

UNITED STATES
DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Region
State, Federal & Constituent Programs Office



COMPLETION REPORT

Grantee: MARYLAND DEPARTMENT OF NATURAL RESOURCES

Project No: N/A

Grant No: NA76FU0166

Project Title: U.S. EPA AQUATIC REEF HABITAT PLAN

Period Covered: 05/01/97 - 08/31/98

Prepared by: GARY SMITH

Approved by: _____

Date: DECEMBER 1, 1998

Statutory Funding Authority: Anadromous Fish Conservation Act
(P.L. 89-304)

- Chesapeake Bay Studies
- Endangered Species Act
- Interjurisdictional Fisheries Act (Title III of P.L. 99-659)
- Magnuson Act
- Oyster Disease Research
- Saltonstall-Kennedy
- Unallied Industry Projects
- Unallied Science Projects



Final Report
for U.S. EPA Maryland Aquatic Reef Habitat Plan
FY96 Funding
Maryland Department of Natural Resources

NA76FU0166

Submitted to

U.S. EPA Region III CBPO
410 Severn Ave. Suite 109
Annapolis MD 21403

NOAA/NMFS/NCO
1 Blackburn Drive
Gloucester MA 01930

From

Mapping and Analysis Project
Cooperative Oxford Laboratory
901 s. Morris St.
Oxford, Md 21654

Contact

Gary F. Smith

Fisheries Service
Maryland Department of Natural Resources

Executive Summary

This report summarizes work performed under federal contract NA76FU0166. Specified work included the construction of high relief oyster reefs at three sites in the Maryland Chesapeake Bay. The majority of funding was applied to the purchase and deployment of dredged oyster shell for reef construction. Additional overhead funding was applied to the pre-survey and post-survey of reef sites as well as to the development of effective habitat assessment tools for both natural and man-made oyster reef and oyster bottom. Due to delays in availability of these FY96 funds, the project was pushed back and run concurrently with follow up FY97 federal funding. As project tasks were similar, the additional funds greatly increased the scope of reef construction and research into oyster habitat assessment technology.

Reef construction was completed in the late summer of 1997 after baseline site assessment. At each of three sites, four mounds of 2,000 cubic yards of oyster shell were constructed. Mounds were approximately 150 ft. long by 75 ft. wide. They rose a maximum of 10 ft. from base to top. Mounds at each site were situated within an approximate six acre site. At one reef site South West Middleground, (west of Tangier Sound) natural spat set was adequate to allow for immediate recruitment. At the other two sites, Cook's Pt. (Choptank River) and Strong Bay (Chester River), seeding of both natural and hatchery produced seed was performed to enhance oyster development.

A key aspect of this project was to begin to develop effective habitat assessment tools for the assessment and mapping of key aspects of oyster habitat. An evaluation of previous oyster reef construction projects identified the need to clearly and accurately characterize habitat at restored sites. This need extended beyond simple habitat assessment to an ability to identify and chart critical habitat components of oyster bottom in need, and potentially capable of restoration efforts. Traditional mechanical methods of physical assessment by patent tong or oyster dredge, are extremely laborious, difficult to quantify, and often very limited in the character of information they extracted from the bottom.

Our project's experience with the application of Geographical Information System (GIS) technology as related to benthic aspects of Chesapeake Bay, allowed us to proceed rapidly on evaluation of oyster habitat assessment technology. After a series of test evaluations, we have settled on specific technologies of Acoustic Seafloor Classification Systems (ASCS) specially linked to Global Positioning System (GPS) locational information, and GIS analysis and display. Critical to proper application of such tools is highly accurate and precise calibration data which serve as categorical examples of specific oyster habitat conditions.

Acknowledgments

The author wishes to express thanks to the many individuals who assisted with work performed under this contract.

Field / Survey Work

Captain John Collier
Lee Daniels
Ann McManus
Kelly Greenhawk

Data Entry and Graphics Generation

Kim Insley
Julie Nace
Ann McManus

Report Preparation and Graphics Generation

Kelly Greenhawk

Contents

| | |
|--|----|
| Site Selection and Pre-Survey | 5 |
| Reef Design and Construction | 6 |
| Post Deployment Surveys | 8 |
| Coordination with Aquatic Reef Habitat Plan | 8 |
| Coordination with FY97 Funding | 9 |
| Joint Status Reports NA76FU0166 / NA76FU0311 April 1, 1998 - September 30, 1998 | 12 |
| Development of Habitat Assessment Technology | 17 |
| Introduction | 17 |
| Methods | 23 |
| Results and Discussion | 27 |
| Literature Cited | 40 |
| Figures and Tables | 43 |

Figures

| | |
|-----------|---|
| Figure 1 | Regional site locations |
| Figure 2a | Strong Bay site location |
| Figure 2b | Cook's Pt. site location |
| Figure 2c | Kedges Straits site location |
| Figure 3 | Grid cell rendition of Bay Bottom Survey results at the Strong Bay site |
| Figure 4 | Illuminated Bathymetry at the Cook's Point location |
| Figure 5a | Strong Bay patent tong pre-survey region |
| Figure 5b | Strong Bay patent tong results (liters/m ²) |
| Figure 6 | 3D integration of bathymetric and patent tong data at the Strong Bay reef site |
| Figure 7 | Photo of deployment of reef shell |
| Figure 8a | 3d bathymetry of reef configuration - Cook's Point |
| Figure 8b | 3d of all four mounds - Cook's Point |
| Figure 9 | Still-frame grabs taken from video transect over one of the Cook's Point reefs |
| Figure 10 | Previous reef locations throughout Maryland |
| Figure 11 | Plum Point area showing material types of deployment |
| Figure 12 | Yates oyster bar boundaries in the Choptank River region |
| Figure 13 | Maryland Bay Bottom Survey in the Choptank River region |
| Figure 14 | OSAP (Oyster Stock Assessment Program data for Royston bar |
| Figure 15 | Sub-bottom survey tracks in the Choptank River region |
| Figure 16 | Choptank River airplane wreck imaged with side-scan sonar gear |
| Figure 17 | Side scan sonar image over computer-generated surface of the edge of Cook's Pt. |
| Figure 18 | Sediment profile graph and diver observations for one calibration site |
| Figure 19 | Sub-bottom profile - buried historic oyster bar edge |
| Figure 20 | Sub-bottom profile - methane gas "plumes" |
| Figure 21 | ROV drop locations on Stone bar with video image and Roxanne transect |
| Figure 22 | Roxanne transect on Stone Rock oyster bar showing E values |
| Figure 23 | QTC data output on portion of Sandy Hill oyster bar showing confidence values |
| Figure 24 | Dimensions of Hierarchical Systems in Oyster Habitat Assessment |
| Figure 25 | Sandy Hill oyster bar QTC survey results |
| Figure 26 | Point data transformation to grid-cell format |
| Figure 27 | Example of using "rules" to interpolate focal generation of data for all cells |
| Figure 28 | 3D representation of QTC survey conducted on Cook's Point |

Tables

| | |
|----------|--|
| Table 1. | Proposed and actual reef material purchase and deployment. |
| Table 2. | Reef sites constructed under prior Aquatic Reef Funding. |
| Table 3. | Milestone chart for extended FY97 funding. |

Site Selection and Pre-Survey

Pre-Survey Analysis

The Chesapeake Bay Aquatic Reef Habitat Plan suggest that the 3-dimensional aspect of oyster reefs enhances oyster recruitment, survival and growth, and may moderate parasitic infective pressure (Chesapeake Executive Council). Until now, Maryland's oyster repletion program has focused on flat shell plants on the bottom. Construction of high (3m) mounds where consistency of design and deployment size and shape is rigorously enforced will provide valid experimental sites from which to evaluate these proposed benefits.

Original planning called for construction of three dimensional oyster reefs at three geographic locations. Reef sites were to be at high, mid, and low salinities within the Maryland Bay. Recommended siting areas were provided to this program by DNR Fisheries Service personnel. These locations were principally based upon site requirements and minimizing impact upon the oyster fishery. Siting locations are referenced by Maryland Named Oyster Bars (Smith et al. 1997) Original locations were Strong Bay - Chester River, Cook's Pt. - Choptank River, and Kedges Straits - Northwest of Smith Island. Department of Natural Resources oyster dredge permits were modified by the Army Corps of Engineers to permit reef construction at these three locations [(MD DNR/Shell Dredging) 92-65749-9]. Figure 1 shows regional site locations.

The selection of three distinct geographic regions for oyster reef construction identifies that there is high variation of environmental conditions related to oyster recruitment and parasitic disease in the mesohaline Maryland Bay. The most northerly site in the mouth of the Chester River would provide some degree of refuge from chronic disease pressures and associated high mortalities. This location is also in an area where the large majority of oyster repletion efforts by means of seeding and shelling occur in Maryland. Thus results from this region would allow for direct comparison with ongoing traditional repletion efforts.

The site at the mouth of the Choptank River would provide information from a region of constant parasitic disease pressure, and potential of high annual recruitment. The Cook's Point location has other features of particular interest to hypotheses pertaining to mounded oyster reefs. The Cook's Point oyster bar has very recently gone barren in the true sense. No live oyster could be found upon it during recent annual population surveys (MDNR). Detailed surveys of oyster bar topography and sediment characteristics indicate a severe sedimentation problem typical of many of the Maryland oyster bars. This location would offer a good example if raised oyster reef could truly provide some protection from accumulation of sedimentation.

The site west of Kedges Strait is near a location where recruitment is traditionally at it's highest in the Maryland Bay. The location also exhibits annually high levels of both of the parasitic shellfish diseases in the Bay.

Two potential reef sites were provided at the Strong Bay and Cook's Pt. Four potential sites were identified in the Kedges Strait location. Subsequent pre-survey by patent tong of the Strong

Bay and Cook's Pt. sites allowed for selection of the best of the two locations. In Kedges Straits, all recommended sites did not meet required criteria. They were either on mud or shifting sands. Further surveying located a site at Southwest Middleground which had substrate suitable for reef construction. An amendment was made to the Corps permit on Aug 20, 1997 to allow for construction at this site. Figures 2a, 2b, and 2c show site locations.

Pre-survey work involved an analysis of bathymetry as well as bottom type from a previous Bay Bottom Survey (1975-1983) (Smith in progress). It was our attempt to assure that sites would have adequate bottom surrounding reef locations for planned oyster reserves. Figure 3 shows a grid cell rendition of Bay Bottom Survey (BBS) results on a one acre cell size of the Strong Bay site. Figure 4 shows a computer enhancement of raw NOAA bathymetric survey data at the Cook's Point site. Similar bathymetric analysis was done at the other sites to assist in determining that reef locations would be on firm substrate.

Preliminary Field Surveys

Detailed field surveys were conducted in August 1997 at each of the planned sites. Two survey methods were applied. First patent tong sampling for surface shell (liters/square meter) was performed in a grid fashion over the entire potential site area. Figure 5a shows the survey area at the Strong Bay location. Figure 5b shows both patent tong surface shell quantities and transects along which bathymetric data was obtained. Sediment type was also recorded. Geographical Information System integration of data (Fig. 6) from each site allowed for the most favorable placement of individual reefs at each site. Close attention to local bathymetry was required due to water depth criteria over the reef surfaces.

Reef Design and Construction

Design Criteria

Original plans called for utilizing funding for both purchase of dredged oyster shell and marine limestone for deployment. Initial plans called for limestone to be used as a base material upon which oyster shell was to be placed. Two issues eliminated the use of limestone. 1) Original projections indicated that limestone might be transported and deployed free of charge from a quarry in North Carolina. Only quarrying costs need be covered. When this transport did not materialize, the cost of limestone became prohibitive compared to dredged shell costs. 2) An existing "blanket" permit allowed for somewhat unrestricted placement of oyster shell in the Bay. Consultation with permit agencies could not rapidly resolve if marine limestone (Marl), was an original shell product or a rip rap material. Permitting may have held up construction. All funding targeted for limestone purchase was fully redirected to fossil oyster shell purchase.

Original design criteria for reef structures needed to be flexible based upon final cost predictions and deployment methodology capable of the contractor. Preliminary design called for a frustrum of a cone for individual reefs (cone with the top cut off level). Ultimately barge carrying capacity, barge maneuverability and deployment method determined number of reefs at each site as well as size.

Shell Construction

At each of the three reef sites, four reefs were constructed. Water depth was approximately 22 ft. at each location. All four reefs are within an approximate 500 ft. radius from a centroid location. Individual reefs are linear, and all run in an east-west direction. A total of 2,000 cubic yards of shell was placed on each of the four individual reefs (Fig 7). The critical dimension of deployment was to have reef 10 feet above the bottom. Fisheries Service directives indicated that total footprint should not exceed 5 acres. Figures 8a and 8b show actual reef configuration on Cook's Pt. in the Choptank River. Other reef sites had similar configuration. All reef were constructed during the last week of August and the first two weeks of September 1997.

Deployment dates were delayed from that originally planned in the proposal due to three factors. 1) Delays in a federal interagency agreement allowing transfer of funds. 2) Lack of a suitable vessel for pre-survey work. 3) Involvement of the shell deployment contractor with another project (Corps of Engineers) prior to our planned deployment.

Funding from both this FY96 and follow up FY97 contract were used to purchase shell for the three sites. Table 1 shows proposed reef material purchase and deployment costs against actual purchases. Proposed material purchases closely matched actual costs. A very minor quantity of shell was deducted from material supplied due to the need to split personnel transport vessel costs with the contractor.

Typical shell on barge deployment for Maryland oyster restoration projects is accomplished by hydraulic hosing of shell into the water. While this technique works well for flat or shallow mounded deployments, it was felt it would not suffice to produce well defined mounds. Project deployment of shell was modified to utilize a crane and bucket deployment. The crane barge had three spuds, with which to firmly plant itself to a fixed position upon the bottom. Each bucket load of shell contained 10 cubic yards. Bucket counts confirmed by shell on barge measurements were utilized to determine shell volume deployed. Reef length was based upon crane reach. A critical component of construction was not to attempt to move and re-spud the crane barge during construction of an individual reef. Shape and depth control was maintained by bucket measurement, and bathymetry from the survey support vessel.

Reef Seeding

Original projections called for the "seeding" of yearling oysters at the two most northern reef sites. It was expected that the southern site west of Kedges Straits would have adequate natural recruitment. Despite the late summer date in reef construction, this proved to be the case, and a large natural spat set colonized the four mounds at Middleground (Kedges Straits).

At the Cook's Point site seeding was accomplished in September of 1997 with the deployment of 700 (5 liter) bags of Piney Point Hatchery seed. Seed was emptied from bags and scattered densely over the four mounds. Additional bags were emptied throughout the seafloor between the mounds. In May of 1998 the Strong Bay site was seeded with 1,290 bushels of seed obtained

from the Bugby region of Eastern Bay. Spat counts per bushel were so high in this region (1997 set) that the seeding densely covered the mounds.

Post Deployment Surveys

High resolution bathymetric surveys to document baseline configuration of deployed reefs have been conducted at the Cook's Point and Kedges Straits sites. Bathymetric surveying at the Strong Bay site will be conducted in fall of 1998 in conjunction with habitat assessment surveying. Surveying at this site has been delayed till this time to allow for the assessment of survivorship of planted seed as well as potential natural spat set of the summer of 1998. Bathymetric point data collected in integration with differential Global Positioning System (GPS) positioning data allowed for precise imaging of reef position and shape.

In July of 1998 a video transect of a side of one of the Cook's Pt. reefs was made. (Fig 9). Advances in our video capability due to this project's funding will allow for high resolution vertical transects to be made of each of the reef sites. This will be accomplished utilizing extended FY97 funds during a clear water window in the winter of 1998-99.

Habitat assessment surveys of the three reef sites are planned for in the fall/winter of 1998-99. Surveys have been delayed until the integrated Seafloor Classification / Geographical Information Systems has proven its validity in accurate assessment of bottom habitat. This system will be employed to chart substrate type and oyster cultch density in conjunction with bathymetric relief in the local "field of influence" of each site.

Coordination with Aquatic Reef Habitat Plan

This project was funded in conjunction with goals and objectives of the Aquatic Reef Habitat Workgroup. Reef construction projects in Maryland were to be an integral part of the Aquatic Reef Habitat Plan, an "agreement / commitment" plan approved by the Chesapeake Executive Council. As such we followed guidelines in the plan as to the construction and monitoring of reef structures. An additional aspect of this project was in contributing to the attainment of Maryland's 5,000 acre designation goal. Our original objectives in conjunction with our role in the Aquatic Reef Workgroup was two fold. 1) Research and represent, using GIS technologies, recent historic efforts in artificial reef construction in Maryland waters. 2) Provide through GIS data integration and field capabilities, the best available information as to actual oyster habitat condition in regions of potential designation for inclusion with the 5,000 acre designation effort.

In September 1997 our program was removed from involvement with the Aquatic Reef Habitat Workgroup. However, our efforts continued in line with project completion for FY96 and FY97 funding. Maryland DNR Restoration and Enhancement Program was to take the lead in tasks related to the Habitat Plan and Reef Workgroup. For fiscal year 1998, project control of reef funding was transferred to DNR's new Oyster Division.

These administrative changes precluded us from immediately applying our capability in examination of oyster habitat quality at potential designation sites within the 5,000 acre plan. Our energies were then focused on two related avenues of investigation. 1) Development of oyster habitat assessment tools, and 2) Assembly of best information on preexisting Maryland oyster reef project sites. For the former, this report documents considerable efforts directed at this applied research. As to the latter, considerable project energies were directed towards collecting available information about previous reef sites in Maryland constructed under the auspices of the Aquatic Reef Habitat program. A wide variety of sources were utilized to determine deployment location and materials utilized. Principal effort was directed at reefs constructed under the previous Maryland Aquatic Reef Program.

Complete data was presented in GIS format to allow for examination of data at a variety of scales. Charts and electronic representations of this data were presented to the current DNR reef program and the Chesapeake Bay Program. Table 2 provides a breakdown of reef sites we identified. Figures 10 and 11 show reef locations in the Maryland Bay as well as detailed deployment locations at a principal reef site.

Project Coordination with FY97 Funding

Duplication in Status Reporting (FY96 and FY97 funding)

Since the inception of both grants, identical status reports have been submitted as to document progress for both FY96 and FY97 contracts. This was done for the following reasons. Maryland FY96 oyster reef project money was processed late due to federal delays in securing a signed NMFS/EPA Interagency Agreement. When funding was finally secured for both projects, fiscal year funding was virtually concurrent.

The original grant proposals submitted called for FY96 funds to be used for construction of one reef in Tangier Sound, and FY97 monies to be used for construction of two reefs in the Choptank and Chester Rivers. At the time of planned construction the State, (as well as DNR necessities) was effectively required by its sole source shell supplier to complete a one-time purchase of all planned shell from both fiscal year contracts. We had yet to receive funding through NMFS and construction had to occur at this time, or logistics would delay it for an entire year. The State underwrote for a short period the shell cost reflected in both fiscal year proposals. Note that "Marl" was never purchased. Budgeted dollars were instead used for shell purchase.

During shell deployment, optimizing barge sizes and loads dictated shell mound size and equalized reef size at all three locations. So, in reality, it is impossible to say which fiscal years budgeted shell went on which of the twelve reefs at the three sites. Sites share shell from both budgets.

A similar situation arose in assigning the 15% of contract costs used for field surveys and habitat assessment work to one particular year. Other than the FY96 addendum funds which were earmarked for shell and special equipment purchases and leases, expenditures in this survey and assessment category could not be segregated into fulfilling the objectives of just one of the

contracts. One contract simply supplemented the other in the scope and scale of reef construction and assessment.

For our first status report, we originally submitted a joint report for both contracts. We were notified that this was unacceptable for accounting purposes. An acceptable alternative was to submit identical reports for both fiscal year contracts. This is what we did for subsequent status reports.

Remaining Project Goals - Extended FY97 Funding

Summary

The revised milestone chart (Table 3) reflects our ongoing efforts to meet the objectives of our proposal under the Aquatic Reef Habitat Plan. Principal efforts which need to be continued in the following year are: 1) Habitat classification and charting at artificial reef sites constructed in 1997. 2) Habitat assessment and charting of designated sanctuary areas within Maryland waters. 3) Continued development of linked Acoustic Seafloor Classification Technology and Geographical Information System display and analysis for the assessment of oyster habitat and oyster habitat restoration efforts. 4) Reporting and project data transfer.

Habitat classification at the three reef sites constructed under the auspices of this and FY96 Aquatic Reef funding will be conducted during the fall and winter of 1998. All sites have previously been pre-surveyed via patent tong methodology prior to reef construction. Sites have had detailed bathymetric surveying conducted after reef construction. Final site surveys utilizing newly developed Acoustic Seafloor Classification System (ASCS) technology were postponed until classification/calibration libraries had been developed and tested. This has been accomplished and reef site habitat charting can proceed shortly.

We wish to apply our developing remote habitat assessment capability to newly designated regions incorporated into Maryland's 5,000 acre oyster sanctuary goal. As these regions were not designated at the time of our original proposal, and our seafloor classification equipment was not yet operational, we were unable to commit to a specific surveying program. Presently very limited information is available as to the baseline conditions of these regions. This is true as to general bottom characteristics as well as the designation of areas most suitable for restoration. We hope to extensively characterize benthic habitat in these regions designated for intensive oyster restoration activities.

A principal goal of this contract has been to begin to develop effective tools for the cost effective, accurate, and precise assessment of oyster habitat. Research into the linkage of Acoustic Seafloor Classification Systems (ASCS) technology and Geographical Information Systems (GIS) analysis and display has led us to the point where habitat charting can be performed at a level never before achievable. There is however much room for improvement, both in the integration of new technology, and the application of the linked systems. Primarily, system calibration and validation needs to be improved. New system components need be added to address the limits of benthic

habitat detection capability. And finally GIS generated hierarchical routines need be developed to assist in producing final data output that addresses the criteria, scope, and detail needed in oyster habitat assessment.

This project has and will continue to generate a large amount of data and results pertaining to the identification, assessment, and mapping of oyster and other benthic habitat. Project plans must include mechanisms for the transfer of knowledge, information, and data and charts of potential need to funding and management agencies involved in aquatic reef issues. Future status reports will directly address product availability and transfer.

Joint Status Reports

Submitted In Conjunction with Final Report for NA76FU0166

Resubmitted for the period
April 1, 1998 - June 30, 1998

New Submittal for the period
July 1, 1998 - September 30, 1998

Submitted

October 31, 1998

For

U.S. EPA Aquatic Reef Habitat Plan. Joint FY96 - FY97 Funding

NA76FU0166 / NA76FU0311

(For Oyster Reef Construction and Oyster Habitat Evaluation in Maryland Waters)

Background

This report is being submitted in fulfillment of reporting obligations for the U.S. EPA Aquatic Reef Habitat Plan for joint FY96 and FY97. These contracts have funded the Maryland Department of Natural Resources to enhance the Chesapeake Bay oyster resource. Initial goals of these contracts were to construct sanctuaries of three-dimensional oyster habitat for the establishment of oyster and other hard surface communities. Such structures are based on the concept of oysters as keystone species in the Bay, supporting shell communities of filter-feeding benthic organisms, and providing structure, shelter and forage for many species of mobile vertebrates and invertebrates.

A secondary aspect of these contracts was to develop effective habitat evaluation tools for the assessment of habitat of both natural and man-made oyster reefs and oyster bottom. It has been realized that effective restoration and evaluation of oyster habitat can only be made if the tools and technology are available with which to evaluate oyster habitat restoration efforts and or determine suitability of bottom for restoration.

As part of this effort, a suite of remote technologies have been evaluated to determine their success in oyster habitat assessment by several criteria at a variety of scales. In conjunction with this work, research has proceeded along areas related to the valid application of remote sensing technologies to this task. These are: 1) Techniques of calibration and validation of newly developed remote technologies. 2) Integration, representation and analysis of output data with Geographical Information Systems (GIS) technologies.

Current Status of Project

Pre-Deployment Surveys:

All potential reef locations were surveyed utilizing bathymetric assessment and patent tongs during July and August of 1997. Survey results linked to Geographic Information System (GIS) interpretation and integration with baseline habitat data files were used for final site selection.

Reef Deployments:

Oyster reefs were constructed in August and September of 1997 at three locations in the Maryland Bay. These are; Southwest Middleground (west of Smith Island), Cook's Pt. (mouth of Choptank River), and Strong Bay (mouth of Chester River). Each reef site contains four mounds of 2,000 cu. yds. of dredged oyster shell. Mounds are located in a rectangular pattern within an approximate 6 acre footprint. Maximum mound height above the seafloor is approximately 10 ft.

Oyster Seeding:

The Southwest Middleground reef site obtained a dense natural spat set in the late summer of 1997. There are no plans to further seed this site as recruitment is typically good on an annual basis in this region.

Seven hundred bags of oyster "seed on shell" produced at the Piney Point facility were placed on the Cook's Pt. reef location in October 1997. Seeding was done on all four of the constructed oyster shell mounds as well as the central area between the mounds.

During this quarter seeding was also accomplished at the Strong Bay site. A total of 1,290 bushels of seed was obtained from the Bugby region of Eastern Bay. This high record count of spat per bushel of shell was placed on each of the four oyster reefs in May of 1998.

In the spring of 1998 it will be determined which of the three reef locations could benefit from additional oyster seeding. As reef sites have not yet been designated as sanctuaries from harvest, we need to identify a level of oyster development on the reefs that is desirable for their ultimate purposes.

Post Survey Planning

Detailed bathymetric and habitat classification surveying is planned for each of the sites. Bathymetric surveys have been completed for the Southwest Middleground and Cook's Point site. We expect to soon map habitat in the area of influence at all three sites (example Fig. 28). Acoustic Seafloor Classification System (ASCS) testing and integration with Geographic Information System (GIS) data analysis and display has been completed to a level to allow habitat mapping. Underwater video transects of reef sites will also be performed at this time to allow for both baseline evaluation of reefs, and validation of habitat

Development of Oyster Habitat Assessment Capability

To date we have evaluated the available range of remote sensing equipment potentially capable of detecting the character and quality of oyster habitat. We have focused our research on the use of Acoustic Seafloor Classification Systems (ASCS) for oyster habitat assessment. Direct goals of this work are to efficiently and correctly evaluate and chart the condition of current oyster bottom, and to assess the short and long-term success in oyster restoration activity. In line with the application of ASCS toward these goals, related activities have begun to allow for the accurate and precise calibration and validation of ASCS and the integration of generated data with Geographical Information Systems display and interpretation.

Reporting for the Period April 1, 1998 - June 30, 1998

After recent purchase of a Questar Tangent Corporation ASCS system, we began system testing onboard the R.V. Laidly. Preliminary evaluations occurred on February 11th utilizing calibration data previously generated during initial testing of the system and additional site evaluations accomplished during the previous quarter. After this initial trial, vessel difficulties and the need to spend time developing system integration with Global Positioning System (GPS) and GIS software and hardware delayed further field trials for over a month. During this time substantial

equipment modifications and additions to the Laidly were performed.

On April 1, field testing of QTC equipment integrated with GPS / GIS began. On this day, and April 7, and May 8, acoustic calibration testing was performed. Underwater video and Ponar grab sampling was additionally performed to provide calibration information. On May 21 final calibration data was collected, and the first survey run was generated.

Preliminary evaluation of results showed the need for great improvement in the quality of calibration data. With legal restrictions on diving removed on May 29th, we began an intensive effort to generate better habitat information on sites to be used to calibrate the ASCS. Data collected at sites included underwater video, diver observations and sediment sample collection. New techniques for sediment sample analysis were developed. Integration of this suite of information into GIS display and analysis continued. These operations continued on June 3, 5, 11, 11, and 25.

On June 9th Piston coring was accomplished on the R.V. Discovery. Previous examination of sub-bottom profiling data obtained under the auspices of this contract indicated the presence of submerged slopes and terraces in correlation with charted oyster bar boundaries. Planned lead 210 analysis of cores taken from soft sediments above such slopes was hoped to indicate if these oyster reef features had been recently buried with sediment.

Reporting for the Period
July 1, 1998 - September 30, 1998

During the previous quarter and the beginning of this quarter, personnel of the Mapping and Analysis Project at the Oxford Laboratory had been reduced from five individuals involved in this work to two. This was the Project Director and a Programmer / GIS analyst. Assistance from University of Maryland graduate students in field work and sediment processing and analysis allowed principal tasks to continue. Field work on July 2 included further site evaluation via diving.

On July 16, testing of our new prototype underwater video system began with divers as observers of system operation. This dragged sled (nick-named "BIRD") was assemble from components to maximize quality of black and white and color video images at close range with minimum disruption to the bottom. Further evolution of the video system through this and the following quarter continually increased imaging capability.

On July 24, and August 11-12 we extensively surveyed the oyster bar "Sandy Hill". Results focused on looking at the effect of different calibration site combinations (catalogs) being utilized over the same bottom. We worked extensively with this data to assess different approaches to GIS data incorporation. We began serious efforts in applying Hierarchical and Scale Theory to the assessment of oyster habitat.

During this quarter, final results from our sediment analysis assessments were available. For each of our calibration sites, material or sediment size by percent of sample was available for replicates from each of the sampling sites. Special techniques utilizing Coulter Counter analysis were employed to rapidly assay the fine (mud, silt, clay) portion of the sample. In conjunction with traditional sieving methods, we hoped such techniques would greatly reduce the cost of total sample processing.

As a final assessment of QTC capability to discern fine variation in cultch composition we took the R.V. Laidly to the mouth of the Nanticoke River on August 24. A Corps of Engineers project had subjected bottom sediments at this location to unreplicated treatments of sediment cleansing. Although water depth was known to be a limiting factor to our success¹, we attempted fine detail surveying of the region. The region where treatments were performed was generally less than 3 m in depth. Due to hurricane warnings we had to leave the area before completion of surveying and underwater video analysis.

¹ The QTC system as currently configured can perform poorly or falsely in water depths of less than 3m. Such difficulty is currently resolved by modification of one of the signal processing algorithms.

Development of Habitat Assessment Technology

Introduction

Background

The chronic and extreme long-term decline of oyster harvest in the Chesapeake Bay has been blamed on a combination of three factors: over-harvest, disease, and loss of oyster habitat. Of the three factors, the chronic effects of habitat loss through destruction of reef structure and sedimentation may be the most difficult to quantify on a large scale over time. In the soft bottom environment of the Chesapeake Bay, live or dead oyster shells protruding above the sediment (cultch) are the principal available substrate for spat settlement and growth. Outside of limited placement by management agencies of fresh or dredged oyster shell, historic oyster bars or reefs are the only suitable areas of such hard substrate for oyster settlement. Given that natural spatfall is currently the only means of viable, large scale, oyster recruitment in the Chesapeake Bay, availability of suitable cultch for the attachment of oyster spat could be considered a principal limiting factor to enhancement of the oyster resource of the Bay.

Habitat loss due to processes such as sedimentation, over harvest, and harvest practices may have lead to widespread destruction of oyster "bottom" or "reef" structure. Detailed documentation of the exact extent of this loss has been difficult to generate due to three major factors: 1) the tremendous extent of historic oyster growing region within Chesapeake Bay; 2) the difficulty of determining exactly what bottom habitat or oyster density is considered as oyster "bottom"; and 3) the difficulty in directly comparing historic and recent survey information on live oyster or cultch content on the bottom.

In Maryland waters three extensive surveys have been made of oyster bottom. At the beginning of the twentieth century, C.C. Yates surveyed Maryland waters by dragged chain along the bottom of known oyster areas. Oyster bottom determined to be of economic significance was demarcated by straight edged polygons to produce individual oyster bars (Graves 1912)(Fig. 12). A recently documented study by Maryland Department of Natural Resources conducted from 1975 through 1983 produced representations of areas comprising cultch and cultch mixed with sand, and cultch mixed with mud. This was referred to as the Maryland Bay Bottom Survey (MBBS)(Fig. 13). For a majority of this survey, bottom characterization was based on acoustic returns from a microphone dragged along the bottom areas initially charted by Yates (Smith et al. 1998).

A final large scale Maryland survey was conducted from 1989 to 1995. Patent tong samples were collected from gridded locations on a large number of designated Maryland's oyster bars. From this data the volume of buried shell and surface shell was estimated (Homer and Jensen 1993)(Fig. 14).

Perhaps of greater importance to oyster recruitment today is not the actual areal decline of oyster habitat but the current extent and suitability of habitat for spat settlement and potential recruitment. Detrimental effects of the lowering of oyster bar profiles within the Chesapeake Bay

due to harvest practices have been discussed (DeAlteris 1988; Seliger & Boggs 1988). It is a general opinion that the remaining habitat is of much poorer quality than previously existed, with live oyster biomass being greatly reduced due to siltation on historic oyster bars. Actual quantifiable documentation of such loss of quality is very limited.

Relevant Questions

Given the great impact that suitable oyster habitat has on potential recruitment of the Chesapeake oyster population and industry, one might form six key questions, the answers to which would be highly relevant to an adequate assessment of Maryland's oyster habitat resource and or rehabilitation efforts. These are as follows:

- 1) What is the current oyster cultch acreage in Maryland waters?
- 2) What is the condition and suitability of this cultch substrate for larval settlement and oyster growth?
- 3) If bottom areas once characterized as oyster bar are not suitable for larval settlement or growth, what is the current character of this bottom?
- 4) Can substantial amounts of cultch be found buried under sediment?
- 5) Is the Maryland Bay Bottom Survey (1975 - 1983) an adequate rendition of cultch and scattered cultch bottom of today? If not, why is it not accurate?
- 6) Are there more effective and economical sampling methods and bottom type classifications capable of being developed than those currently utilized?

With these questions in mind, technologies and equipment were evaluated to determine their potential in gathering information on three aspects of Chesapeake Bay benthic oyster habitat: 1) A rapid, precise and accurate assessment of the density and geographic extent of exposed cultch on the bottom; 2) An ability to identify a level of sedimentation on cultch that could potentially degrade recruitment; and 3) To locate buried oyster bar (reef) substrate.

It is realized that no one type of equipment or technology may be suitable to examine all of these three desired aspects of benthic oyster habitat. The criteria were selected because they reflect conditions of importance to the longevity of habitat capable of supporting natural oyster recruitment. The criteria additionally provide information capable of evaluating the status of the habitat, in terms of condition, degradation, and potential for restoration.

The first of these criteria, a quantification of exposed cultch is of principal importance. On a local scale exposed cultch may be indicative of processes of sedimentation and the effect of harvest practice. On a regional scale such information could be used to quantify the potential of the habitat to sustain oyster populations through recruitment potential.

The second criteria, sedimentation levels on surface cultch, has a clear and detrimental effect upon larval attachment to potential substrate. Levels capable of retarding recruitment most likely may not be documentable via traditional oyster assessment methodologies. It is very likely that very small levels of sedimentation have detrimental effects on potential recruitment. Information is greatly lacking on temporal patterns of oyster bar sedimentation.

The third criteria, identification of buried substrate, attempts to locate either shell or hard terrace where shell once was located. Such a task has value beyond simple identification of historic oyster bar locations. Charting of such substrate would allow for determination of where reclamation activities could be best served.

Newly applied equipment and technology could make accurate and precise habitat assessment in a cost effective manner. Large scale, long-term monitoring of the cultch resource as well as determination of the effectiveness of restoration technologies and harvest practices upon the oyster resource could be realized.

Historically Employed Physical Sampling Gear

The sounding pole, patent tongs, and oyster dredge have been commonly employed in the Chesapeake Bay for oyster habitat assessment. Each have definite advantages and drawbacks in assessing characteristics of oyster bar. The sounding pole is simply a very long pole of metal or wood which simply is used to probe the bottom. It is rapid and effective at cultch discernment in skilled hands. It has definite depth limitations and is exceedingly difficult to quantify or map results on a scale of interest.

Patent tongs, hydraulically operated jaws utilized for oyster harvest, provide an easily obtained quasi-quantifiable sample of the very coarse component of the bottom (Chai et al. 1992). Information about sedimentation on top of cultch or soft sediments lost through the mesh size of the tongs is poor to non-existent. Sample processing can be very time consuming, and in the case of oyster habitat sampling, data can have high variability reflective of bottom heterogeneity.

Oyster dredge sampling is a trawl methodology where oysters and shell above a given mesh size are retained in a bag. It provides for more uniformity between replicates in cultch or live oyster counts than patent tongs, but is highly selective in material entrapped, and virtually impossible to quantify (Smith and Jordan 1993).

Other methodologies were employed in large scale published surveys of Maryland and Virginia waters. The first were of these were by Yates in Maryland waters (Graves 1912); and Baylor in Virginia (Baylor 1894) In both of these surveys a chain was dragged behind survey craft to assess cultch density. This approach was modernized for use in the Virginia oyster seed grounds in the 1970's (Haven et al. 1979; Haven and Whitcomb 1983). A microphone was attached to the end of a long coaxial cable and dragged across the bottom. Bottom sounds or recordings were interpreted as to type of bottom they reflected. A similar procedure was employed during portions of the Maryland Bay Bottom Survey (1975-1983).

Although combinations of the above techniques can work well in trained hands, they are best at providing general information about cultch density and general bottom type. Issues of sedimentation or basement substrate can not be addressed well. With such mechanical techniques, standardization of categorical interpretation can be highly varied between equipment operators or observers.

Equipment and Technology Evaluation Criteria

Remote Sensing versus Physical Sampling

For evaluation purposes benthic habitat data may be generated in one of two fashions; 1) by physical extraction or in situ examination of the substrate, or 2) by remote sensing. In the case of remote sensing, habitat characterization can be made without disruption or manipulation of the substrate. What is of special importance to remote sensing technology is the almost universal need for calibration and validation of remotely sensed data. In most considered cases, remotely sensed data almost universally requires initial calibration prior to collection, and some form of validation after assessment. Such must generally be done via physical means. Thus remote sensing may offer rapid, unique, and specialized capability, but some form of physical (or visual assessment) must be integrated into field surveys.

Approach to Evaluation of Equipment

A great range of instrumentation is potentially available for the assessment of submerged coastal benthic habitats. A review by Rhoads (1996) provides a detailed description of sensors in the operational and or development phase. Our initial planning called for an evaluation of three general categories of acoustic equipment capable of remote evaluation of oyster habitat. These were acoustic profiling equipment, side scan sonar, and seafloor classification systems. These gear categories were chosen after a review of literature and trade publications concerning equipment capabilities. The objective of evaluations were to assess the capability of gear types to determine three criteria of oyster habitat; quantity of exposed cultch, sedimentation on top of cultch, and subsurface shell and substrate.

A principal requirement of any suite of equipment or technology employed for oyster habitat assessment is that data be easily linked, displayed, and analyze via GIS. Such does not imply that field data simply be capable of being tagged with a geographic location, but rather that a large portion of the informational content of the data be capable of visualization and or statistical manipulation within the GIS. This condition is based on an expected dependence upon remotely collected data. Such data, usually linked to GPS locational information typically contains so much information content and or volume that GIS display and charting is the only feasible means of manipulation.

Acoustic Remote Sensing Technologies

Bottom Profiling

With the availability of recording fathometers to determine water depth in the post World War II

era, informal interpretation of acoustic output was accomplished by individuals with knowledge of local bottom conditions. Such local knowledge was often applied to bottom identification for commercial or recreational fishing.

With the advent of acoustic bottom profiling equipment, where survey track is permanently recorded on a grey-tone paper trace, or later, binary file, several researchers have employed such equipment with varying success to examine oyster reef. Low frequency equipment (3-10kHz) was originally employed to characterize oyster reefs in Texas (Bouma 1976 - see DeAlteris 1988, Intro). Low frequency equipment (20-200kHz) has an advantage in benthic assessment over traditional high frequency gear utilized to determine abundance of mid water fish. The transmitted acoustic pulse penetrates the bottom to some degree, providing potential information about substrate.

DeAlteris (1988) used similar low frequency equipment to interpret acoustic transects across the Wreck Shoal - Burwell Bay region of the James River, Virginia. Seliger and Boggs (1988) performed similar transects across regions of the Chester and Choptank Rivers in the Maryland Chesapeake Bay. Transect output in this study was interpreted via the use of grab sample sediment analysis. The application of such techniques were to provide an assessment of oyster habitat loss over time.

Further evaluation of hydro-acoustic gear for large scale surveys of oyster bottom has been done by Simons et al. (1992), and similar techniques applied by Powell et al. (1995) in Galveston Bay Texas. The Powell survey compared the results of oyster reef survey work performed in the 1970's (via sounding pole techniques) to that of the present condition of the reef system as determined by acoustic profiling.

Equipment utilized for the Simons et al. and Powell et al. surveys was dual frequency 27 kHz and 300 kHz gear. Frequency choice was based on gear availability and a compromise between surface rendition and bottom penetration. Regular gear calibration was a major factor in survey procedures, and greatly affected the interpretation of returns (E.N. Powell, Rutgers Univ. N.J. pers. comm.). Other than the above work, the literature appears void in application of acoustic sub-bottom profiling to the assessment of oyster habitat.

Evolving Acoustic Profiling Technologies

Two other technologies in profiling sonar have also been under development, and may, lend themselves well to delineation of oyster bottom and or sub-bottom. The first is the so called "chirp" sonar, developed for deep bottom penetration (Schock 1989). The system can transmit usable energy from 2 to 20 kHz, with wavelets transmitted through an effective bandwidth of 5 kHz. Signal penetration in the bottom varies, but is estimated to be about 3 m in coarse sand and 40 m in clay. Vertical resolution of independent strata is claimed to be in the 5 - 10 cm range.

A second technology has been under development by the Naval Research Laboratory and is a

normal incidence, narrow beam-width, high resolution, seismic system. The system is designated the Acoustic Seafloor Classification System (ASCS) (Lambert et al. 1993). The present ASCS is normally operated at 15 kHz, and qualitatively measures the amplitude (echo strength) and pulse character of the return signal in 10 adjustable-width time windows that correspond to depth increments in the sediment. A high resolution record is produced of the upper few meters of the seabed.

It has not been determined if the “chirp” technology sonar has been knowingly applied to any oyster reef determinations. Industry sources have indicated that it may have valuable application to the charting of oyster reef. The Navy’s ASCS system had previously charted portions of oyster reef at two locations in the upper Chesapeake Bay. Profiling results and interpolated output indicate a high correlation with Bay Bottom Survey results on one of these oyster bars.

Side Scan Sonar

Side Scan Sonar (SSS) has traditionally been employed in the search for shipwrecks or other underwater objects. Typical applications have usually been in coastal or deep ocean waters. The technique is employed by generating a sound pulse obliquely towards the seabed from both sides of a moving vessel. Returning signal strength at any given distance out from the transmission source is an indication of reflectivity of the bottom at that point. Time from that of the initial transmit pulse to that of the returning echo is the determinant of distance. Although no specific literature on SSS application to oyster habitat assessment could be found, an examination of published images and discussions with shellfish researchers indicated that SSS may have application for assessing oyster bars.

Seafloor Classification Systems

Acoustic seafloor classification technology is a recent development that may offer great value in wide area classification of habitat type in general, and specifically, Chesapeake Bay oyster habitat. Existing Seafloor Classification Systems (ASCS)² operate by transmitting sound pulses (such as those generated by recording fathometers) from a vessel to the seafloor and analyze the reflected acoustic signal for waveform characteristics unique to characteristics of particular bottom types (Collins et al. 1996, Heald and Pace 1996). Seafloor Classification systems are increasingly being used by fishers of fin-fish to identify bottom types where sought after species are found. A principal advantage of such systems to such users is that mapping may be accomplished at relatively high speeds without the need of towed devices. Bottom classification is displayed onboard in real time during surveying.

² Acoustic Seafloor Classification System (ASCS) is a published term for such systems. This term was also used by Lambert et al. (1993) to describe a Navy sub-bottom profiling system. For purposes of this review, we will use this term exclusively for those systems employing computer waveform analysis for the two or three dimensional characterization of seafloor types. Such systems have also been referred to in European literature as Acoustic Ground Discrimination Systems (AGDS).

Two available Sea Floor Classification Systems on the market employ different approaches to echo analysis. One system requires apriori knowledge of principal bottom types in the region of interest, and the other does not. Roxanne[®] uses components of the first and second returns of the transmitted sound pulse to characterize the bottom in a two dimensional axis. These axis have a quasi relationship to hardness and roughness. Various combinations of these two (E - values) can be assigned to different types of bottom substrate (i.e. bedrock, cobbles, sand, etc.) (Dyer et al. 1997). Another system, QTC[®] typically requires apriori training of the system to allow particular wave forms of the returning echo to be assigned to pre-determined bottom types held in memory. In such analysis, the confidence, or level of association to a bottom category can immediately be assigned to each returning echo.

Seafloor Classification systems may have high potential for estuarine habitat assessment because their technology mates well with GIS/GPS data integration. Data is displayed in real time, allowing survey adjustments in field. Data can be reduced to simple vectors, with time and location GPS stamps. Survey track data is amenable to a wide range of GIS incorporations.

Methods

Survey Locations

Survey locations for gear evaluations on benthic habitat in Chesapeake Bay were determined by four principal issues. 1) Range from vessel home port. 2) To encounter as many oyster and non-oyster bottom substrates as possible. 3) To have available as much baseline information on bottom composition as possible. 4) Weather conditions at the time of planned surveys. As surveying was largely conducted from the Cooperative Oxford Laboratory, survey efforts were generally conducted in the Choptank River region of Maryland's Eastern Shore.

Baseline/Background Data

GIS Baseline Data

Benthic baseline data with which to evaluate equipment performance came from various sources. All data sources were incorporated into vector based GIS format by the Mapping and Analysis Project at the Cooperative Oxford Laboratory. This allowed for layering of various data sets upon the same printed chart, as well as varying scale to match that of collected data. Integration of GPS and GIS allowed for shipboard display of real time location on top of data sources of choice with real time boat position.

The following GIS integrated data sources were employed.

The Yates Survey - 1906-1911. (Graves 1912, Smith et al. 1997). This survey was an extensive charting of turn of the century Maryland oyster bottom. Named oyster bars were represented as individual straight sided polygons. Survey methodology utilized a dragged chain to identify oyster bottom (Fig 12).

The Maryland Bay Bottom Survey (MBBS)- 1975-1983. (Smith et al. 1998). This survey charted

categorical bottom type principally by use of a microphone dragged along the bottom. For regions used in this study (i.e. lower Choptank River), in appears the BBS used patent tong data to generate bottom type (Smith et al. 1998). Oyster bottom in this survey was segregated into three categories; cultch, cultch with sand, and cultch with mud. Other bottom types represented included, sand, mud, and hard bottom. Bottom types were originally represented as regional objects of each bottom category as derived from point or transect data. Transformation of data into GIS format produced multi-sided polygons (Fig. 13).

Oyster Stock Assessment Program (OSAP) - 1989 - 1995. (Homer and Jensen. 1993). These patent tong surveys provided recent (1989 - 1995) information on cultch density for 1m² locations on a number of oyster bars in the region (Fig. 14)

Survey Gear Employed

Acoustic Profiling Equipment

Our first equipment evaluations focused first on gear types previously employed by researchers for the detection of oyster cultch. Three principal types of sub-bottom profiling equipment were tested for the identification of surface cultch and identification of buried cultch. These were; 1) Dual fixed frequency equipment, 2) "Chirp" sub-bottom profiling gear, and 3) U.S. Navy, one of a kind, narrow beam sonar.

Initial evaluation of oyster bottom began with the use of a DataSonics DFS-2100 Model Acoustic Remote Sensing System. This dual frequency system transmitted at 27kHz and 300 kHz. An EPC graphic recorder produced grey-tone thermal paper output. This equipment was initially chosen due to availability, and because a similar unit had been employed for extensive oyster reef surveys by Powell et al. (1995) in Galveston Bay, Texas. Use of this aging equipment was ended after a few survey runs due to the following reasons; 1) Inability to maintain it in operating condition, 2) Lack of GPS locational information to identify location on the paper output to earth coordinates. 3) Leasing of newer "chirp" technology equipment provided enhanced output detail.

Sub-bottom profiling "Chirp" sonar (Schock et al. 1989) manufactured by Edgetech X-Star and DataSonics SIS-1000 Seafloor Imaging System were then leased or borrowed for demonstration surveys over broad portions of the mid and lower Choptank River System (Fig. 15). Professional operators were used. Data output was on grey-tone thermal paper with differential GPS data logging. Manual transformation of GPS log points to GIS charts of bottom classification and digitally recorded survey track allowed for the identification of key feature points on GIS.

A unique narrow beam Sub-bottom Classification System assembled by the Naval Research Laboratory (Lambert et al. 1993) was additionally employed in the Choptank River system by Navy personnel. Color computer imaging produced sub-bottom profiles of density and impedance. Although output could be digitally stored for replay, color printed images were the principal evaluatory medium.

Side Scan Sonar

Three brands of side scan sonar were evaluated for their ability to discern surface characteristics. Two of these systems were dual purpose sub-bottom and Side Scan units employed in sub-bottom profiling employed above. These were the Datasonics single frequency, and Edgetech dual frequency (100kHz, 300kHz) equipment. Initially equipment was employed over a wide variety of bottom types and conditions selected for concurrent testing of sub-bottom capabilities. Additional sites were selected to explore the full capabilities of the SSS systems in our waters. An attempt was made to visually associate paper and screen output traces with Yates oyster bar or BBS bottom features.

After initial evaluation of the Datasonics and Edgetech SSS systems a third system was tested. A newly developed high frequency (651 kHz) system, Sea Scan PC, which did not incorporate sub-bottom capability was also tested over similar bottom as the other systems.

Working horizontal range on these systems was largely determined by water depth. The first two systems gave best results when operated on a 100m (each side) setting. With the Sea Scan system best results were obtained at 25m to a side. In all cases operators familiar with the equipment were on board. Output for the first two systems was thermal grey-tone paper with GPS tics. Sea Scan data was stored in computer file for later printing via grey-tone or color printing of individual "windows". Operational settings and output quality were verified with each gear type by calibrating on a know aircraft wreck (Fig. 16).

GIS Data Integration

Initially, sections of side scan tracks were scanned as an image file and registered within ArcInfo. Images were then draped upon a three dimensional bathymetric model of the section of the bottom upon which they were obtained. Oyster bar boundaries were then superimposed upon the image (Fig. 17). Although multiple overlapping parallel survey tracks were taken at a few loctations, for potential computer mosaicing (combining multiple survey swaths into one image), this was not done due to time and effort constraints.

Acoustic Seafloor Classification Systems

Acoustic Seafloor Classification Systems (ASCS) were then applied to the task of discerning variation in sediment and cultch characteristics. The two commercial systems on the world market, "Roxanne" (Marine Micro Systems Ltd. Aberdeen Scotland), and QTC (Questar Tangent. Sydney, British Colombia, Canada) were leased. Both were evaluated over identical bottom on and adjacent to named oyster bars, Irish Creek, Royston, Wild Cherry Tree, Stone, and Cook's Pt. A deep mud location "Kelly's Flats" was additionally surveyed.

As the Roxanne system does not require apriori site classification, data values for two vectors defining habitat were generated directly during surveying. These two values (E1 and E2, albeit "roughness" and "hardness"), were stored on GPS logged record with bottom depth. GPS data logging of location at the time of each pulsed bottom interrogation allowed for relatively simple integration of data for GIS display. The sound pulse utilized for acoustic interpretation was that

present upon the vessel available (RV Elsor). This was generated by a Raytheon V850, 200 kHz fathometer. Initial classifications were represented visually by color coding the two dimensional space defined by the two vectors. Color coding were generic categories for worldwide use developed by Marine Microsystems.

To be effectively utilized, the QTC Acoustic Seafloor Classification System required pre-survey calibration on known bottom types in the survey area. The QTC system was calibrated on the RV Elsor using a Furuno FCV-582 fathometer as the transmitter. This system was tied into the existing 200 kHz thru hull transducer on the vessel. Transmit power was 500 watts RMF, pulse duration 0.4ms, and reference depth standardized to 6.0m. The transmitted signal from the fathometer and the first returning echo were captured and digitized.

A total of ten sites were originally chosen as calibration locations. We were hoping to vary sites from mud, sand, gritty sand, and oyster cultch. In the case of cultch, we additionally attempted to utilize locations where shell varied in surface density. Videos obtained previously as well as MBBS and OSAP patent tong data were utilized to position the vessel over the chosen calibration site. Ponar dredge samples were taken to confirm bottom type at the calibration location. On very soft or very hard bottoms we had difficulty in obtaining good Ponar samples.

After review of all calibration data, seven bottom types were utilized for initial surveying. Point data generated in real time over survey transects was depth, bottom classification, percent confidence in classification, and vector units. The three vector units represented an individual bottom classification in three dimensional space as related to the original classification sites.

Habitat Calibration and Validation Techniques for Assessing Seafloor Classification Technology

1. Diver Observation

Diver operations for the calibration and validation of continued Acoustic Seafloor Classification System testing began in the summer of 1998 upon the removal of legal restrictions prohibiting diving. During this season 15 sites were visited for diver observation. Most sites were chosen to lie upon previously surveyed sub-bottom profile tracks where ponar samples indicated desired habitat types. As a principal goal of habitat calibration site choice was to include principal bottom types of interest, some sites could not be located on sub-bottom profile locations. Conditions of visibility dictated diver observation quality. Visibility on the bottom, even with underwater light at most sites only allowed for a visual assessment of bottom characteristics from usually less than 10 cm. Upon surfacing, divers would be debriefed and field conditions recorded.

2. Underwater Video

A "drop and drift" approach was originally employed utilizing a video equipped Remotely Operated Vehicle (ROV). Horizontal and vertical thrusters were not utilized as they disturbed the sediment. This means of deploying the video, by slowly dragging it across the bottom by vessel motion due to wind or tide, was determined to be the only feasible way of obtaining any visual bottom characterizations in visibility conditions encountered throughout the year. Boat speed,

currents, bottom condition, and visibility determine the distance and direction of the visual on the bottom. At most sites ROV lights were utilized. Camera angle was oblique to the bottom with a lens to bottom distance of 30 cm.

In September of 1998 we began operations employing an improved video sled. This frame mounted unit employed two short focal length video cameras; one black and white and the other color (Deep Sea Power and Light). Camera units and lights were adjustable. The black and white unit was positioned approximately 20 cm. from the bottom and was capable of low light operation for initial observer orientation. The color video was positioned approximately 10 cm. from the bottom. Two variable intensity, positional, 110 volt flood lamps illuminated the bottom to the desired intensity.

3. Sediment Analysis

As a means of characterizing bottom type, sediment analysis was employed. Our sediment assessment interests were not typical to those of standard methods of geological classification. For this reason, and not wishing to incur the cost of typical fine grain sieving requirements, we modified our analysis specifications for those typically employed. Our information requirements included a broad assessment of the character of a relatively large footprint of surface (>1 meter). Surface material was of principal importance. Overall information on both surface shell, pebbles, and cobbles, as well as the supporting matrix of grit, sand, silt and clay sediment was required.

Our initial experience with traditional surface deployed grab type devices showed that they performed inadequately over the wide range of hard and heterogeneous bottom we were seeking. With the introduction of diving, hand obtained samples then became the principal means of sediment sampling. At each calibration site, approximately 3 liters of surface substrate was taken by scooping a circular bucket across the bottom. The bucket was immediately capped after obtaining the scoop. Three replicates were typical except on extremely uniform mud bottoms. Wet sieving was employed to determine percent composition of seven size classes from sand to coarse shell (>33 mm.)(Fig 18). To reduce costs in silt and clay component analysis, a Coulter counter was utilized to assess three size classes of the "fines". A standard density of material was used in this calculation. large classes (>5mm) were broken down as to percent material type (ex. oyster, stone, clam shell).

Results and Discussion

Evaluation of Acoustic Remote Sensing Equipment

Sub-Bottom Profiling Equipment

Results were highly mixed in the success of utilizing sub-bottom profiling equipment for oyster habitat evaluation. All systems tested were quite capable in discerning many features (i.e. density discontinuities) down to 15 meters in the sub-bottom profile. These features included valuable

buried terraces and slopes representing buried oyster reef (Fig 19). Previously unexpected quantities of methane gas present in the sediment prevented interpretation of sub-bottom features through many soft-bottomed locations of the mesohaline Bay (Fig. 20), potentially indicative of paleo-channels (Kerin and Halka, MD Geological Survey, unpublished).

Unfortunately, the equipment utilized was incapable of determining fine resolution of surface texture and material. While differences could clearly be seen between surface layers of various sections of surveys, no "rule" other than human interpretation could be applied to characterize surface sediment. As these gear types were representative of "state of the art" profiling equipment, we expect other models to have the same limitations.

In most cases we observed; bottom classification based upon real time screen interpretation or on later paper output, was highly subjective. The positive results generally described in the literature as to the application of such equipment to identify and chart oyster reef were not obvious in our application. Gas features and structure features were often easily confused. As we utilized skilled operators familiar with the specific equipment they were operating, we felt that no additional capability could be extracted from the system.

The two commercial systems evaluated produced a permanent output of grey-tone on a thermal paper role. This output was easily readable and GPS location tics on the role assisted in identifying locational points. The U.S. Navy system, while storing binary files, additionally produced final paper output as a color spectrum scale from screen dump. The analog output of any of these systems did not lend itself to easy GIS incorporation. To effectively map any sub-bottom features, the feature would have to be referenced horizontally and vertically, the location be interpolated from GPS marks on the paper output role, and point or transect position be manually entered into GIS software. As such, it appeared that all of these very capable products were much more effective at locating objects or conditions on or below the bottom than classifying seafloor habitat.

In terms of this equipment's sub-bottom capability, the amazing potential of identifying sub-bottom features has allowed for the discovery of submerged reef slopes and terraces. This has led to further investigation of the processes of creation and reduction of historic oyster bars. Information initially produced under the auspices of this contract has led to further examination of slopes throughout the Choptank River Region. GIS incorporation of locational information as well as coring and dating of sediment has been preparatory work for an upcoming peer review publication concerning oyster reef formation.

As identification of buried shell has been a critical component of oyster habitat assessment, such sub-bottom profiling equipment has potential in assisting investigators in determining where thick shell deposits may potentially lie. The systems do not penetrate well, nor shed much light upon densities of material below existing oyster bar structure. They do however clearly segregate oyster bar structure from that of soft sediments which clearly never allowed for oyster bar development. With improved data logging of these systems to GIS, effective demarcation of potential shell source areas could be identified. Advances in low frequency Acoustic Seafloor Classification

Systems in interpreting buried substrate may parallel such developments.

Side-Scan Sonar

Examination of side-scan sonar output for the assessment of oyster habitat showed some of the same difficulties as did sub-bottom profiling. Equipment types initially utilized were generally developed for the identification of objects in coastal and deep ocean conditions. Utilization of gear in shallow estuarine conditions introduced many constraints. Shallow water operation introduced a high grazing angle (relative angle of pulse direction to where it intersects the seafloor) of the sound pulse at the outer limits of the scan. Such greatly reduced true horizontal coverage. Estuarine hydrographic conditions and boat traffic led to many spurious sound (energy) artifacts throughout the data record. A major difficulty in effective assessment was due to variation of bottom slope. Due to the shallow operating depths of the towed fish, the source of the transmitted acoustic pulse was never far from the seafloor. As such, variation in bottom slope (common in oyster bar boundary areas) caused great variation in signal reflectivity. It was often difficult to discern if reflectivity from a region of bottom was due to habitat characteristics or slope.

Initially it was hoped that side-scan data could be integrated into a GIS output via a method called mosaicing. As such, the continuous data record (strip) being generated along both sides of the survey craft, could be linked to those of other survey tracks running parallel to it. In practice this could be done manually via cut strips, or done through computer enhancement. Several situations led us away from further developments along this avenue. First, any deviation from a straight line survey track produced warpage in the apparent image. In shallow constrained estuaries, it led to great difficulty in generating "clean" data. Secondly, as shallow water greatly reduced the accurate apparent range of usable image, boat survey tracks with a high resolution system would need to be precisely obtained (5-10m apart) over very long transects. Without precise auto-navigation such would prove too difficult. And thirdly, after early successes in applying Acoustic Seafloor Classification Systems to the determination of oyster habitat, we felt that our energies would be better directed at the exploration of these systems.

Utilization of newly developed and specialized high frequency system (Sea Scan) did impress us with the ability to begin to discern surface texture on the bottom at a resolution level close to that capable of identifying oyster shell. As with all Side Scan data, validation effort would be high to determine precisely what was being imaged. The reduced swath of this equipment further compelled the need for extreme navigation tolerance to produce continuous surface output. Such systems are unexcelled at finding and identifying objects, but have high data processing costs to link to GIS habitat mapping.

Recent advances in application of "chirp" technology have generated some extremely high resolution images of the bottom. Potentially such systems may be able to assess bottom habitat without the need for extensive validation of the record. Issues of analog interpretation and mosaicing large quantities of data still exist however.

Acoustic Seafloor Classification Systems

System Performance and Evaluation

Survey transects completed by both Acoustic Seafloor Classification Systems (ASCS) evaluated were chosen to overlay survey tracks previously conducted by sub-bottom profiling sonar. Such helped us locate principal habitat type transitions. On several of the survey tracks, we had previously video taped bottom characteristics along the planned transect by use of a dragged Remotely Operated Vehicle (ROV). While these images were of poor quality due to extremely limited visibility, they did assist us in interpreting some bottom conditions. Data from recent (1989-1995) patent tong sampling upon charted oyster bars was additionally helpful in assessing system accuracy and precision (Homer and Jensen 1993). Utilized in conjunction with Bay Bottom Survey (Smith et al 1998) and field ponar dredge validation, we felt that we had reasonable confidence in assessing true bottom character (Fig. 21). When in shallow enough water we additionally employed a sounding pole to assist in assessing bottom condition.

Survey tracks produced by the Roxanne system did not require an a priori cataloging of calibration sites as did the QTC system. Once the QTC system was programmed with calibration data, surveying methodology and general output was similar for both systems. Both systems generated real time point data from individual transducer pings. Only a selected number of pings were interrogated by the systems. Interval between interrogated pings was minimal, on the order of seconds.

The Roxanne system was impressive in its ability to discriminate between principal bottom types throughout the lower Choptank River region. Acoustic pings generated by the transducer was be evaluated for aspects of hardness and roughness. These values, E1 and E2 could be displayed at the point location, or interpreted in two dimensional space as a particular bottom type (Fig. 22). For demonstration purposes, we allowed color choices determined by the manufacture to represent principal bottom types. These were generic bottom types obtained from surveys worldwide. As shell was potentially acoustically similar to pebbles and cobbles, in areas where we expected shell, the system indicated a pebble like substrate. This was not a difficulty as oyster shell was not a choice in the Cartesian space delineated by the E1 and E2 vectors. We were not able to evaluate if the system could discriminate between variations in oyster shell density and pebble and cobble cover. This was because we could not clearly delineate at the time of trials obvious cobble and pebble bottom.

Prior to utilizing the QTC system we had to devote a day to calibrating the system upon known bottom types. We attempted to select as wide a diversity of bottom types as we expected to find within the region. These ranged from fine muds to dense oyster shell. While we used best available information to identify these sites as well as ponar samples when directly on location, we could not be perfectly sure of some bottom assessments - particularly when characterizing mixed shell and substrate. Generated data nevertheless indicated a high correlation with expected bottom type (Fig 23). Of particular interest was an examination of confidence intervals for each of the data points.

Such confidence intervals were an indication of how close to the geometric center of the cluster of calibration points for an individual calibration site the survey point fell. Poor confidence could be interpreted as one of two factors, or a combination of both. First either the true sampled bottom type did not match closely any of the calibrated sites. Or secondly, the bottom being sampled was a transitional one, sharing characteristics of the bottom exhibited by two calibration sites.

Results were additionally impressive with this system. The incorporation of immediately generated confidence limits produced an additional and important component to our research needs. We could rapidly identify where bottom characterization may be shaky to poor. The system was clearly capable of matching some of our calibration sites to new survey areas which exactly matched them. Our inability to completely validate test data for this system was simply a matter of not having at that time an ability to confidently assess overall bottom character at any given location of our choice.

Calibration and Validation Site Issues

The terms calibration and validation have specific definitions when applied to our habitat assessment work. Calibration is the process of identifying and cataloging information about bottom locations which will be utilized as typical examples of principal bottom types of interest. Such sites must be identified whether one wishes to utilize unsupervised (Roxanne) or supervised (QTC) sampling techniques. In any case the user must be able to adequately characterize and be able to rapidly identify the specific bottom types the system is being expected to classify. In supervised classification (QTC), where a system is "trained" over a given bottom, calibration is also the process of collecting acoustic information about that site to be stored for later usage in computer classification.

The process of validation is one where previously generated survey results are examined to determine the accuracy and precision of results. While the tools of examination should match those employed during calibration, validation site choice should potentially involve some level of randomization.

In terms of our continued efforts in the evaluation and application of Acoustic Seafloor Classification Systems (ASCS) to the assessment of benthic habitat, the designation and assessment of calibration/validation sites has been the most time consuming and frustrating task in our efforts. This has been due to both field conditions and the nature of the information we have been trying to capture. Our site selection and information gathering capability continue to improve however. Utilization of poorly or incorrectly defined calibration site data for supervised surveying will simply not only produce bad survey data, but data of unknown error.

Of primary importance in our work was the criteria for selection of sites for calibration. To date we have 15 designated calibration locations. At many of these we have identified data gaps or other problems with utilization of these sites in a catalog for supervised sampling. As our principal interest has been in the quantification of cultch, we have avoided excessive specificity of uniform mud and sand bottoms. Instead, most of our calibration sites were hoped to reflect subtle variation

in cultch densities, the interstitial sediment matrix between the cultch, and sedimentation levels on cultch.

The greatest difficulty in the selection and assessment of calibration sites has been a near complete lack of visibility throughout most of the year, for visual or video ground truthing, in the portion of the Chesapeake Bay we were working. Visibility on the bottom in the region of the Choptank River System has for close to two years been at or less than 20 cm. For much of this time it has been 5cm. to less than 1 cm. on the bottom. Any disturbance of the soft sediments quickly eliminates any visual imaging. Such has had profound impact upon our ability to evaluate equipment and technologies. We have recently incorporated advances in our underwater video capability. These have greatly improved our capability during "clear" water windows during the year (50 cm or greater on the bottom).

We have found that visual evaluation, either via diver or towed video are necessary to validate sediment analysis. A majority of the oyster bottom we have observed is very heterogeneous in terms of substrate and cultch distribution. Sediment samples, as valuable as they are in quantifying variation between sites, are reflective of only a small section of the bottom. They additionally suffer from two other major difficulties. First, cultch densities in the sample may vary widely from sample to sample due to the small sample size. Secondly, shell densities often increase dramatically just centimeters below the surface. It is often difficult to determine where we want to divide surface strata from lower layers. Presently we are trying to confine our classification efforts to the upper few cm. of substrate. This is effectively accomplished via the use of a 200 kHz. transducer for sound generation. Such a frequency only penetrates a few cm. into the bottom substrate.

A second difficulty with using sediment quantification as the primary methodology to evaluate a site is due to observed site heterogeneity within regions of interest. When sites are acoustically calibrated for supervised surveying, our current transducer beam width is 11 degrees, thus a cone of sound is transmitted to the bottom, impacting upon a footprint dependent upon water depth. For example, at a water depth of 7 m., the diameter of the footprint would be 2.10 m. This region of insonification which is being calibrated upon during the several minutes of acoustic calibration may reflect a high degree of unknown variability in shell density within the footprint. Minor and random ship motion during calibration complicates such. Only a general physical observation of the site characteristics can identify such difficulties. At several of our calibration sites a recent window of clear water has given us visual confirmation that sites were accidentally chosen on a transitional bottom. Even with differential GPS accuracy (5 m.) we can not say if we calibrated on varying densities of surface cultch or bare bottom.

It is ironic that our search for remote techniques that would relieve us from reliance on traditional sampling tools has given us such difficulty in our dependence upon such tools during calibration and validation. Our experience with our current calibration sites has convinced us that we need to greatly expand our efforts in calibration site documentation during application of FY97 funding. Several key areas of development have been identified.

1. Maintain and expand continued evaluation of existing calibration sites.

Temporal change at many of our calibration sites has been evident during the one year that we have had these control sites established. Such change has been identified as both natural and anthropogenic. At one site, commonly named "Gemma gemma", observations from last year indicated a dense almost 100% cultch covering. Diver video observations during the summer of 1998 showed a dense cover of sand and grit over the entire region in which the site was located. This sandy grit appeared iridescent due to the million of minute sequine sized shells of the tiny clam *Gemma gemma* lying on top of the substrate. Approximately 10 cm. below the surface was buried cultch identified from the previous year.

At other sites we have recently observed oyster harvest activity while we were collecting video calibration data. Results of such activity and resultant changes to the calibration site can clearly be seen on video. Through numerous observations conducted during this program it has been made clear that many aspects of the bottom character adjacent or in oyster harvest areas are the direct long term result of harvest practices. Distinctions can be made between bottom impacted by oyster and clam gear. Although such bottom types may not be considered pristine in a successional sense, they are reflective of principal bottom categories present in today's bay.

2. Expand calibration site sampling methodologies

Currently visual observation and description, video taping, and diver obtained sediment analysis are the only means by which we are classifying calibration sites. Ponar and other small grab samples have been discontinued due to poor quality samples on many bottom types. Additional sampling techniques are hoped to be employed during FY97 continuation of work. We hope to 1) better quantify cultch density on the surface, and 2) extract more information about shell density below the surface.

We wish to accomplish the first task because our current estimates are based upon observer inference. We would expect to do so in two fashions. 1) Video quantification, and 2) quadrat sample processing. In the first case we would hope to improve upon our screen video capture capability. Current software only allows for us to "still frame" a degraded video image for subsequent computer quantification of shell cover. In the second case we would like to either sample quadrat shell densities via diver, or patent tong sampling. Both have advantages and drawbacks (Chai et al. 1992), but would greatly increase our confidence in producing maximum quantification of a calibration site.

3. Integrate data capture and display of calibration data within the GIS

Calibration site data is obtained and stored in a variety of formats and media. With calibration site number increasing, it is increasingly difficult to make several comparisons between sites based on multiple criteria. An additional factor is that post survey validation requires the ability to isolate what sampled physical characteristics caused certain bottom to be classified as they were - (i.e. if collected physical or visual baseline data on a calibration site is not adequate to explain why subsequent acoustic surveying classified other bottom areas as similar to that calibration site, the wrong type of information has been collected to document that site).

We currently have a general ability to link all calibration / validation data within the GIS. This capability uses straightforward spatial linking of relational data base information and image data. To more adequately apply calibration site data (and improvements to calibration site data) to advanced site assessment and validation, improvements need to be designed and applied to GIS integration.

Theoretical and Conceptual Development

Acoustical Limitations

Observable or measurable criteria of oyster habitat may not lend themselves to acoustic discrimination. Such may be due to issues of scale, or the highly different properties of acoustic waves as opposed to light waves. The fact that one can see something on the bottom, or measure the material and sediment properties that it exhibits does not mean that sound can discriminate along these identical compartmentalizations. In short, we are saying ASCS just might not see habitat the way we see it.

Our preliminary evaluation of ASCS systems indicates that this is far from the case. Our evidence, plus limited published and unpublished data of others indicates that 1) general exposed cultch quantities can be determined, and 2) fine distinctions of sediment size and density can be obtained in homogeneous sands and muds. Due to our difficulties with calibration data, we have just begun to determine the limitations of detection between combinations of shell, sediment matrix, and sediment cover.

Evolution of ASCS theory and technology directed by users like ourselves will most likely allow for improved equipment capability for discerning various bottom types. For the present we are more concerned with error interjected into the methodology than the capability of the system to perform. This error is caused by three confounding sources; locational accuracy, bottom heterogeneity, and accurate bottom assessment and calibration. As bottom type can change gradually along a gradient, or abruptly within our calibration and validation areas, it is extremely difficult to assess what small footprint of the bottom we were calibrating on, or surveying above. Efforts in improving our calibration and validation techniques should help resolve these difficulties in the future. Confidence in this area will help us address true system evaluation capabilities.

Necessity of Habitat Assessment Formalisms

At this stage of our research it appears that well thought out and correct application of calibration and validation data, surveying techniques, and interpolation and representational methodology could improve oyster habitat assessment quality much more than technical innovation. A current limitation in using ASCS for habitat assessment lies in the lack of structured formalisms to define the mechanisms and approaches to generate the best information base possible. As an example; with ASCS supervised surveying, individuals with identical habitat assessment goals, surveying the identical bottom region, could produce highly different habitat characterizations or charts. Such

differences could be reflected in, among other things, different choices of habitat definitions, different habitat calibration or sampling methodologies, or different methods of representing data of different scales. It is readily apparent that different patterns and properties emerge at different scales of observation or representation. An understanding of such effects is of major importance to a successful evolution of ASCS for oyster habitat assessment.

To address these issues, background in three related disciplines is being applied to the generation, assessment, and representation of ASCS data. These are; landscape ecology, hierarchy theory, and scale. Of these three topics, management of multi-scale issues was the first to become readily apparent in our work. Scale in the context used here does not refer to the ratio of maps or models to the true world. Our usage deals with the level of spatial resolution that one examines, represents, or models a system. In the case of oyster habitat assessment work, we are sampling habitat, identifying habitat components and representing habitat upon a variety of scales. Two definitions pertinent to the application of scale concepts are relevant to our work. "Grain", is the lowest limit of examination an observer can understand something about a system (Allen et al. 1984); and "extent" is the largest distinctions which can be observed. If the analogy of a sediment sieve were to be used to describe our understanding of scale, the mesh size would be the grain, and the diameter of the sieve frame the extent.

Application of hierarchical principals may assist us in structuring and formalizing our approach to habitat assessment. At present, hierarchical principals constitute a loosely integrated set of insights: on scale phenomena (O'Neill 1989). The first and simplest application of this theory has been in an increased conscience of the extent to which our models and measurements are scale dependent (O'Neill 1989). The hierarchical perspective is a useful conceptual construct. It enables the human mind to deal with the otherwise overwhelming complexity of nature by the step-wise development of models of sequential subsystems, each which becomes a component of the next larger systems. In this manner, the full detail of a system can be examined in a piece-wise yet holistic fashion (Kemp et al. 1996).

While hierarchical principals in ecology are most generally applied to complex systems such as ecosystems, the approach may be well suited to the hierarchical levels we have identified as important to the focal level of our habitat assessment. For each of three dimensions of our interest in oyster habitat, a hierarchy of scaled systems of understanding can be conceived (Fig. 24). A goal of our continuing efforts in research toward the application of ASCS to oyster habitat assessment lies in integrating hierarchical structure and information transfer within and across these three dimensions of habitat assessment. For the first two dimensions (habitat assessment and habitat definition), we have yet to adequately address many scale issues. Within the third hierarchy of scale issues (habitat representation), we have begun work towards improving hierarchical information transfer. The following is a brief description of the issues faced in each of these dimensions.

Habitat Component Dimension:

A scale difficulty specific to Chesapeake Bay oyster habitat definition deals with the three habitat

components of interest. These were: 1) Sedimentation on top of cultch 2) quantity of surface cultch, and 3) presence of buried shell or hard substrate under superficial sediment. A different “grain” and “extent” is needed for the accurate assessment of each. In line with principal of hierarchy, there may be a rate specific ordering to these three components. We need to determine what lower and upper grain limitations are present with ASCS.

Habitat Assessment Component Dimension:

There are three apparent layers of scale being gathered for the assessment of habitat character. At the lowest level, visual assessment is currently required for the assessment of sediment on cultch. At the next level, physical methods are used to extract sediment and material for habitat characterization. At the highest level, two components are at play, acoustic sampling and visual assessment of regional heterogeneity. Acoustic methodology causes further complication to scale issues at this level. As water depth over calibration sites or survey areas changes, the actual footprint or bottom being issonified changes greatly due to transducer beam. While such variation in scale is measurable, its effect upon habitat determination currently is not.

Habitat Representation Dimension:

For oyster habitat assessment and rehabilitation goals, information must be able to be understood and represented over a wide variety of scales. This requirement is due to the fact that restoration activities may occur over very limited portions of the bottom, while assessment of the cultch resource may be required at a baywide, landscape level. Continuous data integration from the sampled grain upward, through specific hierarchical rules to a landscape level can produce “the big picture” It additionally allows for an orderly assemble of a large degree of informational content.

We are currently employing four levels of ASCS hierarchy into our representational analysis. These are the: 1) footprint, 2) grid cell, 3) patch, and 4) oyster bar.

1) The lowest level of grain attainable by ASCS is the acoustic footprint of each interrogated sound pulse. At this level data can be displayed by GIS but there is a great deal of “noise” in the data (Fig. 25). While data at this level is capable of being utilized for bottom searches of charting over small areas, when scaled upward, individual trees obscure the forest.

2) The next hierarchal level represented is the grid cell (Figures 26 and 27). Transformation of ASCS point data into a continuous surface rendition may provide three principal advantages. 1) For some interpretive purposes (often management oriented), it is helpful for the GIS cartographer to produce habitat types completely over a continuous surface. 2) Aforementioned scale related problems can be resolved (the forest will begin to appear). Information concerning accuracy and precision of a cell in portraying true habitat as well as information about the cells neighbors may be maintained.

3) Although human aggregation of oyster habitat data often tries to organize around the oyster “bar”, we are inserting an intermediate hierarchical level between the grid cell and the oyster bar.

This level is commonly referred to in landscape ecology as the "patch". It is an aggregation of adjacent grid cells sharing similar habitat characteristics. A comparison of Yates oyster bars (Fig. 12) and Maryland Bay Bottom Survey Results (Fig. 13) indicate a high level of habitat variation within oyster bars comparable to the definition of patch. For habitat assessment needs, as well as restoration activity, information at this scale may be considered of most importance. Hierarchical rules of aggregation using GIS techniques can produce such aggregations (Fig. 28).

4) The highest level of the hierarchy we wish to observe in oyster habitat analysis is the bar. At the informational level of the oyster bar, patterns of landscape within the bay bottom begin to become obvious. Such patterns are based upon large scale and temporally slow processes and rates of hydrology.

Technological and Operational Development

Transducer Design and Deployment

Most ASCS systems are presently employing sound generating transducers developed for "off the shelf" application with fish finders or non-survey quality fathometers. Industry sources indicate that such transducers offer similar results to those obtained with more expensive survey quality equipment in ASCS application. While improvements in transducer design specific to ASCS application must wait for demand, experimentation with transducer deployment may yield great increases in signal quality and interpretation.

An original advantage of ASCS was that specialized towed devices were not required for surveying. Simple thru hull mounting of transducers allowed surveying to be conducted. While this provided for simplicity, it also has drawbacks. Hull configuration on different craft moving at different speeds can cause variation in results from survey to survey and boat to boat. Transducers are subject to fouling, potentially causing unknown distortion of signal. In hull mounted locations, transducers are subject to amplified roll and pitch distortion. Such effectively causes the transmitted energy pulse to strike the bottom obliquely rather than perpendicular.

Hull mounting also dictates that no depth control of the transducer over the bottom is possible. Although there are many physical implications of such, the principal is that depth of water changes the footprint of isonification of the bottom. Such is due to beam width of a transmitted pulse being constant in degrees.

All of the above reasons may cause variation in survey results, or deteriorate acoustic interpretation. We would hope to examine techniques in deploying alternative transducer mountings. Such could either be as a towed body or a rigid deployed fin. In either case, three principal advantages may be obtained. 1) The unit could be deployed between different platforms and produce similar results. Yaw and pitch can be reduced via independence of the transducer unit from the vessel. In the case of a towed body, depth standardization might be realized via control of the units depth.

Frequency Variation - Multiple vs. Chirp

Currently employed transducers utilized on ASCS systems generally range between 38 and 300 kHz. Frequency choice is a tradeoff between three principal factors. 1) Attenuation is much greater with higher frequencies. In deep waters, lower frequencies suffer less attenuation prior to reaching bottom sediments. 2) Beam width is generally much narrower in higher frequencies. With water depth constant, this results in a smaller issonification footprint. and 3) Lower frequencies penetrate further in the sediment than do higher frequencies. For this reason, we had chosen our initial evaluation frequency to be 200 kHz. This frequency penetrates only several cm. into the sediment. This frequency was chosen to minimize complexity in separating surface with buried habitat assessment.

Some evaluation has begun with dual frequency equipment capable of interpreting acoustic returns independently on two wave lengths. Such systems are soon expected to be marketed. Structured application of such systems has yet to be addressed in the literature, yet possibilities are many. Comparative evaluation may be capable between a surface habitat characterization and sub-bottom characterization. Sub-bottom analysis might be trained to identify buried oyster shell. Conceivable systems could be developed to take advantage of "chirp" technologies currently employed on sub-bottom profiling systems similar to those we employed in identifying oyster reef edges.

Limited effort has been devoted to the linkage of ASCS and multi-beam technology. Current Multibeam technology allows for the bathymetric surveying of a wide swatch of the seafloor (Mayer et al. 1998). If linked to ACSC acoustic analysis, habitat could be efficiently mapped as well as bathymetry.

Proprietary Algorithms

A potential impediment to widespread scientific application of commercial ASCS has been their dependence upon proprietary algorithms for the analysis and interpretation of acoustic waveforms. Without the ability to fully describe, and publish, waveform interpretation methodology, limits are placed upon comparative analysis of such systems. It is expected that such restrictions will ease as system use becomes more widespread.

Storage of Full Waveform Content

Current ASCS systems employ "on the fly" wave form analysis. Essentially this implies that raw acoustic interrogation data is lost to the system once categorization of data is complete. The potential for storage of the complete acoustic record for post processing would be advantageous for many applications. Various approaches could be used to analyze the same data set under various scenarios. Manufacturers of ASCS are beginning to develop such capabilities.

Examinations of Other Applicable Remote Technologies for Oyster Habitat Assessment

Other remote sensing equipment and technologies potentially capable of oyster habitat assessment were extensively reviewed as to their ability to provide information about the three components of

oyster habitat desired: 1) surface sedimentation, 2) cultch density, or 3) buried cultch or hard substrate. Of all those reviewed in the literature, or through communication with users, individuals felt that the following offered the most potential.

On Bottom Sensors

Sediment Profiling Imaging Systems were not evaluated directly for this project. Rhoads (1996) and Cutter (1998) provide a good review of the capabilities of such shallow sub-bottom plowing video systems. Such custom devices were highly capable in fine grain assessment of sediments and macro-bio activity in the shallow sediments. It was not determined how effective such a system might be in dense aggregations of surface and buried oyster shell. The highly interpretive video image and slow apparent speed of such devices led to our determination not to physically evaluate such systems.

Other acoustic bottom situated interrogators (Rhodes 1996) were experimental concepts, not yet operational. Due to this, and the small scale of bottom area they were capable of assessing, we did not continue an assessment of potential towards our goals.

In Water Sensors

It was hoped to test capabilities of Laser Line Scanners for oyster habitat assessment. Such equipment has already demonstrated the ability to produce excellent resolution and object discernation even in extremely turbid waters (Tracy et al. 1998). Cost of test deployment was prohibitive.

Airborne Sensors

No methods currently employed or in the conceptual stage, including Light Detection and Ranging (Lidar) technologies have been demonstrated to be effective in highly turbid waters.

Literature Cited

Allen, T.F.H., R.V. O'Neill, and T.W. Hoekstra. (1984). Interlevel relations in ecological research and management: Some working principals from hierarchy theory. U.S.D.A. Forest Service. General Technical Report RM-110. July 1984.

Baylor, J.B. 1894. Method of defining and locating natural oyster beds, rocks, and shoals. *Oyster Records* (pamphlets, one for each Tidewater, VA, county, that lists the precise boundaries of the Baylor Survey). Board of Fisheries of Virginia.

Chai, A.L.Homer, M., Tsai, C.F. and P. Gouletquer. (1992) Evaluation of oyster sampling efficiency of patent tongs and an oyster dredge. *N. Amer. J. of Fisheries Management*. 12:825-832.

Chesapeake Executive Council. 1993. Chesapeake Bay Aquatic Reef Habitat Plan.

Collins, W., R. Gregory, and J. Anderson. (1996). A digital approach to Seabed Classification. *Sea Technology*. August 1996.

Cutter, G.R. and R.J. Diaz. (1998 in publication). Novel optical remote sensing and ground-truthing of benthic habitat using the Burrow-Cutter-Diaz plowing sediment profile camera system (BCD) sled. *Spatial Data and Remote Sensing in Invertebrate Fisheries Workshop*. Fort Walton Beach, Florida. April 19-20, 1997. G.F. Smith editor., to be published in *Journal of Shellfish Research*. December 1998.

DeAlteris, J.T. (1988). The geographic development of Wreck Shoal, a subtidal oyster reef of the James River, Virginia. *Estuaries* 11(4): 240-249.

Graves, C. ed. (1912) Fourth report of the Shell Fish Commission of Maryland.

Haven, D.S., J.P. Whitcomb, J.M. Jiegler, and W.C. Hale. 1979. The use of sonic gear to chart locations of natural oyster bars in lower Chesapeake Bay. *Proc. Natl. Shellfish Res.* 69: 11-14.

Haven, D.S., and J.P. Whitcomb. 1983. The origin and extent of oyster reefs in the James River, Virginia. *J. Shellfish Res.* 3: 141-151.

Homer, M.L. and W.P. Jensen. 1993. American oyster stock assessment in Maryland. Interim report to National Oceanic and Atmospheric Administration, National Marine Fisheries Service. Contract No. 92-ODR-21. Grant No. NA26 FLO390-01. January 1993.

Heald, G.J. and N.G. Pace. (1996). An analysis of 1st and 2nd backscatter for seabed classification. *Proceedings of the III European Conference on Underwater Acoustics, Crete*. June 1996.

Kemp, W.M. M.R. Lewis, J.J. Cunningham, J.C. Stevenson and W.r. Boynton. (1996). Microcosms, macrophytes, and hierarchies: Environmental research in the Chesapeake Bay.

Lambert D.N., J.C. Cranford, and D.J. Walter. 1993. Development of a high resolution acoustic seafloor classification survey system. International Conference on the Acoustic Classification and Mapping of the Seabed. Sponsored by: The Underwater Acoustics Group of the Institute of Acoustics and Defense Research Agency. University of Bath, England. April 1993.

Mayer, L. J.H. Clarke and S. Dijkstra. (1998 in publication). Multibeam Sonar: Potential applications for fisheries research. Spatial Data and Remote Sensing in Invertebrate Fisheries Workshop. Fort Walton Beach, Florida. April 19-20, 1997. G.F. Smith editor, to be published in Journal of Shellfish Research. December 1998.

O'Neill, R.V. (1989) Perspectives in Hierarchy and Scale. In: perspectives in Ecological Theory. Princeton Univ. Press

Powell, E.N., Song, J., Ellis, M.S., Wilson-Ormond, E.A. (1995). The status and long-term trends of oyster reefs in Galveston Bay, Texas. J. Shellfish Res. Vol. 14, No. 2, 439-457.

Rhoads, D.C., J.A. Muramoto, and R. Ward. (1996). A review of sensors appropriate for assessment of Submerged coastal habitats and biological resources. U.S. Army Corps of Engineers. Technical Report EL-96-10. August 1996.

Schock S.G. L.R. LeBlanc, and L.A. Mayer. 1989. Chirp subbottom profiler for quantitative sediment analysis. Geophysics. Vol. 54. No. 4. P. 445-450.

Seligier, H.H., Boggs, J.A. (1988). Evidence for loss of habitat for oysters in tributaries of the Chesapeake Bay. In: Understanding the estuary. Advances in Chesapeake Bay Research. U.S. EPA CBP/TRS 24/88. CRC Publication 129. Chesapeake Bay Research Consortium, Solomons, MD. P. 570-583.

Simons, J.D., et al. (1992). An improved method for mapping oyster bottom using a global positioning system and an acoustic profiler. J. Shellfish Res. Vol. 11, No. 2, 431-436.

Smith, G.F. and S.J. Jordan. (1993) Monitoring Maryland's Chesapeake Bay Oysters. Chesapeake Bay Research and Monitoring Division. Maryland Department of Natural Resources. CBRM-OX-93-3.

Smith, G.F. Maryland's Historic Oyster Bottom: A Geographical Representation of the Traditional Named Oyster Bars. Maryland Department of Natural Resources, Fisheries Service, Cooperative Oxford Laboratory, Mapping and Analysis Project. October 1997.

Smith, G.F. et al. (In Progress) A digital representation and examination of Maryland Bay Bottom

Survey results (1975- 1983).

Tracy, G.A., E. Saade, B. Stevens, P. Selvitelli, and J. Scott. (1998). Laser line scan of crab habitats in Alaskan waters. Spatial Data and Remote Sensing in Invertebrate Fisheries Workshop. Fort Walton Beach, Florida. April 19-20, 1997. G.F. Smith editor, to be published in Journal of Shellfish Research. December 1998.

Winslow, F., 1878. Sheet 1 U.S. Coast Survey. Chart of Tangier Sound Showing the Oyster Beds, and Approximate Limits of Scattered Oysters. August, September & October 1878.

Winslow, F., 1881. Deterioration of American Oyster Beds. Popular Science Monthly. 20: 29-43.

Winslow F., 1882. Report of the oyster beds of the James River, Tangier Sound and Pocomoke Sounds, Maryland and Virginia. Appendix # 11. Report for 1881. United States Coast and Geodetic Survey. U.S. Government Printing Office Washington D.C. (Smithsonian Archive).

Yates, C.C., 1911. Survey of the oyster bars [by county of the State of Maryland]. Department of Commerce and Labor - Coast and Geodetic Survey. U.S. Government Printing Office.

Table 1. Oyster reef shell procurement costs, FY96 and FY97 contracts. Planned vs. actual expenditures.

Reef construction material costs specified in proposals:

| | FY96 Funding | FY97 Funding |
|-----------------------------|------------------|------------------|
| Shell | \$55,250 | \$67,750 |
| Marl | \$38,250 | — |
| | FY96 Addendum | |
| Shell | \$20,000 | |
| Total FY | \$113,500 | \$67,750 |
| Total Combined Years | | \$183,250 |

Actual Shell Expenditures:

| | |
|--|------------------|
| 23,970 cubic yards dredged at cost of \$3.21 per cu. yd. | \$76,943 |
| Tow and Plant (rate \$3.79 cu. yd.) | \$30,320 |
| Tow and Plant (rate \$4.14 cu. yd.) | \$33,120 |
| Tow and Plant (rate \$5.11 cu. yd.) | \$40,726 |
| Total | \$181,109 |
| Difference Between Planned and Actual | - (1.16%) |
| | \$2,140 |

Due to one short barge load, and trade in shell for crew boat usage at Strong Bay site.

Table 2. Reef sites constructed under prior Aquatic Reef funding.*

| <u>Sitename</u> | <u>Date</u> | <u>Materials</u> | <u>Acres</u> | <u>Comments</u> |
|--------------------------|-------------|---------------------------|--------------|--|
| PLUM POINT | 06/22/1996 | SHELL | 28.0 | CENTROID ONLY |
| PLUM POINT | 06/20/1996 | SHELL | 20.0 | CENTROID ONLY |
| PLUM POINT | 06/19/1996 | SHELL | 19.5 | CENTROID ONLY |
| PLUM POINT | 06/15/1996 | SHELL | 15.5 | CENTROID ONLY |
| PLUM POINT | 06/24/1996 | SHELL | 13.0 | NO COORD INFO |
| PLUM POINT | 06/01/1996 | CUBES | 5.0 | NO COORD INFO |
| PLUM POINT | 06/01/1996 | CUBES | 10.0 | NO COORD INFO |
| PLUM POINT | 07/10/1996 | CUBES | 21.0 | NO COORDINATE INFO |
| PLUM POINT | | CAUSEWAY #2 | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | CONCRETE CULVERT | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | COUNTER WEIGHT #1 | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | COUNTER WEIGHT #2 | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | DOLPHIN CAP | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | CULVERT PIPE | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | CAUSEWAY #1 | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | CONCRETE CULVERT | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | SEVERN R BRIDGE | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | SEVERN R BRIDGE | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | SEVERN R BRIDGE | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | SEVERN R BRIDGE | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | SEVERN R BRIDGE | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | SEVERN R BRIDGE | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | SEVERN R BRIDGE | UNKNOWN | CENTROID ONLY |
| PLUM POINT | | SEVERN R BRIDGE | UNKNOWN | PLUM1 |
| PLUM POINT | | SEVERN R BRIDGE | UNKNOWN | PLUM2 |
| PLUM POINT | | BOAT | UNKNOWN | "POCO" |
| PLUM POINT | | CONCRETE CULVERT | UNKNOWN | CENTROID ONLY |
| HACKETTS POINT | | SHELL | UNKNOWN | NO COORD INFO |
| LITTLE COVE POINT | 06/26/1996 | SHELL | UNKNOWN | CENTROID ONLY |
| LITTLE COVE POINT | | BEACH PRISMS | UNKNOWN | NO COORD INFO |
| CEDAR POINT | 06/26/1996 | SHELL | UNKNOWN | CENTROID ONLY |
| CEDAR POINT | | FIBERGLASS JAPANESE REEFS | UNKNOWN | NO COORD INFO |
| CEDAR POINT | | CONCRETE PRISMS | UNKNOWN | NO COORD INFO; 6 PER GROUP |
| CEDAR POINT | | SCATTERED ROCKS | UNKNOWN | NO COORD INFO; 500 T |
| CEDAR POINT | | ROCK PILES | UNKNOWN | NO COORD INFO; 500 T @ 1.5 T/YD |
| OLMSTEAD POINT | | SHELL | 1.0 | NO COORD INFO; DONATION TO COMMUNITY EFFORTS |
| FORT POINT | | SHELL | 1.0 | NO COORD INFO; DONATION TO ORP |
| HOLLICUTTS NOOSE | | BRIDGE RUBBLE | UNKNOWN | LINE |
| PLUM POINT | | SAILBOAT | UNKNOWN | 23' SAILBOAT "ROSENSHINE" |
| PLUM POINT | 06/13/1996 | SHELL | UNKNOWN | POLYGON |
| PLUM POINT | 06/18/1996 | SHELL | UNKNOWN | POLYGON |
| PLUM POINT | 06/14/1996 | SHELL | 21.0 | POLYGON |
| HOLLICUTTS NOOSE | 06/26/1996 | SHELL | 5.0 | POLYGON |
| PLUM POINT | 07/01/1996 | SW CUBE | 13.0 | POLYGON |
| OLD FORT BAR | 06/1996 | OYSTER SHELL | 12.0 | POLYGON |
| HACKETTS POINT | 06/1996 | OYSTER SHELL | 53.0 | POLYGON |
| OLMSTEAD POINT | 06/1996 | OYSTER SHELL | 12.0 | POLYGON |
| MAGOTHY RIVER SITE | | OYSTER SHELL | UNKNOWN | NO COORD INFO |
| BAY BRIDGE, EAST END | | OYSTER SHELL | UNKNOWN | NO COORD INFO |
| DOLLY'S LUMP | | OYSTER SHELL | UNKNOWN | NO COORD INFO |
| SEVERN RIVER, CARR CREEK | | OYSTER SHELL | UNKNOWN | NO COORD INFO |
| PLUM POINT | | OYSTER SHELL | UNKNOWN | NO COORD INFO |
| LITTLE COVE POINT | | OYSTER SHELL | UNKNOWN | NO COORD INFO |

| <u>Sitename</u> | <u>Date</u> | <u>Materials</u> | <u>Acres</u> | <u>Comments</u> |
|----------------------|-------------|--|--------------|---------------------|
| CEDAR POINT | | OYSTER SHELL | UNKNOWN | NO COORD INFO |
| CEDAR POINT | | ROCK PILES, CONCRETE UNITS, FIBERGLASS | UNKNOWN | POLYGON |
| CEDARHURST | | CONCRETE RUBBLE | 50.0 | POLYGON |
| CHESAPEAKE | | BEACH TIRE UNITS | 50.0 | POLYGON |
| CHOPTANK BRIDGE PIER | | CONCRETE RUBBLE | 50.0 | NO COORD INFO |
| DOLLY'S LUMP | | CONCRETE PIPE | 50.0 | POLYGON |
| GALES LUMP | | CONCRETE PIPE | 50.0 | NO COORD INFO |
| HOLLICUTTS NOOSE | | CONCRETE RUBBLE, TIRE UNITS, STEEL TUG | 50.0 | POLYGON |
| JANES ISLAND | | TIRE UNITS | 50.0 | POLYGON |
| LITTLE COVE POINT | | TIRE UNITS | 75.0 | POLYGON |
| LOVE POINT | | TIRE UNITS | 50.0 | POLYGON |
| PLUM POINT | | CONCRETE CUBES | 3440.0 | POLYGON |
| POINT NO POINT | | BARGES(5), SHELL PILE | 1050.0 | POLYGON |
| POINT LOOKOUT | | CLAM SHELL | 50.0 | SPAR BUOY NE CORNER |
| POINT LOOKOUT | | CLAM SHELL | 50.0 | SPAR BUOY SE CORNER |
| POOLES ISLAND | | CONCRETE RUBBLE | 230.0 | POLYGON |
| SEVERN RIVER BRIDGE | | CONCRETE RUBBLE | 2.5 | NO COORD INFO |
| TANGIER SOUND | | ROCK PILE | 56.0 | POLYGON |
| TILGHMAN ISLAND | | ROCK PILES, CONCRETE RUBBLE, TIRE UNITS, BARGES(2) | 50.0 | POLYGON |
| TOLCHESTER BAY | | CONCRETE RUBBLE | 50.0 | POLYGON |

* A variety of sources were consulted in the compilation of this database, but the primary information source was DNR personnel from previous years' reef programs. This table represents the best information we were able to obtain pertaining to prior reef construction. There is potential in the future to improve upon this database, particularly in regards to *locational* information pertaining to reef construction.

Table 3. Milestone Chart for Extended FY97 Funding

Nov. '98

- Post Construction Habitat Assessment Surveys - Reefs constructed under (FY96-FY97 funds)

Strong Bay - Chester River
Cook's Pt. - Choptank River
Middleground - Kedges Straits

Habitat characterization as to substrate type and oyster cultch density and quality. Integration with bathymetric information. Underwater video documentation of reef development and recruitment.

- Status Report

Jan. '99

- Continued maintenance, development and evolution of necessary seafloor classification calibration sites and files.

To include: Improved video imaging
Replacement of impacted calibration sites (oyster harvest in progress)
Improved oyster cultch quality gradation
Sediment grain size analysis review
Improved quadrat cultch counts and/or core information

- Improvements in Acoustic Seafloor Classification System/Geographic Information System signal collection, data integration and display (thru August)

Mar. '99

- Status Report

- Finalize habitat calibration catalog for oyster habitat assessment surveys
- Finalize capability in collecting and storing full survey (FFV) wave form vector during survey transects (allows post processing of survey data on shore for increased flexibility and information content)

- Begin Maryland 5,000 acre Aquatic Reef Designation oyster habitat charting

May '99

- Complete habitat charting of designated Aquatic Reef Designation areas

- Status Report

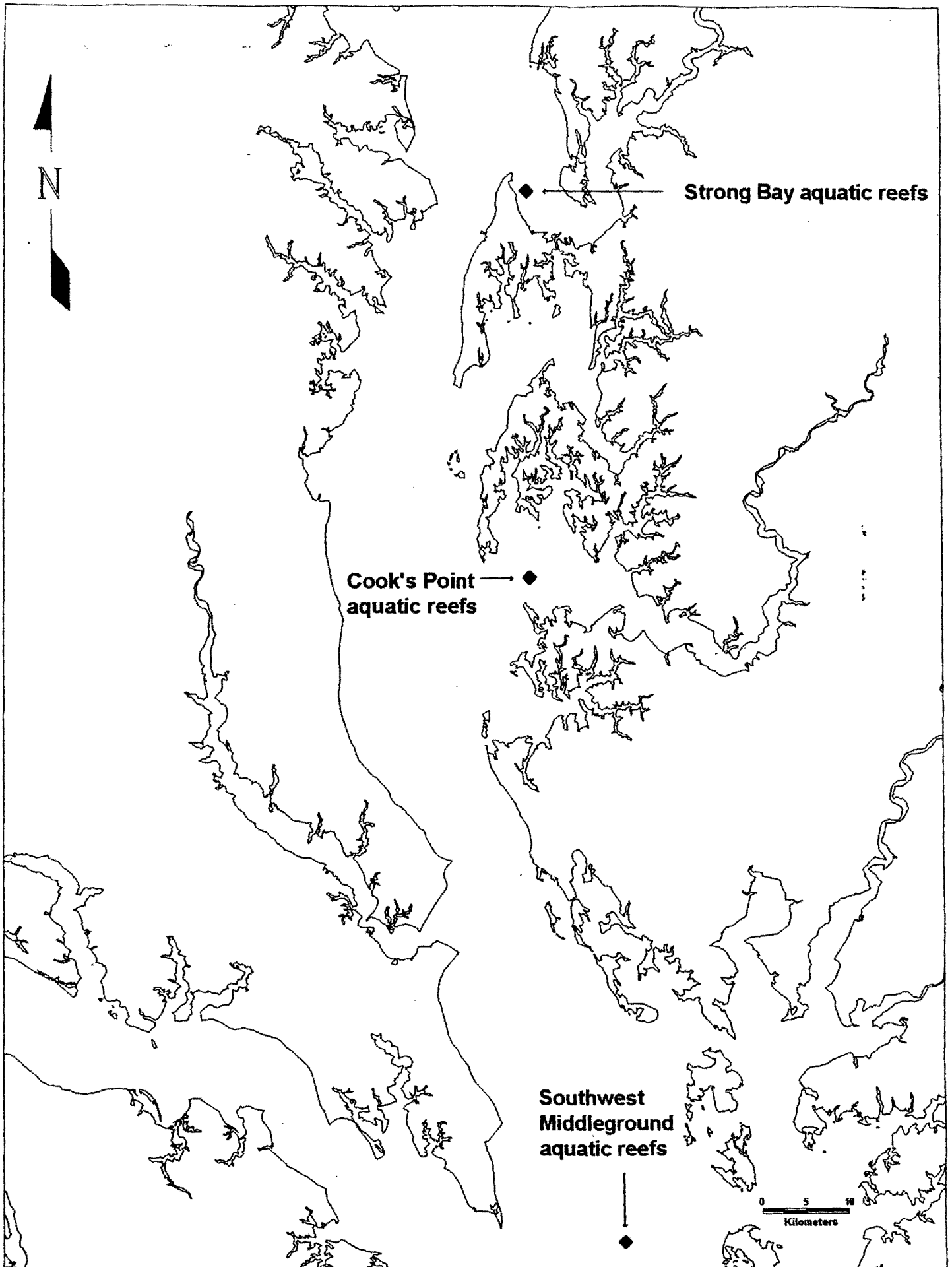
Jul. '99

- Begin integration of prototype Geographical Information System hierarchical data analysis modules into habitat charting routines (thru August)

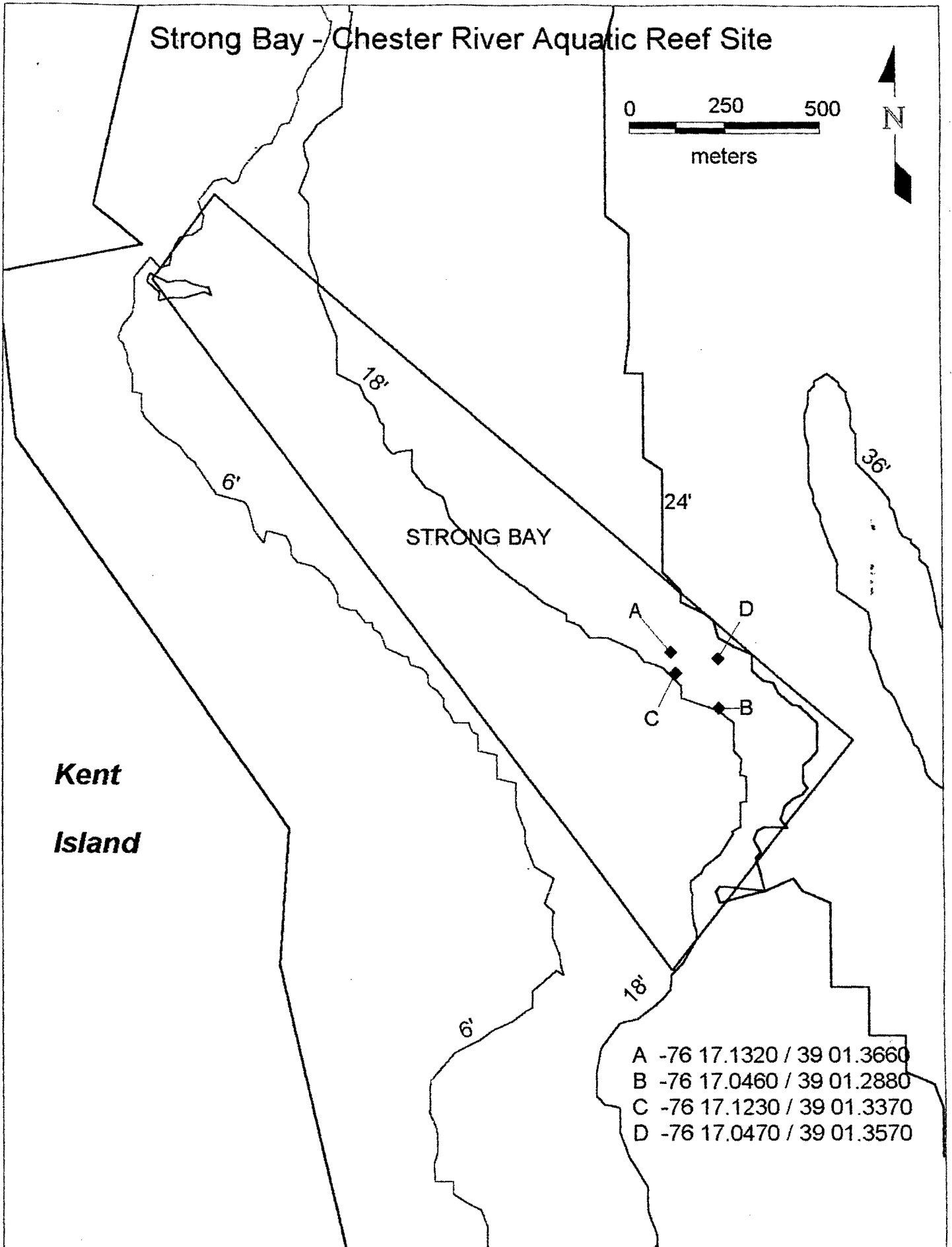
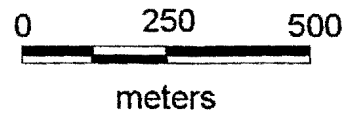
- Proof of concept demonstration charting of oyster habitat restoration projects

- Deliver final report, habitat charts, references to research publications

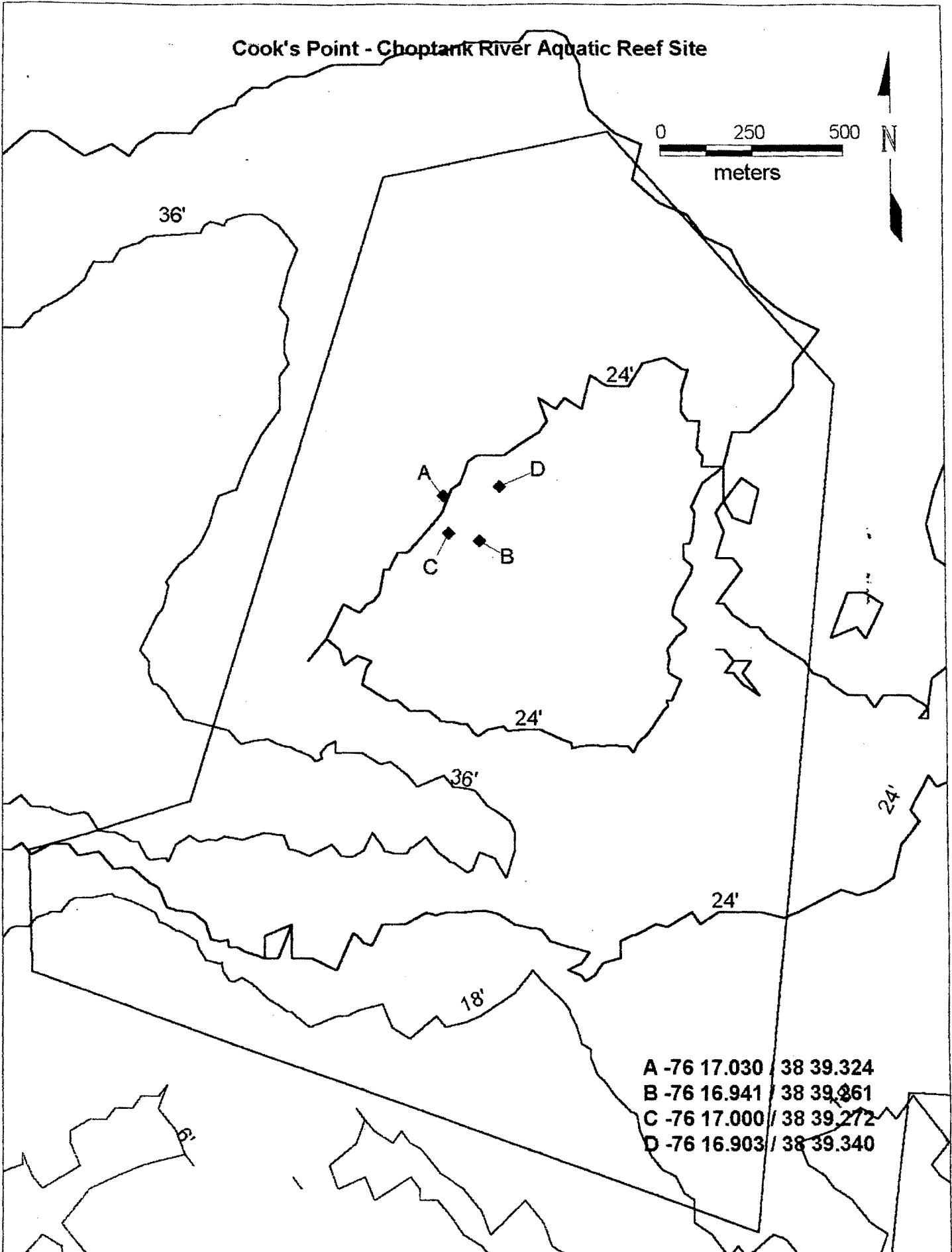
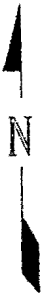
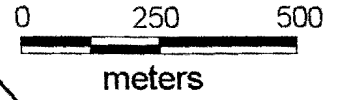
Sept. '99



Strong Bay - Chester River Aquatic Reef Site

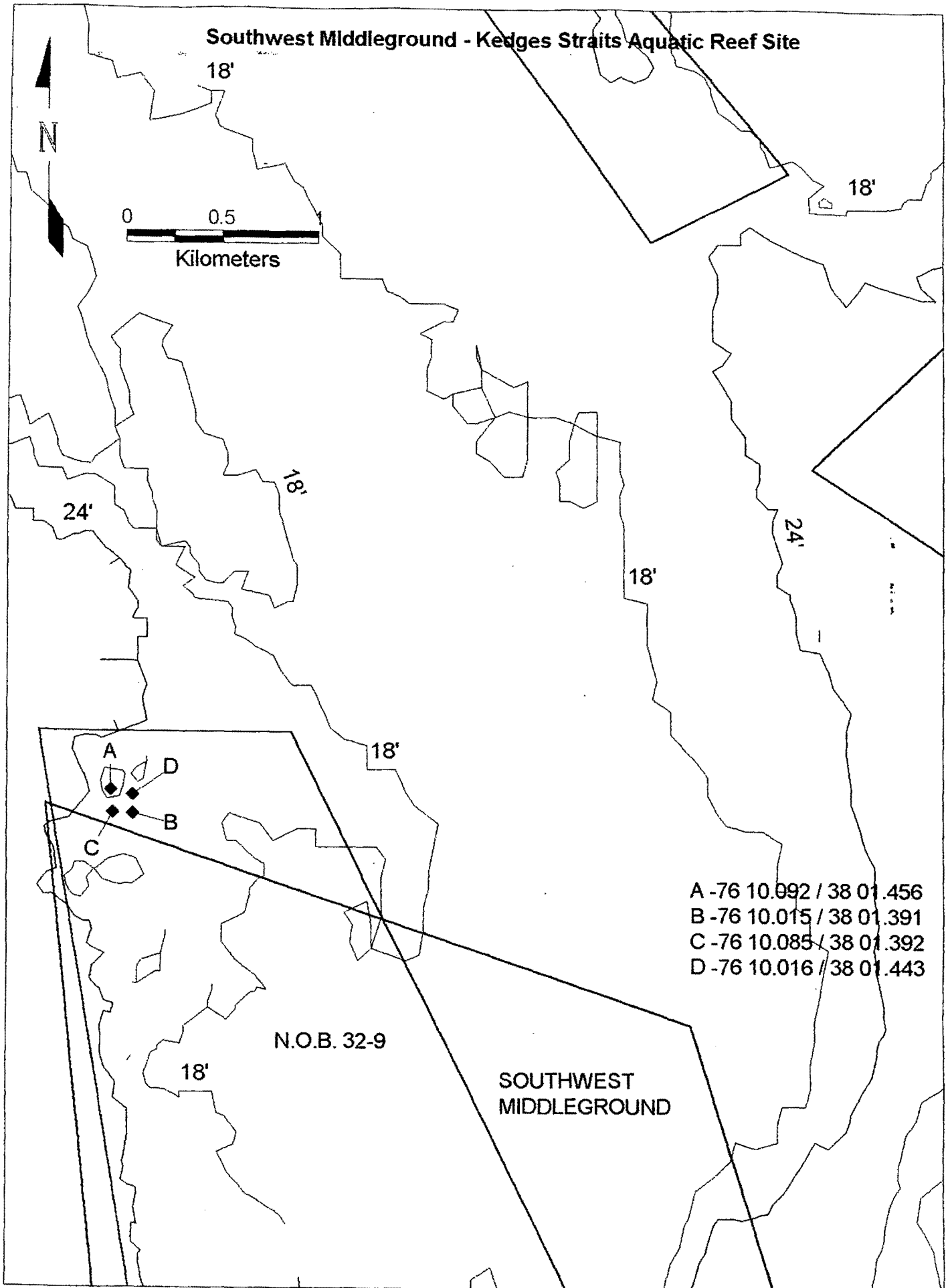
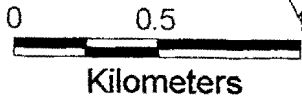
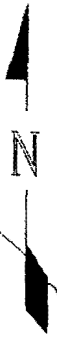


Cook's Point - Choptank River Aquatic Reef Site



| | | | |
|---|------------|---|-----------|
| A | -76 17.030 | / | 38 39.324 |
| B | -76 16.941 | / | 38 39.361 |
| C | -76 17.000 | / | 38 39.272 |
| D | -76 16.903 | / | 38 39.340 |

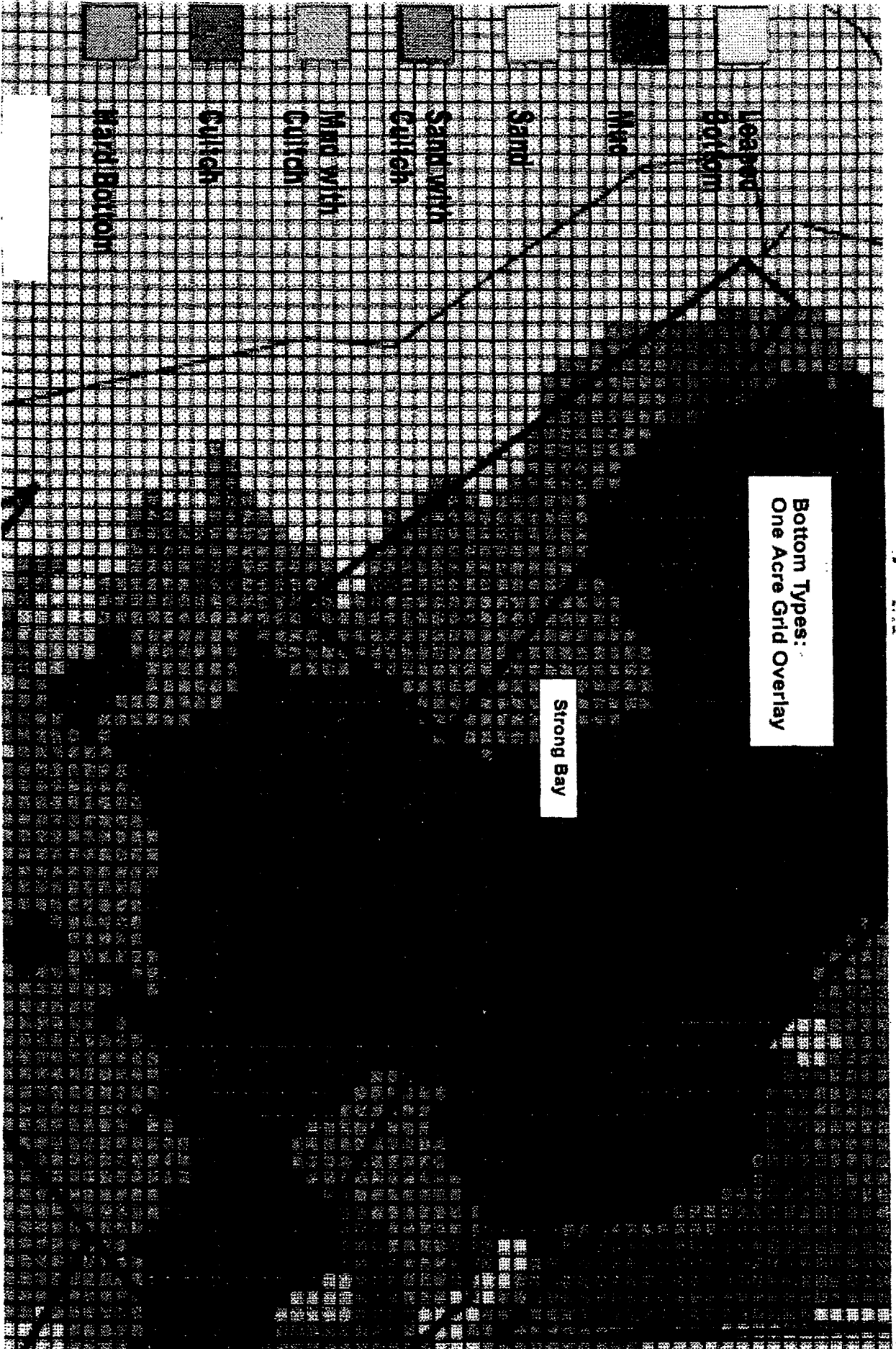
Southwest Middleground - Kedges Straits Aquatic Reef Site



- A -76 10.092 / 38 01.456
- B -76 10.015 / 38 01.391
- C -76 10.085 / 38 01.392
- D -76 10.016 / 38 01.443

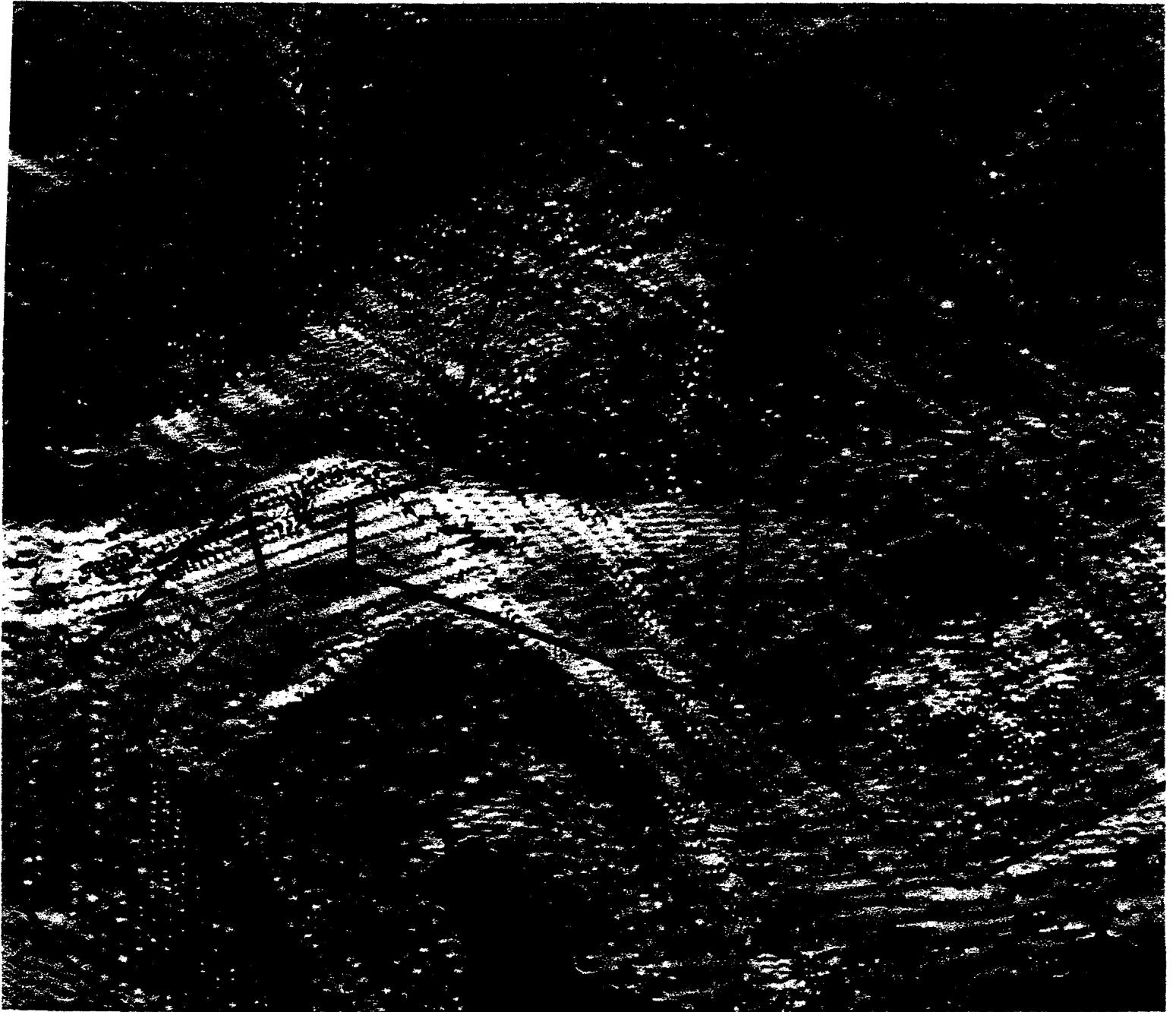
N.O.B. 32-9

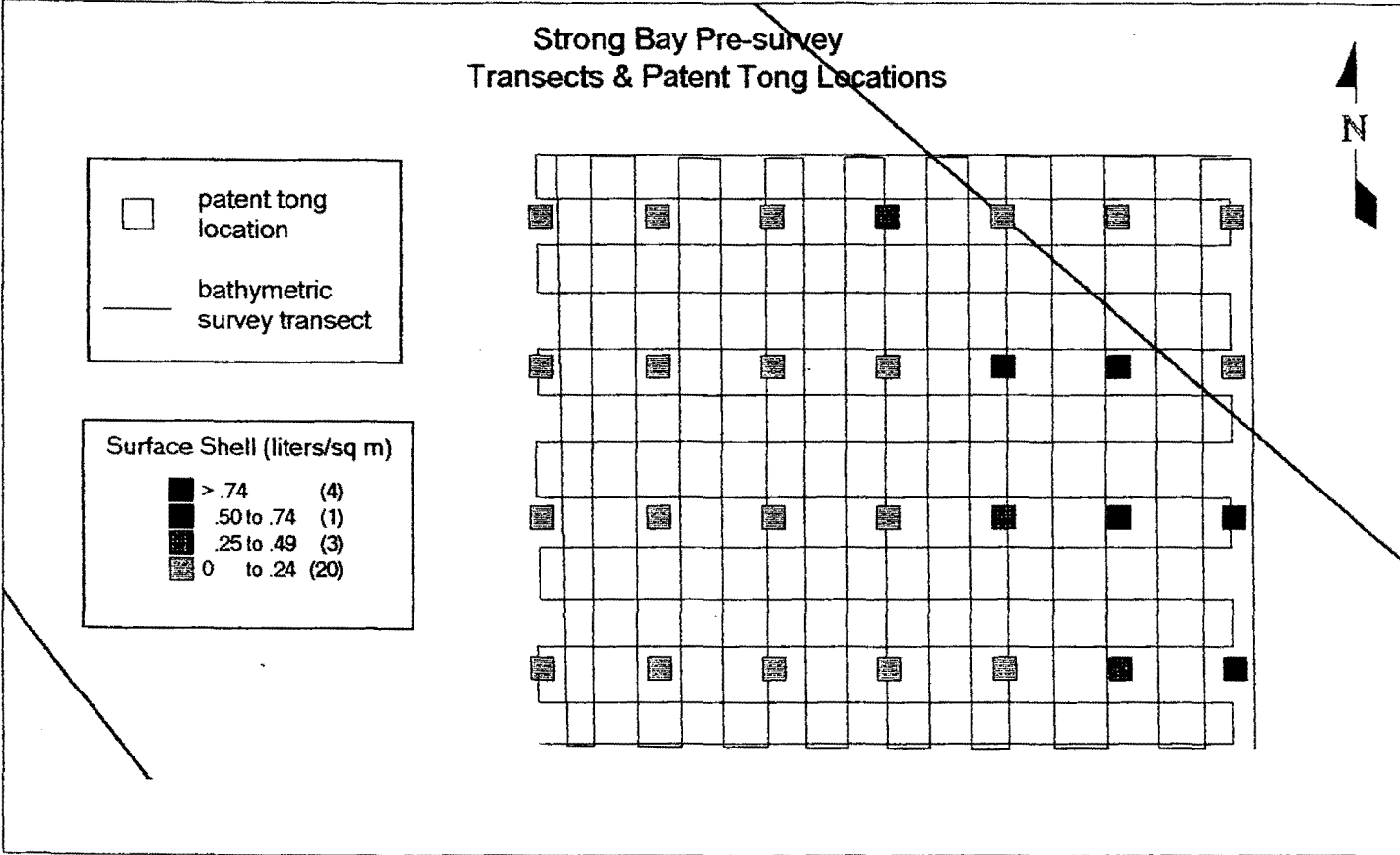
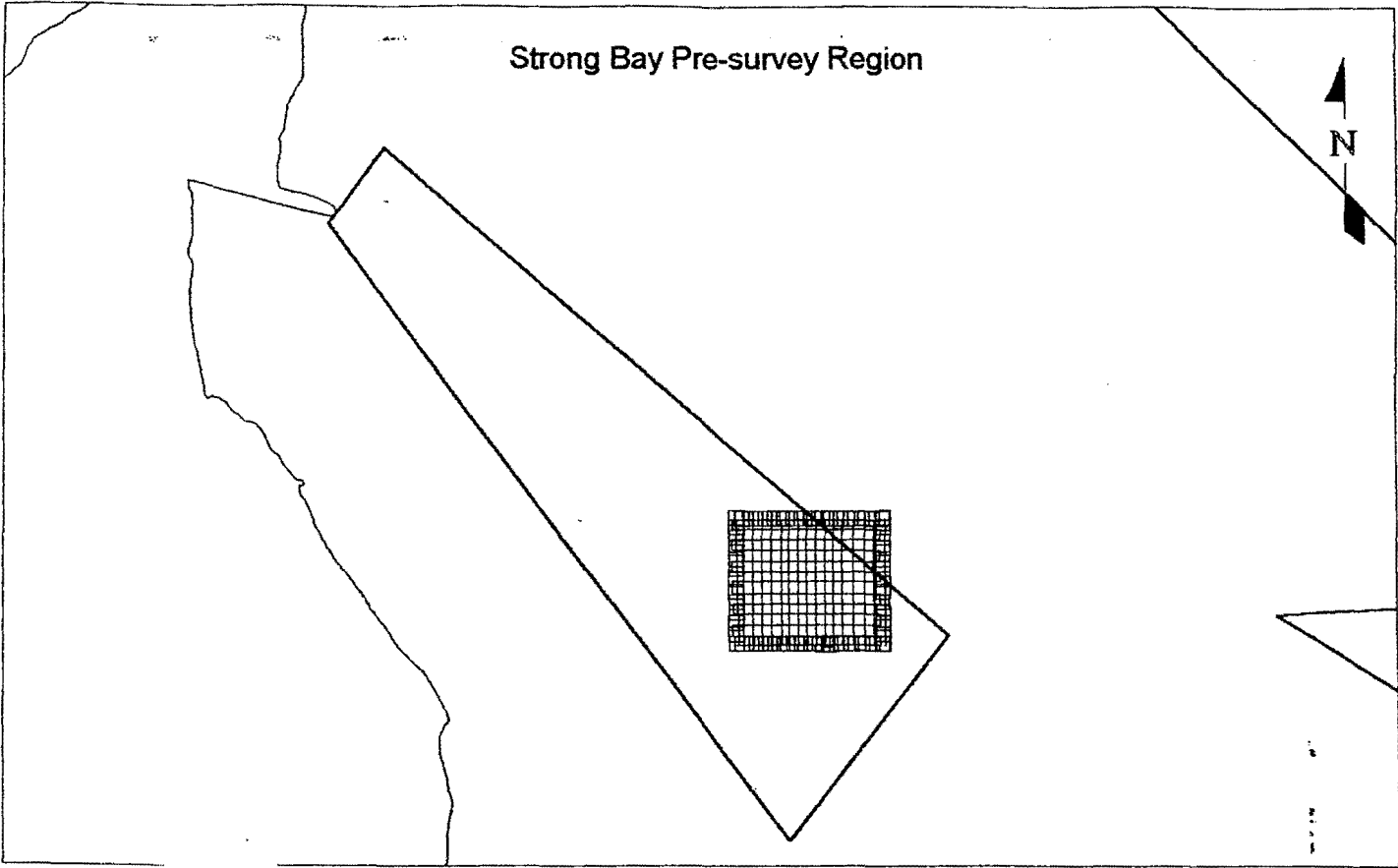
SOUTHWEST MIDDLEGROUND

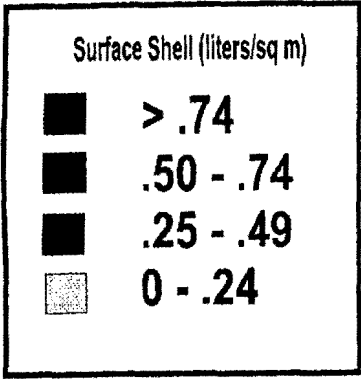


Bottom Types:
One Acre Grid Overlay

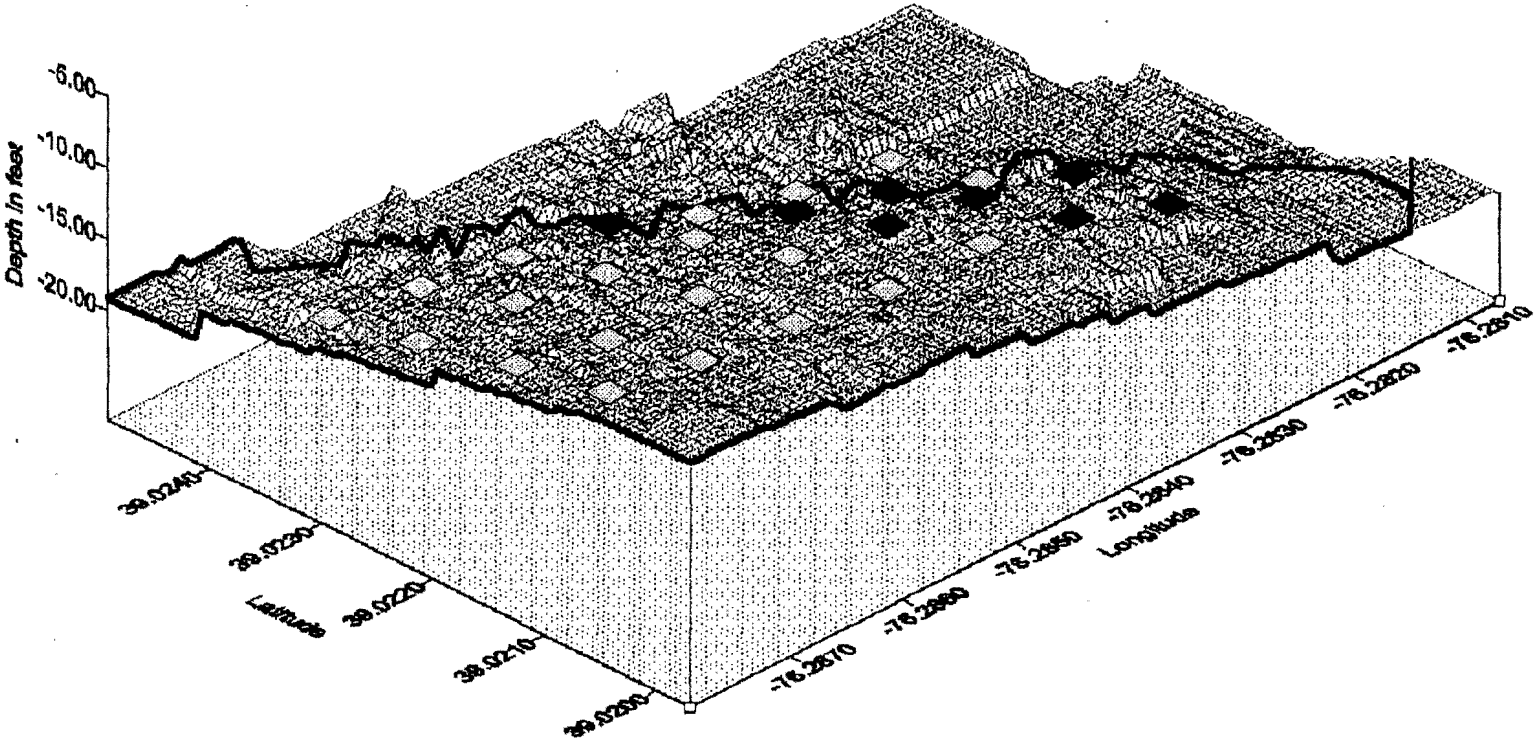
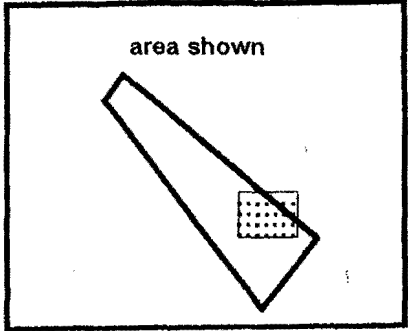
Strong Bay

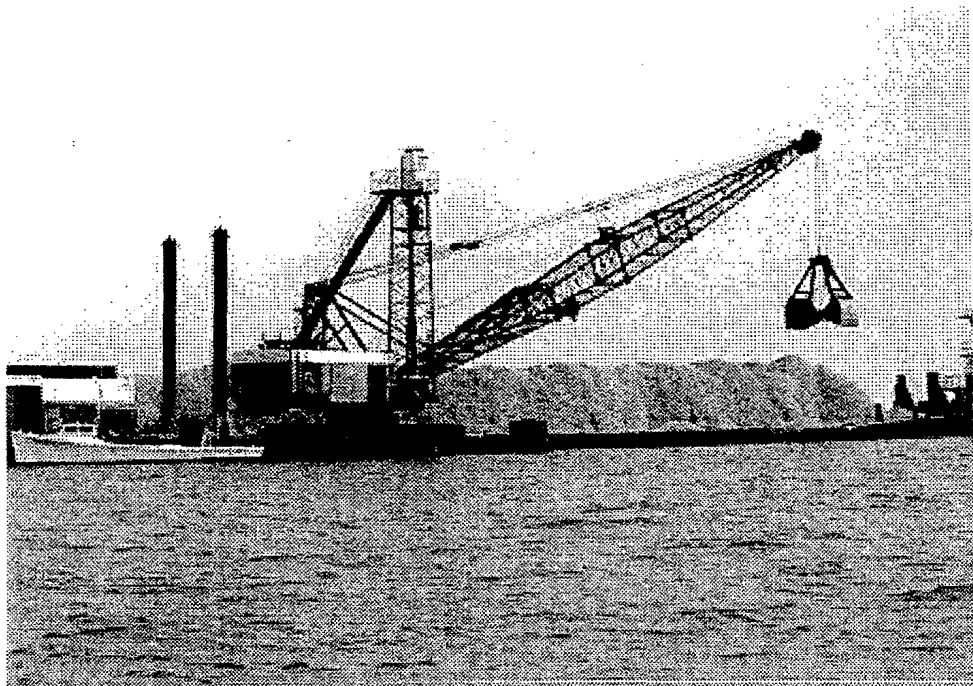






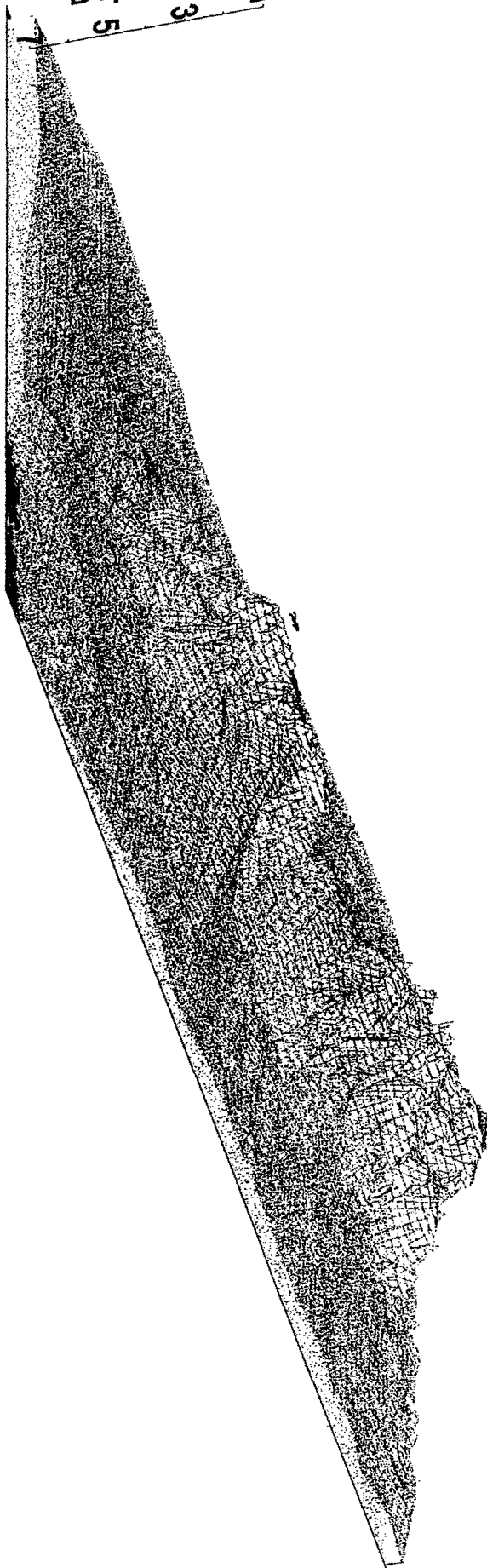
Pre-survey Results - Strong Bay Oyster Bar, Chester River

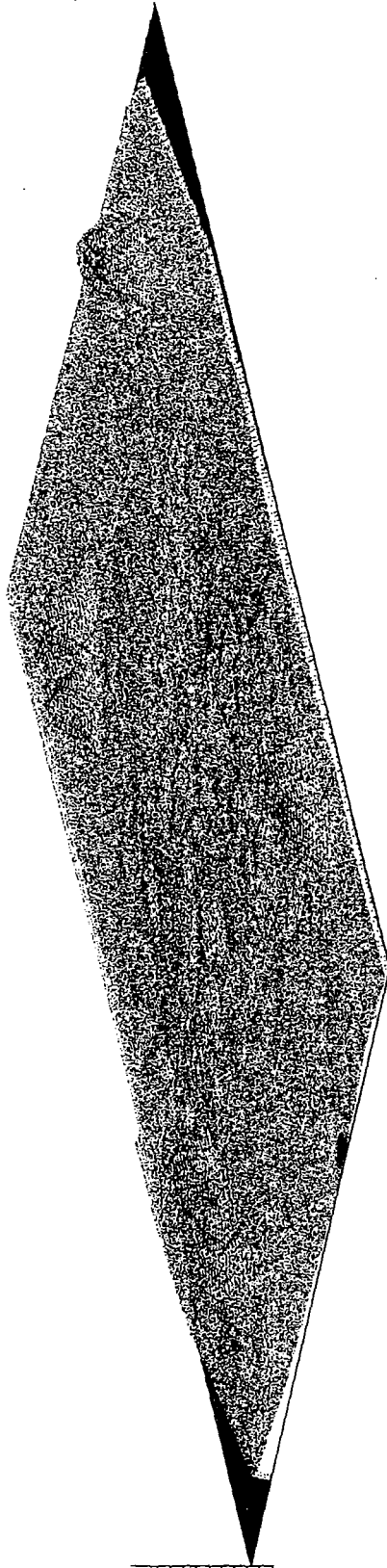




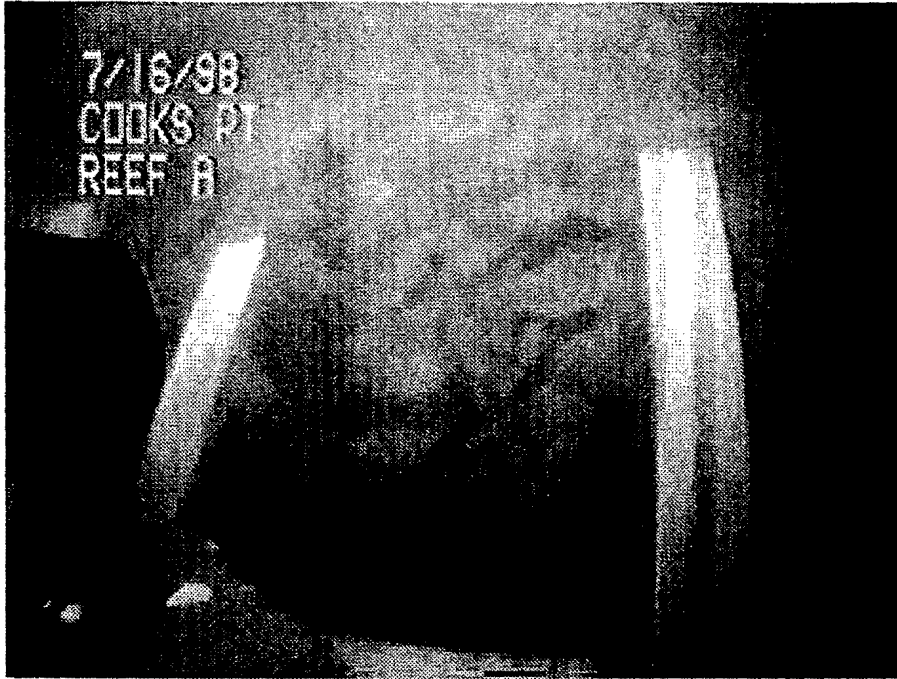
Depth (m)

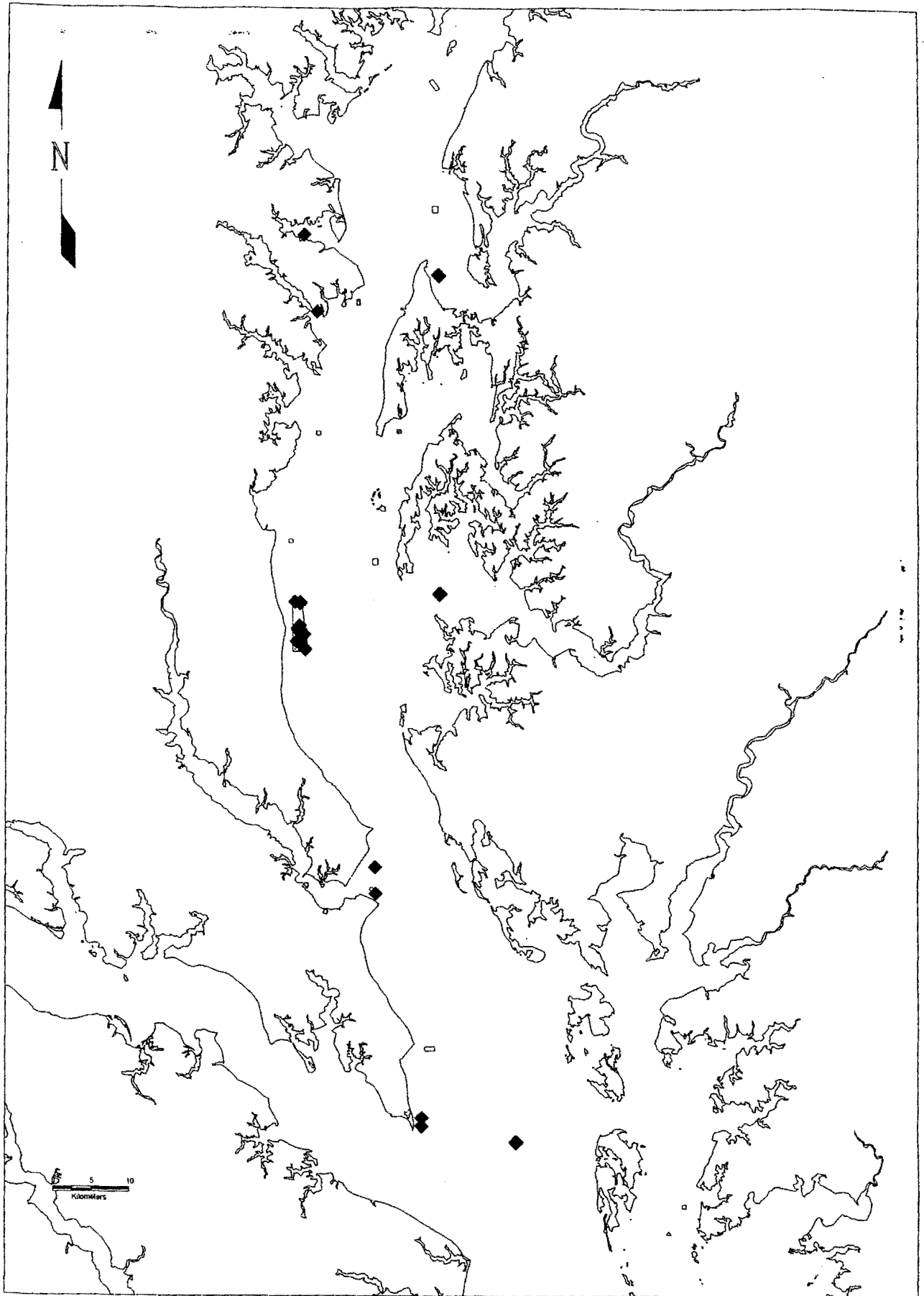
0 5

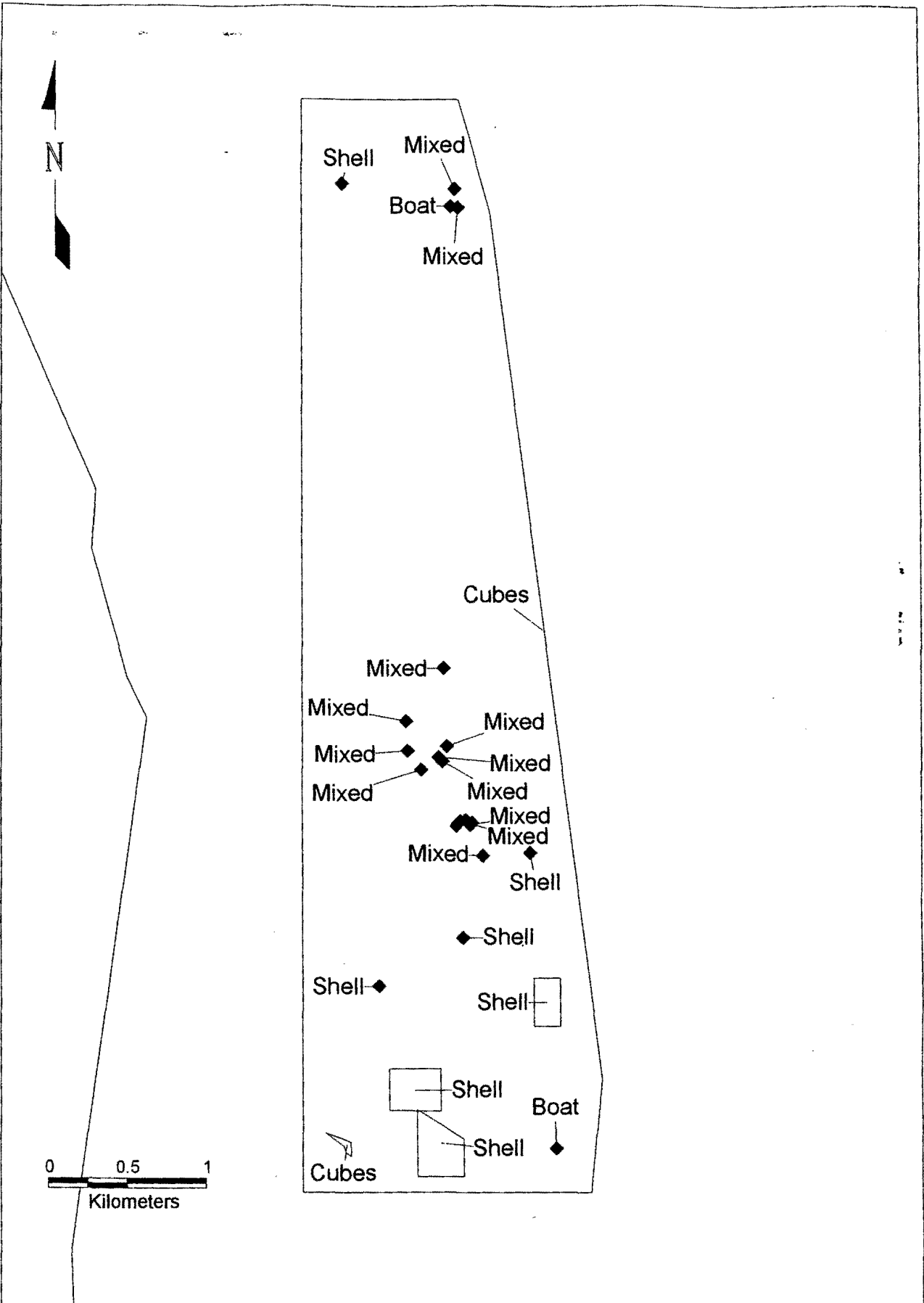


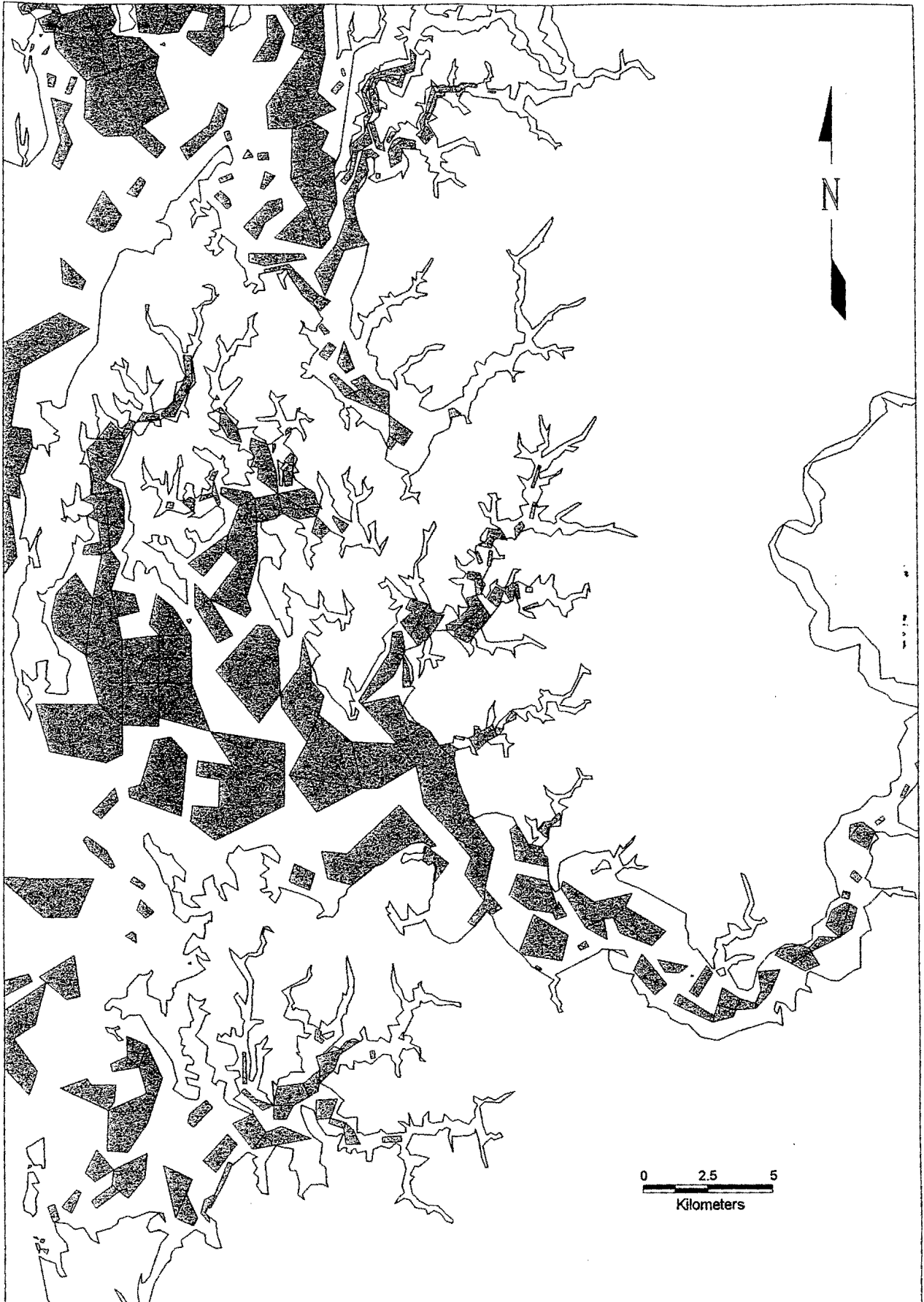


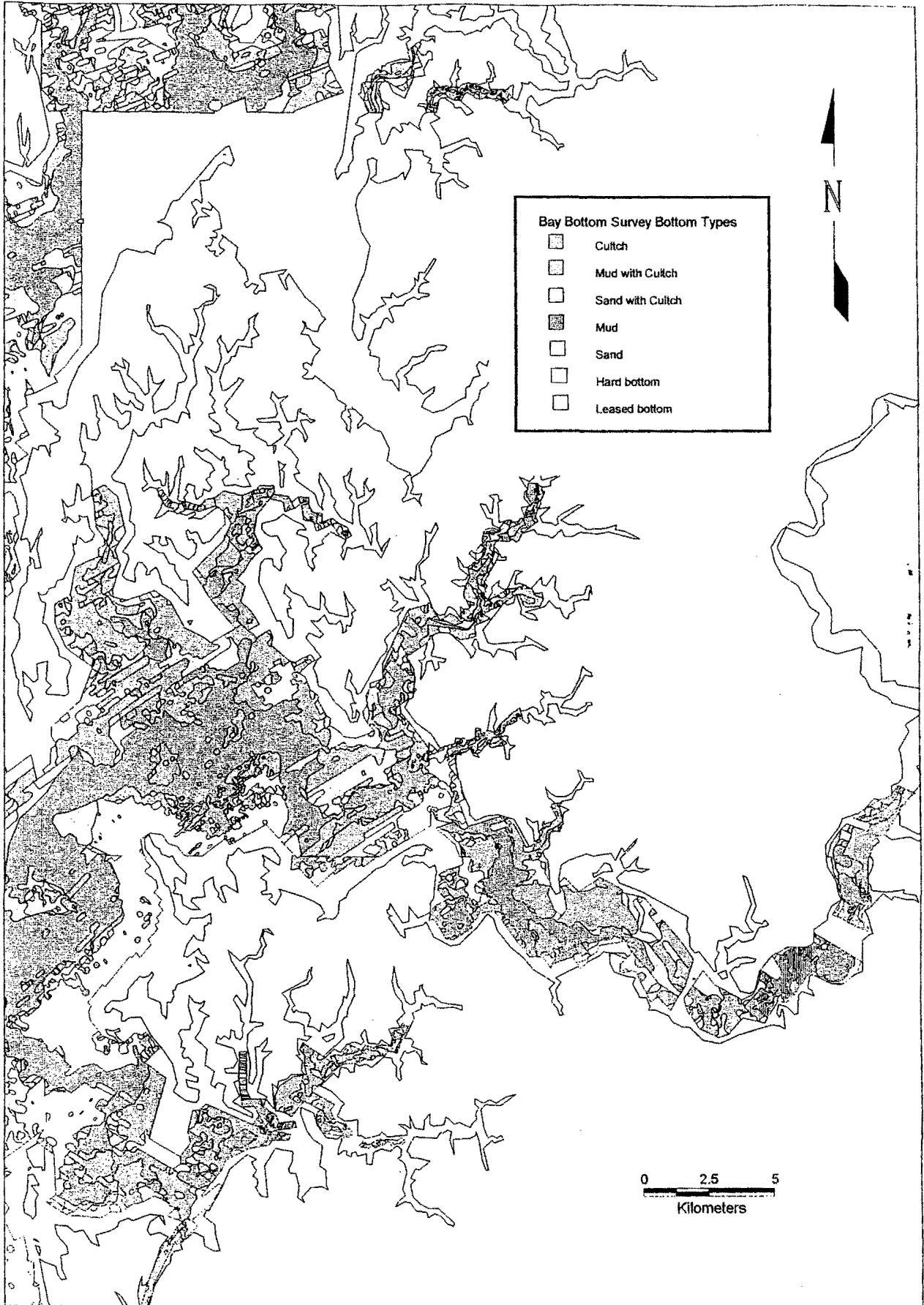
Depth (m)
5 4 3 2 1

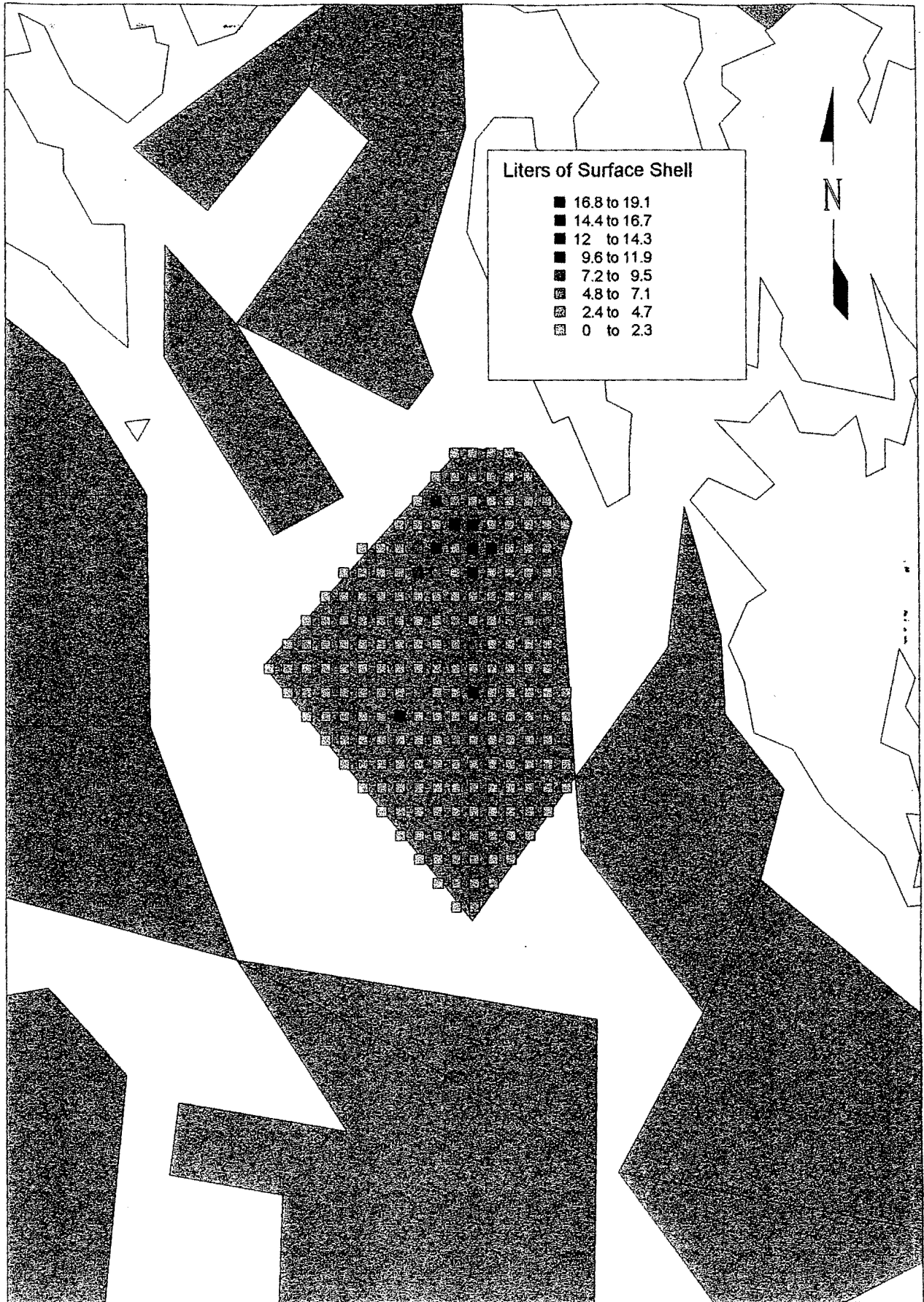


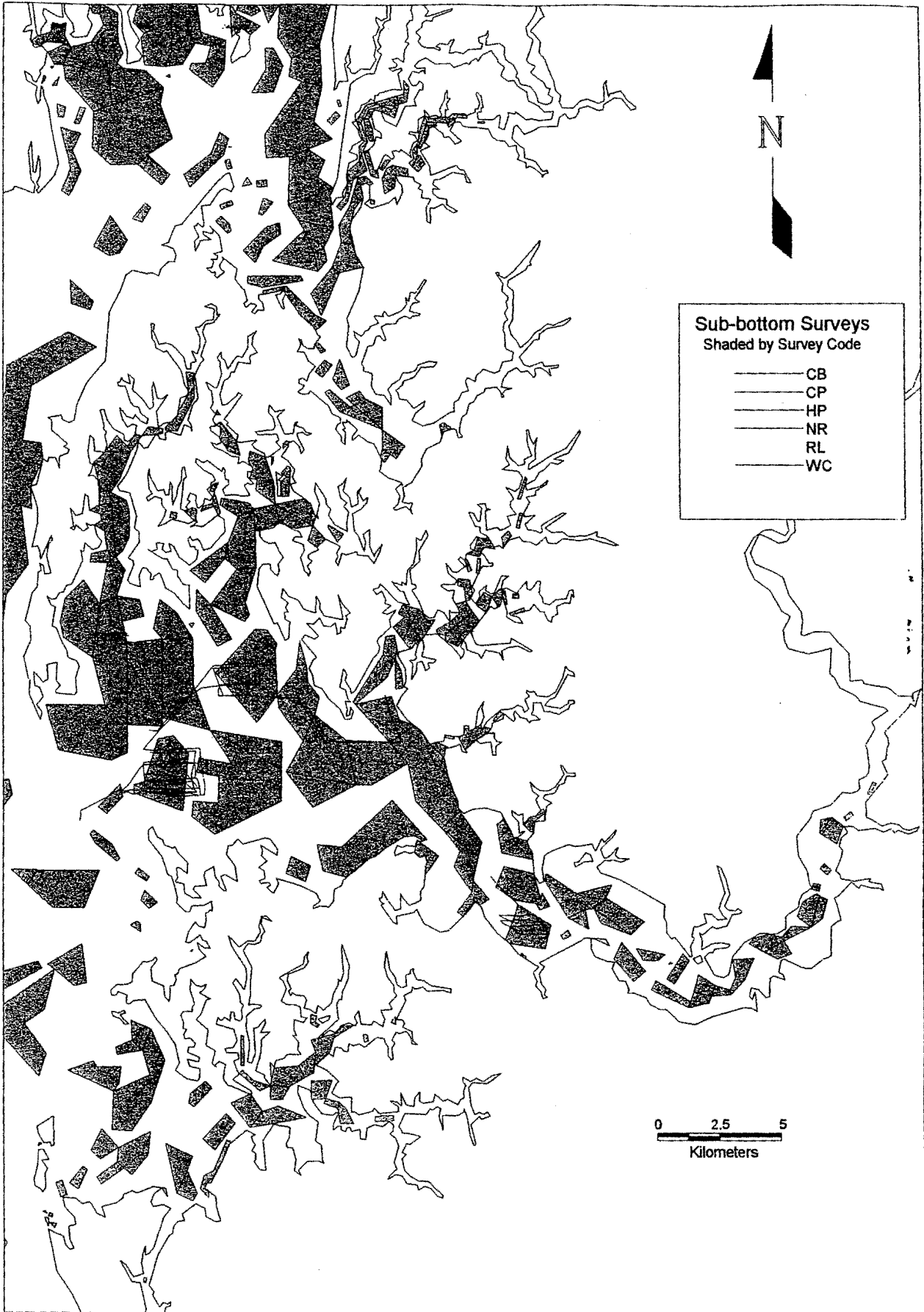








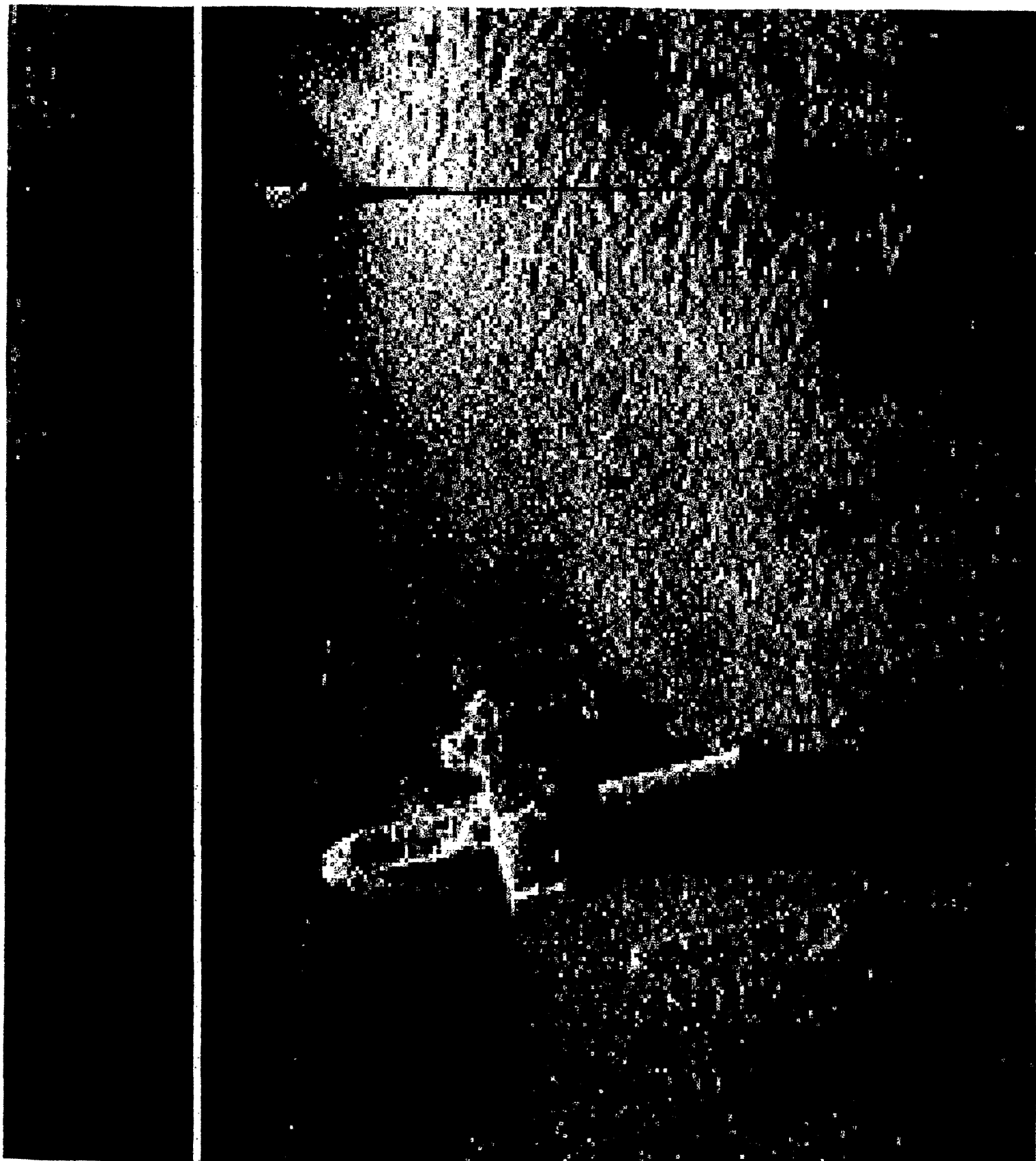


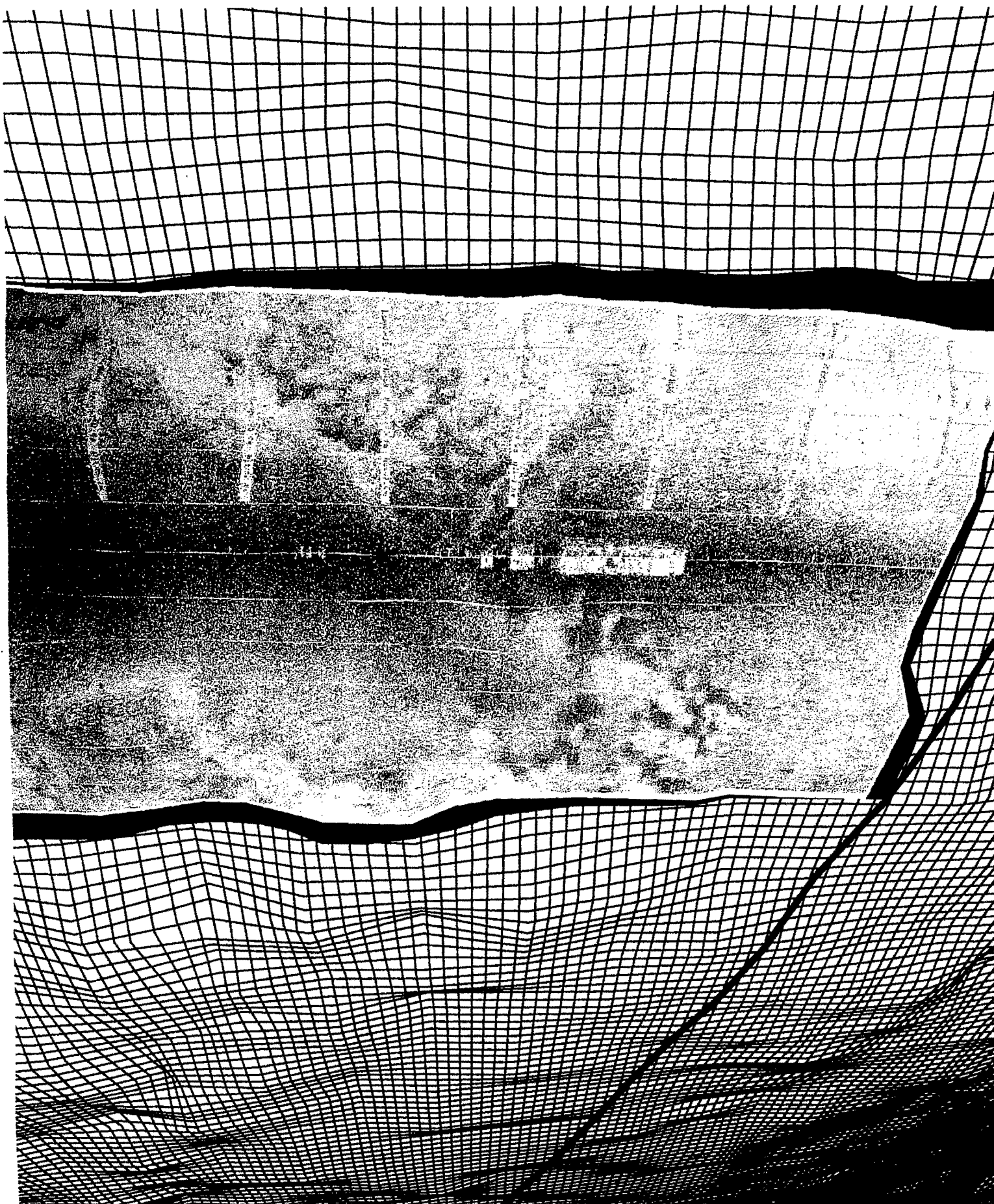


Sub-bottom Surveys
Shaded by Survey Code

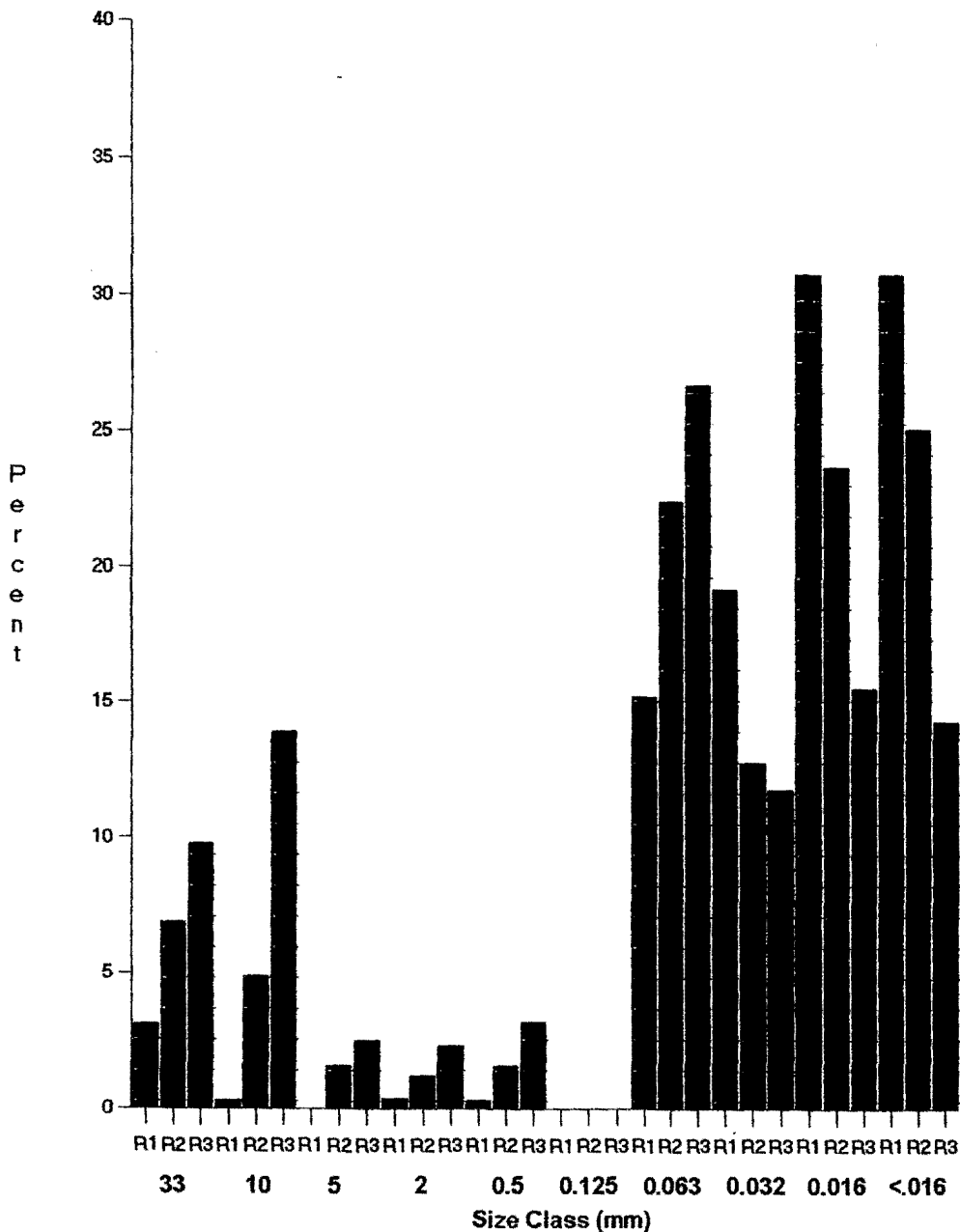
- CB
- CP
- HP
- NR
- RL
- WC

0 2.5 5
Kilometers





Sediment Composition at TA1A1



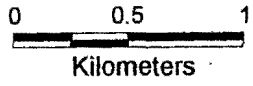
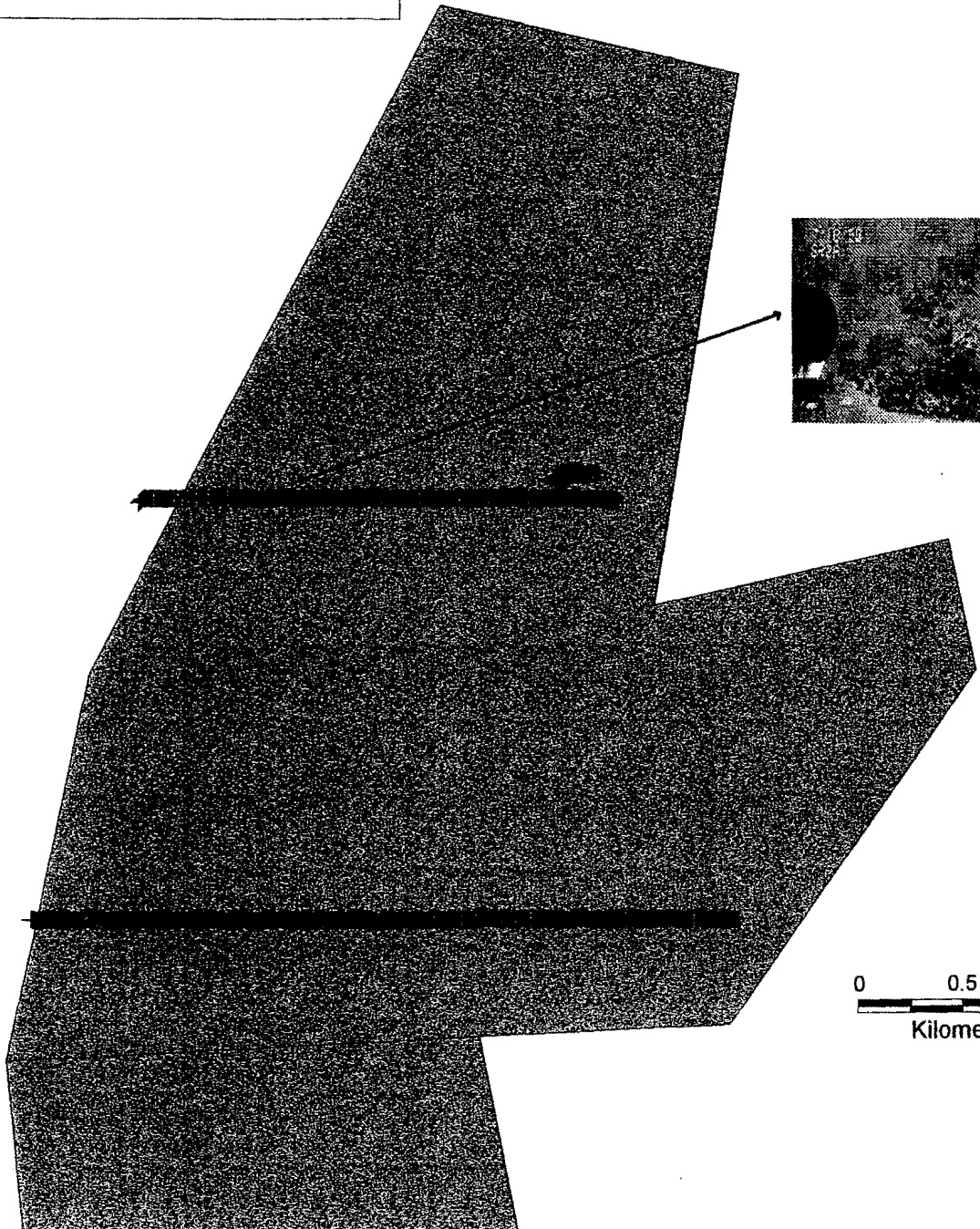
SURVDATE: 06/03/1998
 NICKNAME: BELLEVUE
 SITECODE: TA1A1
 BARNAME: TOWN POINT
 METHOD: DIV
 ANNOT:
 GTC: Y
 QTCDATE: 06/03/1998
 SUB: N
 SDEPTH: -9.0
 CDEPTH: 0.0
 TIME: 0
 B_VIZ: 0
 QL: 3
 COVER: 75-100
 CD: UN
 SD: Y
 AM: HV
 PROBE:
 SUBMAT:
 OS: N
 OSPB:
 OSCB:
 OSCL:
 OSRK:
 OSBD:
 SC: Y
 SCMD: Y
 SCES: Y
 SCSD:
 SCRIP:
 SCGR:
 BIOTA: Y
 BITB:
 BISP: Y
 BIAL:
 BISV: Y
 BICV:
 BISPAT:

Diver Observations:

6/03/98 - Dense uniform shell, some intact valves, largely covered with thick mud. Shells under this few centimeter thick layer were 75-100% coverage. Possibly an old shell plant? Shell could be felt at least a hand's depth down in the sediment. Many portions of shells extending above the mud. Some live oysters were oriented vertically to feed. Ten percent surface cultch or less. Occasional finger-sized animal hole. Very occasional and small stunted SAV.

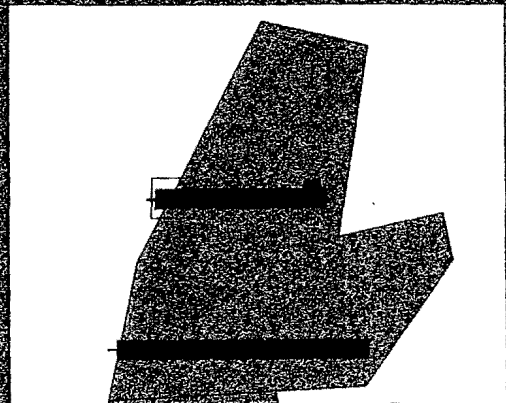
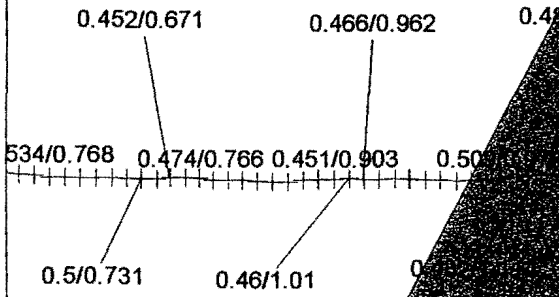
Roxanne Bottom Classifications

- +BOULDERS
- +COARSE SAND
- +CORAL
- +COURSE GRAVEL
DENSE WEED ON SAND
- +FINE GRAVEL
- +FINE SAND
- +FLAT ROCK
- +HARD PACKED SAND
- +MEDIUM SAND
- MUD
- +ROUGH/SOME SEAGRASS
- SILT



Roxanne Bottom Classifications

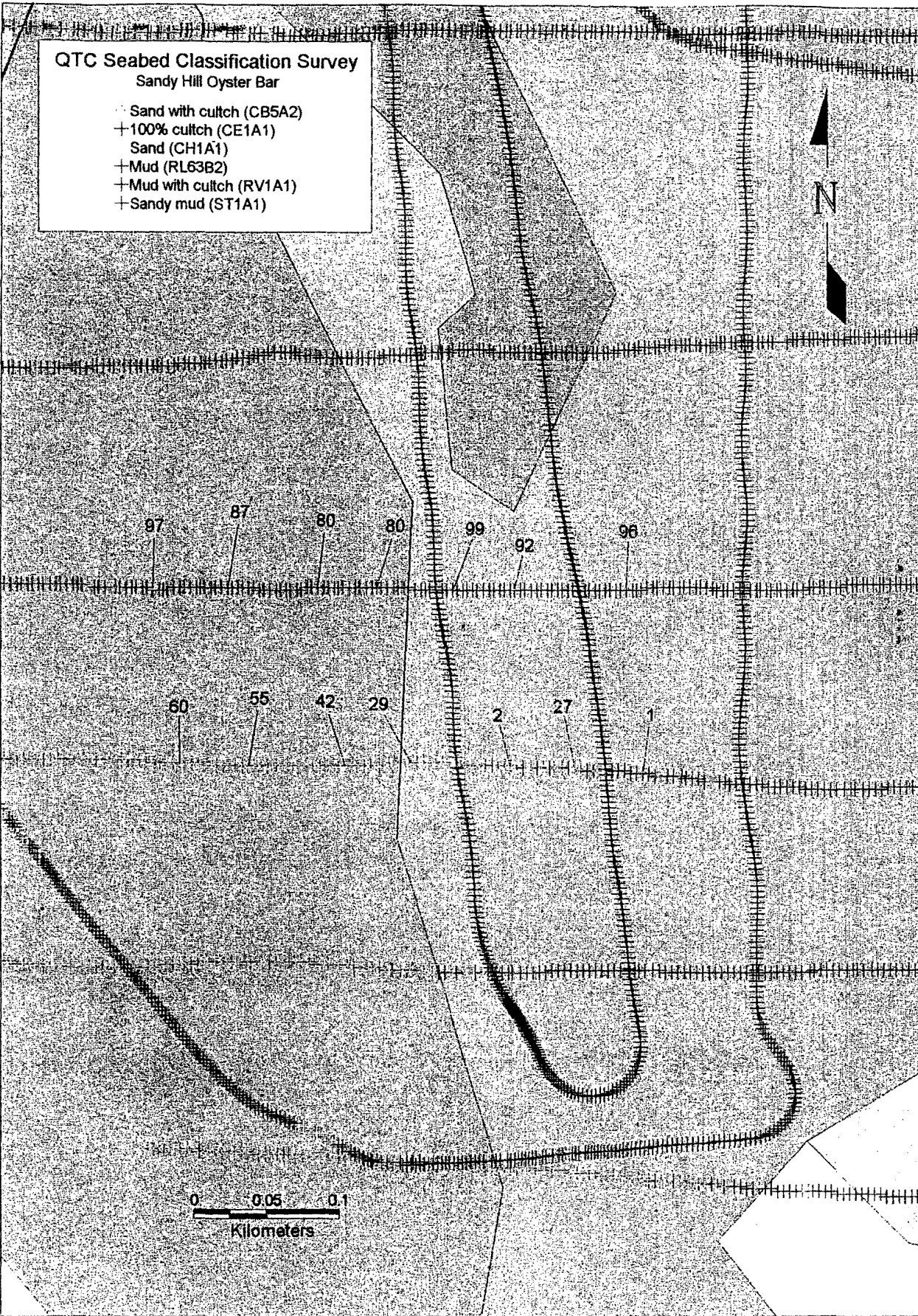
- +BOULDERS
- +COARSE SAND
- +CORAL
- +COURSE GRAVEL
- DENSE WEED ON SAND
- +FINE GRAVEL
- +FINE SAND
- +FLAT ROCK
- +HARD PACKED SAND
- +MEDIUM SAND
- MUD
- +ROUGH/SOME SEAGRASS
- SILT



QTC Seabed Classification Survey

Sandy Hill Oyster Bar

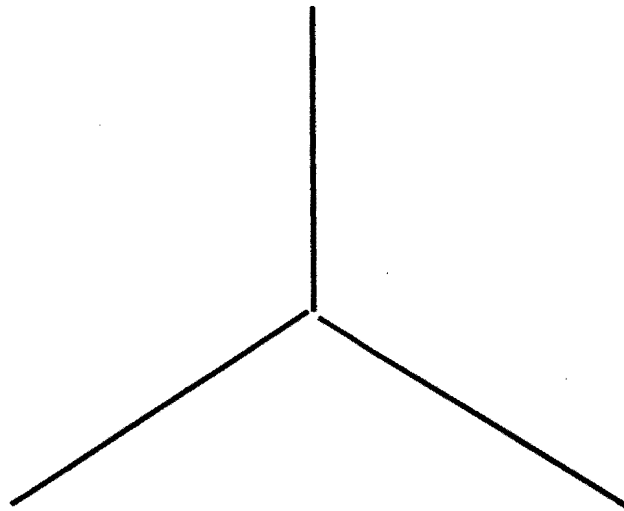
- Sand with cultch (CB5A2)
- + 100% cultch (CE1A1)
- Sand (CH1A1)
- + Mud (RL63B2)
- + Mud with cultch (RV1A1)
- + Sandy mud (ST1A1)



0 0.05 0.1
Kilometers

Habitat Definition Components

*sediment
cultch
buried substrate*



Habitat Representation Components

aerial assemblages

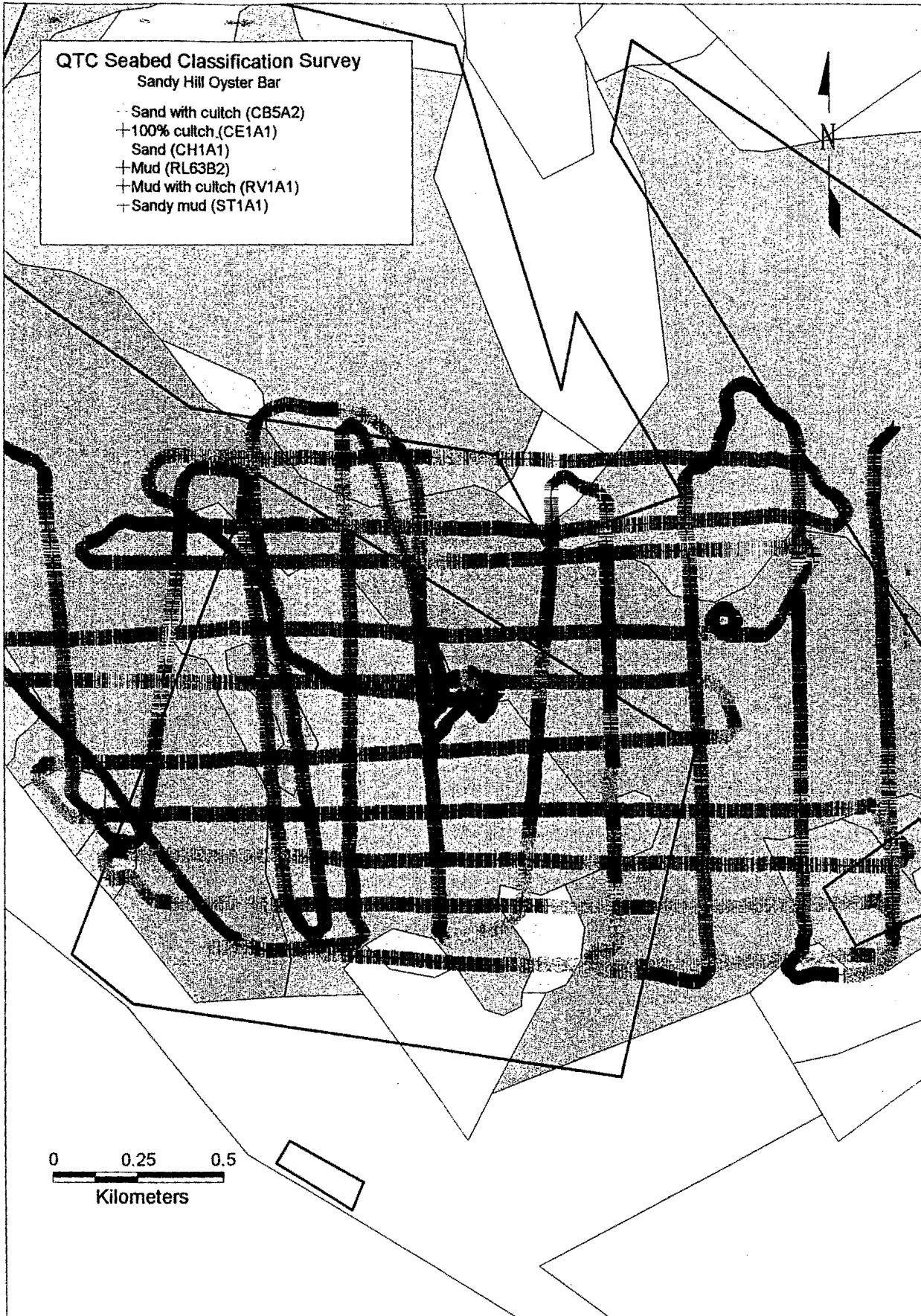
Habitat Assessment

*sampling methods
calibration methods*

QTC Seabed Classification Survey

Sandy Hill Oyster Bar

- Sand with cultch (CB5A2)
- +100% cultch (CE1A1)
- Sand (CH1A1)
- +Mud (RL63B2)
- +Mud with cultch (RV1A1)
- +Sandy mud (ST1A1)

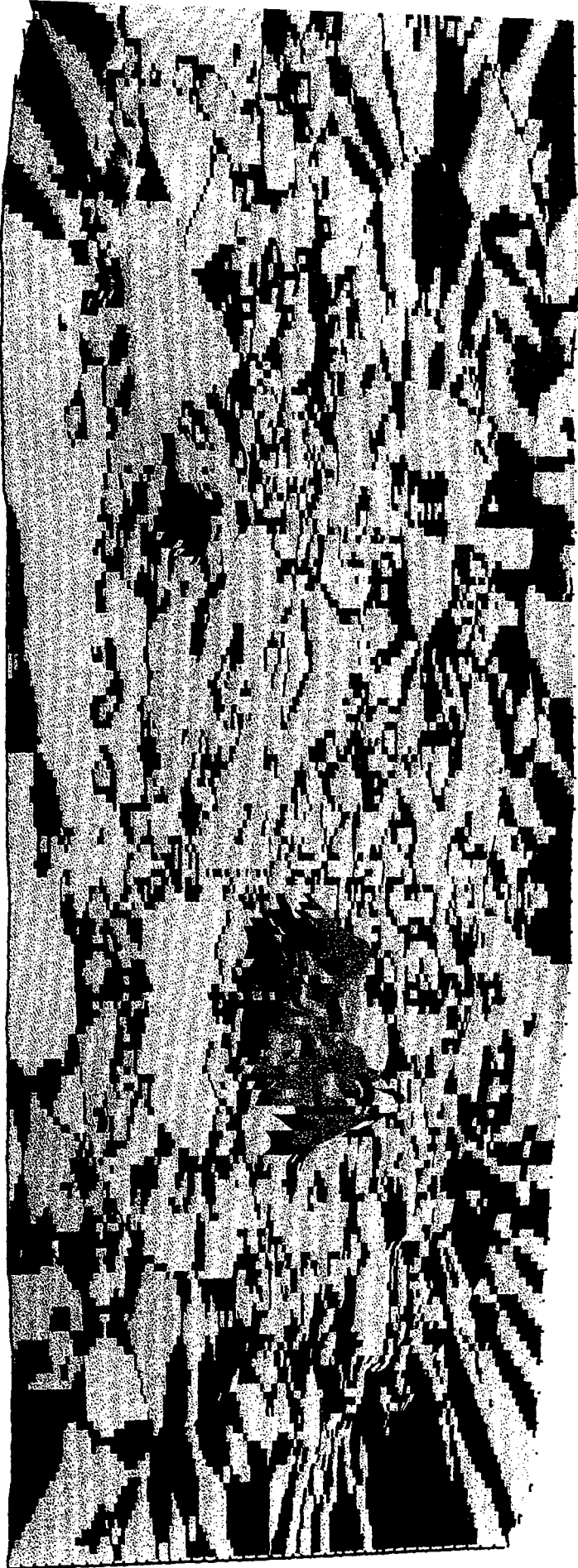


input grid

| | | | | | | |
|--|---|---|---|---|---|---|
| | | | | 3 | | |
| | 2 | | 3 | | | 5 |
| | 2 | 1 | | 5 | 5 | |
| | 2 | | 5 | 4 | | |

output grid

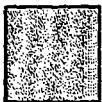
| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | 2 | 2 | 3 | 3 | 3 | 5 |
| 2 | 2 | 2 | 3 | 3 | 5 | 5 |
| 2 | 2 | 2 | 3 | 5 | 5 | 5 |
| 2 | 2 | 2 | 5 | 5 | 5 | 5 |



mud

Benton sand

old shell plant



sand

COB plant

Kelly's sand



SMOY TP

50-150m cobb