614	11.7	11.1	0.6	M,S	U,C	L	mud over sand
HP7-3	C	1619	8.2	7.5	0.8	S,M	U		mud at interface
HP7-3	D	1638	4.2	2.7	1.5	S,M	B?	L	thin subsurface mud layer
HP8-3	A	1631	13.2	11.8	1.4	M,S	U	L,burrow	mud/sand layers
HP8-3	B	1633	8.6	7.5	1.1	S,M	U,C		
Cruise 4 11-19-90									
HP1-4	B	1453	2.6	0.9	1.7	S	B		
HP1-4	C	1455	2.1	0.4	1.7	S	B		
HP2-4	A	1504	4.9	4.2	0.7	S	B		
HP2-4	C	1507	2.9	1.5	1.5	S	B		
HP3-4	A	1519	1.0	0.5	0.5	S			
HP3-4	B	1520	1.7	0.4	1.3	S	B		
HP3-4	C	1521	3.6	2.7	0.9	S			
HP4-4	A	1531	3.2	1.7	1.5	S	B		
HP4-4	B	1532	5.1	3.9	1.3	S,SH	B,TF		
HP5-4	A	1542	3.1	1.5	1.6	S	B		
HP5-4	B	1543	4.9	1.1	3.8	S,M	B,TF	L	mud layer,large tube
HP5-4	C	1543	4.7	2.1	2.6	S,M	B	L	mud layer
HP6-4	A	1554	11.5	9.7	1.8	S,M	U,TF	L	
HP6-4	B	1554	9.9	9.0	0.9	M,S	B,TF	L	ampeliscid amphipod tubes
HP6-4	C	1555	0.0	0.0	0.0				
HP7-4	A	1603	6.0	4.6	1.4	S,M			blue crab
HP7-4	B	1603	8.0	7.5	0.4	S,M		L	
HP7-4	C	1605	6.9	5.6	1.3	S,M	C	L	
HP8-4	A	1616	9.7	8.8	0.9	S,M		L	
HP8-4	C	1616	6.2	5.5	0.7	S,M	C	L	

Sta.	Rep.	Time	D-max	D-min	R	Sed.	Surface	Subsurface	Other
Cruise 5 2-19-91									
HP1-5	A	N/A	2.1	0.3	1.7	S	B		
HP2-5	A		1.6	0.0	1.6	S	B		
HP2-5	B		2.9	2.5	0.4	S	B		
HP3-5	A		2.1	1.3	0.9	S	B		
HP3-5	C		3.3	1.5	1.8	S	B		
HP4-5	A		2.5	1.2	1.3	S	B		
HP5-5	B	1129	3.2	2.3	0.9	S,SH	B		
HP5-5	C	1131	2.6	1.5	1.1	S	B		
HP6-5	A	1139	2.9	1.8	1.1	S,M		L	
HP6-5	B	1147	6.4	5.1	1.3	S,M	U	L	
HP6-5	C	1151	8.8	8.3	0.5	S,M		L	sand/mud layers
HP6-5	D	1153	5.1	4.5	0.6	S,M	U		
HP7-5	A		2.3	1.5	0.8	S,M			
HP7-5	B		2.3	1.2	1.1	S,M	U		
HP8-5	A		9.4	8.0	1.5	S,SH,M	U		
HP8-5	B		6.6	5.5	1.1	S,M,SH	U		
Cruise 6 5-30-91									
HP1-6	A	1738	4.3	0.9	3.4	S	TF,FP	V	
HP1-6	B	1745	3.0	2.1	0.9	S,SH			anemone
HP2-6	A	1750	5.1	1.1	4.0	S			large mound
HP2-6	B	1751	3.3	2.7	0.6	S,M	U		
HP2-6	C	1752	2.7	1.9	0.9	S	U		
HP3-6	A	1757	2.3	1.4	0.9	S			
HP3-6	B	1757	3.2	0.9	2.3	S	U		
HP3-6	C	1758	2.5	1.5	1.0	S	U		mound (gray)
HP4-6	A	1803	2.6	0.9	1.7	S			
HP4-6	B	1804	1.9	1.4	0.5	S			
HP4-6	C	1805	3.7	2.6	1.1	S,SH	U,TF		
HP5-6	A	1810	3.1	2.7	0.4	S	TS		
HP5-6	B	1812	3.2	1.9	1.3	S	U		
HP6-6	A	1816	1.5	0.9	0.6	S			
HP6-6	B	1817	0.0	0.0	0.0				
HP6-6	C	1818	8.6	7.3	1.3	S,M	U,TS	L	
HP7-6	A	1821	3.2	1.7	1.5	S	U		
HP7-6	B	1822	7.3	6.4	0.9	M,S	U	L	anoxic mud over sand
HP7-6	C	1823	6.2	5.5	0.7	M,S	U,TS	L	mud over sand
HP8-6	A	1829	6.0	5.1	0.9	M,SH	U,TS		mud over shell
HP8-6	B	1830	5.6	4.3	1.3	M	C,TS		hydroids

Sta.	Rep.	Time	D-max	D-min	R	Sed.	Surface	Subsurface	Other
Cruise 7	11-20-91								
HP1-7	A	1409	6.8	3.9	2.9	S,SH	U	burrow	large mound
HP1-7	B	1422	3.3	1.7	1.6	S	B,FC		
HP1-7	C	1423	2.9	1.7	1.2	S	B		
HP2-7	A	1451	2.9	1.9	1.0	S			
HP2-7	B	1452	3.2	2.3	0.9	S	U,FC		large coil
HP2-7	C	1453	5.0	3.9	1.0	S	U		
HP3-7	A	1458	3.4	2.6	0.9	S	B		
HP3-7	B	1459	3.1	1.8	1.3	S,SH	B,TF		
HP3-7	C	1500	4.5	2.4	2.1	S	B,U		mound, hydroid, root
HP4-7	A	1506	3.2	1.9	1.3	S	B		
HP4-7	B	1507	3.3	1.6	1.6	S	U,TF		
HP4-7	C	1508	3.6	1.2	2.4	S	B		
HP4-7	D	1510	3.3	2.7	0.7	S,M	U	L	thin mud layer
HP5-7	A	1517	0.0	0.0	0.0				
HP5-7	B	1518	0.0	0.0	0.0				
HP5-7	C	1519	5.9	4.8	1.1	M,S	U		large tube
HP6-7	A	1525	6.4	4.9	1.5	S	B,FP		
HP6-7	B	1526	3.8	2.0	1.8	S	B		
HP6-7	C	1527	5.4	4.6	0.8	S,SH,M	U	L	thin mud layer
HP7-7	A	1538	6.8	6.5	0.3	S,M,SH		L	mud layer
HP7-7	B	1539	11.3	10.7	0.6	M,S		L	mud/sand layers
HP7-7	C	1540	9.0	8.0	1.0	M,S	U	L	mud/sand layers
HP8-7	A	1548	0.0	0.0	0.0				
HP8-7	B	1549	6.6	5.7	0.9	S,M	U	L	mud layer
HP8-7	C	1550	2.9	1.8	1.1	S,M	B	L	mud layer
HPC-7	A	1534	14.6	14.6	0.0	M,S		burrow, void	
HPC-7	B	1554	13.0	13.0	0.0				
HPC-7	C	1555	6.6	6.2	0.4	S	U		
HPC-7	D	1557	5.5	4.5	1.0	S,M	U		
HPC-7	E	1556	4.5	3.4	1.0	S,M	U	L	mud layer, mound

Sta.	Rep.	Time	D-max	D-min	R.	Sed.	Surface	Subsurface	Other
Cruise 8	3-3-92								
HP1-8	A	1057	2.3	0.9	1.4	S	U		
HP1-8	B	1100	5.9	4.2	1.7	S			
HP1-8	C	1101	3.8	2.1	1.7	S	B		
HP1-8	D	1102	5.1	2.1	3.0	S	B		
HP2-8	A	1120	1.0	0.8	0.3	S			
HP2-8	B	1123	2.7	1.8	0.9	S	B		hydroid
HP2-8	C	1124	2.9	1.8	1.1	S	B		
HP3-8	A	1128	2.7	1.5	1.3	S			
HP3-8	B	1130	2.5	0.9	1.5	S			
HP3-8	C	1131	2.1	0.9	1.2	S	B		mud layer at surface
HP4-8	A	1137	2.7	0.8	1.9	S	B		
HP4-8	B	1138	2.6	0.9	1.7	S	B		
HP4-8	C	1139	2.4	1.4	1.0	S	B,FP		
HP5-8	A	1147	15.7	15.7	0.0	M	TF		sand pockets
HP5-8	B	1150	13.6	13.3	0.3	M	TF	L	mud/sand layers
HP5-8	C	1152	1.7	1.7	0.0	M			large bryozoan and hydroid
HP6-8	A	1158	3.0	2.3	0.7	S	B		
HP6-8	B	1200	2.1	1.4	0.7	S,M	B	L	mud layer at surface
HP6-8	C	1201	2.6	1.9	0.7	S			
HP7-8	A	1209	8.0	7.0	0.9	S,SH	B	L	mud layer
HP7-8	B	1210	6.4	5.3	1.1	S,M	U	L	mud layer
HP7-8	C	1211	14.4	14.4	0.0	M,S		L	sand layer
HP7-8	D	1211	15.0	13.7	1.3	M,S	TF	L	mud/sand layers
HP7-8	E	1212	13.7	12.4	1.3	M,S	TF	L	mud/sand layers
HP8-8	A	1217	3.6	2.1	1.5	S,SH			
HP8-8	B	1221	7.3	6.2	1.1	S,M			mud layer at interface
HP8-8	C	1222	6.4	4.1	2.3	S,M			mud layer at interface

Station	Replicate	Time	D-max	D-min	R	Sediment	Surface	Subsurface	Other
Cruise 9	9-10-92								
HP1-9	A	1225	4.1	1.7	2.4	S	B		
HP1-9	B	1246	4.4	3.4	1.0	S	B,TF		
HP1-9	C	1247	6.5	3.9	2.6	S	U	void	large mound
HP2-9	A	1252	3.2	2.5	0.7	S, SH			
HP2-9	B	1254	3.5	2.6	0.9	S	U, TF		
HP2-9	C	1256	3.9	2.8	1.1	S, SH	U		
HP3-9	A	1301	3.6	2.4	1.2	S	B		
HP3-9	B	1306	3.9	2.5	1.4	S	U, TF		
HP3-9	C	1307	4.4	2.8	1.6	S	B		
HP4-9	A	1315	2.9	1.8	1.1	S	B		
HP4-9	B	1316	3.4	2.2	1.2	S	B, TF		
HP4-9	C	1318	4.3	2.9	1.4	S	U, TF		
HP5-9	A	1329	11.2	10.4	0.8	S,M		L	sand/mud layers
HP5-9	B	1331	6.4	5.6	0.8	S		void	
HP5-9	C	1335	10.1	9.1	1.0	S, M	U, DT	L	sand/mud layers
HP6-9	A	1339	21.3	21.3	0.0	S, M		burrow, L	mud layer
HP6-9	B	1344	6.2	4.4	1.8	S	B		large tube
HP6-9	C	1348	11.7	11.3	0.4	S, M	TF	L	sand/mud layers
HP7-9	A	1354	15.6	15.3	0.3	S, M	TF	void, L	sand/mud layers
HP7-9	B	1356	7.7	6.9	0.8	S, M	TF	L	mud layer
HP7-9	C	1357	5.3	4.7	0.6	S			
HP8-9	A	1359	4.7	3.7	1.0	S, SH	B		
HP8-9	B	1401	10.9	10.7	0.2	S, M	B, TF	L	sand/mud layers
HP8-9	C	1402	11.3	11.0	0.3	S, M	TF	L	large tube, sand/mud layers
HP8-9	D	1404	6.9	6.3	0.6	S		voids	
HP9-9	A	1408	16.8	15.0	1.8	S, M	U	L, void	sand/mud layers
HP9-9	B	1409	4.5	3.0	1.5	S			
HP9-9	C	1410	12.8	11.5	1.3	S, M	U	L	mud layer, large tube

Station	Replicate	Time	D-max	D-min	R	Sediment	Surface	Subsurface	Other
Cruise 9	9-10-92								
HP1-9	A	1225	4.1	1.7	2.4	S	B		
HP1-9	B	1246	4.4	3.4	1.0	S	B,TF		
HP1-9	C	1247	6.5	3.9	2.6	S	U	void	large mound
HP2-9	A	1252	3.2	2.5	0.7	S, SH			
HP2-9	B	1254	3.5	2.6	0.9	S	U, TF		
HP2-9	C	1256	3.9	2.8	1.1	S, SH	U		
HP3-9	A	1301	3.6	2.4	1.2	S	B		
HP3-9	B	1306	3.9	2.5	1.4	S	U, TF		
HP3-9	C	1307	4.4	2.8	1.6	S	B		
HP4-9	A	1315	2.9	1.8	1.1	S	B		
HP4-9	B	1316	3.4	2.2	1.2	S	B, TF		
HP4-9	C	1318	4.3	2.9	1.4	S	U, TF		
HP5-9	A	1329	11.2	10.4	0.8	S,M		L	sand/mud layers
HP5-9	B	1331	6.4	5.6	0.8	S		void	
HP5-9	C	1335	10.1	9.1	1.0	S, M	U, DT	L	sand/mud layers
HP6-9	A	1339	21.3	21.3	0.0	S, M		burrow, L	mud layer
HP6-9	B	1344	6.2	4.4	1.8	S	B		large tube
HP6-9	C	1348	11.7	11.3	0.4	S, M	TF	L	sand/mud layers
HP7-9	A	1354	15.6	15.3	0.3	S, M	TF	void, L	sand/mud layers
HP7-9	B	1356	7.7	6.9	0.8	S, M	TF	L	mud layer
HP7-9	C	1357	5.3	4.7	0.6	S			
HP8-9	A	1359	4.7	3.7	1.0	S, SH	B		
HP8-9	B	1401	10.9	10.7	0.2	S, M	B, TF	L	sand/mud layers
HP8-9	C	1402	11.3	11.0	0.3	S, M	TF	L	large tube, sand/mud layers
HP8-9	D	1404	6.9	6.3	0.6	S		voids	
HP9-9	A	1408	16.8	15.0	1.8	S, M	U	L, void	sand/mud layers
HP9-9	B	1409	4.5	3.0	1.5	S			
HP9-9	C	1410	12.8	11.5	1.3	S, M	U	L	mud layer, large tube

Station	Replicate	Time	D-max	D-min	R	Sediment	Surface	Subsurface	Other
Cruise 10	2-3-93								
HP1-10	A	1338	3.5	2.3	1.2	S, SH	B, FP, DT		
HP1-10	B	1341	2.6	1.5	1.1	S, SH	B, TF		
HP1-10	C	1342	3.1	1.2	1.9	S	B, TF		
HP1-10	D	1343	3.5	2.2	1.3	S	B, TF		
HP2-10	A	1347	4.0	1.0	3.0	S	B		
HP2-10	B	1348	4.0	2.1	1.9	S, SH	B, TF		
HP2-10	C	1349	3.2	1.6	1.6	S, SH	B		
HP2-10	D	1350	3.1	2.0	1.1	S	B		
HP3-10	A	1357	2.9	1.7	1.2	S	B		
HP3-10	B	1358	3.2	0.8	2.4	S	B, TF		
HP3-10	C	1359	2.6	0.8	1.8	S, SH	B, TS		
HP3-10	D	1400	3.1	2.2	0.9	S	TF		
HP4-10	A	1407	2.7	1.1	1.6	S	B, TF		
HP4-10	B	1408	2.5	1.9	0.6	S	TF		
HP4-10	C	1409	2.8	2.1	0.7	S			
HP4-10	D	1410	3.1	1.4	1.7	S	B, TF		
HP5-10	A	1414	20.3	19.7	0.6	S, M		L	sand/mud layers
HP5-10	B	1416	12.2	11.5	0.7	S, M	DT	L	sand/mud layers
HP5-10	C	1417	15.3	14.8	0.5	S,M		L	sand/mud layers
HP5-10	D	1419	6.6	6.2	0.4	S, SH			
HP6-10	A	1423	13.5	12.7	0.8	S, SH, M		L	sand/mud layers
HP6-10	B	1425	6.2	5.5	0.7	S, M	B		
HP6-10	C	1427	9.7	8.3	1.4	S, M	B	burrows	
HP6-10	D	1428	16.4	15.6	0.8	S, M		L	sand/mud layers
HP7-10	A	1431	8.9	7.3	1.6	S, M	B	L	sand/mud layers
HP7-10	B	1432	3.6	2.4	1.2	S, SH	B		
HP7-10	C	1433	6.5	5.3	1.2	S, SH	B, DT		
HP7-10	D	1434	4.4	2.9	1.5	S	B		
HP8-10	A	1437	15.4	14.8	0.6	S, M	B	L, burrow	sand/mud layers
HP8-10	B	1440	15.1	13.7	1.4	S, M	B	L	sand/mud layers
HP8-10	C	1441	9.6	8.8	0.8	S, SH	B		
HP8-10	D	1444	15.6	15.1	0.5	S, M		L	sand/mud layers
HP9-10	A	1346	18.1	16.6	1.5	S, M	B	L, void	sand/mud layers
HP9-10	B	1249	4.1	2.4	1.7	S, M	B		gastropod
HP9-10	C	1250	4.4	3.1	1.3	S, M	B		sand over mud
HP9-10	D	1252	5.6	4.5	1.1	S, M	B	burrow, L	mud at interface and in burrow

Station	Replicate	Time	D-max	D-min	R	Sediment	Surface	Subsurface	Other
Cruise 11	**8-11-93**								
HP1-11	A	1012	3.8	3.2	0.6	S, SH			
HP1-11	B	1017	4.3	3.6	0.7	S		void	
HP1-11	C	1019	3.8	2.9	0.9	S, SH			
HP2-11	A	1026	4.5	3.1	1.4	S	B		
HP2-11	B	1028	4.1	2.6	1.5	S	B		
HP2-11	C	1030	4.2	3.2	1.0	S	TF		
HP3-11	A	1035	4.2	2.9	1.3	S	B		
HP3-11	B	1037	4.7	2.4	2.3	S	B, DT	void	
HP3-11	C	1042	3.9	3.2	0.7	S, SH	B		
HP4-11	A	1049	4.2	3.2	1.0	S	B		
HP4-11	B	1051	4.1	2.7	1.4	S	B		
HP4-11	C	1053	5.1	3.1	2.0	S, SH			large mound
HP5-11	A	1059	8.7	7.1	1.6	S, M		L	sand/mud layers
HP5-11	B	1102	10.1	8.8	1.3	S, M		L	sand/mud layers
HP5-11	C	1104	7.3	6.1	1.2	S, M			hydroid
HP6-11	A	1112	10.9	9.5	1.4	S, M			burrow
HP6-11	B	1114	11.2	10.0	1.2	S, M	FP	L	sand/mud layers
HP6-11	C	1118	10.5	8.9	1.6	S, M	U		
HP6-11	D	1121	11.4	10.4	1.0	S, M	void		
HP7-11	A	1127	9.6	8.0	1.6	S, M		L	sand/mud layers
HP7-11	B	1129	11.1	10.1	1.0	S, M		L	sand/mud layers
HP7-11	C	1131	8.5	7.5	1.0	S, M		void,L	sand/mud layers
HP8-11	A	1137	8.5	7.5	1.0	S, M	B	voids	
HP8-11	B	1139	10.4	9.3	1.1	S, M	FP	void	
HP8-11	C	1142	13.8	12.5	1.3	S, M		voids	
HP9-11	A	1148	12.3	10.6	1.7	S, M		voids	
HP9-11	B	1153	13.3	11.8	1.5	S, M		L, voids	sand/mud layers
HP9-11	C	1157	8.8	7.8	1.0	S, M		L, void	sand/mud layers
HP9-11	D	1200	7.9	6.9	1.0	S			

Station	Replicate	Time	D-max	D-min	R	Sediment	Surface	Subsurface	Other
Cruise 12	2-28-94								
HP1-12	A	509	4.7	3.8	0.9	S	DT		
HP1-12	B	510	4.4	2.5	1.9	S	B		
HP1-12	C	511	4.9	4.5	0.4	S	B		
HP1-12	D	512	4.4	2.2	2.2	S, SH	B		
HP2-12	A	515	3.3	3.1	0.2	S, SH			
HP2-12	B	517	5.1	2.8	2.3	S, SH	B, TF		
HP2-12	C	518	3.1	1.7	1.4	S, SH	B		
HP2-12	D	520	3.8	2.4	1.4	S, SH	B		
HP3-12	A	524	3.2	2.2	1.0	S, SH	B, TF		
HP3-12	B	526	3.2	2.6	0.6	S, SH	B		
HP3-12	C	527	4.8	2.7	2.1	S, SH	B		
HP3-12	D	527	4.3	2.4	1.9	S, SH	B		
HP4-12	A	532	4.7	3.1	1.6	S, SH	B		
HP4-12	B	533	4.2	2.6	1.6	S	B		
HP4-12	C	534	4.2	2.3	1.9	S	U, TF		
HP4-12	D	535	4.5	3.3	1.2	S, SH	B		
HP5-12	A	541	5.3	3.9	1.4	S, M	B, DT	L	sand/mud layers
HP5-12	B	542	5.8	5.4	0.4	S, M	DT	L	sand/mud layers
HP5-12	C	544	6.0	5.7	0.3	S, M		L, burrow	sand/mud layers
HP5-12	D	545	11.9	11.4	0.5	S, M			
HP6-12	A	551	9.9	9.8	0.1	S, M		L, void	sand/mud layers
HP6-12	B	552	19.5	19.2	0.3	S, M	DT	L, voids	sand/mud layers
HP6-12	C	554	18.1	14.2	3.9	S, M	U, DT	L	sand/mud layers
HP6-12	D	554	11.5	9.9	1.6	S, M, SH	DT	L, void	sand/mud layers
HP7-12	A	600	17.1	16.8	0.3	S, M	DT	L	sand/mud layers
HP7-12	B	601	18.0	17.2	0.8	S, M	U	L	sand/mud layers
HP7-12	C	602	16.7	16.6	0.1	S, M	DT	L, burrow	sand/mud layers
HP7-12	D	603	19.0	18.8	0.2	S, M	U, DT	L	sand/mud layers
HP8-12	A	608	8.1	7.4	0.7	S, SH, M		L, burrow	sand/mud layers
HP8-12	B	610	7.9	7.0	0.9	S, M	U, DT	void	large hydroid
HP8-12	C	611	4.5	3.7	0.8	S	pit, DT		hydroid, plant stem
HP8-12	D	611	4.3	2.5	1.8	S, SH	B, TF		
HP9-12	A	617	9.8	9.4	0.4	S, M		L	sand/mud layers
HP9-12	B	620	13.3	12.9	0.4	S, M	DT	L, voids	sand/mud layers
HP9-12	C	621	12.4	11.5	0.9	S, M		burrow, L	sand/mud layers
HP9-12	D	621	9.4	9.0	0.4	S, M		L	sand/mud layers

Station	Replicate	Time	D-max	D-min	R	Sediment	Surface	Subsurface	Other
Cruise 13	8-24-94								
HP1-13	A	906	15.8	15.2	0.6	S	B		
HP1-13	B	910	4.2	3.4	0.8	S, SH			
HP1-13	C	912	5.2	3.8	1.4	S, SH	B, TF		
HP1-13	D	913	4.4	4.1	0.3	S, SH	B		
HP2-13	A	918	5.6	3.8	1.8	S, SH	B, TF		
HP2-13	B	920	3.8	2.8	1.0	S, SH	B		
HP2-13	C	921	4.9	4.7	0.2	S, SH			
HP2-13	D	922	4.6	3.0	1.6	S, SH			
HP3-13	A	927	4.7	3.6	1.1	S, SH	B		
HP3-13	B	929	3.4	3.2	0.2	S, SH	TF		
HP3-13	C	930	5.0	2.7	2.3	S	TF		
HP3-13	D	931	3.8	2.6	1.2	S, SH	B, FP, TF		
HP4-13	A	935	4.7	3.6	1.1	S, SH			
HP4-13	B	937	3.8	2.9	0.9	S	TF		
HP4-13	C	938	4.1	3.4	0.7	S, SH	TF	void	
HP4-13	D	940	4.8	3.7	1.1	S, SH			
HP5-13	A	947	5.7	3.7	2.0	S, SH	B, DT		
HP5-13	B	950	8.6	7.7	0.9	S, SH			
HP5-13	C	952	9.0	8.1	0.9	S, SH	DT		
HP5-13	D	954	6.8	5.9	0.9	S, SH	DT	burrow	
HP6-13	A	1000	21.5	21.5	0.0	S, M		L, voids	sand/mud layers
HP6-13	B	1003	13.5	12.6	0.9	S, M	DT	L	sand/mud layers
HP6-13	C	1004	14.4	13.7	0.7	S, M		L	sand/mud layers
HP6-13	D	1005	7.3	5.5	1.8	S, M		L	sand/mud layers
HP7-13	A	1009	4.5	3.6	0.9	S, SH	B		
HP7-13	B	1011	1.4	0.0	1.4	S, SH	U, TF		algae, hydroid, fouled object
HP7-13	C	1012	15.6	14.9	0.7	S, SH, M	voids		
HP7-13	D	1014	5.6	3.4	2.2	S, SH	B		hydroids
HP8-13	A	1019	21.5	21.1	0.4	S, M	U	L, voids	sand/mud layers
HP8-13	B	1021	12.2	11.2	1.0	S, M		L	mud layer
HP8-13	C	1023	4.2	3.8	0.4	S			
HP8-13	D	1024	4.2	3.6	0.6	S	TF		
HP9-13	A	1034	8.7	6.0	2.7	S, M	B	L	sand/mud layers
HP9-13	B	1036	4.1	3.3	0.8	S	B, TF		
HP9-13	C	1037	6.8	4.3	2.5	S			
HP9-13	D	1039	2.8	2.2	0.6	S	FP, DT		

Station	Replicate	Time	D-max	D-min	R	Sediment	Surface	Subsurface	Other
Cruise 14	2 -28 - 95								
HP1-14	A	859	5.8	3.9	1.9	S	B	voids	
HP1-14	B	900	4.5	3.0	1.5	S, SH	B		
HP1-14	C	900	4.4	3.0	1.4	S, SH	B		
HP2-14	A	906	4.1	2.6	1.5	S, SH	B		
HP2-14	B	909	2.5	1.8	0.7	S, SH	B		
HP2-14	C	909	3.5	2.2	1.3	S, SH	B		
HP2-14	D	909	3.1	1.6	1.5	S, SH	B		
HP2-14	E	909	3.9	2.8	1.1	S, SH	B		
HP3-14	A	918	4.4	2.7	1.7	S, SH			
HP3-14	B	918	3.7	2.4	1.3	S	B		
HP3-14	C	918	2.8	1.8	1.0	S	TF		
HP3-14	D	918	4.3	2.8	1.5	S	B		
HP4-14	A	928	3.2	1.6	1.6	S	B, TF		
HP4-14	B	928	4.3	2.5	1.8	S, SH	B		
HP4-14	C	928	3.8	2.4	1.4	S	B		
HP4-14	D	928	3.5	2.2	1.3	S	B		
HP5-14	A	934	16	15.6	0.4	S, M		L	sand/mud layers
HP5-14	B	934	10.3	9.7	0.6	S, M		burrow, void	
HP5-14	C	934	7.8	5.3	2.5	S, M		L, void	sand/mud layers
HP6-14	A	940	3.6	2.3	1.3	S, SH, M	B		hydroid
HP6-14	B	940	10.2	9.7	0.5	S, M		L, void	sand/mud layers
HP6-14	C	940	7.8	7.2	0.6	S, M		L, void	sand/mud layers, large tube
HP7-14	A	945	10.5	10	0.5	S, M		L	sand/mud layers
HP7-14	B	945	11.8	11.4	0.4	S, M	FP	L	sand/mud layers
HP7-14	C	945	3.5	3.0	0.5	S, M		L	sand/mud layers
HP7-14	D	945	2.5	1.9	0.6	S, M		L	sand over mud
HP8-14	A	956	11.2	9.1	2.1	S, M	TF	L	sand/mud layers, hydroid, algae
HP8-14	B	956	18	17.9	0.1	S, M	U	L	sand/mud layers
HP8-14	C	956	8.8	8.6	0.2	S, M	DT	L	sand/mud layers
HP9-14	A	1003	7.4	7.4	0.0	S, M		L	sand/mud layers, hydroid, algae
HP9-14	B	1003	13.8	13.5	0.3	S, M		L	sand/mud layers
HP9-14	C	1003	3.4	2.3	1.1	S			hydroid
HP9-14	D	1003	5.3	5.3	0.0	S, M		L	sand/mud layers

APPENDIX II

Thimble Shoal Sand-Mining Study SPI Analysis - Surface Photographs

Note: Station key as given for Appendix I

Sta.	Rep.	Time	Bedforms	Shell	Tubes	Pits	Mounds	Other
Cruise 1	6-14-90							
HP1-1	A	1332		X	X	X		
HP1-1	B	1333	X	X	X			
HP1-1	C	1334	X		X			
HP1-1	D	1335	X		X	X		
HP1-1	E	1336	X	X	X			
HP1-1	F	1336	X		X	X		
HP1-1	G	1336		X	X	X		
HP1-1	H	1337	X		X			
HP1-1	I	1337	X	X	X			
HP1-1	J	1337	X	X	X			
HP2-1	A	1342		X				fish disturbance?
HP2-1	B	1343	X	X	X	X		
HP2-1	C	1345	X	X	X	X		
HP2-1	D	1346	X	X	X			
HP2-1	E	1347	X	X	X	X		
HP2-1	F	1347	X	X	X			
HP2-1	G	1347	X	X	X			
HP2-1	H	1348	X	X	X	X		Diopatra tube
HP2-1	I	1348	X	X	X			
HP2-1	J	1349	X	X	X			
HP3-1	A	1351	X	X	X			
HP3-1	B	1352	X	X	X	X		
HP3-1	C	1353	X	X	X			
HP3-1	D	1355	X	X	X			
HP3-1	E	1355	X	X	X			
HP3-1	F	1355	X	X	X			
HP3-1	G	1356	X	X	X			
HP3-1	H	1356	X	X	X			
HP3-1	I	1357	X	X	X			
HP4-1	A		X	X	X			
HP4-1	B		X	X	X			
HP4-1	C		X	X	X			
HP4-1	D		X	X	X			
HP4-1	E	1403	X	X	X			
HP4-1	F	1403	X	X	X			
HP4-1	G	1404	X	X	X			
HP4-1	H	1404		X	X			
HP4-1	I	1405		X	X			
HP4-1	J	1405	X	X	X			
HP5-1	A		X	X	X			
HP5-1	B		X	X	X			
HP5-1	C	1410	X	X	X			
HP5-1	D	1411	X	X	X	X	X	
HP5-1	E	1412	X	X	X			
HP5-1	F	1412	X	X	X	X		
HP5-1	G	1412	X	X	X			
HP5-1	H	1413	X	X	X			
HP5-1	I	1413	X	X	X	X		
HP5-1	J	1414	X	X	X		X	
HP6-1	A		X	X	X			
HP6-1	B		X	X	X	X		
HP6-1	C		X	X	X	X		
HP6-1	D		X	X	X	X		
HP6-1	E	1421	X	X	X	X		Diopatra tube
HP6-1	G		X	X	X			
HP6-1	H		X	X	X			
HP6-1	I	1433	X	X	X	X		
HP8-1	C		X	X	X			

Sta.	Rep.	Time	Bedforms	Shell	Tubes	Pits	Mounds	Other
Cruise 2 8-23-90								
no surface photographs								
Cruise 3 9-20-90								
HP1-3	A	1507	X	X	X			
HP1-3	C		X	X	X			
HP1-3	E		X	X	X			
HP1-3	F	1645	X	X	X			
HP1-3	G	1645	X	X	X			
HP1-3	H	1646	X	X	X			
HP1-3	I	1646	X	X	X			
HP1-3	K	1646	X	X	X			
HP2-3	A	1518	X	X	X			
HP2-3	C			X	X			
HP2-3	D	1523	X	X	X			
HP2-3	E	1649	X	X	X			
HP2-3	G	1649	X	X	X	X		
HP2-3	H	1649	X	X	X			
HP2-3	I	1649	X	X	X			
HP2-3	J	1650	X	X	X			
HP2-3	K	1650	X	X	X			tracks?
HP3-3	C	1537	X	X	X			
HP3-3	F	1656	X	X	X			
HP3-3	G	1656	X	X	X			
HP3-3	H	1656	X	X	X			
HP4-3	A	1545	X	X	X			
HP4-3	B	1548	X	X	X			
HP4-3	C		X	X	X			
HP4-3	D	1706	X	X	X			
HP4-3	E	1706	X	X	X	X		
HP4-3	F	1706	X	X	X	X		
HP5-3	A	1556				X		
HP5-3	B	1557						
HP5-3	C	1558			X	X		
HP6-3	A	1604						

Sta.	Rep.	Time	Bedforms	Shell	Tubes	Pits	Mounds	Other
Cruise 4	11-19-90							
HP1-4	A		X	X				poor quality
HP1-4	B		X	X				
HP1-4	C	1453	X	X				
HP1-4	D	1454	X	X	X			
HP1-4	E		X	X	X			onuphid tube
HP1-4	F	1455	X	X	X			
HP1-4	G	1455	X	X	X			
HP1-4	H	1456	X		X			
HP1-4	I	1456	X		X			
HP1-4	J	1456	X	X	X			
HP2-4	A	1502	X	X				
HP2-4	B		X	X	X			
HP2-4	D	1507		X			X	onuphid tube?
HP2-4	E		X	X	X			
HP2-4	F	1509	X	X				filamentous material
HP2-4	G	1509	X	X	X			
HP2-4	H	1512	X		X			
HP2-4	I	1512	X	X	X			
HP2-4	J		X	X	X			
HP3-4	A	1517	X	X	X			
HP3-4	B	1518	X	X				?
HP3-4	C		X	X				
HP3-4	D	1520	X	X	X	X		
HP3-4	E	1521	X	X	X			
HP3-4	F	1522	X	X	X			
HP3-4	G	1522	X	X	X			
HP3-4	H	1522	X	X	X		X	
HP3-4	I	1522	X	X	X			
HP3-4	J	1523	X	X	X			
HP3-4	K	1523	X	X	X			snail trace
HP4-4	A	1529	X	X				
HP4-4	C	1531	X	X				
HP4-4	D		X	X				
HP4-4	E	1533	X	X	X			plant stem
HP4-4	G	1534	X	X	X			
HP4-4	H	1534	X	X	X			
HP4-4	I	1534	X	X	X			
HP5-4	A	1540	X	X				
HP5-4	B	1541	X	X	X			
HP5-4	C	1542	X		X			
HP5-4	D	1545	X		X			tracks
HP5-4	E			X	X			tracks
HP5-4	F		X	X	X			tracks
HP5-4	G	1546	X	X				tracks
HP5-4	H	1547		X	X			burrowed crab
HP5-4	I	1547		X				
HP5-4	J	1547	X	X				
HP6-4	A	1552					X	
HP6-4	B	1553	X					
HP6-4	D	1555	X	X				tracks
HP6-4	F	1556	X	X	X			tracks
HP6-4	G	1556	X	X	X		X	
HP6-4	H	1557	X	X				
HP6-4	I	1557		X	X			
HP6-4	J	1557	X					tracks, blue crab
HP7-4	A	1601	X	X	X			hermit crab
HP7-4	B	1602	X		X			tracks, blue crab
HP7-4	C	1603	X					hydroids?
HP7-4	D	1605		X				tracks
HP7-4	E				X			tracks, filamentous material
HP7-4	F	1606			X			crab parts, debris

Sta.	Rep.	Time	Bedforms	Shell	Tubes	Pits	Mounds	Other
HP7-4	G	1606	X		X			tracks, disturbed?
HP7-4	H	1606						crabs legs, disturbed
HP7-4	I	1607	X					tracks
HP8-4	A	1613	X					filamentous material
HP8-4	B	1614			X			filamentous material, tracks
HP8-4	D	1617	X	X	X			tracks
HP8-4	F	1618	X		X			burrowed crab
HP8-4	G	1618	X					tracks
HP8-4	H	1618	X		X			tracks
HP8-4	I	1619	X		X			tracks
HP8-4	J	1619	X	X	X			tracks

Sta.	Rep.	Time	Bedforms	Shell	Tubes	Pits	Mounds	Other
Cruise 5 2-19-91 no surface photographs								
Cruise 6 5-30-91 poor quality for entire series								
HP1-6	A		X	X	?			
HP1-6	C			X			X	numerous large mounds
HP2-6	D		X	X	?			
HP2-6	E		X	X				
HP2-6	G		X	X				
HP2-6	H		X	X		X		
HP3-6	D						X	large mounds
HP3-6	E			X				
HP4-6	A		X	X			X	
HP4-6	B						X	
HP4-6	G		X				X	
HP8-6	F			X	X	X		
Cruise 7 11-20-91 photographs are poor quality								
HP-7	CONTR		X	X	?			
HP-7	PIT		X	X	?			
Cruise 8 3-3-92 no surface photographs								