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## Mapping and Characterizing Subtidal Oyster Reefs Using Acoustic Techniques, Underwater Videography, and Quadrat Counts

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**Abstract.** Populations of the eastern oyster *Crassostrea virginica* have been in long-term decline in most areas. A major hindrance to effective oyster management has been lack of a methodology for accurately and economically obtaining data on their distribution and abundance patterns. Here, we describe early results from studies aimed at development of a mapping and monitoring protocol involving acoustic techniques, underwater videography, and destructive sampling (excavated quadrats). Two subtidal reefs in Great Bay, New Hampshire, were mapped with side-scan sonar and with videography by systematically imaging multiple sampling cells in a grid covering the same areas. A single deployment was made in each cell, and a 5-10-s recording was made of a 0.25-m<sup>2</sup> area; the location of each image was determined using a differential global position system. A still image was produced for each of the cells and all ( $n = 40$  or  $44$ ) were combined into a single photomontage overlaid onto a geo-referenced base map for each reef using Arc View geographic information system. Quadrat (0.25 m<sup>2</sup>) samples were excavated from 9 or 10 of the imaged areas on each reef, and all live oysters were counted and measured. Intercomparisons of the acoustic, video, and quadrat data suggest: (1) acoustic techniques and systematic videography can readily delimit the boundaries of oyster reefs; (2) systematic videography can yield quantitative data on shell densities and information on reef structure; and (3) some combination of acoustics, systematic videography, and destructive sampling can provide spatially detailed information on oyster reef characteristics.

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### Introduction

Overharvesting, disease, pollutants, and other factors have resulted in long-term declines in populations of the eastern oyster *Crassostrea virginica* in many areas

(Rothschild et al. 1994; MacKenzie 1996; Hargis and Haven 1999), including the present study area in New Hampshire (Langan 1997,2000; Smith 2002; Trowbridge 2002). Hence, oysters are a major concern of coastal managers, and in most areas, they are regularly monitored. In the present study area, New Hampshire, oyster distributions and abundances have been monitored using various methods, including quadrat sampling by divers, tonging, and dredging (Ayer et al. 1970; Nelson 1982; Banner and Hayes 1996; Langan 1997, 2000). Shellfish managers in other areas use similar approaches (e.g., Jordan et al. 2002). Typically, these "traditional" methods yield distribution maps that are useful with respect to general location and average abundances in selected areas, but they rarely provide spatially detailed data because of costs and other constraints.

Recent research has explored remote sensing techniques as supplements to traditional methods for characterizing and mapping oyster reefs. Aerial photography has been used effectively for intertidal oyster reefs (Grizzle 1990; Finkbeiner et al. 2001; Grizzle et al. 2002). Subtidal reefs, however, usually require techniques such as acoustic sounders and underwater videography. Acoustic techniques can differentiate between oyster bottom and other substrate types, particularly soft sediments (Powell et al. 1995; Mayer et al. 1999; Wilson et al. 2000). Hence, they can provide high-resolution maps of reef location and spatial extent, but their potential for determining reef characteristics such as densities of living oysters versus nonliving shell has not been demonstrated. Underwater videography only recently has been explored as a routine monitoring tool for oysters (Paynter and Knoles 1999; J. R. Adams, R. E. Grizzle, L. G. Ward, S. Dijkstra, and J. Nelson, abstract from Benfthic Ecology Meeting, 2002).

The objective of this research note is to provide a preliminary assessment of a comprehensive mapping-monitoring protocol involving acoustic techniques, underwater videography, and destructive sampling (quadrat counts).

## Methods

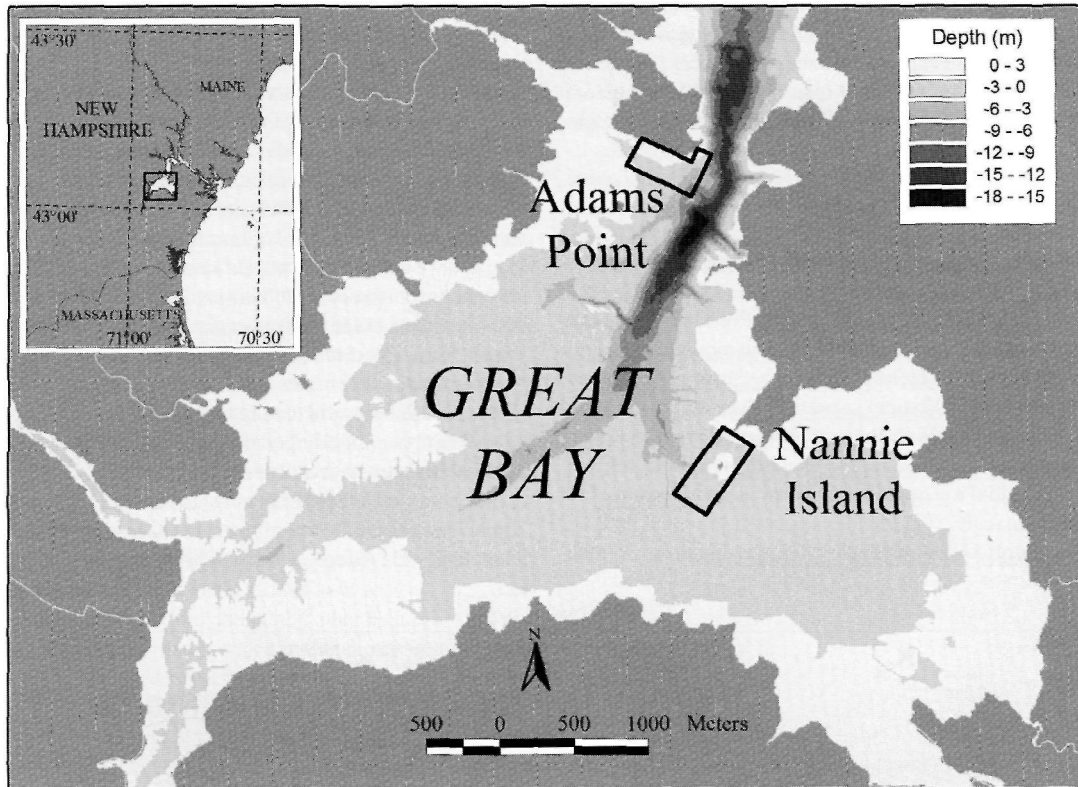
Two oyster reefs (Nannie Island and Adams Point) in Great Bay, New Hampshire, were mapped in fall 2001 (Figure 1); the mapping techniques included acoustic remote sensing by multichannel vertical incidence and side-scan sonar, underwater videography, and quadrat sampling by divers. Both reefs are worked regularly and extensively by recreational harvesters (mostly with tongs) and have low vertical relief (see Discussion below). Water depths over both reefs range from 1 to 3 m at mean low water. The surficial sediments in Great Bay range from

muds to silty sands, with some sand deposits (Armstrong 1974). The substrates near the Nannie Island study site are primarily silts to sandy silts. The surficial sediments at the Adams Point site are largely muds to silts.

All acoustic mapping work was done using standard hydrographic surveying techniques by laying out a series of grid lines. Side-scan sonar (a developmental version of the system 5000 MKII loaned to us by the its manufacturer Klein Associates, Inc., Salem, New Hampshire) was used for both the Adams Point and the Nannie Island reefs. This system has a dynamically focused multibeam transducer array with five simultaneous digitally formed beams per side. To enable work in the very shallow water covering the reefs, the sonar was hull mounted on the R/V *Little Bay*, a pontoon boat that was specially adapted for acoustic mapping in extremely shallow water. The operating frequency was 255 kHz, and the pulse length was 50 ms, resulting in an across-track resolution of approximately 3 cm. The range scale was set to 50 m, leading to an along-track resolution of better than 20 cm. A regular grid with 40-m line spacing was used on both reefs. This protocol allowed us to make better radiometric corrections than normally possible. A PosMV system was used for motion sensing and differential global positioning system (DGPS) was used for positioning.

Multichannel vertical incidence data were obtained using a Navitronic Seadig 21 system only at the Adams Point reef, for bottom characterization. The Navitronic system was installed on the Canadian Department of Public Works vessel R/V *Miramichi Surveyor* that was on location as part of a different project. As installed, the Seadig 21 system had 12 channels and used a 50-ms pulse length, logging a single depth value for each ping on each channel. A 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 that performed an analog to digital conversion (Collins et al. 1996). This procedure allowed identification of the bottom and extraction of over 160 features from this return, both from the time and frequency domains using the Quester Tangent Impact software. The number of features was then reduced to three using principal component analysis, followed by a cluster analysis in a three-dimensional feature space that provided characterization of the data (Quester Tangent 2002).

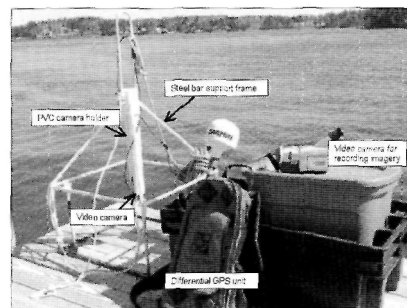
Video imagery was obtained on both reefs using a custom-made camera system consisting of an underwater black and white camera (Aqua-Vu model IR) with integral infrared lighting (not used in present study) mounted on steel frame, Garmin DGPS unit (model GPS 76), and Sony digital video camera (model DCR-TRV103) for



**Figure 1.** Location of two study reefs, Adams Point and Nannie Island, in Great Bay Estuary, New Hampshire. Note that polygon shapes of reefs approximate shapes and orientations of areas video imaged as shown in Figure 3.

recording (Figure 2). The approximate area of each reef was overlaid with a systematic sampling grid consisting of 40-44 sampling cells. A 5-10-s recording was made of a single position in each cell. Each recording was reduced to a still image using a combination of Environmental Systems Research Institute's ArcInfo and Adobe Photoshop, and all the stills (40-44) from each reef were combined into a geo-referenced photomontage. At 9 or 10 of the video-imaged cells on each reef, divers excavated a 0.25-m<sup>2</sup> quadrat by hand, removing only the surface layer of shell. All living oysters were counted and measured (shell height to nearest mm) using calipers. Quadrats were taken from the exact area that was video imaged, thereby allowing a direct comparison of data derived from video imagery with quadrat counts.

Three individuals examined each of the 19 video images from the two reefs independently. In each image, all objects that could be identified as an oyster shell were counted. This count was further refined by counting all obviously dead shells, usually identified by observation of a light-colored shell interior with dark adductor muscle scar. This yielded three numbers for each image: total



**Figure 2.** Custom-made videographic camera system consisting of underwater black and white camera (Aqua-Vu model IR) with integral infrared lighting (not used in present study) mounted on steel frame, video camera for recording imagery, and differential global positioning system.

shells, dead oysters, and possibly live oysters (equal to number of total shells minus number of dead oysters). For the present study, the number of possibly live oysters was emphasized and used to compare with the quadrat data that consisted only of live oysters excavated by divers.

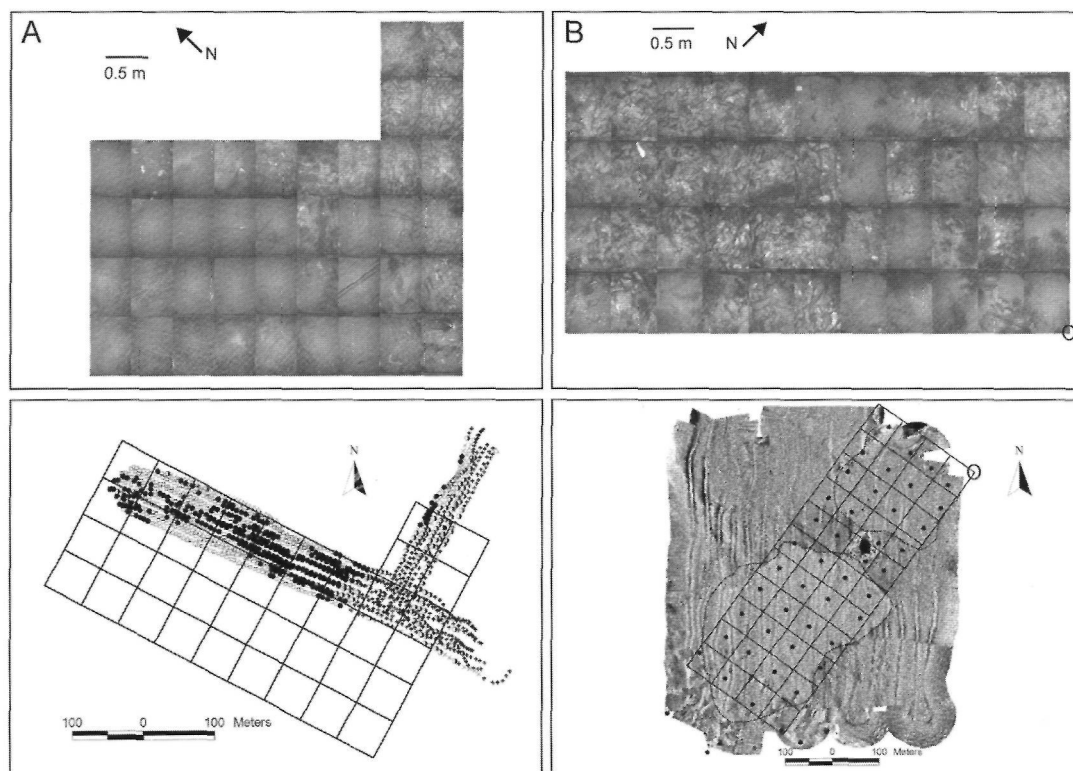
## Results and Discussion

Side-scan sonar produced easily interpretable imagery data at the Nannie Island location, clearly showing reef boundaries (Figure 3). At the Adams Point reef, the acoustic data identified reefs boundaries but required an experienced analyst to interpret the data because of differences in topography. Vertical incidence data at Adams Point showed a number of distinctly different areas that were not depth dependent. Hence, these data indicate substantial potential for single-beam sonar as a low-cost tool for mapping reefs.

Comparison of maps produced by acoustic tech-

niques and videography indicated that both approaches were capable of delimiting reef boundaries (Figure 3). A major difference between the two is that much higher resolution of reef boundary shape was obtained acoustically. It should be noted, however, that the number of images obtained determines boundary resolution in video maps. Although it is possible to approach the resolution of acoustics using video imaging, this would be practical for only small areas due to the number of images that would have to be taken and processed. Another difference between the two techniques is that data on shell densities (and potentially size distribution) can be obtained from video images. Hence, video maps (photomontages) directly provide information on reef characteristics potentially useful to managers.

The present study corroborates previous research by demonstrating that acoustic techniques can effectively differentiate oyster bottom from surrounding substrate types. For example, research in the Chesapeake Bay, Maryland (DeAlteris 1988); Galveston Bay, Texas



**Figure 3.** Videographic photomontage (top) and acoustics-derived map (bottom) from study reefs shown in Figure 1, (A) At Adams Point reef, multichannel vertical incidence data showed five different sediment classes; black dots represent shell bottom and approximate reef area. Note that sampling grid chosen for this reef was too coarse to give adequate video coverage of the actual reef area. (B) Side-scan sonar map of Nannie Island reef; dashed lines indicate outline of southern and northern portions of reef. Note, match circles in corners for proper orientation of images.

(Simons et al. 1992; Powell et al. 1995); and Louisiana (Roberts et al. 1999; Wilson et al. 2000) has demonstrated the utility of single-beam sounders and side-scan sonar in mapping subtidal reefs and discriminating between oyster bottom and several other bottom types. Ongoing programs in several areas continue to refine the use of side-scan sonar and single-beam techniques (e.g., Roberts et al. 1999; Smith et al. 2001). Multibeam approaches show considerable promise for reef mapping, but they need to be fully tested (Mayer et al. 1999).

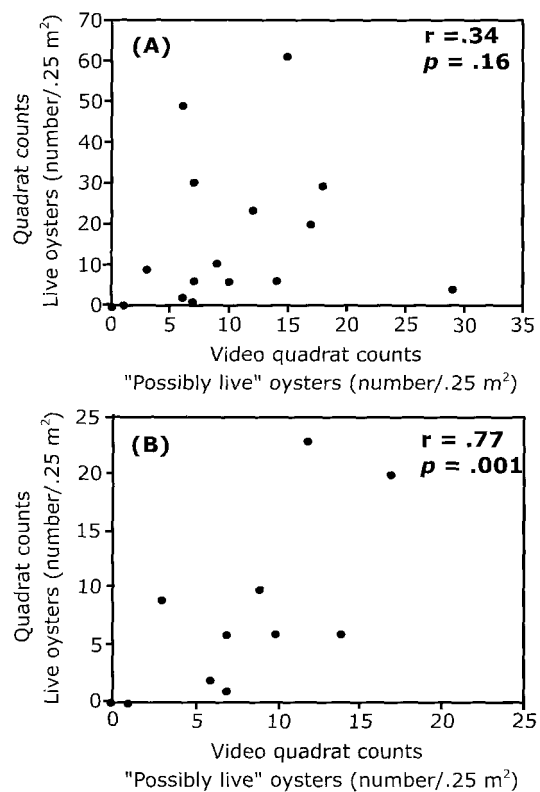
To our knowledge, very little research has been done on videography for mapping and characterizing oyster reefs. Paynter and Knoles (1999) used video to characterize the general conditions of constructed oyster reefs in the Chesapeake Bay but did not rely on videography for mapping. The photomontage approach described here is a new technique we are developing to make maximum use of video imagery in bottom habitat mapping generally. At a minimum, it provides a "picture" consisting of geo-referenced photographs of the mapped bottom area. In the case of oyster reefs, the picture shows relative shell densities, orientation, and potentially other features. Each image, however, is exaggerated in two dimensions because each of the stills represents only a small portion of the actual area occupied by that image on the overall map. In other words, the overall boundaries of the reef are spatially accurate and geo-referenced, but each individual still image is at a much larger scale. For example, if the still images in Figure 3 were at the same scale as the overall map, each would represent only about 1/16,000 of the cell it fills. In a photomontage, the amount of exaggeration decreases as the number of cells imaged increases.

As mentioned above, both reefs have low vertical relief probably because they are heavily worked by harvesters using tongs. Most oysters on both reefs occurred as singles or in small clumps. These characteristics are particularly evident in the images from Nannie Island (Figure 3b). Other reef characteristics potentially inferable from videography include the level of sediment accumulation, presence and extent of shell fouling, and presence of larger reef-associated organisms (Paynter and Knoles 1999; Smith et al. 2001).

One important question that has not been assessed for videography is its potential for counting live oysters. Counts of possibly live oysters made directly from our video imagery from both reefs were only weakly correlated with quadrat data (live oysters extracted from each quadrat by divers) for the entire 19-sample data set (Figure 4a). However, when counts exceeding 25 oysters per quadrat (for either live oysters or video counts) were omitted, there was a strong correlation between the two (Figure 4b). This suggests that videography might only be useful when oyster densities are low, perhaps less than 100 individuals/m<sup>2</sup>. The explanation, however, is a bit

more complicated for our data set. Two of the omitted data pairs had high numbers of small oysters, many less than 40 mm in shell height. Oysters of this size would be more easily missed in video counts than would larger individuals. A third data pair had large numbers of dead shell, suggesting that some empty valves were among the oysters counted as possibly live. Overall, these data suggest that videography potentially can be used to infer density and other reef characteristics, but limitations exist. This will be an important area of research in future studies.

At least three conclusions can be drawn from the present study: (1) acoustic techniques and systematic videography can readily delimit the boundaries of oyster reefs; (2) systematic videography can provide data on shell (whether live or dead) densities, reef characteristics such as vertical relief, and potentially data on densities of live oysters; and (3) reef characteristics such as shell den-



**Figure 4.** (A) Possibly live oysters counted (mean of three different individuals independently inspecting each image) from video images of quadrats versus corresponding quadrat counts of all live oysters extracted by divers from same 0.25-m<sup>2</sup> area,  $n = 19$ ,  $r = 0.34$ ,  $P = 0.16$ . (B) Same data set except all counts (video or live counts) exceeding 25 oysters were omitted,  $n = 14$ ,  $r = 0.77$ ,  $P = 0.001$ .

sity may be extracted from acoustic data, but its full potential remains to be tested. Taken together, these findings suggest that some combination of acoustics, systematic videography, and destructive sampling can improve upon traditional methods by providing more spatially detailed information on oyster reef characteristics.

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