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Bottom Habitat Mapping Using Towed Underwater Videography: Subtidal Oyster Reefs as an Example Application

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ABSTRACT

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Towed underwater video has become a widely used method for bottom habitat mapping in coastal waters, but very little has been published on this relatively new and effective approach. We use a case study on two oyster reefs to illustrate the pros and cons of towed video, visualization techniques, and future research topics. Towed video is deployed in similar fashion to single-beam sonars, yielding narrow swaths of video imagery that are recorded concurrently with global positioning system (GPS) data for georeferencing. The major advantages over acoustic (sonar) methods are that image processing and interpretation are relatively simple, and there is little or no need for subsequent ground-truthing. The system used in the present study consists of an underwater black and white camera mounted on a steel frame, differential GPS unit, and digital video camera for recording. It was assembled from off-the-shelf items, and total cost was approximately $3500 (2006 US$). The imagery from both study reefs was of sufficient quality to allow classification of the surveyed bottom into three categories: nonreef, low-density shell, and high-density shell. Some reef characteristics such as the amount of vertical relief were easily discernable and showed substantial differences between the two reefs. Reef bottom areal coverages determined from the video imagery compared well with recent previous studies on the two reefs using other methods. Water clarity limitations represent the major obstacle to widespread use of video for routine mapping of oyster reefs. Turbidity–image quality relations remain to be quantified.

ADDITIONAL INDEX WORDS: *Multibeam, single beam, sonar, acoustics,* Crassostrea virginica.

INTRODUCTION

Bottom mapping in subtidal waters typically is accomplished using remote sensing techniques such as multibeam or single-beam sonars followed by ground-truthing with underwater videography or extractive sampling (*e.g.,* OJEDA *et al.,* 2004; RIEGL *et al.,* 2005). Multibeam bathymetry and sidescan sonars are uniquely capable of providing high-resolution data over large areas because they insonify wide swaths of seafloor, providing large and complex data sets on seafloor characteristics (MAYER, HUGHES CLARKE, and DIJKSTRA, 1999; NRC, 2004). These acoustic techniques are the focus of rapidly developing fields of research as well as widely applied approaches to seafloor mapping (ALLEN *et al.,* 2005; ICES, 2003; KOSTYLEV *et al.,* 2001; SMITH, BRUCE, and ROACH, 2001; SMITH, ROACH, and BRUCE, 2003; SMITH *et al.,* 2005; ZAJAC *et al.*, 2000). However, they are expensive, and high-quality data sets require substantial effort and expertise to obtain, process, interpret, and visualize. Hence, seafloor mapping using multibeam bathymetry or sidescan sonar is not always practical.

Single-beam sonars provide potentially low-cost alternatives to multibeam, and reasonably priced commercial units are available that include hardware as well as software for processing and analyzing the data. Single-beam sonars used in seafloor mapping include relatively inexpensive echo sounders (KVERNEVIK, AKHIR, and STUDHOLME, 2002), subbottom profiling devices (SMITH, BRUCE, and ROACH, 2001; SMITH, ROACH, and BRUCE, 2003), and units designed specifically for discriminating different bottom characteristics (RIEGL *et al.,* 2005). A major difference between multibeam and single-beam sonars is that the latter only insonifies a narrow swath of the seafloor along each ship track. In a typical application, a relatively small portion of the overall mapped area is actually imaged, then interpolation tech-

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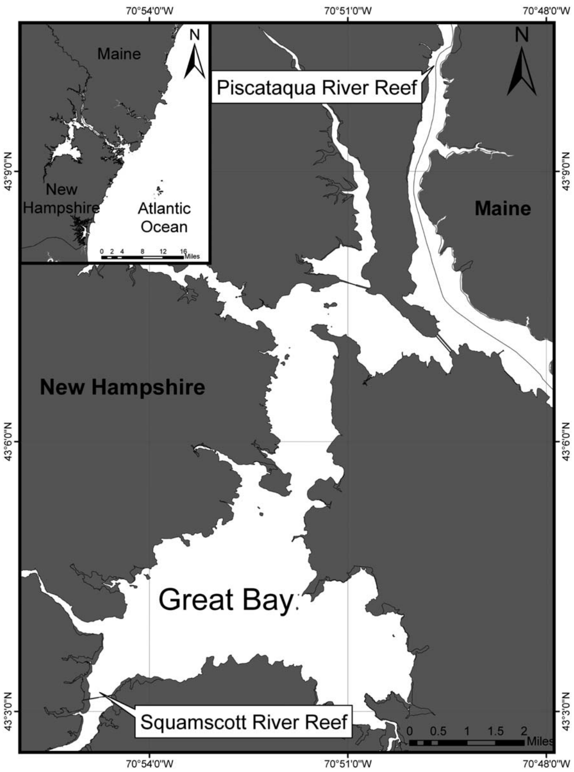

Figure 1. Locations of study reefs in the Piscataqua River and at the mouth of the Squamscott River, New Hampshire, U.S.A.

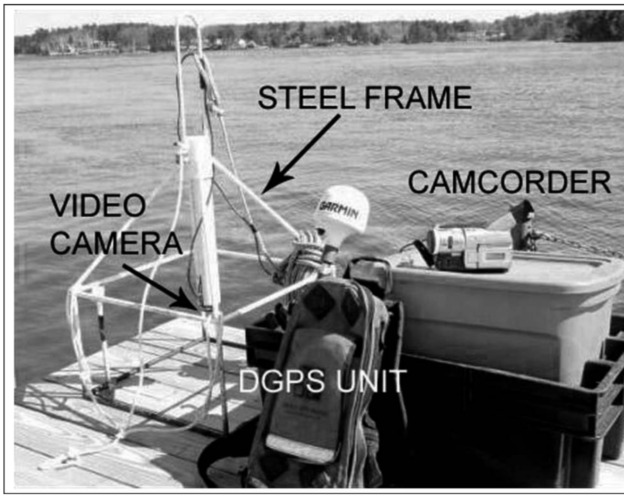

Figure 2. Towed, underwater videography system (laptop computer not shown).

niques are used to infer bottom characteristics between ship tracks. The resulting data set, however, still requires substantial processing and interpretation effort as well as ground-truthing.

Underwater video is often used to ground-truth sonar data, but when water clarity is sufficient and when deployed in conjunction with a global positioning system (GPS) it also can be used as a primary mapping tool. Its application as such has been limited even though underwater photographic techniques in general have been available for decades (Holme, 1982; Rhoads *et al.*, 2001). For mapping purposes, video can be deployed as a "drop camera" for stationary imaging of multiple small areas of the seafloor, where each still image represents a videographic sample of the bottom, or as a towed unit with continuous recording of swaths of imagery (and GPS data). A major example of the stationary imaging approach is the Georges Bank sea scallop monitoring program at the University of Massachusetts Dartmouth (Stokesbury, 2002; Stokesbury *et al.*, 2004). Towed video typically produces a data set similar to single-beam sonars consisting of a series of relatively narrow swaths of imagery of the seabed. The primary difference is that high-quality video imagery can be quickly interpreted and classified, and there is little or no need for ground-truthing. Standard geographic information system techniques are then used to produce georeferenced maps of the seafloor.

Towed video has been used in dozens of bottom habitat mapping projects in North America, but very little has been published on this work. For example, John Harper and colleagues have been using towed video as a cost-effective, primary mapping tool on the Pacific coast for over a decade (*e.g.,* Harper and Berry, 2001). Kvernevik, Akhir, and Studholme (2002) successfully used towed video to map coral reefs in Malaysia, and they argue that it represents a particularly important method for low-budget user groups in developing countries. Towed video represents a powerful and relatively inexpensive mapping tool but its limitations and potential remain to be fully explored.

As an example of the use of towed video as the primary tool for bottom habitat mapping, we describe its application on two eastern oyster (*Crassostrea virginica*) reefs in New Hampshire, U.S.A. We discuss the advantages and disadvantages of towed video, visualization techniques, and potential future research topics.

MATERIALS AND METHODS

The present study was conducted in the Great Bay/Piscataqua River estuarine system in New Hampshire (Figure 1). Two subtidal oyster reefs, one at the mouth of the Squamscott River and the other in the Piscataqua River, were mapped using a custom-made underwater videography system consisting of an underwater black and white camera (Aqua-Vu model IR) with integral infrared lighting (not used in present study) mounted on a steel frame, Garmin differential GPS unit (model GPS 76), laptop personal computer (PC) for navigation and GPS data logging, and Sony digital video camera (model DCR-TRV103) for recording (Figure 2). The entire system was assembled for approximately $3500 (2006 US$).

In a typical operation, the frame with camera is suspended in the water column with a steel cable on a manually operated winch with a short arm extending over the boat's gun-

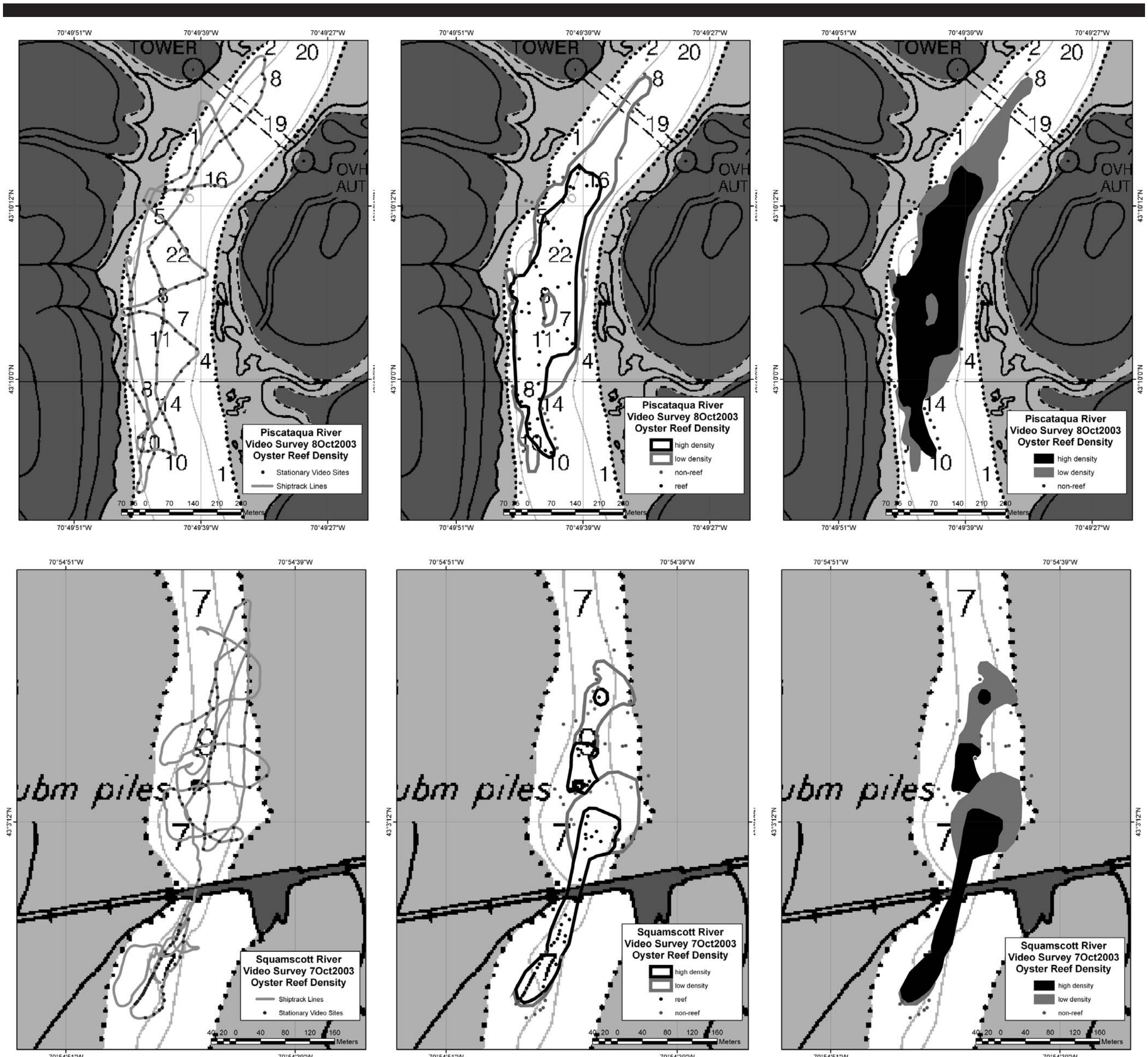

Figure 3. Three-step process for constructing oyster reef density maps for the two study reefs. Left, ship tracks with locations of stationary video images; middle, shell density contours determined by visual inspection of video imagery; right, filled polygons based on shell density.

wale. After positioning the camera at a height suitable for obtaining adequate image quality and swath width (typically about 0.5 m for our system), the unit is slowly towed (at speeds up to about 1.5 knots) so that it remains directly below the winch. The video image is split onboard to a camcorder for recording and a monitor so the operator can see the imagery in real time. This allows for quick adjustments of the camera as the survey proceeds. Ship tracks are monitored in real time on the PC that has navigational software installed, and GPS data are logged. The video imagery and GPS data are synchronized by time, which is recorded in both data sets.

For the present study, continuous video imagery was acquired along three or four parallel transects spanning the longest axis of each reef and seven to ten transects obliquely oriented to them (Figure 3). At approximately 90 points for the Squamscott reef and 115 points for the Piscataqua reef, stationary (for 3 to 5 s) video imagery was taken within the overall matrix of transects. Concurrently and synchronized with respect to time with the imaging, digital GPS output was logged at 0.5-second intervals to provide georeferencing of the imagery. Approximately 1.5 hours of video imagery was recorded on the Squamscott reef on 7 October 2003, and 2 hours on the Piscataqua reef on 8 October 2003. The continuous imagery was visually inspected and assigned a classi-

Table 1. *Recent historical data on oyster reef bottom areal coverages compared to present study. All pre-2003 data from Langan (1997).*

Reef Location	1991	1993	1997	Present Study (2003) Low Density	Present Study (2003) High Density
Piscataqua River	5.0 ha (12.3 ac)	5.0 ha (12.3 ac)	5.2 ha (12.8 ac)	3.0 ha (7.4 ac)	5.1 ha (12.5 ac)
Squamscott River			0.7 ha (1.7 ac)	0.8 ha (2.0 ac)	0.8 ha (1.9 ac)

fication of "nonreef" (<10% bottom coverage by oyster shells), "low-density reef" (10% to 50% coverage by oyster shells), or "high-density reef" (>50% coverage by oyster shells). The entire video stream was inspected and breakpoints between classes were determined. Stills taken from each stationary imagery site were also individually classified in this way. Notes were also made on reef characteristics such as vertical relief, relative amounts of empty shells, and evidence of sediment accumulation.

The classification types were then plotted on the base map and polygons were constructed manually, drawing each boundary line approximately midway between bottom-type classes. Areas of polygons for high-density reef and low-density reef were determined using ArcView software for each of the reefs. One representative still image from each stationary video site was assembled in a systematic grid overlaid on the overall imaged area to provide a photomontage of bottom images for each reef.

The accuracy of the maps was assessed by visiting 11 sites on the Piscataqua reef and 27 sites on the Squamscott reef using latitude and longitude read directly from the ArcView map files. At each site, a 0.25 m^2 area of the bottom was thoroughly worked using oyster tongs to remove as much bottom material as practical. All live oysters and empty shells retrieved were counted. The resulting data were compared to the mapped classification (high-density reef, low-density reef, and nonreef) for each of the sites as an assessment of the accuracy of the video-derived bottom classes.

RESULTS

The video imagery was of sufficient quality to allow classification of "shell bottom" into two density classes, "low" (10% to 50% bottom coverage by oyster shell) and "high" (>50% bottom coverage by oyster shell), in nearly all areas imaged on both reefs (Figure 3). If it is assumed that low- and high-density oyster shell coverages reflect oyster reef bottom, the Piscataqua reef had an areal extent of 8.06 ha (19.9 ac) and the Squamscott reef covered 1.58 ha (3.9 ac) (Table 1). If only high-density bottom represents oyster reef, the Piscataqua reef covered 5.06 ha (12.5 ac) and the Squamscott 0.77 ha (1.9 ac). If at least the high-density areas would have been considered oyster reef bottom in recent previous studies, then areal coverages from the present study compare well with prior surveys suggesting that total bottom areal coverage may not have changed appreciably for either reef since the 1990s.

There were dramatic differences in vertical relief and densities of what appeared to be live oysters discernable from the video imagery when comparing the two reefs. In both high- and low-density areas, the Piscataqua reef consisted mainly of individual shells lying on one valve scattered across the bottom, and it was difficult to differentiate between empty valves and live oysters (Figure 4). In contrast, many areas of the Squamscott reef consisted of vertically oriented, dense clusters of live (based on valve gape or visible movements) oysters. A photomontage constructed for the Piscataqua reef provides information on spatial variations in reef characteristics (Figure 5).

For checks on mapping and bottom classification accuracy, a total of 11 sites were sampled with oyster tongs on both reefs in areas mapped as high-density reef, and live oysters were found at all 11 sites, along with abundant empty shells. Live oysters and empty shells also were collected from 10 of the 12 sites in areas mapped as low-density reef. In contrast, live oysters and empty shells were only collected from 4 of the 15 nonreef sites. These data indicate that the mapping process was probably highly accurate for oyster bottom in general, when including areas designated as high (100% of sampled sites with live oysters) and low (83% of sampled sites with live oysters) densities. The tong samples, however, did not show a clear distinction between the two density classes. These data also indicate that live oysters were found in some areas adjacent to mapped reef areas but in most cases only at very low densities.

DISCUSSION

Water clarity is probably the most serious limitation on the use of towed video as a primary bottom habitat mapping tool, particularly in estuarine waters. Eastern oyster (*Crassostrea virginica*) reefs occur in estuaries along the North American Atlantic coast from the intertidal zone into shallow subtidal waters (Bahr and Lanier, 1981; Burrell, 1986; Stanley and Sellers, 1986). This range of water depths, in combination with the wide range of water turbidity conditions that occur in many estuarine areas, makes remote sensing of oyster reefs challenging. A variety of techniques involving aerial imagery have been successfully used for mapping, and characterizing to some extent, intertidal reefs (Finkbeiner, Stevenson, and Seaman, 2001; Grizzle, 1990; Grizzle, Adams, and Walters, 2002; Martin *et al.*, 2003; Vincent *et al.*, 2003). Subtidal reefs, however, often cannot be mapped using aerial techniques. Multibeam and single-beam sonars are capable of differentiating between oyster bottom and other substrate types, particularly soft sediments (DeAlteris, 1988; Grizzle *et al.*, 2005; Powell *et al.*, 1995; Smith, Bruce, and Roach, 2001; Smith, Roach, and Bruce, 2003; Smith *et al.,* 2005; Wilson, Roberts, and Supan, 2000). Hence, they can provide maps of reef location and spatial extent, but their potential for determining reef characteristics such as densities of living oysters *vs.* nonliving shell has not been demonstrated. Underwater videography only recently has been explored as a monitoring tool for oysters.

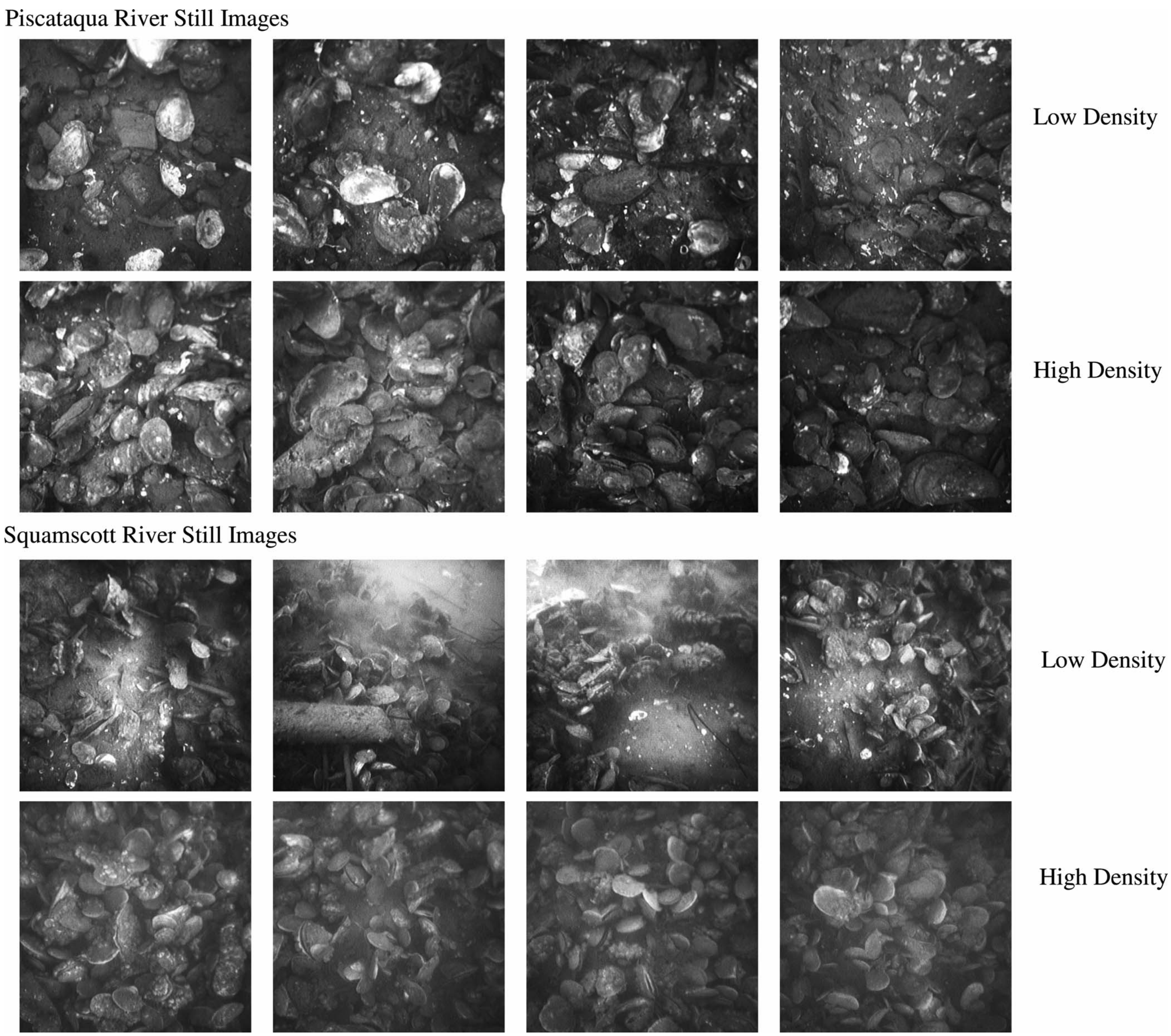

Figure 4. Still images illustrating low-density and high-density areas from both study reefs.

To our knowledge, very little research has been done on videography for mapping and characterizing oyster reefs. PAYNTER and KOLES (1999) used video to characterize the conditions of constructed oyster reefs in Chesapeake Bay, but did not rely on videography for mapping the areal extent of the reefs. The present study and previous research on other oyster reefs in the area (GRIZZLE *et al.*, 2005) show that when water clarity is not limiting, towed video is a low-cost and effective mapping tool. And when transects (ship tracks) are properly spaced, accurate estimates of reef size and shape are readily obtained. We typically set up a minimum of three transects along the main axis of the reef combined with multiple cross-transects (as in the present study), but the number and spacing should be appropriate for the overall shape of the reef and meeting mapping objectives of each project.

The ship tracks shown in Figure 3 illustrate a navigation difficulty related to transect spacing: maintaining direction and speed in swift currents. Our video can be towed up to about 1.5 knots, but slower speeds yield better image quality and positional accuracy. We have successfully deployed our system in areas with tidal currents exceeding 2 knots (1 m/s), but this required attaching weights to the camera frame to keep it directly below the winch arm and GPS antenna. A sled might also be used to deploy the camera to better maintain position horizontally and distance off the bottom.

Video can yield information on reef characteristics such as

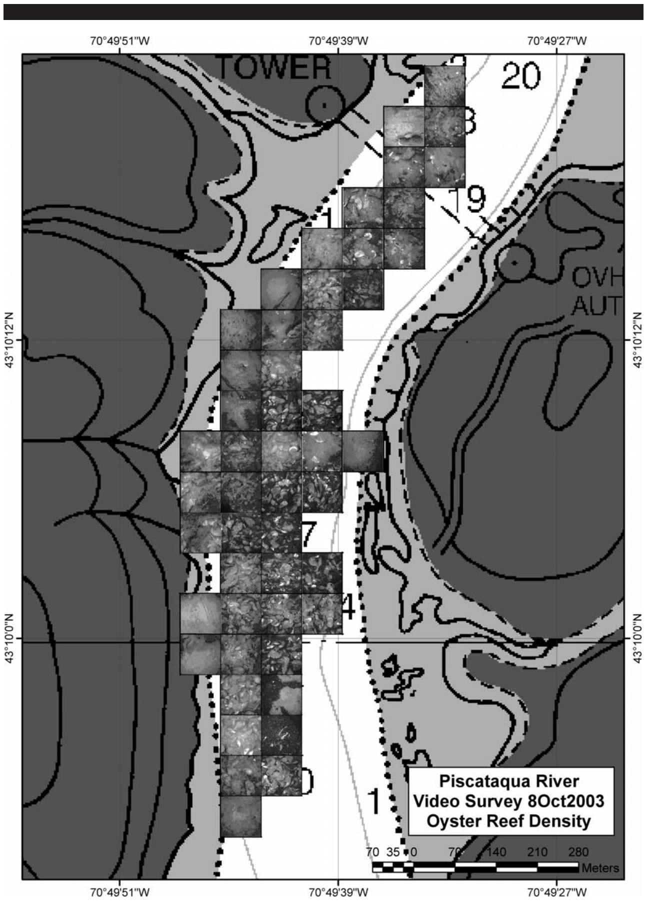

Figure 5. Photomontage of the Piscataqua River reef.

vertical relief and relative numbers of live oysters perhaps not available with other mapping methods. The Piscataqua reef had low vertical relief in all areas and mainly consisted of singles or small clusters of oysters. In contrast, the Squamscott reef consisted largely of live oysters with many clusters extending several centimeters into the water column (Figure 4). Vertical structure is a major characteristic of oyster reefs that contributes to their value as habitat for other organisms, as well as health of the reef itself (LENIHAN, 1999; LENIHAN *et al.*, 1999; PETERSON and ESTES, 2001). This is an important reef characteristic that should be a part of monitoring programs for reef restoration projects (COEN and LUCKENBACH, 2000; LUCKENBACH *et al.*, 2005). GRIZZLE *et al.* (2005) compared diver-obtained quadrat counts of live oysters with counts of "possibly live" oysters from video imagery on New Hampshire reefs, and suggested that video imagery may have the potential to quantify differences in densities of live oysters. Other reef characteristics potentially inferable from videography include the level of sediment accumulation, presence and extent of shell fouling, and the presence of larger reef-associated organisms (PAYNTER and KOLES, 1999; SMITH, BRUCE, and ROACH, 2001).

Visualization methods for video imagery are typically restricted to presentation of a few selected stills, as Figure 4 is used herein to illustrate reef characteristics. The photomontage approach (Figure 5) is a new technique to provide visualization of spatial aspects of reef characteristics. At a minimum, it provides a "picture" consisting of georeferenced 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 georeferenced, but each individual still image is at a much larger scale. The amount of exaggeration decreases as the number of cells imaged increases.

In conclusion, the use of underwater videography for routine mapping and monitoring of oyster reefs is in the early development stages. The major advantages of towed video relative to acoustics methods are cost, straightforward image interpretation and processing, and little or no need for ground-truthing. Off-the-shelf, underwater cameras and other components make fabrication of inexpensive systems quite easy. Complete systems are also available commercially (*e.g.,* the Seabed Imaging and Mapping System [SIMS]; Coastal and Ocean Resources, Inc.; www.islandnet.com/~cori/). The major topic that needs attention is quantification of the relation between imagery quality and water clarity (turbidity); we have ongoing research aimed at this goal. A better understanding here will allow informed decisions on whether video is practical for a particular area or project.

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