ARTIFICIAL REEF CONSTRUCTION AS A SOFT-BOTTOM HABITAT RESTORATION TOOL

Final Technical Report

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Sarasota Bay National Estuary Program
North Tamiami Trail
Sarasota, Florida

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ABSTRACT

The Sarasota Bay Project of the National Estuary Program (NEP) sponsored an early action demonstration project submitted by Mote Marine Laboratory. The project evaluated the feasibility and methods for restoration of an eight acre dredged hole in northern Sarasota Bay. The dredged hole is located in the center of a mixed seagrass bed, and has accumulated a thick layer of anoxic fine grained sediments of the silt-clay particle sizes. The central basin of the hole was inspected for flora and fauna and found to be depauperate. The organic fine grained sediments produce hydrogen sulfide which depletes substrate and water column dissolved oxygen. Restoration through capping and filling was considered feasible but not practical due to the large quantity of material required and difficulties associated with obtaining permits. Enhancement of the habitat value of the hole was considered a feasible option through the development of artificial reef structures. The thick fine grained sediment was problematic for traditional massive artificial reef structures. Therefore innovative reef designs were constructed of lightweight PVC pipe and conduit. Two reef types were deployed, one which floats on the surface of the substratum and a second elevated above the substratum by means of a monopile. Monitoring included grain size analysis, reef biomass production and substratum faunal cores. One year-post deployment the reefs were evaluated and determined to be functioning as intended. The reefs were heavily colonized by invertebrates and fishes and the shell debris falling from the reef was increasing productivity of the adjacent substratum. The application of this approach to other areas was discussed.

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I. INTRODUCTION

I.1 Background and Problem Discussion

Loss of marine coastal habitats as a result of development has not been limited to shorelines, Dredge and fill activity has physically altered large expanses of former seagrass and unvegetated, but productive, bottom habitat. In many instances the dredging has created a new bottom profile much deeper than the natural configuration.

These basins typically exhibit poor circulation and act as sinks for fine particulates and organic debris. The Sarasota Bay National Estuary Program's Bay Bottom Habitat Assessment project identified in excess of 4,800 acres of Sarasota Bay bottom (14% of total Bay area) that were classified as disturbed habitat (Culter, 1992). This designation was assigned to areas that had been altered by human activity to an extent that they no longer had the same habitat value as natural bay bottom. Typically dredge and fill operations were conducted in the 1950's and 1960's as a means of building waterfront property. The dragline or hydraulic dredging techniques often resulted in anomalistic "pockets" with water depths of 12-18 ft in otherwise shallow bay areas. In some cases subtidal canals were created to serve as boat access, but in others the bay bottom was dredged only for fill material and the resultant hole did not serve a navigational function. Many material borrow areas were originally productive seagrass beds and the fill areas often replaced mangrove shoreline.

When such holes were created in bay areas which had low velocity currents, they accumulated fine particulate sediment and organic material of varying thickness. The resultant organic build-up and poor circulation result in anaerobic decomposition and the production of hydrogen sulfide gas. This depletes near bottom dissolved oxygen. There are virtually no bottom dwelling fauna in this type of habitat, with the surface of the substratum often covered by unicellular algae or a fungal mat. This type of bottom alteration does not recover within a reasonable time scale. The net result is a bottom habitat very different from the natural bay bottom; one that exhibits anoxic sediments and supports very little plant or animal life.

In this type of substratum benthic infauna, when present, are generally represented by pollution indicator species of annelids such as the polychaetes *Capitella capitata* or *Streblospio benedicti*, or small oligochaete species tolerant of low dissolved oxygen levels and fine organic sediment. These areas may also contribute to other water quality problems by acting as a long-term source of episodic turbidity during storm events or when prop wash from boats suspend the flocculent bottom layer.

A number of these dredged holes can be found within Sarasota Bay, but one of the largest is in the vicinity of the Cortez Bridge, near Leffis Key. **Figures 1** and 2 illustrate the location of this site. Very little attention has been focused on the restoration or improvement of such bottom areas for two principal reasons: some areas (unlike the Leffis Key site) continue to be used as small boat moorings, or access channels; and, the sites typically are not presently vegetated, nor easily observable. In addition, some degree of professional biological training is often necessary to recognize the immense difference between a disturbed "soft-bottom" versus a natural "soft-bottom" habitat. The Cortez dredged hole selected for this project, may have been dredged in the 1950's, and remains an unproductive and unnatural habitat, quite different from the former grass bed.

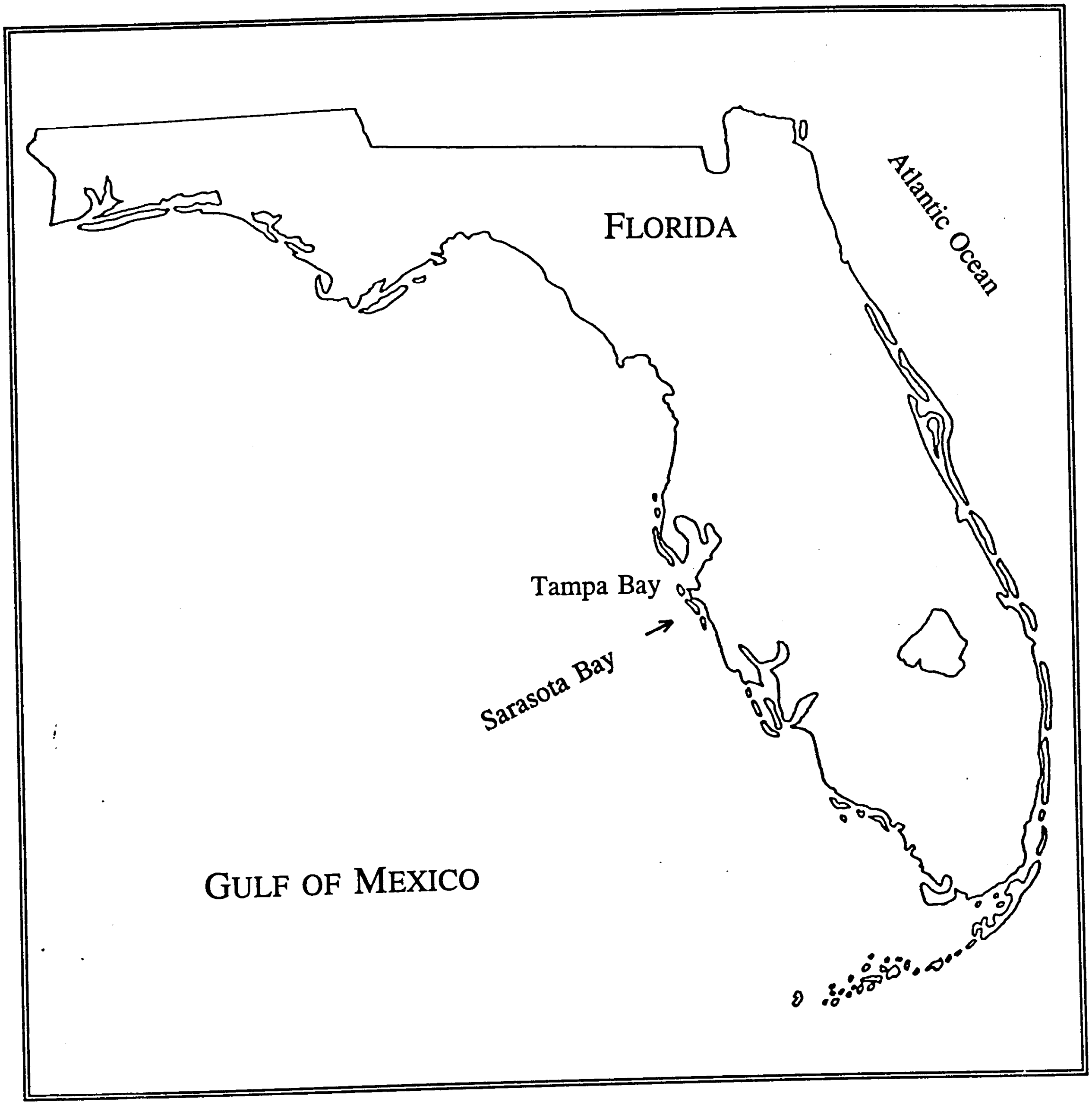


Figure 1. Location of Tampa Bay, Florida.

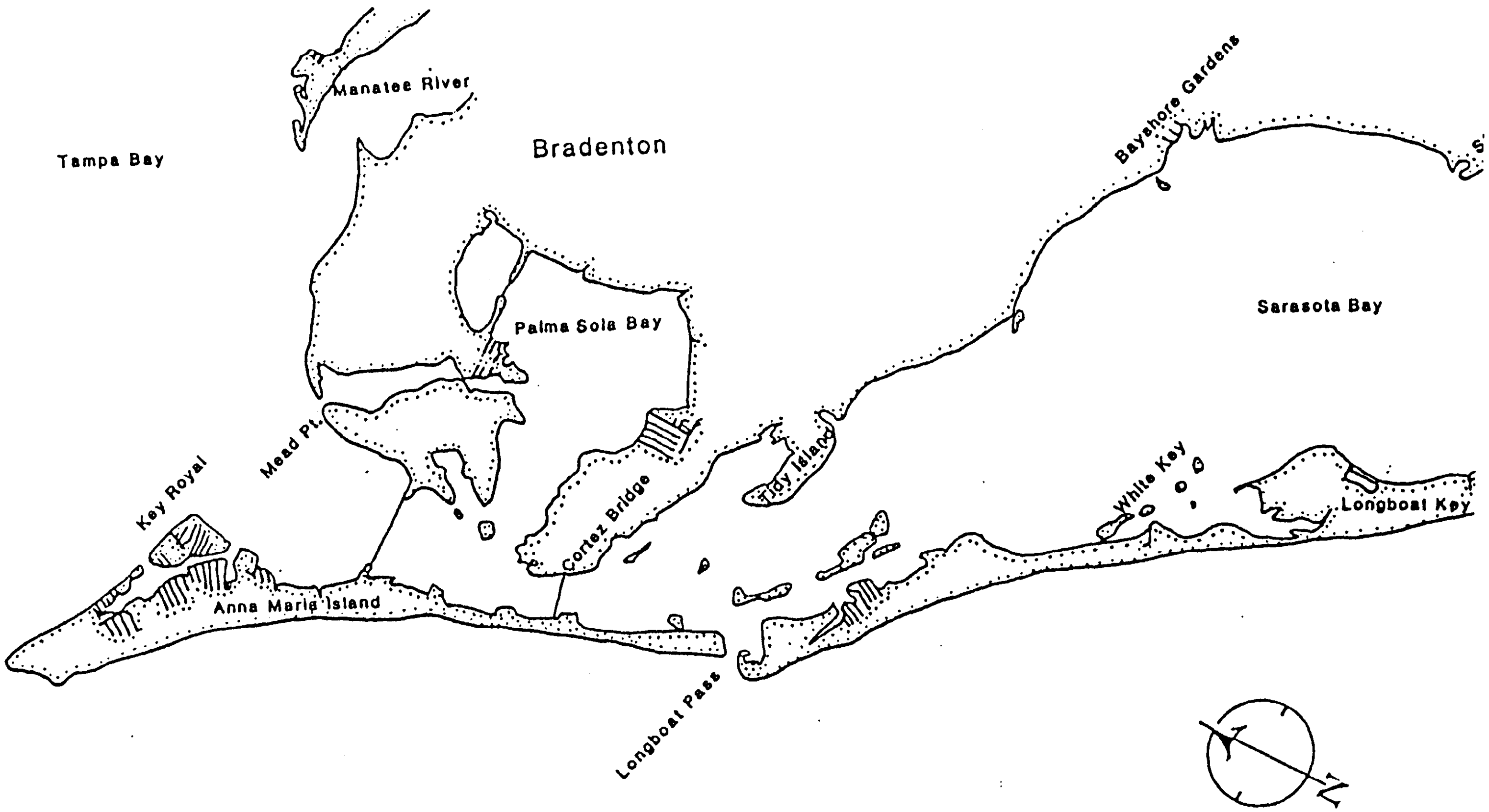


Figure 2. Location of study site in north Sarasota Bay, near Longboat Pass.

One such borrow area was filled in Lassing Park (Tampa Bay) St. Petersburg in the early 1980's because it was a hazard to waders and swimmers. Because it was not a restoration project, the site was not monitored for change or "recovery" but has exhibited some natural re-colonization by seagrasses. Also within Tampa Bay, there was a hole recently filled at Simmons Park, under the auspices of the Tampa SWIM project (personal communication Tampa DER). In this instance the fill material was dumped into the hole with the resultant expulsion of the fine grained material. Biscayne Bay has an ongoing project involving the filling of a small borrow hole. In this instance the fill material is from ICW maintenance, which is pumped to a de-watering site, and then barged to the hole to be dumped by a clamshell. The site is initially being monitored only for turbidity and surficial sediment grain-size.

None of the above described projects were designed for the combined purpose of habitat restoration and isolation of fine grained material. Within Sarasota Bay there has never been an attempt to restore any of these poor quality bottom types to a more desirable productive habitat.

I.2 Restoration Alternatives Considered

There were two possible methods considered for the restoration of the above described dredged holes. True habitat restoration would have consisted of the filling the hole to original contours utilizing compatible fill material. A second possibility was the enhancement of the habitat through the addition of elevated substrates *(artificial reefs).* For the benefit of providing background information, both methods are described below. However, for this project only the artificial reef approach proved to be a feasible method.

The Capping Concept. The Cortez dredged hole has a thick layer of soft organic sediment. Simply filling the hole by the dumping of sand/shell material would displace a large volume of silt/clay sized material into the Bay, clearly an undesirable and unacceptable effect. However, it is possible to "cap" fine grained material with coarser heavier material if the fill is placed in a particular manner.

A simple definition of capping is the controlled, accurate placement of clean isolating material over a deposit of contaminated or otherwise undesirable sediment. At a project site such as this, a thickened cap would have the added benefit of raising the elevation of part of the capped area into the photic zone. Field experience with capping is somewhat limited, but by no means is the concept completely unproven. Truitt (1987) identified 11 major projects which had used capping to that date. Further progress has been made since then, including the acceptance of capping by EPA as a standard remediation alternative for marine "Superfund" sites.

Many larger projects to date used split-hull barges to sprinkle the cap sediment over the target layer. Contrary to intuition, the actual field data has shown that this technique can be very successful and does not result in displacing even soft underlayers. However, split barges would not have been appropriate for the Cortez project site because of very shallow water depths, confined maneuvering and concern over turbidity in the water column during decent of the cap material. An alternative would have been to place the cap through a submerged diffuser, somewhat analogous to a tremie, which is connected to the discharge pipe of a small conventional dredge **(Figures 3 and 4).** The diffuser minimizes upper water column impacts, improves placement accuracy and controls sediment spreading, which in turn reduces benthic

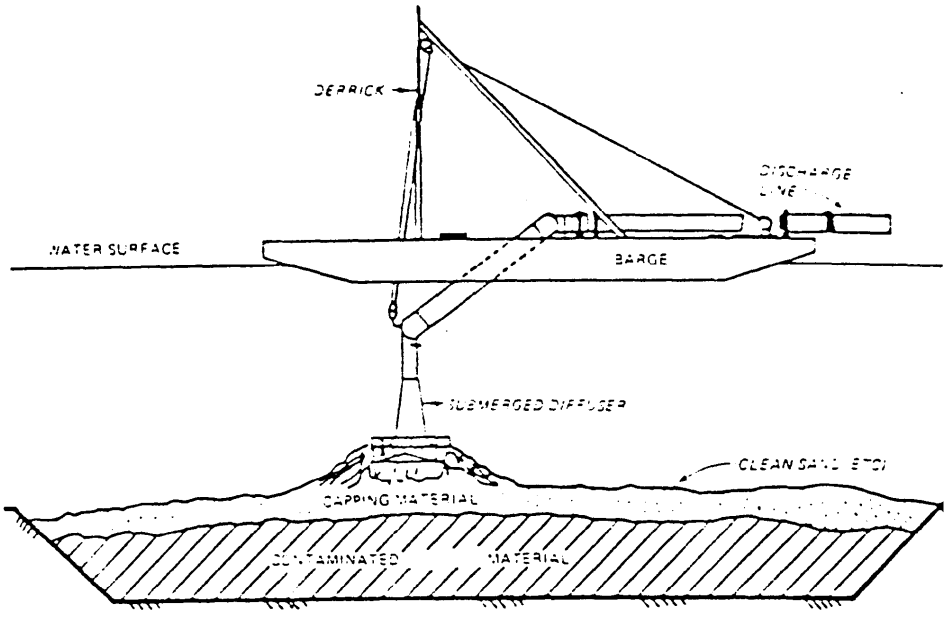


Figure 3. Diagram of capping process.

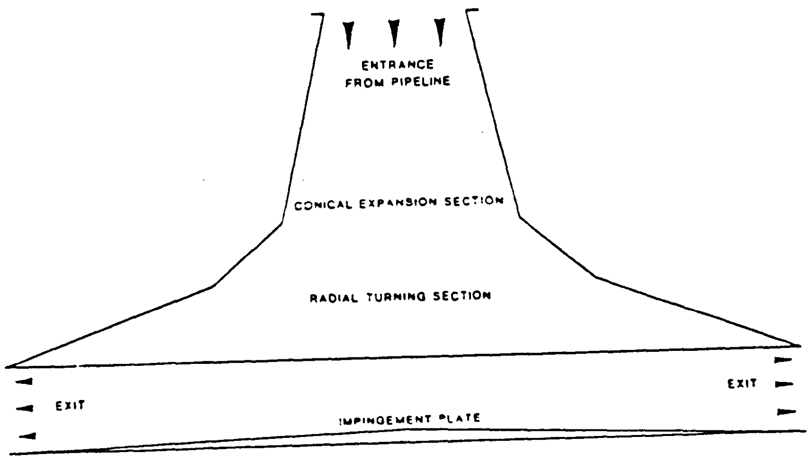


Figure 4. Details of diffuser used for sediment capping.

impacts. By routing the cap slurry first through a conical expansion and then a combined turning and radially divergent diffuser section, the discharge is released parallel to the bottom and at a velocity less that 25 % of the pipeline velocity. This means that the target area could be filled with little or no effect on surrounding grass beds.

The capping concept was the original preferred restoration tool considered for this site, which would have returned the area to the original seagrass habitat. However, implementation proved to be impossible due to: the large quantity of fill material required (the volume of material necessary to fill the entire hole to the level of the photic zone was estimated at 80,000-100,000 cubic yards), high cost associated with obtaining and placing the fill material, and the reluctance of Florida Department of Environmental Regulation to "dump" material into a designated Outstanding Florida Water.

Artificial Reef Habitat Enhancement

Restoration of dredged holes is difficult if not nearly impossible (from a regulatory agency standpoint). In many cases the "holes" have commercial functions such as a marina basins or navigation channels. However, as with the Cortez hole, some of these areas were merely borrow pits for upland fill material. Two drawbacks to filling these holes are the large quantity of high quality material necessary for a compatible natural restoration, and the difficulty in obtaining FDEP permits for a "fill' project even for the purpose of restoring a degraded habitat.

Occasionally it has been rationalized that dredged holes offer an unplanned "benefit" by trapping fine particulates and thus improving local water clarity. These unsubstantiated claims do not, however, balance the net habitat loss, the concentration of problem materials, the creation of an unnatural habitat type, and the potential that the holes may be robbing essential nutrients and particulates that would otherwise be uniformly distributed throughout the bay.

This project suggested a novel approach of using artificial reef structures to enhance a degraded habitat by providing a productive epifaunal community and through the biotic alteration of the surface sediments, as a result of carbonate shell material dropping from the reef. Within the Cortez hole an innovative artificial reef enhancement was used to increase the productivity of the existing "unnatural" bottom.

Three types of artificial reef habitats were utilized for this study: a commercially available cast concrete module (Reef Balls™), an open square module designed to "float" on the soft substratum, and a tree-shaped module supported by a 10 inch PVC conduit driven vertically into the substratum to firm bottom. The later two modules consisted of scrap pieces of various sizes of PVC pipe and conduit assembled by hand into an open, but geometrically complex shape. The PVC modules were placed within the central portion of the hole and the reef balls were deployed around the perimeter of the hole on firm substratum.

Artificial reefs are known to have substrate altering effects through the production and subsequent deposition of carbonate (barnacle and mollusc shell fragments). It was hypothesized that this carbonate deposition would serve to "cap" and enhance the quality of the soft anaerobic bottom sediments.

II. STATEMENT OF OBJECTIVES RELATED TO THE PROBLEM

The project consisted of a unique application of artificial reef technology for the purpose of rehabilitating an undesirable benthic habitat consisting of soft anaerobic, fine-grained silt accumulated in a dredged hole. The two objectives of the project were:

> to enhance the productivity of a low diversity dredged hole by the construction of non-traditional artificial reef structures, designed to provide habitat for juvenile stages of fishes, which is known to be a limiting factor for fisheries abundance.
>
> to "cap" or alter a portion of the fine-grained anoxic sediments in the vicinity of the reefs through biodeposition of carbonate from the reef structure.

The project technology will be transferable to many bays and estuaries within Florida where there are numerous dredged holes of this type.

III. METHODS AND MATERIALS

III. 1 Project Location

In 1993 a dredged hole was recommended for a restoration project under the Sarasota Bay NEP early action project program. The project site is located in the north end of Sarasota Bay, near the Manatee County boat ramp on south Anna Maria Island, **Figures 1 and 2.** The dredged site, approximately 12-14 feet in depth, is located near Leffis Key. The hole was dredged from the middle of a mixed species grass bed (primarily *Halodule wrightii* and *Thalassia testudinum)* which remain in the shallows surrounding the hole. Preliminary probes of the existing bottom showed that the original depth of dredging was approximately 10 to 15 feet below the present average bottom. The substratum of the hole consists of soft silt/clay sized material. The sediments were anoxic and did not contain a significant infaunal community.

The site represents approximately 8 acres of bay bottom habitat. The project did not interfere with boat navigation as the hole was surrounded on three sides by shallow grass flats and was not part of the ICW. The water depth at the center of the dredged hole was approximately 18 feet deep. The volume of material necessary to fill the entire hole to the level of the photic zone was estimated at 80,000-100,000 cubic yards.

III.2 Reef Design

Traditional artificial reef structures are massive to reduce the probability of movement by waves and currents. The chosen study area is protected from strong currents and severe wave climate by the very shallow surrounding grass flats and a short fetch.

In general, most traditional artificial reefs have not been the result of any true "design" process. This is because for cost reasons, typical reef-building materials were taken from opportunistic sources such as rubble from structure demolition, unused or waste building materials, or scrapped vehicles, parts, or similar items. If any selection criteria were used (other than considering safety and/or contamination), it was usually that the materials be as large and heavy as possible to avoid displacement by currents and wave-induced water motion. Subsequent experience and monitoring results have shown that certain material types and/or shapes result in better habitat and this information now forms the basis for most reef design; but, stability is still an important issue in offshore reefs. In cooperation with the Sarasota County artificial reef program two sets of Bay Balls were also placed at two locations along the periphery of the hole. These units constructed of cast concrete can be considered a variation of the traditional massive reef structure. Because of their weight they were placed on firm sand bottom near the edge of the hole. **Photo 1** illustrates Bay Balls being prepared for loading on the transport barge.

For the large expanse of soft bottom the design challenge for this project was the opposite problem. The silty soils in the Cortez, and similar dredged holes, have a very low shear strength and would not be able to support the weight of typical reef building materials.

The first task was to develop designs which overcame the soil's lack of bearing capacity while providing enough surface area and complexity to encourage colonization and provided predation shelter for juvenile fishes. Creating these designs was part of the project and was anticipated to require some trial and error and possible experiments with scaled prototypes before the designs could be finalized. However, we identified three basic methods of supporting the reef superstructure: a) a mono-pile placed through the silt into the denser sands below; b) multiple, short piers with spanning members; c) and a lightweight/large surface area platform "floating" in the silt layer. Two designs based on concepts "a" and "b" were finalized and three units of each produced for deployment in the dredged hole.

In developing the superstructure designs, information was incorporated from earlier Mote Marine Laboratory studies conducted by Dr. Randy Edwards, a fisheries ecologist with extensive experience in reef and habitat module design. For the mono-pile reef the preliminary superstructure concept centers on a tree-type of configuration, with main attachment points to the mono-pile and lightly loaded smaller secondary branches increasing habitat complexity, **Figure** 5. The vertical height of the exposed tree portion was approximately 5 feet. The second type of unit consisted of a square (10 ft x 10 ft) main base frame with three arched spans, **Figure** 6. The vertical height of this structure was approximately 4 feet. The main structure was increased in complexity by the placement of small diameter (1 inch) PVC, 1 inch plastic mesh, and short lengths of 3/8 inch polypropylene line. Each comer of the square units rested on a 4 foot length of 10 inch PVC equipped with an end cap. These short pilings provided the frictional force necessary to support the weight of the superstructure and stabilize the reefs. The primary material used for the construction was PVC pipe, and polypropylene line. The objective was to provide a geometrically complex framework which has a large surface area, but is also very lightweight. The colonization by fauna added strength and rigidity over time.

Photos 2-4 show views of the square "floating" reef module, and **Photos** 5 and 6 show views of the tree modules being placed into the water.

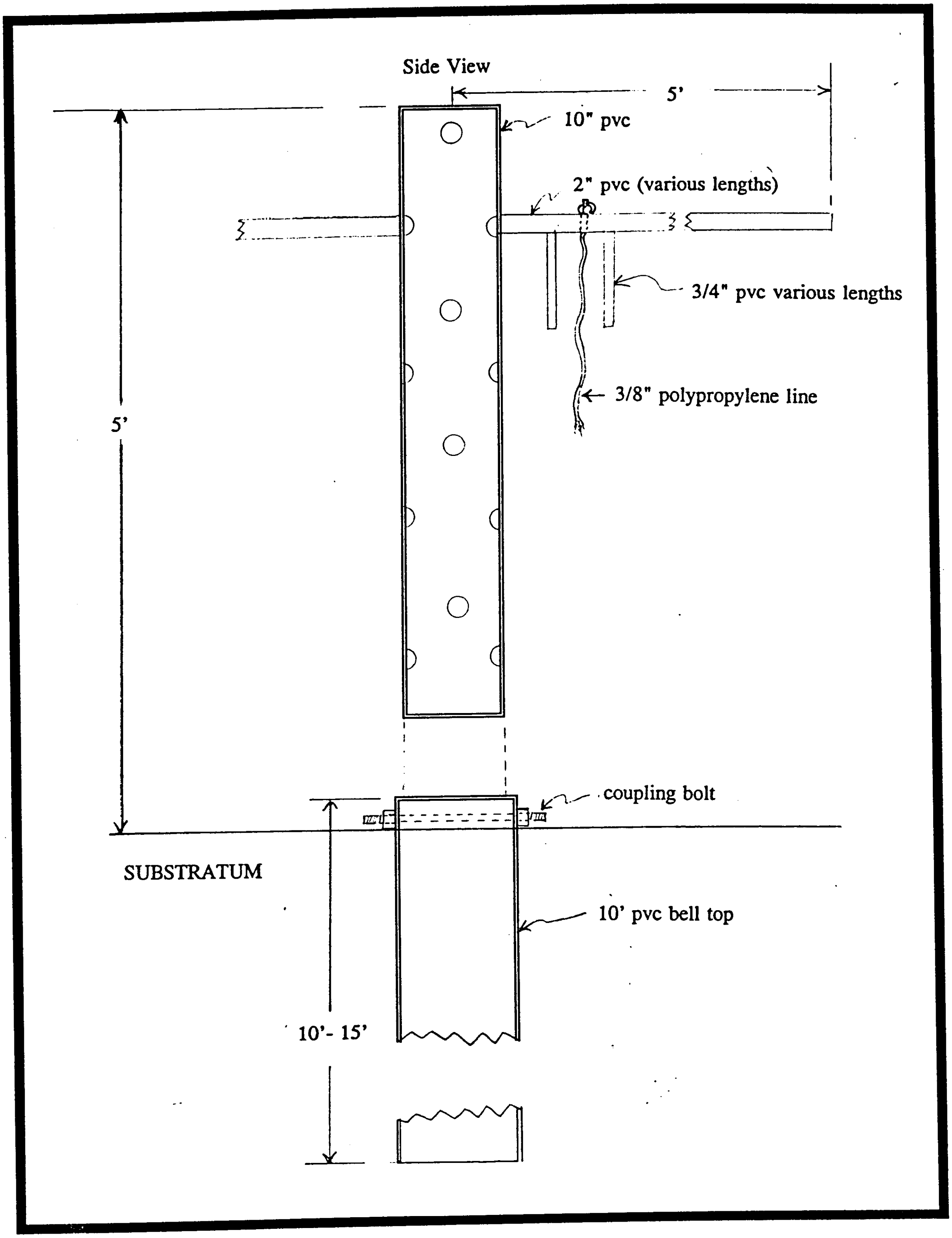


Figure 5. Monopile tree reef schematic.

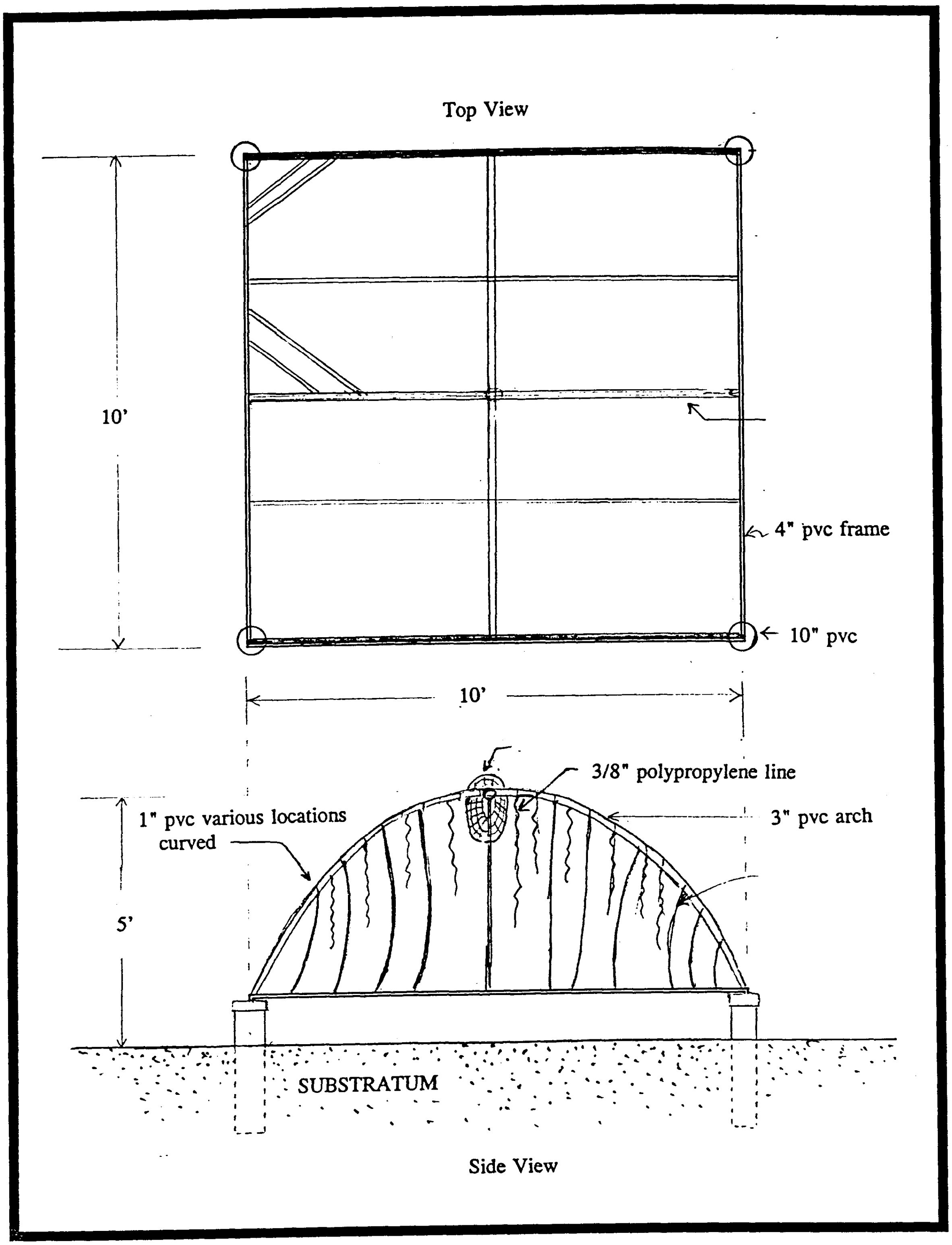


Figure 6. Schematic of basic square "floating" reef design.

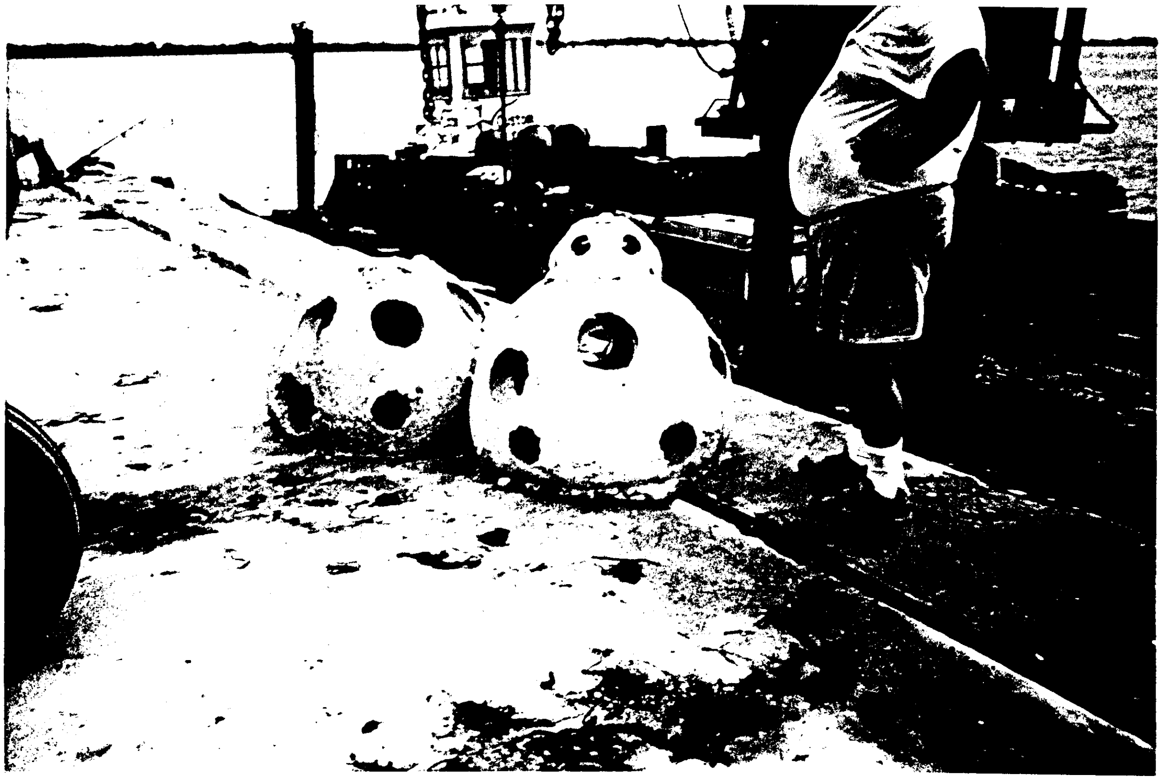


Photo 1. Bay Balls at dock prior to loading on barge.

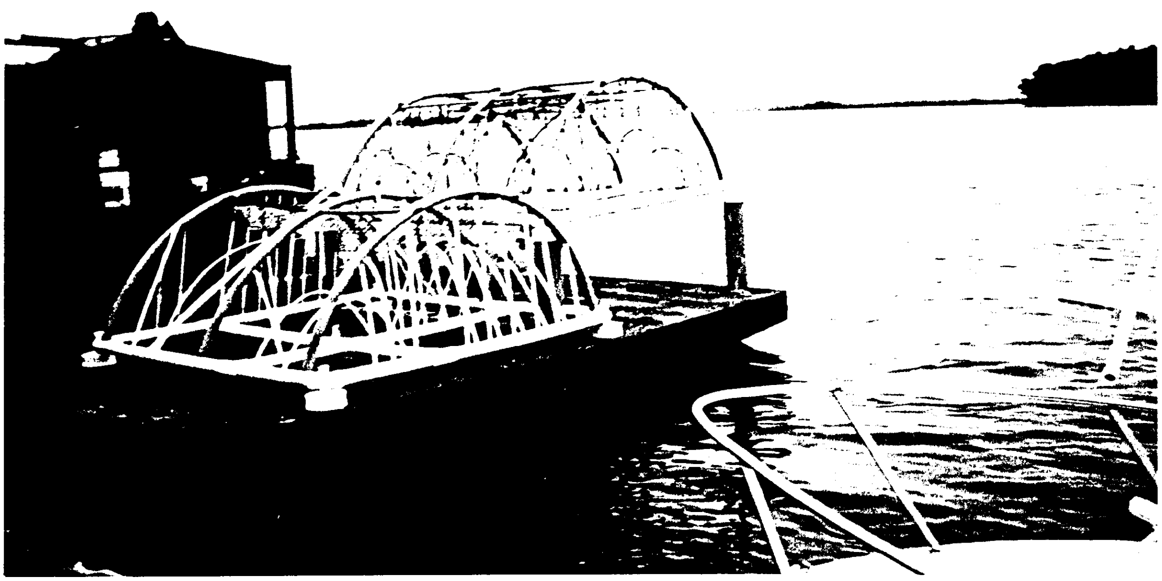


Photo 2. Square "floating" reef modules, showing one unit with pipe supports.

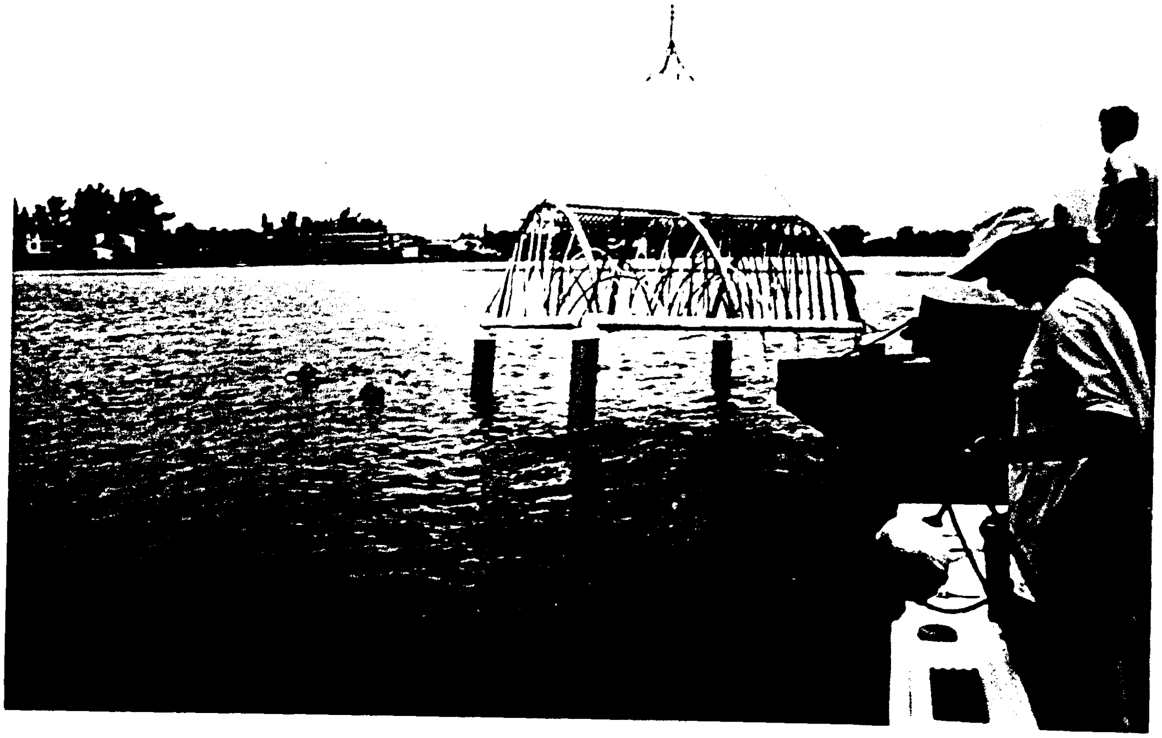


Photo 3. Square reef module being placed on site.

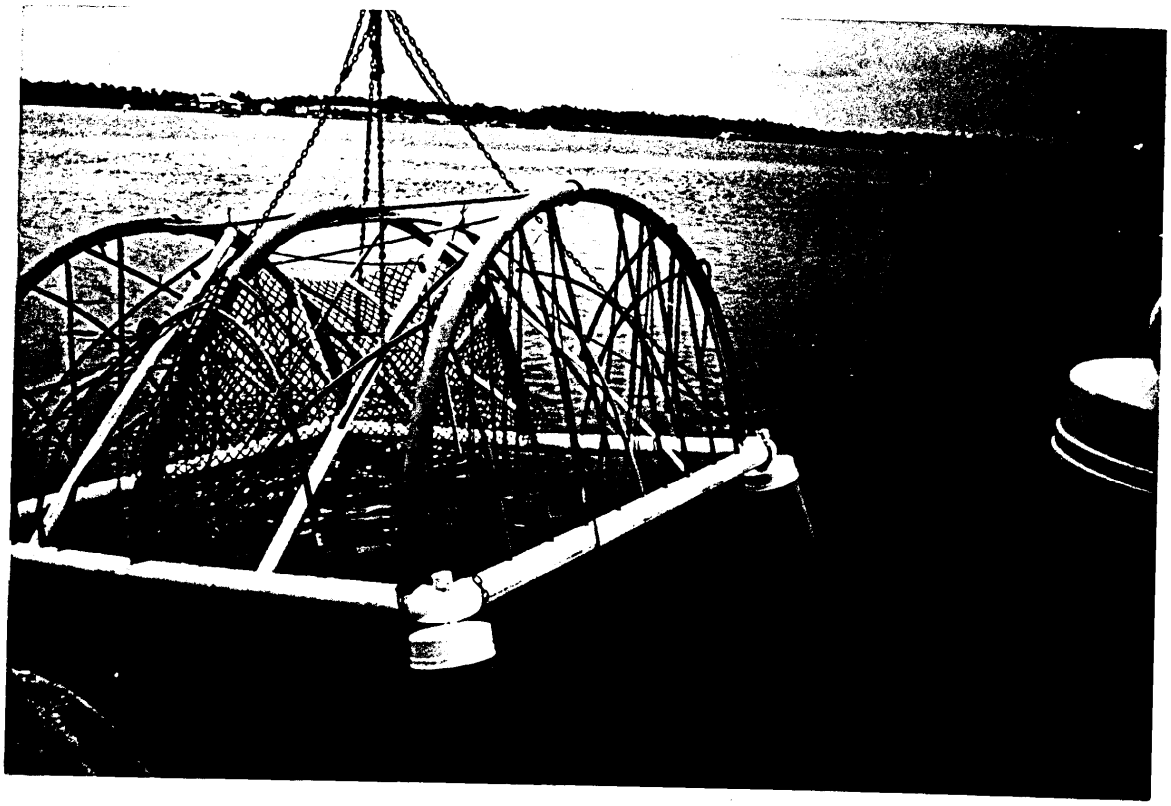


Photo 4. Close up view of square reef module being placed on site.

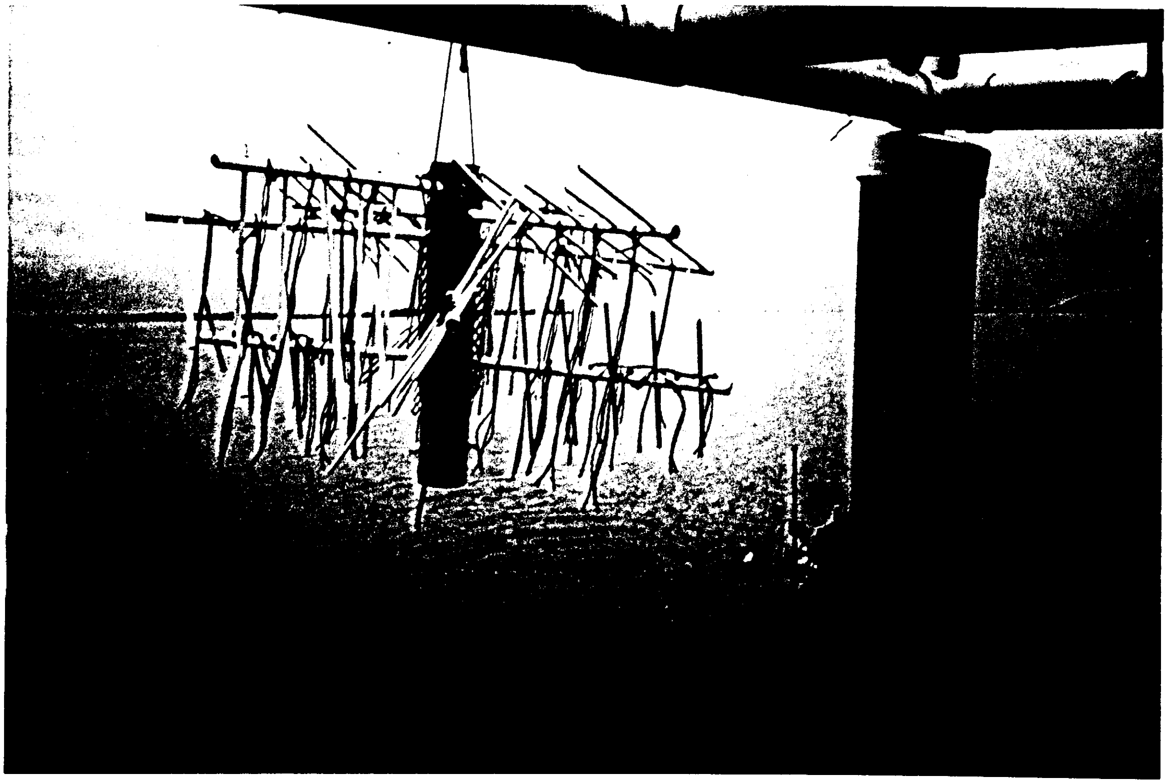


Photo 5. Tree module being lowered with crane for placement on support piling.

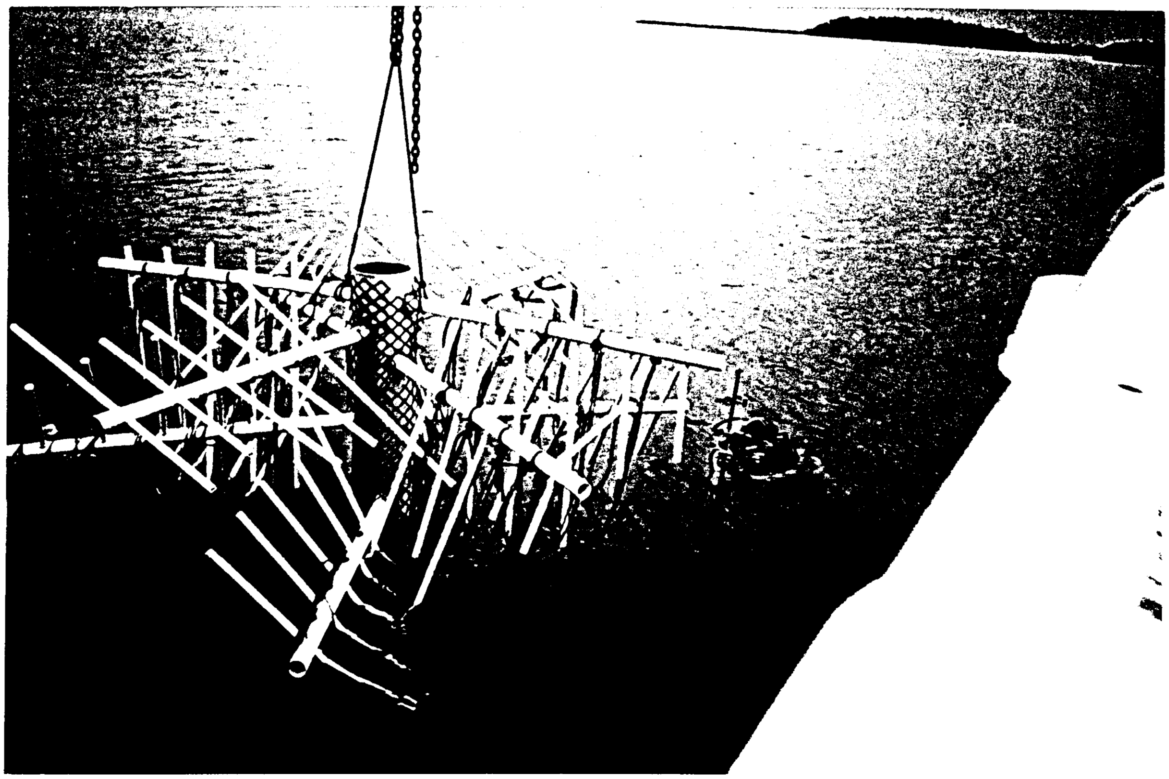


Photo 6. Tree module being lowered into water for placement on support piling.

III.3 Monitoring Field Methods

Samples collected as part of the reef monitoring included: sediments for grain size analysis, faunal core samples for macroinfaunal analysis, and reef scrape samples for productivity estimates.

Sediment Samples
Surface core samples (approximate top 10 centimeters) were obtained for grain size and organic content analysis. Samples were taken prior to the placement of the reefs at representative positions within the dredged hole as well as several areas outside the hole in the adjacent seagrass beds. Samples were again taken from beneath the reefs eleven months after deployment. Sediment samples were placed on ice in the field and refrigerated prior to processing.

Faunal Samples
Prior to reef placement benthic core samples were obtained for macroinfaunal analysis. Samples were taken prior to the placement of the reefs at representative positions within the dredged hole as well as several areas outside the hole in the adjacent seagrass beds. Samples collected with a 12.5 cm x 12.5 cm stainless steel core, the collected material washed through a 0.50 mm mesh sieve, and the retained material preserved with 10 percent buffered Formalin" containing rose bengal stain. Samples were again taken from beneath the reefs at six and eleven months after deployment.

Scrape samples were taken from each reef type at six and eleven months post-placement to determine relative productivity. For the reefs a single scrape was taken from a 15 centimeter (6 inch) length of 3/4 inch PVC pipe. For the Bay Balls" a 15 cm x 15 cm scrape was taken from the concrete surface of a representative ball. Data were converted to a common unit area.

All faunal samples were preserved with 10% buffered Formalin" and returned to the laboratory for processing.

III.4 Laboratory Methods

Sediment Analysis
Sediment grain size analysis was conducted with a standard Wentworth series of six nested sieves (Folk, 1974). Sediment organic content was determined by loss on combustion at 500-525°C.

Each sediment samples was first wet sieved through a 0.063 mm sieve to remove the silt-clay size particles. Samples were washed through the sieves with deionized water, and the fine fraction centrifuged for 30 minutes to consolidate the silt-clay fraction. This fraction was then oven dried to a constant weight at 105-110°C. The coarse fraction (> 0.063 mm) was, oven dried at 105-110°C for a minimum of 36 hours, then mechanically sieved through a cascade of sieves at 2.00, 1.00, 0.50, 0.25, 0.125, and 0.063 mm to identify the distribution of material at whole-phi (ϕ) increments. Phi (ϕ) units are a base 2 logarithmic transformation of the above size classes and are calculated from the sieve mesh sizes using the following formula:

$$\phi = -\log_2(\text{mesh size, mm})$$

Negative phi sizes are particle sizes larger than 1.00 mm, while silt and clay fractions have ϕ values greater than 4.0.

Sample statistics were computed according to Folk (1974). Mean and median grain sizes were computed through linear interpolation between adjacent phi (ϕ) sizes and sample percentages. The phi (ϕ) sizes representing selected percentages (5, 16, 50, 84, and 95%) of sample were also computed through linear interpolation between adjacent values and used to calculate additional sample statistics.

The sorting coefficient (or inclusive graphic standard deviation, σ_I) is a measure of the spread in phi (ϕ) units for a sample with higher absolute values representing poorly sorted material. This statistic was calculated using phi (ϕ) size percentages discussed above and the following formula:

$$\sigma_I = (\phi84 - \phi16)/4 + (\phi95 - \phi5)/6.6$$

Skewness (inclusive graphic skewness, SK_I) measures the degree of symmetry in the size distribution of material. Skewness numbers at or near 0 indicate nearly symmetrical distributions, with positive numbers (+) indicative of an excess of fine sediments and negative numbers (-) indicative of an excess of coarse sediments (-). The statistic was calculated using the phi (ϕ) size percentages discussed above and the formula:

$$SK_I = [(\phi16+\phi84-2\phi50)/2(\phi84-\phi16)]+[(\phi5+\phi95-2\phi50)/2(\phi95-\phi5)]$$

Kurtosis (K_G), or peakedness, indicates departure of the individual percents from the normal distribution. Sediments are considered leptokurtic when the central portion of the distribution curve is better sorted (more material in the central grain sizes) and platykurtic when the tails of the distribution curve are better sorted. Strongly platykurtic samples are often bimodal in distribution. Values lower than 0.90 are considered platykurtic, and values higher than 1.1 are considered leptokurtic. The formula used to calculate this statistic follows:

$$K_G = (\phi95 - \phi5) / 2.44(\phi75 - \phi25)$$

Table 1 illustrates descriptive categories based on calculated phi (ϕ) values for grain size parameters.

<u>Faunal Analysis</u>
Benthic core samples were processed as follows. After a minimum of 72 hours in 10% Formalin, to ensure proper fixation, samples were rinsed and 70% isopropyl alcohol added as a preservative. Invertebrate samples were first rough sorted beneath a stereozoom dissecting microscope. Fauna were removed from detritus and sorted to major taxonomic groups consisting of: annelids, molluscs, crustaceans and miscellaneous groups. After rough sorting, each group was identified to the lowest practical taxonomic level, which in most cases was the genus or species level. If insect larvae are present they are first mounted on microscope slides with CMCP™ mounting media and allowed to clear before identification.

Table 1. Descriptive categories based on calculated phi (ϕ) values for grain size parameters. (Sediment classification by particle size Wentworth classification).

Particle Size-Class	**Phi**	**Grain Size Millimeters**
Gravel	<-1	>2.0
Very coarse sand	0	>1.0 ≤ 2.0
Coarse sand	1	>0.5 ≤ 1.0
Medium sand	2	>0.25 ≤ 0.5
Fine sand	3	>0.125 ≤ 0.25
Very fine sand	4	> 0.0625 ≤ 0.125
Silt clay	> 4	≤ 0.0625

Degree of sediment sorting based on inclusive graphic standard deviation (Folk, 1974).

Standard deviation	**Degree of sorting**
<0.35 ϕ	Very well sorted
0.35 ϕ - 0.50 ϕ	Well sorted
0.50 ϕ - 0.71 ϕ	Moderately well sorted
0.71 ϕ - 1.00 ϕ	Moderately sorted
1.00 ϕ - 2.00 ϕ	Poorly sorted
2.00 ϕ - 4.00 ϕ	Very poorly sorted

Classification of sediment by skewness (Folk, 1974)

Sk values	**Degree of skewness**
+1.00 - +0.30	Strongly fine-skewed
+0.30 - +0.10	Fine-skewed
+0.10 - -0.10	Near symmetrical
-0.10 - -0.30	Coarse skewed
-0.30 - -1.00	Strongly coarse-skewed

Classification of sediment by kurtosis (Folk, 1974).

Kg values	**Degree of kurtosis**
< 0.67	Very platykurtic
0.67 - 0.90	Platykurtic
0.90 - 1.11	Mesokurtic
1.11 - 1.50	Leptokurtic
1.50 - 3.00	Very leptokurtic
> 3.00	Extremely leptokurtic

Biomass scrape samples were first blotted of excess moisture and wet weighed. Samples were then dried at 105-110°C, and weighed. Dry samples were crushed and mixed and an aliquot removed and burned at 500-525°C for 1 hour. Organic content was considered the weight lost to combustion.

Community Analysis Techniques

Benthic data are often unable to satisfy the requirements of normality of distribution and heterogeneity of variance, both underlying assumptions of parametric statistics. Failure to meet these criteria do not necessarily invalidate statistics such as the ANOVA, but it considerably lowers the ability of the test to detect real differences in the data.

Community analysis techniques offer alternatives to parametric statistics. Faunal similarity, principal component analysis and descriptive community parameters were calculated as follows:

Faunal Similarity Analysis was used to compare the community composition among areas and within areas through time, using the Bray-Curtis Index (Bray and Curtis, 1957; Field and McFarlane, 1968; Krebs, 1989). The index is a dis-similarity measure with a range of 0 to 1, with a value of 0 representing identical composition. The Bray-Curtis Index was calculated for selected pair-wise combinations of station and sampling dates. The pair-wise combinations of the index were then used as input for the cluster analysis. The computational formula for the index is:

$$B = \frac{\sum_{i=1}^{s} |X_{ij} - X_{ik}|}{\sum_{i=1}^{s} (X_{ij} + X_{ik})}$$

Where B = Bray-Curtis measure of dissimilarity; X_{ij} = individuals for the *i* th species in the *j* th sample; $X,_{ik}$ = individuals for the *i* th species in the *k* th sample and *s* = the number of species over all samples.

Agglomerative Hierarchical Cluster Analysis was conducted using the Czekanowski's Index as the matrix of association coefficients. The agglomerative technique starts by linking the highest similarity pairs and then proceeds to the next highest in order. Hierarchical refers to the tree-like branching form of the output. The group average sorting technique was used as the clustering method (Sneath and Sokal, 1973), where the similarity between a sample and an existing cluster equals the arithmetic mean of similarities between the sample and all the members of the cluster (Krebs, 1989).

Similarity and cluster analyses were conducted using the BioStat II® Software (Pimentel and Smith, 1993).

Standard descriptive community parameters were also calculated for each sample. These parameters are:

Faunal density was calculated as the number of organisms per square meter of substratum by the formula: **FD = i/a** where "i" is the total number of individuals collected at a station, and "a" is the total area sampled, in square meters.

Species richness was calculated as the number of identifiable taxa present for each sample and each area (total species for 10 samples).

Species diversity was calculated as the Shannon-Wiener Index (Shannon and Weaver, 1972) using the formula:

where s = total number of species for the sample and p_i = the proportion of total individuals for the i^{th} species. The index was calculated using various log bases (log,,, $\log_2$, ln) to enable comparisons to other data sets.

The Shannon-Wiener Index has been strongly criticized by several authors (Hurlbert, 1971; Goodman, 1975; Patten, 1968; Washington, 1984) as to the biological meaning of the index. An increase or decrease in H' does not necessarily indicate an improvement or decline in the quality of a benthic community. Environmental impact assessments must consider the natural state of the community under consideration. Caution should be used when interpreting values of H'as related to impact assessments.

Equitability, or evenness of distribution of fauna among species was calculated by Pielou's conventional method (Pielou, 1975). Values for the index range from O-l, with a value of 1 being the maximum possible evenness of distribution in the community. The computational formula is:

$$J' = \frac{H'}{\log_e S}$$

where e = 2.30, H' = value for Shannon-Wiener Index, and S = total number of species for a sample.

IV. RESULTS

IV. 1. Bathymetry

A detailed bathymetric survey of the site was conducted in January and February 1995, **Figure 7.** Probes of the existing bottom showed the original depth of dredging was approximately 10 to 15 feet below the present average bottom. Cross-sections are shown in

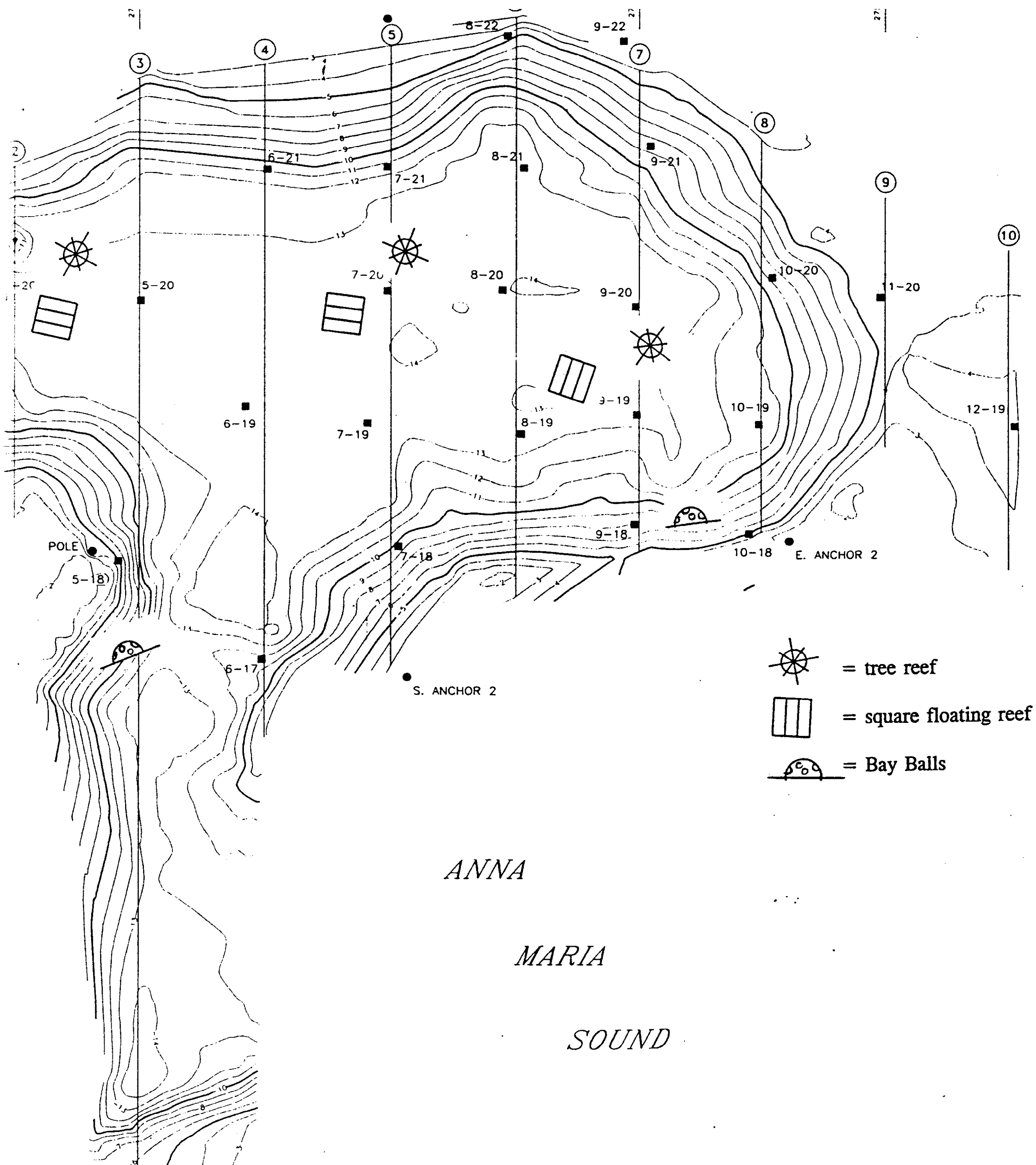
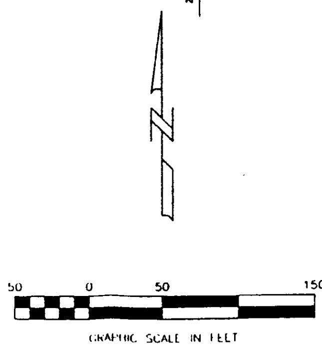


Figure 7. Detailed bathymetric survey of the dredged hole conducted in January and February 1995.



NOTES :

1. DATE OF BATHYMETRIC SURVEY : JANUARY 31, 1995.
2. DATE OF PROBE SURVEY : FEBRUARY 15, 1995.
3. TRACKLINE SPACING WAS 100 FEET RUNNING NORTH-SOUTH ACROSS SURVEY AREA, WITH SHORT EAST-WEST LINES RUN TO DEFINE THE EAST AND WEST EDGES.
4. COASTAL OCEANOGRAPHIC HYDROGRAPHIC DATA COLLECTION/PROCESSING POSITIONING SYSTEM (HYPACK) WAS INTERFACED TO A TRIMBLE 4000SE LAND SURVEYOR II AND A TRIMBLE PRO BEACON DIFFERENTIAL GPS BEACON RECEIVER FOR NAVIGATION CONTROL AND POSITIONING.
5. DEPTHS OBTAINED BY AN INNERSPACE 448 DIGITAL FATHOMETER.
6. COORDINATES SHOWN HEREON ARE BASED ON THE FLORIDA STATE PLANE COORDINATE SYSTEM, WEST ZONE (NAD 1927).
7. PROBES OBTAINED BY MANUAL PENETRATION WITH GRADUATED ROD TO REFUSAL.
8. ELEVATIONS SHOWN HEREON ARE BASED ON NATIONAL GEODETIC VERTICAL DATUM (NGVD) 1929.

11-20 ■ DENOTES PROBE LOCATION AND NUMBER.

(10)—— DENOTES CROSS-SECTION LOCATION AND NUMBER.

SURVEY CONTROL DATA				
STATION	NORTHING	EASTING	WATER DEPTH	TOP ELEVATION
POLE (WEST)	1136199	275162	−4.4	±+2.6
ANCHOR (NORTH)	1136623	275397	−2.5	±−1.8
ANCHOR (SOUTH)	1136098	275413	−2.3	±−1.7
ANCHOR (EAST)	1136206	275723	−2.6	±−1.8

PROBE DATA				
PROBE NUMBER	NORTHING	EASTING	PENETRATION	ELEV. OF SAND
3-19	1136306	274996	0	NO PENE.
4-20	1136401	275091	13.0	-27.0
4-21	1136522	275083	0	NO PENE.
5-18	1136191	275183	0	NO PENE.
5-20	1136398	275201	10.5	-24.4
6-17	1136112	275298	0	NO PENE.
6-19	1136313	275285	14.0	-28.0
6-21	1136502	275302	9.0	-20.0
7-18	1136202	275406	3.1	-14.0
7-19	1136300	275381	8.0	-16.0
7-20	1136405	275397	8.0	-16.1
7-21	1136504	275397	2.5	-13.4
8-19	1136292	275504	12.0	-25.3
8-20	1136406	275489	14.5	-28.6
8-21	1136504	275506	12.0	-25.2
8-22	1136610	275493	0	NO PENE.
9-18	1136220	275596	0	NO PENE.
9-19	1136307	275598	10.5	-24.0
9-20	1136393	275597	11.0	-24.9
9-21	1136521	275609	0	NO PENE.
9-22	1136605	275587	0	NO PENE.
10-18	1136212	275690	0	NO PENE.
10-19	1136299	275698	12.0	-23.6
10-20	1136416	275709	0	NO PENE.
11-20	1136400	275796	0	NO PENE.
12-19	1136298	275905	0	NO PENE.

Figure 8 (note that the vertical scale is distorted to 10 times the horizontal). The substratum of the hole consists of soft silt/clay sized material. Field investigations indicated the sediments were anoxic with bubbles of hydrogen sulfide released from the substratum when disturbed. The substratum of the area was very flocculent and easily resuspended. The accumulation of such sediment indicated that currents and wave action have had very little effect on the bottom.

Diver inspections of the site also revealed that other materials are present within the dredged hole. Whether intentionally placed or the result of accidental sinking there are three small boat hulls within the site as well as some concrete and metal rubble near the south entrance channel where the sediment is more firm. There was also a small area of rock near the entrance channel which was colonized with sponges, tunicates and a few hard corals.

IV.2. Sediments

By January 1996 (6 months post-deployment), the square "floating" reefs had settled closer to the bottom. One reef was resting on the 4" frame although the other two had 5 to 10 centimeters of space between the bottom of the frame and the substratum. Divers observed an accumulation of shell, primarily barnacle shell, around the base of the reefs. The tree reef exhibited a conical accumulation of sediment around the base of the support piling. This accumulation consisted of a mix of barnacle shell and fine organic sediment, most likely pseudo-feces from the filter feeding organisms present on the reef.

Results of the sediment grain-size and organic content analysis are presented in Table 2 and **Figures 9-12.**

The February 1996 data represent pre-deployment baseline conditions for three locations in the surrounding seagrass beds and five locations distributed throughout the central portion of the dredged hole. The June 1997 data represent samples taken from beneath each of the six fabricated reefs. Divers observed clumps of barnacles and barnacle fragments mixed with the substratum beneath the reefs. Three of the locations (reef 2, 3, and 5) showed no apparent difference from the pre-deployment conditions. The other three reefs showed a considerable effect of the shell material, with a more coarse mean grain size which also reflects in other measures such as percentage silt/clay and percentage organic content.

IV.3. Fauna

Species Utilization - Reef Habitats

Colonization of the reef habitats was rapid. All surfaces were well covered in a layer of epifauna within 3 months. Barnacles began settling immediately. Unpublished studies at Mote Marine Laboratory indicate that barnacles begin to settle on suitable substrates within 24 hours of immersion, and can reach reproductive maturity in less than 30 days. The base layer of barnacles became covered with layers of various organisms such as; tunicates, encrusting sponges, hydroid colonies, algae, etc. Micro-crustaceans such as small mud crabs and amphipods were very abundant, and were easily observed by disturbing the larger epifauna.

Table 2. Grain size parameters for sediment analysis for samples obtained from a dredged hole in Sarasota Bay off Bradenton Beach, Florida, February 1996 and June 1997.

Station	Median	Mean	Skewness	Sorting coefficient	Kurtosis	% Silt/clay	% Organic	% Moisture
February 1996								
SG 1	2.56	2.56	.15	0.48	1.14	0.1	0.7	25.7
SG 4	2.65	2.74	.27	0.58	1.09	1.8	0.8	91.0
SG 7	2.62	2.69	.24	0.58	1.13	2.2	1.2	78.2
Hole 2	4.14	3.56	-.62	1.38	0.89	58	23.3	29.7
Hole 3	4.25	3.65	-.67	1.41	1.05	66.5	23.9	89.8
Hole 5	4.15	3.79	-.51	1.06	0.84	58.5	20.7	88.3
Hole 6	4.16	3.32	-.72	1.87	1.15	59.3	20.6	38.5
Hole 8	4.24	3.9	-.52	0.97	0.93	65.5	21.9	83.3
June 1997								
S(C) Reef 3	4.21	2.79	-0.79	2.33	0.91	63.6	21.5	85.4
S(E) Reef 1	-1.11	0.54	0.78	2.56	0.49	28.9	9.8	69.2
S(W) Reef 5	4.14	2.44	-0.79	2.59	0.47	58.2	15.4	79.4
T(C) Reef 4	2.57	1.88	-0.32	2.59	0.47	48.4	10.0	68.2
T(E) Reef 2	4.06	2.39	-0.77	2.60	0.47	53.0	19.2	83.6
T(W) Reef 6	-0.89	0.67	0.72	2.59	0.48	38.6	17.2	81.4

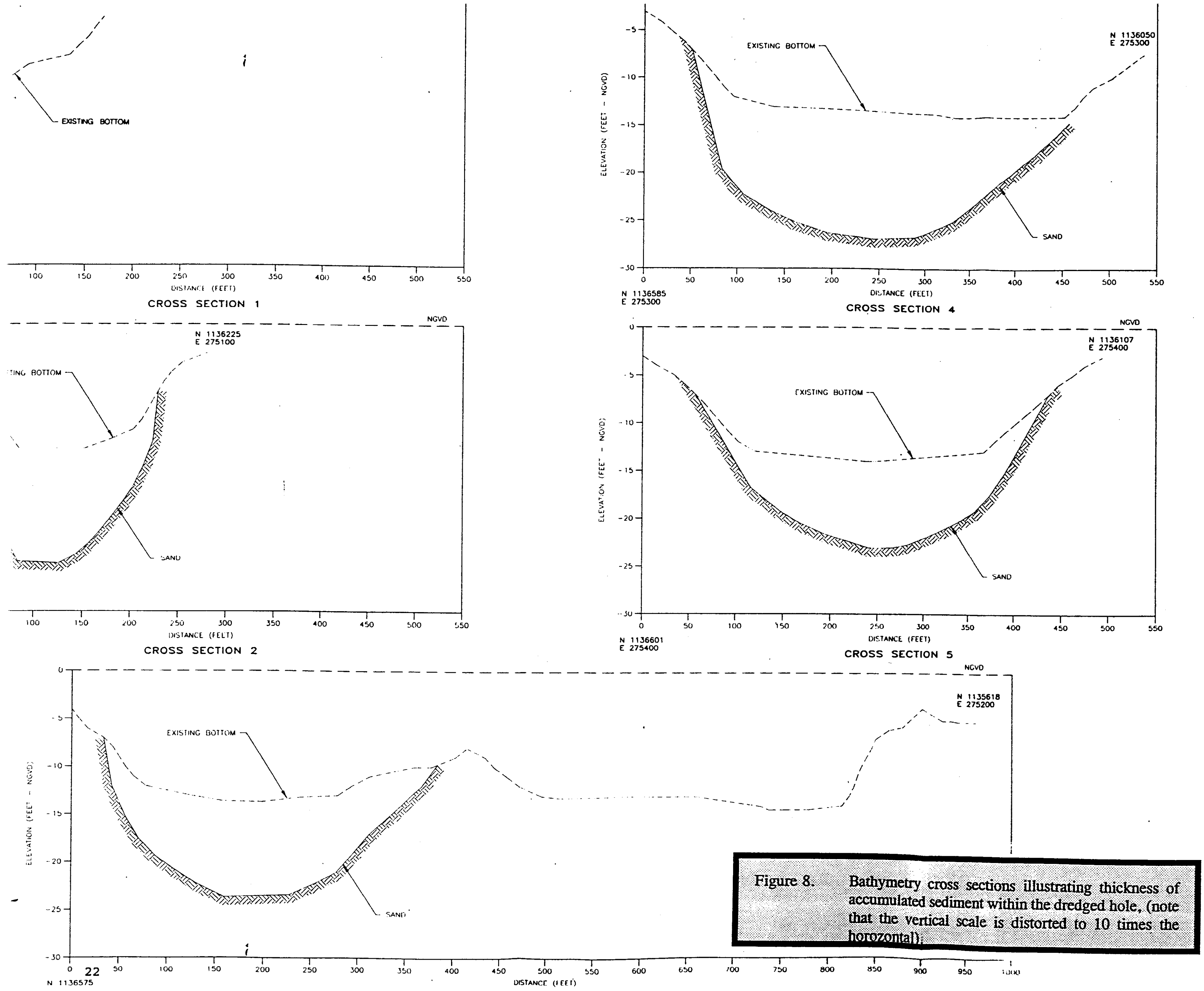
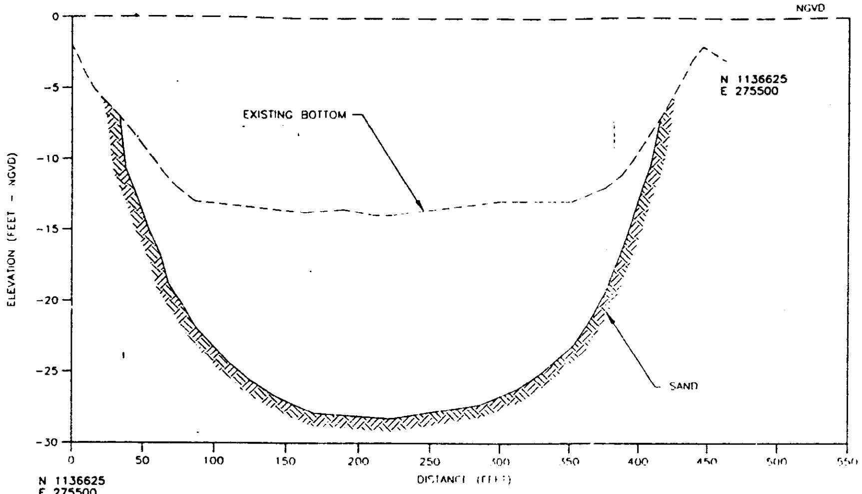
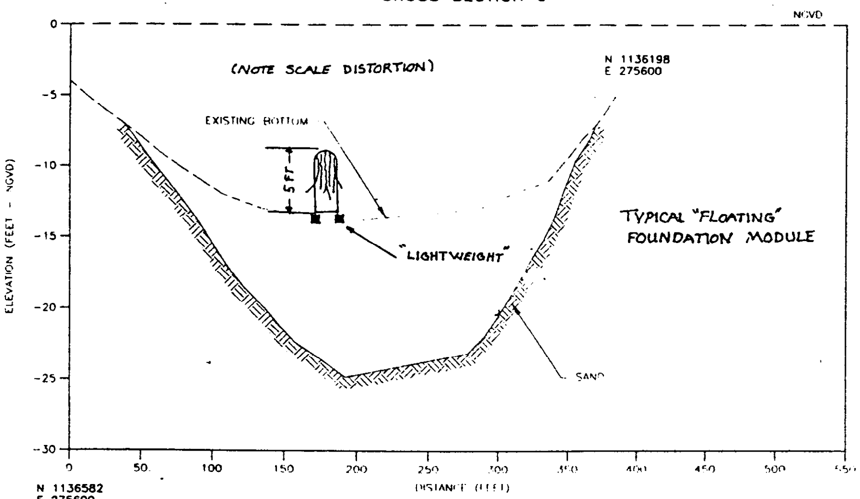


Figure 8. Bathymetry cross sections illustrating thickness of accumulated sediment within the dredged hole, (note that the vertical scale is distorted to 10 times the horozontal).



CROSS SECTION 6



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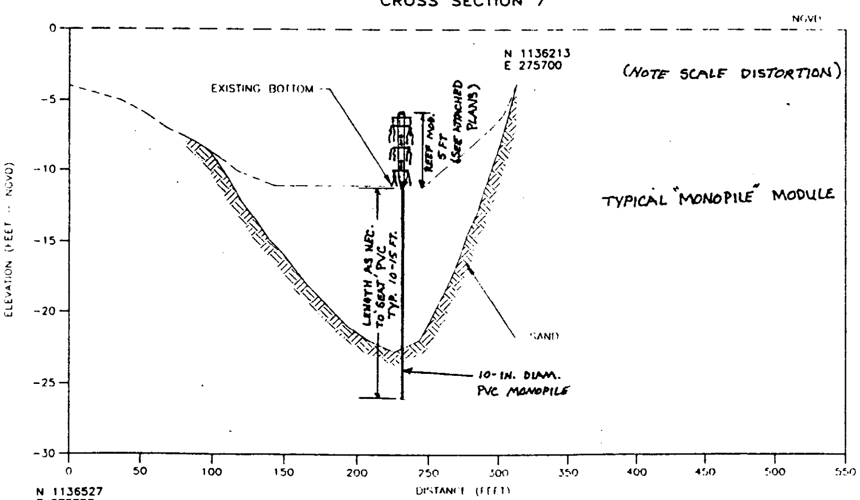

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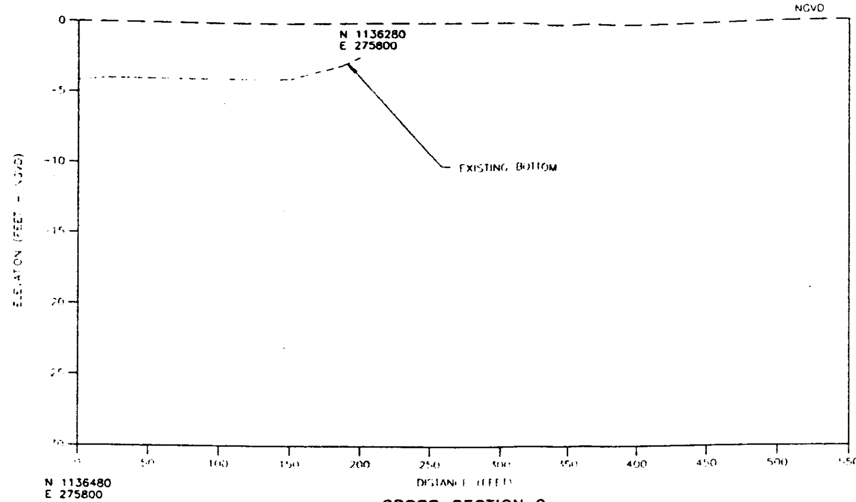
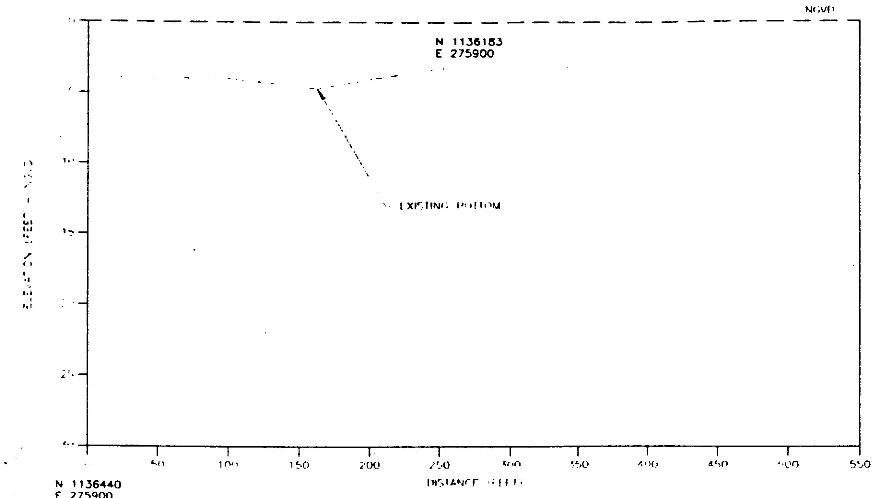


CROSS SECTION 9



CROSS SECTION 10

Figure 8. (continued). Artists rendering of reef modules shown in cross sections 7 and 8.

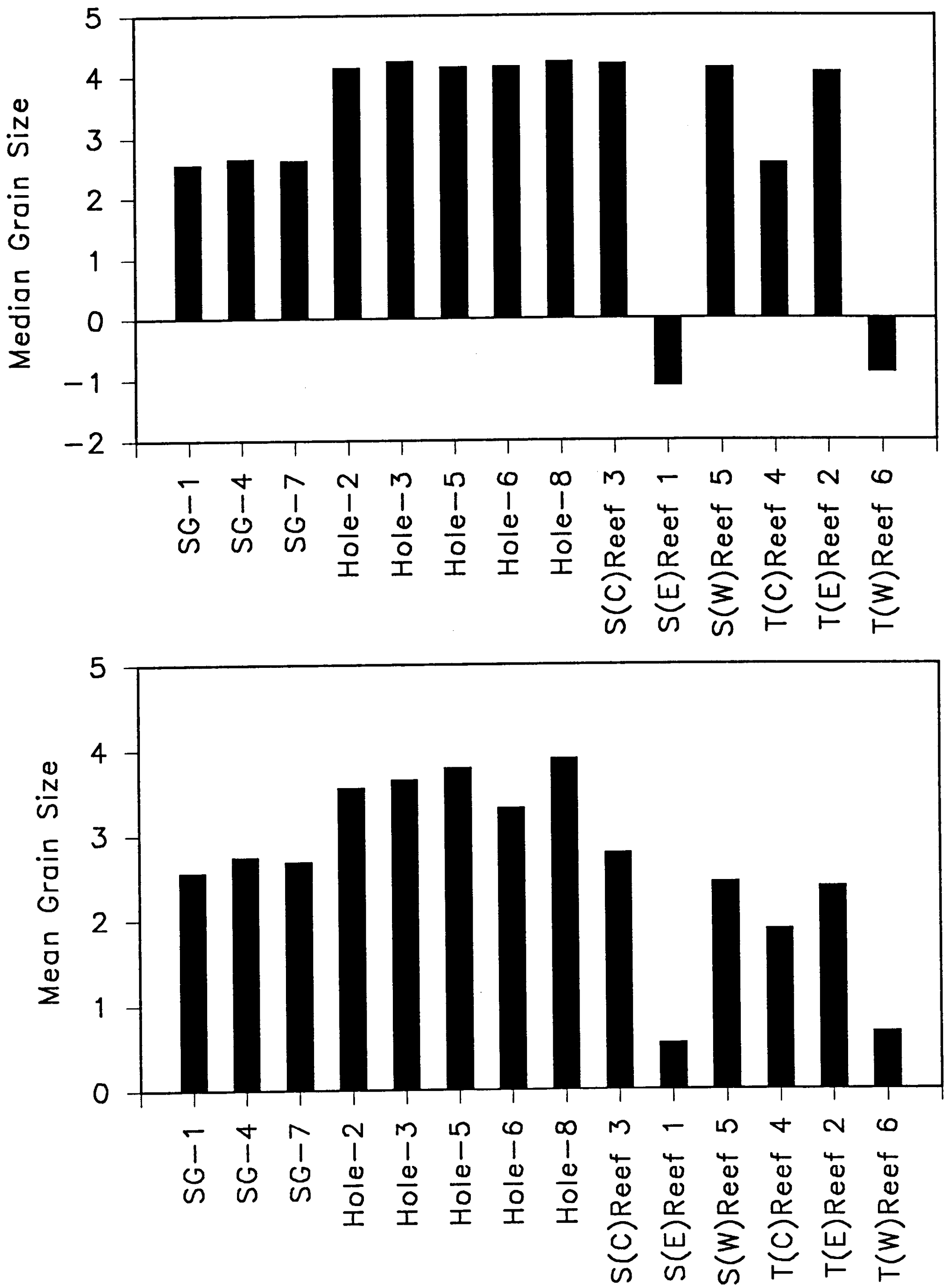


Figure 9. Comparisons of median grain size (top) and mean grain size (bottom) for all samples. SG and Hole samples taken May 1996, Reef samples taken June 1997.

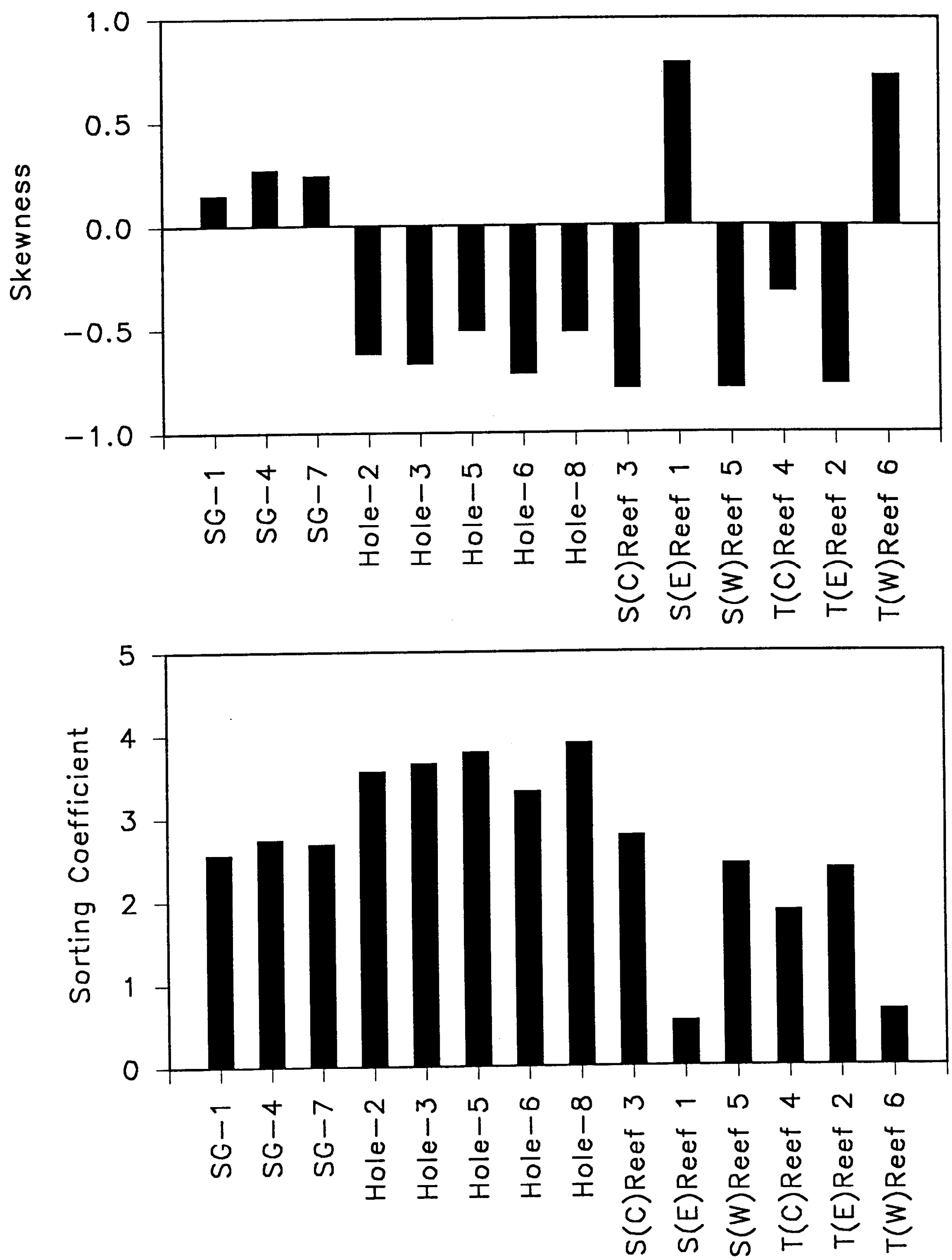


Figure 10. Comparisons of sediment skewness (top) and sorting coefficient (bottom) for all samples. SG and Hole samples taken May 1996, Reef samples taken June 1997.

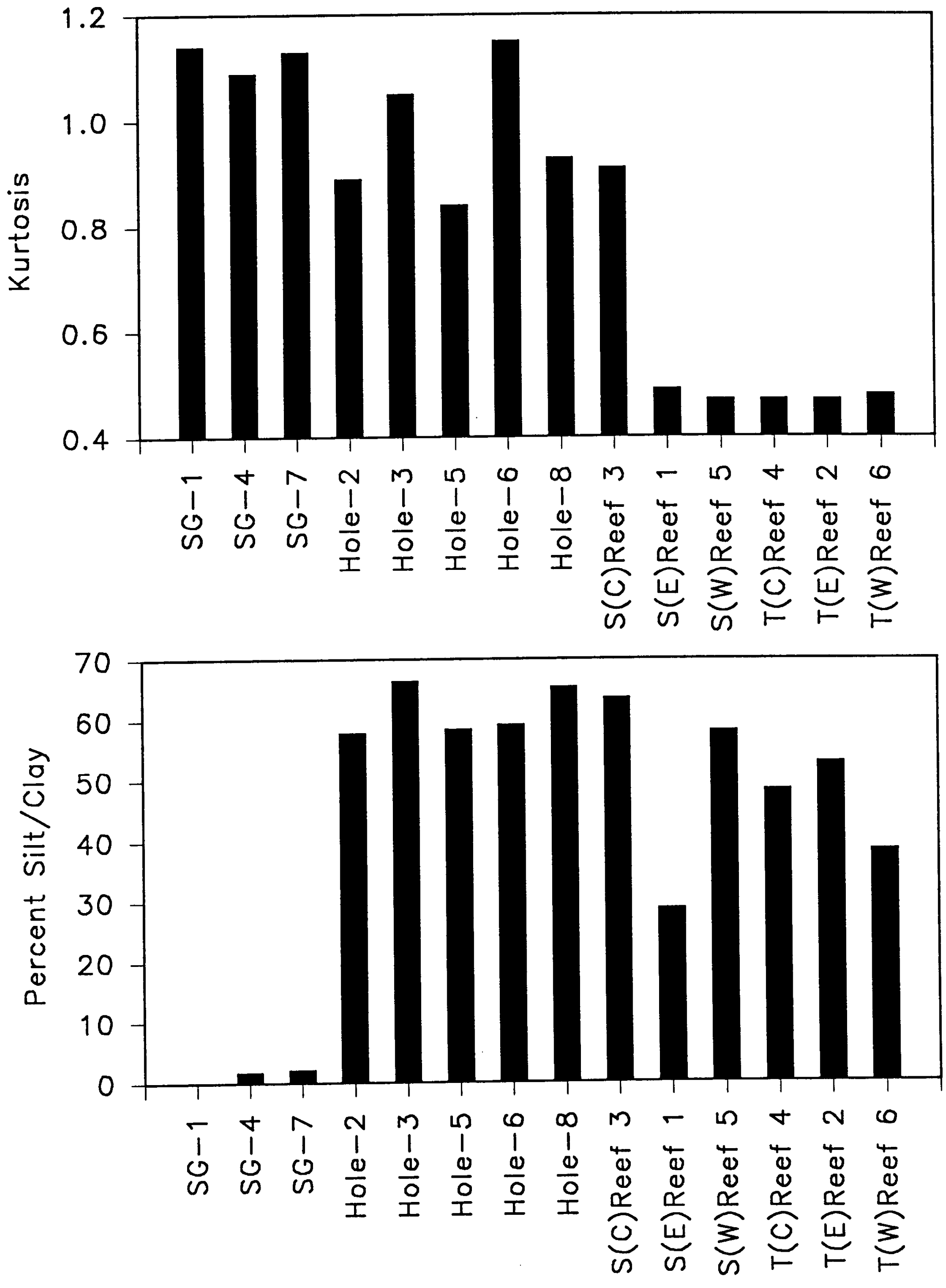


Figure 11. Comparisons of sediment kurtosis (top) and percentage silt/clay (bottom) for all samples. SG and Hole samples taken May 1996, Reef samples taken June 1997.

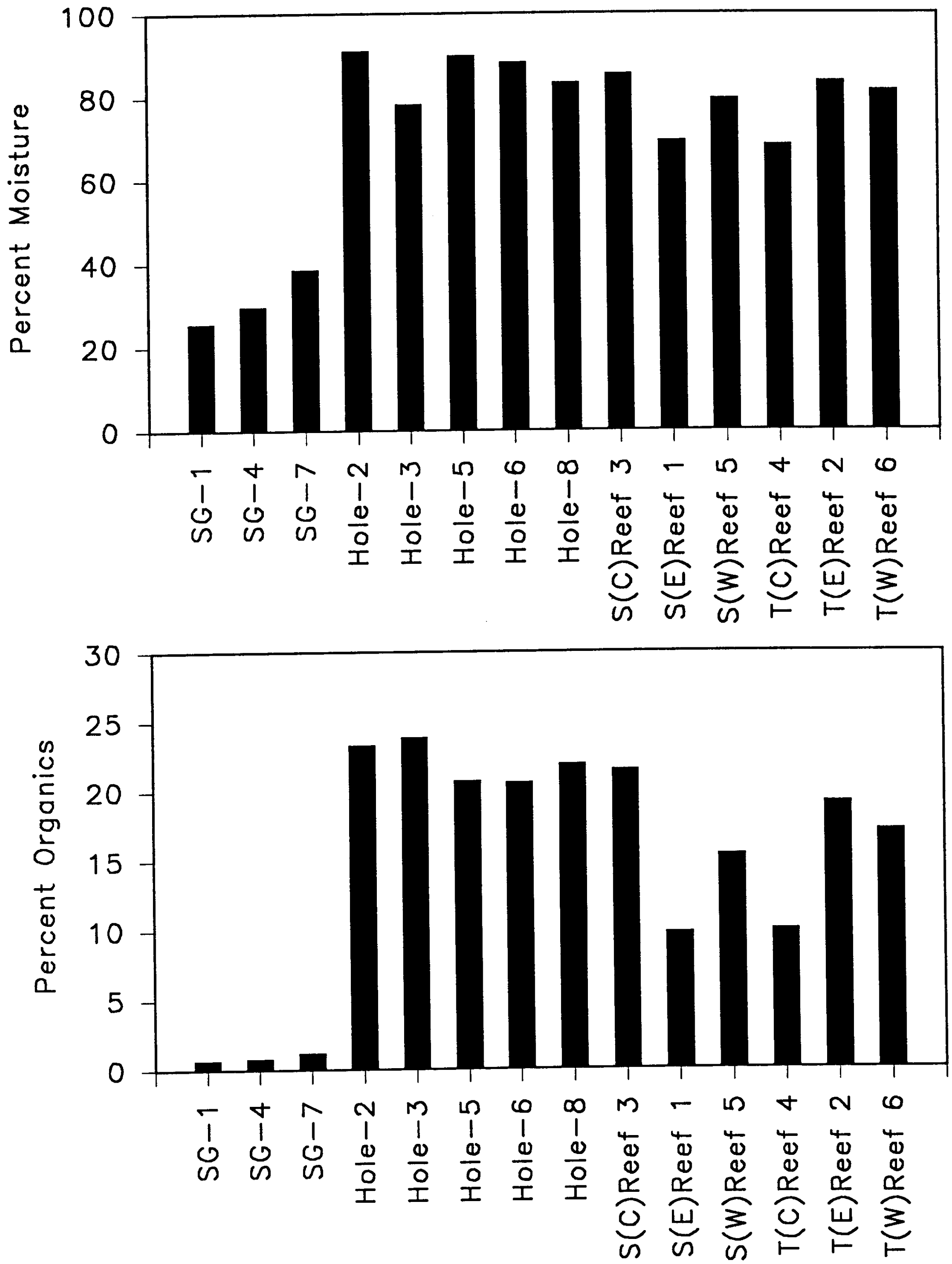


Figure 12. Comparisons of sediment moisture (top) and percentage organics (bottom) for all samples. SG and Hole samples taken May 1996, Reef samples taken June 1997.

Fish of various sizes were observed at all sites although the larval and juvenile stages were more abundant at the PVC reefs. This was likely due to the greater complexity of "spaces" on the PVC reefs. In addition to the invertebrates, algae and fish bottlenose dolphins and manatees were observed in the near vicinity of the reefs on several occasions. A list of the larger epifauna, fish and mammals identified by divers is in **Table 3.**

The polypropylene line worked very well as colonization substrate. During reef construction the line was unraveled after securing to the structural members. The unraveled line consists of 720 filaments each providing a point of attachment for colonizing organisms. Upon initial deployment the polypropylene floats. At some point the colonization provides enough weight to sink the line to the "down" vertical position. By January the large number of lines had the appearance of "dreadlocks". The strands are not rigid and can move back and forth due to currents, wave action or swimming fish.

A species occurrence list was prepared for the January scrape samples. This information is presented as **Appendix Table 1** by rank order of number of occurrences in **Table 4.** The average number of taxa recovered from the three types of reefs was similar; 24.5 for the Bay Balls, 33.7 for the square reefs and 28.0 for the tree reefs, **Table** 5, bottom.

Species Composition

Data for the faunal analysis are presented in Appendix Tables. **Appendix Table 1** contains a list of the species collected by core samples for all three sampling events. **Appendix Table 2** contains a list of the species collected by the reef scrapes for the January survey. Species composition for the scrapes was only determined for January. **Appendix Table** 3 presents the faunal data from the core samples in rank order by abundance.

A total of 234 taxa was identified from the combination of core and scrape samples. Of these 195 taxa were identified from all of the benthic core samples. Sixty-seven taxa were recovered from the scrape samples. For core samples 95 taxa were recovered in May 1996, 79 taxa in January 1997 and 86 taxa in June 1997. The most abundant organism was the polychaete *Capitella capitata. Capitella* was most abundant in the January samples taken near the reefs and was also common in the seagrass samples taken in May of 1996. *Capitella* was nearly absent from the June 1997 samples taken near the reefs. This was probable due to higher water temperatures resulting in increased hydrogen sulfide production. For comparisons of reef alterations on fauna the January and June samples were compared to the May 1996 samples taken in the hole. The seagrass samples taken in May 1996 were taken to illustrate the original faunal associations which would have been present prior to the dredging of this site. **Table 6** presents a summary of the faunal parameters for each type of sample (hole, seagrass, and reef).

The May 1996 samples (pre-reef deployment) from the hole illustrate the lack of benthic infauna. From five cores there was an average of 5.6 species and 16 individuals present, compared to a mean of 35.2 species and 438 individuals taken from the seagrass beds. By January the number of species found beneath the reefs had increased to 6.3 and 9.7 for the square and tree reefs respectively. The control sites had an average of 18.5 taxa and represented bare sand samples taken adjacent to the seagrass beds. By June the number of species collected at the reef sites was 14.7 for the square reefs and 13.3 for the tree reef. No control samples were taken in June.

Table 3. Invertebrates and fish identified inhabiting the Cortez hole artificial reef structures one year post-deployment.

VERTEBRATA	
PICES (fish)	
OSTEICHTHYES (alphabetical order)	
Archosargus probatocephalus	sheephead
Chaetodipterus faber	Atlantic spadefish
Epinephelus morio	red grouper
Haemulon plumieri	white grunt
Lutjanus griseus	grey snapper
Hippocampus erectus	lined seahorse
Lagodon rhomboides	pinfish
Bodiahus rufus	Spanish hogfish
Parlaichthys albiqutta	Gulf flounder
Clinidae	blenny
MAMMALIA - Mammals	
CETACEA	
Tursiops truncatus	bottlenose dolphin
SIRENIA	
Trichechus manatus	West Indian Manatee
INVERTEBRATES	
ANTHOZOA	
CNIDARIA	
HYDROIDEA	unidentified species
ANTHOZOA	unidentified anemones
ARTHROPODA	
CRUSTACEA	
Menippe mercenaria	stone crab
Libinia emarginata	spider crab
Eurypanopeus depresus	mud crab
Balanus spp	barnacles
Crassostrea virginica	oyster
ECHINODERMATA	
ECHINOIDEA (sea urchins)	
Lytechinus variegatus	purple urchin
ASTEROIDEA	
Echinaster sp.	seastar
CHORDATA	
UROCHORDATA	
ASCIDIACEA (sea-squirts)	
Diademnidae	encrusting colonial tunicates
Clavelina sp.	colonial tunicates
PLANTS	
ALGAE	
CHLOROPHYTA (green algae)	
Caulerpa prolifera	green rhizophytic algae
Codium decorticatum	soft, spongy finger-like clump
Avrainvillea rawsonii	short fingerlike projections
RHODOPHYTA (red algae)	unidentified species

Table 4. Total biomass values for three artificial reef types, Bay Balls (BBall), Square PVC reef (S) and Tree style PVC reef (T). C, E, and W represent relative positions, center, east and west. Numbers represent grams weight per square meter of surface area.

Date	Reef	Wet Wt.	Dry Wt.	Ash Free Wt.	Percent Organic
Jan	BBall (E)7	3715	2159	136	6.3
June	BBall (E)7	34203	10235	675	6.6
Jan	BBall (W)8	837	362	38	10.5
June	BBall (W)8	18790	12227	450	3.7
Jan	S(C) Reef 3	39110	19578	1828	9.3
June	S(C) Reef 3	107044	29810	4779	16.0
Jan	S(E) Reef 1	40842	19801	1102	5.6
June	S(E)Reef 1	130577	57446	5782	10.1
Jan	S(W) Reef 5	17432	7006	531	7.6
June	S(W) Reef 5	23440	8869	635	7.2
Jan	T(C) Reef 4	45696	24106	1722	7.1
June	T(C) Reef 4	111737	45067	4156	9.2
Jan	T(E) Reef 2	45417	28297	1445	5.1
June	T(E) Reef 2	97575	36304	3230	8.9
Jan	T(W) Reef 6	38182	17233	1188	6.9
	T(W) Reef 6	70153	30967	2222	7.2

Table 5. Fauna from scrape samples in rank order of number of occurrences (n= 8) form each station (“X” = present, “-” = absent).

Taxa	BBall(E) 7	BBall(W) 8	S(C)Reef 3	S(E)Reef 1	S(W)Reef 5	T(C)Reef 4	T(E)Reef 2	T(W)Reef 6	Total Occurrence
Syllis (Typosyllis) cf. lutea	X	X	X	X	X	X	X	X	8
Eupolymnia	X	X	X	X	X	X	X	X	8
Sabella sp.A	X	X	X	X	X	X	X	X	8
Balanus eburneus	X	X	X	X	X	X	X	X	8
Paracerceis caudata	X	X	X	X	X	X	X	X	8
Corophium insidiosum	X	X	X	X	X	X	X	X	8
Bryozoa	X	X	X	X	X	X	X	X	8
Nereis falsa	X	X	X	X	X	X	X	–	7
Streblosoma hartmanae	X	X	–	X	X	X	X	X	7
Balanus reticulatus	X	–	X	X	X	X	X	X	7
Amphipoda sp. L	–	X	X	X	X	X	X	X	7
Lysianopsis alba	X	X	X	X	–	X	X	X	7
Caridea	X	–	X	X	X	X	X	X	7
Ascidiacea	X	X	X	–	X	X	X	X	7
Turbellaria	X	X	X	X	X	–	X	–	6
Cirriformia	–	–	X	X	X	X	X	X	6
Panopeus herbstii	–	–	X	X	X	X	X	X	6
Chaetozone	X	–	–	X	X	–	X	X	5
Crassostrea virginica	X	–	X	X	X	X	–	–	5
Leucothoe spinicarpa	–	X	X	–	X	–	X	X	5
Porcellanidae	–	–	X	X	X	X	X	–	5
Polydora socialis	–	–	X	X	X	–	X	–	4
Branchiomma nigromaculata	–	X	X	–	–	X	X	–	4
Hydroides dianthus	X	X	–	X	–	–	–	X	4
Polycera	–	X	X	–	–	X	X	–	4
Musculus lateralis	–	X	X	X	X	–	–	–	4
Amphipoda	X	–	–	X	X	–	–	X	4
Erichthonius brasiliensis	–	–	X	–	X	X	–	X	4
Lepidonotus sublevis	–	–	X	X	X	–	–	–	3
Brania clavata	–	–	–	X	X	–	–	X	3
Naineris	X	–	–	X	–	X	–	–	3
Polydora ligni	–	–	–	X	X	–	X	–	3
Branchiomma nigromaculata	–	–	–	X	X	–	–	X	3
Carinobatea	–	–	X	–	–	X	X	–	3
Phyllodocidae	X	X	–	–	–	–	–	–	2
Eumida sanguinea	–	–	–	X	–	X	–	–	2

Table 5. Continued.

Taxa	BBall(E) 7	BBall(W) 8	S(C)Reef 3	S(E)Reef 1	S(W)Reef 5	T(C)Reef 4	T(E)Reef 2	T(W)Reef 6	Total Occurrence
Neanthes succinea	–	–	–	–	X	–	X	–	2
Caulleriella	X	X	–	–	–	–	–	–	2
Capitella capitata	X	–	–	–	–	X	–	–	2
Ampithoe ramondi	X	–	–	–	–	–	–	X	2
Ampithoe ramondi	–	–	–	–	–	X	X	–	2
Brachyura	–	X	X	–	–	–	–	–	2
Holothuroidea	X	–	–	X	–	–	–	–	2
Gobiidae	–	–	–	–	–	X	X	–	2
Podarke obscura	–	–	X	–	–	–	–	–	1
Branchiosyllis oculata	–	–	–	X	–	–	–	–	1
Nereidae	–	–	–	–	–	–	X	–	1
Schistomeringos	–	–	–	–	–	–	X	–	1
Mediomastus	–	–	–	X	–	–	–	–	1
Sabellidae	–	–	X	–	–	–	–	–	1
Gastropoda	–	X	–	–	–	–	–	–	1
Crepidula plana	–	–	–	X	–	–	–	–	1
Mitrella lunata	–	–	X	–	–	–	–	–	1
Cantharus multiangulus	–	–	X	–	–	–	–	–	1
Marginella lavalleenana	X	–	–	–	–	–	–	–	1
Gastropteron rubrum	–	X	–	–	–	–	–	–	1
Haminoea succinea	–	–	–	–	–	X	–	–	1
Aeolidiidae	–	–	–	X	–	–	–	–	1
Anadara transversa	–	–	X	–	–	–	–	–	1
Sphenia antillensis	–	–	X	–	–	–	–	–	1
Gastrochaena hians	–	–	X	–	–	–	–	–	1
Pantopoda	–	–	–	X	–	–	–	–	1
Hargeria rapax	X	–	–	–	–	–	–	–	1
Erichsonella attenuata	–	–	–	X	–	–	–	–	1
Elasmopus	–	–	–	–	–	X	–	–	1
Latreutes fucorum	–	–	X	–	–	–	–	–	1
Pelia mutica	–	–	–	–	–	X	–	–	1
Eurypanopeus depressus	–	–	X	–	–	–	–	–	1
Menippe mercenaria	–	–	–	–	–	X	–	–	1

Table 6. Summary statistics for benthic fauna collected from each diver core and scrape sample for each date and station.

Date	Sampler	Station	Number of Taxa	Number of Individuals	Individuals per m2	Shannon-Wiener Index $\log_e$	Shannon-Wiener Index $\log_{10}$	Shannon-Wiener Index $\log_2$	Pielou's Index J'
96-May	Core	Hole-1	5	15	647	1.34	.58	1.93	.83
96-May	Core	Hole-2	3	3	129	1.10	.48	1.58	1.00
96-May	Core	Hole-3	6	13	560	1.48	.64	2.14	.83
96-May	Core	Hole-4	7	27	1164	1.33	.58	1.92	.68
96-May	Core	Hole-5	7	21	905	1.66	.72	2.40	.85
		Hole-Mean	**5.6**	**16**	**681**	**1.38**	**.60**	**1.99**	**.84**
96-May	Core	Seagrass-1	29	377	16250	2.39	1.04	3.45	.71
96-May	Core	Seagrass-2	61	1194	51466	3.00	1.30	4.32	.73
96-May	Core	Seagrass-3	4	14	603	.90	.39	1.29	.65
96-May	Core	Seagrass-4	41	310	13362	2.67	1.16	3.85	.72
96-May	Core	Seagrass-5	41	295	12716	2.91	1.26	4.20	.78
		Seagrass-Mean	**35.2**	**438**	**18879**	**2.37**	**1.03**	**3.42**	**.72**
97-Jan	Core	BBall(E) 7	27	116	7436	2.66	1.16	3.84	.81
97-Jan	Core	BBall(W) 8	32	103	6603	2.76	1.20	3.99	.80
		Bay Ball Mean	**29.5**	**110**	**7019**	**2.71**	**1.18**	**3.92**	**.80**
97-Jan	Core	Ctrl N 9	20	63	4038	2.52	1.10	3.64	.84
97-Jan	Core	Ctrl So 10	17	37	2372	2.62	1.14	3.77	.92
		Ctrl Mean	**18.5**	**50**	**3205**	**2.57**	**1.12**	**3.71**	**.88**
97-Jan	Core	S(C)Reef 3	10	93	5962	.70	.30	1.01	.30
97-Jan	Core	S(E)Reef 1	4	95	6090	.26	.11	.38	.19
97-Jan	Core	S(W)Reef 5	5	74	4744	.34	.15	.49	.21
		Sq. Reef Mean	**6.3**	**87**	**5598**	**.43**	**.19**	**.62**	**.23**
97-Jan	Core	T(C)Reef 4	7	296	18974	.36	.16	.52	.19
97-Jan	Core	T(E)Reef 2	12	390	25000	.49	.21	.70	.20
97-Jan	Core	T(W)Reef 6	10	164	10513	.49	.21	.71	.21
		Tree Reef Mean	**9.7**	**283**	**18162**	**.45**	**.19**	**.64**	**.20**

Table 6. Continued.

Date	Sampler	Station	Number of Taxa	Number of Individuals	Individuals per m2	Shannon - Wiener Index H' log_e	Shannon - Wiener Index H' log_{10}	Shannon - Wiener Index H' log_2	Pielou's Index J'
97-June	Core	BBall(E) 7	28	171	10962	2.30	1.00	3.31	.69
97-June	Core	BBall(W) 8	35	576	36923	1.91	.83	2.75	.54
		Bay Ball Mean	**31.5**	**374**	**23942**	**2.10**	**.91**	**3.03**	**.61**
97-June	Core	S(C)Reef 3	9	28	1795	1.97	.85	2.84	.90
97-June	Core	S(E)Reef 1	26	188	12051	1.75	.76	2.52	.54
97-June	Core	S(W)Reef 5	9	17	1090	1.87	.81	2.70	.85
		Sq. Reef Mean	**14.7**	**78**	**4979**	**1.86**	**.81**	**2.69**	**.76**
97-June	Core	T(C)Reef 4	22	90	5769	1.89	.82	2.73	.61
97-June	Core	T(E)Reef 2	9	13	833	2.03	.88	2.93	.92
97-June	Core	T(W)Reef 6	9	14	897	1.97	.85	2.84	.89
		Tree Reef Mean	**13.3**	**39**	**2500**	**1.96**	**.85**	**2.83**	**.81**
97-Jan	Scrape	BBall(E) 7	26						
97-Jan	Scrape	BBall(W) 8	23						
		Bay Ball Mean	**24.5**						
97-Jan	Scrape	S(C)Reef 3	36						
97-Jan	Scrape	S(E)Reef 1	36						
97-Jan	Scrape	S(W)Reef 5	29						
		Sq. Reef Mean	**33.7**						
97-Jan	Scrape	T(C)Reef 4	31						
97-Jan	Scrape	T(E)Reef 2	30						
97-Jan	Scrape	T(W)Reef 6	23						
		Tree Reef Mean	**28.0**						

Samples were also taken near the Bay Balls. However, these units were placed on firm sandy substratum, therefore the results are not directly comparable to the soft-bottom reefs.

Figure 13 illustrates the relationship between numbers of animals found (in a core) to the number of taxa collected. The figure clearly shows the low numbers of species and individuals that were present for the hole samples prior to reef deployment. The figure also shows that species abundance and richness are increasing for samples taken beneath the reefs. Thus the reef structures are manifesting an effect on both the sediment structure and the biota of the substratum.

Faunal Similarity

Faunal similarity comparisons of each core sample from each station and sampling date are represented by the cluster diagram of **Figure 14.** The analysis was based on Bray-Curtis similarity index and group averaged sorting. With only a few exceptions habitat types and date of sampling clustered independently. This shows that the faunal communities beneath the reefs are different from both the pre-deployment condition (hole samples) and the seagrass community. The analysis also illustrates that the community beneath the reefs are changing through time.

Biomass

Biomass values are presented in **Table 4** and graphically illustrated by **Figures 15-18.** Ash-free dry weight ranged from 38 to 5,782 grams per square meter. The PVC reefs maintained a greater level of biomass than the concrete Bay Balls. For six months post-placement the Bay Balls exhibited an average of 87 grams ash-free weight per square meter (n= 2) compared to an average of 1,302 grams ash-free weight per square meter (n **=6)** for the PVC reefs. For the 11 month samples the Bay Balls exhibited 562 grams ash-free weight per square meter (n=2) compared to 3,467 grams ash-free weight per square meter (n= 6) for the PVC reefs.

The principal reason for this difference is the configuration of the surface area. The Bay Balls, although curved, present a relatively flat surface for colonization. The area above the surface remains constant and the volume above a unit surface is roughly equivalent to a box. The areas sampled for the reefs was a 15 centimeter length of 3/4 inch pipe. The surface area is strongly curved. Because of this curve the volume of habitat space increases in the form of concentric cylinders as the pipe becomes colonized. For both types of habitat barnacles represented the first layer of macrofauna followed by larger colonial invertebrates such as tunicates. For the pipe habitat each successive layer increases the available colonization area. For a flat or slightly curved surface the colonization area remains constant (or nearly so) regardless of the number of layers of epiphytic cover.

V. SUMMARY AND CONCLUSIONS

As a Sarasota Bay National Estuary Program, early action project, a study was designed to demonstrated the technical feasibility and effectiveness of artificially enhancing dredged holes within the bay. The project concept was innovative in two ways: it directly converted an existing negatively impacted area into a more productive habitat by use of simple, minimal technology; and it utilized the known effects of artificial reefs on a soft muddy bottom.

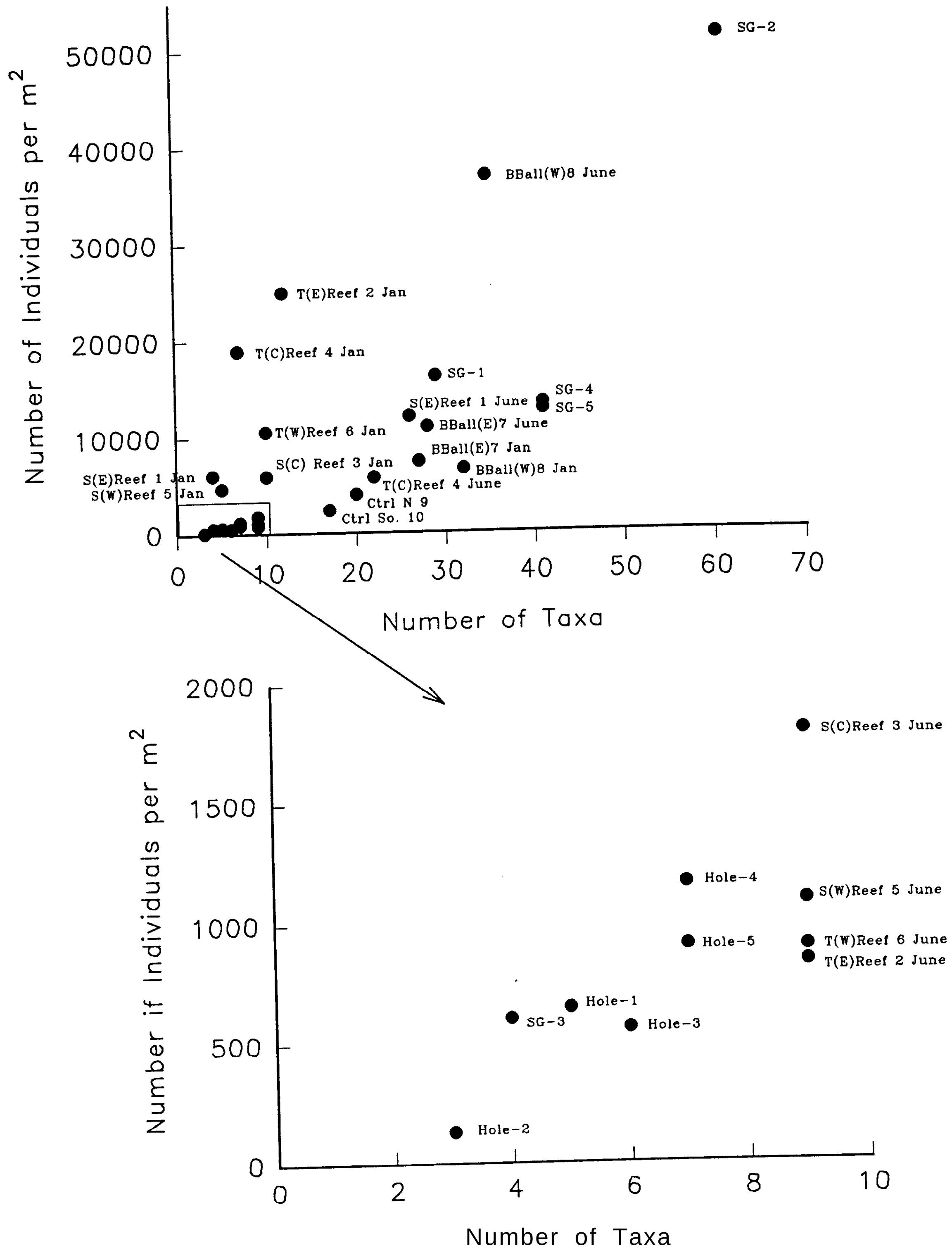


Figure 13. Relationship between abundance and species richness for all reefs.

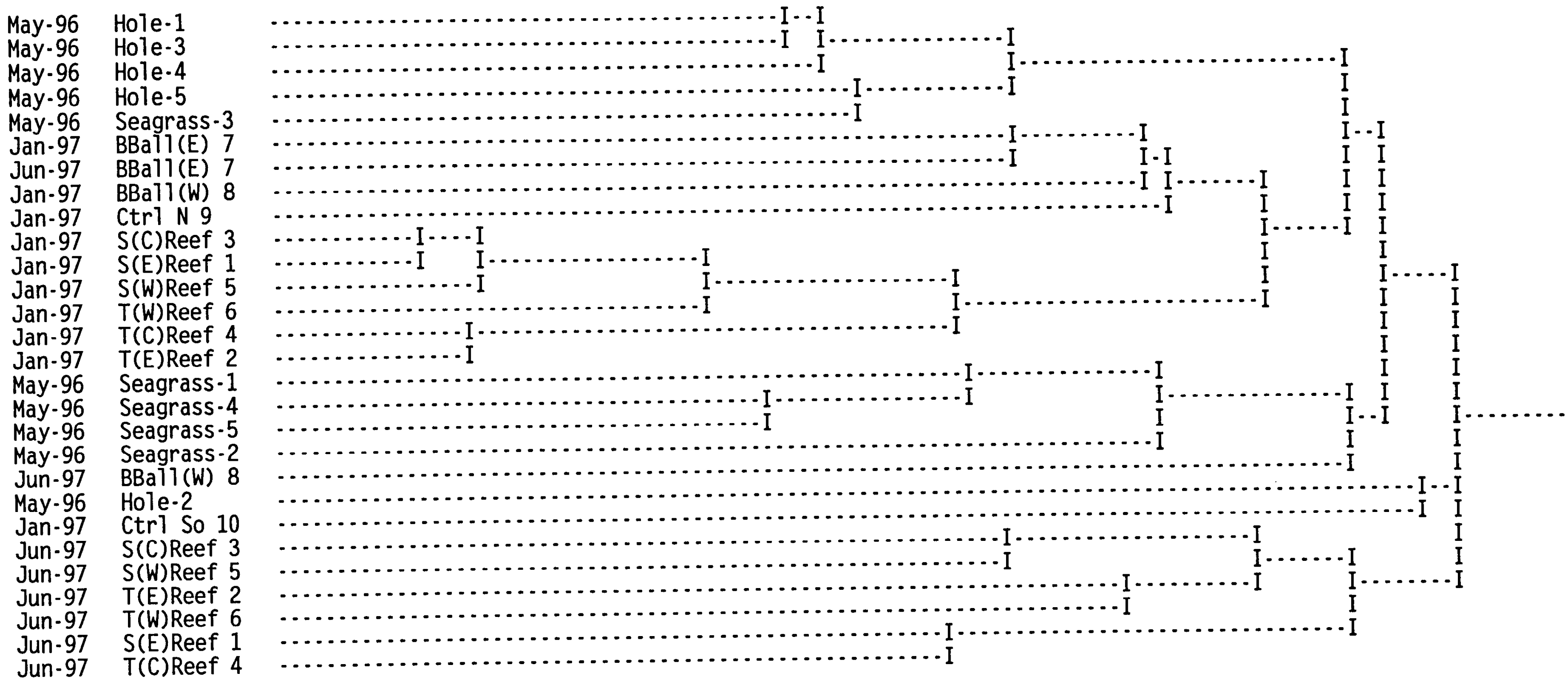


Figure 14. Cluster diagram of each core sample from each station and sampling date. Based on Bray-Curtis similarity index and group averaged sorting.

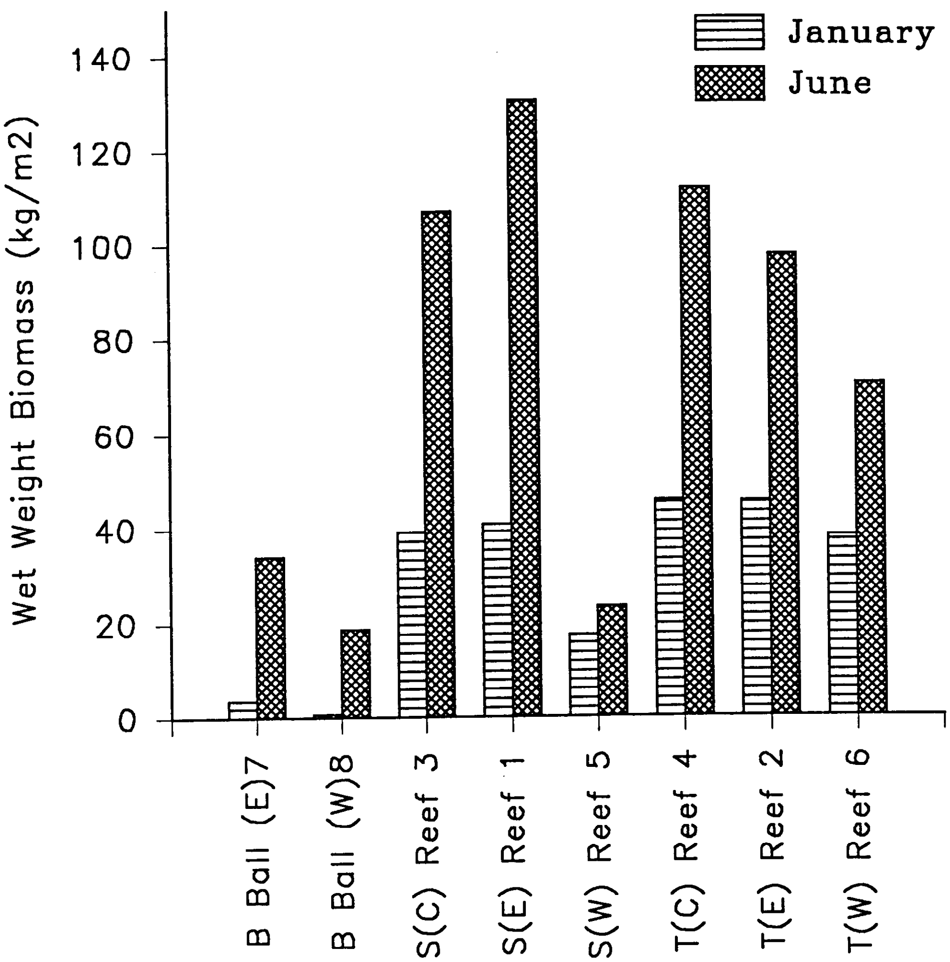


Figure 15. Comparisons of wet weight biomass values between reefs.

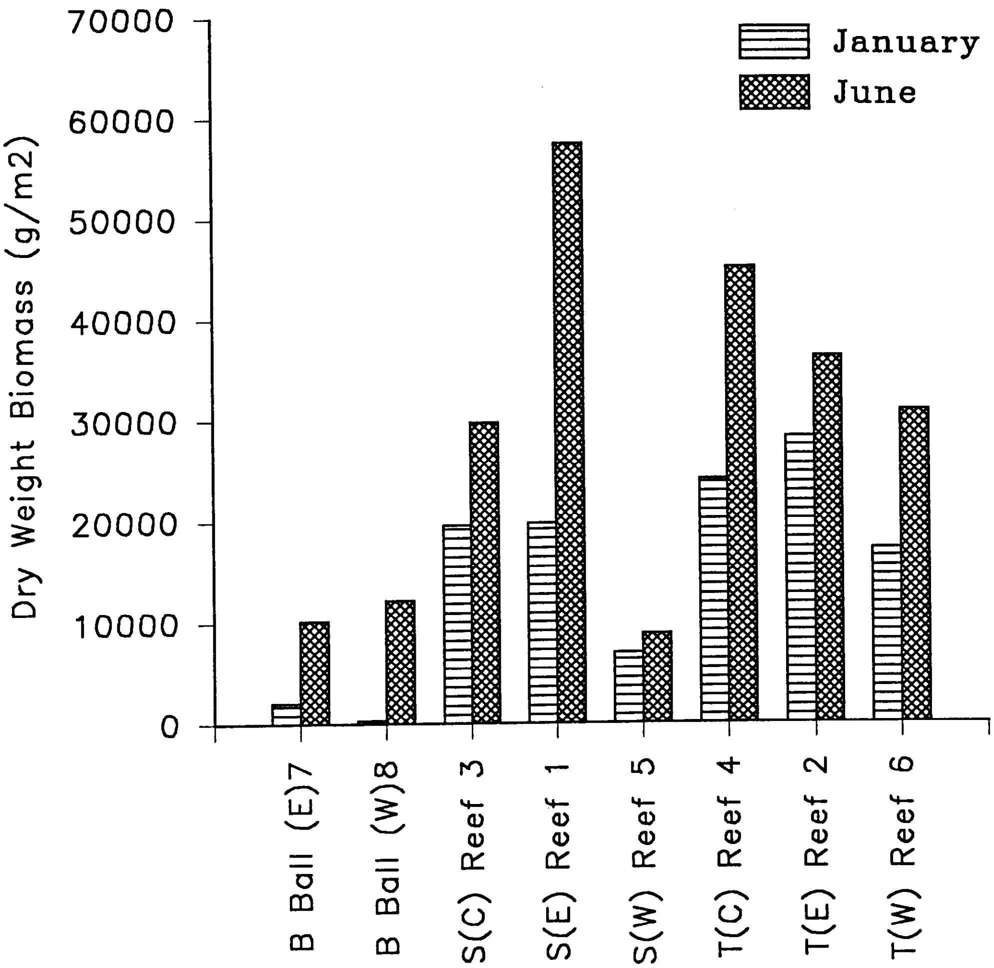


Figure 16. Comparisons of dry weight biomass values between reefs.

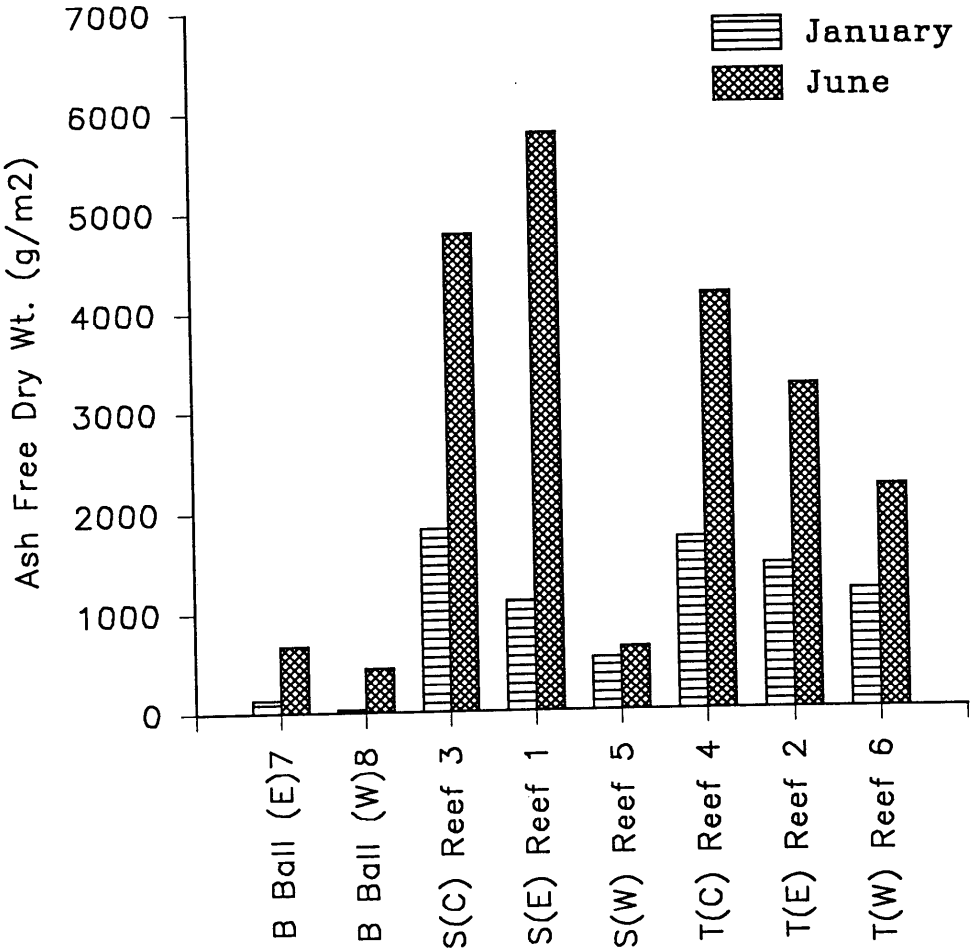


Figure 17. Comparisons of ash-free dry weight biomass values between reefs.

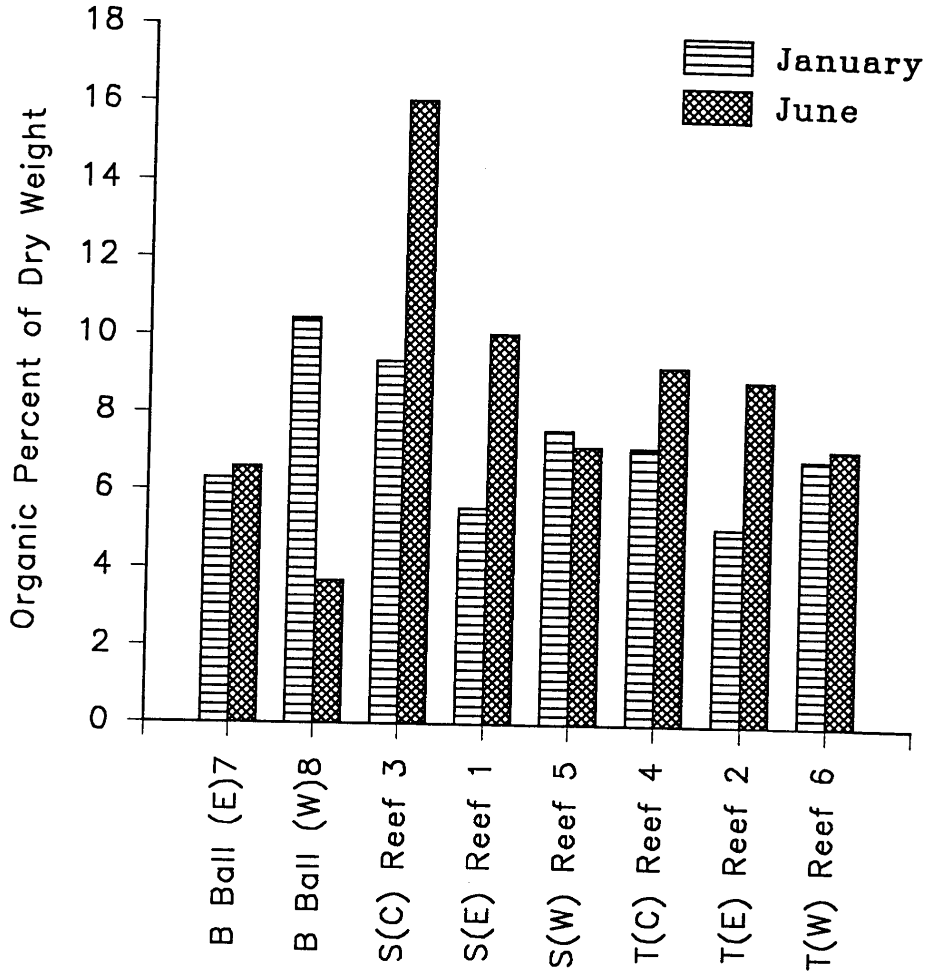


Figure 18. Between reef comparisons of organic content as a percentage of dry weight.

Two reef designs were tested for deployment over a thick layer of fine grained anoxic sediments. One design dubbed a tree module was supported above the mud by a monopile which penetrated to firm substratum. The second module was square with a domed superstructure, and was designed to float on the soft mud. The modules were constructed from readily available PVC pipe and conduit of various circumference. The rigid spaces were made more complex through the addition of short lengths of polypropylene line secured only at one end. It was hypothesized that the reef modules would have two basic enhancement effects:

> create new complex habitat through the colonization of the reef by an epifaunal invertebrate community, and
>
> the reef modules would alter the substratum beneath them through the shedding of carbonate shell material (barnacles, molluscs) from the reef structure. This would have a positive effect on the benthos by increasing the overall grain size of the substratum.

Monitoring of sediment grain size, biomass scrapes and infaunal samples showed that both hypothesis were correct. The reefs have increased productivity and are having an effect on the sediment structure.

This unique application of artificial reefs has excellent potential for basinwide application with additional similar anomalistic sites already known to exist in the Sarasota Bay system. The dredging practices which created these sites were common throughout Florida at the time, and there are identical opportunities for restoration which exist statewide.

VI. LITERATURE CITED

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APPENDIX

LIST OF APPENDIX TABLES

Information available from Mote Marine Laboratory Library upon request.