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# Shellfish Population and Bed Dimension Assessment in the Great Bay Estuary

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A Final Report to

The New Hampshire Estuaries Project

Submitted by

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New Hampshire Estuaries Project

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## Executive Summary:

This final report details a study funded by the NHEP over the course of 2001-02. The NHF&G Department was funded to delineate oyster bed size and density, monitor oyster disease, and examine the density of clam concentrations in the Great Bay Estuary.

Oyster bed delineation efforts were carried out in a cooperative study including participants from UNH C-COM, UNH JEL, and NH F&G during the fall of 2001. Data were collected at four Great Bay Estuary oyster beds during the fall of 2001. The extent of oyster shell coverage was surveyed using a combination of acoustic, video, and SCUBA techniques. Maps of the spatial extent of shell coverage were produced for all locations sampled. The Nannie Island bed is by far the largest followed by AdamsPoint, Woodman Point, and the Oyster River bed in that order. Estimates of mean density (# oysters/m$^2$) were produced as well. The highest density was recorded at Nannie Island followed by Woodman Point, the Oyster River, and AdamsPoint beds respectively.

Surveys of three soft-shelled clam (*Mya arenaria*) concentrations in the Great Bay Estuary were conducted over the summer and fall of 2002. The clam concentrations were sampled using randomly placed 1/8 m$^2$ quadrats. Densities of clams were generally low, but of the sites visited, Royalls Cove had the highest density of harvestable clams followed by Woodman Point and Fox Point respectively. A significant portion of the individuals recorded measured greater than 50mm in size. Recruitment seems to have been low for several years at each of the locations visited.

Testing of oysters for the presence of two diseases, MSX and DERMO, was conducted during both years. A report was previously submitted by NH F&G on oysters collected in 2001. During 2002 twenty five individuals from 4 sites were collected by divers and sent to the Haskins Shellfish Research Lab at Rutgers' University where testing is currently being conducted.

## Acknowledgements:

This oyster delineation effort presented in this study would not have been possible without the cooperation of the University of New Hampshire's Center for Coastal and Ocean Mapping (C-COM) and Jackson Estuarine Laboratory (JEL). The efforts of Semme Dijkstra at C-COM, Ray Grizzle (JEL), Jamie Adams (JEL/C-COM), and Jenn Greene (JEL) are greatly appreciated. Personnel at UNH C-COM provided the acoustic data and interpretation presented in this report. The staff at UNH JEL collected and processed the video imagery with some field assistance from New Hampshire Fish and Game. Each of the collaborating entities mentioned provided text and reviews of the document that were essential for its completion. Jamie Adams also provided GIS layers and much needed support during the preparation of the figures. The clam sampling effort was supported by preliminary video sampling efforts undertaken in cooperation with Randy Cutter, a C-COM graduate student. Phil Trowbridge of the New Hampshire Estuaries Program provided valuable statistical support, as well as some much appreciated field time. The fine field crew at NH F&G should also be thanked for digging 36 clam pits during one of the hottest weeks of the summer.

## Introduction:

Shellfish species play a key role in the recreational use of the Great Bay Estuary as well as being of vital ecological importance in the benthic community. The major species of interest from the recreational fishery standpoint are the soft-shelled clam (*Mya arenaria*) and the eastern oyster (*Crassostrea virginica*). These two species have been utilized by humans dating back to native Americans and are currently one of the most sought after resources in Great Bay.

Commercial oyster fishing, which is no longer legal in Great Bay, began around 1875. A combination of tongs, rakes, and dredges were used, even through the ice, which resulted in major damage to the beds within five years time (Goode 1887). The first regulation of shellfish harvest in the Great Bay occurred around this time as a result of this early pressure on the beds. These initial regulations forbid the use of a dredge, closed the fishery during the months of June, July, and August and stopped the practice of fishing thru the ice.

Early documentation of oyster beds in the 1880's speaks of roughly a dozen well defined beds, mostly in the Greenland Bay area. Nannie Island, still our largest concentration, is mentioned as an important harvesting area. Other beds in the Squamscott, Lamprey, and Oyster Rivers are described as well. Although oysters are still present in these areas, it is unlikely that densities will ever reach the level present prior to commercial harvest in the late 1800's.

One factor limiting the recovery is the presence of introduced disease pathogens, such as MSX and DERMO. These two pathogenic diseases have decimated oyster populations up and down the eastern seaboard. These diseases now affect oysters throughout the estuary but the initial severe epizootic was first reported in the Piscataqua River in 1995 (Barber et. al. 1997). Management of this important resource requires a clear understanding of population characteristics such as bed density, distribution, reproductive constraints, and the variability around each of these factors. Knowledge of these factors will increase the likelihood that shellfish populations will continue to serve their vital ecological role as well as support a sustainable fishery.

Although commercial harvest no longer occurs in the Great Bay, recreational use of clams and oysters is still very active. The Nannie Island and AdamsPoint beds are currently the most recreationally important oystering areas in the estuary. Soft-shelled clam concentrations are scattered around the estuary but have historically been documented in areas such as Royalls Cove, Fox Point, Broad Cove, Woodman Point, and the western shore of Little Bay to name a few. The New Hampshire Fish and Game Department (NH F&G) has been continually monitoring oyster beds in the estuary since the early 1990's. Assessments by the Department and University of New Hampshire (UNH) scientists have been conducted over time concerning both clams and oysters (Ayer et. al. 1970, Banner and Hayes 1996, Jackson 1944, Langan 1997, Langan 1999, and Nelson 1982).

The current study focuses on examining oyster beds at four locations and clam concentrations at three locations around the Great Bay Estuary. Oyster beds were mapped using a combination of acoustic, video imaging, and SCUBA techniques. Clam concentrations were sampled to provide information on the density and size structure of the population. Oyster samples were tested for the presence to the two disease causing agents MSX and DERMO as well. The information is intended for managers to aid in their continual assessment of the health of the resource. The scientific community should use this document to guide future research projects. This process should further our understanding of these populations and improve the ability of the management community to make decisions regarding acceptable exploitation limits and enhancement potential.

## Section I – Oyster Bed Delineation

### Project Goals and Objectives:

The overall goal of this portion of the investigation is to generate GIS data layers and maps of four oyster beds in the Great Bay Estuary. Specific objectives include:

- Collect and integrate acoustic, video, and SCUBA generated data at four oyster beds in Great Bay.
- Incorporate the data generated in objective one into a finished map of each location.

### Methods:

Four oyster beds (Adams Point, Nannie Island, Oyster River, and Woodman Point) in the Great Bay Estuary, New Hampshire were mapped in Fall 2001; the mapping techniques used included acoustic remote sensing by multi channel vertical incidence and side scan sonar, underwater videography and quadrat sampling by divers (Fig. 1).

<u>Acoustics</u>

Side scan sonar (a developmental version of the system 5000 MKII loaned to UNH C-COM by its manufacturer Klein Associates Inc.) was used at all four beds. This system has a dynamically focused multibeam transducer array with 5 simultaneous digitally formed beams per side. To enable work in the very shallow water covering the beds, the sonar was hull mounted on the R/V Little Bay, a pontoon-boat specially adapted for acoustic mapping in extremely shallow water. The operating frequency was 455 kHz and the pulse length was 50 µsec, resulting in an across-track resolution of approximately 3 centimeters. The range scale was set to 50 meters, leading to an along-track resolution of better than 20 centimeters. A regular grid with 40-m line spacing was used on both beds. This protocol provided better radiometric corrections than is normally possible, although in the case of Nannie Island the bottom showed so little topographic expression that it mattered little. A PosMV system was used for motion sensing and a differential global positioning system (DGPS) for positioning; P-DOP values were typically below one meter. The data acquisition software handled system artifacts and compensation for signal loss. The data was then fed to an algorithm that merges the information into a mosaic of the bottom that allows the interpretation of the bottom in a proper spatial context. In this case the actual data interpretation is visual and relies on an experienced technician. Efforts are underway at C-COM to automate this step. Regions of data with common texture properties are identified in the image resulting from the mosaicing. The resulting segmentation may then be used to accurately delimit boundaries of areas with common bottom characteristics such as oyster reefs. The data may then be used to optimize the planning of in-situ sampling and video imaging, the result of which acts as ground truth for the acoustic data.
Multi-channel vertical incidence data were obtained for bottom characterization using a Navitronic Seadig 21 system only at the Adams point bed. The Navitronic system was installed on the Canadian Department of Public Works vessel 'RV Miramichi Surveyor' which was on location as part of a different project. As installed, the Seadig 21 system had 12 channels and used a 50-µsec pulse length, logging a single depth value for each ping on each channel. Differential GPS (DGPS) was used for positioning, so no motion sensor was required. For bottom characterization, the signal coming out after the rectification stage (before any variable

gains are applied) was fed to a Quester Tangent ISAH-S system, which performed an analog to digital conversion. This procedure allowed identification of the bottom return and extraction of over 160 features from this return, both from the time and frequency domains. The number of features was then reduced to three using principal component analysis, followed by a cluster analysis in a 3D feature space, which provided characterization of the data.

Video imaging

Video imagery was obtained on all beds using a custom-made drop camera system consisting of a black and white/infrared camera (designed for use in low-light conditions) mounted on a steel frame, differential global positing system (DGPS) unit, and camcorder for recording. The approximate area of each bed was overlaid with a systematic sampling grid consisting of 40 to 50 sampling cells. A 5 to 10 second recording was made of a single position in each cell. Each recording was reduced to a still image using a combination of ESRI's ArcInfo and Adobe Photoshop, and all the stills (40 to 50) from each bed were combined into a geo-referenced photomontage. At nine or ten of the video-imaged cells on each bed, divers excavated a 0.25 $m^2$ quadrat by hand. All living oysters were counted and measured (shell height to nearest mm) using calipers. Quadrats were taken of the exact area video imaged, thereby allowing a direct comparison of data derived from video stills with quadrat counts.

SCUBA

Divers collected samples from each bed following a stratified random design to provide a representative sample of the oysters in the whole bed. At each bed, the project team approximated the boundaries of oyster beds based on their years of experience working in the area and generated a rough map on which an orthogonal grid was superimposed. At least five cells at each bed were randomly selected. In each selected grid cell, a 0.25 $m^2$ quadrat was randomly placed and all oyster shell, if present, was collected from within the quadrat.

Data Analysis

Oyster bed boundaries were qualitatively determined by visually assessing a combination of the data described above. A geo-referenced photomontage generated for each oyster bed was compared to acoustic data output in an Arc-View GIS platform. In the Oyster River, and a small section of the Adams Point bed where vertical incidence information was lacking, boundary determination was based on video data alone. Visual interpretation of shell coverage within each grid cell and adjacent cells was conducted using photomontages. Boundary lines were placed where video and acoustic data signals indicated sparse shell coverage. The boundary lines were drawn closer to the points within gird cells where video images and acoustic data indicated sparse shell coverage and toward the edge of those with heavier shell concentration. The lines were then connected to construct a continuous boundary. Video and side scan sonar data collected at Nannie Island provided the best opportunity for direct comparison of these methods. The correspondance between acoustic and video derived data at the Nannie Island and Woodman point beds was nearly exact. In this case, the side scan sonar data were used to draw a boundary where substrate texture transition was abrupt and video data became more important in areas where the boundary was not as clear on the side scan sonar image. Analysis of the Adams Point data proceeded using the vertical incidence acoustic data, which were superior to the side scan output at this particular location.


Figure 1. Shellfish sampling locations for surveys conducted during 2001-2002 in the Great Bay Estuary, NH.

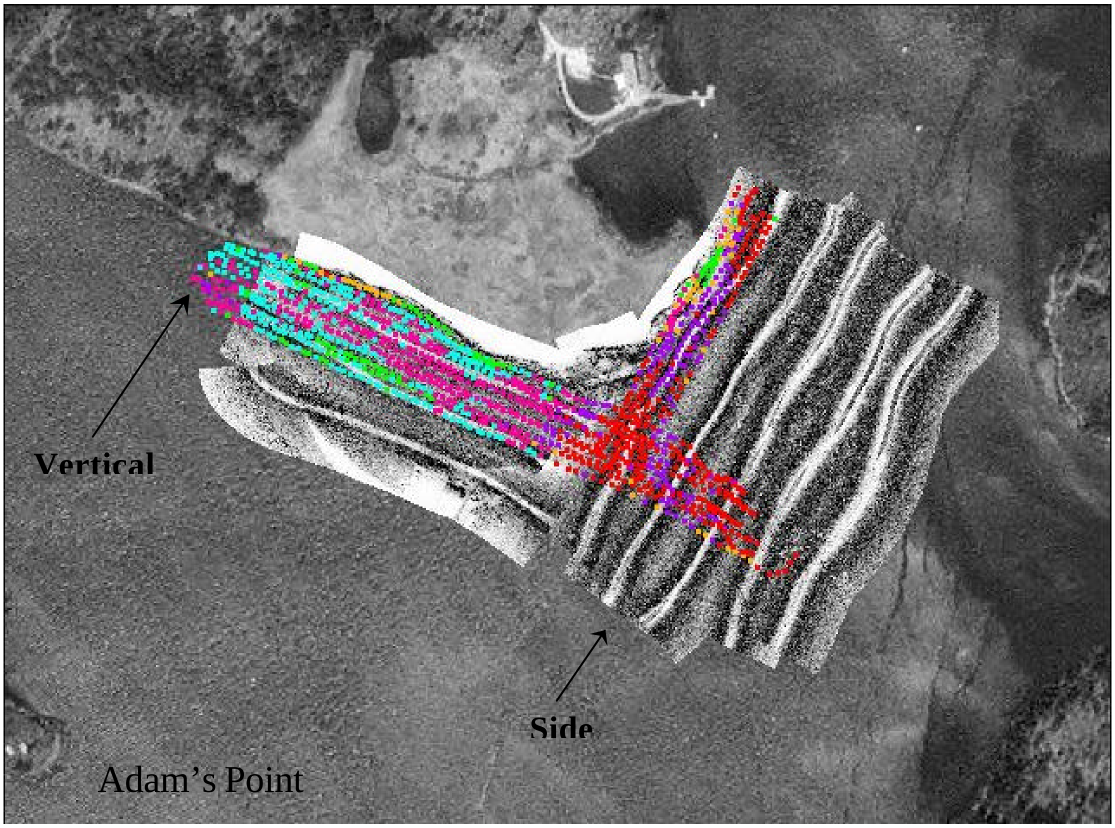
**Results:**

Acoustic data

The spatial extent of data collected for the Adams Point, Nannie Island, and Woodman Point oyster beds is presented in the form of post processed acoustic signal (Figure 2). The colors on the Adams Point image indicate the location of vertical incidence data collection. The vertical incidence data were statistically grouped into six categories sharing common attributes. The areas that agreed with video data for oyster shell coverage are violet and purple and match the eventual boundary that was determined using both types of data. Data collection at the Oyster River site resulted in unusable data and is not included. The degree of variability in substrate topography was the main difference between Adams point and the Nannie Island/Woodman point areas. The banding pattern present in the side scan data reflects the vessel track. The strength of acoustic signal from the side scan unit is strongest closest to the boat and attenuates with increased vertical and horizontal distance from the vessel. The colors present in the vertical incidence output reflect areas of common attributes as determined by the software used to process the data. The software, named LASSO, is a proprietary product developed by UNH Center for Coastal and Ocean Mapping. Characterization of bottom habitats proceeds according to shared attributes determined by comparisons made after the data are condensed using multivariate statistical techniques such as principal components and cluster analysis.

Video data

Static images were produced from a total of 136 plots surveyed over the four sampling locations. The exact location of each video sample taken over the four beds is presented in Appendix I. A sample video image is pictured here. The video stills were condensed into photomontages that appear in Appendix II. The delineated areas for oyster beds characterized during this survey are represented by Figures 3, 4, and 5.



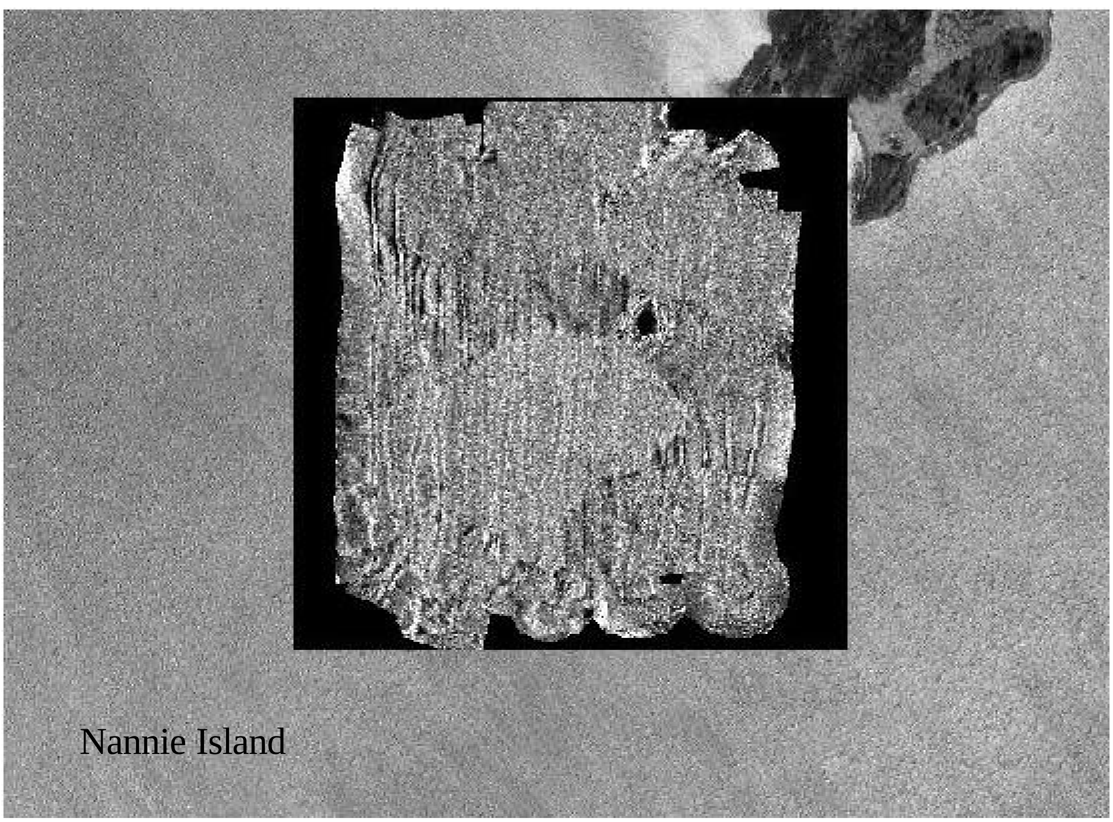




Figure 2. Extent of acoustic data collection at the AdamsPoint and Nannie Island oyster beds during fall 2001 sampling in Great Bay, NH.

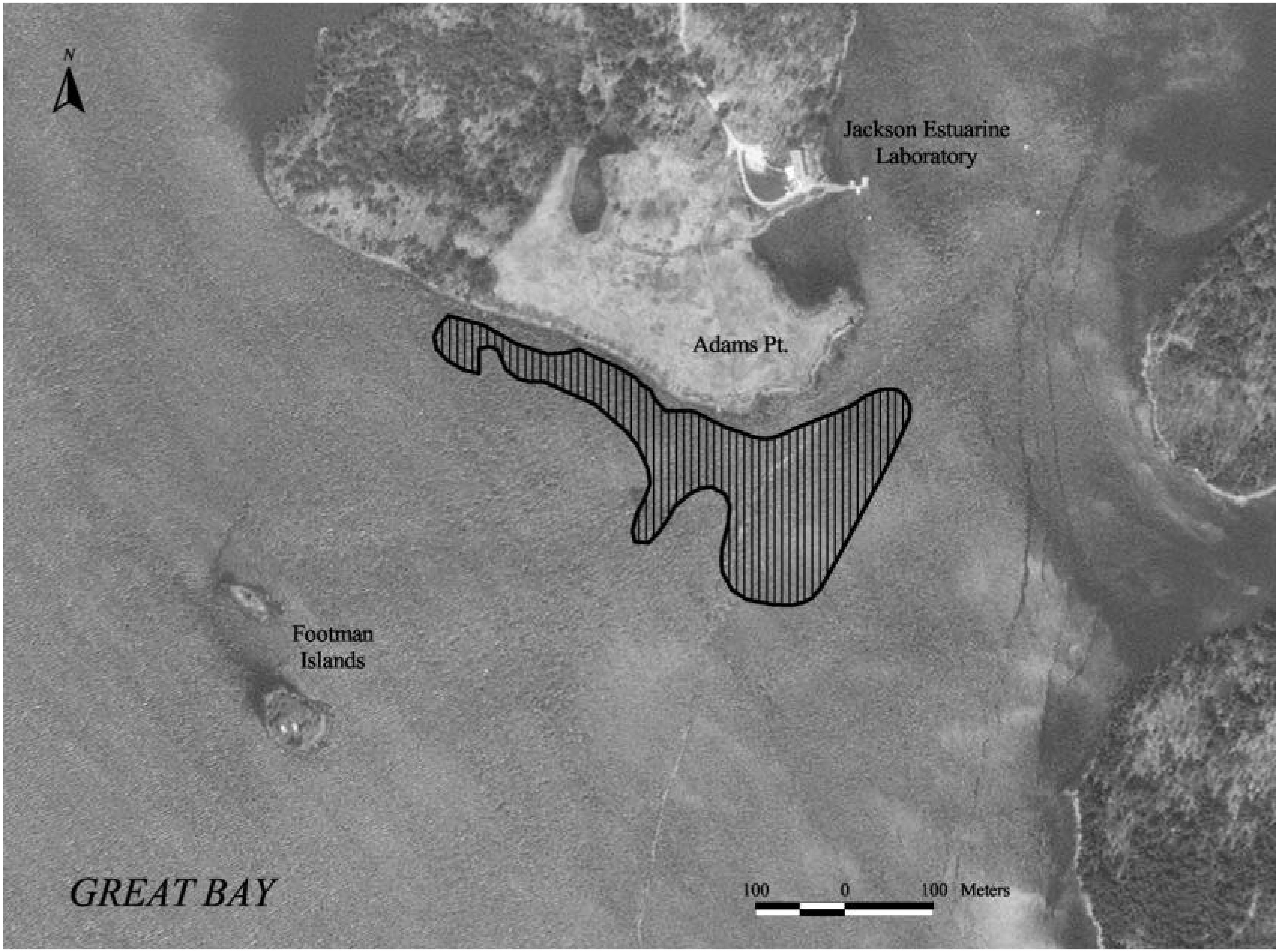



Figure 3. Spatial extent of oyster shell at AdamsPoint in Great Bay, NH determined by interpretation of acoustic, video, and SCUBA derived data sources (fall 2001).

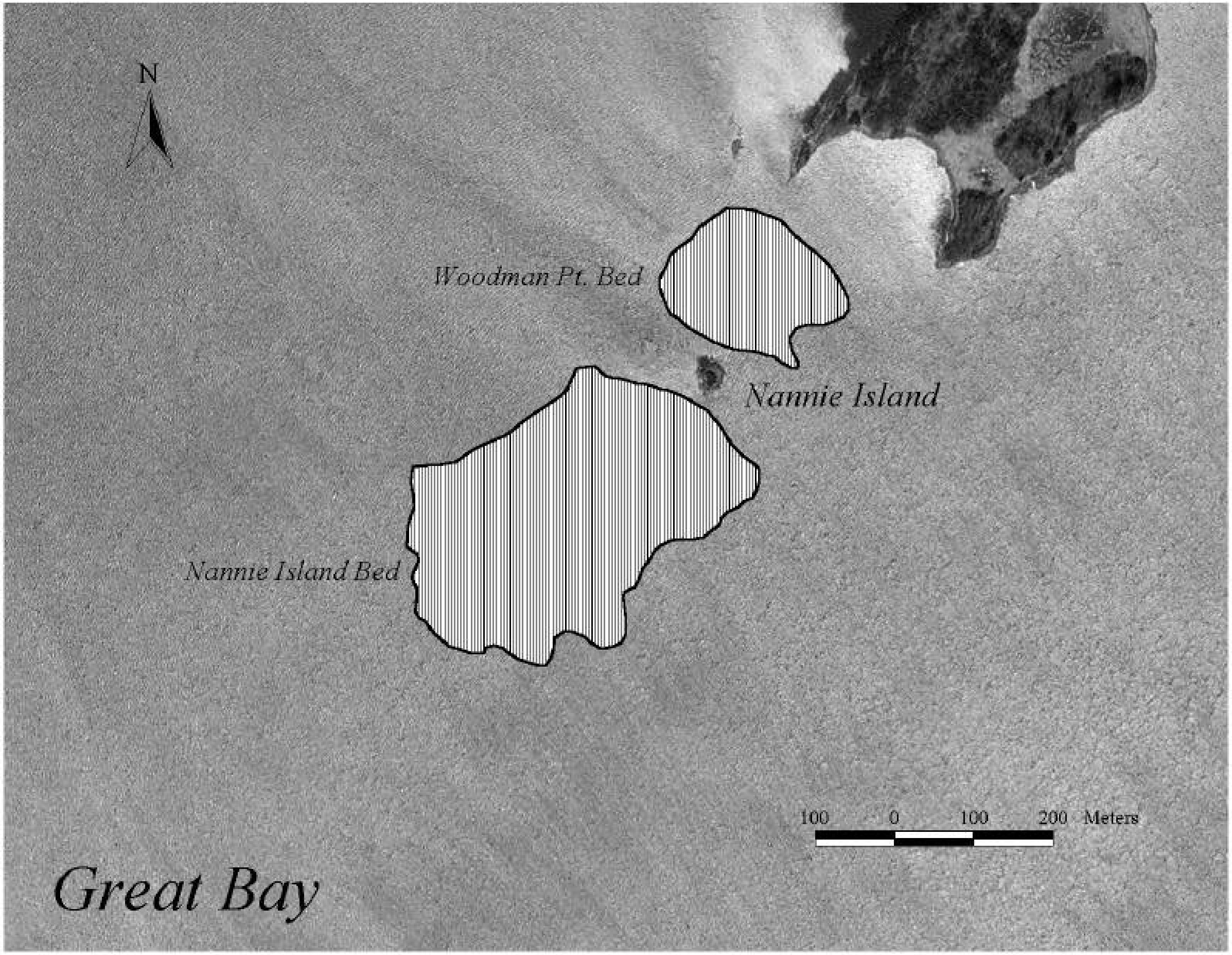


Figure 4. Spatial extent of oyster shell at Nannie Island and Woodman Point in Great Bay, NH determined by interpretation of acoustic, video, and SCUBA derived data sources (fall 2001).

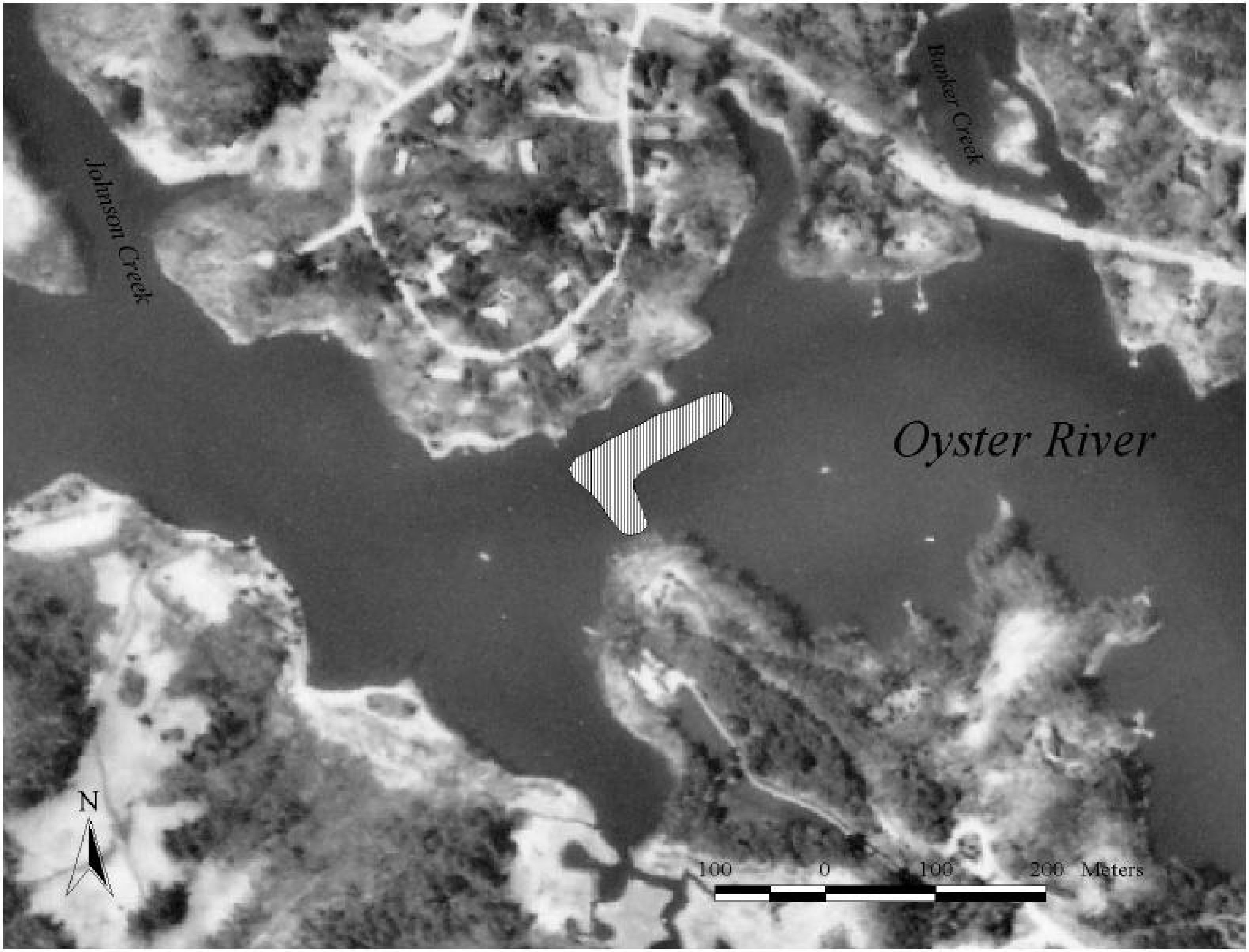



Figure 5. Spatial extent of oyster shell in the Oyster River in Great Bay, NH determined by interpretation of video and SCUBA derived data sources (fall 2001).

SCUBA

A total of 27 0.25$m^2$ quadrat samples were taken at the four locations during the fall of 2001. Of the 9 stations sampled at Adams Point, 5 were intentionally placed in areas with little to no shell coverage to act as ground truth samples for acoustic data interpretation. The ground truth samples were not included in oyster density estimates at the site. Oyster density estimates calculated from SCUBA collected quadrat samples are detailed in Table 1. Counts of possibly live oysters from the video images were only weakly correlated with SCUBA quadrat data. The correlation was lowest when all oysters counted in all quadrats were included and increased when quadrats containing >25 individuals from video or SCUBA derived counts were not included ($R^2$ = 0.11 and 0.59 respectively).

**Table 1. Oyster density and bed size at four beds surveyed in the Great Bay Estuary during the fall of 2001**

| Location | Density (#/$m^2$) | Harvestable (#>80mm/$m^2$) | Acreage |
|---|---|---|---|
| Adams Point | 37 (n=4) | 6.8 | 13.1 |
| Nannie Island | 102.7 (n=6) | 13.2 | 24.7 |
| Oyster River | 86.4 (n=5) | 15.2 | 1.7 |
| Woodman Point | 98.8 (n=7) | 8.0 | 7.3 |

The number of quadrats included in each density estimate appears in parentheses.

**Discussion:**

Acoustic data collected at the four locations resulted in very different returns. The basic difference in side scan sonar signal between the Adams Point and Nannie Island/Woodman Point locations can be largely explained by the degree of variability in the topography of the substrate at each site. Adams Point was much more variable than Nannie Island in terms of the substrate topography. This difference is apparent in the degree of vertical banding seen in the data depicted in Figure 2. The functional result of this difference is increased effort in post processing of the Adams Point data before the portion of the signal indicating oyster shell can be isolated. Therefore, it may still be possible to increase the amount of information provided by the side scan data collected at Adams Point with continued post processing of this data. The side scan signal combined with the vertical incidence information, video images, and destructive sampling provided adequate information on bed dimensions to support map production.

The lack of usable acoustic data for the Oyster River location was the result of sampling difficulties due, at least in part, to very shallow water. Further, the vessel experienced difficulty traversing lines across the full extent of oyster shell during the time available for sampling. Therefore, the information collected was incomplete and C-COM was not able to repeat the effort. The map produced (Figure 5) for the Oyster River bed is the result of video and diver information only.

The video images collected at each location allowed for greatly increased spatial coverage over SCUBA sampling alone. The resolution of a map produced using video and SCUBA derived data is limited by the number of images collected. Each image collected is exaggerated in two dimensions. The images accurately depict conditions at the specific location they were recorded, however, assumptions are made regarding the accuracy of each image representing the condition within an entire grid cell. In this particular study, caution must be used when interpreting the Oyster River map because it was generated without the benefit of acoustic information. The possibility does exist for video data to approach the resolution of acoustics in areas small enough that the collection of sufficient images is feasible. The number of images collected in this study does not approach that threshold, however. Therefore, the accuracy of the boundary generated for the Oyster River bed would be greatly improved by further data collection using video or acoustic technology.

The density estimates based on the destructive SCUBA sampling conducted through this project represent greater spatial coverage of quadrats over the beds surveyed than in previous years. The sampling was conducted according to a stratified random design and the specific quadrats were located using D-GPS. Sampling in accordance with this methodology considerably increased dive time and effort. During previous years, samples had been collected at random intervals around a single anchoring position requiring only one diver entry. This project required that divers collect a single sample and then return to the boat to navigate to the next anchoring position where they would re-enter the water.

Some sample assignments at the Adams Point location were intentionally placed in areas where little to no shell coverage existed. These samples were collected for the purposes of aiding the interpretation of acoustic data and were not included in density calculations per se. It was necessary to dive at these locations because it is not always readily apparent on the video screen if sufficient quantities of shell exist for destructive sampling. To maintain continuity with previous years of destructive sampling, only quadrats placed within the bed proper were used in the estimation of live and harvestable oyster density.

Comparison of video derived counts of possibly live oysters to the SCUBA data did not show a strong relationship in this study. The relationship was stronger at lower densities of oysters implying that obstructed oysters in high density images present one potential problem in establishing a relationship. More work in this area needs to be done to determine if a consistent relationship can be found using video counts of possibly live oysters potentially by only counting quadrats below a density of 25 oysters/quadrat or in specific size classes (Grizzle et. al. 2002, submitted). Limitations exist, but some bed characteristics can be inferred from video images.

Analysis of the data collected with all three methodologies resulted in a highly refined and rigorous estimation of the spatial extent of oyster shell at four beds in the Great Bay Estuary. The method, however, is still qualitative to a certain extent. There is still no way to assign statistical confidence to the bed boundary estimates. Therefore, estimation of standing stock should take this into account and should proceed with caution. There is, however, tremendous opportunity with the use of a low cost method such as video imaging at high resolution to periodically track changes in bed size. This increase in spatial and temporal resolution of shell coverage indices coupled with density information will maintain a higher level of confidence in estimates of stock density over the long term.

**Conclusions:**

The combination of acoustic, video, and diver collected data provided very detailed information for interpretation during map development. This is a methodological improvement over previous techniques used to gather similar information. Previously it would have been necessary to survey and mark the perimeter using SCUBA or probing for shell from a vessel. Both of these methods are intuitively more likely to underestimate the true extent of a bed due to increased likelihood of miss classification of bed edges or areas where shell coverage changes drastically over a relatively short horizontal distance. It is likely that the exhaustive acoustic surveys ground truthed by video and SCUBA techniques increased the resolution of the maps produced as part of this project.

**Recommendations:**

Future surveys focused on determining standing stock or bed boundaries may wish to consider analyzing field collected video images using percent shell coverage standards of some kind. These standards could be used to classify field images during a video interpretation phase. The resultant series of images and percent cover estimates could be used to determine boundary placement based on percent shell coverage. Further, bed maps indicating areas of differing density could be produced. Therefore, this method could also be used to refine estimates of stock density by improving stratification strategies for the placement and numbers of quadrats needed for SCUBA sampling efforts.

## Section II – Clam Assessment

**Project Goals and Objective:**

The overall goal of this section of the project is to provide information on the condition of soft-shelled clam populations in the Great Bay Estuary. Specific objectives include:

- Assess density and size structure of clams at three locations in the Great Bay Estuary
- Provide recommendations on sampling design and approach

**Methods:**

Three soft-shelled clam concentrations in the Great Bay Estuary (Fox Point, Royalls Cove, and Woodman Point) were sampled in the summer of 2002 (Figure 1). In an attempt to decrease variance around the mean, sampling at Fox Point was more intense than at the other two locations. The description of methods will therefore differ between Fox Point and the other locations.

An attempt was made to use video imaging with a towed camera to assess soft-shelled clam distribution at Fox Point. This effort was completed in cooperation with a graduate student from UNH C-COM. The method used was designed to sample habitats much deeper than the inter-tidal clam habitat found around Fox Point. Attempts to adapt the gear and methodology to shallow water use were not successful and no usable data resulted. A siphon hole survey was then conducted on foot instead and those data were later used as a surrogate for clam distribution to aid in subsequent sampling design.

The data collected in this preliminary assessment were used to aid in the determination of numbers and locations of the quadrat sampling effort. Twenty-three 50m long 1m wide transects were walked at low tide. The number of siphon holes, substrate type, and amount of dead shell present was recorded for each transect. Sediment cores were collected on a 1 per every 100m covered basis. The location of each transect was recorded using DGPS and later downloaded into ArcView GIS. The siphon hole counts were added to the GIS coverage and transferred to the NHEP coastal scientist for assistance with sampling design development. The Visual Sampling Plan software package produced by Pacific Northwest Laboratories was used to calculate the number and location of 1/8$m^2$ quadrats based on the variability seen in siphon hole numbers (Normandeau Associates provided their quadrats for use on this project, they measure 1 foot X 2 Feet = 30cm X 61cm = 0.183$m^2$ or roughly 1/8$m^2$). The software was used to aid in the determination that two strata were necessary, one containing 8 quadrats and another with 27 for a total of 35.

Sampling was conducted by 4 crews of 2 members each and one supervisor. The supervisor directed each crew to a starting point using a DGPS. The crews then navigated to subsequent plots on a grid using a map, compass, and a known length of line. Slight modifications were made to the grid in the field to deal with issues such as differences in tidal elevation between the date of the siphon hole count and later quadrat sampling. Some point locations needed to be moved to the nearest suitable location because they landed on substrate such as rock or salt marsh. Finally, several pits were added in the field to ensure adequate coverage in the upper intertidal area. Navigation to the list of points generated by the computer resulted in an apparent shift of the grid slightly lower in the intertidal area. The difference was minimal (i.e. – less than 5m) but several plots were added to the grid in the field to ensure the high inter-tidal was adequately represented. Each pit was excavated to a depth equivalent to the length of the fork handle (~ 45cm) and all clams were placed in a labeled bag for examination in the lab where they were enumerated and measured for total length.

The methods employed at the Royalls cove and Woodman Point locations followed those detailed in past NHEP funded assessments (Langan 1997 and 1999). The areas visited at the Royalls Cove site were selected to repeat the sampling conducted there by Langan in 1997. Site selection at Woodman Point proceeded in a similar fashion at randomly placed quadrats. Plot excavation and data collection proceeded in the same manner as detailed above.

**Results:**

During the summer and fall of 2002 a total of 63 1/8 $m^2$ quadrats were excavated at three areas of soft-shelled clam concentration in Great Bay (*e.g.* - Fox Point – 36, Royalls Cove – 13, and Woodman Point – 14). The density of clams per $m^2$ is detailed in the table below. Arithmetic Mean density was used for the Woodman Point and Royalls Cove. The stratified sampling conducted at Fox Point required different equations for the calculation of means and standard deviations (Gilbert 1987). The highest density of clams was found in Royalls Cove and nearly all of those were of harvestable size. A representation of the size frequency found at each site can be seen in Figure 6. There is very low abundance in the small size classes. The specific locations sampled at each site appear in Figures 7, 8, and 9.

Table 2. Clam Density represented by arithmetic mean at selected sites within the Great Bay Estuary August - October 2002

| **Location** | **Average #/$m^2$** | **Standard Deviation** | **# Harvestable/$m^{2*}$** |
|---|---|---|---|
| Fox Point | 1.82 (n=36) | 0.92 | 0.96 |
| Royalls Cove | 8.69 (n=13) | 16.95 | 8.28 |
| Woodman Point | 8.45 (n=14) | 11.69 | 5.38 |

* - clams >50mm were considered harvestable

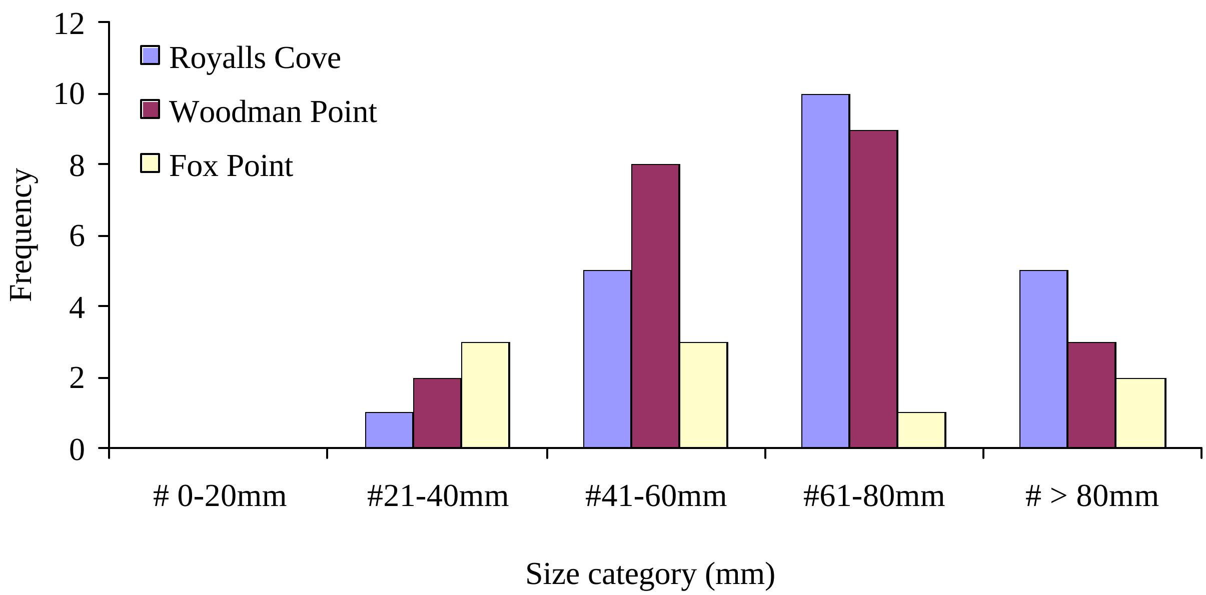



Figure 6. Size Frequency Distribution of soft shell clams (Mya arenaria) in the Great Bay Estuary summer 2001.


Figure 7. Clam sampling locations at Fox Point in the Great Bay Estuary, NH (summer 2001).

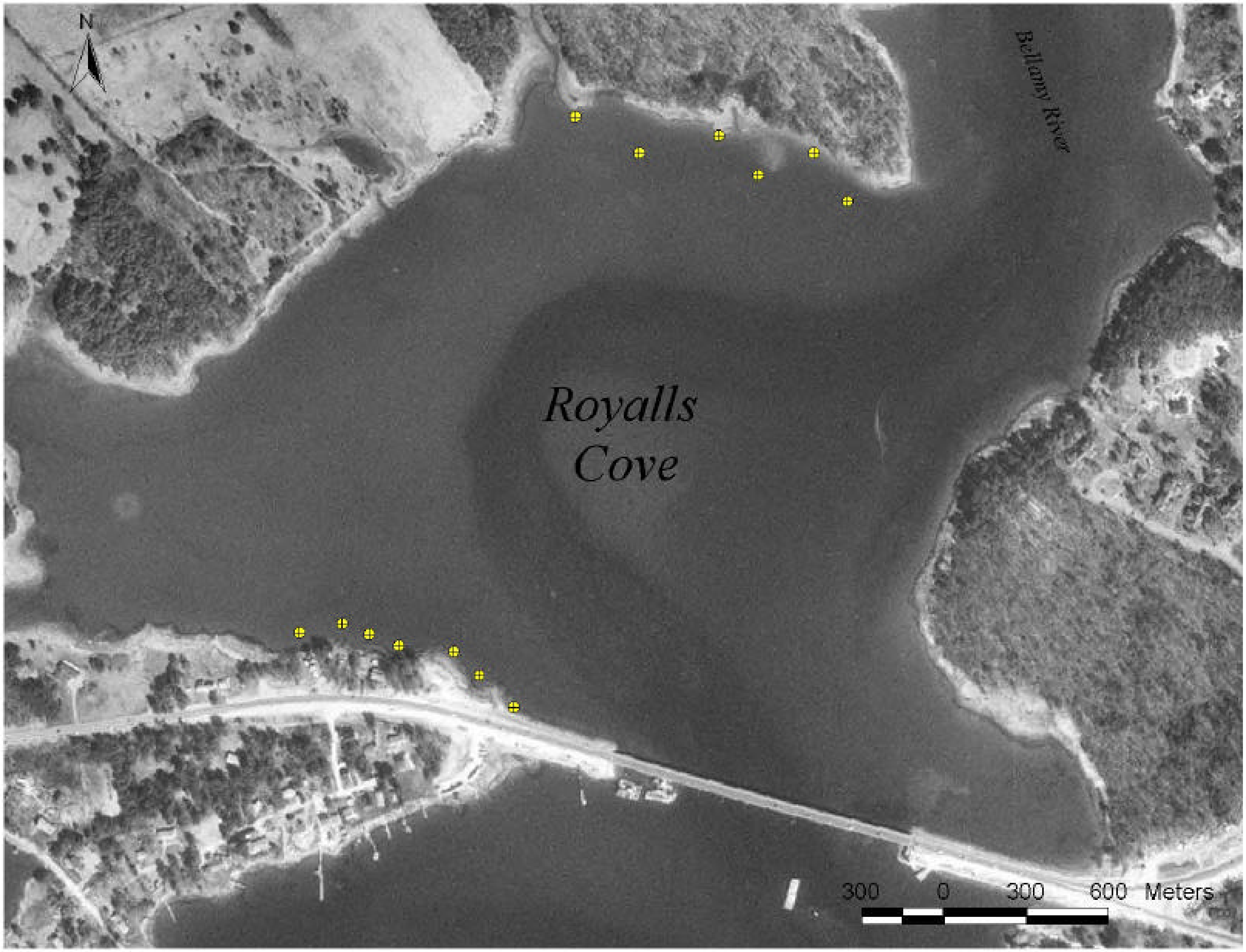



Figure 8. Clam sampling locations at Royalls Cove in the Great Bay Estuary, NH (Fall 2001).

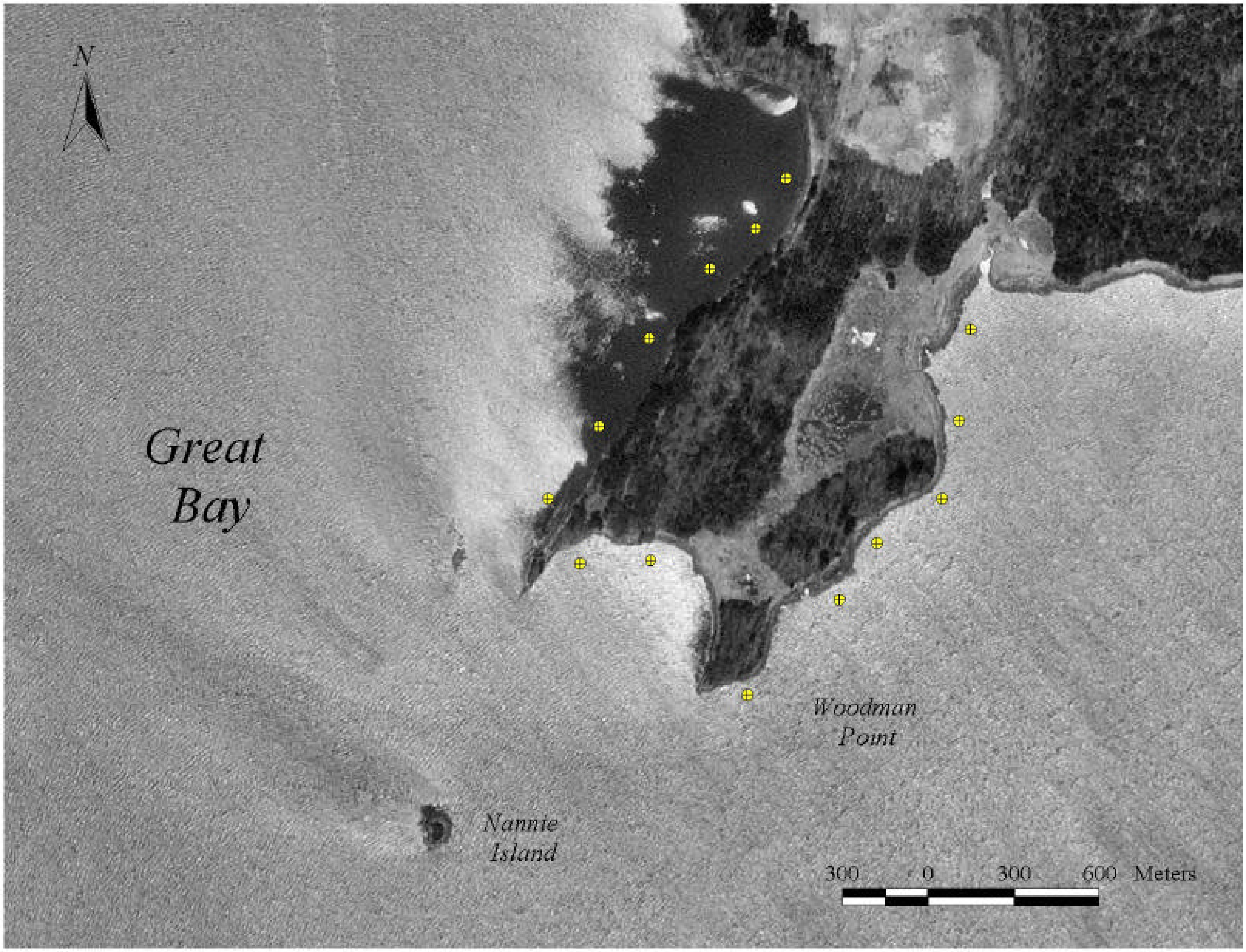



Figure 9. Clam sampling locations at Woodman Point in the Great Bay Estuary, NH (Fall 2001).

**Discussion:**

Clam densities were low at all three locations sampled. The lowest densities were encountered at Fox Point, an area previously reported to have relatively high clam densities for the Great Bay Estuary (Nelson 1982). Nelson documented soft-shelled clam densities, for individuals >50mm, approaching 19/m$^2$ at Fox Point. The Fox Point area was also reported to have relatively high clam densities in internal NH F&G memoranda generated based on data collected in response to the 1996 oil spill. The maximum density reported in Langan's 1997 report was 18.66/m$^2$ for all size classes combined at Royalls Cove. The highest density found in the present study in terms of total numbers and harvestable clams was in Royalls Cove. The density found in the present study, however, is considerably lower than what was found by Langan in 1997.

The size frequency distribution for this study is skewed slightly to the right especially in Royalls Cove. There were a large number of *Macoma* found in the samples as small as 13mm. Therefore, it seems likely that had soft-shelled clams in the <20mm size range been present in the samples, they would have been found and recorded. Further, a significant majority of clams sampled were of harvestable size (>50mm). The low sample size of 9 clams at Fox Point makes interpretation of size frequency patterns difficult, especially given the large sampling effort at this site. None of the sites, however, reflect an even size distribution with high levels of juveniles ready to recruit to the harvestable population.

The data collection methods and statistical design around which a study is framed obviously affect the resultant data and types of analyses it will support. In this study, a great deal of effort was put into the survey at Fox Point to produce data collected in a manner that would allow for a statistically non-biased estimate of mean clam density over the areas surveyed. Unfortunately, a very low number of clams were found during this effort. Stratification allows for estimates of mean density to be produced that do not require a large effort to be placed in unsuitable habitat. Stratification on substrate type should be considered in future studies instead of using siphon counts as a surrogate of clam density. The siphon count method employed in this study had limitations because of obstructed siphons in gravel substrate and the difficulty differentiating *Mya*, *Ensis*, and *Macoma* sp. siphon holes. It is also possible that the sampling grid needed to be placed farther to the west toward the tip of Fox Point on the southern shore. The map generated by Nelson in 1982 overlaps the area surveyed in this study but also extends westward. Therefore, it is possible that higher clam densities do still exist in isolated patches along the south west shore of Fox Point that were not covered by this design. The high number of samples collected did, however, significantly decrease the variance seen in the data collected at Fox Point compared to the other locations.

The samples collected at Woodman Point and Royalls Cove were not randomized prior to visiting these locations. The quadrats were thrown ahead of the diggers in a random fashion but this is not as statistically rigorous as the Fox Point design. Therefore, these data should not be used as a representation of clam density across all of Royalls Cove for example. A more rigorous sampling of multiple habitats in Royalls Cove would need to be completed before the means could be multiplied by area to produce a statistically defensible estimate of standing stock.

The data indicate that not only is density very low, recruitment has not been strong for at least several years. These data, however, were intended to elucidate patterns in terms of density and size frequency of the soft-shelled clam population in Great Bay. Therefore, it is not possible to determine from this study the factors driving these patterns. As a general rule, however, soft-shelled clam recruitment follows a pattern of a dominant year-class/es that should sustain the population through a series of subsequent bad years. The common factors controlling recruitment and year-class size are spawning effort, current patterns, and predation (Ellis 1998). Further, the timing of gamete release, length of time spent in the water column prior to settlement, and abundance of potential food and predators pre and post settlement are likely contributors shaping year-classes as well. Locally, green crab and horseshoe crab predation could be playing a role at each of the sites surveyed for this project. Beyond the biological controls on this population, clam harvest plays a role as well. Harvest is not legal at the Royalls Cove location and therefore, theoretically should not be a significant factor. Fox and Woodman Points are both open, and harvest could potentially be playing a role in the low densities there. Larval supply, however, dictates that soft-shelled clam concentrations in open and closed areas be managed in concert. It is not very likely that all or even most of the juvenile clams in an area are the progeny of adults residing there. The management reality of a pelagic larval stage is the potential that some very important clam concentrations in closed areas support those occurring in open areas. Therefore, as a result of all the complexities discussed here, many potential research projects could be carried out to help explain the density and size frequency patterns presented in this report.

**Conclusions:**

Soft-shelled clam densities at the three locations surveyed in Great Bay were lower in this study than data reported in previous studies. The size frequency distribution contained mostly larger individuals with low representation in smaller size classes. The three clam concentrations therefore seem to have experienced poor recruitment in recent years. A combination of sampling design and environmental factors controlling survival of the all life stages explain the patterns seen here. More extensive research into specific areas is needed to define the exact mechanisms at work and their level of significance in this particular system.

**Recommendations:**

Future sampling efforts could potentially be stratified based on substrate type instead of siphon counts or costly random sampling. At present, a substrate map detailing sediment type throughout the Great Bay Estuary does not exist at sufficient resolution to support this. Therefore, future projects should be encouraged to collect sediment cores at each of the sampling locations. In the interim, site specific maps suitable for use in stratification could be generated by walking areas with DGPS along transects and qualitatively assessing substrate type. This georeferenced qualitative information would provide sufficient information to stratify based on available habitat and would strengthen the resultant clam density estimates. Eventually, enough sediment core data will exist that a high resolution substrate map could be produced. This information could also to be used in the current Banner and Hayes model to improve upon its predictive ability.

## Sections III – Oyster Disease Testing

Testing of oysters for the presence of two diseases, MSX and DERMO, was conducted during both years. A report was previously submitted by NH F&G on oysters collected in 2001. During 2002 twenty five individuals from 4 sites were collected by divers and sent to the Haskins Shellfish Research Lab at Rutgers' University where testing is currently being conducted. Results will be provided as soon as they become available.

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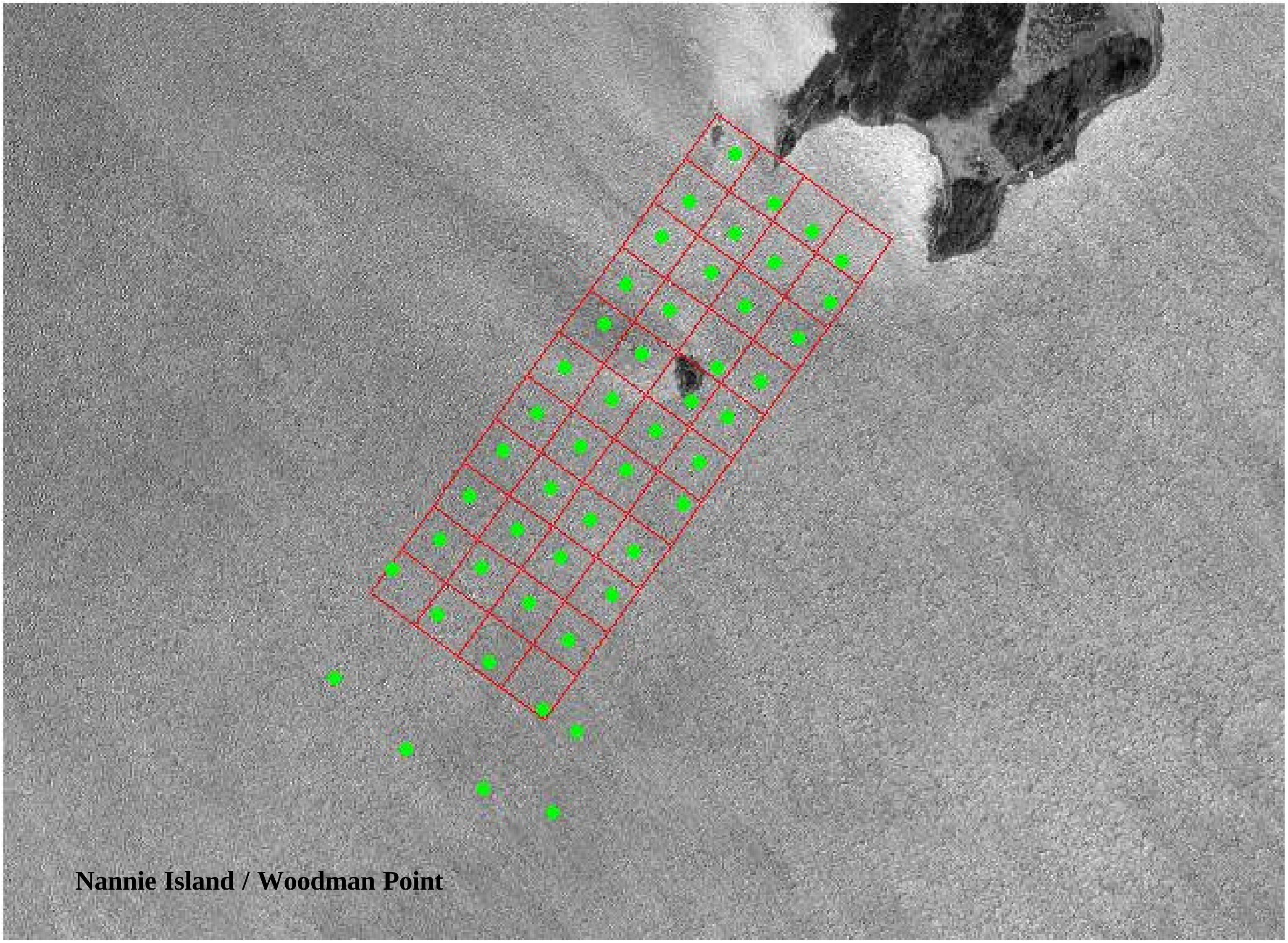
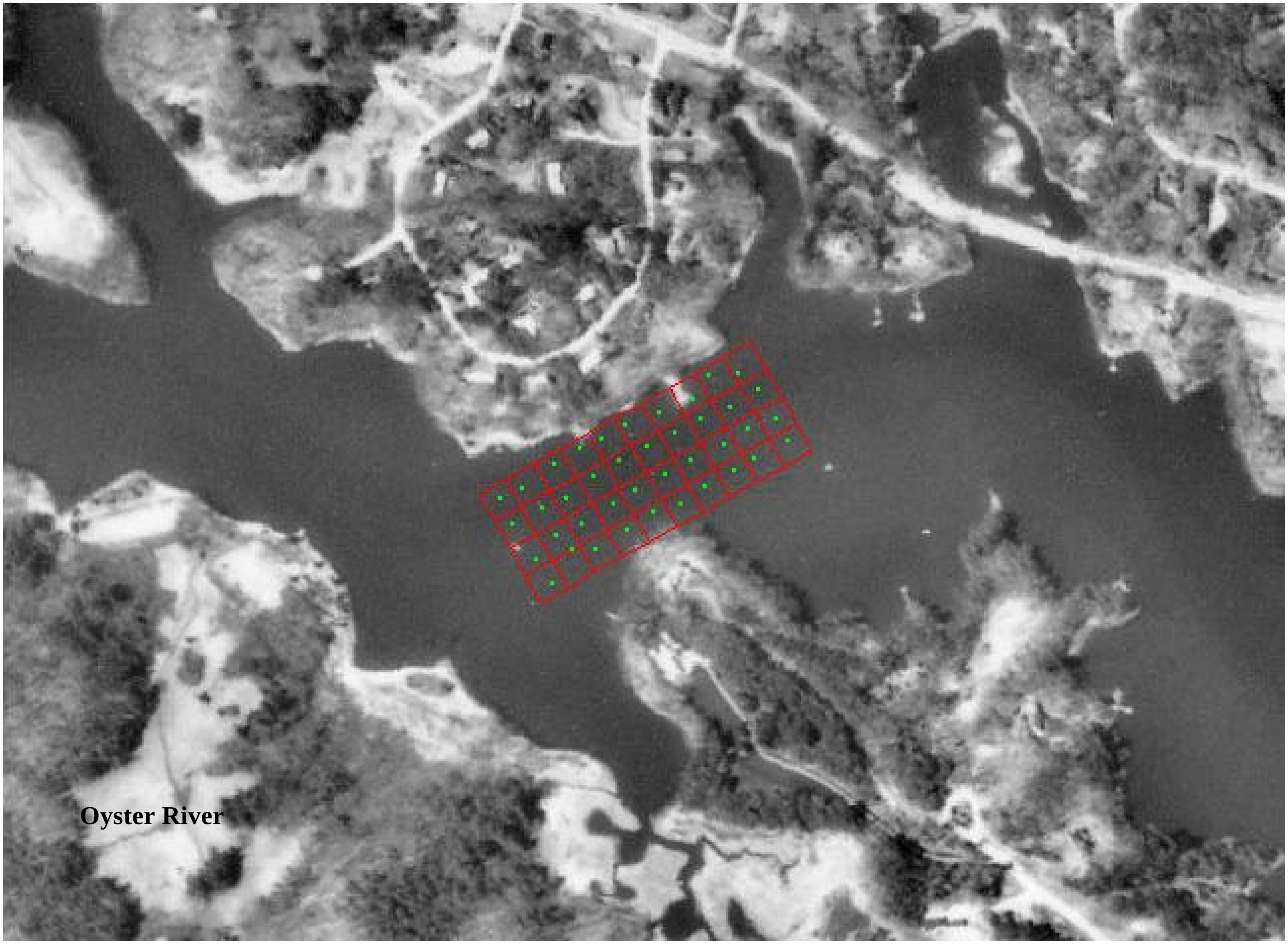
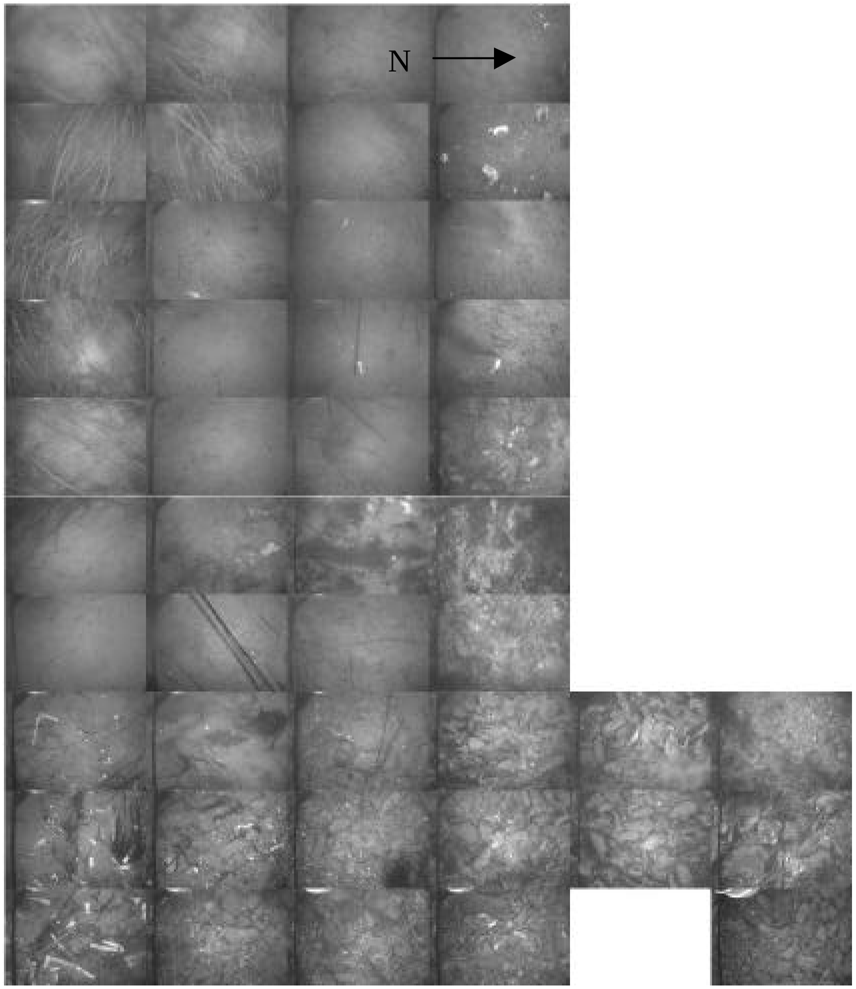
**Appendix I:** The following images represent the location of video images collected at each location

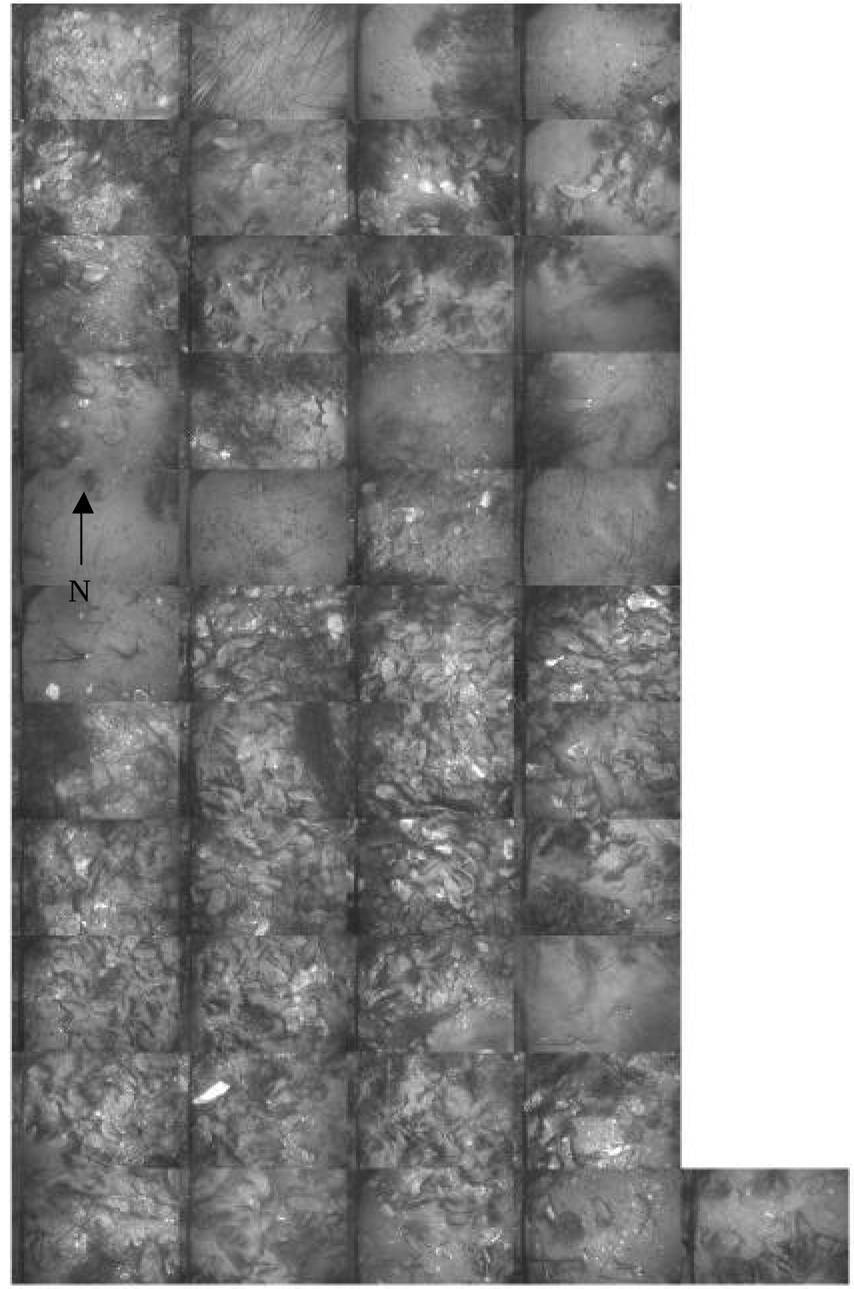

Nannie Island / Woodman Point


Oyster River

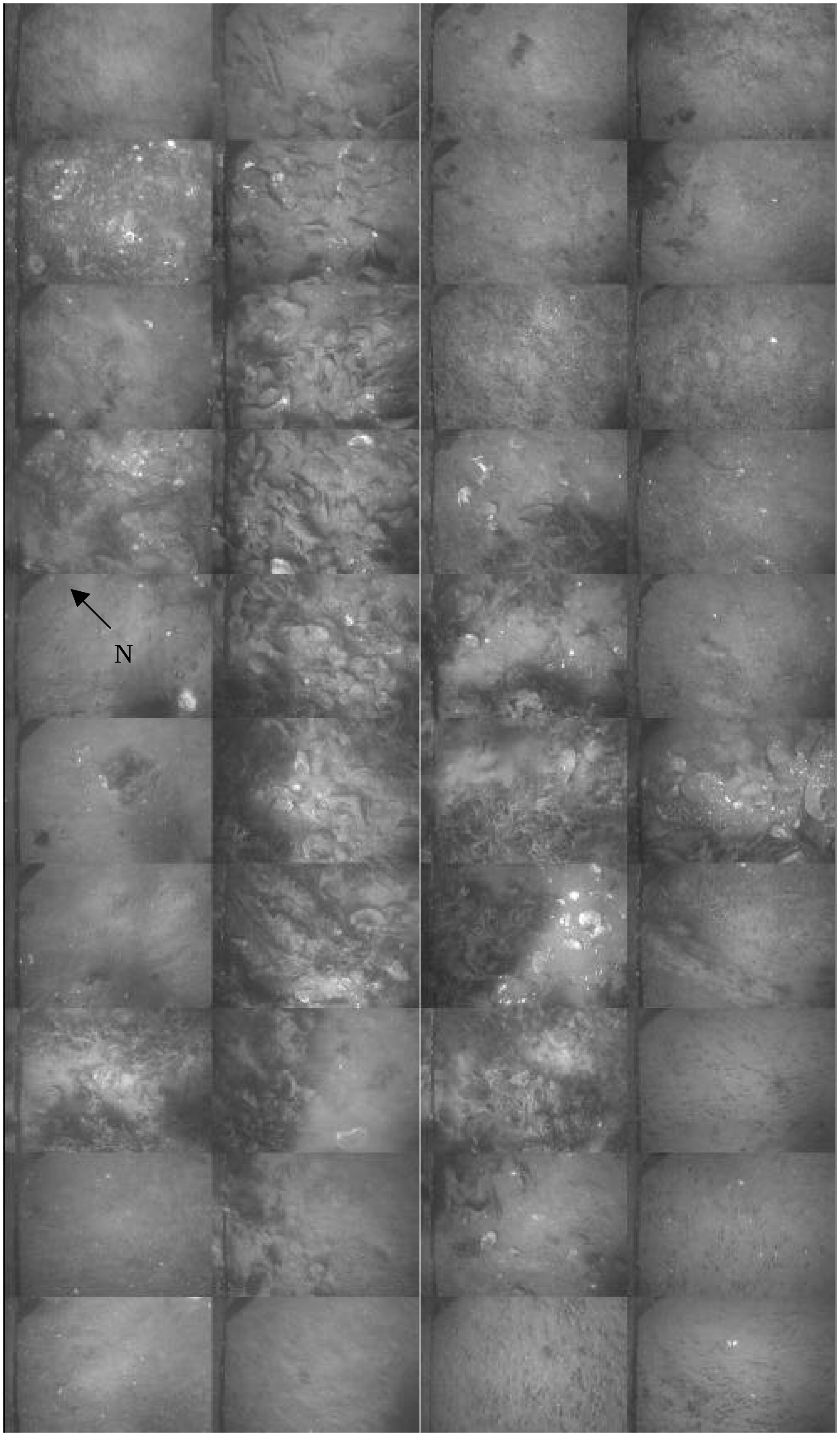
**Appendix II:**




**Adam’s Point**




**Nannie Island / Woodman Point**




**Oyster River**