Ecosystem approaches to aquatic health assessment: linking subtidal habitat quality, shoreline condition and estuarine fish communities

Final Report to NOAA/ NOAA Chesapeake Bay Office

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Abstract

In the Chesapeake Bay, there is currently no comprehensive assessment of aquatic habitat heterogeneity or understanding of the effects of multiple stressors on the viability of these habitats. To assess the use of side-scan sonar technology with specially designed classification software, QTC SIDEVIEW developed by Quester Tangent Corporation as a tool to define subtidal nearshore habitat, two representative watersheds of the Chesapeake Bay were surveyed. Relationships between subtidal habitat and shoreline condition as well as linkages of habitat condition to fish community indices were assessed. Side-scan technology had the ability to image habitat at a resolution of less than 1 meter. Automated seabed classification shows promise as a delineation tool for broad seabed habitat classes. In the James River, relationships between shoreline condition and fish community indices were observed, while no association with bottom type was reflected in the data possibly due to the limited availability of vertical structure in this system. Observed relationships and habitat mapping protocols have the potential to be extrapolated to additional watersheds in the coastal plain, and become tools for future development of habitat indices and ecosystem management.

Introduction

Coastal plain estuaries have become progressively more degraded due to anthropogenic stressors, evident in increases of hypoxic events, algal blooms and biodiversity losses. Given the proximity of nearshore habitats to upland activities, these ecosystems may be particularly sensitive to changes in land use and developmental pressures. Nearshore, shallow-water habitat provides critical nursery and spawning areas, protection from predators, and foraging opportunities for numerous fish species. The heterogeneity and complexity of the habitat is a driving influence on fish diversity and abundance (Angermeier and Karr 1984; Eadie and Keast 1984; Everett and Ruiz 1993; Hoss and Thayer 1993). This critical resource area is often under intense and increasing pressure from a variety of uses and users and generally exists without an operative comprehensive management plan. In Chesapeake Bay, there is currently no comprehensive assessment of aquatic habitat heterogeneity or understanding of the effects of multiple stressors on the viability of these habitats.

Throughout the coastal plain of Virginia, the conversion of natural shoreline to stabilization structures is occurring at a rapid pace. The cumulative impact of shoreline armoring has been demonstrated to drastically reduce available habitat structure and associated fish communities (Beauchamp et al. 1994; Jennings et al. 1999; Bilkovic et al. 2005). For example, over the past 10 years in Virginia, it is estimated that 342 km of tidal shoreline have been altered with riprap (stone revetments) and retaining walls (bulkheads) (Center for Coastal Resources Management (CCRM), Tidal Wetlands Impacts data [www.vims.edu/rmap/wetlands]).

For the past four years, Virginia Institute of Marine Science (VIMS) researchers, in association with the Atlantic Slope Consortium (affiliated with US Environmental Protection Agency's Science to Achieve Results (STAR) Estuarine and Great Lakes (EaGLe) program), have conducted research throughout the Chesapeake Bay to develop indicators of aquatic ecosystem health. A component of this research has examined relationships between habitat condition, including subtidal habitat abundance and shoreline features, and nearshore fish community indices, which consisted of several metrics designed to describe the composition, structure and function of assemblages (Bilkovic et al. 2005). Biotic responses to intense watershed and riparian alterations in freshwater, and to a lesser extent in estuarine systems, have typically been characterized by lower species diversity, less trophic complexity, altered food webs, altered community composition and reduced habitat heterogeneity (Angermeier and Karr 1984; Howarth et al. 1991; Schlosser 1991; Everett and Ruiz 1993; Hoss and Thayer 1993; Roth el al. 1996). In support, we observed evidence of fish community structural and functional changes in relation to extreme habitat alterations.

As an extension of previous work, we assessed the ability of acoustic survey technology to quantify spatial diversity of subtidal nearshore habitat in the James and Piankatank rivers. A further goal of this research was to determine relationships between subtidal habitat and shoreline condition (from CCRM shoreline inventory surveys) as well as linkages of habitat condition to fish community indices. This work enabled us to determine deficiencies and refine protocols for quantitatively defining subtidal habitat, as well as provide further support of habitat linkages with nearshore fish communities.

The delineation of aquatic habitat was accomplished with side-scan sonar technology (Sea Scan Marine Sonics, 600 kHz). This high-resolution remote sensing system acquires imagery and data for habitat characterization of the surface of the seafloor, particularly, physical structure (e.g. shellfish beds, submerged aquatic vegetation) (Figure 1). This allows for the estimation of area covered by subtidal habitat, and is particularly useful in the assessment of environmental quality of aquatic resources, and may become a critical component in the quantification of the spatial extent of fish habitat resources (e.g. Yoklavich et al. 2000; NOAA 2001; Woodruff et al. 2001).

Project Objectives

To test the use of side-scan sonar technology with specially designed classification software, QTC SIDEVIEW developed by Quester Tangent Corporation, as a tool to define subtidal nearshore habitat in two representative watersheds of the Chesapeake Bay. Relationships between subtidal habitat and shoreline condition as well as linkages of habitat condition to fish community indices were assessed. Observed relationships and habitat mapping protocols will have the potential to be extrapolated to additional watersheds in the coastal plain, and become tools for future development of habitat indices and ecosystem management. *This document has been subdivided into two focal research topics: Benthic Habitat Mapping and Fish Community Habitat Associations.*

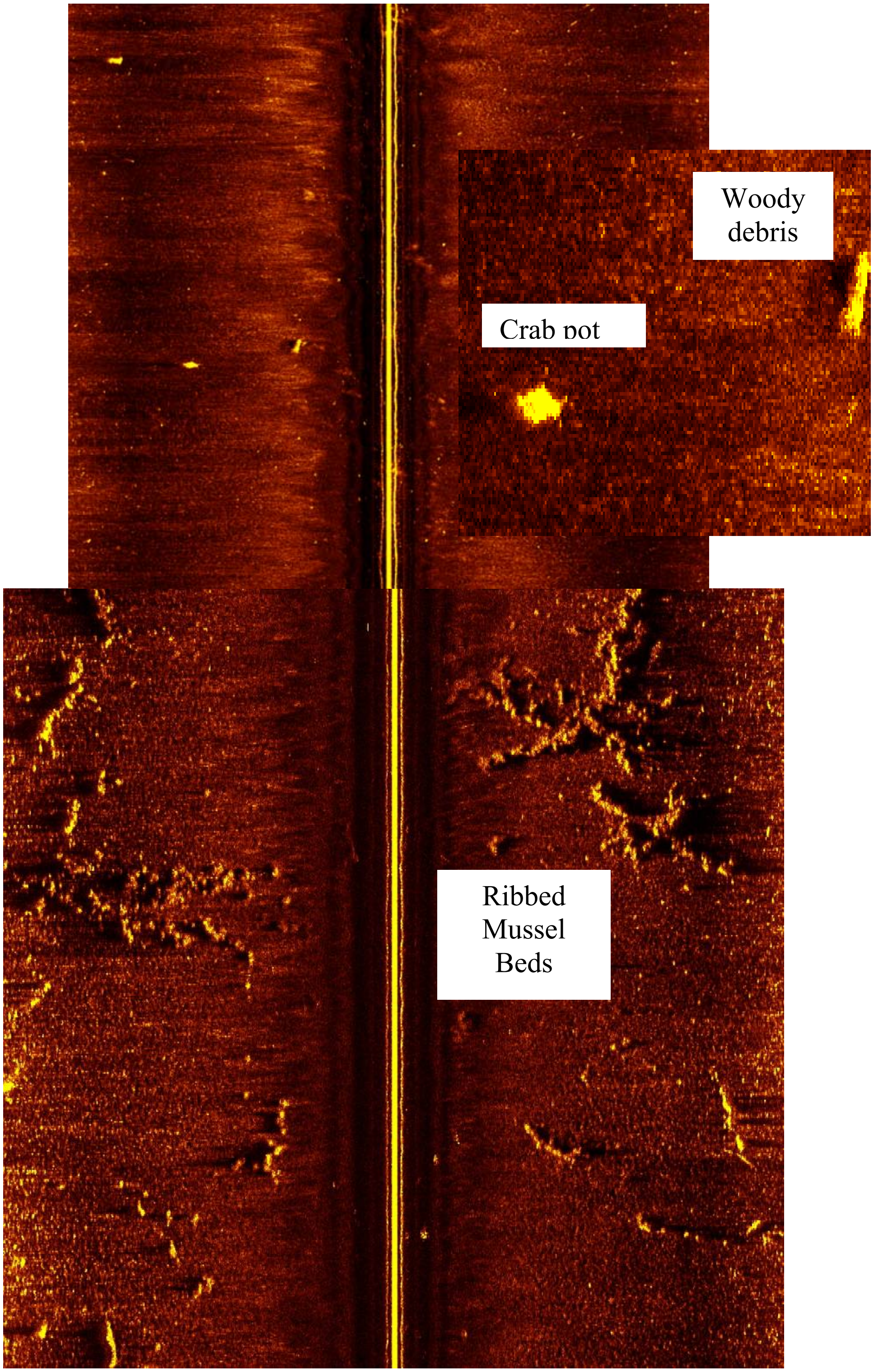

Figure 1. Examples of side-scan sonar images from Marine Sonics Sea Scan (600 kHz).

I. Benthic Habitat Mapping

Background

Interest in the classification of aquatic habitat and the assessment of critical habitat linkages to ecosystem components has increased as anthropogenic stressors in nearshore coastal systems have intensified effectively decoupling ecosystem functions. This is exemplified in actions by governing agencies to identify and protect essential habitat, such as ‘essential fish habitat’ (Benaka 1999). Identification of essential habitat requires an array of tools and strategies, especially appealing are those with the ability for broad-scale mapping. Ecological application of remote sensing and acoustic technologies to benthic habitats has increased in use and scope in recent times, ranging from the identification of critical habitat for specific species to general resource mapping (Greenstreet et al. 1997; Cutter and Diaz. 1998; Moore et al. 2000; Diaz et al. 2003; Kenny et al. 2003; Smith et al. 2003; Hewitt et al. 2004). Side-scan sonar and swath bathymetry have become notably effective tools in many seabed mapping applications. The challenge lies in the marrying of ecologically relevant benthic habitat classifications with seabed delineations (Diaz et al 2004).

Methods

Side Scan Survey

Side scan uses sound echoes to produce an image. The pulses transmitted from the towfish are sent in a wide angular pattern down to the bottom, and the echoes are received back in fractions of a second. The shape of an echo trace is influenced by the seabed providing an acoustic signature. The intensity or strength of the returning acoustic signal is controlled primarily by the slope and substance of the seafloor. A stronger return is received if the seafloor slopes toward the instrument, or if the seabed consists of dense sediment (e.g. bare rock). The strength of the return is much lower if the seafloor is covered by soft sediment (e.g. mud or fine sand). Features that protrude above the surrounding seafloor will cast acoustic shadows. Variations in shadow length and size can help determine what the identity of the structure or object. Sonar units of high frequency (e.g. 600 kHz) are used to assess surficial conditions of the seafloor and do not penetrate to depth. While higher frequency systems (300 kHz and above) can provide high-resolution images, the range coverage is reduced.

The nearshore benthic habitat of the James and Piankatank rivers was surveyed with a bow-mounted Marine Sonics Sea Scan PC 600 kHz unit appropriate for shallow-water conditions (< 5m depth). An external JRC D/GPS system (accuracy 3-5m) was used to acquire ship position and control line planning. The Sea Scan side-scan sonar has the ability to map swath transects of subtidal habitat parallel to the shore, and was towed to collect real-time, geo-referenced, riverbed mosaic data with overlapping edges matched to form a continuous profile of the bottom. The area was surveyed in 40 m swaths following shorelines. Approximately 127 kilometers were surveyed on the North and South shores of the James River from the James River Bridge (Route 17) upriver to the Chickahominy River, and 47 km on the North and South shores of the Piankatank River from the mouth of the river at Fishing Bay upriver to Freeport. The approximate survey areas for the James and Piankatank rivers were 6.7 km^2 and 1.9 km^2, respectively. Geo-referenced profiles were then converted to Geographic Information Systems (GIS) coverages for the depiction of areas of classified habitats. The classification of bottom type is based on an unsupervised classification of the imagery signatures. Combined with ground-truth sampling this enables separation of major classes of bottom type (e.g. sand, submerged aquatic vegetation (SAV), coarse debris, etc.).

Post-processing of acoustic images with QTC SIDEVIEW

Image-based seabed classification is the organization of bottom types (seabeds, lake beds, river beds) into discrete units based on a characteristic acoustic response. Seabed classification can be completed in a variety of ways, including with manual inspection of raw images and automated classification software. Automated classification characterizes acoustic diversity not the physical properties of the seabed; therefore, ground-truthing to determine precise associations of acoustic signals with benthic habitat is essential.

QTC SIDEVIEW is an integrated software package developed by Quester Tangent^{TM} that classifies sediments using the statistical properties of backscatter images. This package includes tools to perform quality assurance, analysis and classification. Raw sonar images were processed with QTC SIDEVIEW to assess the ability of automation classification software to interpret side scan sonar acoustic signals into bottom types. The processing steps outlined in Figure 2 include compensation of raw images, generation of continuous rectangles to overlay on images, generation and clustering of image descriptions, and selection and mapping of optimal acoustic signal classes (further details below and in QTC SIDEVIEW User's Manual and Reference, 2004; http://www.questertangent.com/manuals/QTCSIDEVIEWManual.pdf). The unsupervised classification output from QTC SIDEVIEW was ground-truthed for each designated acoustic class with on-site sediment-probes, sediment samples and visual assessments.

Specific processing steps completed in QTC SIDEVIEW for both the James and Piankatank rivers were

1) Raw acoustic images were downloaded into QTC *SIDEVIEW*
2) Images underwent texture analysis and compensation for quality control, e.g. a mask may be used to exclude regions of poor quality from further processing
3) Continuous rectangles (129 X 33 pings) were generated and overlaid onto the images. Rectangle sizes were selected to achieve high resolution (~5-9m^2 of area/rectangle) and a manageable processing time (~4 days per river) (Figure 3)
4) For each rectangle, 135 full feature vectors (image descriptors) were generated from the backscatter intensities using a suite of algorithms.
5) The features were then classified in two steps: 1) principal components analysis (PCA) over the entire dataset with the first three principal components (PCs) to be applied in subsequent clustering; and 2) cluster analyses using a Simulated Annealing K-means algorithm in order to find the optimal number of classes within the three-dimensional space of the three PCs.
6) During the cluster analysis, a selected range of possible acoustic signal classes (e.g. 2 to 20) were run through five iterations of clustering to determine the optimum number of acoustic signal classes described in the dataset. QTC SIDEVIEW designates the optimum number of classes based on the lowest score (tightest clusters). Other numbers of classes with similar low scores are also considered candidates.
7) For the selected optimum number of classes, bottom type seabed data were generated. This data include for each rectangle, it's assigned one class based on the confidence that a

record is in the correct class, and the probability density of each class (determined by the distance a point is to the centroid of a class cluster

8) Bottom type seabed data (XYZ file) were exported from SIDEVIEW to GIS (e.g. ARCMAP) for spatial representation. Each rectangle was represented by an XYZ data line that was imported as points and converted into shapefiles.

Seabed data may also be interpolated to fill in data gaps in the survey. We utilized the software program CLAMS (Quester Tangent^{TM}) which assigns intelligent color to acoustic classes—meaning similar colors are more closely related acoustically. The user selects the input parameters for the search radius, search size and nodal size which may lead to variable outputs. To retain data resolution the search parameters chosen for interpolation were a node spacing of 4m, a search radius of 10m and a search size of 8m.

During the automated classification process, there are several decision branches that may dictate the final outcome and account for variance in acoustic signal classification (Figure 2). For instance,

- Selection of size of rectangles that divide the image for classification
- Selection of final number of classes from cluster analysis to describe acoustic signals
- Interpolation: variation in node size, search radius and search area

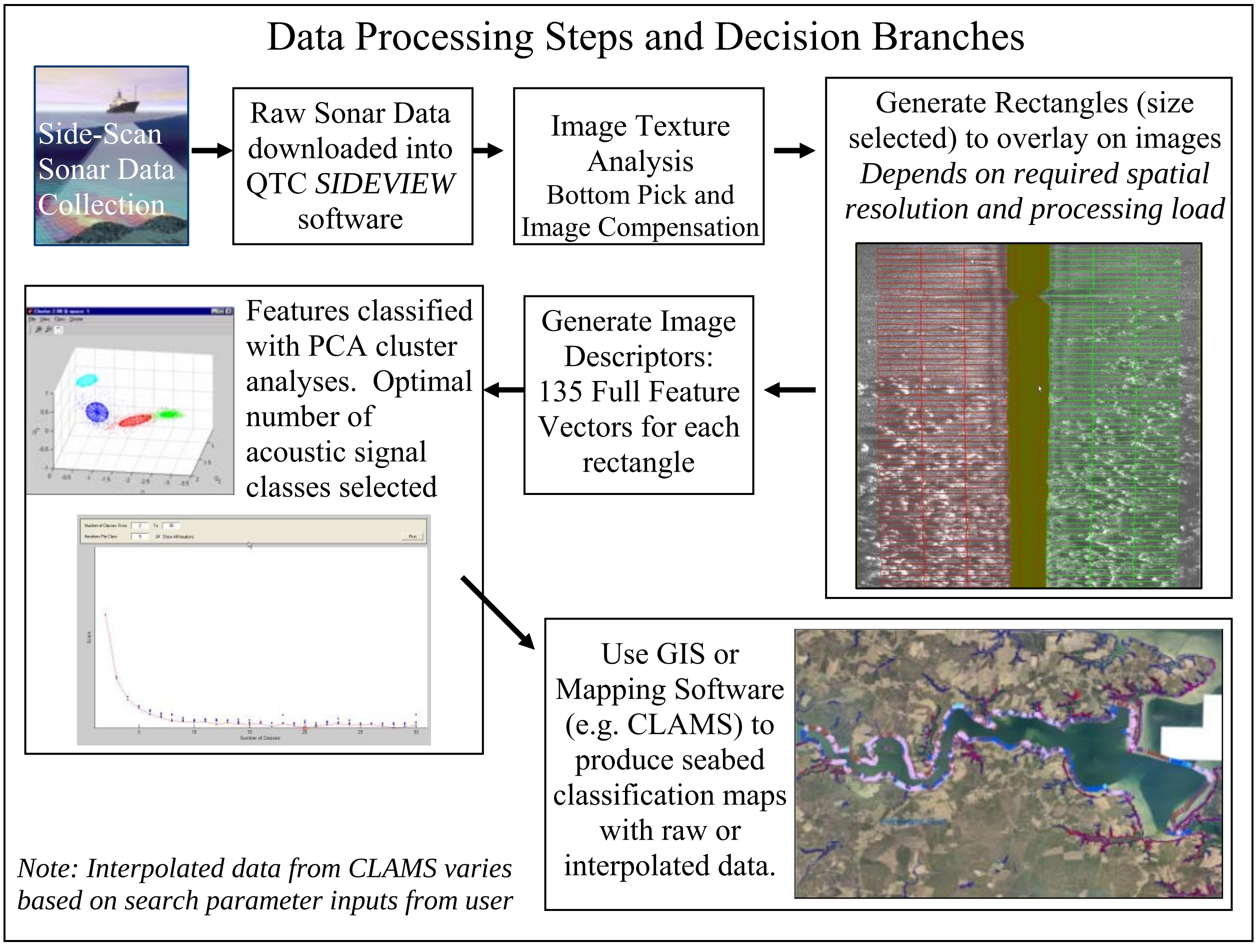

Figure 2. Data processing steps and decision branches for classification of acoustic sonar images in QTC SIDEVIEW and CLAMS.

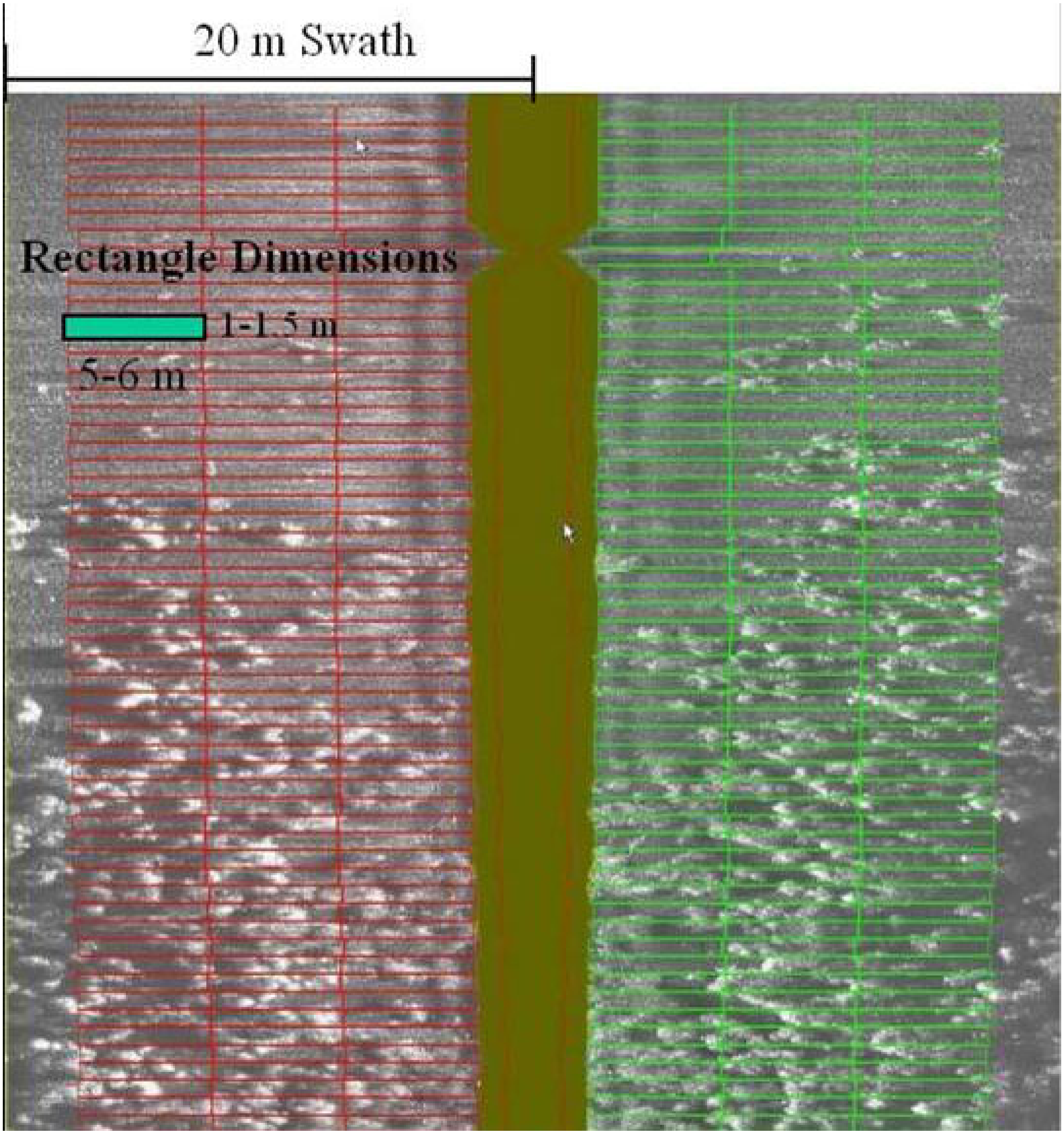

Figure 3. Raw sonar image with generated rectangles from QTC SIDEVIEW overlaid. Each rectangle is 129 by 33 pings which was approximately 5-6 m in width (across track) by 1 – 1.5 m in height (along track) for the James and Piankatank river surveys. Ping size is influenced by vessel speed only because swath size was kept constant throughout the survey.

Manual Processing

To verify aspects of the QTC SIDEVIEW classification system, the Piankatank River acoustic images were visually inspected and discernable subtidal structures were delineated. Marine Sonic raw MST image files were converted in SONARWEB to fine resolution geo-referenced TIFF (Tagged Image File Format) files (pixel size 0.01m) for display in ARCGIS. The fine resolution allowed for the identification of individual patches of habitat (e.g. SAV). For the James River, images could only be combined at a lower resolution (pixel size 0.5m) due to processing limitations of the large file sizes of images obtained in this system. In ARCMAP images were scanned for obvious structural habitat based on the presence of hard returns with shadows behind the object(s). For example, using the color scheme *Sonarweb Gray*, a hard return appears black or dark gray and the shadows are white. Pilings appear as a black dot with a narrow white line behind them. In Figure 4, the right side of the image is light gray with no shadows (sand) and the left side of the image contains many dark returns with white shadows (delineated as SAV). Polygons of structural habitat were created in ARCMAP and auxiliary datasets were overlaid for verification of habitat where possible (Aerial Imagery © 2002 Commonwealth of Virginia; 2004 Chesapeake Bay SAV Coverage). Manual delineations were then compared with interpolated multivariate software classification (QTC SIDEVIEW; with software update).

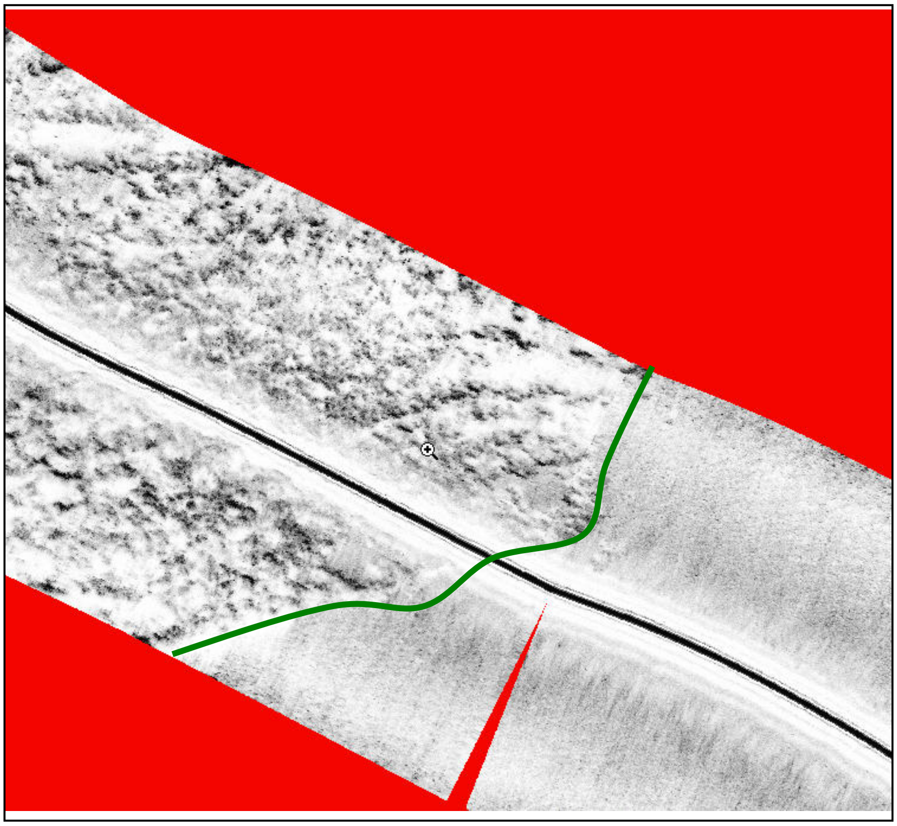

Figure 4. Side-scan sonar image from the Piankatank River. The upper left side of the image depicts SAV patches as numerous dark returns, while the lower right section of the image is shadowless reflecting no vertical structure or hard seafloor.

GIS Products

Acoustic survey data (for both tributaries) were merged to create a full-coverage mosaic that was saved as geo-referenced TIFF files for use in ARCGIS for display, query, and analyses. An ARCMAP project for each tributary was generated to house the numerous data layers, which include acoustic survey data as well as auxiliary support data used in analyses. Each coverage or shapefile has associated digital metadata (see enclosed DVDs entitled Lower James River Nearshore Seabed Classification; Piankatank River Nearshore Seabed Classification; Lower James River Original Acoustic Images (MST format); Piankatank River Original Acoustic Images (MST format)). Digital products on DVD include:

1) Acoustic image mosaics created with SONAR WEB and exported as GEOTIFFS
2) Acoustic seabed classification data generated in QTC SIDEVIEW and interpolated in CLAMS and imported as Shapefiles (points). Two classifications per river are represented in each project: a) initial seabed classification utilized for ground-truth surveys; and b) a seabed classification used for interpolation in CLAMS which was generated after a software adjustment to automate nadir removal (received in September 2005)
3) Shoreline structure continuous linear coverage
4) National Land Cover Dataset (NLCD) coverage for Lower James River
5) Fish Survey Locations (James River) with associated fish community metrics, indices and auxiliary data
6) Aerial County Imagery (Piankatank River)
7) Hydrology and watershed boundaries
8) Original digital acoustic data in MST file format for each river (links to download Marine Sonics Sea Scan Application are included for viewing of MST files)

James River Benthic Habitat Mapping

Benthic Mapping Survey

The benthic mapping survey of the nearshore James River was completed in 5 days, April 18, 19, 20, May 10 and May 11, 2005. The area was surveyed in 40 m swaths following shorelines. Approximately 127 kilometers were surveyed on the North and South shores of the James River from the James River Bridge (Route 17) upriver to the Chickahominy River, covering an area of approximately 6.7 km^2 (Figure 5)

Post-processing of acoustic images with QTC SIDEVIEW

In QTC SIDEVIEW, raw sonar images were compensated and overlaid with medium-sized rectangles (129 X 33 pings) which allowed for high resolution (~5-9m^2 of area/rectangle) with a manageable processing time (4 days) (Figure 3). The next smaller size of rectangles (65 X 17 pings) allowed for a finer resolution, but processing time was in excess of 10 days and hardware/software interface problems resulted. In the case of the James River survey, 11 acoustic classes were determined by the software to be optimal. Bottom type seabed data (XYZ file) was exported from SIDEVIEW to a GIS software program (e.g. ARCMAP) for spatial representation and selection of ground-truth locations.

Ground-Truth Protocol

Acoustic classes were georeferenced and random locations were selected from each class for verification of unique signals as a result of unique bottom types. For each class, 30 sites are randomly selected for ground-truthing. In the case of Class 2 there were only 14 points associated, thus all 14 were targets for ground-truthing protocols (Table 1). Ground-truthing general protocols for the James River consisted of 1) assessing bottom type at each site with three sediment-probes taken within a 5 m circle of the coordinates, and 2) replicate benthic grabs at every sixth site (2 per site) for grain-size analyses. A total of five sites per class will have replicate benthic grabs taken, with the exception of Class 2 at which grabs were taken at every second site for a total of five samples. Sediment-probes were conducted with a handheld PVC rod with an adaptive piece at the end for sampling the top 7-8 centimeters of sediment. Descriptions of the top and bottom layers of the sediment plug were recorded independently.

Information on bottom type recorded for each site included 1) the type and amount of sediment by layer (top and bottom) with auxiliary descriptors (e.g. poorly sorted); 2) the presence and estimated amount of biogenic accumulations (shell, shell hash, live or dead shell, SAV etc) structure; and 3) A description of the sediment surface: rippled, or smooth including a qualitative roughness measure: hard versus soft (see Table 2 for more detail).

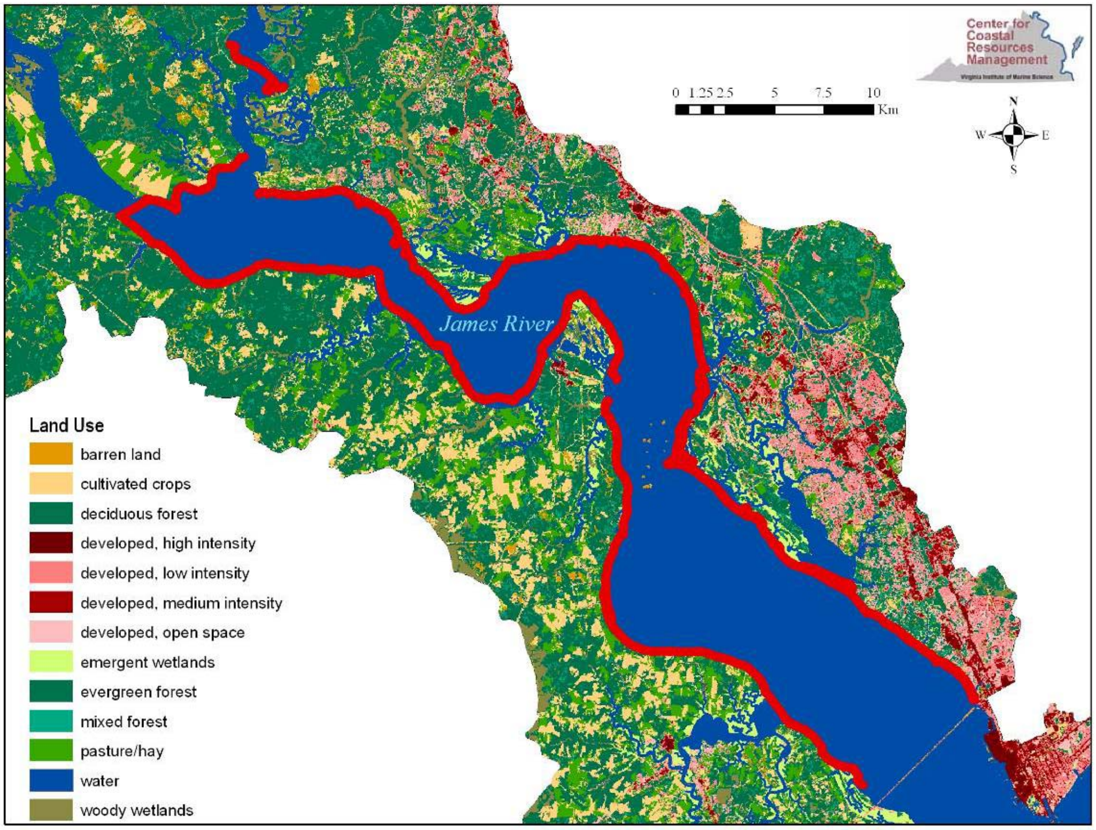

Figure 5. Trackline of sidescan sonar acoustic survey in the Lower James River. Twenty meter swaths were surveyed on either side of the centerline depicted. Depicted digital data are available on the DVD: Lower James River Nearshore Seabed Classification.

Table 1. Seabed classification of the James River with QTC SIDEVIEW with estimated percentages of survey area and assigned number of ground-truth sites for each class. Each site represents a classified rectangle (129 x 33 pings) of bottom habitat approximately 5-6 m in width (across track) and 1-1.5 m in height (along track) laid horizontally across the swath (5-9m^2 of area/rectangle). Estimates of total area classified range from 1.3 to 2.4 km^2.

Class	Total Sites	% of Survey Area	# of Ground-truth Sites
1	1,404	0.53	30
2	14	0.01	14
3	6,379	2.40	30
4	10,768	4.05	30
5	37,653	14.18	30
6	102,208	38.49	30
7	1,087	0.41	30
8	46,533	17.52	30
9	27,480	10.35	30
10	2,663	1.00	30
11	29,389	11.07	30
TOTAL	265,578	100	314

Table 2. Benthic habitat categories and codes for ground-truth protocols (probes and visual assessments).

Sediment Type or Benthic Descriptor	**Code**
Gravel	G
Sand-Pure (no shell etc)	S
Fine-grained sand	FS
Coarse-grained sand	CS
Medium-grained sand	MS
Variously grained sand	VS
Silt	SILT
Clay	CLAY
Silty and clayey silt	SCLS
Silty sand	SIS
Sandy clay	SCL
Peat	PEAT
Pebbles	PEB
Rocks	ROCK
Shell (shell hash or whole)	SHELL
Vegetated sand (sand with grass or vegetation)	VegS
Hard sand--sand with cover of dead or live shells	HS
Organic matter	ORG
Live Clams, Oyster	CLAMS, OYS
Roots or rootmat	ROOT
Vegetation	VEG
Poorly-sorted	PS
Well-sorted	WS
Amount Categories	**Code**
Abundant (> 50%)	Ab
Moderate (20-50%)	Mod
Some (10-20%)	Some
Little (2-10%)	Lit
Few or sparse (< 1%)	Few
None (0%)	No

Results

Ground-truth surveys were conducted on the James River for eight days, 21-30 June, 2005. Of the potential 314 ground-truth sites, 24 were inaccessible due to depth, and 13 were associated with steep shorelines or other extreme hard signals such as shipwrecks (predominately observed for Class 10).

One acoustic class (Class 4) was predominately associated with oyster or mussel beds, and was considered the criteria for designating a region as hard bottom. Other classes with high (>50) percentages of ground-truth sites designated as hard (presence of shell, shell hash, vegetation, gravel, cobble or rock) were classes 5 and 9. These classes were often found in combination with Class 4 and typically consisted of shell hash (the surrounding region of the oyster reef or mussel bed). Classes predominately associated with featureless bottoms (soft) were 3, 6, 7, and 8. Anomalous classes removed based on ground-truth surveys included ones that were: rare (1, 2, and 7), channel associated or depth related (11), or associated with extreme hard signals such as ‘end of file’, or steep shoreline (Class 10) (Table 1; Figure 6).

Fine distinctions in sediment type (e.g. sand versus silt) were not clearly defined acoustically due to inherent errors in GPS location capabilities, differences in acoustic signal due to depth variations, indistinct bottom types, and limitations in the side-scan sonar unit (600kHz reflects surficial seabed conditions only). Additionally, two broad benthic habitat classifications were considered ecologically appropriate for associations with fish communities in the James River: featureless bottom (Soft) and structural habitat (Hard) (e.g. reef, vegetation). Therefore, we combined and placed acoustic classes into two major categories: Hard and Soft. Hard bottom was defined to include classes associated with structure such as oyster or mussel beds, and Soft bottom encompassed classes associated with structureless benthic habitat, typically sand and/or silt sediments. For the majority of the area surveyed on the Lower James, benthic habitat was classified as soft (featureless), approximately 29% of the area was classed as hard (Table 3).

Data used for interpolation in QTC CLAMS differed from the original classification (Shapefile: James Initial Seabed Classification) used in ground-truth surveys because a new software adjustment (patch) was obtained from Quester Tangent, in September 2005, after the surveys were completed. The update automated the procedure to remove the nadir from the images prior to classification. Previously, this was accomplished through a time-intensive manual inspection of individual images. Differences between the two procedures resulted in the area of the nadir removed not being consistent. Therefore, the assigned class numbers in the two shapefiles (James Initial Seabed Classification; James Interpolated Seabed Classification) will not coincide (numbers are assigned arbitrarily during the process). Additionally, in the initial classification, clustering indicated that 11 classes were optimal; this number was used for ground-truthing. However, ground-truth surveys indicated that the described optimal number of acoustic classes did not match the actual limited number of seabed types in the James. Therefore, the lowest possible number of classes that displayed similar low scores (tight clusters) in clustering was used for subsequent interpolation (6 classes) to best reflect observed conditions.

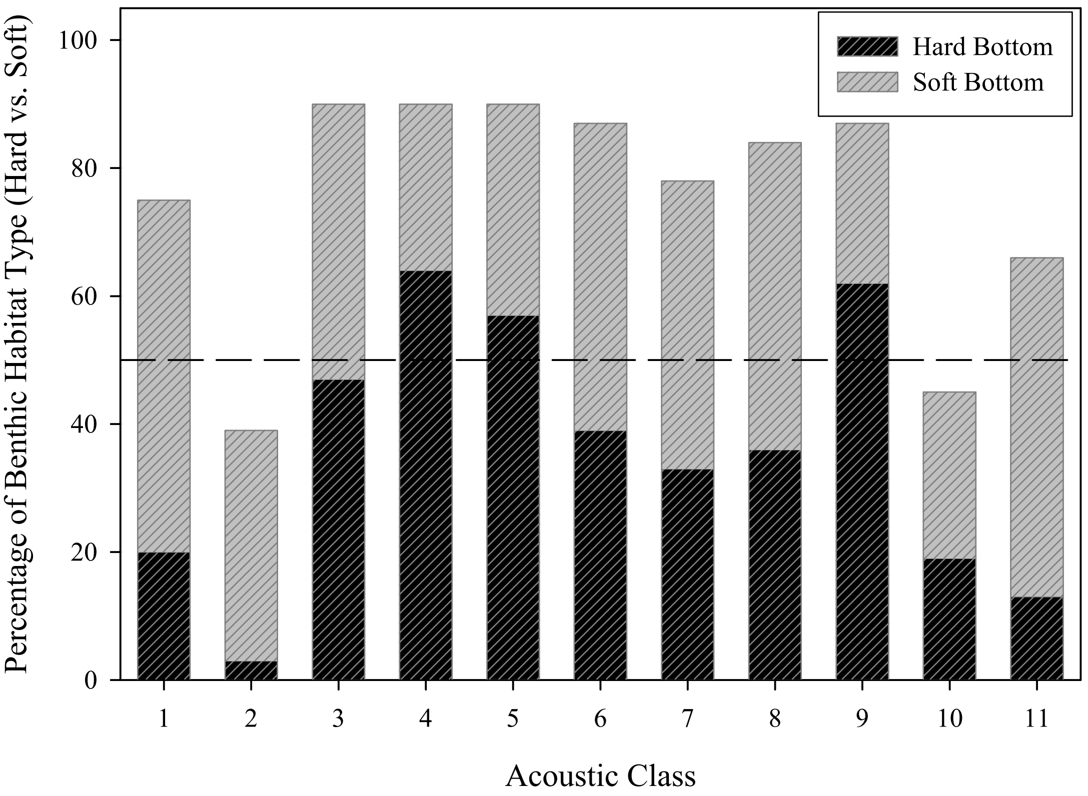

Figure 6. Percentage of benthic habitat categorized as hard or soft bottom based on ground-truth surveys for each acoustic class derived in seabed classification processing with QTC SIDEVIEW. Hard = structural benthic habitat, e.g. mussel beds; Soft = featureless benthic habitat (sand, mud or silt).

Table 3. Broadly categorized acoustic classes utilized in fish survey site selection. Hard = structural benthic habitat, e.g. mussel beds; Soft = featureless benthic habitat (sand, mud or silt). Rare and anomalous acoustic classes were removed.

Class	Total Sites	% of Survey Area	Designated Category
3	6,379	2.40	Soft
4	10,768	4.05	Hard
5	37,653	14.18	Hard
6	102,208	38.49	Soft
8	46,533	17.52	Soft
9	27,480	10.35	Hard
TOTAL	231,021	87	

Summary

In general, the Lower James River nearshore consisted of soft featureless benthic habitat (typically sand and/or silt). Limited subtidal structure was present and included mussel beds and oyster shell, with submerged aquatic vegetation notably absent in survey images. Interpolated data indicated that six classes described the acoustic signatures adequately, and that broad-scale differences in habitat were observed between the lower North and South shores of the James River (DVD-Lower James River Nearshore Seabed Classification). Deficiencies in GPS accuracies, and side-scan sonar penetration capabilities limited the ability to associated specific habitat classes with acoustic signatures. However, with modification, side-scan imaging in combination with automated seabed classification show promise as tools to elucidate patterns in essential habitat.

Application of Acoustic Benthic Mapping Protocols to the Piankatank River

Benthic Mapping Survey

To examine the transferability of benthic mapping survey protocols after refinement based on the test case of the Lower James River, the Piankatank River was surveyed. Benthic habitat was classified both automatically (QTC SIDEVIEW) and manually (visually examination of sonar images) and classification were compared. The benthic mapping survey of the nearshore Piankatank River was completed in 3 days, June 1, 8 and 9, 2005. The river was surveyed in 40 m swaths following shorelines. Approximately 47 kilometers were on the North and South shores of the Piankatank River from the mouth of the river at Fishing Bay upriver to Freeport covering an approximate 1.9 km^2 area (Figures 7 and 8).

Post-processing of acoustic images with QTC SIDEVIEW

In SIDEVIEW, the raw sonar images were compensated and overlaid with medium-sized rectangles (129 X 33 pings) which allowed for high resolution (~5-9m^2 of area/rectangle) with a manageable processing time (3 days). In the case of the Piankatank River survey, 15 acoustic classes were determined by the software to be optimal. However, based on the results of the James River survey and knowledge of the homogenous nature of coastal plain estuarine tributary benthic habitats, this large number of classes did not represent biologically-significant habitats. Cluster iterations indicated that 6 classes captured the variability in the dataset, which was a practical number to assess. Bottom type seabed data (XYZ file) for 6 classes was exported from SIDEVIEW to a GIS software program (e.g. ARCMAP) for spatial representation and selection of ground-truth locations.

Data used for interpolation in QTC CLAMS differed from the original classification (Shapefile: Piankatank Initial Seabed Classification) used in ground-truth surveys because a new software adjustment (patch) was obtained from Quester Tangent in September 2005 after the surveys were completed. This software update automated the procedure to remove the nadir from the images prior to classification (bottom compensation) and was subsequently applied to generate seabed classification for interpolation in QTC CLAMS. Prior to the software update, nadir removal was accomplished through manual inspection of individual images. Differences between the two procedures resulted in the area of the nadir removed not being consistent. Data gaps of seabed classification occurred because during manual examination of images to remove the nadir (a no data zone), any poor image quality areas were also removed from the analyses. This often occurred when crossing deep channels. Because a fixed sonar mount was used in order to map shallow zones, it was not possible to adequately image deep channel reaches (for deeper waters the fish should be lowered closer to bottom to derive the best image). In subsequent analyses that utilized the automated bottom compensation program from Quester Tangent TM, the deep water regions were retained (only the nadir removed) and therefore clustered into a unique class which reflected the poor image quality. Therefore, the assigned class numbers in these two shapefiles (Piankatank Initial Seabed Classification; Piankatank Interpolated Seabed Classification) will not coincide (numbers are assigned arbitrarily during the process).

Ground-Truth Protocol

Modifications to ground-truthing protocols were made due to reoccurring difficulties on the James River to accurately locate sites because of inherent GPS error which limited our ability to effectively implement site specific ground-truthing. To offset potential GPS error, reaches of the river were selected that had large clusters of a particular class type (~100m or more) in appropriate depths (< 2 m). There were some instances in which plots were < 100m due to the lack of a particular class throughout the river (e.g. Class 1). At least 5 plots per class were assessed. One rare Class (4) was eliminated prior to ground-truthing because it represented the "end of file" signal and other hard anomalous returns similar to those observed in the James River survey (Class 10).

Upon location of the site using GPS coordinates, ground-truth protocols were as follows

1. Buoys are placed at each corner of the plot
2. Three or more probes are conducted at least 10 m apart throughout the plot. Grain size, biogenic, organic and surficial characteristics are noted
3. One sediment grab per plot is taken of the surface layer of the seabed
4. Two crew members walk the entire length of the plot on opposite sides to assess bottom type coverage throughout the plot

Results

The ground-truth locations were categorized as 100% soft for all classes except Class 2 which had > 40 % hard sites (other Class 2 locations contained raised bottoms-mounds of soft sediment that were most likely considered structure by the software's interpretation of the acoustic signal) (Table 4). Class 4 was determined to be the 'end of file' or very hard return signal. Extrapolating ground-truth results, hard structural seabed made up approximately 7.6 % of the surveyed and classified area of the Piankatank River (Table 4).

Manual delineation of discernable subtidal structures in acoustic images to contrast with the automated QTC SIDEVIEW classification system indicated that the most prominent structure was SAV (2.6%), with the majority of nearshore habitat reflecting soft, featureless seabeds (Table 5; Figures 9, 10). Manual delineations compared with interpolated multivariate software classification (QTC SIDEVIEW; with software update) indicated that Classes 4 and 1 are most frequently associated with SAV (Figures 11 and 12).

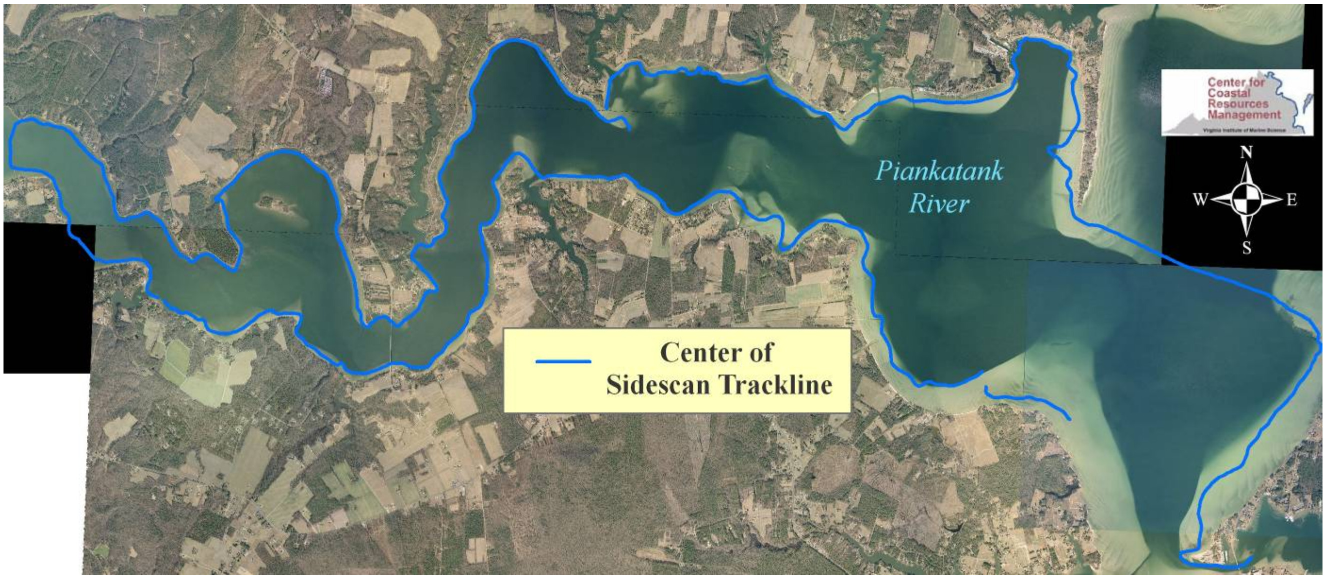

Figure 7. Trackline of sidescan sonar acoustic survey in the Piankatank River. Twenty meter swaths were surveyed on either side of the centerline depicted.

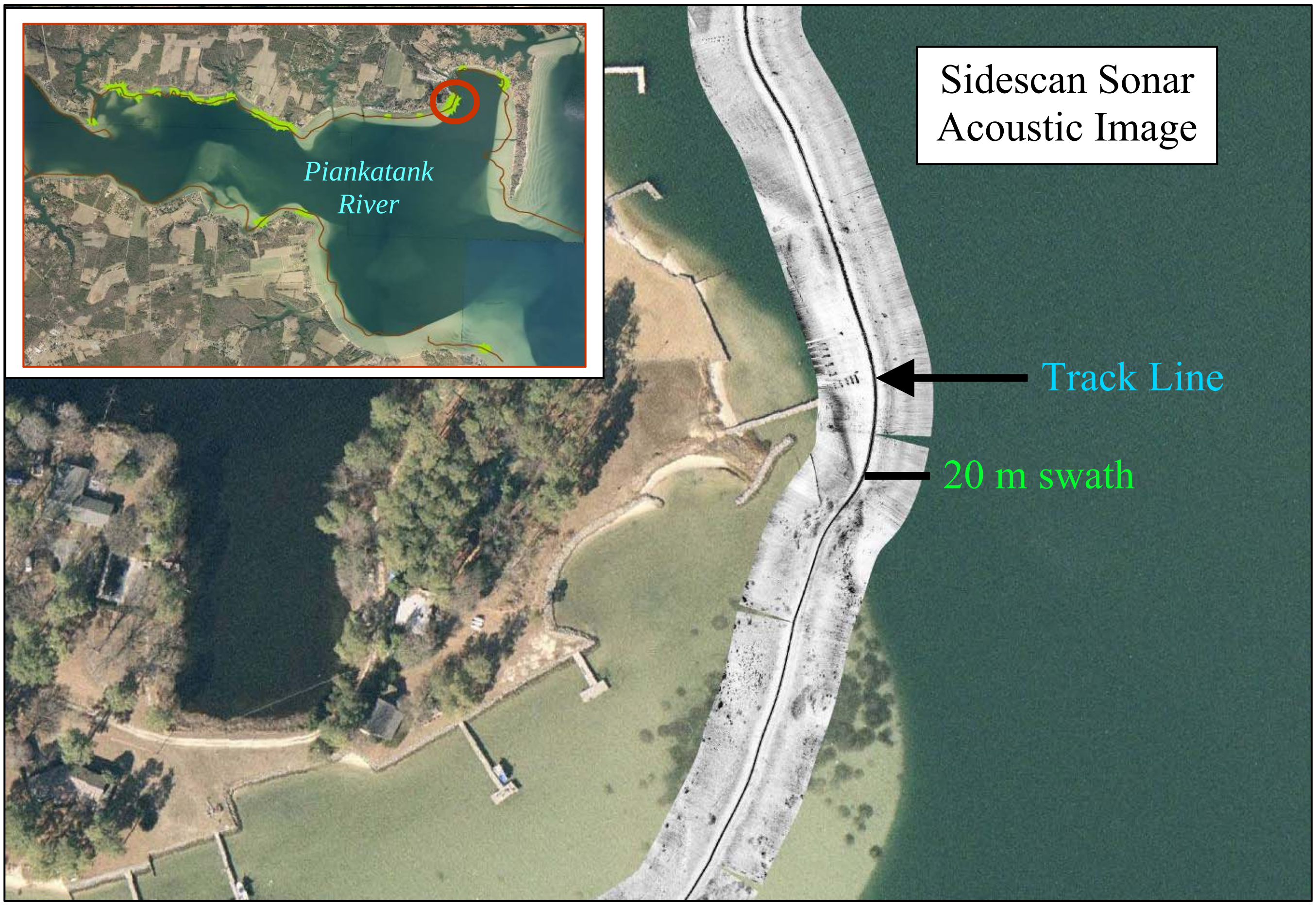

Figure 8. Enlarged region on the Piankatank River of the Sidescan sonar acoustic image. Track line and 20 m swath distances are depicted. Digital data are available on DVD: Piankatank River Nearshore Seabed Classification.

Table 4. Broadly categorized acoustic seabed classes from QTC SIDEVIEW.

Class	Total Sites	% of Survey Area	Designated Category
1	4,989	4.7	Soft; fine sand, silt
2	8,005	7.6	Hard; structural-SAV
3	28,317	26.9	Soft; varied grain size
4	817	0.8	End of file/hard signal
5	7,240	6.9	Soft; deep water
6	55,741	53.0	Soft; fine sand, silt
TOTAL	105,109	100.0	

Table 5. Area and percentage of manually delineated benthic habitat within the nearshore surveyed reaches of the Piankatank River.

Benthic Habitat	Total Area (m^2)	% of Total Area
Featureless; sand or silt	1,878,294	97
SAV	49,754	2.6
Mud	1,305	0.07
Unknown Structure	104	0.03
Rocks; Groins	172	0.009

Figure 9. Example of side-scan sonar survey images with manual delineation of structural subtidal habitat, such as submerged aquatic vegetation (SAV). Delineated areas were converted to polygon shapefiles for further analyses. Digital data are available on the DVD: Piankatank River Nearshore Seabed Classification.

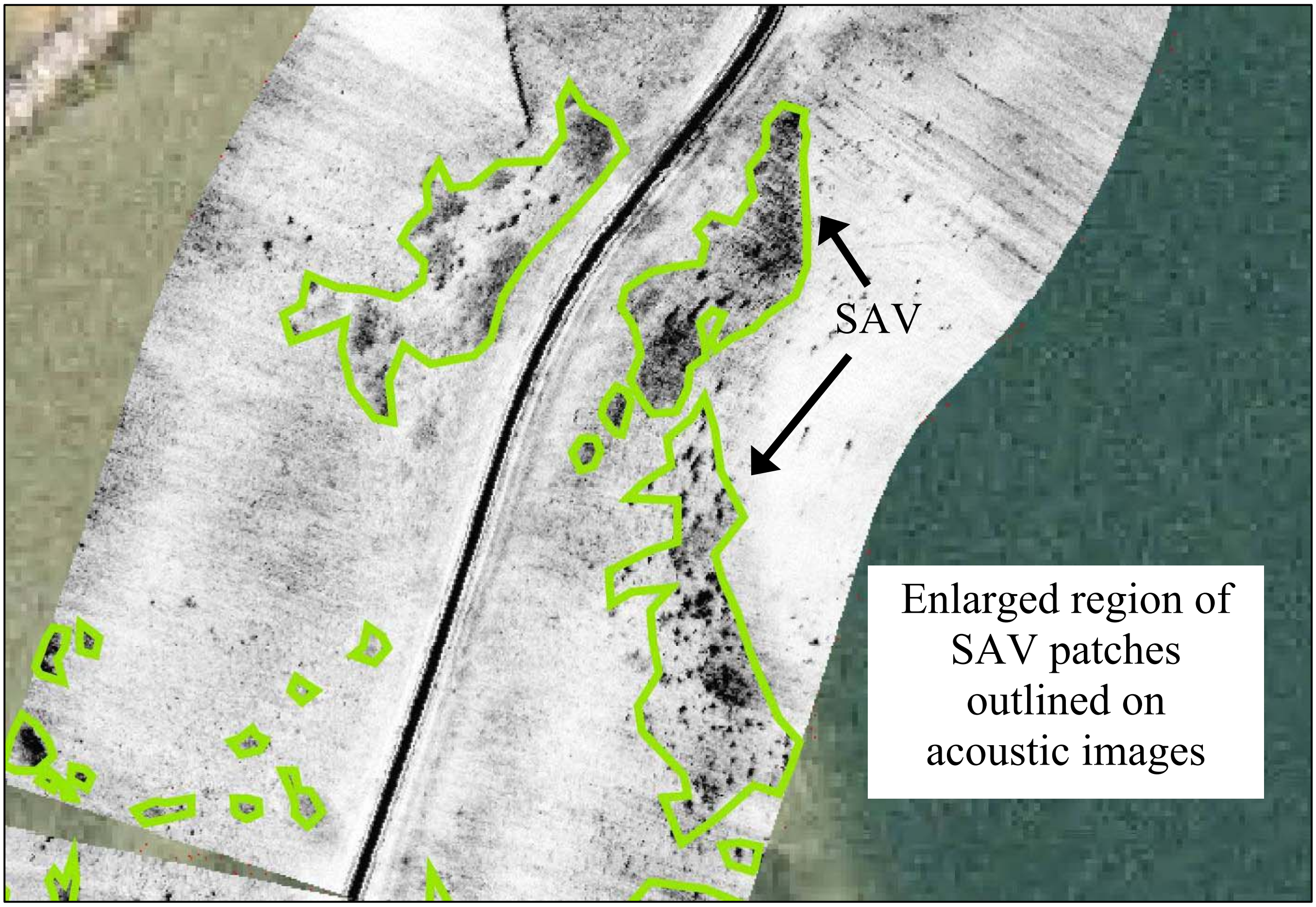

Figure 10. Enlarged region of submerged aquatic vegetation (SAV) beds outlined on acoustic images from the Piankatank River.

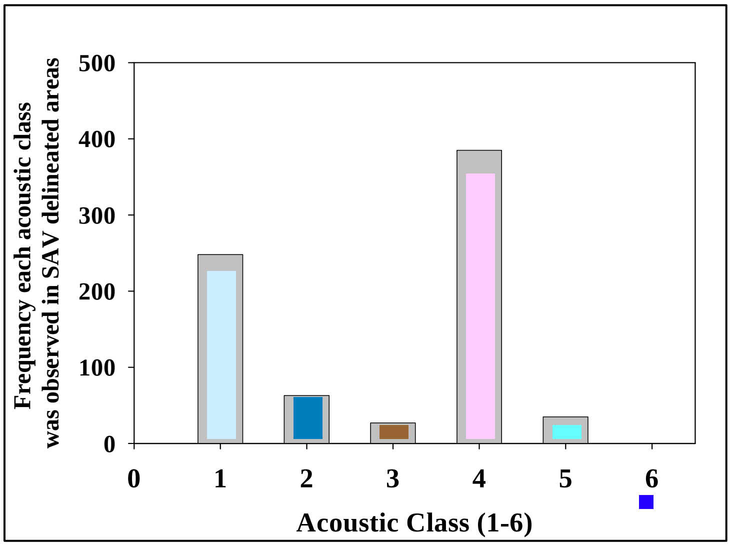

Figure 11. Frequency each acoustic signature class (obtained from interpolated seabed classification data (QTC CLAMS)) was observed with submerged aquatic vegetation (SAV) manually delineated areas. Since the interpolated classification utilized the software update the class numbers produced does not correspond to those used in ground-truth surveys (Table 4, DVD- Piankatank River Nearshore Seabed Classification).

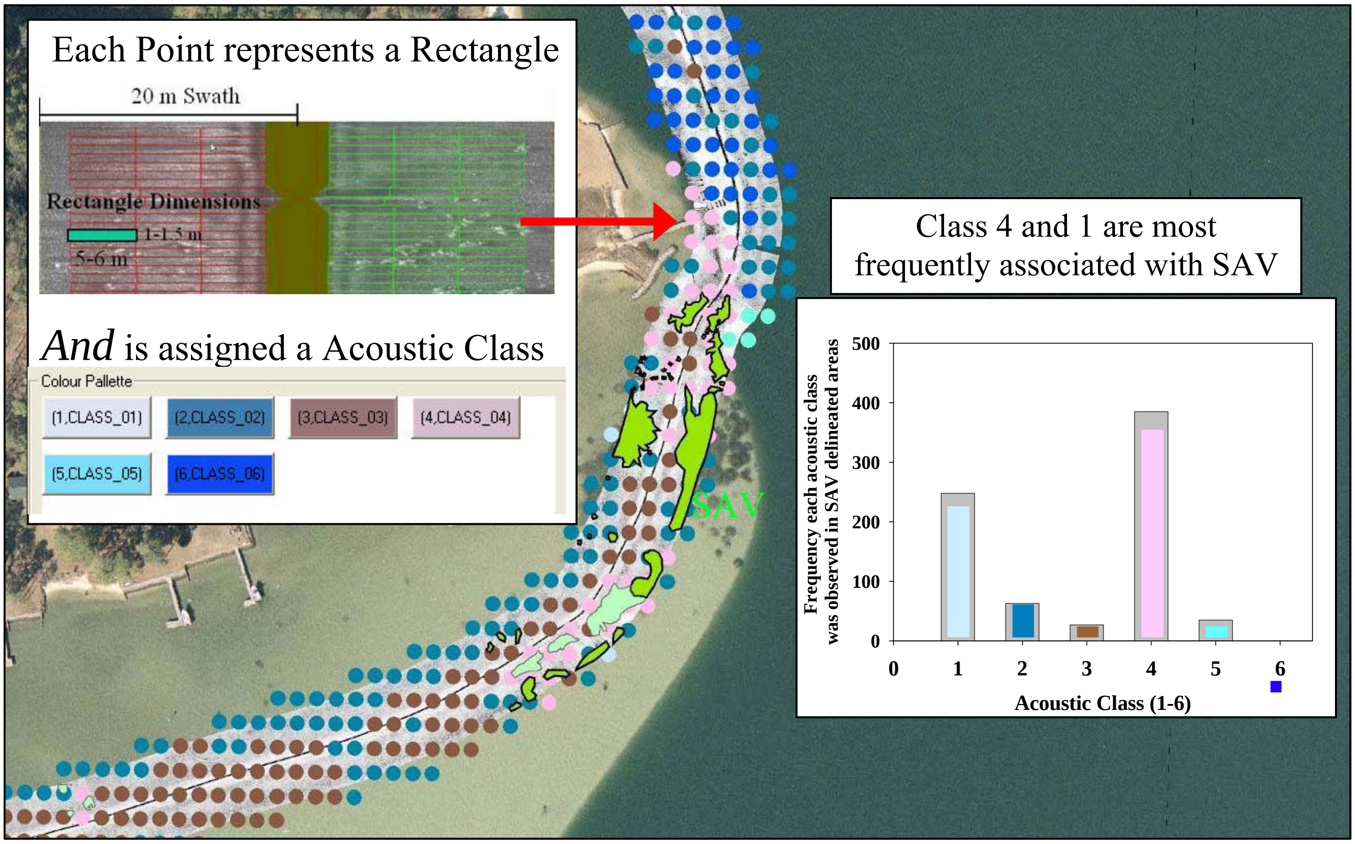

Figure 12. Automated classification of benthic habitat in relation to manual submerged aquatic vegetation (SAV) delineation on the Piankatank River. Similar acoustic classes have similar colors assigned to them in CLAMS. Depicted digital data are available on DVD-Piankatank River Nearshore Seabed Classification.

Summary

Modifications to the seabed classification and ground-truth protocols allowed for a more refined and accurate examination of the correlation between acoustic signature and seabed habitat type in the Piankatank River. Manual delineation of structural habitat indicated that the acoustic classification was able to discern and group similar structures (e.g. SAV). However, since the automated classification was not able to consistently isolate specific habitat types in its current configuration with the side-scan sonar unit, generalizations about the bottom types should be made cautiously. The side-scan images are of high resolution and individual patches of habitat are observable; therefore, the system may be used to augment or verify remote-sensing surveys (e.g. Baywide submerged aquatic vegetation aerial surveys). Further methodology refinement and systems upgrades are being pursued and/or implemented to reduce potential systematic errors in surveying shallow-water systems. For example, following recommendations from workshop participants using this technology for similar applications (see the Benthic Mapping and Characterization Workshop section below), we are attempting to obtain a more sophisticated GPS unit to reduce the latency of the signal and increase positioning accuracy. Additional upgrades desired include auxiliary hardware with subbottom profiling capabilities to enhance sediment information extracted from reaches covered with a fine silt layer which is common in the Chesapeake Bay. This will enhance our abilities to discern historic and potential oyster reef habitat, as well as support other habitat restoration activities.

Benthic Mapping and Characterization Workshop

This project was a first step in the development of transferable protocols for subsequent application to additional watersheds in the coastal plain. This could ultimately lead to consistent large scale mapping of indices of habitat heterogeneity and quality throughout the Bay, which would aid ecosystem management efforts. Efforts are currently underway to collaborate with NCBO's Habitat Characterization Program to ensure compatibility between protocols and classification schemes. To this end, CCRM hosted a 'Benthic Mapping and Characterization Workshop' in February 2006 with participants from various groups throughout the U.S. and Canada, including NCBO (Appendix 1 and 2). The objective was to link efforts to establish a more comprehensive approach to describing benthic habitat Bay-wide. As a result of the workshop, equipment and software upgrades and associated training are currently being pursued by CCRM in cooperation with NCBO to ensure compatibility with their habitat mapping program. During the workshop, several benthic habitat mapping systems were used to survey the same seabed area for comparison of products and efficiencies. The anticipated comparative analyses are expected to guide users in their selection of the most appropriate habitat mapping technologies for specific objectives.

II. Fish Community Habitat Associations

Background

Fish community characteristics have been used since the early 1900s to measure relative ecosystem health (Fausch et al. 1990). Within the last 20 years, advances stem from the development of integrative measures of ecological condition, such as the Index of Biotic Integrity (IBI), which relates fish communities to abiotic and biotic conditions of the ecosystem. Fish community IBIs were first developed for use in freshwater, Midwestern streams, and subsequently modified for application in Great Lakes bays, reservoirs, streams and large rivers throughout the United States and other countries. The common thread that connects the various IBIs is a multimetric approach, which describes biotic community structure and function and relates it to the ecosystem or habitat. The use of fish community-level response as an indicator affords many advantages: 1) high public interest; 2) multi-trophic response that integrates aquatic condition; 3) assessment of both habitat and biotic condition as well as cumulative effects; 4) assessment of large-scale regional effects due to their mobility; 5) ease of identification on-site; and 6) availability of long-term monitoring data.

Estuarine systems are arguably some of the most complex aquatic systems. Their natural variability compounds the problems of detecting anthropogenic impacts. Until now, use of fish community IBIs in estuarine systems has been limited, with varying degrees of success (Carmichael et al. 1992; Deegan et al. 1997; Jordan and Vaas 2000; Hughes et al. 2002; Meng et al. 2002). With growing recognition that effective management of estuarine systems can only occur at ecosystem levels, the need for further development of these metrics is widely accepted. Evaluation of essential habitat in conjunction with descriptions of biological communities (e.g. IBI) may be used to establish links between landscape and the biota, elucidate ecological thresholds, and guide research on processes and functions affecting ecosystem services. Research that incorporates shoreline and watershed land use measures may lead to viable management tools with local and regional applications, in particular on small watershed scales. Additionally, as efforts to manage fisheries evolve towards an ecosystem approach, information on the habitat quality of the nearshore and riparian zones becomes invaluable. To this end, relationships between subtidal habitat and shoreline condition as well as linkages of habitat condition to fish community indices were assessed.

Methods

Fish Survey on the James River

The James River was initially stratified into three 20 km strata: Lower, Middle and Upper. Each of the three strata of the James River was segmented into nearshore reaches no larger than 100 m based on adjacent shoreline type (riprap, bulkhead, natural) and surveyed bottom type (hard or soft). Site categories were a combination of estimated nearshore seabed type and associated shoreline: hard bottom natural (HN), hard bottom riprap (HR), hard bottom bulkhead (HB), soft bottom natural (SN), soft bottom riprap (SR) and soft bottom bulkhead (SB) (Figure 13). Attempts were made to randomly select four sites from each category in each stratum; however, some combinations were not present in each stratum or in the same abundance as other sites (Table 6). Extra locations were randomly selected to replace misidentified remotely sensed shoreline or bottom type when necessary. In this manner, additional ground-truthing on the James was completed after stratified random fish site locations were selected. Each site was visited and if the bottom type was not the predicted class from QTC SIDEVIEW then it was excluded and replaced by the next random site. Observations on every site visited were noted and estimates of accuracy of prediction of bottom type could be ascertained. Fifty-four sites were sampled during the fish survey; thirty-four additional sites were assessed for the possibility of inclusion in the sampling effort. The additional sites were excluded due to access difficulties (depth), misclassification or other complications (e.g. strong currents). Of the 88 potential survey sites visited; 94 % were classified correctly by the acoustic software as either hard or soft bottom and 6% were misclassified (e.g. hard bottom classification for a featureless silty bottom).

Table 6. Number of stations sampled versus the number of stations assessed for sampling (#/#) for each surveyed strata on the James River[1]

Category	Stratum 1	Stratum 2	Stratum 3	Total	% of sites surveyed sampled
Hard Bottom					
HN	3/11	2/15	4/6	***9/32***	28.1
HR	1/4	0/4	0/7	***1/15***	6.7
HB	1/2	0/0	0/1	***1/3***	33.3
Soft Bottom					
SN	5/5	5/5	5/5	***15/15***	100.0
SR	5/5	5/5	5/5	***15/15***	100.0
SB	7/9	0/1	6/6	***13/16***	81.3

[1] *The availability of HB and HR sites was limited throughout the surveyed area of the James River*

Two replicate seine hauls (30.5 m x 1.22 m bagless seine of 6.4 mm bar mesh) were conducted at each site during July-August 2005. One end of the seine was held on shore or as close to shore as possible. The other was fully stretched perpendicular to the shore and swept with the current over a quarter circle quadrant. Ideally, the area swept was equivalent to a 729 m^2 quadrant. When depths of 1.22 m or greater were encountered, the offshore end was deployed along this depth contour. An estimate of distance from the start of the seine to this depth was recorded. After encircling an area the mouth of the seine was closed by crossing over the lead lines of each wing of the net. The seine was slowly hauled closed and the lead line continually checked to ensure contact with the bottom. Distance offshore estimates were used to calculate area encased by the haul for relative density measures. Replicate hauls were combined and counts and total lengths recorded for each finfish species (or a subsample of at least 25 individuals); select crustacean species were also enumerated. Community measures were calculated for each site, including relative abundance, density, diversity and fish community index (FCI) scores. At each site, auxiliary data were collected, including dissolved oxygen, salinity, conductivity, pH, turbidity, current speed, tides, air and water temperature, wind speed and direction, as well as riparian land use, subtidal habitat, shoreline condition.

Guild Development

As a first step in the calculation of metrics included in the FCI, fish species were placed into several guilds based on their documented life histories. Guilds were constructed based on reproductive strategy, trophic level, primary life history, habitat preference, and origin. Primary sources of life history information included Lippson and Moran (1974); Hardy (1978); Jenkins and Burkhead (1994); and Murdy et al. (1997). Categorization is based on the predominant behavior of each species at the life stage typically observed in nearshore estuarine waters from July-September. The reproductive strategy guild categorizes species by spawning location. Within the trophic level guild, species are classed as omnivores, carnivores or benthivores based on their primary prey items. Categorization of the primary life history guild is based on how each species relates to the estuarine system, for example non-resident species that have estuarine-dependent larval or juvenile stages are placed in the estuarine-dependent nursery category. The habitat guild broadly classifies species by typical position in the water column (i.e., pelagic or benthic). The origin guild separates species in estuarine residents (present year-round) and non-residents (Table 7).

Metric Selection

The fish community index (FCI) was developed and applied previously in the nearshore estuarine environs of the Chesapeake Bay (Bilkovic et al. 2005). The FCI was applied in the James River system in this study to assess relative measures of fish community structure and function. Briefly, in the manner of Karr et al. (1986), eight metrics were assessed for consistency as indicators of aquatic ecosystem health based on fish community structure and function. Metrics were chosen that represent key aspects of fish community integrity, as well as the elements of life history that are dependent on estuarine condition. Several metrics were extracted from current literature that addressed similar estuarine environments. Metrics were placed into four broad categories: taxonomic richness and diversity, abundance, trophic composition and nursery function (Table 8). For each site, individual metric values were calculated based on observed species composition and abundance in 2005.

Metric Analyses

Metric distributions were normalized with natural logarithms or square-root transformations when necessary (only in two instances). The metrics abundance and proportion of benthic species required transformations (natural logarithms and square-root, respectively), but all other metrics had normal distributions and were not transformed. Individual metrics were standardized based on each metric distribution and aggregated, without weighting, into a Fish Community Index (FCI) score. For example, each species richness metric value was divided by the largest observed richness measure to standardize values (0-1) based on existing conditions for the year (no reference condition was considered); standardized metrics were then added to obtain the aggregate Fish Community Index.

The applicability of metrics and variability of the FCI and metrics were assessed by calculating correlation coefficients for metric scores, graphing relationships between individual metrics and the FCI, and examining principal component analysis (PCA) coefficients of the metrics. By plotting the FCI versus individual metrics, the variability of the FCI can be visually assessed. The precision of the FCI can be estimated based on the proximity of points to a 45° line when relating individual metrics to the aggregate FCI. PCA was applied to individual fish community metrics to evaluate the usefulness of the multi-metric index (FCI) as a descriptor of ecosystem integrity. Those metrics that are supported in a multi-metric index should exhibit similar associations. Metrics that exhibited similar trends in correlation (high and positive) with the aggregate FCI of all eight tested metrics were combined into a final FCI by summing standardized individual metric values.

Relationships among fish community measures (FCI, metrics) and habitat measures (shoreline type, bottom habitat (hard, soft) were examined with One-Way ANOVA and nonparametric changepoint analysis. Scatterplots of fish community indices and developed land metrics suggested a potential threshold response, so changepoint analysis (nCPA) (King and Richardson 2003; Qian et al. 2003) was used to test for the presence of an ecological threshold in the FCI due to developed land use at three spatial scales: 100, 200 and 1000m buffers. Buffers were generated in GIS using the survey location as the central point (Figure 14). The nCPA detects changes in the mean and variance of a response variable (in this case FCI) due to variation in a forcing factor (in this case land use at three spatial scales). It examines every point along a continuum of predictor values (developed lands) and determines the probability that a value can split the data into two groups that have the greatest difference in means and/or variance. With bootstrap simulations repeated 1000 times, a distribution of changepoints is estimated and illustrated with a cumulative probability curve that describes the probability (frequency) of a changepoint occurring at various levels of disturbance. When probabilities were < 0.05, the cumulative probability curves were assumed to accurately assess the likelihood of an ecological threshold occurring. Changepoint analyses were conducted in S-Plus using the custom function nopar.chngp (Qian et al. 2003).

Results

A total of 8626 fish consisting of 33 species were collected from July 19 to August 10, 2005 at 54 sites. By percentage of catch, the most abundant species were Atlantic menhaden (61.4%), Atlantic silverside (14.8%), white perch (9.6%), bay anchovy (2.6%), and spot (2.3%). Overall average length of fish captured was 10.4 cm ±0.8 cm with a size range of 7.2-16.1 cm (Table 9). Number of species collected at each site ranged from 2 to 14, and Fish Community Index (FCI) scores ranged from 1.2 to 6.7 (Maximum score possible = 7.0).

All but one of the examined fish community metrics were positively and highly correlated ($r \geq 0.5$) with the summed metrics (FCI). The majority of correlations among metrics were positive. Total number of individuals (transformed into natural logarithms) had low, non-significant correlations with the FCI and negative correlations with other individual metrics. Similarly, plots of FCI and individual metrics indicated strong linear relationships in all but one metric (i.e., abundance, natural logarithm transformed) (Figure 15). Principal components analysis of individual fish community metrics supported the use of all but one of the metrics (i.e., abundance, natural logarithm transformed) in a composite FCI. The first and second principal components accounted for 83% of the variance in the dataset (Table 10; Figure 16). All metrics were positively associated with PC1, except for low negative loading for total abundance. When considering correlation patterns and PCA analyses, the use of all the metrics, with the exception of total abundance, was supported for the application of a nearshore FCI in the James River.

The lack of hard bottom locations on the James River in the nearshore became evident only after sites were surveyed for fish collection and restricted our ability to quantify differences between fish communities and bottom type. Only 11 sites could be designated hard bottom, and many of these sites consisted of a seabed layer of shell hash, not large structural reef features. Therefore, the fish survey data could only be effectively compared with adjacent shoreline types. To offset the lack of discriminate bottom type locations, we selected 6 sites in close proximity to one another for auxiliary surveying that represented each of the shoreline/bottom type categories. However, the best available hard bottom sites were represented by small mussel beds with limited vertical structure. No significant difference in fish community structure measures (individual fish metrics and FCI) was evident between hard and soft bottom locations. Nonetheless, the amount of hard bottom cover was highest at sites with natural shoreline (30%) conditions as opposed to hardened shoreline (riprap or bulkhead; 6%) (One-way ANOVA; p =0.009)(Figure 17), indicating a potential land-water nexus.

The lowest FCI scores were associated with bulkhead shorelines while similar scores occurred at sites with natural or riprap shorelines (One way ANOVA; p=0.04 (Figure 18)). Of the measured chemical and physical variables, only salinity and dissolved oxygen were significantly related to the biotic endpoints (p<0.0001, r=-0.598; p=0.031, r=-0.306, respectively). Dissolved oxygen was also positively correlated with water temperature and time of day; suggesting the possibility that as shallows warm up, fish migrate into deeper waters which is reflected as depressions of FCI scores in relation to dissolved oxygen. Since salinity is correlated with FCI scores and diversity measures, distinguishing robust relationships with shoreline conditions is problematic. However, species diversity minimums in the James River have previously been observed between 8-10 ppt (Wagner et al. 1999), while our data indicated that species depressions occurred between 10-18 ppt and this trend was primarily driven by sites with bulkhead shoreline in intensely development reaches over a large area (Figure 19). Notably, the higher salinity region where species diversity is depressed is also the area of the river with the most intense development (Figure 13). It is possible that in river reaches where species numbers are expected to be higher then observed, intense development has suppressed this effect. In support, when examining single metrics that are independent of salinity regime limitations (e.g. trophic index), the lowest values are likewise associated with the highest development density in the furthermost downstream reaches of the river (Figures 18 and 20).

Changepoint analyses indicated that ecological thresholds existed in response to developed land use (urban and suburban) at all three spatial scales 100, 200 and 1000m. Particularly strong patterns were evident at the 200 and 1000m spatial scale, where the cumulative probability curve indicated a 94 % probability of a changepoint occurring at > 23 % developed riparian land use for the FCI scores (Figure 21). At the smaller 100m scale, the ecological threshold (94 % cumulative probability) occurred at 68% developed lands.

Discussion

Ecological thresholds that mark breakpoints at which a system or community notably responds (perhaps irreversibly) to a disturbance have been supported in a variety of systems. As in this study, several studies of aquatic systems have noted thresholds ranging between 10 and 20 %. DeLuca et al. (2004) observed responses in marsh bird community integrity at land-use disturbance thresholds of approximately 14 %. As little as 10 % watershed development within a large estuary and between 10-20 % urbanization within streams have been linked with degradation of fish communities (Limburg and Schmidt 1990; Wang et al. 1997). A review of reported thresholds of impervious surface area within stream catchments indicated that between 10 and 20 % was associated with stream and fish community degradation (Paul and Meyer 2001).

Biotic responses were correlated with habitat condition at multiple spatial scales in the riparian zone. Fish Community Index (FCI) scores were lower at sites with developed land cover within 200 and 1000m, and there were also negative impacts associated with local shoreline condition. The lowest average FCI scores were found in areas with highly altered shoreline conditions (bulkhead) and with developed lands greater than 23%. Additionally, there was a reduction in subtidal structure when adjacent shoreline conditions were altered. Direct biotic response may be due to changes in nearshore habitat, with indirect impacts due to watershed land use. These results are supported by recent studies describing the relationship between shoreline alteration and nearshore/littoral habitat condition (Jennings et al. 1999; Scheuerell and Schindler 2004). Furthermore, watershed land use and shoreline condition may be effective representations of integrative measures of stress that relay the state of degradation in a system. Future research that incorporates shoreline and watershed land use measures may lead to viable management tools with local and regional applications, in particular on small watershed scales.

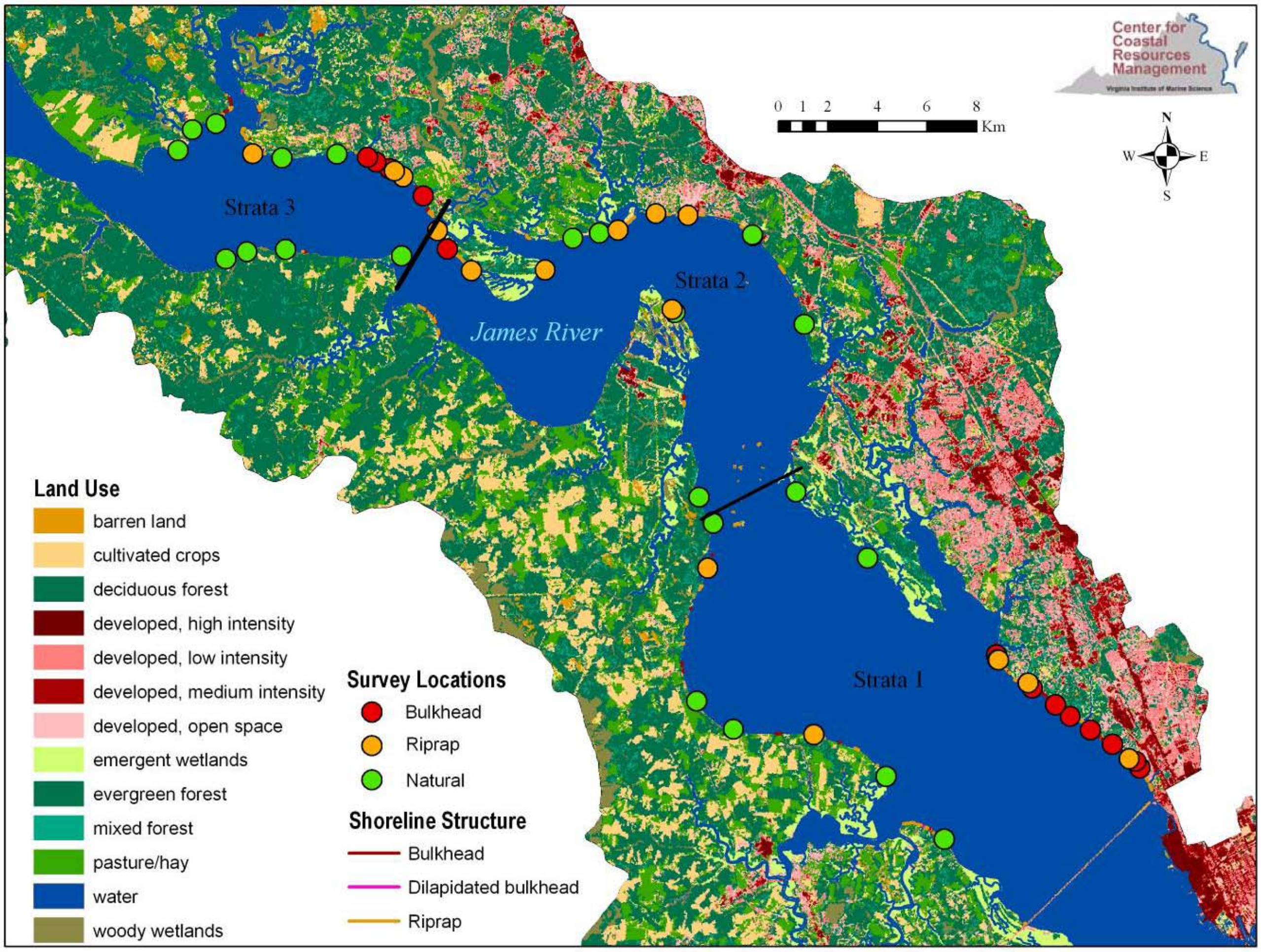

Figure 13. Fish Community Survey Locations on the James River, 2005

Table 7. Fish guild categories used in the development of metrics. Categorization is based on the predominant behavior of each species at the respective life stage typically observed within the nearshore estuarine waters from July-September. The reproductive guild categorizes the location of spawning of each species. Species are placed in respective trophic level categories based on their primary prey items. The primary life history guild describes a critical aspect or primary ecosystem for which the species success depends. The habitat guild broadly classifies the position in the water column where each species spends the majority of its time. The origin guild separates species that are year-round estuarine species.

Fish Guilds	Categories
1) Reproductive	Marine Spawner
	Anadromous
	Freshwater Spawner
	Estuarine Spawner
2) Trophic Level	Carnivore
	Planktivore
	Benthivore
3) Primary Life History	Marine
	Estuarine
	Freshwater
	Diadromous
	Estuarine-Dependent Nursery
4) Habitat	Pelagic
	Benthic
5) Origin	Estuarine Resident
	Estuarine Non-Resident

Table 8. Fish community metrics assessed for use in a multi-metric index and associated source.

Fish Community Metrics	Reference
Species Richness/Diversity	
Species Richness (SR = No. of Species-1/log(No. of individuals))	Bilkovic et al. 2005
Proportion of benthic-associated species (No. of benthic-associated species/Total no. of species)	Deegan et al., 1997
Number of dominant species (No. of species that make up 90% of total abundance)	Deegan et al., 1997
Number of resident species	Deegan et al., 1997
Fish Abundance	
Ln Abundance	Deegan et al., 1997
Trophic Composition	
Trophic Index (Relative proportions of three broadly-defined trophic guilds: piscivores, planktivores and benthivores (scaled to 5)	Jordan and Vaas, 2000
Nursery Function	
Number of estuarine spawning species	Deegan et al., 1997
Number of estuarine nursery species	Deegan et al., 1997

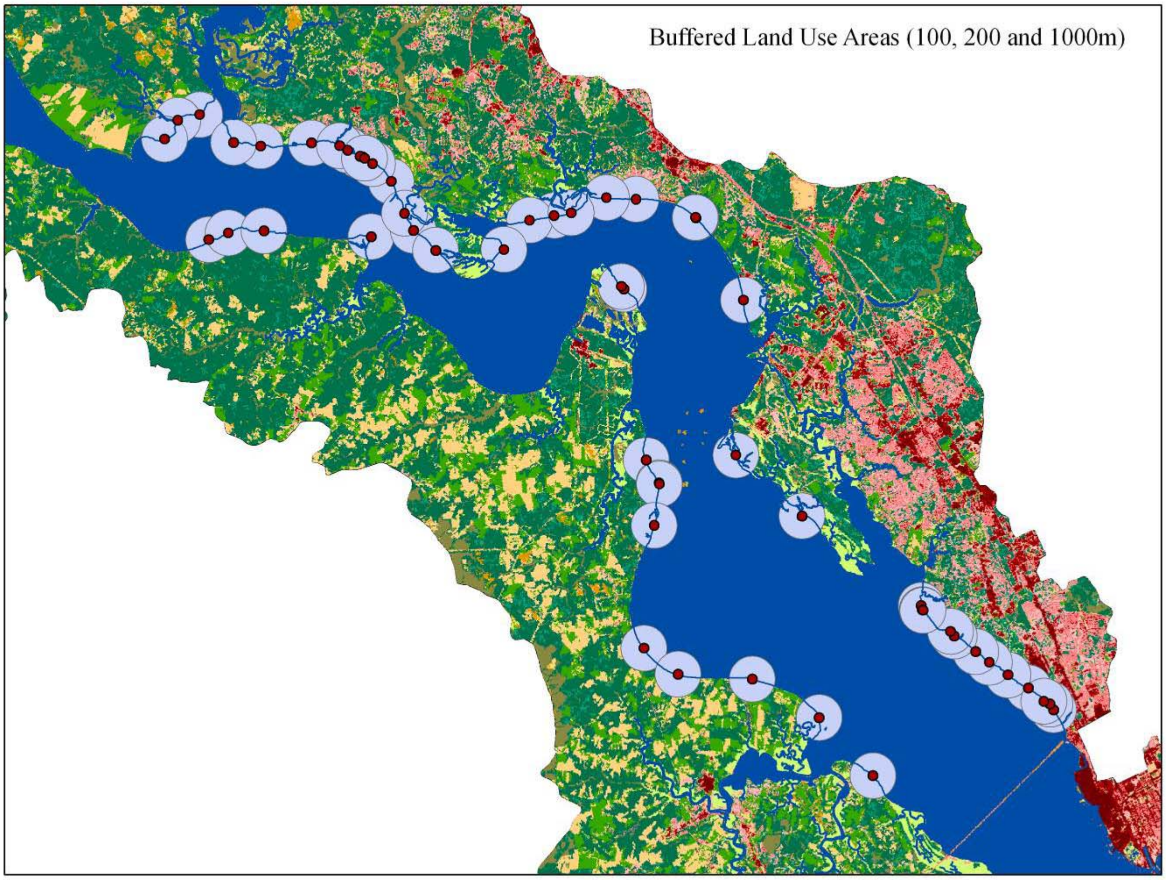

Figure 14. Survey locations buffered at three spatial scales (100, 200 and 1000 m) to examine land use patterns in relation to fish communities in the nearshore.

Table 9. Summary Statistics for James River Fish Survey, 2005.

Common Name	Latin Name	Number of Fish	% of catch	Average length (cm)	Standard error (length)	Minimum length (cm)	Maximum length (cm)
Atlantic Menhaden	*Brevoortia tyrannus*	5297	61.41	10.2	0.3	5.3	21.4
Atlantic Silverside	*Menidia menidia*	1277	14.80	6.1	0.1	0.5	16.0
White Perch	*Morone americana*	826	9.58	10.7	0.5	3.7	24.5
Bay Anchovy	*Anchoa mitchilli*	228	2.64	4.8	0.1	3.2	7.9
Spot	*Leiostomus xanthurus*	200	2.32	7.6	0.1	0.8	11.1
Blue Catfish	*Ictalurus furcatus*	153	1.77	18.6	1.3	9.6	45.2
Spottail Shiner	*Notropis hudsonius*	138	1.60	6.5	0.4	3.5	10.4
Striped Bass	*Morone saxatilis*	96	1.11	6.3	0.4	3.8	21.4
Gizzard Shad	*Dorosoma cepedianum*	78	0.90	23.2	1.3	5.8	39.0
Mummichug	*Fundulus heteroclitus*	74	0.86	6.7	0.2	4.5	9.8
Hickory Shad	*Alosa mediocris*	51	0.59	7.0	0.3	5.1	11.3
Atlantic Croaker	*Micropogonias undulatus*	46	0.53	12.1	1.3	2.8	23.7
Blue Crab (YOY)	*Callinectes sapidus*	30	0.35				
Banded Killifish	*Fundulus diaphanus*	16	0.19	6.9	0.6	5.4	7.5
Striped Anchovy	*Anchoa hepsetus*	16	0.19	6.0	0.3	5.0	7.7
Blue Crab (+1)	*Callinectes sapidus*	14	0.16				
Channel Catfish	*Ictalurus punctatus*	13	0.15	14.6	1.4	10.7	21.5
Atlantic Needlefish	*Strongylura marina*	11	0.13	23.1	1.6	16.7	32.7
Hogchoker	*Trinectes maculatus*	11	0.13	8.7	0.6	5.8	12.6
White Mullet	*Mugil curema*	10	0.12	9.6	0.8	8.1	12.5
Golden Shiner	*Notemigonus crysoleucas*	8	0.09	9.3	0.9	6.7	11.6
Striped Mullet	*Mugil cephalus*	8	0.09	16.4	2.2	10.5	39.4
White Catfish	*Ameiurus catus*	5	0.06	12.5	0.5	11.2	13.7
American Shad	*Alosa sapidissima*	3	0.03	6.6	0.4	5.9	7.2
Bluefish	*Pomatomus saltatrix*	3	0.03	11.3	3.2	8.1	14.6
Rough Silverside	*Membras martinica*	3	0.03	9.5	0.2	9.2	9.6
Blackcheek Tonguefish	*Symphurus plagiusa*	2	0.02	9.0	0.2	8.8	9.1
Pumpkinseed	*Lepomis gibbosus*	2	0.02	8.7	0.1	8.6	8.8
Striped Killifish	*Fundulus majalis*	2	0.02	8.6	2.5	6.1	11.0
Alosa	*Alosa spp*	1	0.01	9.5		9.5	9.5
Brown Bullhead	*Ameiurus nebulosus*	1	0.01	6.5		6.5	6.5
Inshore Lizardfish	*Synodus foetens*	1	0.01	5.9		5.9	5.9
Pigfish	*Orthopristis chrysoptera*	1	0.01	14.6		14.6	14.6
Silver Perch	*Bairdiella chrysoura*	1	0.01	17.0		17.0	17.0
Overall Number of Fish and Average Lengths		*8626*		*10.4*	*0.8*	*7.2*	*16.1*

*excludes auxiliary sampling events.

Table 10. Eigenvectors and accountable variances of the first two principal components (PC) based on individual fish community metrics. PC1 and PC2 accounted for 83% of the variance in the data.

PC1	PC2	Variable
0.43	-0.06	Species richness
0.28	-0.37	Proportion of benthic-associated species
0.41	-0.16	Number of dominant species
0.38	0.28	Number of resident species
-0.12	0.68	Ln total abundance
0.38	-0.22	Trophic index
0.34	0.36	Number of estuarine spawning species
0.39	0.34	Number of estuarine nursery species
60	23	% variance accounted for

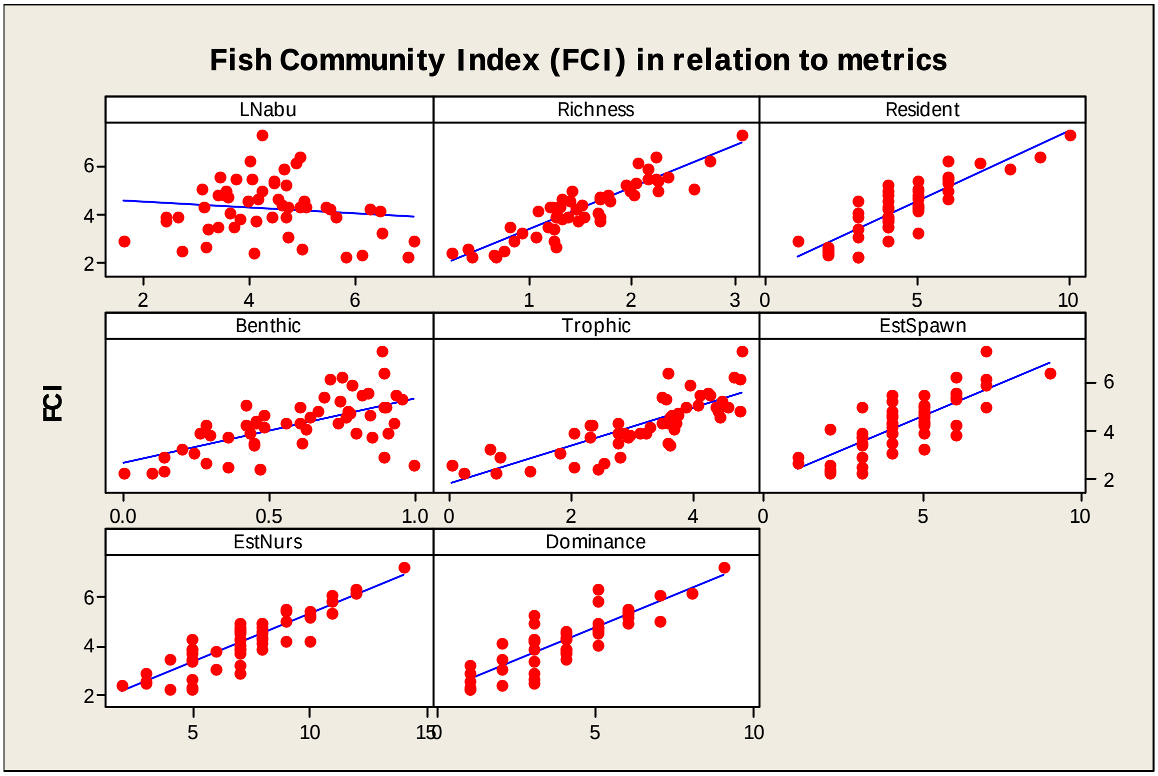

Figure 15. Individual raw metrics scores A) abundance, natural logarithm transformed, B) species richness, C) number of resident species, D) proportion of benthic-associated species, E) trophic index, F) number of estuarine spawning species, G) number of estuarine nursery species, and H) number of dominant species versus an aggregate fish community index (FCI) of all eight metrics. Metrics showed constantly increasing responses to increasing FCI scores, with the exception of abundance, natural logarithm transformed (A).

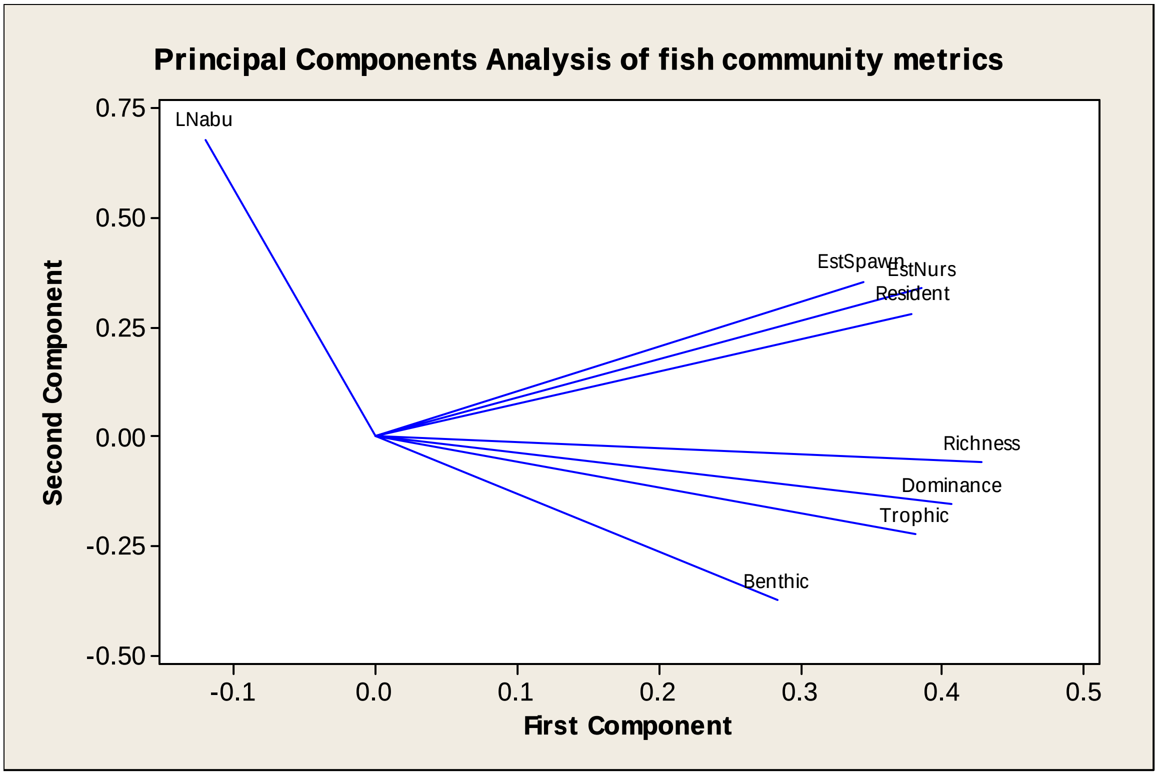

Figure 16. First and second principal components of fish community metrics. All metrics were correlated with the exception of LN(Abundance). LNabu=natural log of abundance, EstSpawn=number of estuarine spawning species; EstNurs=number of estuarine nursery species; Resident=number of resident species; Richness=species diversity; Dominance=number of dominant species; Trophic=Trophic Index; Benthic=proportion of benthic associated species.

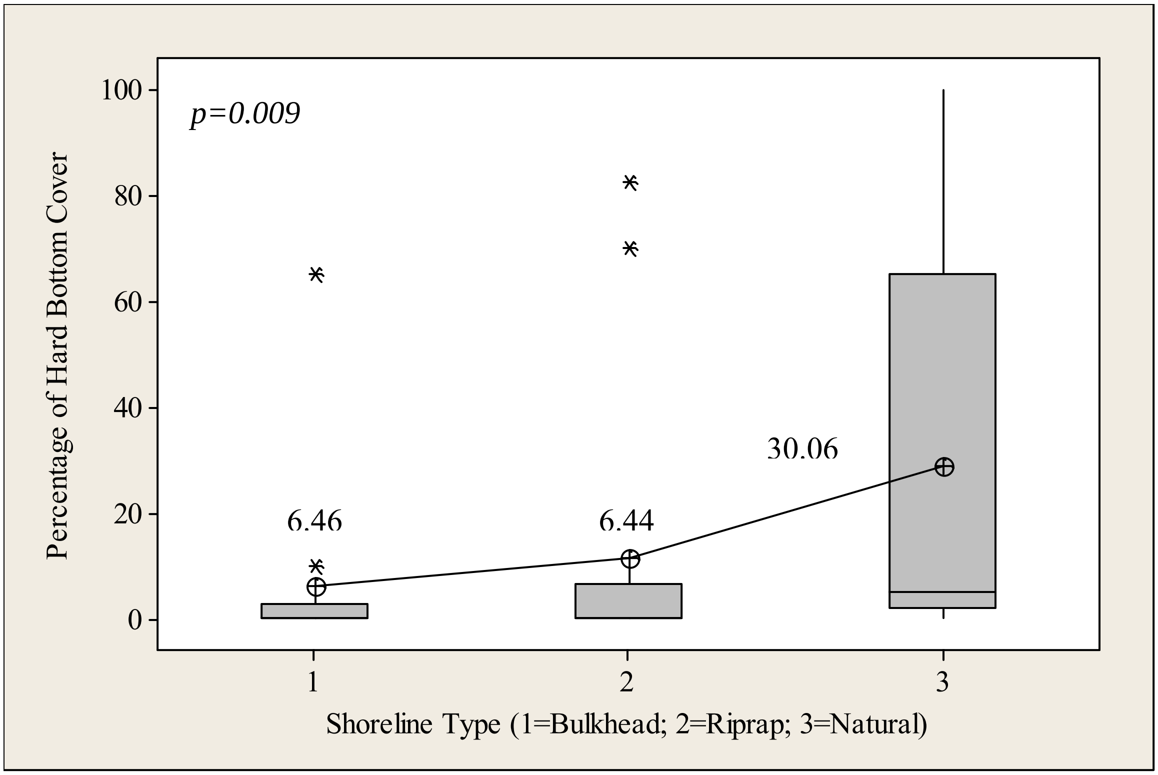

Figure 17. Hard bottom cover variability by shoreline type: bulkhead, riprap or natural for fish survey sites on the James River.

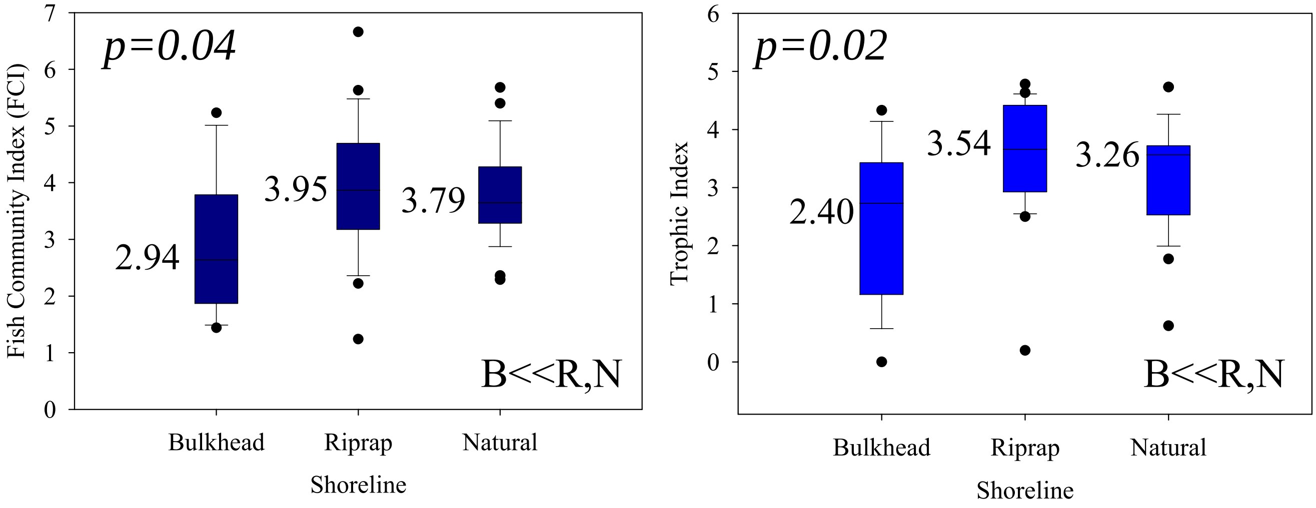

Figure 18. Fish Community Index and Trophic Index score variability by shoreline type: Bulkhead, Riprap or Natural. One-way ANOVA (p=0.04; 0.02, respectively). Mean values by shoreline type are depicted adjacent to each boxplot. In both cases, scores associated with bulkhead shorelines were significantly lower than riprap or natural conditions.

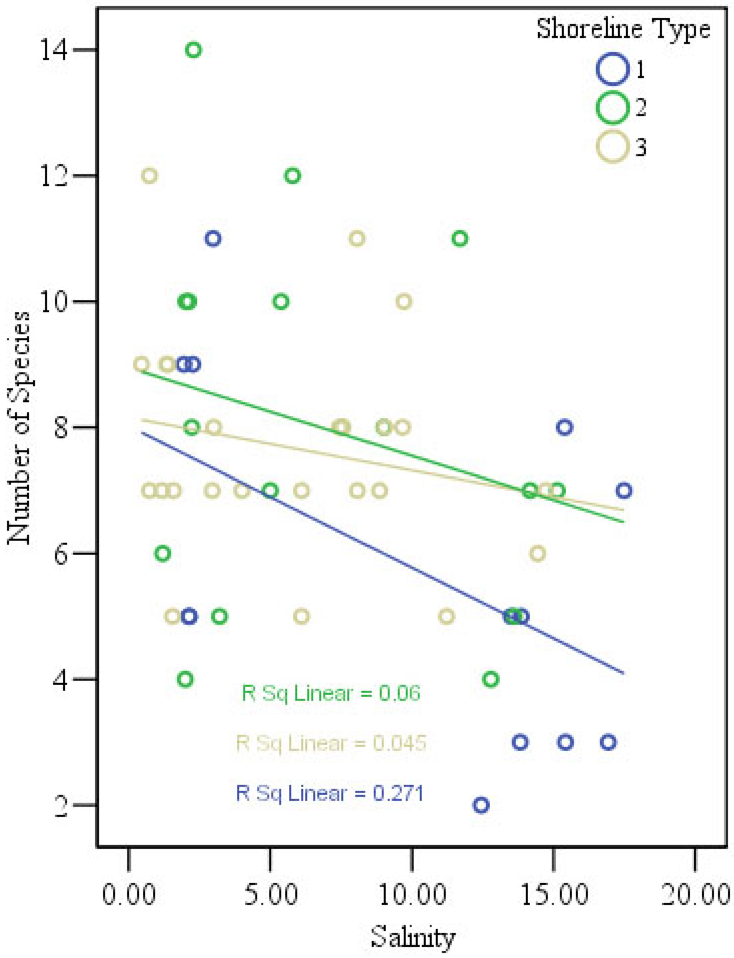

Figure 19. Number of species at each site in relation to salinity (ppt) discriminated by shoreline type (1=Bulkhead; 2=Riprap; and 3=Natural shoreline). Individual regressions by shoreline type are noted; the highest R^2 value was associated with bulkhead shoreline conditions.

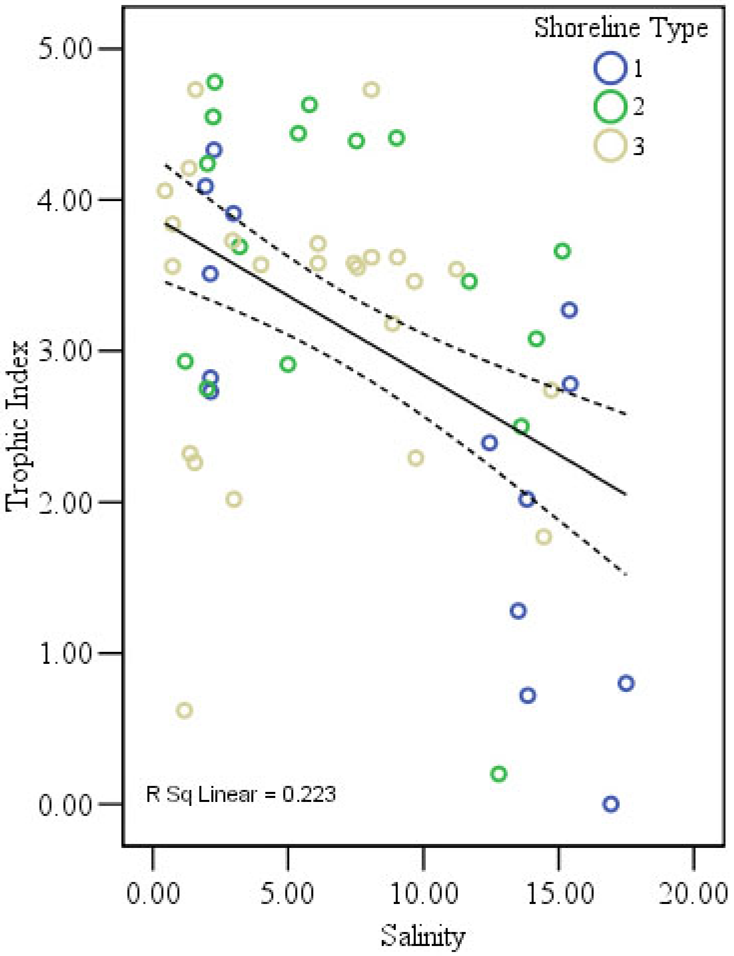

Figure 20. Trophic Index in relation to salinity (ppt) discriminated by shoreline type (1=Bulkhead; 2=Riprap; and 3=Natural shoreline). Estimated regression line and 95% confidence intervals are displayed for all the data.

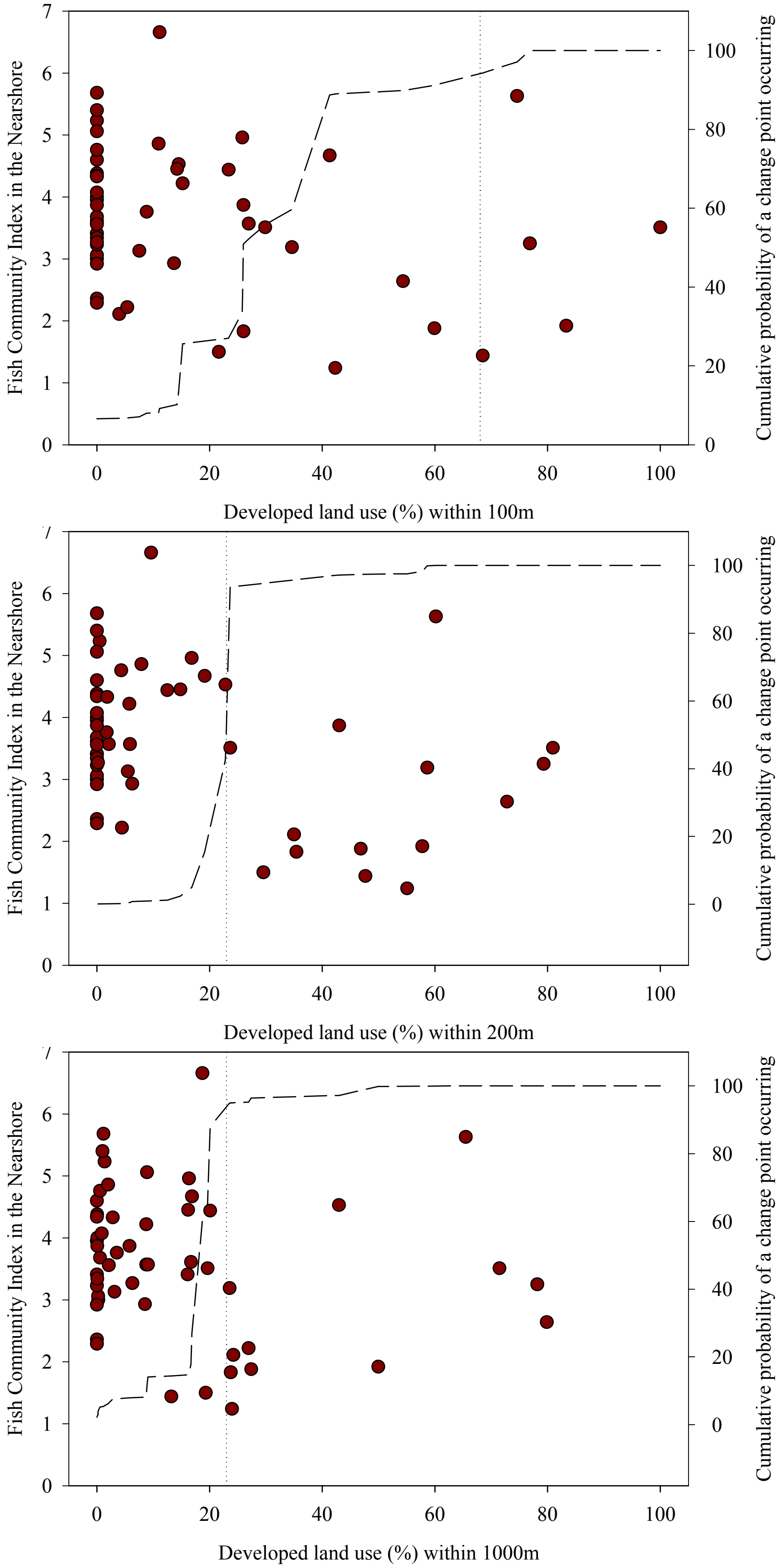

Figure 21. Significant fish community responses ($p \leq 0.05$) were measured with the FCI in relation to the amount of developed lands within a 100, 200 and 1000m buffer. There was a 94 % cumulative probability of an ecological threshold occurring at 23 % developed lands for the FCI at the 200 and 1000m spatial scale. At the 100m scale, the ecological threshold (94 % cumulative probability) occurred at 68% developed lands.

Overall Summary

Side-scan imaging, in combination with automated seabed classification, shows promise as a tool to elucidate patterns in essential habitat. We are currently examining ways in which the system can be standardized and upgraded to the NOAA system/methodologies which will increase both groups' abilities to survey large areas in the Chesapeake Bay. Additionally, discussions have been initiated on the development of a standardized marine seabed habitat classification which has potential relevance to numerous management issues such as delineation of essential fish habitat and habitat restoration targeting (SAV; oyster). In this study, modifications to the seabed classification and ground-truth protocols from the James River allowed a more refined and accurate examination of the correlation between acoustic signature and seabed habitat type in the Piankatank River. Manual delineation of structural habitat verified that the automated classification was able to discern and broadly group similar structures (e.g. SAV). As a next step to creating user-friendly access to the seabed data, we are preparing to administer the data using the web-based ArcIMS data interface system that will run off the newly acquired ArcSDE (Arc spatial data engine) server which will enhance performance and output. ArcIMS brings interactive map and query systems to the desktop through the Internet without any external software or system requirements for the user. ArcIMS in concert with ArcSDE facilitate rapid data response and retrieval.

Habitat conditions at multiple spatial scales are correlated with the Fish Community Index scores. Habitat measures may be used as indicators of estuarine condition in addition to the biological functional response as reflected in the FCI. For instance, since correlations between habitat and biota were noted, if mechanistic processes can be determined and thresholds of response established, then shoreline condition surveys become an essential diagnostic management tool. Links among habitat conditions were substantiated in the relationships between subtidal habitat and shoreline condition, which indicated a negative association between shoreline alterations and available subtidal structural habitat. Further refinement of threshold responses to stressors by fish communities as reflected in the index will enhance restoration and management practices.

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GIS Data Sources

2004 Chesapeake Bay Submerged Aquatic Vegetation (SAV) Aerial Survey
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Virginia Based Mapping Program (VBMP) digital imagery. Aerial Imagery © 2002 Commonwealth of Virginia

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Appendix 1. Benthic Mapping Workshop participants

21 February 2006
Location: Virginia Institute of Marine Science, Gloucester Point, Virginia

List of Participants

Name	Organization	Contact
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Appendix 2. Benthic Mapping Workshop Agenda

Benthic Mapping and Characterization Workshop: Technology, Protocols and Collaboration

Meeting Location: Virginia Institute of Marine Science, Center for Coastal Resources Management, Gloucester Point, Virginia (CBNERRVA Wilson House Conference Room)

Tentative Agenda

February 20, 2006; Monday Night
5:00 pm--? Meet and Greet at a local watering hole—The Yorktown Pub

February 21, 2006 (High Tide at 1430)
Tuesday

830-1000	Welcome; goals of workshop; review of Monday night discussions; preparation for survey
1000-1200	Survey Sarah's Creek with multiple bottom mapping set-ups; this area has a variety of sediment bottom types and numerous crab pots*
1200-1300	Lunch
1300-1600	Survey Allen's Island and Goodwin Island. These areas and surrounds have SAV beds, oyster reefs, and a variety of sediment bottom types*
1600-1700	Begin post-processing of survey data (set-up to run overnight)

February 22, 2006 (High Tide at 1545)
Wednesday

830-1200	Open discussion and examination of post-processing results. Potential Topics: types of post-processing; how information is presented; compatibilities among protocols and technologies; classification schemes; comparison of marine debris survey methods; collaboration
1200-1300	Lunch
1300-1600	Additional survey time if necessary (coincides with tides)
1600-1700	Post-processing or continuing discussions

February 23, 2006
Thursday

900-1200	Conclusions, Collaborations, Future Work