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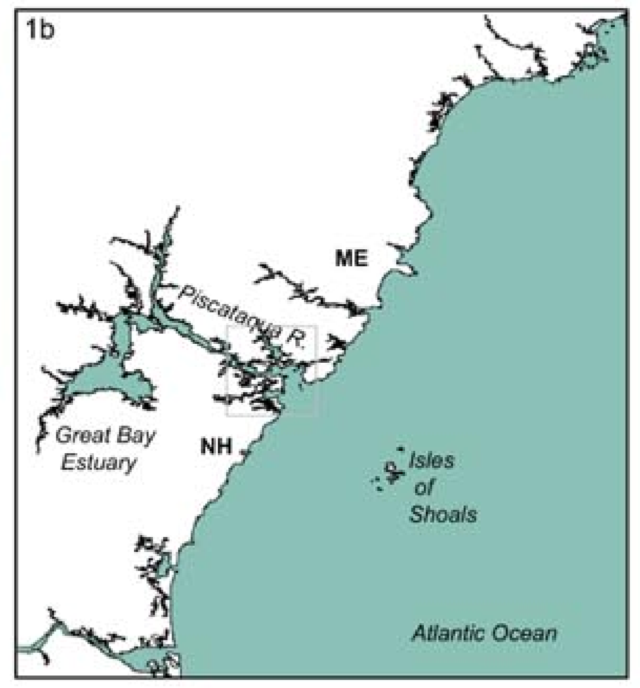
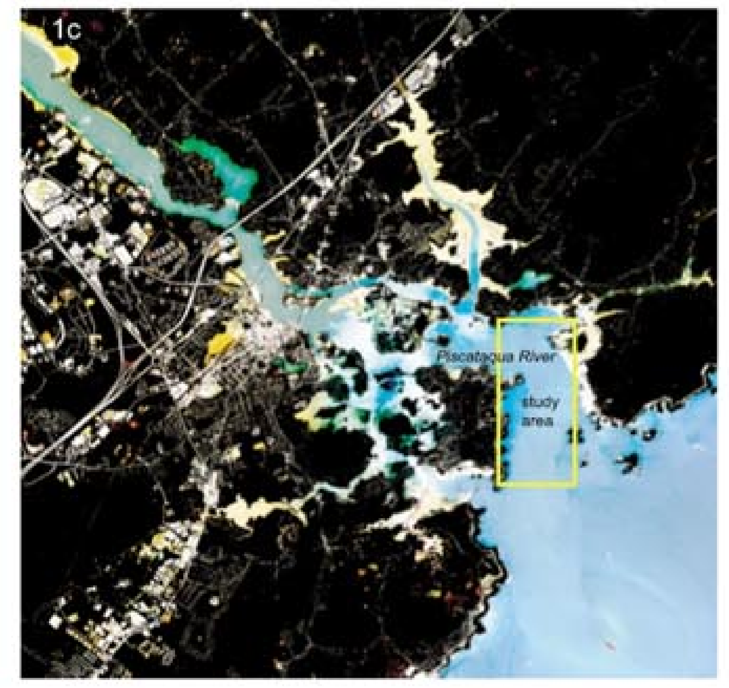
INTRODUCTION

Topographic variability of the seafloor influences benthic community structure and function at many spatial scales. Seafloor topography and biogenic features can be remotely sensed by acoustic and optical devices, and their expression in the data can be considered as textural components. Texture analysis has been applied to acoustic backscatter data to distinguish substrate regions, but the effects of acoustic shadows and uncalibrated returns have caused problems. Recently a technique using local Fourier transforms has been used successfully to classify standard textures in grayscale images and retrieve digital images from archives according to texture content (Zhou, et al., 2001). We implemented a modified form of that approach by varying the spatial scales at which local Fourier transforms are calculated. We applied the technique to multibeam echosounder (MBES) data for automatic delineation of a seafloor elevation map into regions of distinct geomorphology and apparent benthic habitats.

STUDY AREA


1a





The study area was located in the mouth of the Piscataqua River, a well-mixed estuary (Swift, et al., 1996) flowing between New Hampshire and Maine, USA (Figure 1 a, b, c). The estuary empties into and exchanges tidal water with the Gulf of Maine. The mouth channel is oriented north-south, then turns abruptly to near due west at Fort Point, NH. Portsmouth Harbor has been a major shipping port for over 200 years.

METHODS

Dataset

The dataset used for developing an automated segmentation procedure was a one meter gridded surface representing the bathymetry in the mouth of the Piscataqua River, New Hampshire, USA (Figure). The gridded bathymetry was constructed using data from a Reson 8125 multibeam echosounder, collected aboard the R/V Coastal Surveyor (UNH) by Science Applications International Corporation (SAIC) for the National Oceanic and Atmospheric Administration (NOAA), November 2001. Positioning was accomplished using a POS MV 320. Data were cleaned and the grid was constructed by Lt. Shep Smith (NOAA) using CARIS; data were projected to Universal Transverse Mercator (UTM) projection, zone 19 north. The dataset covered 839 by 2034 meters, where the center of the lower left corner grid cell originated at UTM Easting, Northing 360918.86, 4768915.16 (xllcenter, yllcenter).

LFH texture analysis technique

We use a modified implementation of the local Fourier histogram (LFH) texture analysis and discrimination technique described by Zhou, et al. (2001). Our implementation allows for varying radii and blocksize at which the local Fourier transforms (FT) and LFH's are accumulated. The processing procedure involves calculating a local FT for every data point (cell). A one dimension FT was calculated for every cell using eight values obtained from the neighborhood surrounding the cell. Separate analyes were done using varying radii to accommodate variation of different seafloor configurations at different spatial scales. Input data to the FT consisted of either the nearest 8 neighbor values to the center, or the data values for cells within a specified radius that occurred in each pi/4 radian angle sector. Blocks for accumulating LFH's: block size was specified, 10 meters squared was used in most cases. In order to construct a LFH, more than one observation was necessary. The average depth value from the block was removed from the zeroth coefficient (DC value) because when that was not done, mean depth effects dominated the resultant classifications.

Class grouping

Classes were constructed using fuzzy k-means cluster analysis (Minasny, B., McBratney, 2000). Numbers of classes (cluster groups) were arbitrarily set to seven after examination of several results.

Representative histograms, (Representative LFH's)

After cluster analysis classification was done, representative histograms were constructed using all LFH's from each class.

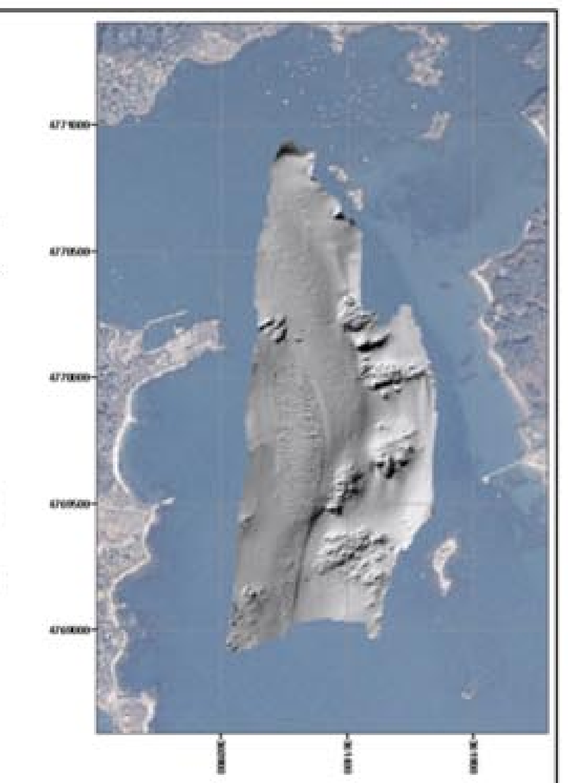


Figure 2. Bathymetric digital terrain model (DTM) from the mouth of the Piscataqua River, NH, gridded to 1 meter, UTM projection, zone 19N. Constructed from Reson 8125 multibeam echosounder data, collected by SAIC for NOAA & UNH JHC-CCOM, Fall 2000.

RESULTS

The Local Fourier Histogram (LFH) texture feature classification segmentations of the seafloor corresponded well with the various geomorphological regions in the study area. LFH classification results were robust, generating similar segmentations across several spatial scales of application. Seven cluster classes were chosen as best representing the variety of apparent geomorphological features in the study area. Fewer classes led to clearly different morphologies classified as the same; more led to subdivisions within groups.

Application of LFH to cell nearest neighbors (radius = 1 m) corresponded directly to the procedure described by Zhou et al. (2001). The resultant map showed several regions with mixed texture classes. Because more uniform regionalization was sought, the neighborhood scales were increased. Results for radii of 1, 3, and 5 meters are shown (Figure 3 a-c), though radii were varied at 1 m increments through 10 m.

With increasing neighborhood scale (radius), more uniform regions were produced, at the expense of potentially missing small patches of unique texture class. Using a radius of 1 m, just the 8 nearest neighbors, there were many texture feature blocks that might be considered misclassifications such as the obviously different classes in the sand wave field. Increasing the scale to a radius of 3 m, resulted in more consistency within regions. The best balance between region consistency and oversimplification was produced using a radius of 5 m for these data at this grid size.

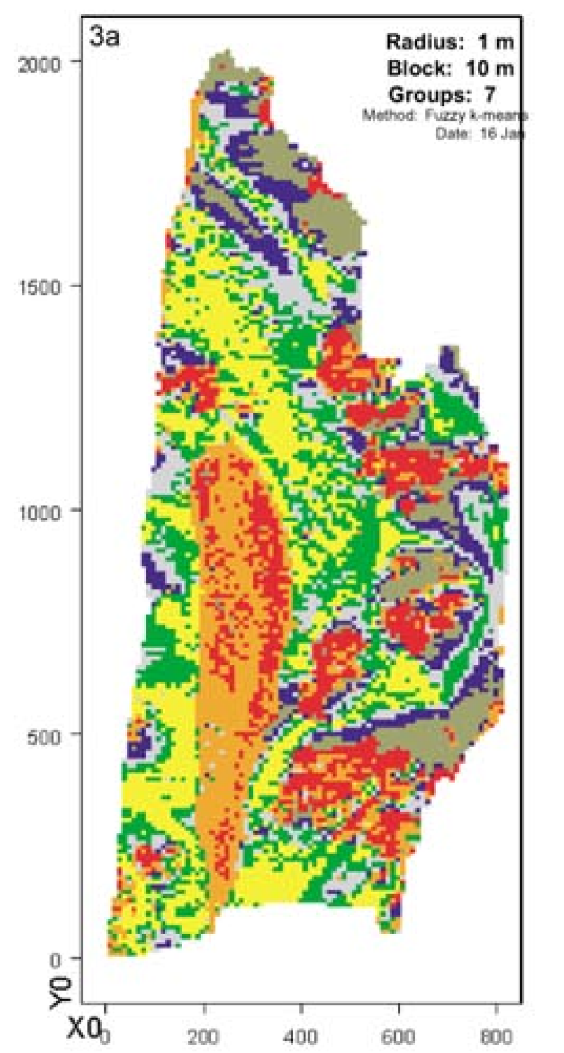


Figure . Segmentation of Piscataqua River mouth bathymetry by local Fourier Histogram (LFH) analysis using coefficients 0 through 3. Mean depth from block removed from coefficient 0, therefore difference from mean depth used to remove mean depth effect from results. LFH's for blocks grouped using fuzzy k-means clustering.
Local FT radius = 1 meter.
LFH block size = 10 by 10 meters.
Classes = 7.
Histogram bin maximum values set automatically using:
(because Variance(coeff[1]) < 1)
histmin[0]=0.5*(SDcoeff[0])
histmax[0]=0.0+0.5*(SDcoeff[0])
histmax[i]=meancoeff[i]+varcoeff[i]
Data: Reson 8125 multibeam sonar, collected by SAIC for NOAA (UNH-JHC) and UNH-CCOM.
LFH analysis: LFH - v 5.3a, 12 Jan. 2002, R. Cutter, UNH-CCOM.
Clustering done using FuzME2 - v 2.1 (c)2000, Australian Centre for Precision Agriculture.

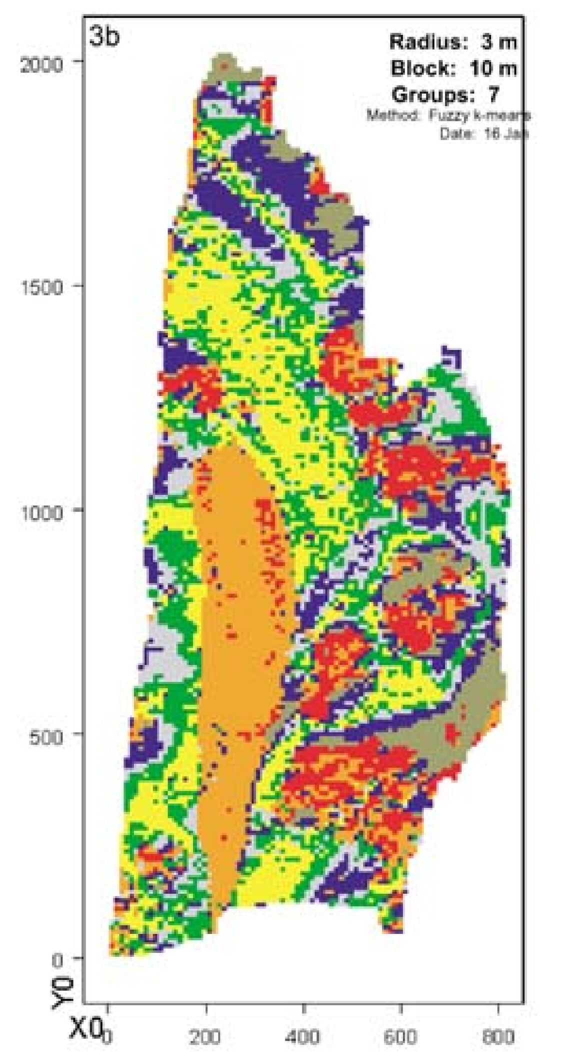


Figure . Segmentation of Piscataqua River mouth bathymetry by local Fourier Histogram (LFH) analysis using coefficients 0 through 3. Mean depth from block removed from coefficient 0, therefore difference from mean depth used to remove mean depth effect from results. LFH's for blocks grouped using fuzzy k-means clustering.
Local FT radius = 3 meters.
LFH block size = 10 by 10 meters.
Classes = 7.
Histogram bin maximum values set automatically using:
(because Variance(coeff[1]) < 1)
histmin[0]=0.5*(SDcoeff[0])
histmax[0]=0.0+0.5*(SDcoeff[0])
histmax[i]=meancoeff[i]+varcoeff[i]
Data: Reson 8125 multibeam sonar, collected by SAIC for NOAA (UNH-JHC) and UNH-CCOM.
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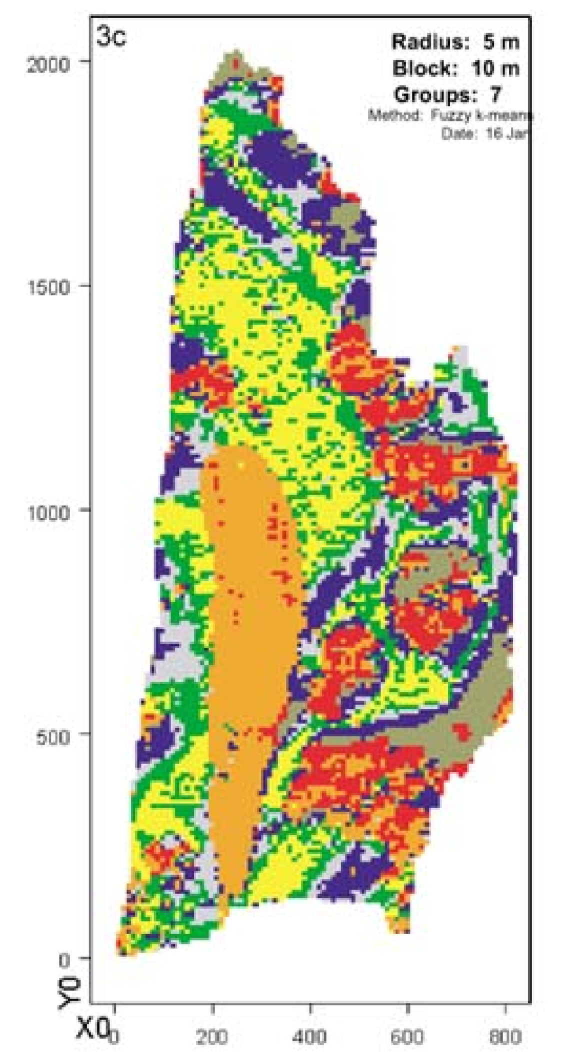


Figure . Segmentation of Piscataqua River mouth bathymetry by local Fourier Histogram (LFH) analysis using coefficients 0 through 3. Mean depth from block removed from coefficient 0, therefore difference from mean depth used to remove mean depth effect from results. LFH's for blocks grouped using fuzzy k-means clustering.
Local FT radius = 5 meters.
LFH block size = 10 by 10 meters.
Classes = 7.
Histogram bin maximum values set automatically using:
(because Variance(coeff[1]) < 1)
histmin[0]=0.5*(SDcoeff[0])
histmax[0]=0.0+0.5*(SDcoeff[0])
histmax[i]=meancoeff[i]+varcoeff[i]
Data: Reson 8125 multibeam sonar, collected by SAIC for NOAA (UNH-JHC) and UNH-CCOM.
LFH analysis: LFH - v 5.3a, 12 Jan. 2002, R. Cutter, UNH-CCOM.
Clustering done using FuzME2 - v 2.1 (c)2000, Australian Centre for Precision Agriculture.

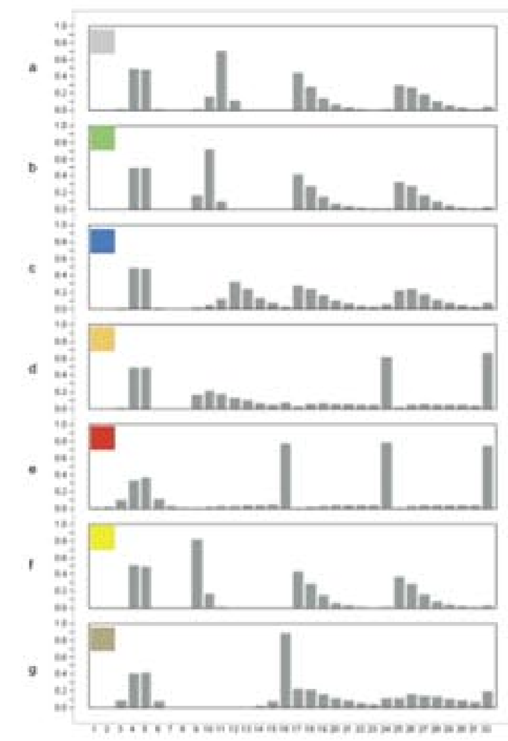


Figure 4. Representative histograms for 7 LFH cluster groups (r=1, b=10). Bins 0-7 represent localFT coefficient 0 - mean, bins 8-15 represent coefficient 1 magnitude (sqrt(re2+im2)), bins 16-23 represent coefficient 2 magnitude, and bins 24-31 represent coefficient 3 magnitude. Clustering was done using fuzzy k-means method (Minasny & McBratney, 2000).

Representative LFH's (Figure 4) were produced using the mean of all LFH's by class. Generating representative LFH's using on apparently correctly classified data provides feature vectors that can then be applied to other data. Thus, these are training features representative of particular geomorphologies, and can be used to directly determine the bottom texture and type for ne data.

The LFH map produced using a 5 m radius was filtered to generate more coherent regions by adopting the majority value from 30 by 30 m blocks as the new cell value (Figure 5). These regions are used as sampling strata.

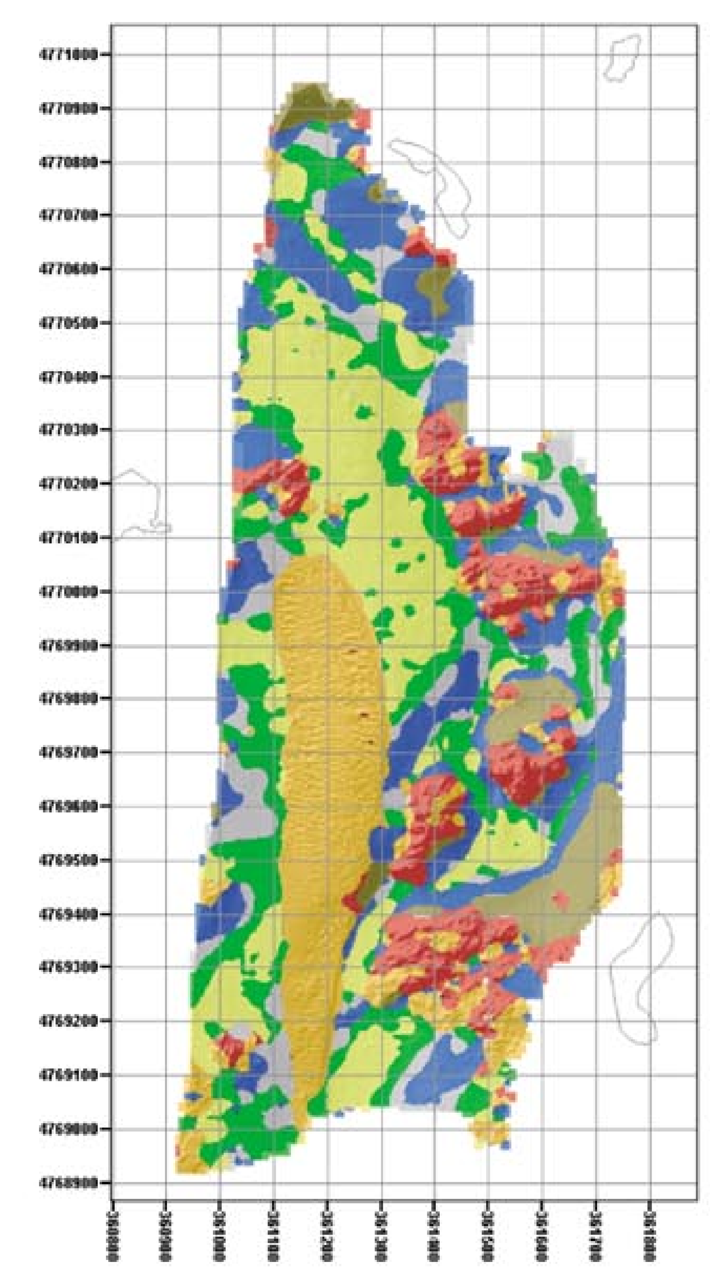
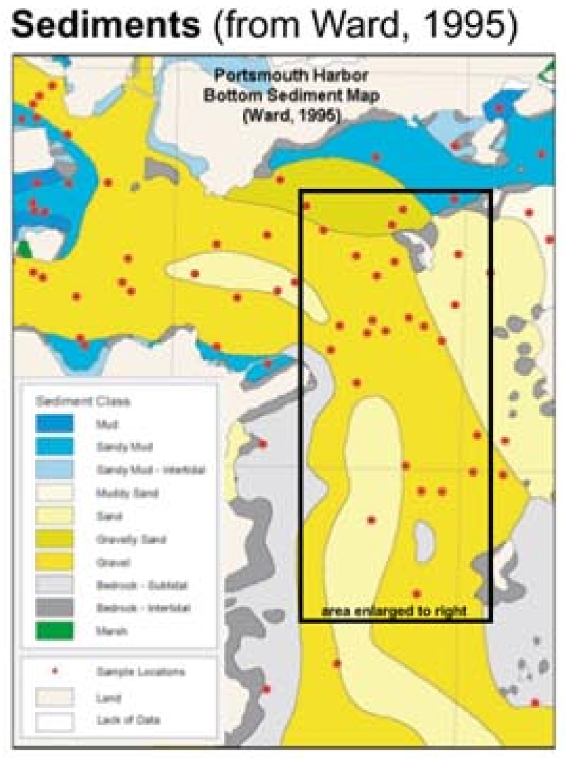


Figure 5. Majority (30 by 30 m block) filtered 5 m radius LFH texture feature map, draped on bathymetry terrain model surface.

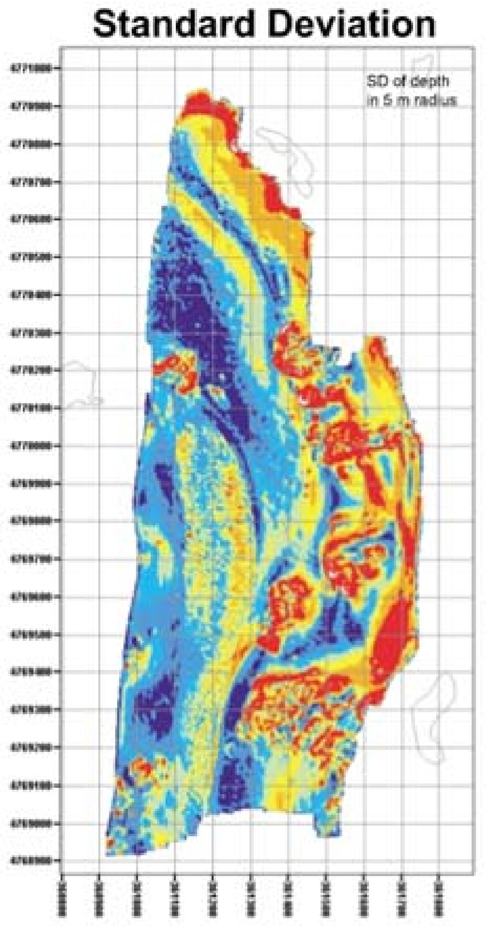
MAP COMPARISONS

Sediments (from Ward, 1995)

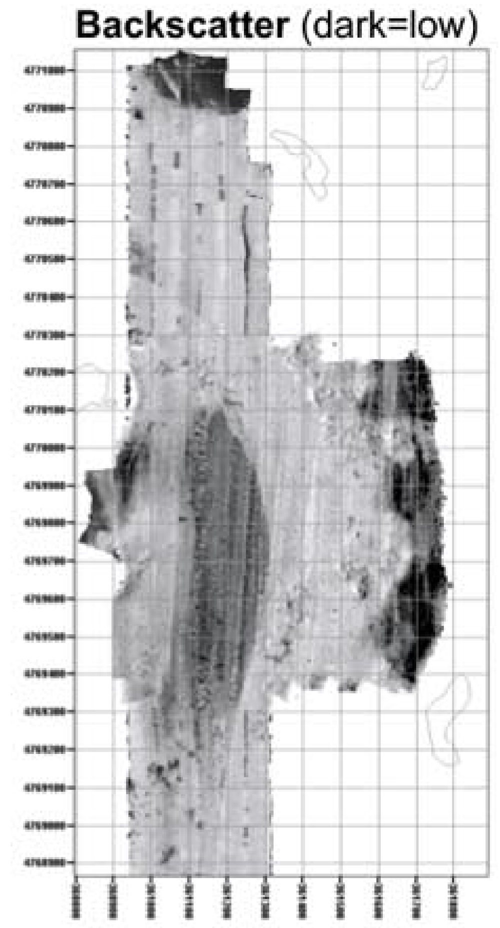


The physical habitat model includes the texture map results, sediment samples, other roughness proxies (SD), acoustic backscatter, and flow regime properties.

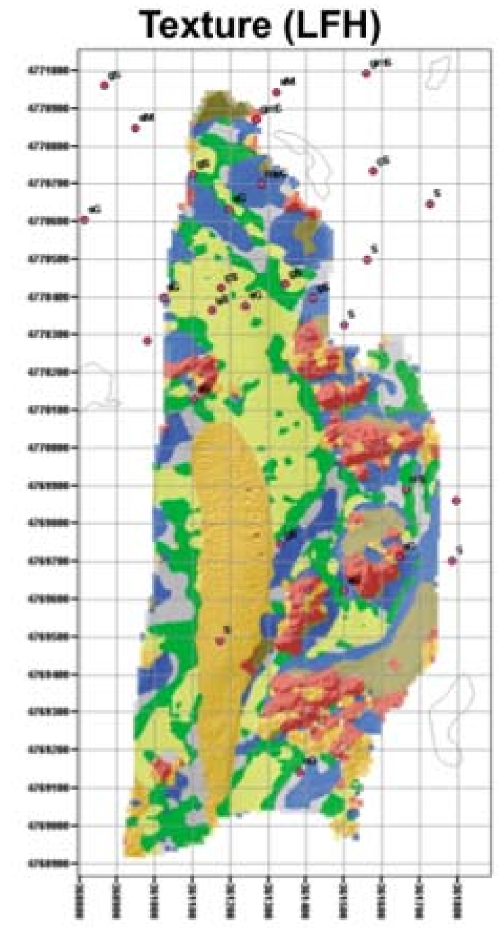
Standard Deviation



Backscatter (dark=low)



Texture (LFH)



SOME ASSOCIATED FAUNA AND SUBSTRATES

Ripples superimposed upon sand waves, mosaiced from infrared video, scale approximately 1 by 4 meters.
Homarus americanus
Henricia spp. (blood star) and the introduced tunicate *Diplosoma listerianum*
Gravelly shelf substrate, laser scales = 5 cm.
Metridium senile (fringed anemone), fish, and tunicates.
Buccinum undatum (waved whelk).
Cancer borealis (rock crab).

Determinations of biological constituents, habitat asscociations, and small-scale seafloor configurations involve optical imagery and direct sampling. Representative megafauna and where observed during reconaissance sampling are shown above.

DISCUSSION

Geomorphological regions were discriminated with high efficiency using LFH analysis. Regions distinguished by LFH analysis were suggestive of substrate and sediment distributions. LFH regions were correlated with relative backscatter intensity and with substrate regions delineated from point samples by Ward (1995). Clearly, LFH regions corresponded to rock outcrops, sand wave field, and gravelly channel regions delineated by Ward (1995) in addition to other bottom textures suggestive of slightly different geomorphologies that were either lumped into broad substrate classes or unsampled. Because of the resolution of the dataset, discrimination of region types by LFH was done to much finer scales. Such is the strength of multibeam-derived bathymetry data.

The spatial scales of feature variation was important and did cause some apparent misclassifications, the most apparent were the areas within the rock regions that were classified the same as the sand wave field. The geometry of the rocks and sand waves was similar enough in those cases to inhibit distinction by LFH analysis. However, there may be a physical and biological basis for the apparent misclassifications: sediments may be accumulating in the depressions among rocks, or soft-bodied animals and plants may cover the rocks, thereby affecting the acoustic returns. Those areas must be examined directly to determine their character. We sought an automated, objective method for delineating physical benthic habitats that can be used to model biological habitats, without sampling the biology, but depending upon organism-substrate associations. LFH texture feature classification served that purpose, and was automated, except for the choices of number of classes and texture spatial scale. The appropriate scales of application of LFH should be determinable by optimization procedures. In addition, alternative texture analyses and segmentation techniques are to be compared.

REFERENCES

Minasny, B., McBratney, A.B., 2000. FuzME version 2.1,Australian Centre for Precision Agriculture,The University of Sydney, NSW 2006. (http://www.usyd.edu.au/su/agric/acpa).

Swift, M. R., Fredriksson, D. W., Celikkol, B. 1996. Structure of an axial convergence zone from acoustic Doppler current profiler measurements. Estuarine, Coastal and Shelf Science, 43, 109-122.

Ward, L. W. 1995. Portsmouth Harbor bottom sediment map.

Zhou, F., Feng, J., Shi, Q. 2001. Texture feature based on local Fourier transform. ICIP conference proceedings. IEEE 0-7803-6725-1/01.