FINAL REPORT

For

SOUTH CAROLINA'S 2004-05 INTERTIDAL OYSTER SURVEY AND RELATED REEF RESTORATION/ENHANCEMENT PROGRAM:

An Integrated Oyster Resource/Habitat Management and Restoration Program Using Novel Approaches

By the
Marine Resources Division
South Carolina Department of Natural Resources
Charleston, SC 29412

With Assistance From

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NOAA Center for Coastal Environmental Health and Biomolecular Research, Charleston, SC
US Geological Survey, Sioux Falls, SD
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Contributors

This program could not have been accomplished without the assistance of many individuals from several agencies and institutions. A summary of the project participants follows:

South Carolina Department of Natural Resources, Marine Resources Division.
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The Marine Resources Division served as the primary agency for this effort. Robert Van Dolah was the Program Coordinator and Lead Principal Investigator. Bill Anderson and Loren Coen were Co-Principal Investigators. Kristin Schulte and Mike Yianopoulos served as the leads for the ground-truthing field efforts and were the primary editors of the imagery products received from GeoVantage and Photo Science Inc. They were assisted by Amanda Powers, Lee Taylor, Ben Dyar, Steve Roth, Andy Hollis, Mike Hodges, Phil Weinbach, Susan Tobias, Margaret Gokturk, Jessica Boynton, Jordan Felber, Yvonne Bobo, and Donnia Richardson. Other MRD staff who assisted in this project included Martin Levisen, George Riekerk, and field staff for the SCECAP program during 2005-2006.

NOAA Coastal Services Center.
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The Coastal Services Center played a major role in assisting the MRD with the acquisition of imagery products and technical expertise in developing protocols for analyzing the imagery. Primary collaborators included Steve Raber, Mark Finkbeiner, and Bill Stevenson.

US Geological Survey.
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The US Geological Survey was also instrumental in assisting the MRD in obtaining the imagery products and served as the primary agency in hiring Photo Science Inc. to obtain the imagery and complete imagery analyses. Robert Kelly, Eric Anderson (at the CSC), and Eddie Schwertz were the principal individuals assisting us.

Photo Science Inc.
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Photo Science Inc. served as the primary contractor for obtaining the imagery products and assisting the MRD in developing analytical protocols to assess the imagery. They also completed much of the imagery analysis, with assistance from another subcontractor (MDA Federal).
Gary Florence and David Loy were the primary individuals contributing to this effort from Photo Science, Inc. and Francois Smith, Binesh Maharjan, and Kyle Cavanaugh were the primary staff involved from MDA Federal.

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The NOAA CCEHBR Laboratory was instrumental in assisting the MRD with Objective 5, which involved analyzing oysters for bacterial and metal contaminant concentrations. Primary individuals assisting in this effort were Jill Stewart, Jan Gooch, Laura Webster, Mike Fulton, Ed Wirth, and their support staff.

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Virginia Shervette, who was originally working at the MRD during the course of this project, continued to assist the project with respect to the analysis of Objective 5.

Project Description

Background and Rationale

The eastern oyster *Crassostrea virginica* was once a dominant feature of most Western Atlantic and Gulf coast estuaries, but has declined drastically across the U.S due to declines in water quality, increased disease pressure, other anthropogenic affects and changes in related ecosystem dynamics (Rothschild *et al*. 1994, Lenihan 1999**,** Jackson *et al*. 2001, Coen and Luckenbach 2000). These perturbations include: (1) over-harvesting, (2) physical disturbances by storms, harvesting, and boat wakes, (3) diseases, (4) nutrient enrichment through runoff, (5) natural predators, (6) alteration of natural flow regimes and salinity patterns, and (7) loss of appropriate substrate for new recruits.

Once valued primarily as a fisheries resource, oysters are now recognized as key elements of many estuarine ecosystems (Coen *et al*. 1999a,b, Luckenbach *et al*. 1999, Jackson *et al*. 2001, Lehnert and Allen 2002). Oysters create complex three-dimensional habitats that are utilized by fish, crustaceans, bivalves, birds, and mammals. Oysters filter large quantities of water, improving water clarity and quality, while linking the overlying water column with the benthos through the process of 'benthic-pelagic coupling' (Dame 1996**,** Lenihan 1999, Dame *et al*. 2001). In South Carolina, as elsewhere in the southeastern U.S., oysters are predominantly intertidal, often forming protective breakwaters that retard shoreline erosion (Grizzle et al. 2002, Coen and Fischer 2002, Coen and Bolton-Warberg 2003). Oyster reefs also serve an important ecological role as an 'Essential Fish Habitat' (EFH) as they form living structures that support diverse assemblages of associated organisms that are generally not found in surrounding sand or mud habitats (Coen *et al*. 1999a,b, Harding and Mann 1999, Coen and Luckenbach 2000, Peterson *et al*. 2003, Luckenbach *et al*. 2004).

Recognizing their importance as both critical habitat and a harvestable resource, in 1980 the SCDNR initiated a comprehensive statewide oyster resource assessment. This field intensive intertidal oyster survey determined the areal extent of natural populations, bushels per unit area, live and total volume (including dead shell) and quantities of the northern quahog (*Mercenaria mercenaria)* through on-site measurements. Ancillary data, including identification of nine oyster bed strata (characteristic spatial dispersions of natural oyster populations), shell matrix depth, bottom type, salinity and identification of bottom areas suitable for shellfish propagation, were mapped on 115 quarter-quads (1:12,000 scale) for resource management purposes.

Estuarine areas closed to harvesting by fecal coliform pollution were surveyed first, followed by surveys of commercial leases. State shellfish grounds (common property harvest areas) were assessed last. Public shellfish grounds and some intertidal shellfish grant areas were not surveyed due in part to limited State jurisdiction on bottomlands conveyed by the State legislature or British Crown to individuals and estates.

The results of this significant oyster bed survey were documented originally on field maps, later transferred to Mylar® film, and subsequently digitized into the SCDNR's Geographic Information System (GIS). Attribute data were then linked to each digitized polygon. GIS data layers consisting of shellfish management categories and resource data have

been used to quantify culture permits (formerly leases), and determine annual rental fees and shellfish husbandry requirements. Certified maps (8.5" x 11") have been issued with commercial shellfish permits. Additionally, management categories have been used by the South Carolina Department of Health and Environmental Control (SCDHEC) to track harvest areas for public health requirements.

Survey efforts required more than 10 years of intensive field assessments interspersed with some extended periods without surveys due to the complexity of the SC coastal habitats, which include many tidal creeks that wind through extensive vegetated wetlands and shorelines associated with the larger bays, sounds and tidal rivers. An updated resource assessment is critically needed for management and research purposes as coastal populations and development have increased significantly and environmental perturbations occur more frequently on shellfish bottoms. Of particular interest is the resource status within common property boundaries that include State Shellfish Grounds (SSGs) and Public Shellfish Grounds (PSGs) that are harvested both commercially and recreationally—some more intensely than others.

From 2003-2006, the SCDNR and NOAA's Coastal Services Center (CSC) conducted Phase I of a project intended to determine the distribution and general characteristics of SC's intertidal oyster beds through the analysis and ground-truthing of digital aerial high-resolution multi-spectral imagery (MRD 2007). The objectives completed and reported in Phase I that pertain to the current Phase 2 study included: 1) acquisition and analysis of 0.25 m^2 multi-spectral imagery covering the coastal zone of SC containing known oyster resources; 2) extensive ground-truthing of these areas to confirm the accuracy of image analysis; and 3) providing the SCDNR and other users with a map of SC oyster resources as well as the imagery used to produce this map. All imagery was acquired in Phase I; however, due to weather, plane availability, and the need to re-fly some imagery to meet CSC criteria, the initial subcontractor (GeoVantage Inc.) conducting the flights was unable to complete their task. Photo Science Inc. subsequently acquired the remainder of the imagery using a different camera system. Areas flown were organized by state digital ortho-photo quarter quads (DOQQs), and in total 123 DOQQs were captured. The imagery was posted on the SCDNR ftp site for public download. SCDNR staff partially ground-truthed 60 of the DOQQs by boat, capturing data for approximately 100 GPS measured reefs in each. Image analysis was completed by Photo Science Inc. for 75 DOQQs, but they were unable to complete the remaining analysis in a timely manner with the required accuracy.

The current Phase II project, developed in conjunction with the Phase I study efforts to obtain low altitude, high resolution digital imagery of the SC coastal zone, represents a significant update to the SCDNR's knowledge of the distribution and condition of SC's extensive oyster resources. This product will be invaluable for future management decisions and will ultimately allow us to better understand how oyster conditions have changed in the past 20+ years.

In addition to better understanding the current distribution and status of oyster beds in SC, SCDNR staff is exploring their value as a sentinel of habitat condition. In 1999, the SCDNR initiated a major new cooperative monitoring program with the SCDHEC to evaluate the condition of our estuaries with respect to general environmental quality and biotic condition.

This program, entitled the South Carolina Estuarine and Coastal Assessment Program (SCECAP, Van Dolah *et al.* 2002) provides an unbiased, state-wide assessment of estuarine habitat quality, but it currently does not include any measures of biotic condition using oysters. The expansion and coordination of both the shellfish and environmental monitoring programs offers considerable opportunity to enhance the SCDNR's understanding of relationships between general environmental quality (water and sediment quality) and the condition of SC's oyster resources. The Phase II effort of the Oyster Survey Project therefore includes a component to evaluate oyster condition in conjunction with the SCECAP sampling effort.

Program Goals and Objectives

The primary goal of this project was to build additional value into the Phase I study that involved collecting high resolution 0.25 m^2 digital airborne multi-spectral imagery in order to analyze the distribution and extent of intertidal oyster beds in South Carolina to the extent feasible by the imagery. Using this imagery and other information, we also planned to enhance some of SC's oyster grounds through the addition of shell substratum in areas where existing beds were in poor condition. Additionally, we initiated efforts to evaluate the potential of oysters to serve as environmental sentinels in conjunction with the ongoing SCECAP effort.

Specific objectives included:

1. Completing additional post-processing of the imagery obtained during Phase I of this program, as needed, to improve our characterization of oyster bed condition;

2. Completing additional ground-truthing of the aerial imagery in DOQQs that were not visited during Phase I of the program (approximately 50%) to confirm imagery results and conduct additional field assessments of areas of special concern, such as selected oyster culture permit areas, SSGs, and habitats with high potential for restoration;

3. Finishing development of GIS products that provide both the imagery and shellfish resource information and delivering those products through the SCDNR's web site to maximize the availability of data to all users;

4. Conducting large- and small-scale restoration efforts directed by the SCDNR's scientific and management staff using adaptive management approaches that build upon past studies and techniques developed by the SCDNR;

5. Conducting a pilot assessment of the condition of SC's oyster beds and associated habitats with respect to water quality, sediment quality, oyster bed 'condition' including incidence and prevalence of diseases, bacterial and contaminant concentrations, and oyster physiological condition in cooperation with the ongoing SCECAP monitoring program.

Summary of Activities Completed:

Objective 1. Completing additional post-processing of the 0.25 m^2 digital aerial multi-spectral imagery obtained during Phase I of this program, as needed, to improve our characterization of oyster bed condition.

SCDNR staff developed a detailed Scope of Work for analysis of the imagery that had a "Base" analysis as well as Option 1 and Option 2 analyses (Table 1.1, Appendix 1, 2).   The successful subcontractor, Photo Science, Inc., was only able to provide the "Base" analysis with the funding available during Phase I of this study. With additional funding for Phase II, Option 1 and 2 analyses were authorized to be completed and we modified our agreement with USGS, who subsequently modified their agreement with Photo Science, Inc.

Table 1.1. Minimum Intertidal Oyster Strata--Combined SCDNR Classifications.

Product	Class	Description
Base	1	All vertical and horizontal oyster beds – i.e., predominantly live oyster shell matrix
	2	Washed shell – i.e., bleached (bright) shell deposits
Option 1		Class 1 from the base product with a modifier that provides a measure of live or dead vertical shell – best described as percent "shadows" in each polygon and or reflectance that equates to complex shell beds
	1.a	Oyster polygons with a high percentage of vertical oyster "texture" per area
	1.b	Oyster polygons with medium percentage of vertical oyster "texture" per area
	1.c	Oyster polygons with a low percentage of vertical oyster "texture" per area
	2	Washed shell
Option 2	1.1	Vertical and horizontal oysters, representing consolidation of SCDNR strata E, A, F, and F1
	1.2	Vertical standing oysters surrounded by mud matrix generally less than 1 meter apart, representing SCDNR strata G and C
	1.3	Low intertidal horizontal oysters and shells, representing SCDNR strata B and D
	2	Washed shell (see Base, class 2 above)

After repeated attempts to complete a successful analysis of the imagery that incorporated Option 1 and Option 2, the subcontractor was unable to provide us with analysis products that met the required QA/QC requirements (70% accuracy for Options 1 and 2) for the first 4.5

imagery batches (approximately 50% of the total). Option 1 was tested in half of Batch 5 using the new imagery flown by Photo Science, Inc., but it failed to perform any better than the imagery used for the first four batches. They were then unable to meet the 80% accuracy requirement of the Base product for the remaining three batches.   The agreement with Photo Science, Inc. was therefore terminated, and project staff at the DNR began intensive efforts to evaluate the remaining imagery and fix known errors in the imagery products provided by Photo Science, Inc.

Much of the protocol used for the final analyses conducted on the imagery incorporated the analysis protocols developed by Photo Science, Inc. and associated staff. A summary of their process is provided in Appendix 1 for the Base analysis, and in Appendix 2 for the attempted effort to complete the Option 1 and 2 analyses.

Photo Science, Inc. tested several methods for mapping oyster reefs and delivered their final recommended methodology, which they judged to be the most accurate and efficient. Complete automation of the process was not possible due to the variable appearance of the oyster reefs and the imagery itself. The process developed was applied to each photo individually for the best product. Training polygons were created for each photo and entered into Feature Analyst for automated feature extraction/creation. Most reefs selected as training polygons were considered to be representative of the majority of reefs in the image. Excessive variation in a training set gave poor results. Generally, training sets were developed separately for fringing reefs, patch reefs, and washed shell due to differences in appearance of the three shell bed types.

A mask was created to segment the image and remove areas devoid of oyster habitat. Photo Science Inc. accomplished this by training Feature Analyst to extract the creeks. A buffer around the creeks was added to include all fringing reefs. This file was selected as a "region of interest" in Feature Analyst, and oyster beds were classified only within these boundaries. Patch reefs were trained separately and a mask for those areas was created by hand. The settings used within the software to run the extraction were as follows:
- Within Feature Analyst's Set-Up Learning step, the Image Resolution was set at 1 ft.
- The Manhattan 5x5 Input Representation was determined to be the most versatile and was used for most extractions.
- Within Learning Options, "Aggregate Areas" was set at a minimum area of 64 pixels
- "Find rotated features" was checked.
- All primary extractions were run with the learning algorithm "Approach 1".
- When layers were filtered for incorrect features (clutter), "Approach 2" was used.
- When using Approach 2, better results were sometimes obtained using the Foveal Input Representation instead of Manhattan 5x5, and pixel aggregation was set at 120 instead of 64.

After the files were created, the washed shell file was used to clip the live shell file to remove any overlapping polygons. The products were then reviewed for stray slivers remaining from clipped reefs, missed creeks, and any other obvious errors. Manual edits and additions were generally minimal. Extensive manual editing was only used if an acceptable product could not be derived from automation.

Photo Science, Inc. also subcontracted MDA Federal, Inc. (formerly Earth Satellite Corp.) to develop a method for oyster bed classification based on the percentage of vertical oyster to deliver Options 1 and 2. While this effort was not ultimately successful, a brief summary of the approach is provided in Appendix 2.

After the contract was ended with Photo Science, Inc. in April 2007, the SCDNR took over the duties of mapping the remaining imagery. The methodology was amended slightly in that all masks were hand digitized since the process for training water and adding a buffer was too time-consuming for the purpose it served. Additional training sets for fringe reefs and patch reefs were also used when the color or texture of shell differed widely within an image due to light angles, dryness of the shell, or degree of contrast with surrounding mud. Using the resulting files from all training sets, a new final layer was created to incorporate the best polygons from each file. Any manual edits deemed necessary such as clipping, hand delineating new reefs, or deletions were also done at this time. Although a bit more time consuming, this provided a more satisfactory product. Further editing was only needed after the official QA/QC process was completed, and field data were used to correct any additional errors.

The SCDNR is continuing to manually check and edit all products completed by Photo Science Inc. using known information about oyster resources. This includes using additional data collected by boat, from viewing low-altitude photographs collected by helicopter, and visual interpretation of the images. Only obvious errors are corrected, so as not to decrease any accuracy scores an image received during the QA/QC assessment.

QA/QC Procedures:

The accuracy of the base product was scored using two metrics: 1) the presence/absence of oyster reefs adjoining each field transect measured, and 2) the extent of the reef that was captured. For presence/absence, a matrix of four possible scoring categories are available: 1) Correct positive (correct shell), 2) Correct negative (correct mud), 3) False positive (mud incorrectly classified as shell), and 4) False negative (shell incorrectly classified as mud) based on actual field verification using the ground-truthing protocols described in Objective 2. If 25% of the measured transect contained the correct classification, it was scored as correct. If the reef was covered by vegetation or submerged underwater in the image, the transect was not included. The score reported for presence/absence was calculated as the number of correct classifications divided by the total number of scores. To score extent, if more than 10 m of the field transect was incorrectly classified as oyster, it was scored as incorrect. If the extent of the mapped reef exceeded that of the field transect, we reviewed the video records (see Objective 2 for methods). If the tide in the video appeared to be covering shell that was captured on the image, the length was not graded. Oyster reefs that extended past the transect could be graded as correct if notes were made in the field record about the inaccessibility of the remaining shell from the boat. Reefs that extended past a transect could only be graded as incorrect if there was no doubt on the error. A set of additional rules was created for our grading system because nearby transects and oyster reefs often overlapped each other. These rules are included in Appendix 3. Extent was scored as the number of correct lengths divided by the total number of scores.

The accuracy of reefs using Options 1 and 2 were graded using a pass or fail method. Percent vertical estimates were considered correct if they were within 20% of the DNR's estimate using the video protocols described in Objective 2. If there were multiple reefs per DNR transect, a weighted average was calculated from the reefs. If there were multiple DNR transects per digitized reef, a weighted average was calculated for the transects and one score was recorded. The nine strata used to assess oyster reefs were condensed into three classes for Option 2: 1) High to medium percent vertical oyster on a horizontal shell matrix (SCDNR classes A,E,F,F1); 2) Vertical oyster on a mud matrix (SCDNR classes G and C), and 3) Low percent vertical oysters on a horizontal shell matrix (SCDNR classes B and D). A reef was scored as correct if the classification included DNR's reported dominant strata. If there were multiple reefs covered by one SCDNR transect, the dominant strata by area among the reefs was used for comparison. If there were multiple SCDNR transects covering one digitized reef, the dominant strata among the transects was used and only one score was assigned. Appendix 3 contains further details of these rules.

The accuracies of the Base option, and Option 1 were assessed using low-altitude helicopter photos (see Objective 2 for processing methods). The scoring methods used for the boat GPS transects had to be amended slightly for the hand-drawn polygons created using the helicopter photos. For scoring the presence/absence of reefs, a > 25% overlap in the area of the helicopter polygon and the Photo Science, Inc. polygon was required. To grade extent, a 1 m buffer on either side of each polygon was created. This accounted for digitizing errors of the often indistinct and "fuzzy" edges of reefs. If there was an area of 10 m^2 (with a 1 m width minimum) that Photo Science Inc. either missed or captured in excess, reefs failed the extent score. Strata were also recorded from the helicopter assessments and were used to score Option 1 using a range of values for the percentage of vertical oysters. These ranges were determined from our video database records (Objective 2) of percent vertical oysters and strata. These ranges and details of helicopter QA/QC rules are included in Appendix 3.

The images were processed based on batches of 15 DOQQs. Half of the DOQQs in each batch were partially ground-truthed. For each DOQQ scored, the two base product metrics were averaged for an overall score. If the cumulative score of the batch was greater than 80%, it was accepted. If not, the failing DOQQs were returned for reprocessing, as well as any images that were not ground-truthed and had obvious problems. Individual DOQQs that failed in an "accepted batch" are currently being edited by the SCDNR. For Option 1 and Option 2, scores had to exceed 70% accuracy to be accepted.

Edge-matching:

Edge-matching of the shellfish polygons was performed by SCDNR staff on both live and washed shell layers produced from the Feature Analyst software for each DOQQ. There were two general steps to editing these layers; editing within DOQQs, and working between DOQQs. For each of these steps, the washed shell layer was processed prior to analyzing the live shell layer.

Editing within DOQQs began once all completed shape file DOQQQs (a quarter of a DOQQ) were received. There were between 1 and 4 DOQQQs per DOQQ depending on the

location within SC's coastal zone. Sections comprising each DOQQ were merged together into one DOQQ file and imported into a geodatabase. The adjoining DOQQQ boundaries within each DOQQ were checked for overlapping or duplicate polygons. These polygons were either merged or one was deleted. When choosing between polygons, the polygon with more attribute information (e.g. helicopter data, see Objective 2) or the polygon associated with the photo within the same DOQQ was chosen. Washed shell layers were used to clip the live shell layer using the Erase tool. After the washed and live shell layers were edited, a new ID column was created that identified the quad, the quarter quad, the year, and whether it was live or wash shell (e.g. adamrNE2008oysterW).

After all DOQQs had been added to the geodatabase, edges between adjacent DOQQs were edited. Starting with the washed shell layer, several adjacent DOQQs were opened and compared, presenting three possible issues to be resolved. First, any polygons that crossed DOQQ boundaries were cut and appended into one or the other DOQQ washed/live feature class. Second, because polygons were digitized from several photos, some polygons were associated with the wrong quarter quad. Any polygons that appeared in the wrong quarter quad were selected, appended to the proper file, and then deleted from the original file. Finally, some polygons were duplicated or overlapped multiple quarter quads. These polygons were either merged or one of the duplicate polygons was deleted. If necessary, these polygons were appended into the appropriate quarter quad feature class. When choosing between polygons that represented the same shellfish bed, we always chose the polygon associated with the photo in that quad, not the adjacent quad and photo, unless the combination of the polygons better represented the shellfish bed, in which case, we merged the two polygons. Our final product was a geodatabase containing a live shell file and sometimes a washed shell file for each DOQQ photographed. These DOQQs were merged into one statewide live shell file, and one statewide washed shell file for posting on the internet. This merged file is edge-matched, but contains seams along the boundaries of each DOQQ.

Results and Discussion:

Project staff has successfully completed editing of 63 of the 123 DOQQs (total of 443 DOQQQs). This slightly exceeds our planned assessment of 50% of the DOQQs flown (Appendix 4). Many other DOQQs have been partially edited and staff continues to work on the database to make the DNR shellfish maps as accurate as possible.

The accuracy scores for the ground-truthed DOQQs are listed in Appendix 4. These scores represent a minimum accuracy level for each DOQQ. However, many of these DOQQs have been improved by SCDNR, so the actual quality of the map will be some degree higher than the reported accuracy. Additional data would have to be collected to rescore the edited DOQQs. Overall, the data set as a whole has an average score of 88% (S.D. = 7.94) for presence/absence of oyster reefs and 84% correct (S.D. =9.32) for extent. Of the 60 DOQQs scored, 10 failed to meet the 80% correct accuracy level for presence/absence, and 14 failed for extent. None of the scores for presence/absence, however, were less than 70%, and only 5 were less than 70% for extent. Low scores tended to reflect poor image quality or poor visibility of oyster reefs. Reef edges often taper off with decreasing oyster density, so errors were often

higher for extent than for reef presence/absence. Errors will be continually corrected as they are encountered.

An example of the oyster map product resulting from this effort is shown in Figure 1.1. A map of the DOQQs that were flown and have been fully edited is shown in Figure 1.2. Although many of the DOQQs have not been fully edited, the data products are available online with appropriate metadata to indicate the status of final editing (see Objective 3 for more information).

The latest SCDNR oyster maps have identified a total of 139,166 live oyster beds that represent a total of 1,930 hectares (4,768 acres) located throughout the SC's coastal waters. An additional 207 hectares (512 acres) of washed shell beds were also identified.

While not perfect, these oyster maps represent an update to SC's historical data on the distribution of oyster reefs. In the future, beyond the scope of this project, we plan to utilize these new maps in management efforts, and research activities, including a detailed change analysis of how the distribution and extent of South Carolina's oyster resource has changed over the past 20+ years. We will continue to update and edit these maps as new data become available.

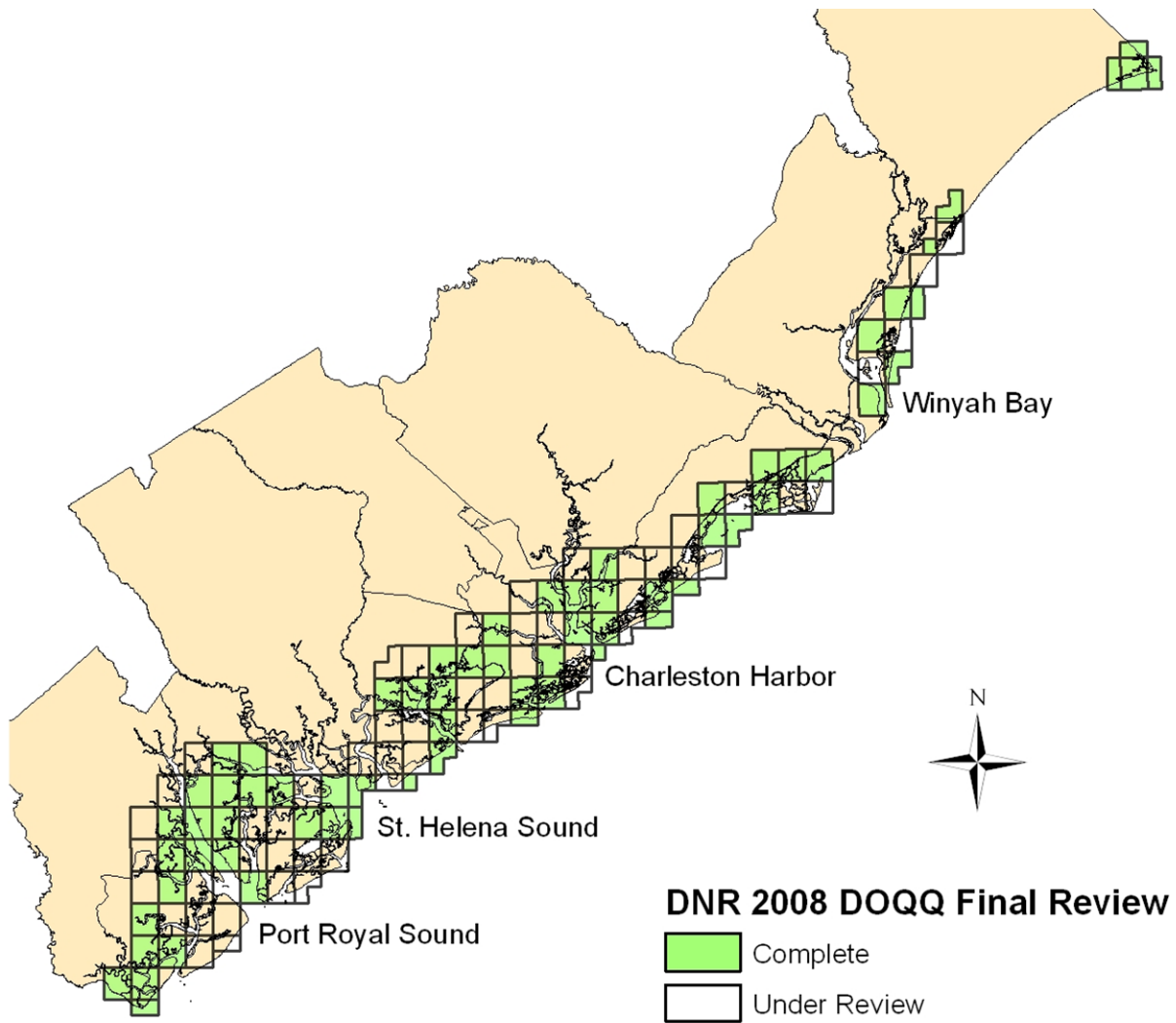Figure 1.1. Example of oyster polygons overlaid on imagery product.

Figure 1.2. Summary of DOQQs that have undergone final review. Additional DOQQs have been partially edited and efforts will continue beyond the specified grant period.

Objective 2. Completing additional ground-truthing of the aerial imagery in DOQQs that were not visited during Phase I of the program (approximately 50%) to confirm imagery results and conduct additional field assessments of areas of special concern, such as selected oyster culture permit areas, SSGs, and habitats with high potential for restoration;

Ground-truthing:

Sixty of the 123 DOQQs flown for this project were partially ground-truthed by boat for accuracy assessments. Using a Trimble XR GPS unit, approximately 100 reefs in each DOQQ were measured. The areas had to be assessed before the imagery was available, so efforts were made to randomly select reefs spread out over the DOQQ using historical maps of oyster reefs as a guide. Some DOQQs did not have 100 accessible reefs to measure, so in these cases as many reefs as were accessible were measured. Reefs had to be ≥ 10 m^2 in area as per the contract agreement with Photo Science, Inc. Using the GPS unit, transects were measured lengthwise for each reef by collecting points at each end of the reef. At the end of each transect, the dominant strata and the estimated average width was recorded. If an edge of a reef could not be reached with the GPS, an offset distance was estimated and noted for correction within GIS software. Alternatively, if there was an extensive area that was not accessible by boat, a note was made that the reef was not measured completely. The end of a reef was normally marked where there was an adjacent area devoid of oysters at least 5 meters in length and 10 m^2 in area. For oyster hummocks, additional points were sometimes collected around the mound to better estimate its size. For oyster flats that were too large to estimate width, a "sample width" was recorded and noted as such. Within this "sample width" the dominant strata within that area was recorded. In addition to the oyster reefs, approximately 30 areas of textured mud or sand were marked to check for occurrences of mud classified as oysters. Ground-truthing efforts were conducted no more than 2 hrs before or after low tide. Data collected from these efforts were used to score the accuracy of the digitization process.

A video of the entire length of each reef was filmed, and subsequently used to approximate the percentage of vertical live shell contained in each reef. As each reef was recorded, changes in oyster strata and reef width were announced as they became apparent. During the video process, the boat maintained a speed of approximately 2-3 mi/hr and a distance of 3-6 m. from the reef edge when possible. Notes were made if these limits were exceeded. These videos were reviewed by two staff members. One person viewed the entire video, and the other reviewed a portion for quality control purposes. Assessments of the video footage were made at five second intervals. For each video segment an estimate of the percentage of vertical oyster and the dominant strata was entered in an Access database. The data was averaged for each reef and was used for scoring the accuracies of Option 1 (percentage of vertical oyster) and Option 2 (oyster strata).

Low-Altitude Helicopter Validation:

Areas not accessible by boat or not previously ground-truthed have been photographed from a helicopter at an altitude of 200-400 feet. They were initially taken to aid in the QA/QC process of assessing Photo Science, Inc.'s accuracy, but since the termination of the contract, the photos have been used as a tool to correct mapped areas. A Trimble Pro XRS GPS was used in the helicopter to collect continuous points along the flight path r. In conjunction with the

positional data, information regarding the oyster strata and its variability were entered into the Trimble TSCe datalogger. Photos were collected using a Canon EOS 30D 8.2 megapixel SLR digital camera. All photos were collected +/- 45 minutes around negative low tide during mid-day to ensure all oyster reefs were exposed and sun angle problems minimized.

Helicopter photos were used to create hand-drawn reefs on the multi-spectral imagery for QA/QC purposes and to correct errors in the automated maps. For initial QA/QC, a few select areas were flown in DOQQs, mainly over oyster flats. These areas were manually mapped by DNR for comparison to the automated map product. More recently, helicopter photos have been taken to cover an entire DOQQ for the purpose of completing the accuracy of the map product. Using GPS points as a guide and the chronological file of photos, all reefs along the flight patch were checked and edited for accuracy in ArcGIS 9.2 using the original georeferenced photo mosaic imagery as a base map. For each reef edited, a linked table was created to reference the photo used for editing the designated strata of the reef. A map was created for each mission that showed the flight path and select photos were marked on the map as an index for referencing photo location. A large data storage system is being devised to house this data as well as other related oyster monitoring data. The helicopter survey approach used in conjunction with the georeferenced imagery has proven to be highly accurate as well as expeditious, allowing staff to categorize oyster reefs using the more detailed DNR oyster reef density classification scheme, and allowing for a relatively easy and accurate way to correct the existing aerial imagery with respect to the location and extent of the reefs. DOQQs not yet ground-truthed by helicopter are scheduled for future flights that will significantly enhance the accuracy of the final product.

Results and Discussion:

Project staff were able to measure the location and extent of 5,059 live oyster reefs, 170 washed shell beds and 1,278 mud banks (for the evaluation of potential false positives) as part of the ground-truthing effort. All live and washed shell beds were documented with respect to oyster strata using the 9 classifications defined by the SCDNR. An additional 25,597 live oyster beds and 1,909 washed shell beds were surveyed using the helicopter photography, and 4,697 of these beds were edited or added to the database by the end of the project period. The area of reefs surveyed by helicopter covered approximately 3,395 hectares of live shell beds (839 acres) and approximately 636 hectares of washed shell. This combined effort completes the most significant ground-truthing effort ever conducted on South Carolina oyster beds since the original survey was completed in the 1980s and early 1990s. Such an intensive survey effort would not have been possible without the funding provided by NOAA.

Based on the ground-truthing efforts completed by boat, which should be representative of the state's overall oyster resources due to the large number sites visited throughout each DOQQ, we have a much better understanding of the current distribution of shell bed types based on SCDNR's 9 strata classifications (Figure 2.1; Appendix 5).

The most abundant strata were F1 and G, which comprised 27% and 25% of the living shell bed types, respectively. F1 oyster beds represent a mix of vertical standing and horizontal oysters and G oyster beds represent beds with vertical clusters separated by mud or muddy sands. The next most abundant strata were C, D, and F oyster beds, which represented 14.5%, 14% and 14% of the living oyster beds surveyed, respectively. C strata represent vertical oyster stands

that are less spatially dense than those found in G strata, D strata represent mostly horizontal oyster shell with very little live crop, and F strata represent primarily vertical standing crop with little mud substratum in between the standing oysters, as compared to G and C strata. The most dense strata, A and E, represented only 5% of all live oyster beds evaluated, and the ninth strata (M), which is not shown in Figure 2.1, was too dispersed in small clumps to warrant inclusion. M strata that have very little standing crop, would not normally be identifiable using the remote digital survey techniques.
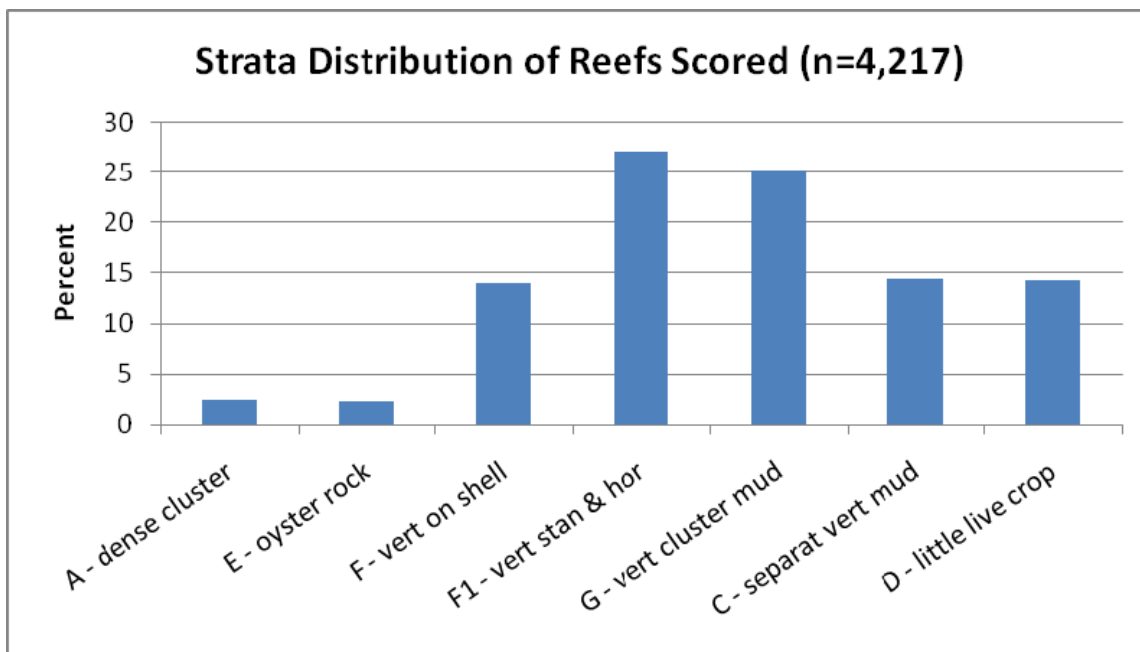
Figure 2.1. Distribution of the 9 oyster strata classifications based on ground-truthing surveys by boat in 60 DOQQs located throughout South Carolina's coastal zone. Due to matching errors in the database files, fewer reefs were used in this graphic than were actually ground-truthed.

A similar evaluation was made using just the helicopter surveys, which were more targeted to oyster flat areas. The results of this survey identified C strata as the most abundant class of oyster bed (47%) followed by the G and F1 strata (26% and 20% respectively, Figure

2.2). The remaining strata never represented more than 5% of the live oyster beds.
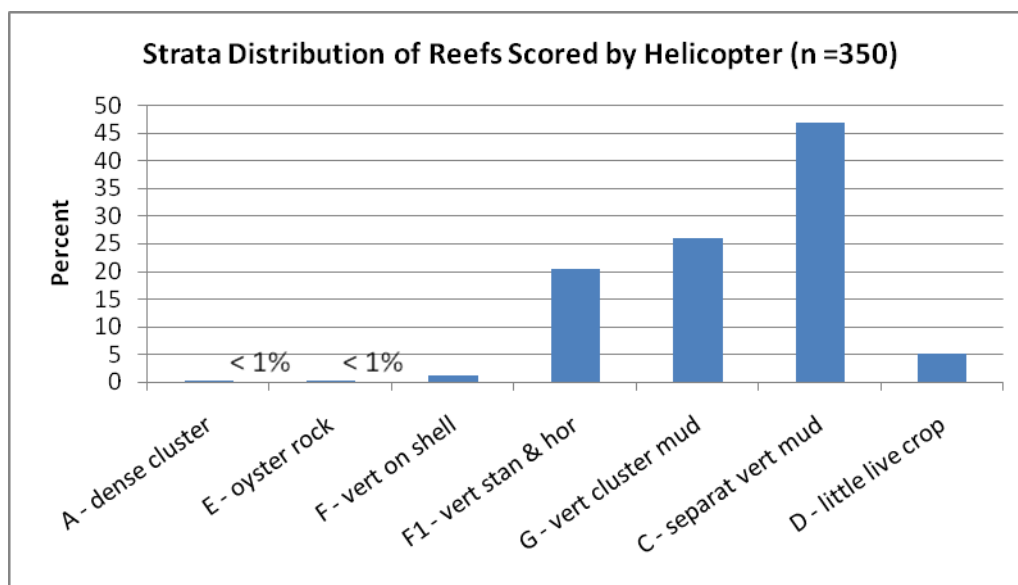
Figure 2.2. Distribution of the 9 oyster strata classifications based on ground-truthing surveys by helicopter in DOQQs located throughout South Carolina's coastal zone. The majority of helicopter flights were targeted towards oyster flats which were not readily accessible by boat.

The ground-truthing effort provides useful data on the percentage of oyster beds representing each strata that was missed or the bed length was incorrectly identified, based on the boat and helicopter surveys (Table 2.1). Results indicated that C strata were not well documented by the imagery compared to the other classes assessed by boat, and those areas ground-truthed by helicopter indicated that F1, G, and C strata were omitted in near equal proportions (21-24%). It is important to note that the helicopter ground-truthing was done primarily over oyster flats. It was initially assumed that oysters in flats would be easily visible; that assumption is often not true. The contrast in color between the mud and oyster is sometimes low, and if the oyster clusters are small or sparse, they can be easily overlooked. Additionally many flats are composed of clusters of oysters that are so spread out, they lack a cohesive edge (mostly C strata). These areas are not easily captured by computer or by manual digitizing.

Strata representing dense clusters (A and E) were missed in the aerial imagery 5-19% of the time. These strata were relatively rare, however, so each overlooked reef accounts for a larger percentage of the total for that reef strata compared to the much more abundant strata (e.g. G and F1). Dense clusters were expected to be easily identifiable, but they often had widths (≤ 1 m.) and were located up against the marsh, making them less visible.

The percentage of reefs with incorrectly identified lengths in the imagery ranged from 0-24%, depending on the strata and ground-truthing protocol. The greatest errors were observed in C and D strata for beds assessed by boat, and in F1, C and D strata for beds assessed by helicopter (Table 2.1). Most of the beds with incorrect lengths were underestimated by the

imagery. This would be expected since the ends of an oyster bed often grade off into fewer and fewer oyster clusters compared to the middle of the bed. Reefs comprised of primarily C and D strata have a low percentage of live oyster, so they might be more likely to have poorly defined edges.

Table 2.1. Mapping Errors by Strata: Reef errors were totaled by strata and divided by the total number of reefs scored for that strata type.   Reefs were counted as missed (False Negative) if less than 25% of the area of a reef was captured for scoring with boat and helicopter data. Reef extent (horizontal length) was considered incorrect if more than 10 consecutive meters of shell were missed using boat data. For helicopter data, the extent was incorrect if there was a cohesive area of $10m^2$ or more that did not overlap with the reef manually digitized from helicopter photos. This $10m^2$ was calculated after the subtraction of a 1 m. edge buffer from the manually digitized reef.

Oyster Strata	Groundtruthed by Boat		Groundtruthed by Helicopter	
	Missed Reefs (%)	Incorrect Extent (%)	Missed Reefs (%)	Incorrect Extent (%)
A - dense cluster	19.42	11.11	0.00	0.00
E - oyster rock	5.10	6.45	0.00	0.00
F - vert on shell	7.81	15.24	0.00	0.00
F1 - vert stan & hor	9.17	18.02	21.13	17.86
G - vert cluster mud	14.61	15.57	24.18	5.88
C - separat vert mud	28.52	23.93	24.39	16.95
D - little live crop	9.27	23.83	5.56	23.08

Objective 3. Finishing development of GIS products that provide both the imagery and shellfish resource information and delivering those products through the SCDNR's web site to maximize the availability of data to all users.

The DNR maintains a Geographic Information System (GIS) Data Clearinghouse that provides access to digital soils, wetlands, digital line graphs, digital raster graphics, digital orthophoto quarter quadrangles (DOQQs), digital elevation models and other natural resource information through its Internet portal. This is implemented through quadrangle-based queries and downloads of Arc-Exported vector and MrSid compressed raster data. These data must then be imported by the user group into client resident software for subsequent analysis and display. The system was developed using the Oracle Application Server and relational database management system. Although successful, the system lacks the ability to view more than a cursory number of GIS map and image files. As a result, the SCDNR began converting the GIS Data Clearinghouse from a download-only format to an Arc Internet Map Server base, thus providing users with the functionality to display, query and download digital spatial data using standard quadrangle-based templates or customized project boundaries. This enhanced system is currently operational.

This oyster survey project has generated an enormous volume of high-resolution multispectral data that will benefit a wide variety of researchers, resources managers and public citizens. These data are highly desired by staff in the SCDNR for management purposes, as well as by staff in other agencies, such as DHEC for a variety of purposes. In addition to the oyster maps, the SCDNR is providing the actual image files to the public and other local, state and

federal agencies as needed. These may include enforcement actions in the coastal critical zone, assessment of the number and size of dock structures, analysis of land use patterns, evaluation of distribution, size and characteristics of marsh hummock islands, and many other possible uses.

Approximately 300 gigabytes of 4-band (Red, Green, Blue and Near-Infrared), 0.25 m^2 resolution uncompressed imagery has been generated. One significant objective of the program was to make these data available over the World Wide Web for display and access. The Technology Development Section of the SCDNR has partnered with the Marine Resources Division to develop an 'information infrastructure' to provide high speed access to the imagery and relevant vector data layers as requested.

Our *web implementation strategy* has two basic objectives: (1) to provide viewable high resolution, multispectral imagery over the Internet; and (2) to provide file transfer capabilities for user-download of selected data.   The large-scale spatial resolution of the imagery (0.25 x 0.25 meters) results in orthophoto images that are over 600 megabytes each in their native format, so they have been compressed to 25 megabytes each in Jpeg2000 format with negligible data loss or effects on display. They are available for download in natural color or near infrared format from our ftp site, ftp://www.dnr.sc.gov/pub/gisdata/doqqq/. A link is provided from a web page describing the imagery, http://www.dnr.sc.gov/GIS/descdoqqq.html. The vector shape files of the digitized oyster footprints are also available on the ftp for download and can be linked to from the main project webpage, http://www.dnr.sc.gov/GIS/descoysterbed.html.   General metadata for the oyster layers are also available on this webpage.

There are two other options for accessing our data online. Users of any GIS software, including ESRI's free version ArcExplorer, can connect to the imagery and oyster data through an internet connection with a GIS service. A link to instructions for use of this GIS service is at the bottom of the main project web page. This service uses a raster catalog for easy viewing of imagery in GIS software. For users that do not wish to use GIS software, a second option will be available in the coming months. SCDNR has an interactive "Data Viewer" that will enable users to view and conduct simple queries of various data layers directly online. This service is currently online at http://scdata.dnr.sc.gov/website/dnrviewer/viewer.htm, but has limited data and is still under development. Our data is not posted here at this time.

Objective 4. Conducting large- and small-scale restoration efforts directed by the SCDNR's scientific and management staff using adaptive management approaches that build upon past studies and techniques developed by the SCDNR.

Project staff were able to complete both large scale and small scale restoration efforts as a result of this grant. Project staff developed a scope of work to plant shell in several locations in Beaufort County along shorelines that have been documented to be in poor condition, but which should support oyster beds. Planting was also completed in the Murrells Inlet area using some of the funding from this grant. A summary of planting activities is provided in Table 4.1

Table 4.1. Summary of oyster bushels planted during 2005 as part of this program.

Beaufort County

Dates 2005	Shellfish Ground	Amount Planted (bushels)	Length of Shoreline (m)	Area Planted (m^2)
5/23 thru 6/23	Distant Island Creek S-117	19,578	440	4,062
6/28 thru 8/09	Wallace Creek S-118	13,562	302	6,228
6/28	Capers Creek R-121	1,800	28	275
Totals for 5/23 thru 8/09	Distant Island Wallace, and Capers Creeks	34,940	770	10,565

Georgetown County (Murrells Inlet) Same as table above.

Dates 2005	Shellfish Ground	Amount Planted (bushels)	Length of Shoreline (m)	Area Planted (m^2)
8/9 thru 8/26	Drunken Jack Creek S-357	4,673	150	808
8/9 thru 9/9	Woodlands Creek S-358	3,577	70	608
Totals for 8/9 thru 9/9	Drunken Jack and Woodlands Creeks	8,250	220	1,416

All sites received good shell coverage, were planted at an appropriate depth of 3" -5"(not evenly planted throughout, but with good general area coverage). Most sites were in areas with somewhat firm substrates (including some shell), although we purposely chose some to be soft so that we could experiment with site pretreatments to enhance success.

Further shell plantings were carried out by the South Carolina Restoration and Enhancement program (SCORE), a community-based habitat restoration program which complements SCDNR's other shellfish research and restoration efforts. The SCORE program engages the public in oyster restoration activities which simultaneously augments our work capacity while educating the public and creating a constituency for the resources. In 2005, the SCORE program constructed oyster reefs at five sites and incorporated a new experimental reef

configuration at one site. 282 volunteers spent 725 hours bagging oyster shells and building reefs in 2005. Approximately 1,400 bushels of shell weighing close to 30 tons were used in this effort, which resulted in about 250 m^2 of new reef.

Objective 5. Conducting a pilot assessment of the condition of SC's oyster beds and associated habitats with respect to water quality, sediment quality, oyster bed 'condition' including incidence and prevalence of diseases, bacterial and contaminant concentrations, and oyster physiological condition in cooperation with the ongoing SCECAP monitoring program.

The SCDNR has initiated expanded efforts to monitor both the condition of shellfish beds and estuarine habitat quality (water quality, sediment quality, and general biotic condition measures) on an annual or as needed basis (see Coen *et al*. 2004). The SCDNR shellfish monitoring program has involved staff from both the SCDNR's Shellfish Research Section of the Marine Resources Research Institute and the Office of Fisheries Management (OFM). Efforts have included the evaluation of general bed condition, ecology and related development of intertidal oyster habitats, state-wide recruitment studies, limited oyster disease (MSX and Dermo) monitoring, and monitoring of planted beds to evaluate the effectiveness and durability of newly established shell substrate (see for example Bobo et al. 1997, Coen *et al*., 1999a,b, Coen and Luckenbach 2000, Coen *et al*. 2004, Luckenbach *et al*. 2004). Estuarine habitat quality is also assessed annually by MRRI's Environmental Research Section, in cooperation with the SCDHEC. This program, entitled the "South Carolina Estuarine and Coastal Assessment Program" (or SCECAP) was initiated in 1999 and includes numerous measures of water quality, sediment contamination and toxicity, and biotic condition using a probability-based sampling design that provides state-wide coverage in an unbiased manner (Van Dolah *et al*. 2002).

As part of the Oyster Survey Project, a pilot study was conducted in 2005 and 2006 to merge and expand both the shellfish and environmental sampling programs to provide better information on shellfish bed health and condition by monitoring one or more oyster habitats located close to SCECAP sites sampled in 2005. Three goals of the effort were: (1) to determine if oysters could serve as biological indicators of environmental health, (2) to relate oyster condition to environmental data where feasible, and (3) to collect information on oyster condition that has not been routinely conducted in the past in South Carolina (e.g., information on tissue contaminant and bacterial levels).

Overview of SCECAP:

SCECAP sampled 50 stations per year during 2005-2006 using a probability-based, random tessellation, stratified sampling design (Stevens 1997, Stevens & Olsen 1999), with new station locations assigned each year. This program is conducted in conjunction with the USEPA National Coastal Assessment Program (NCAP) and is largely standardized with respect to the water quality, sediment quality and biological condition measures collected in each state. South Carolina's program is unique in that the state agencies conducting the program have added many additional measures of estuarine condition beyond those required for NCAP. Sampling protocols for the SCECAP program are described by Bergquist *et al*. (2008).

The distribution of SCECAP stations ranges from Little River Inlet at the South Carolina - North Carolina border to the Savannah River at the South Carolina - Georgia border and extends from the saltwater-freshwater interface to near the mouth of each estuarine drainage basin.

Site Selection and Oyster Collection:

Prior to each oyster sampling period, a subset of the SCECAP station array was selected based on known proximity of oyster beds such that the environmental data could be utilized without additional cost. Several additional non-random stations were also added to the station array each year. These sites represented oyster beds that have been monitored for many years by the SCDNR Shellfish Research Section for disease incidence. Oyster beds sampled in this study ranged from Murrells Inlet, SC to Calibogue Sound along the South Carolina coastline (Table 5.1, 5.2).

SCECAP stations are primarily sampled once during the summer months (late June through August), although water quality is monitored at a subset of the SCECAP stations monthly throughout the year. Oyster collections for the summer period were generally obtained at the end of the summer (late August, September). Oyster collections for the winter sampling period were generally obtained in February. Approximately 45-60 oysters were collected from the oyster beds located at each site by sampling 9-12 oysters at five different locations along the shoreline separated by at least two meters. All oysters were 5–7.6 cm in shell height and no more than two oysters were collected from any one cluster of oysters. To ensure spatial separation of the oysters used for any analysis, oysters collected at each location were separated into mesh bags designated for the different analyses. Oysters were kept cool during transport to the various processing laboratories. At least 15 oysters were analyzed for microbes, 10 for disease, 10 for contaminants, and 10 for physiological condition by randomly assigning oysters to the analysis groups.

Oyster Tissue Measures:

Disease (Dermo/MSX)
Perkinsus marinus (Dermo) was determined with oyster gill, rectal and mantle tissues using the Ray's Fluid Thioglycollate Method (RFTM). Prevalence (% infected) and mean infection intensity were calculated for each site following Quick and Mackin's scale (1962) of 0-6. *Haplosporidium nelsoni* (MSX) was assessed using oyster cross sections that were fixed and processed histologically using standard Harris hematoxylin and eosin (HHE) procedures. Infection and intensity levels were rated following Bobo *et al*. (1997).

Microbes (bacterial)
Two DNA non-radioactive probes (alkaline phosphatase labeled) targeting the species-specific thermolabile direct hemolysin gene (*tlh*-AP) in *Vibrio parahaemolyticus* and the hemolysin-cytolysin (*vvh*-AP) in *Vibrio vulnificus*, were purchased from DNA Technology A/S (Aarhus, Denmark) and used for enumeration of the two *Vibrio* strains. Oysters were scrubbed, shucked, and mixed with an equal weight (1:1) of sterile phosphate buffered saline (PBS), and the mixture was blended for 90 sec in a sterile Waring blender (DePaola et al. 1997). Aliquots of oyster homogenate (0.2g of a 1:1 mixture in PBS [equivalent to 0.1g]), were taken directly from a blender, used to make serial dilutions (-1 to - 3) and spread onto duplicate T1N3 (1% tryptone, 3 % sodium chloride, 15% agar) plates for *V. parahaemolyticus* and *V. vulnificus*(20 g peptone, 30g sodium chloride, 25g agar, 10mL of bromthymol blue dye stock solution in 900mL distilled water). To the 900mL, add 100mL of 10% cellobiose (10 g ellobiose/100 mL distilled water and

Table 5.1. SCECAP stations sampled in 2005 that had oyster beds also sampled. RO and RT designate open water and tidal creek stations, respectively, that were randomly selected. Stations at the bottom of the table represent long-term or non-random shellfish monitoring sites.

Station	Station Type	Latitude Decimal Degrees	Longitude Decimal Degrees	DHEC Classification 2005	County	Development Code*	Approximate Location
RO056092	Open	32.88686	79.87643	A	Berkeley	R>1	Beresford Creek NE of Wando/Cooper River confluence
RO056093	Open	32.57146	80.22095		Charleston	NDV	Ocella Creek northwest of Townsends River
RO056096	Open	32.32822	80.52306	A	Beaufort	NDV	Story River northeast of Trenchards Inlet confluence
RO056100	Open	33.09634	79.39247	R	Charleston	NDV	Casino Creek east of McClellanville
RO056102	Open	32.15794	80.80637	A	Beaufort	R>1	Calibogue Sound west of Hilton Head Island
RO056104	Open	32.30936	80.76254	A	Beaufort	NDV	Chechesee River southeast of SC 170 near Daws Island
RO056105	Open	32.36655	80.64191	A	Beaufort	R<1	Cowen Creek east of Port Royal
RO056106	Open	32.29963	80.84103	A	Beaufort	R<1	Colleton River northeast of Bluffton
RO056107	Open	32.35050	80.81168	A	Beaufort	R<1	Chechesee River near Spring Island
RO056112	Open	32.99827	79.91013		Charleston	I<1	Cooper River south of US 17 near Hog Island Shore
RO056114	Open	32.66459	79.93485	A	Charleston	R<1	Folly River northeast of Folly Island
RT052094	Creek	32.93901	79.63921	A	Charleston	NDV	Unnamed creek to Sewee Bay west of Bull's Bay
RT052095	Creek	32.60793	80.21160	A	Charleston	R>1	Adams Creek west of Rockville
RT052096	Creek	32.32364	80.48735	P	Beaufort	I<1	Unnamed creek from Fripp Island to Old House Creek
RT052100	Creek	32.86558	79.82256	R	Charleston	R<1	Boone Hall Creek northwest of US 17 and SC41
RT052104	Creek	32.26831	80.63504	A	Beaufort	R<1	Creek to Morse Island Creek east of Port Royal Sound
RT052106	Creek	32.16005	80.84331	A	Beaufort	NDV	Creek to Cooper River west of Hilton Head
RT052110	Creek	33.55408	79.01981	P	Georgetown	R<1	Main Creek south of Whale Creek
RT052118	Creek	32.71365	80.08588	R	Charleston	R<1	Church Creek southeast of SC 700 Bridge
RT052198	Creek	33.34641	79.18391	A	Georgetown	NDV	Bly Creek southwest of Waverly Mills
RT052200	Creek	32.31447	80.84546	A	Beaufort	R<1	Calawassie Creek northeast of Bluffton
MLT06	Creek	33.57880	79.00450	R	Horry	R<1	Creek in Murrells Inlet at bridge to Garden City on causeway
OLT06	Creek	33.58333	79.19302	R	Georgetown	NDV	At Baruch Dock
PLT06	Creek	32.88330	78.35000	A	Charleston	NDV	In creek off Price Creek
ILT06	Open	32.798679	79.82810	A	Charleston	R<1	In Inlet Creek
TLT06	Creek	32.78410	79.84960	P	Charleston	R<1	Tolers Cove Inlet, off AIWW
WLT06	Open	32.43730	80.60909	R	Beaufort	R>1	Bank in Warsaw Flats

* Development codes: NDV = no development visible, R<1 = residential less than 1 km away, R>1 = residential greater than 1 km away, I<1 = industrial site less than 1 km away, I>1 = industrial site located greater than 1 km away.

Table 5.2. SCECAP stations sampled in 2006 that had oyster beds also sampled. RO and RT designate open water and tidal creek stations, respectively, that were randomly selected. Stations at the bottom of the table represent long-term or non-random shellfish monitoring sites.

Station	Station Type	Latitude Decimal Degrees	Longitude Decimal Degrees	DHEC Classification 2006	County	Development Code*	Approximate Location
RO06305	Open	32.13280	80.89194	A	Beaufort	NDV	Cooper River west of Hilton Head Island
RO06312	Open	32.92805	79.65802	A	Charleston	NDV	Sewee Bay south of Morse Landing
RO06315	Open	32.63713	80.20726	A	Charleston	R<1	Leadenwah Creek northwest of Rockville
RO06320	Open	32.79245	79.91029	P	Charleston	I>1	Cooper River northwest of USS Yorktown
RO06321	Open	32.21142	80.83881	A	Beaufort	R>1	May River southeast of Bluffton
RO06324	Open	32.86528	79.88023	R	Charleston	R>1	Wando River northeast of I-526 over Wando River
RO06325	Open	32.52419	80.82480	A	Beaufort	NDV	South Haulover Creek southwest of Sheldon
RO06326	Open	32.45163	80.60735	A	Beaufort	R<1	Lucy Point Creek southeast of SC 802 Bridge
RT06002	Creek	32.27398	80.62653	A	Beaufort	NDV	Morse Island Creek northeast of Port Royal Sound
RT06006	Creek	32.35752	80.50870	A	Beaufort	R>1	Harbor River southwest US 21 Bridge
RT06007	Creek	32.49724	80.37920	A	Colleton	NDV	Pine Island Creek northwest of Edisto Beach
RT06008	Creek	32.78627	79.83340	A	Charleston	R>1	Conch Creek northeast of Sullivans Island
RT06013	Creek	32.30275	80.81205	A	Beaufort	NDV	Creek to Colleton River southeast of SC 170 Bridge
RT06014	Creek	32.38805	80.59650	A	Beaufort	R<1	Capers Creek southwest of St. Helena Sound
RT06018	Creek	32.30811	80.58398	A	Beaufort	NDV	Tributary to Trenchards Inlet southeast of Port Royal
RT06020	Creek	32.65852	79.96515	p	Charleston	R<1	Cutoff Reach northwest of Folly Beach
RT06024	Creek	32.81405	79.75846	A	Charleston	R>1	Seven Reaches Creek south of Whitehall Terrace
RT06027	Creek	32.55611	80.23526	A	Charleston	R<1	Creek to Ocella Creek southeast of SC 174 Bridge
RT06028	Creek	32.90037	79.68524	A	Charleston	R<1	Clausen Creek northeast of Whitehall Terrace
RT06031	Creek	32.61168	80.12521	A	Charleston	R>1	Kiawah River southwest of Legareville
RT06032	Creek	33.04429	79.46753	A	Charleston	NDV	Little Papas Creek southwest of McClellanville
RT06033	Creek	33.34778	79.17606	A	Georgetown	R>1	Old Man Creek southeast of Georgetown
RT06035	Creek	32.43852	80.51772	R	Beaufort	R>1	Creek to Eddings Point Creek northwest of US 21 Bridge
RT06036	Creek	32.67282	79.92780	A	Charleston	R<1	Creek to Folly River northeast of Folly Island
RT06037	Creek	32.45024	80.88676	A	Jasper	R<1	Euhaw Creek southeast of US 278 and SC 462
SCA06	Open	32.79085	79.92524	P	Charleston	I<1	South Carolina Aquarium, Charleston Harbor
MLT06	Creek	33.57880	79.00450	R	Horry	R<1	Creek in Murrells Inlet at bridge to Garden City on causway
OLT06	Creek	33.58333	79.19302	R	Georgetown	NDV	At Baruch Dock
PLT06	Creek	32.88330	78.35000	A	Charleston	NDV	In creek off Price Creek
ILT06	Open	32.798679	79.82810	A	Charleston	R<1	In Inlet Creek
TLT06	Creek	32.78410	79.84960	P	Charleston	R<1	Tolers Cover Inlet, off AIWW
WLT06	Open	32.43730	80.60909	R	Beaufort	R>1	Bank in Warsaw Flats

* Development codes: NDV = no development visible, R<1 = residential less than 1 km away, R>1 = residential greater than 1 km away, I<1 = industrial site less than 1 km away, I>1 = industrial site located greater than 1 km away.

filter sterilize) to test for *V. vulnificus*. After overnight incubation at 35°C, colony lifts, probe hybridization, and colorimetric detection analyses were done as described by Gooch *et al*. (2001) and McCarthy *et al*. (1999). After color development, colonies that hybridized with either probe were determined visually.

Most Probable Numbers (MPNs) of fecal coliform bacteria for oyster samples were determined using the 1:1 oyster/PBS homogenate and the multiple tube fermentation technique in A-1 media according to Section 9221 E of Standard Methods for the Examination of Water and Wastewater (APHA 1998). Fecal coliform samples collected from the surface waters at each SCECAP sites were processed by SCDHEC using standardized procedures (SCDHEC, 1998b, 2001, 2005).

Most Probable Numbers (MPNs) of *Enterococci* bacteria from oyster samples were determined using the multiple tube-fermentation technique in Azide Dextrose broth according to Section 9230 B of Standard Methods for the Examination of Water and Wastewater (APHA 1998). Bacterial growth of *Enterococci* from positive Azide Dextrose tubes was confirmed on Brain Heart Infusion (BHI) agar with 6.5% sodium chloride.

Tissue Contaminants:
A group of 10-12 oysters collected from each site were scrubbed of mud and debris and opened using pre-cleaned stainless steel knives. The tissue was collected in a Teflon cup and homogenized using a ProScientific homogenizer. All contaminants were analyzed using ICP/MS methods similar to those described by the USEPA. Analysis of the oyster tissue samples was limited to the following metals: aluminum, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, nickel, silver, thallium, tin, uranium, vanadium, and zinc.

Oyster Health Measures:
The lysosomal destabilization assay was conducted following the methods described in Ringwood *et al.* (1998). Briefly, digestive gland tissue was homogenized, incubated on a shaker in calcium/magnesium-free saline (CMFS), disaggregated with trypsin, filtered (23 μm mesh) and centrifuged. The pellet was washed and resuspended in CMFS. This suspension was mixed with a neutral red solution (NR) and incubated for 1 hour. Digestive gland cells containing lysosomes were examined under a light microscope to evaluate NR retention. A minimum of 50 cells were scored as either stable (NR retention in the lysosomes) or destabilized (NR leaking into the cytoplasm), and the data were expressed as the percentage of cells with destabilized lysosomes per oyster.

The thiobarbituric acid (TBA)-malondialdehyde test was used to measure lipid peroxidation in oyster gill tissue (Gutteridge & Halliwell 1990). Malondialdehyde (MDA) is a cellular byproduct commonly used to quantify lipid peroxidation. Digestive gland tissues were homogenized in potassium phosphate buffer and centrifuged. A subsample of the supernatant was mixed with trichloroacetic acid (containing TBA) and butylated hydroxytoluene, heated for 15 min and centrifuged to remove the precipitate. The resulting MDA was detected at 532 nm, and quantified using a standard curve.

Glutathione concentrations of individual oysters were determined using the enzymatic recycling assay (Anderson *et al.* 1995, Ringwood *et al.* 1999), an assay that determines the rate of 5-thio-nitrobenzoic acid (TNB) formation. Digestive gland tissues were homogenized in 5% sulfosalicyclic acid and centrifuged. The supernatant was mixed with reduced β-nicotinamide adenine di-nucleotide phosphate buffer containing 5,5'-dithiobis (2-nitrobenzoic acid). Glutathione reductase was added, and the rate of TNB formation was monitored at 405 nm over a 100 second interval. Glutathione concentrations were calculated from a standard curve.

Water Quality Sampling:

Basic water quality measurements collected for SCECAP were obtained at the specific location designated for each SCECAP station. Generally, sites were within 200 m of the shellfish bed sampled, and only a few of the water quality parameters collected for SCECAP were considered relevant to the oyster collection effort since all oyster beds were in intertidal locations. These measures included average salinity, temperature and pH values collected at 15 min over a 25 hr period near the bottom using Yellow Springs Instrument (YSI) Inc. Model 6920 water quality multiprobes. Due to South Carolina's generally shallow water habitat and the fact that the SCECAP sites used for the oyster sampling were restricted to those relatively close to the shoreline, near-bottom and near-surface measures of these parameters are very similar based on instantaneous measures collected at both depths during the initial site visit (SCDNR data unpublished). An additional water quality parameter collected by SCECAP considered useful for this study was fecal coliform bacteria concentration, which was collected during the SCECAP visit from the surface waters.

To evaluate sediment contaminant concentrations in the vicinity of the site, bottom grab samples were collected at each station using a stainless steel 0.04 m^2 Young grab deployed from an anchored boat. The boat was repositioned between each sample to ensure that the same area of bottom was not resampled and to spread the samples over a 10-20 m^2 area. The grab was thoroughly cleaned prior to field sampling and rinsed with isopropyl alcohol between stations. The surficial sediments (upper 3 cm) of the remaining grab samples were homogenized on site and placed in precleaned bottles for analysis of sediment composition, contaminants, and sediment toxicity. All sediment samples were kept on ice while in the field and then frozen until analyzed.

Statistical analyses:

To test the null hypothesis that no significant difference existed for Dermo prevalence and intensity between 2005 and 2006 randomly chosen sites, we used separate Student-T's test. Data were left untransformed because they did not violate the assumption of homogeneity of variance. To test the null hypothesis that no significant difference existed for Dermo prevalence and intensity between 2005 and 2006 randomly chosen sites and long-term disease sites, we used separate two factor ANOVAs. Again, data were left untransformed because they did not violate the assumption of homogeneity of variance. To test the null hypothesis that no significant difference existed for fecal coliform concentrations in oyster tissue between summer and winter samples and among DHEC designated open-conditionally open, restricted, and prohibited areas across the two year study period, we used a two factor ANOVA. We evaluated the same hypothesis for *Enterococcus* and the two *Vibrio* species using additional two factor ANOVAs.

To test the null hypothesis that metal concentrations in sediments significantly predict metal concentrations in oyster tissue we used regression analysis for the following metals: cadmium, copper, mercury, lead, arsenic, and selenium. We chose these metals for two reasons: 1) Hollister *et al*. (2007) found that cadmium, copper, mercury, and lead demonstrated the strongest individual relationships with developed land in coastal watersheds; and 2) USEPA has established tissue contaminant guidelines of arsenic, cadmium, mercury, and selenium for use in fish advisory guidelines that include lower and upper level concentrations associated with non-cancer health endpoint risks for consumption of four 8-oz meals/month (Table 5.3). In addition to the regression analyses, we tested the null hypothesis that no significant difference existed in oyster metal tissue concentration for the aforementioned seven metals among SCDHEC designated areas.

Table 5.3. Risk guidelines for recreational fishers consuming shellfish and fish with contaminant loads. Data are compiled from US EPA guidance for assessing chemical contaminant data for use in fish advisories (USEPA 2000). The second and third columns indicate the range of concentrations associated with non-cancer health and cancer health endpoint risk for consumption of four 8-oz meals per month, respectively.

Metal	Non-Cancer health endpoints	Cancer health endpoints
Arsenic	3.5 - 7.0	0.008-0.016
Cadmium	0.35 - 7.0	
Mercury	0.12 - 0.23	
Selenium	5.9 - 12.0	

To test the null hypothesis that oyster health measures do not vary significantly among the SCDHEC oyster harvesting area designations, we used a one factor ANOVA for each oyster health measure. In addition, we tested the null hypothesis that oyster health is independent of metal concentrations in tissues for the aforementioned seven metals using individual regression analyses. In order to assess if oysters with higher disease levels show evidence of greater physiological impairment we divided sites into three levels relating to Dermo intensity: low intensity (0-1.5), medium intensity (1.6-2.3), and high intensity (2.4-5). For each of the three oyster health measures, we tested the null hypothesis that no difference existed in oyster health among the three Dermo levels using a one factor ANOVA.

Results:

Dermo/MSX

Dermo intensity and prevalence was evaluated for 27 sites in 2005 (20 randomly selected sites and seven LTD sites) and 32 sites in 2006 (25 randomly selected sites and seven LTD sites). Dermo was found at all sites sampled over the two year period. Mean intensity for 2005 and 2006 sites was 2.01 +/- 0.143 S.E. and 1.85 +/- 0.111 S.E., respectively. Dermo intensity for randomly selected sites in 2005 and 2006 ranged from 0.3 -3.8 and 0.5-2.9, respectively (Figures 5.1). Dermo intensity in 2005 and 2006 for LTDs fell within the ranges of the randomly selected sites (Figure 5.2). Dermo prevalence ranged from 20-100% in 2005 and 40-100% in 2006 (Figures 5.1-5.3). Mean prevalence for LTD sites sampled in 2005 and 2006 was 86.7% +/- 3.37

SE and 82.1% +/- 2.74 SE, respectively. No significant difference existed in mean Dermo intensity (p = 0.216) or prevalence (p = 0.070) between random and long-term sites, or between years when all sites were considered collectively (p = .392 for intensity, p = .429 for prevalence) based on a two-factor ANOVA. There were no significant interaction relationships for either variable (p > 0.810).   Both the prevalence and intensity of Dermo infections in the oysters sampled in 2005-2006 are consistent with previous studies conducted by the MRD (Bobo, *et al.*, 1997). While the data also indicate that the index sites provide an adequate representation of Dermo infection intensities in oysters located throughout the stated, the broader spatial array of randomly located stations provides confirmation that there are no obvious patterns with respect to general location within the state's waters since no longitudinal trends in Dermo prevalence or infection were detected along the SC North-South gradient.

The evaluation for MSX at the same sites identified the presence of this disease at only one of the 27 sites sampled in 2005 and eight of the 32 sites sampled in 2006. Prevalence of MSX among the oysters at the one site ni 2005 was 10% and ranged from 4-10% among oysters sampled at the eight sites sampled in 2006 (Figure 5.3).   Bobo *et al.* (1997) found that only 8 percent of all oysters they examined (1,924) had MSX in their study, but noted that 52% (11 of 21) of their sites had one or more oysters with MSX infections. This is much higher than we noted. It is unclear why the incidence of MSX was so much less in the current study, but both studies support the hypothesis that MSX is not a major problem in South Carolina waters, and the current study provides updated information on MSX incidence compared to the sampling conducted from 1972-1996 by Bobo *et al.* (1997).

Bacteria:
Means and ranges for fecal coliform bacteria are provided in Table 5.1 and concentrations found at each of the sites sampled are provided in Appendix 6. One site near the South Carolina Aquarium in Charleston had extremely high concentrations of FC in oyster tissue (Figure 5.5). The Aquarium site was not included in the statistical analysis. Based on a two factor ANOVA, there was no significant difference in tissue fecal coliform bacteria concentrations between sites located in the different SCDHEC harvest designation areas (p = 0.749), nor was there a significant difference between the two seasons sampled (p = 0.297). Since growing areas are classified according to overlying water quality and pollution source surveys, there is no established standard/action level based on shellfish tissue. The NSSP, however, does list an unsatisfactory shipping condition bacteriological criteria, which is 330 FC MPN/100g for shucked shellfish tissue. This number is presented here as a baseline, strictly for comparative purposes. Among the stations that were located in approved harvesting areas, there were a surprising number of oyster samples that exceeded the 330 FC MPN/100g concentration. While 13 of these sites were sampled in the summer when oysters cannot be legally harvested, nine stations exceeded this limit in the winter samples (Figure 5.4). Most of these sites had estimated concentrations of about 50 MPN/100g. Three sites sampled in 2006 and 2006 located in restricted harvesting areas also had elevated fecal coliform concentrations in the summer, but not the winter, and five sites had noticeably higher concentrations in the winter versus the summer, although only three of those sites exceeded 330 FC MPN/100g (Figure 5.5). Finally, it was interesting to note that two of the sites in prohibited waters (RO056112 located in the Cooper River, and the South Carolina Aquarium site, had extremely high concentrations of fecal coliform bacteria in the summer sampling period (Figure 5.5)
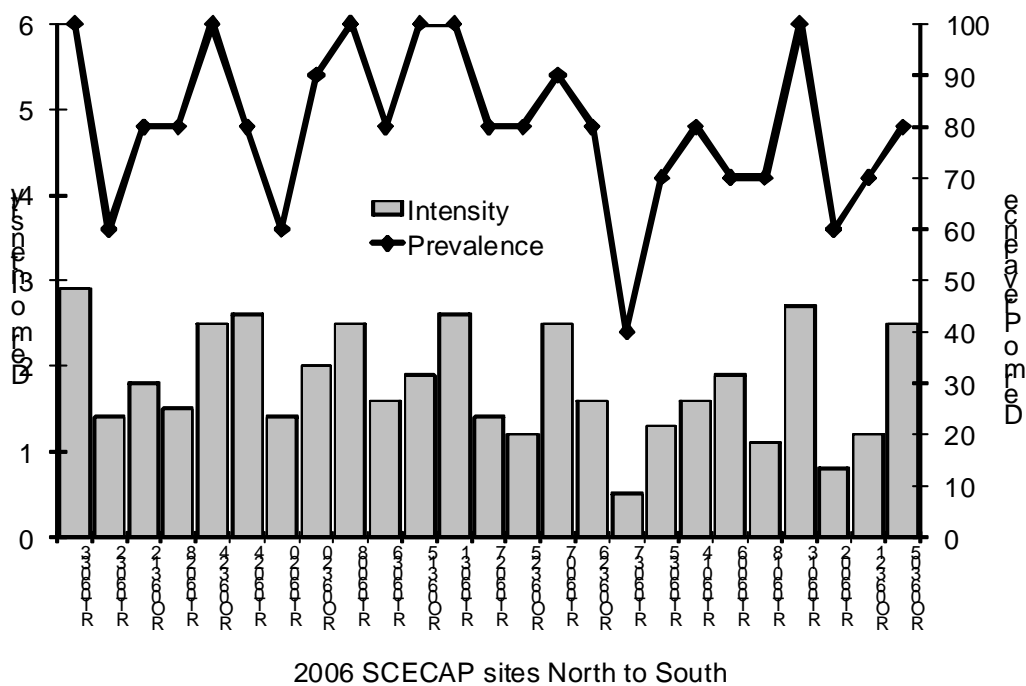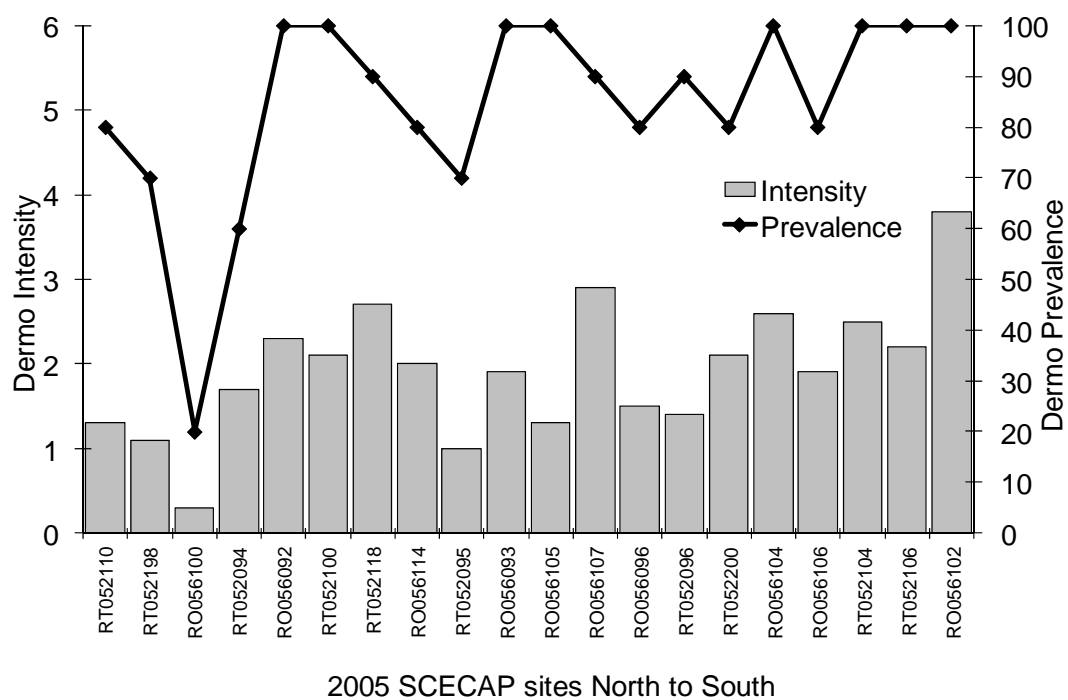
Figure 5.1. Intensity and prevalence of Dermo for oysters from sites chosen randomly in 2005 and 2006. Sites are listed in order from north to south.
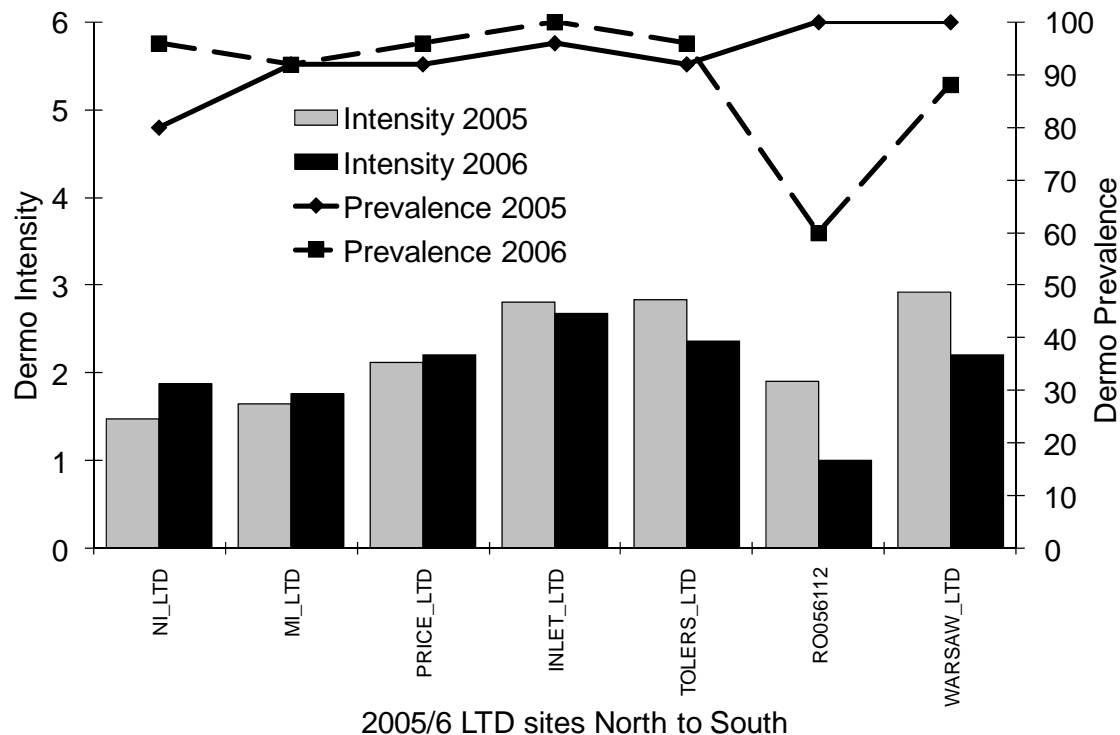
Figure 5.2. Intensity and prevalence of Dermo for oysters at Long-Term Disease (LTD) sites sampled in 2005 and again in 2006.
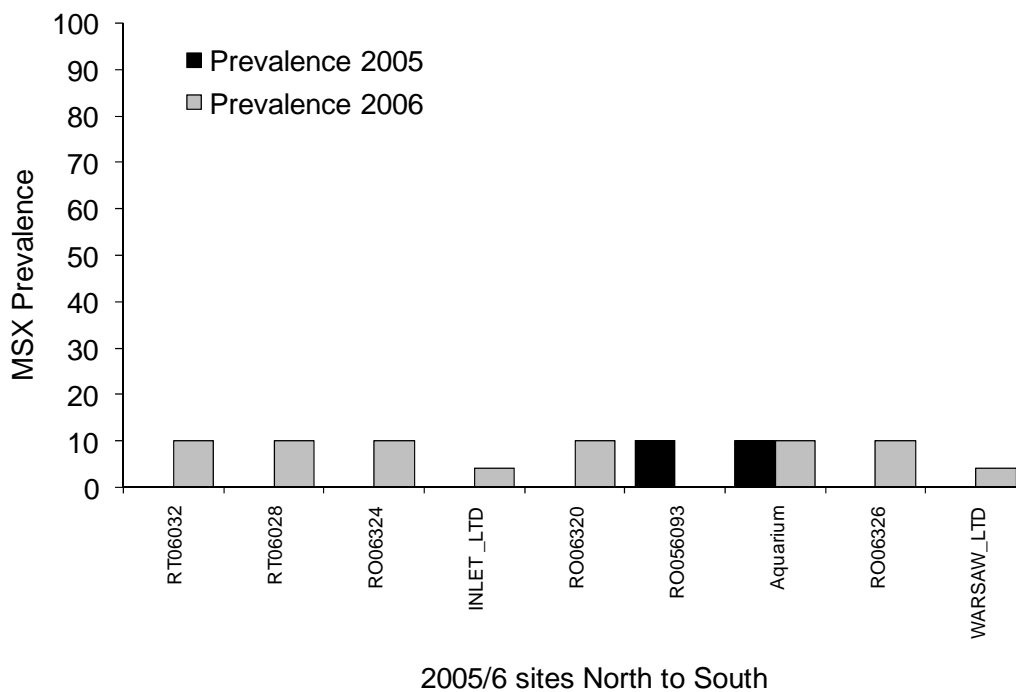
Figure 5.3. Prevalence of MSX for oysters from site where MSX was identified. This includes sites that were randomly chosen and LTD sites for both years.

Table 5.1. Mean bacterial concentrations (SE) and ranges for summer and winter samples at sites in the SC DHEC shellfish harvesting designations.

Bacteria	Approved	Restricted	Prohibited
Fecal coliform summer	220 (32)	377 (166)	11,954 (8,033)
	0-480	26-1,600	46-60,000
Fecal coliform winter	193 (35)	287 (90)	980 (669)
	46-1,000	46-1,000	100-5,600
Enterococcus summer	7,351 (1,775)	3,935 (1,902)	4,093 (878)
	34-4,8000	60-18,000	80-6,000
Enterococcus winter	433 (134)	394 (303)	603 (378)
	8-4,800	4-3,400	4-3,200
Vibrio vulnificus summer	173 (270)	438 (89)	165 (20)
	0-690	100-1,000	80-240
Vibrio vulnificus winter	204 (65)	86 (15)	280 (78)
	10-170	10-170	50-600
Vibrio parahaemolyticus summer	466 (94)	847 (248)	490 (153)
	30-2,600	95-2,900	60-1,200
Vibrio parahaemolyticus winter	64 (11)	88 (19)	152 (108)
	20-210	20-210	5-900

Means and ranges for *Enterococcus* concentrations in oysters of summer and winter sampling periods are given in Table 5.1 and the distribution of oyster samples with varying *Enterococcus* concentrations is shown in Figures 5.6 and 5.7. A large number of the stations located in Approved Harvesting Areas had very high *Enterococcus* concentrations, but most of those samples were collected in the summer. *Enteroccus* tissue concentrations were significantly higher in summer versus winter samples ($p < 0.001$). In addition, concentrations were also significantly higher in oysters from Approved Harvesting Areas relative to Restricted Harvesting Areas ($p < 0.05$ for comparison among watershed types; Bonferroni post hoc $p = 0.048$ for specific comparison). There was no significant seasonal by site designation interaction in this two factor ANOVA ($p = 0.719$). As noted for fecal coliform bacteria, there are no state standards for *Enterococcus* concentrations in shellfish tissue, but the average of 433 MPN/ 100 g of oyster tissue in Approved Harvesting Areas during the winter harvesting season is greater than we anticipated.

Mean concentrations of *Vibrio vulnificus* and *V. parahaemolyticus* in oysters sampled during the summer 2005 and winter 2006 (20 randomly selected sites and seven LTD sites) and 32 sites in summer 2006 and winter 2007 (25 randomly selected sites and seven LTD sites) are provided in Table 5.1, and the distribution of *Vibrio* concentrations in the tissue at the various sites is summarized in Figures 5.8 – 5.11. *Vibrio vulnificus* concentrations differed significantly between the seasons, but this was due to a significant interaction between the two independent factors ($p = 0.038$ for season effect, $p = 0.005$ season versus site class). Concentrations did not differ significantly among the three harvesting designations ($p = 0.086$).
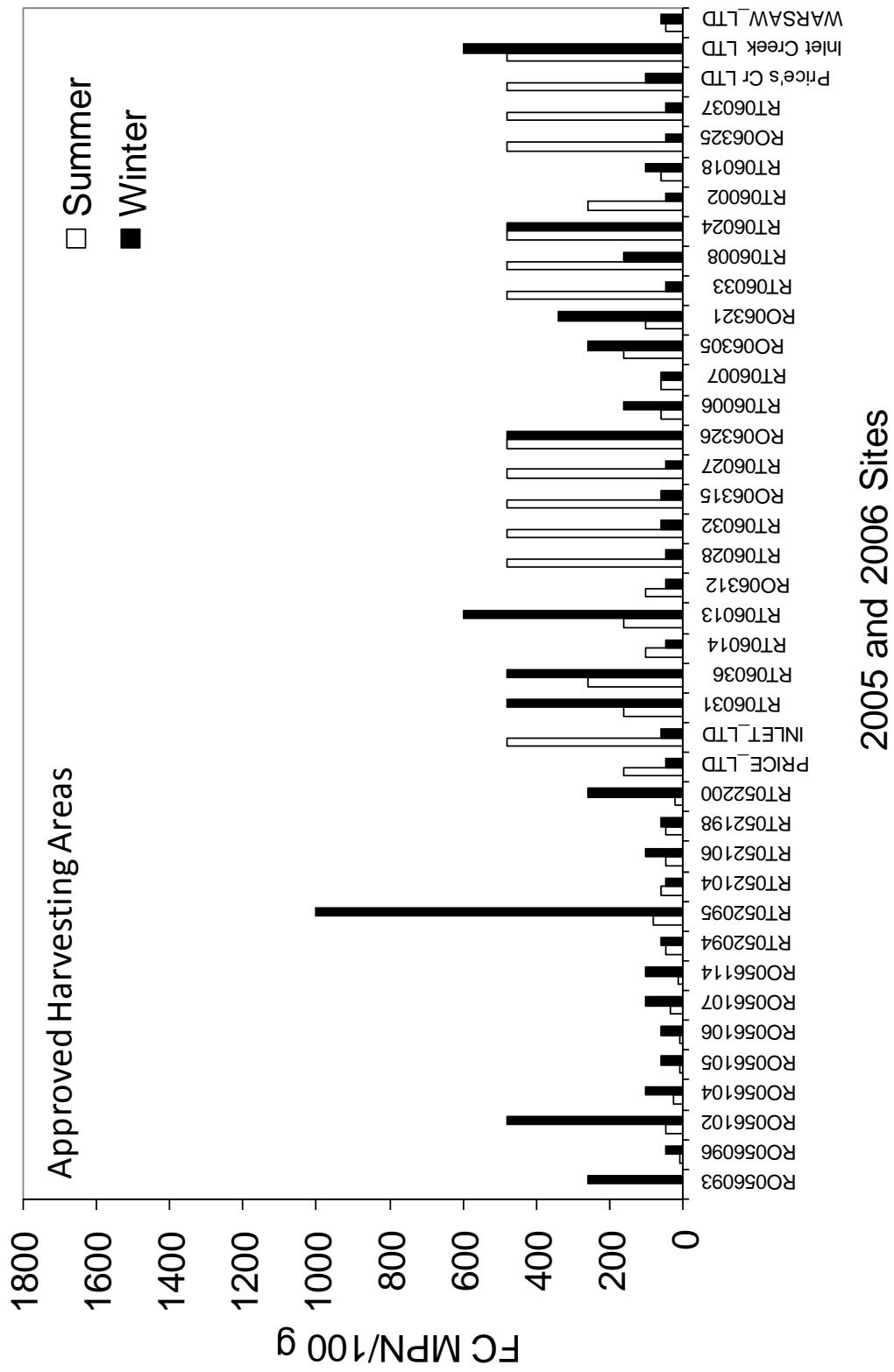
Figure 5.4. Fecal coliform concentrations in oyster tissues collected from 2005 and 2006 sites occurring in Approved Harvesting areas as designated by SCDHEC.

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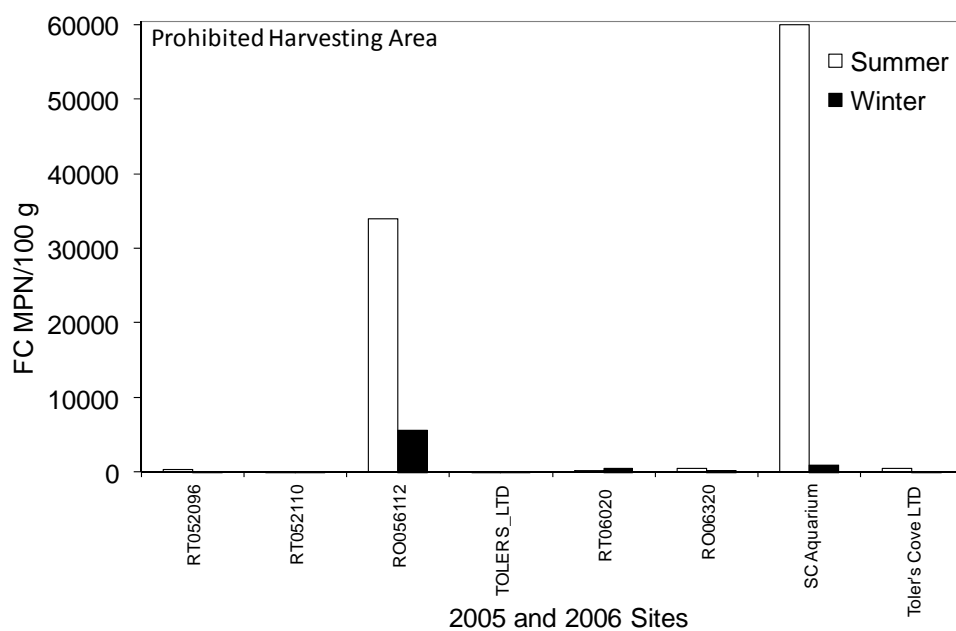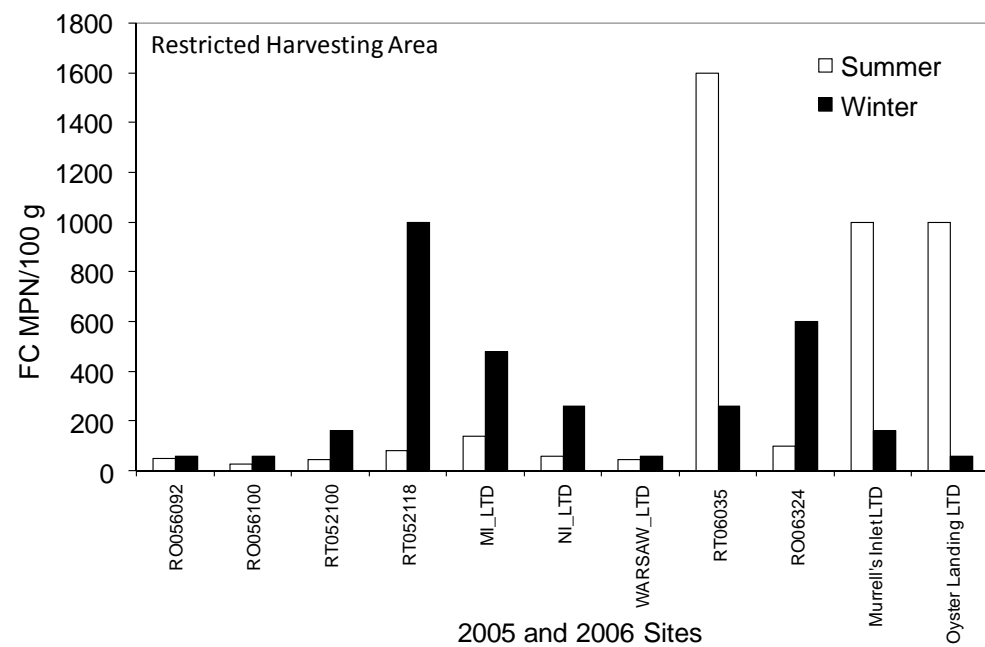
Figure 5.5. Fecal coliform concentrations in oyster tissues collected from 2005 and 2006 sites occurring in Restricted and Prohibited Harvesting areas as designated by SCDHEC.
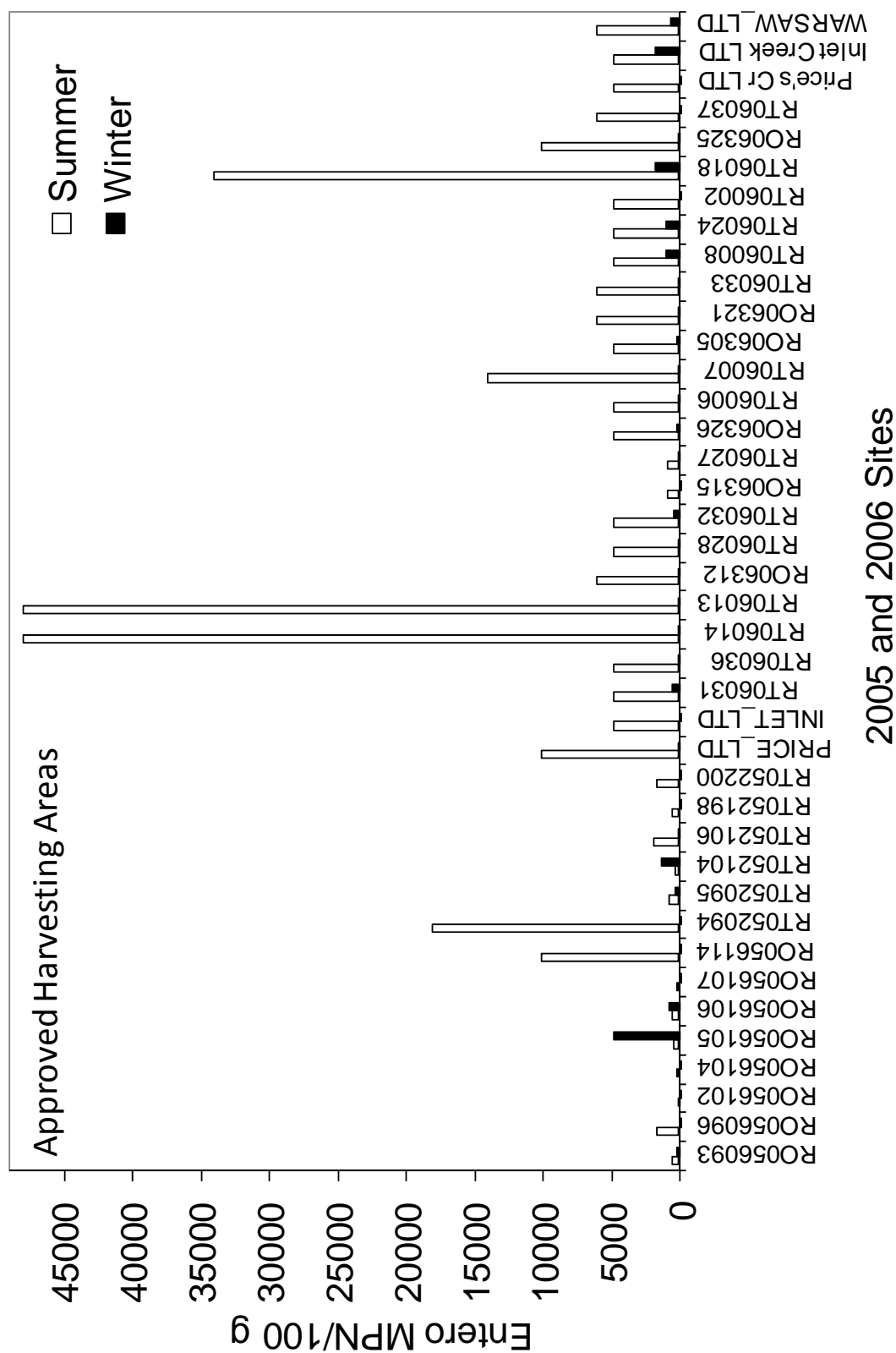
Figure 5.6. *Enterococcus* bacteria concentrations in oyster tissues collected from 2005 and 2006 sites occurring in Approved Harvesting areas as designated by SCDHEC.
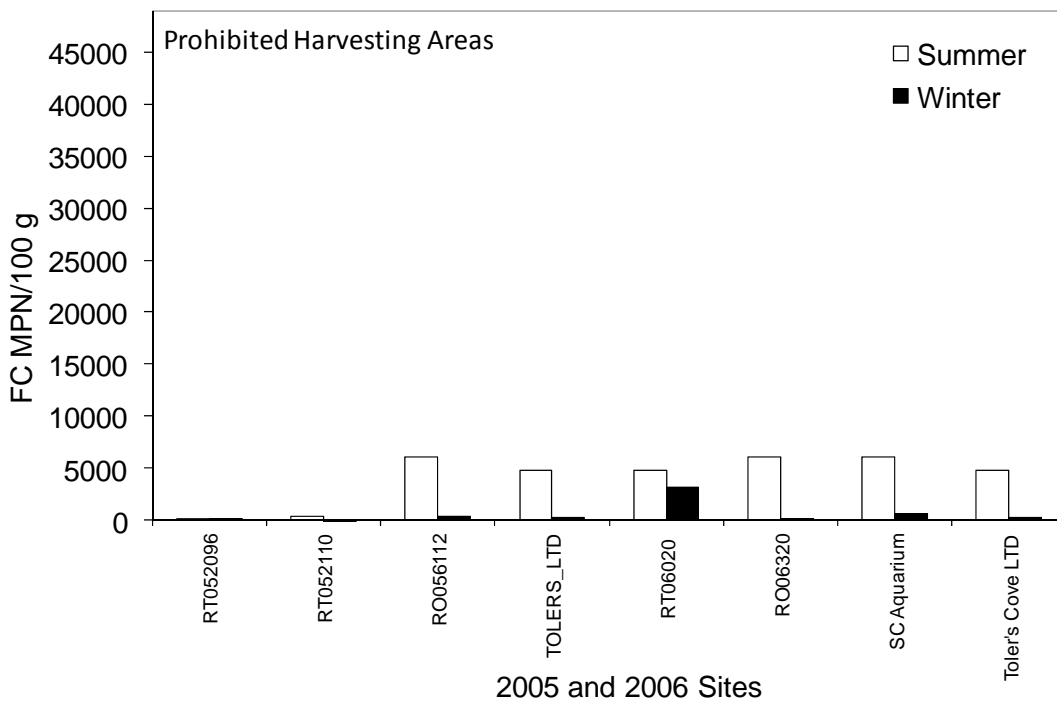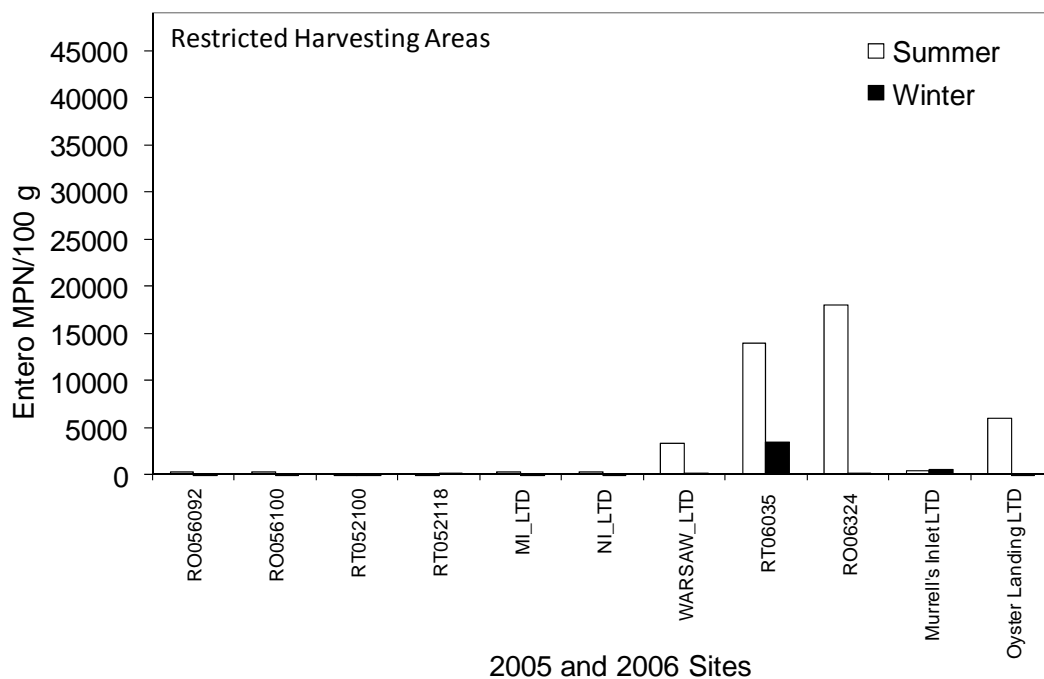
Figure 5.7. Enterococcus bacteria concentrations in oyster tissues collected from 2005 and 2006 sites occurring in Restricted and Prohibited Harvesting areas as designated by SCDHEC.
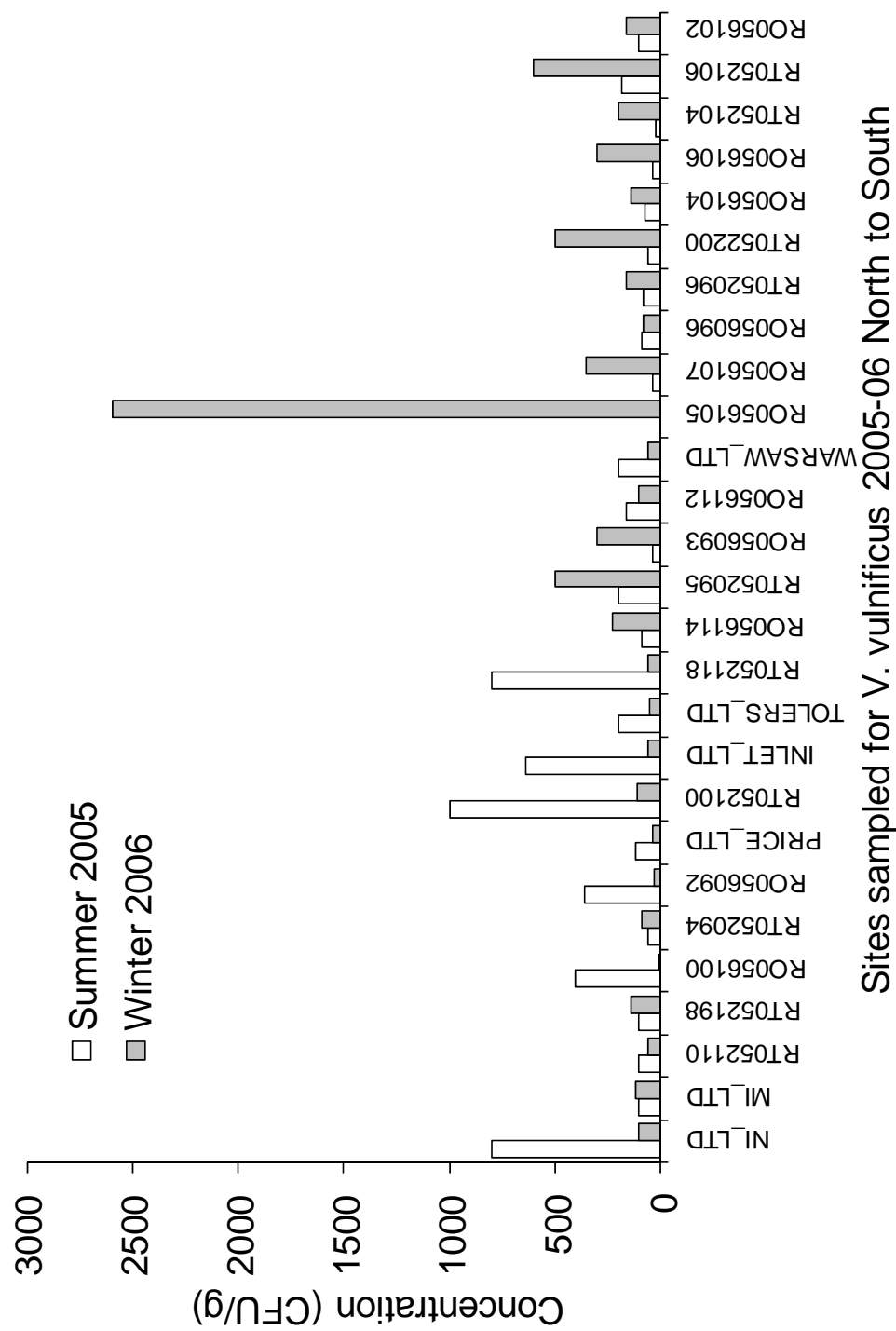
Figure 5.8. *Vibrio vulnificus* concentrations measured in oyster tissue at sites sampled during the summer of 2005 and winter of 2006.

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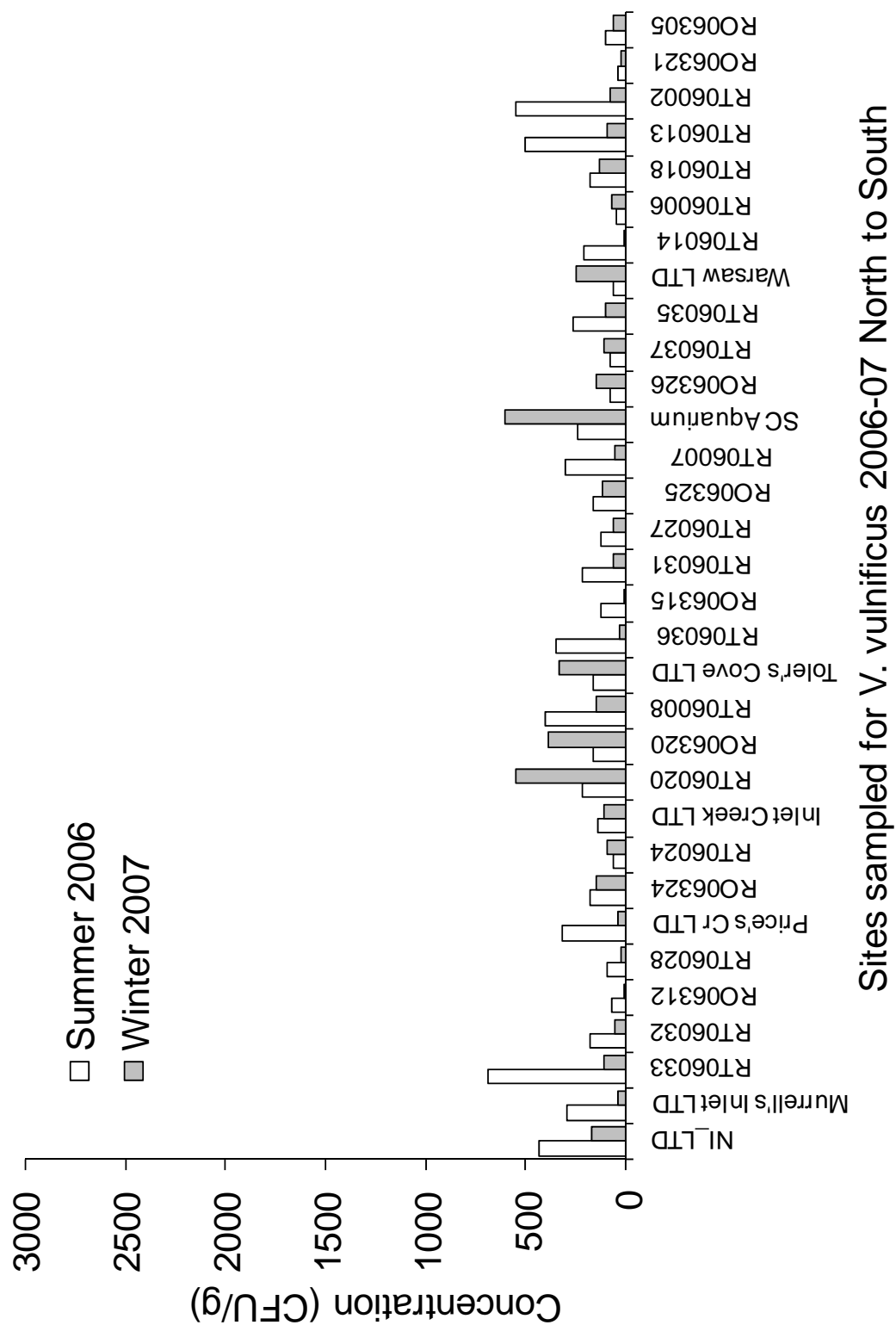
Figure 5.9. *Vibrio vulnificus* concentrations measured in oyster tissue at sites sampled during the summer of 2006 and winter of 2007.
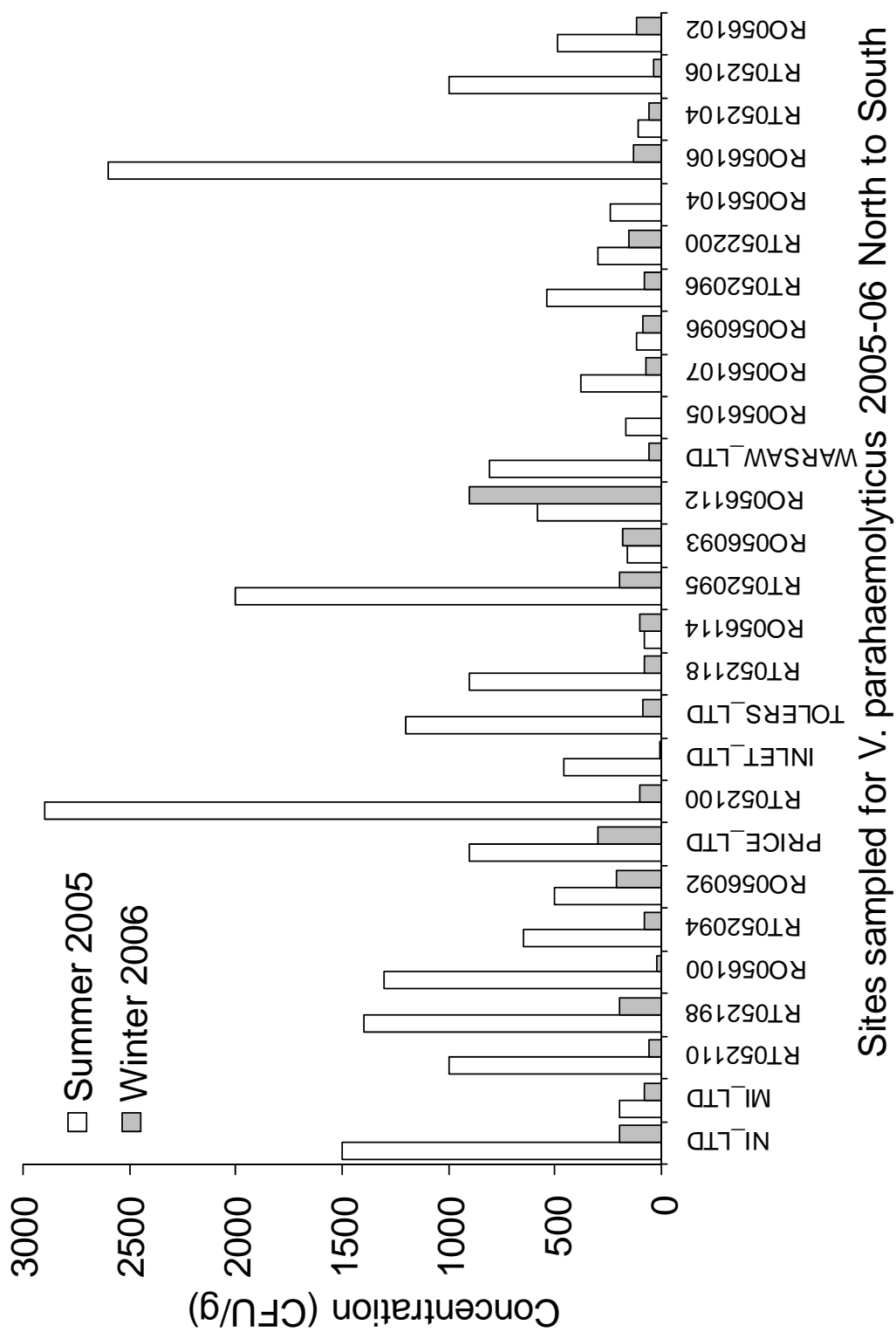
Figure 5.10. *Vibrio parahaemolyticus* concentrations measured in oyster tissue at sites sampled during the summer of 2005 and winter of 2006.
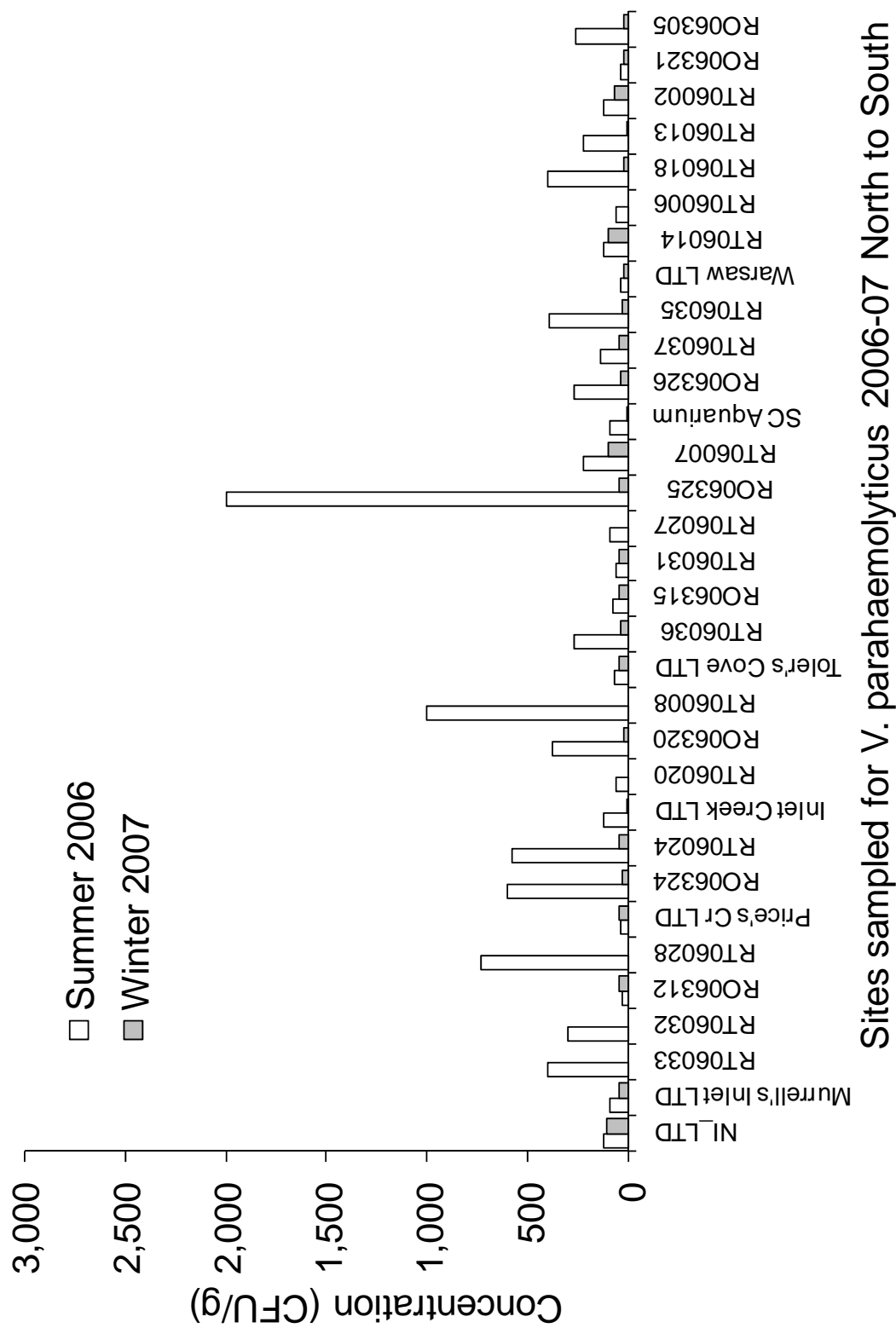
Figure 5.11. *Vibrio parahaemolyticus* concentrations measured in oyster tissue at sites sampled during the summer of 2006 and winter of 2007.

Vibrio parahaemolyticus concentrations were significantly higher in summer samples than winter samples (p < 0.001) and concentrations from Restricted sites were significantly higher than those from Approved sites (p = 0.039 for site class effect; Bonferroni post hoc p = 0.035). No other significant differences occurred for this species.

The FDA/EPA guidance level for *V. vulnificus* in any ready-to-eat fishery product is the presence of pathogenic organisms. The problem is that any *V. vulnificus* bacterium can be pathogenic, depending upon the situation. Although some of these sites are located in restricted or prohibited harvesting areas, most sites we sampled exceeded this criteria during the winter harvesting season, including the majority of those sites located in Approved Harvesting Areas. The FDA/EPA *V. parahaemolyticus* guideline for any ready-to-eat fishery product is equal to or greater than 1×10^4 bacteria /g of tissue. None of the sites exceeded this criteria during the winter harvesting season in either of the two years sampled. To the best of our knowledge, this is the first extensive sampling effort in South Carolina to document the distribution of the fecals, *Enterococcus,* and *Vibrio* spp. in the state oyster resources.

Metals:

Metal concentrations in oyster and sediment samples collected from all sites sampled in 2005 and 2006 are provided in Appendix 7 and 8. Arsenic concentrations in the oyster tissue samples we analyzed were all greater than the upper concentration limit for non-cancer health endpoints (Table 5.2, Figure 5.12). Cadmium concentrations in oyster tissue, were all above the lower limit and below the upper limit of non-cancer health endpoints. For mercury, 54% of sites fell within the lower and upper limits while and an additional 46% exceeded the upper limits. For selenium, 51% of sites fell within the lower and upper limits and 49% exceeded the upper limit. Lead and copper concentrations did not exceed the EPA's thresholds for non-cancer endpoints. As noted in Figure 5.12, metal concentrations were as high or higher in oyster tissue samples collected from oyster beds in waters Approved for Harvesting as those located in

Table 5.2. Mean metal concentrations (SE) and ranges in oyster tissues for summer and winter samples at sites in the SC DHEC shellfish harvesting designations.

Metal	Approved/Conditionally	Restricted	Prohibited
Arsenic	20.4 (1.28) 8.4-48.5	15.6 (2.84) 8.1-33.2	25.4 (5.33) 18.0-38.9
Cadmium	2.3 (0.16) 1.0-4.9	1.7 (0.29) 0.7-3.6	1.5 (0.19) 0.9-2.4
Copper	74.3 (5.64) 26.0-187.0	123.8 (21.98) 54.4-237.0	181.9 (51.2) 42.0-371.0
Lead	0.33 (0.009) 0.22-0.44	0.38 (0.021) 0.26-0.48	0.36 (0.03) 0.27-0.46
Mercury	0.08 (0.003) 0.04-0.13	0.07 (0.01) 0.04-0.10	0.06 (0.004) 0.05-0.08
Selenium	12.9 (0.62) 5.9-20.8	12.6 (0.09) 8.5-17.1	11.4 (0.78) 9.7-15.3
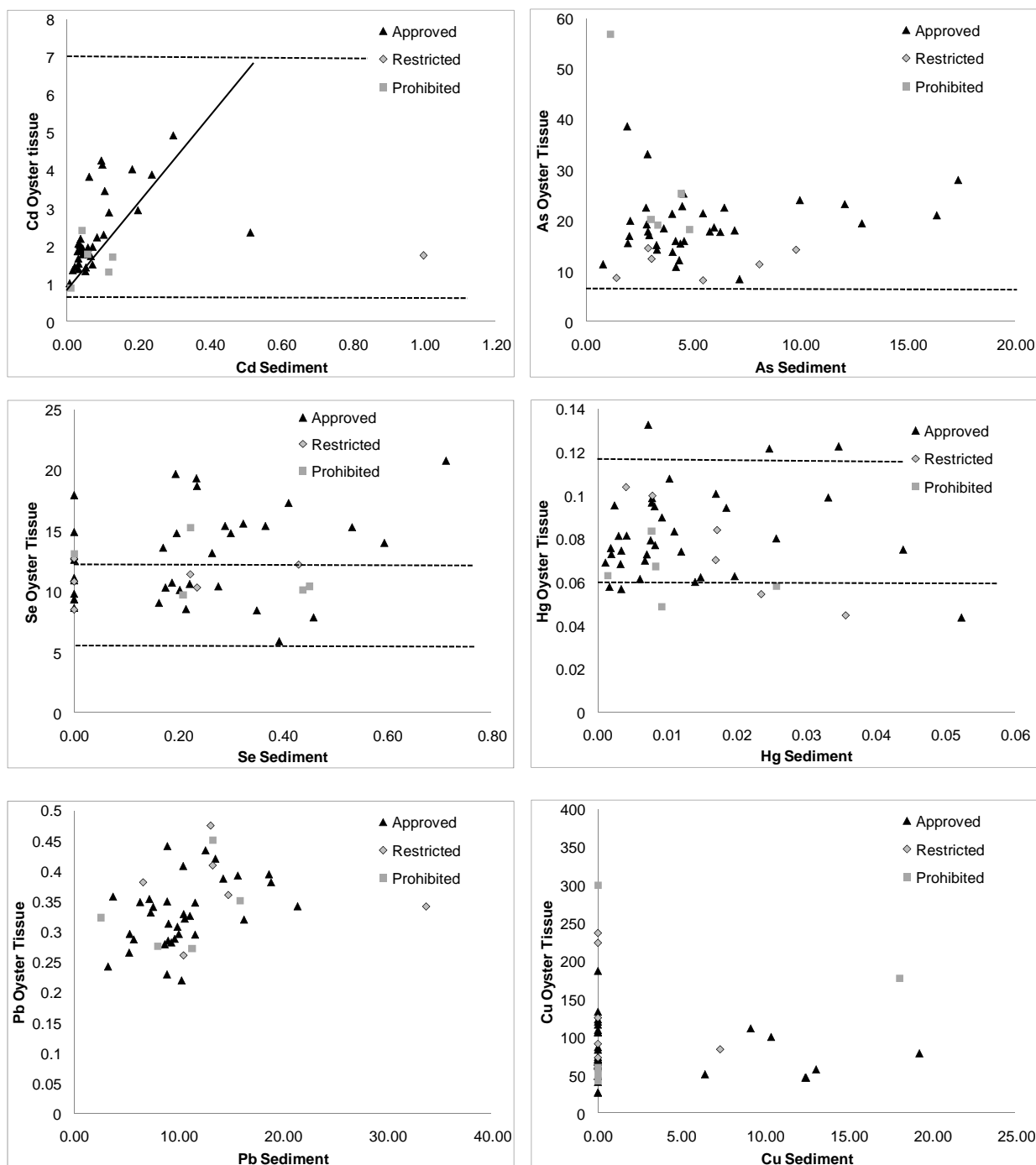
Figure 5.12. Relationship of the concentration of cadmium (Cd), arsenic (As), selenium (Se), mercury (Hg), lead (Pb) and copper (Cu) in sediments versus oyster tissue at the sites sampled in 2005 and 2006. All concentrations are in mg/kg dry weight. Horizontal lines in some of the graphs represent the lower and upper threshold of non-cancer health endpoints (USEPA, 2000).

Restricted or Prohibited waters. Of the six metals examined, only one demonstrated significant differences among the three SC DHEC shellfish harvesting designations. Mean mercury concentration was significantly higher in Approved sites relative to Prohibited sites (ANOVA: p = 0.03; Bonferroni post hoc: p = 0.04).

Linear regression analysis demonstrated that cadmium concentrations in oyster tissues were significantly related to concentrations in sediment ($R^2 = 0.27$; $p < 0.01$). Lead also demonstrated a significant relationship ($R^2 = 0.10$; $p = 0.03$). We did not find a significant relationship for arsenic, mercury, copper, or selenium levels in oyster tissue and in sediment.

Oyster Health:
A relatively high percentage of the SCECAP sites (44%) had oysters with lysosome destabilization rates above 35%, which represents exposure to toxins or serious toxicity (LSD > 35%; Figure 5.13). Additionally, 27% of the sites had oysters with lipid peroxidation levels that represent an exposure to toxins or reflect serious stress responses (LPx > 200 nMol/g; Figure 5.13). Only 5% of the sites had glutathione concentrations that represented exposure to toxins (GSH > 900 nMol/g; Figure 5.13).

Lysosomal destabilization, lipid peroxidation, and glutathione concentration means and ranges are given for the three SCDHEC shellfish harvesting designations in Table 5.3. We did not detect significant differences for any of the oyster health measures among oysters collected from sites in the three SCDHEC shellfish harvesting designations.

Linear regression yielded several significant relationships between metal concentrations and oyster health measures. Lysosomal destabilization was significantly related to arsenic concentration ($R^2 = 0.121$, $p = 0.01$) and copper concentration ($R^2 = 0.131$, $p = 0.008$). Lipid peroxidation levels were not significantly related to any of the six target metals. Glutathione concentrations were significant related to arsenic ($R^2 = 0.396$; $p < 0.01$), and copper ($R^2 = 0.097$; $p = 0.023$).

Table 5.3. Mean oyster health measures (SE) and ranges at sites in the SCDHEC shellfish harvesting designations.

Oyster Health Measure	Approved/Conditionally	Restricted	Prohibited
Lysosome	33.9 (0.68)	36.8 (1.80)	35.6 (1.38)
	27.6-42.4	28.1-46.1	31.3-42.8
GSH	1589 (63.1)	1304 (119.5)	1602 (201.6)
	899-2725	824-1918	972-2493
LPx	179 (10.1)	182 (17.9)	149 (22.6)
	103-362	125-276	102-158
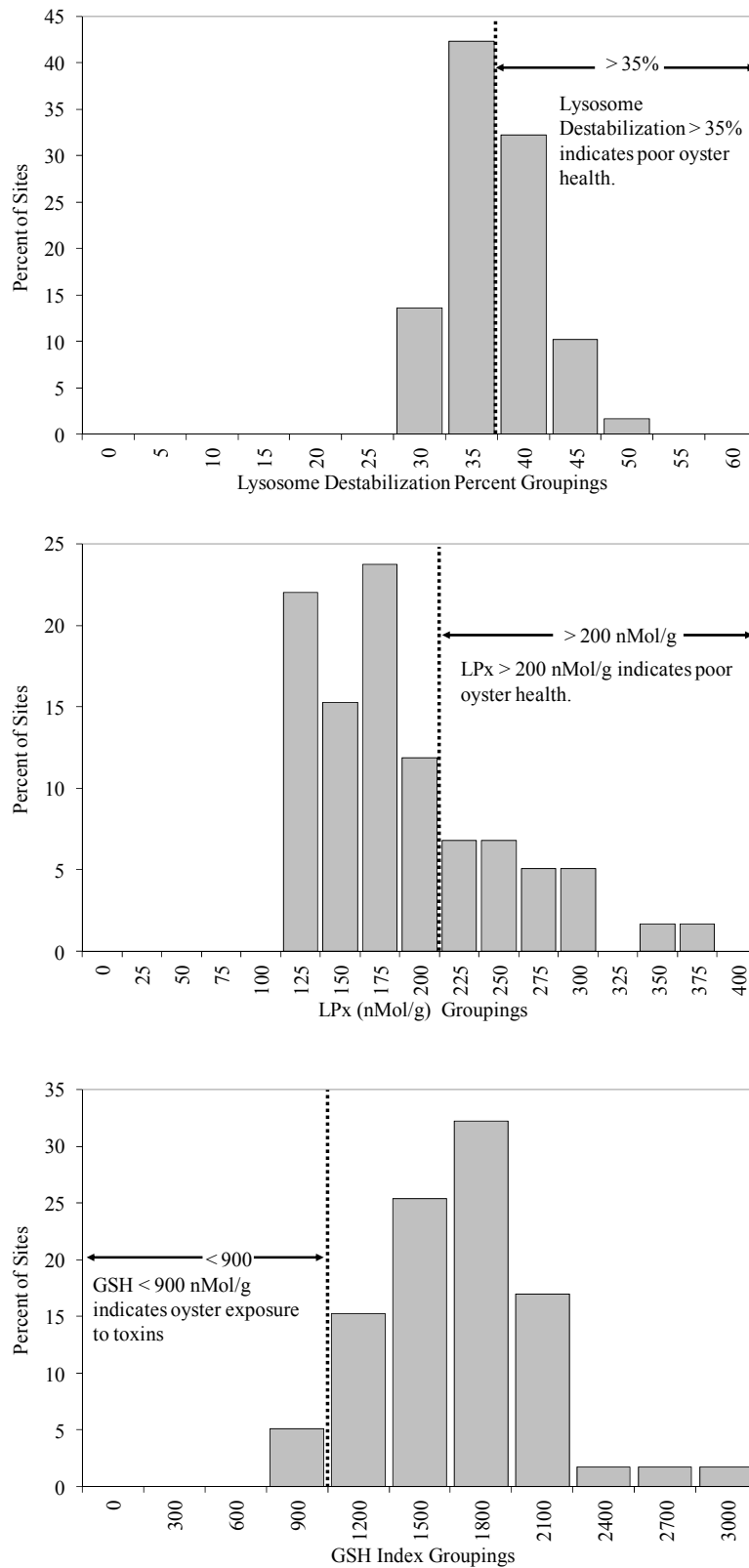
Figure 5.13. Summary of samples that exceeded thresholds of concern related to potential stress in oysters using lysosomal destabilization, lipid peroxidation, and glutathione bioassays.

Lysosomal destabilization, lipid peroxidation, and glutathione concentration means are given for oysters from the three levels of Dermo Intensity in Table 5.14. Lysosomal destabilization did not vary significantly among the three Dermo intensity levels. Glutathione concentrations were significantly higher in oysters from the low intensity level than in oysters from the high intensity level (ANOVA: $F = 4.0$, $p = 0.02$; Bonferroni post hoc: $p = 0.03$). Lipid peroxidation levels were not significantly different in oysters from the three Dermo Intensity levels.

Table 5.14. Mean oyster health measures (SE) and ranges at sites in categorized based on the mean Dermo Intensity levels.

Oyster Health Measure	Dermo Intensity Low	Dermo Intensity Medium	Dermo Intensity High
Lysosome	36 (1.0)	34 (0.7)	34 (1.1)
GSH	1745 (86.7)	1498 (88.6)	1409 (74.9)
LPx	170 (9.6)	167 (13.3)	196 (16.4)

The collective assessment of oyster beds in throughout the state for bacterial, disease, and metal contaminant concentrations provides some unexpected results that warrant further study, especially since elevated concentrations of bacteria and some metals were found in tissue samples collected from harvestable beds. Since much of South Carolina's coastal zone is relatively pristine, particularly in the areas were shellfish harvesting is approved, these results suggest that such concentrations are more common in the southeastern US estuaries than previously anticipated. Some of the elevated

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Appendix 1

Base Option Methodology - Photo Science Inc.

Photo Science Inc submitted the following methodology, outlining the steps needed to produce Base Option oyster reef maps using Feature Analyst software. Photo Science used this methodology to complete 6 batches imagery each containing15 DOQQs. SCDNR completed the final 2 batches using most of these techniques. SCDNR created hand-drawn rough mask layers rather than use the buffer technique mentioned in this document.

Photo Science, Inc.

Intertidal Oyster Bed Mapping
Using Feature Analyst Automated Feature
Extraction Software

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February 2007

Comments

This document details the methodology used by Photo Science in the last iterations of the project. Several other permutations were employed throughout the early deliveries and this was found to be the most accurate, as well as time efficient. These methodologies should be universally applicable across all versions of the Feature Analyst software, however Photo Science is currently running version 4.1.   Due to image quality variations, the prescribed methodology will need to be repeated for each individual image. Feature Analyst has the ability to save learning parameters in .AFE files and apply these files to adjacent image tiles, however this was met with limited success due to those imagery fluctuations. Another potential option is to mosaic multiple images together and color balance, that way a larger footprint can be mapped at a time – however, due to the fact that maximum spectral integrity would need to be maintained for the creation of Option 1 and 2 products, this method was not used. Additionally, analyses of these mosaics actually added to the processing time.

Methodology

I. **Stratification of Oyster Habitat (Several Ways to Approach)**
   A. **Creation of Water AOI**
   B. **Creation of Water Buffer Shapefile**
   C. **Creation of Marsh Shapefile**
   D. **Creation of Oyster Habitat Shapefile**

II. **Delineation Oyster Polygons using Feature Analyst**
   A. **Creation of Fringing Reef Training Set**
   B. **Creation and Editing of Fringing Reef Results**
   C. **Creation of Patch Reef Training set**
   D. **Creation and Editing of Patch Reef Results**
   E. **Creation of Washed Shell Training Set**

III. **Cartographic Clean-Up**
   A. **Eliminate Errors of Commission for Live Shell File**
   B. **Eliminate Errors of Commission for Washed Shell File**
   C. **Eliminate Overlap Areas**
   D. **Check for Slivers**
   E. **Edge-Match with Adjacent Imagery**

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For most extractions we use:
Manhattan 5X5 Input Representation
It is the most versatile of the kernel sizes and does well with most Features (Linear and Circular).

I. A.
- **Create the Training set for the water. Try to incorporate all spectral variations and really hit transition areas (i.e. where water goes from high glare to no glare), represented in one polygon.**
- **Set the Aggregate threshold to fairly high (between 1000 – 1500 pixels) that way you avoid tons of individual fragment polygons.**
- **Run the learner and clean up any obvious clutter.**

B.

- **Through ArcToolbox use the buffer tool to buffer the water shapefile the correct distance so that all the mud banks are contained by the file. Set the buffer parameters so that all internal linework are dissolved. (in ArcGIS 9.1 you would set Dissolve type field to "ALL".**
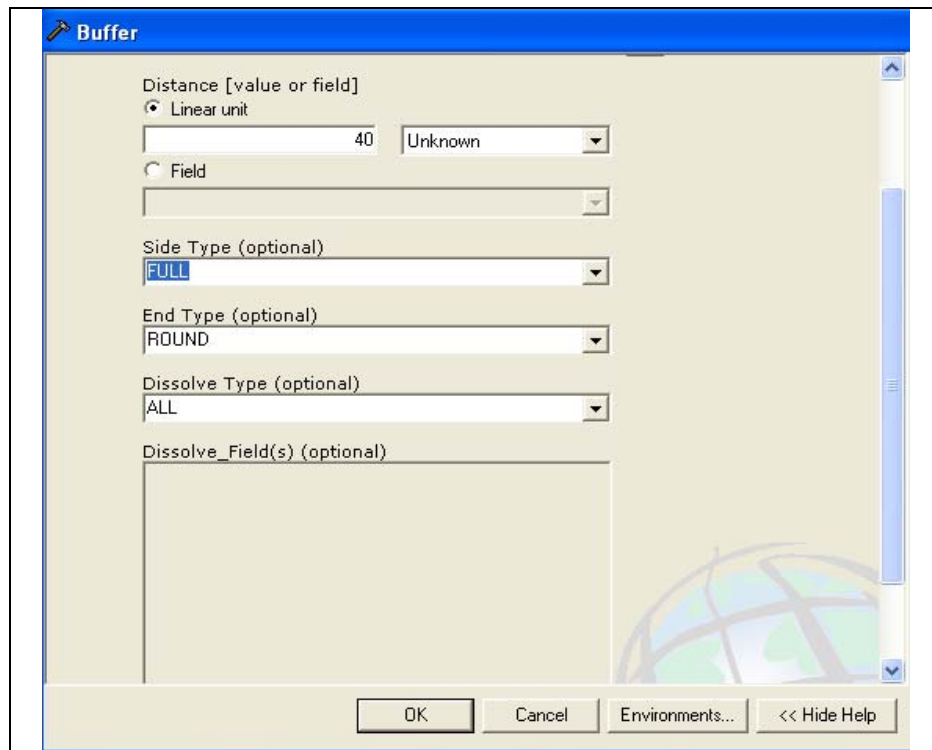
- **Run the buffer process. This file will be your AOI (AKA Oyster Habitat)**

C.

- **Make sure the Oyster Habitat File encompasses all the water, plus the adjacent mud banks where the fringing reefs occur. Don't worry about the large mud flats where the patch reefs occur. Those will be run as a separate process due to the unique spectral qualities of those beds.**
- **(NOTE: Anytime you have significantly different signatures, in this case Patch reef vs. Fringing, always train the learner on them separately and run them separately. Having too much variation in the same training class can lead to poor results.)**

- (NOTE: This file can be used in two ways. You can bring it into ERDAS Imagine and clip the imagery to this shapefile, or you can just use this vector file during the Learning process as your Region of Interest under the Masking Tab. The latter usually saves time.)
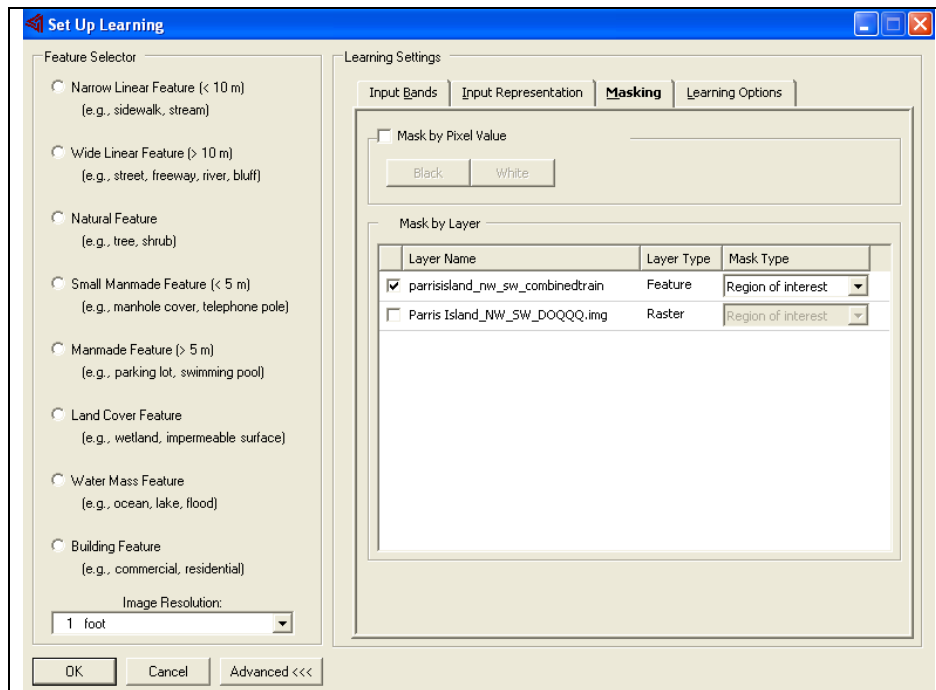
- (NOTE: An alternate approach to the image segmentation and producing your Oyster Habitat Shapefile is to incorporate NWI data. These data can be accessed using the FWS Wetlands Data Extraction Tool. (http://wetlandswms.er.usgs.gov/imf/imf.jsp?site=extract_tool) It is coarse resolution linework, but can be effectively used to quickly segment your image by eliminating upland areas. These data are shapefiles in GCS NAD 83 projection, so they will need to be reprojected to UTM.
- The segmentation process can be handled by one analyst working ahead of the second, primary analyst, who will be working on the oyster delineations. This way there is no down time.

- **NOTE: At this point it is good to have another Analyst QC the generated file to ensure that all the possible oyster habitat is included.**

II. **A. Oyster Delineations**
- **Create the training set either on the clipped imagery, or on the entire image, with your oyster habitat shapefile loaded into the TOC as well.**
- **Usually I go into the Properties of the image and manipulate the Histogram setting, by clicking and dragging the Red band to the left. This will enhance the Red portion of the visible spectrum and will in a lot of cases make the fringing reef more obvious to Feature Analyst. The red response from the oyster is usually due to algal growth on the beds, or sometimes from Ulva.**
- **Once resultant shapefile is produced, take a look and make sure**
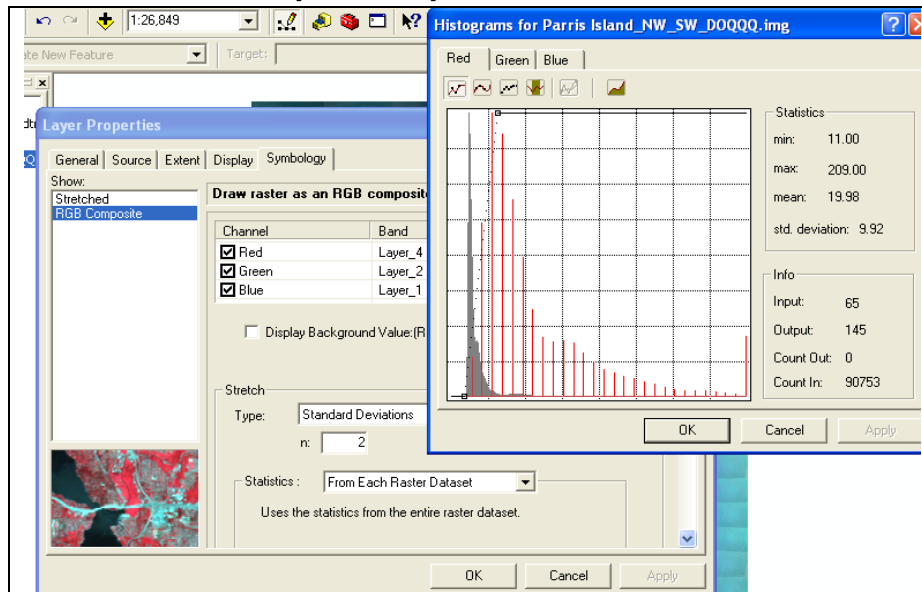
  that on average, you have more errors of commission than omission. It is easier to take out than add. The delineations should be confined to the oyster habitat AOI if you included that in your parameters.

B.
- **If you have significant missed areas, don't go through the Add Missed function (this often creates the push down-pop up paradigm) - instead just go back to the initial training set and add those areas into the training polygons and run again.**
- **Take those results and clean them. If you didn't include the Oyster Habitat shapefile in your learn parameters, a quick way to**

get rid of all the clutter that occurs in the Spartina and upland areas, is to Select by Location. In the dialog box choose it to select features from the fringing reef shapefile that Intersect the oyster habitat shapefile. When those are selected, open the Attribute table of the selected layer and click Options -> Switch Selection. This will then select all the polygons that fall OUTSIDE the oyster habitat shapefile. Simply hit Delete. This will delete hundreds of polygons (that shouldn't represent oyster) that otherwise would have to be manually deleted. This will speed up the process considerably.

C.

- Create a Patch Reef AOI shapefile by simply drawing a polygon encompassing these areas, using the Feature Analyst Create New Feature Class function.
- Make sure to include all areas that are potential oyster habitat up to the Spartina vegetation line.
- Design your Patch Reef training set to include all signature permutations of the feature. Do not include too many reefs that have "sparse" oyster coverage b/c the mud matrix within the bed will cause Feature Analyst to overestimate the boundaries of the beds and you'll get a halo effect.
- There will need to be some manual cleaning at the end of the process, but it should capture all the obvious beds well. Some beds will require the Cut Polygons tool to edit them and some faint beds might be missed.

D.

- Now edit the patch reef results. Once you've completed the editing you can combine the Patch Reefs with the Fringing Reefs by using the Append function in ArcToolbox. (However, keeping these two files separate will help the Option 1 product if you continue with this).
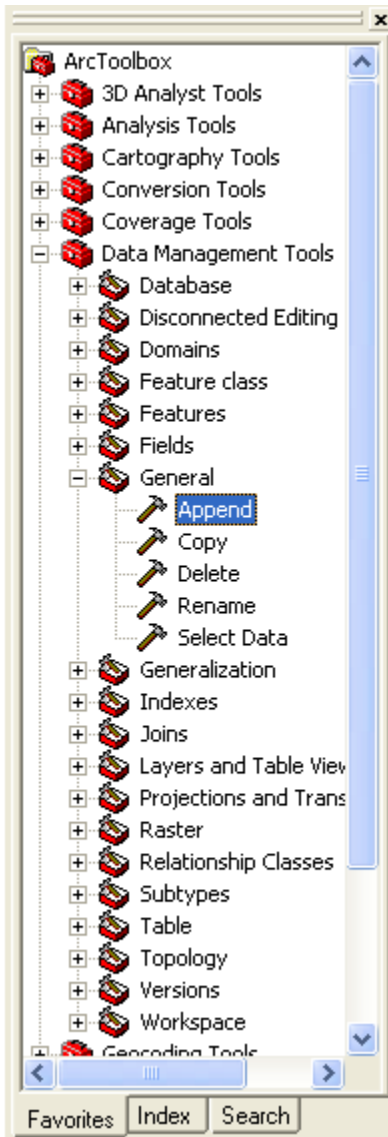
E.

- **Now you must train for the Washed Shell. I usually double check to make sure all stretches are removed from the imagery and scan through it for the washed shell signature. Before you start the training, use the historic shell data to make sure you aren't miss identifying in your training.**

- **Include a good sample of washed shell. You CAN train/produce the Live and Washed shell at one time by using the Prepare Multi Class Input Layer function, but I sometimes didn't get as good a result that way.**

- **Once you get your initial results for Washed Shell, you need to have it QC'ed along with the other three classes to make sure is not missing anything obvious.**

- **You will have overlaps between your Washed Shell polygons and the Live Shell polygons, which will result in slivers. This would be completely avoided if you used the Multi Class function, so if you get good results that way use it! If not, there is a methodology for getting around this problem pretty easily. Once you have the Washed Shell and Live Shell beds and you find that they overlap in small areas, you use the Erase Tool in ArcMap.**
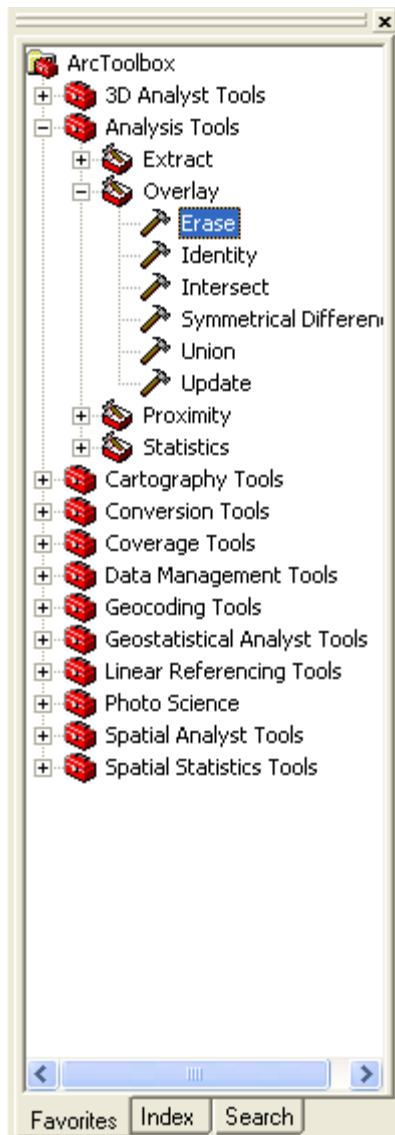
- **When you go into this tool, it will prompt you to pick which feature will be your input and which is your Erase feature (shown below). I usually chose the Washed Shell to be my erase feature, but you can play with it to find which gives you a better "breakline".**
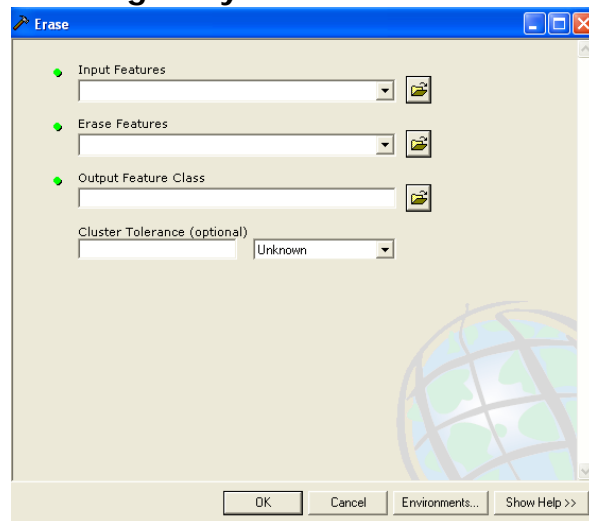
- **Name your output file and accept the default cluster tolerance. (it should come up the same resolution as your image file).**
- **It will then clip your input file to the shape of the washed shell file. You can also, go through Feature Analyst and utilize the Combine Classes file and set it to Use Learning to Resolve Ambiguity. However, the Washed Shell files are usually one of the more accurate, so it's fine to clip the Live shell with the Washed Shell file.**
- **Again, you this is a spot where having another Analyst QC the results is necessary to make sure no erroneous results occur. There shouldn't be any slivers.**

III. A-E
- **Once you have combined the all the features for that particular DOQQQ, there should be an overall QC to check for several things:**
Slivers
Errors of Commission
Errors of Omission
Missed Creeks (which should have been caught in Segment. QC)
Bed Width Errors

Bed Length Errors
Halos Around Patch Reefs
Duplicate Beds Within Classes

- **After all the QC is done for each individual DOQQQ, it is good to do an overall delivery QC using two different Analysts (if you can) to check all the above mentioned details, in addition to include checking for Duplicate Polygons between adjacent image DOQQQ's.**
- **Once you have the QC'ed files, you can either keep them as shapefiles, or you can add them to an existing personal geodatabase by using the Commit to Geodatabase Tool.**

Appendix 2

Option 1 and 2 Methodology – MDA Federal Inc.

This document was created by Photo Science and MDA Federal Inc.(previously Earth Satellite Corp.) in the early stages of the project for the 2005 American Society for Photogrammetry and Remote Sensing Conference. These methods only worked well on "ideal" images. If there was too much variation in image quality and color, or if reef types/densities did not have unique color signatures within an image, it was difficult to implement and accuracy tended to be lower than 70%. The majority of the aerial imagery was too variable to use this technique. Option 2 was abandoned after two batches of imagery or a total of 51 images. Option 1 was abandoned after 4.5 batches of imagery or 140 images. Half of batch 5 was a new type of imagery and Option 1 was tested on just those, but there was no improvement.

SOUTH CAROLINA OYSTER BED MAPPING

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ABSTRACT

Intertidal oysters (Crassostrea virginica) are dispersed throughout most of the coast of the State of South Carolina (SC). These oysters serve as an important economic and environmental resource to the state. SC Department of Natural Resources (SCNR) has contracted with Photo Science, Inc., a provider of professional geospatial services, to determine the location, extent, condition, and category of the intertidal oyster reefs throughout the state. Oyster reef areas are assigned to various categories of "strata". Strata classes range from dead washed shell to dense live clusters with vertical relief. The state has used these strata to correlate expected yields and to manage commercial leases.

Due to the unique combination of spectral and spatial characteristics associated with oyster features, they are identifiable from remotely sensed imagery. The data source used for this project is airborne multi-spectral imagery acquired by GeoVantage Inc.'s GeoScanner system during the 2003 and 2004 oyster growing seasons. This system produced 4-band multi-spectral imagery in an ERDAS Imagine *.img format. Image data was obtained with a 0.25 m2 spatial resolution (0.25 m x 0.25 m pixels) during negative low tide periods when the shellfish beds were exposed.

A combination of semi-automated feature extraction techniques and ground truth field verification are used by Photo Science and its subcontractor; Earth Satellite Corporation, to create a continuous data layer to determine three class distinctions of the Oyster strata. Visual Learning System's Feature Analyst Software is being successfully used by the Photo Science – EarthSat Team to incorporate both spatial and spectral properties during the feature extraction process. This software has been effective to inventory and determine the health or condition of the oyster beds. The resultant shapefiles are committed directly to a Geodatabase utilizing Feature Analyst's Commit to Geodatabase tools.

This paper will present the production methodology and results obtained including spatial and thematic accuracies.

INTRODUCTION

Previously, South Carolina's intertidal oyster resources were mapped by classifying characteristic spatial dispersions of oyster populations or "strata" as the natural populations were identified and measured within the field. This database was completed in the early 1980's by SCDNR (South Carolina Department of Natural Resources) and is in need of update in order to map the spatial distributions and extent of oyster beds along the SC coast and to make statements on the health and viability of the resource, as well as identifying any trends.

This document describes the results and methodology of a pilot study produced by the Photo Science – EarthSat Team to map six scenes of GeoScanner imagery. Each scene corresponds in size to one DOQQQ (Digital Orthophoto Quarter Quarter Quadrangle) or 1/16 of a DOQ (Digital Orthophoto Quadrangle). The GeoScanner imagery was flown at low tide from an aerial platform by GeoVantage inc. in April 2002. Three products are being created for each individual DOQQQ scene:

- Oyster Extent (Base Product) – Outline of individual oyster beds.
- Oyster Verticalness – Characterization of percent of vertical growing oyster features within those beds.
- Oyster Strata – Classification of the oyster beds according to SCDNR Strata categories.

OYSTER BED DELINEATION

The primary goal of the Oyster Extent product is to create a vector shapefile product that accurately delineates the perimeter boundaries of individual intertidal shellfish beds $>/= 10$ square meters in size. These polygons are then attributed as either Class1- defined as "living oyster reefs", or Class2- defined as "washed shell accumulations". The goal is to delineate both of these categories of oyster beds to gain areal estimates of accumulations across the state.

Table 1. Classification Scheme for Base product

Product	Class	Description
Base	1	All vertical and horizontal oyster beds – i.e., predominately live oyster shell matrix
	2	Washed shell – i.e., bleached (bright) shell deposits

Methods

The initial strategy in the development of the Base product was to isolate areas of oyster in the image, beginning with the creation of a water mask. This was accomplished by training Feature Analyst to delineate the channels, creeks and all navigable waterways throughout the image (Figure 1). The software is very efficient at extracting all the water features within a given scene, including small "feeder creeks" where oysters can typically be found, and generating a subsequent shapefile.

Figure 1a. Raw Image
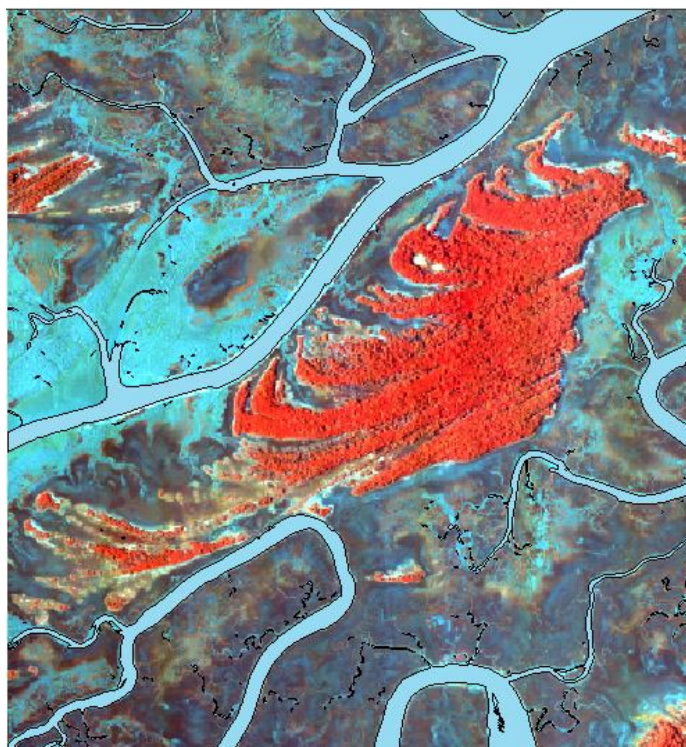
Figure 1b. Water mask shapefile

A 40-meter buffer was generated around the waterways so as to include all banks and areas of vegetation (Spartina alterniflora), that may have oyster interspersed there. In the pilot area there were large mud flats, where significant patch reef accumulations were present. In order to include these areas, a wetland class from the most recent National Wetland Inventory (NWI) coverage for the area was incorporated into the Feature Analyst derived water layer using ArcMap.
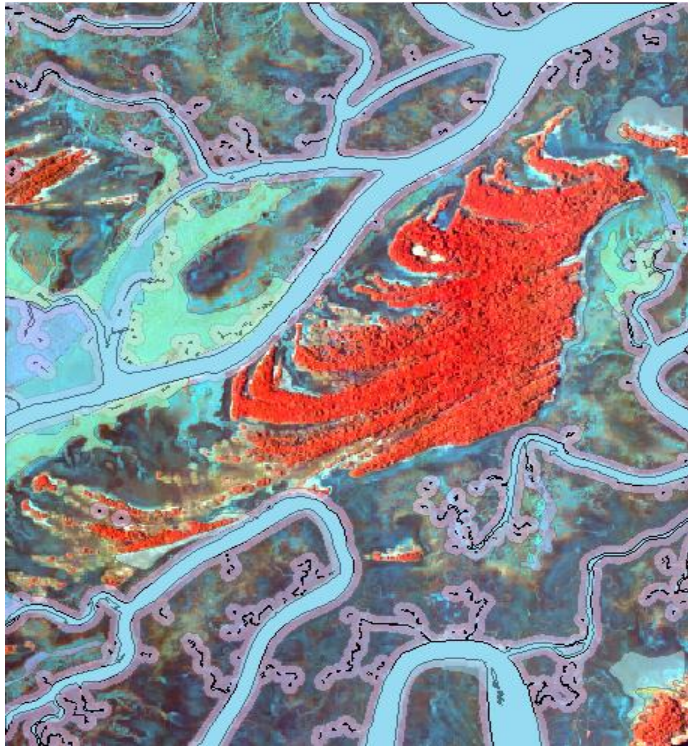
Figure 2a. Image with water mask and NWI layer.   **Figure 2b.** Image clipped to water mask.
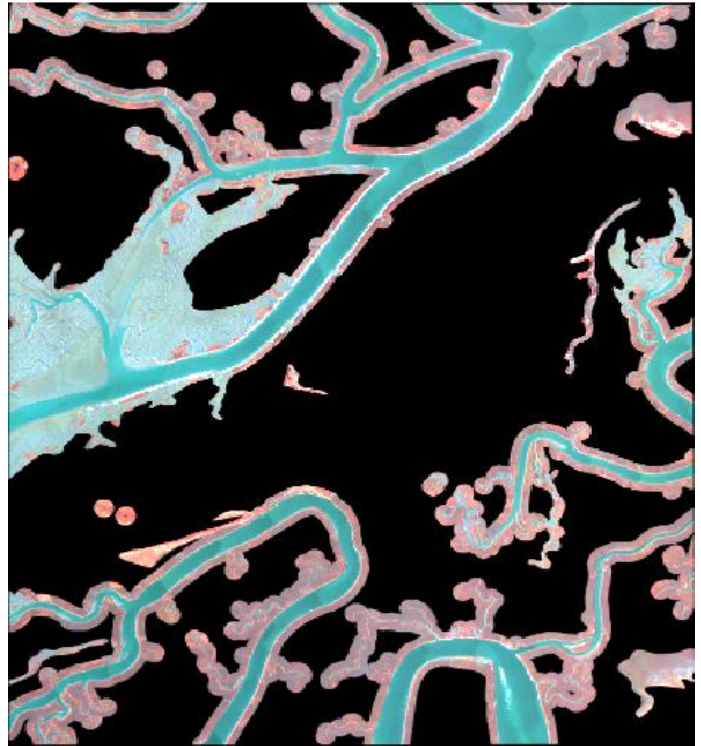
Once these shapefiles were merged, and it was determined that all areas defined as potential habitat for intertidal oyster were covered, the imagery was then clipped to these shapefiles (Figure 2). Clipping the imagery was found to be advantageous because it eliminated extraneous data therefore speeding up the classification process, as well as minimizing, and in some cases, eliminating, potential sources of confusion.

Once the imagery was clipped, the training set was produced for the initial pass. In this process considerable attention was given to the selection of the best representatives of the oyster, as well as ensuring it to be a diversified sample, both spatially and spectrally. Three separate training sets were developed, consisting of washed shell, fringing and patch reefs. This was done because of the wide range of sizes, shapes and spectral signatures evinced among the varying types. Once these separate training sets were completed, the learning set up was executed and parameters selected that would produce the best result for each oyster type. One parameter which was found to significantly alter the results was the input representation, or the kernel that is passed over the image in the classification process. Instead of just looking at a central pixel to identify a feature, which is much like looking through the end of a soda straw, feature analyst takes into consideration an arrangement of pixels surrounding the central (target) pixel in order to classify the feature. The input representation that was most effective for both the patch reefs and the more linear fringing reefs was the Manhattan 5X5 kernel. There was evidene that the Bull's Eye input representation could be better at delineating the linear orientation of the fringing reefs, however differences were found to be negligible.

The initial aggregation option was set to aggregate polygons of 60 pixels or less. This was intentionally set low in order to produce more potential oyster polygons at the start . In subsequent passes the results were gradually weaned or tailored to remove areas of commission. Error of commission was preferred over omission at this stage to avoid the inefficiency of adding omitted areas later.

It was determined that once the initial pass was performed, a subsequent clutter removal pass was required in order to retrain the software on the areas of both commission and omission, if there were some present. Results were best when the Foveal input representation was used, which functions similar to the way our eyes see by focusing on a central arrangement of pixels and looking at surrounding pixels in a weighted fashion, much like our peripheral vision.

At this stage, a series of post processing functions are performed. A final aggregation is run using approximately 120 pixels to ensure that all polygons below the designated 10 square meters MMU are removed. This threshold can be adjusted to ensure no mappable oysters are removed; however this setting was found to be fairly successful and inclusive.

The final step taken in the generation of the Base product is a Smoothing function. In Feature Analyst version 3.4 a vertex removal function is used which can remove some of the blocky nature of the polygons, producing a smoother appearance. A concern is that if incorrect smoothing thresholds are selected, there could be a degradation of the integrity of the polygon boundary. Therefore, minimal amounts of the smoothing function were performed on the polygons because accurate delineation of these system boundaries is of highest priority. The latest version of Feature Analyst has a smoothing function that, rather than removing vertices, applies an averaging algorithm between successive vertices, creating a rounding effect. This could be an effective way of producing more aesthetic polygon boundaries, though this would not necessarily improve accuracy.

OYSTER BED VERTICALNESS MAPPING

The verticalness of the oyster bed is the degree to which each component oyster shell stands on end, or vertical, within a contiguous patch of oysters. The verticalness of the shells is related to the health of the oyster feature. A highly vertical patch indicates a healthier oyster bed than a more horizontal one. The results are polygon-based such that each polygon has a unique value. The classification scheme for the Verticalness product is as follows:

Table 2. Classification Scheme for Option 1.

Class	Description
1	Background
2	High percentage of vertical oysters
3	Medium percentage of vertical oysters
4	Low percentage of vertical oysters
5	Washed shell – conveys from Base product

A pixel-based spectral classification is also created as an intermediate file with the following classification scheme:

Table 3. Classification Scheme for pixel-based oyster bed map.

Class	Description
1	High percentage of vertical oysters
2	Medium percentage of vertical oysters
3	Low percentage of vertical oysters
4	Mud with sparse vertical oysters
5	Vegetation
6	Washed shell – conveys from Base product

This file is used in the polygon-based file production to determine the percent of certain features falling within the larger polygon (see Figures 3a and 3b).

	Background
	High % Vertical
	Medium % Vertical
	Low % Vertcial
	Mud w/ Sparse Vertical
	Vegetation
	Washed Shell

	Background
	High % Vertical
	Medium % Vertical
	Low % Vertical
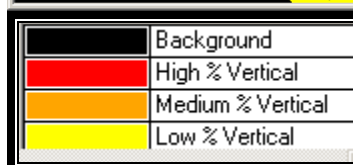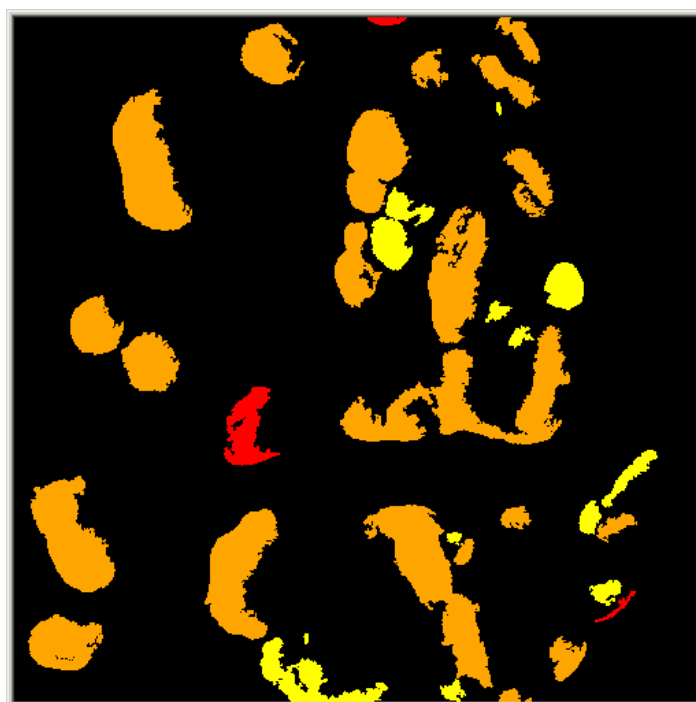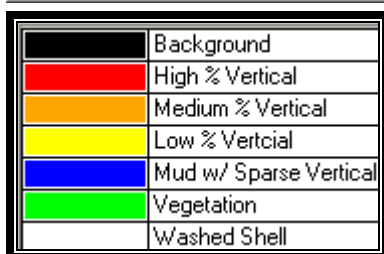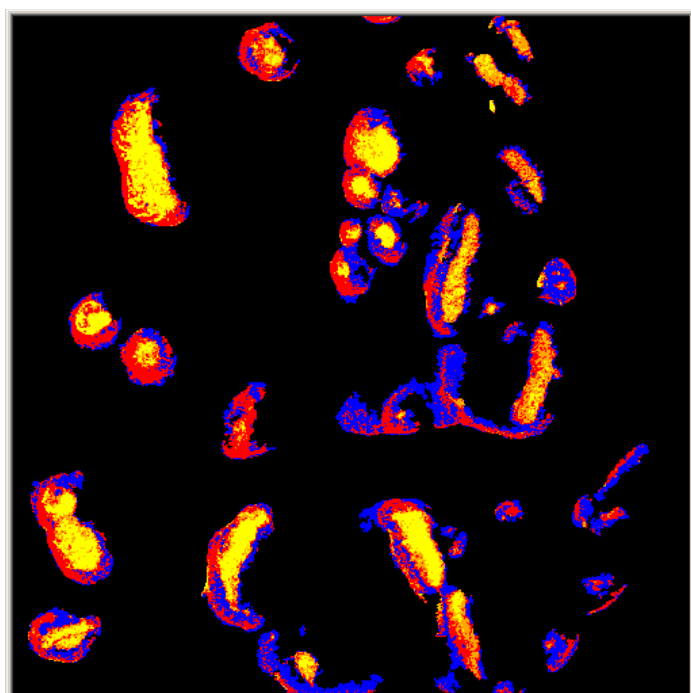
Figure 3a. Patch reef oyster beds represented in the pixel-based classified product.

Figure 3b. Patch reef oyster beds represented in the polygon-based classified product.

The classified pixel-based file is used to produce another ancillary data product, the clump analysis file. This file is a raster polygon-based file created by ordering the pixel-based data according to spatially contiguous areas. It contains the information used to produce the final Verticalness polygon-based product. Each oyster bed has an independent value and is associated with the following attributes: Most Frequent Class (majority pixel value occurring within a spatial clump of pixels), Class n (number of pixels in the intersection of a clump and Class n, where n = 1 through 6), and Class n% (percent of pixels of class n falling within a certain clump where n = 1 through 6).

Methods

The process for creating the Verticalness Product began with the classification of the GeoScanner multispectral imagery. First, the Base product polygons were used to stratify the imagery so that only live (not washed) oyster beds still remained in the imagery. Then each Base product stratified DOQQQ of GeoScanner data was spectrally clustered and classified. A staff member that had visited the field and was familiar with the oyster bed features then interpreted this clustered file. The clusters were labeled and recoded to create a 6-class pixel-based product (Figure 3a.). This product was delivered to SCDNR and was analyzed using rulesets to derive Verticalness and Strata products.

The next step is to clump the pixel-based classified file. Clumping is the process of mapping the connectivity of pixels by like value and applying a unique value to each spatially separated unit. In this project, the unit boundaries are established in the Base product. The shapefiles that were created to delineate oyster beds are polygons. Those polygons were then used to stratify the imagery. Only the area of imagery within those polygons was classified.

Clumps were created by setting the Base product stratification of the imagery to a single value and then running the clump program. The connectivity was set to four, meaning that a clump would consist of pixels connected by north, south, east, and west bounding pixels, not diagonal, to maximize the number of clumps. The pixel values of the clump file correspond to the spatially contiguous areas where all pixels within each contiguous area contain the unique value of that polygon. The polygon values are numbered from 1 to n based on the order of the polygon starting from the upper left corner and going to the lower right corner. This file is still pixel-based as it is a raster. But the pixel values correspond to the polygons in the Base product thus allowing for polygon-based analysis. The clumps are the raster version of polygon data.

After establishing the clumps, it was necessary to determine the percent of each class in the pixel-based classification intersecting each clump. These values were added as attributes in the clump file thus creating the Clump Analysis file. Each class, 1 through 6, was given a column populated by the percentage of that class in the clump. These percentage values were then used in a ruleset to determine what value to give the clump. The rules were based on thresholding the percentages. Overlap in the rules is overridden by the first rule. The rules that were used in this study are as follows:

Table 4. Ruleset for deriving the Verticalness Product from the Clump Analysis file.

Conditional Statement	Outcomes
Percent of Class 6 within a polygon > 0.66	Class 5
Percent of Class 1 + percent of Class 2 within a polygon > 0.66	Class 2
Percent of Class 1 + percent of Class 2 within a polygon > 0.33	Class 3
Percent of Class 1 + percent of Class 2 within a polygon > 0	Class 4
Anything left over	Class 10

The classes in the conditional statement are the same as the pixel-based classification (Table 3). The classes in the outcomes of the ruleset correspond to the polygon-based product (Table 2). Class 10 is created just in case there are pixels that were not classified by the previous rules. If class 10 is populated in the results then the thresholds or rules must be changed to compensate. This set of rules was used universally. It should be noted that within the structure of this process, both the rules and even more so the thresholds, can be changed to optimize the results.

The rules were applied to the clump layer to produce a polygon-based raster file. This file was then incorporated into the vector Base product layer created earlier.

Discussion

The most important factors in the accuracy of the Verticalness Product are the appropriateness of the rules in the rulesets and the thresholds set within those rules. These rules are flexible and can be changed easily. The structure of the process allows for an efficient workflow and thus access to rules for fine-tuning is very important. The ruleset has a built-in QC in the form of class 10. If class 10 is populated then the rules did not account for every scenario.

Another important factor affecting the accuracy of this model approach to classification is the accuracy of the Base product. If the Base product includes multiple reef systems within a single polygon then the analysis will be less accurate. The more each oyster bed is delineated individually in the Base product, the more accurate the polygon-based analysis will be. Ideally, each independent oyster bed system will be contained entirely within only one unique polygon. This makes the analysis more accurate because the thresholds in the rules correspond best to one system. Often a polygon in the Base product does not contain one and only one oyster bed system. For example, sometimes there are small mud "bridges" between two patch reefs covered with oysters. This is not as confounding a factor if the two reefs are very similar in percent of verticalness of oyster features covering them, but it can be confounding if a patch reef occurs beside a mud flat with sparse oyster coverage. Then the analysis will include both types of land cover and thus make less accurate both areas. Usually when two individual reef systems are lumped into one polygon, they are similar. This may be an unavoidable factor when mapping some fringing reefs, because sometimes a contiguous fringing reef contains within it many different categories.

Also a factor in the accuracy of the final product is the accuracy of the initial classification of the GeoScanner imagery into six classes. This should be performed by staff that have experienced the ground truth collection. Accuracy would also be higher in this product if a substantial amount of field-collected data were available in the

same area covered by the pilot study data. In this case there was little overlap to aid in interpretation. This intermediate layer is the basis of the model approach and is used to derive the Clump Analysis layer. The more accurate the classification is, potentially the more accurate the final product. However there is some room for error in the initial classification. Because this approach to mapping is polygon-based and deals with ranges of percentages, the proportions of verticalness classes in a clump are more important than the pixel accuracy.

OYSTER BED STRATA CLASSIFICATION

The Strata Classification Product is based on a grouping of SCDNR-defined strata that correspond with oyster beds of interest. These classes are realistic descriptions of oyster beds as they occur in nature. Table 4 contains the classes and lay descriptions for this product.

Table 5. Classification Scheme for Option 2.

Class	SCDNR Strata	Description
1	-	Background
2	A, E, F, F1	Vertical and horizontal oysters mixed, marsh vegetation, little or no mud or washed shell features
3	G, C	Vertical oysters surrounded by mud, little or no horizontal oysters
4	B, D	Horizontal oysters mixed with washed shells, low Intertidal, little or no vertical oysters
5	-	Washed shell – conveys from Base product

The strata categories take into account the context of the oyster beds as well as the verticalness. This is why the initial classification of the GeoScanner imagery contains categories for mud (with sparse oyster coverage) and vegetation (marsh grass). These categories are used in the ruleset. They do not convey to the final product. The different combinations of the six classes of the initial classification (Figure 4a) are sufficient to model the strata categories (Figure 4b). Both verticalness and context are attributes of the initial classification.
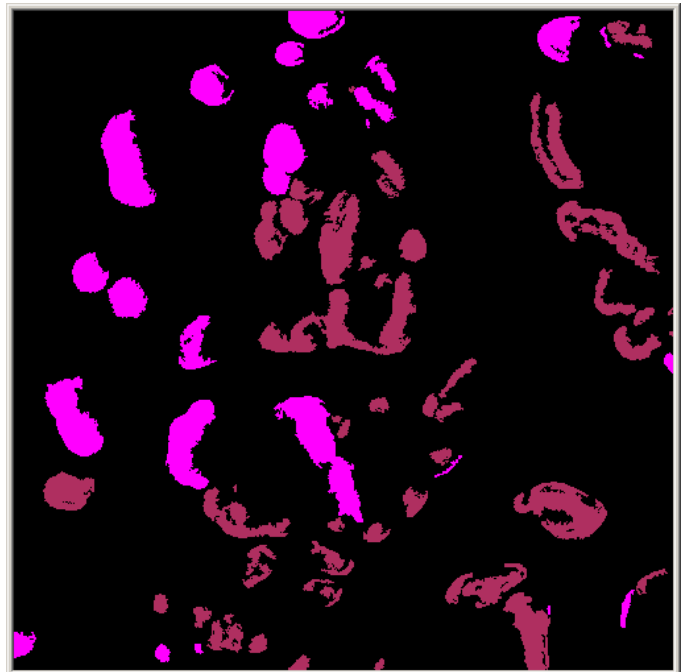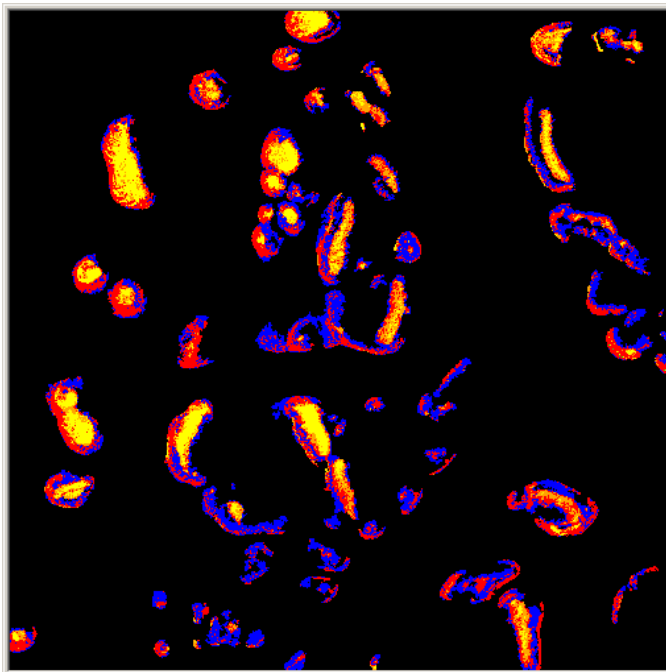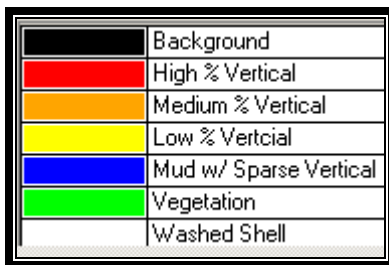
Figure 4a. Patch reef oyster beds represented in the pixel-based classified product.
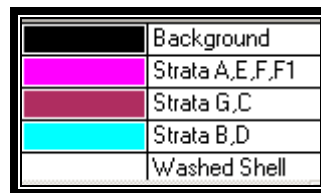
Figure 4b. Patch reef oyster bed polygon-based classification according to strata as defined by SCDNR.

Methods

The process for creating the Strata Classification Product began with the creation of the clump analysis file mentioned in the Verticalness methods. The Strata Classification Product utilized the same clump analysis file that the Verticalness product was derived from. The Strata Classification methodology also used a ruleset approach to model the target categories. The rules used in this classification are as follows:

Table 6. Ruleset for deriving the Strata Classification Product from the Clump Analysis file.

Conditional Statement	Outcomes
Percent of Class 6 within a polygon > 0.66	Class 5
Percent of Class 4 >= 0.33 and percent of Class 3 < 0.33 within a polygon	Class 3
Percent of Class 3 + percent of Class 6 within a polygon > 0.66	Class 4
Percent of Class 1 + percent of Class 2 + percent of Class 3 + percent of Class 5 within a polygon > 0.66 and percent of Class 4 < 0.33 and percent of Class 6 < 0.20	Class 2
Percent of Class 6 within a polygon > 0.20	Class 4
Anything left over	Class 10

As in verticalness, the classes in the conditional statements refer to the initial pixel-based classification (Table 3). The classes in the outcomes correspond with the strata classification scheme (Table 5). Class 10 absorbs pixels that were not referred to in the ruleset. All of the live oyster bed polygons delineated in the Base product also have an attribute related to verticalness and strata.

The strategy for producing the Strata Classification is similar to the production of Verticalness. It involves the initial classification of the GeoScanner data into six categories. Then the layer is spatially clumped and percentages of each category per clump are calculated to produce a clump analysis layer. Both products rely on applying rulesets to this clump analysis layer. The rulesets are different however. The Verticalness Product is based entirely on the percent of vertical pixels occurring in each clump and applying thresholds to these percentages. The Strata Classification relies more on the logic of the rules themselves than merely the appropriateness of the thresholds.

RESULTS

An external validation was performed by the SCDNR. This validation is based on the results of the products submitted to fulfill a pilot project consisting of six DOQQQ's. These products covered all of the DOQQ called St. Phillips NE near Charleston SC and half of the DOQQ called Ft. Moultrie, also near Charleston SC. The validation was conducted independently by the SCDNR using filed point collection techniques, which included the collection of digital video taken from boat for later lab review.

The method for accuracy assessment, or validation, began with an experienced field crew visiting as much of each DOQQQ area as possible in the field via boat. The entire trip was filmed by digital videography. The video was time-stamped and a marker was placed in front of the screen at each physiographic division of oyster feature. The divisions usually corresponded well to oyster bed delineations. The markers allowed for a system of reference for laboratory interpretation revisits. Each division corresponding to an oyster bed was treated as an independent unit with attached scores pertaining to the Extent, Verticalness, and Strata.

ASPRS 2005 Annual Conference
Baltimore, Maryland ◆ March 7-11, 2005

For each unit, the Extent was measured by two factors: Presence/Absence and Length. The Oyster Bed Extent Product has two categories: Live Oyster Bed and Washed or Dead Shell. The assessment of the presence of the oyster bed polygon was divided into four categories of Correct Positive (Oyster Bed Extent Product correctly shows oyster as existing in the validation unit and calls it the correct category, i.e. live or washed shell), Correct Negative (Oyster Bed Extent Product correctly shows oyster as existing in the validation unit but calls it the incorrect category, i.e. live or washed shell), False Positive (Oyster Bed Extent Product shows oyster in the wrong area but regardless calls it the correct category, i.e. live or washed shell), and False Negative (Oyster Bed Extent Product shows oyster in the wrong area (or completely misses it altogether) and also calls it the incorrect category, i.e. live or washed shell). This breakdown was used for analysis of the error. For the purposes of this validation the Correct Positive and Correct Negative were counted as correct and the False Positive and False Negative scores were labeled incorrect. Then the ratio of the correct calls to incorrect calls for Extent were averaged with Length score. The length score was based on a binary pass/fail score. If the length for a unit was basically correct, it passed. If the length of an oyster bed clearly deviated from the validation unit then it was given a failing score. The formula for the accuracy of the Oyster Bed Extent Product could be expressed as:

$$A_{OE} = [(CP + CN)/N_E) + (L_P/N_L)] * \frac{1}{2}$$

where CP = Correct Positive, CN = Correct Negative, N_E = Number of Extent points, L_P = correct Length calls, and N_L = Number of Length validation points.

The Verticalness and Strata classes were assessed by a binary pass/fail label of the oyster bed polygon. For each of these, the number of correctly called polygons was divided by the number of incorrect polygons to produce the final accuracy assessment number. The validation units were determined by reviewing the field data in the lab while cross-referencing with the vector Oyster Bed Product's Verticalness and Strata attributes. The interpreter viewed the oyster bed while referencing the field data at the same location. Then he/she made a determination of whether the call was correct or not.

This accuracy assessment was deterministic and not fuzzy. The minimum mapping unit for validation was one meter. The subset of correctly called Extent polygons were assessed for the accuracy of Verticalness and Strata classes. This was necessary because if the oyster bed did not exist in the Extent Product, then the descriptors of verticalness and strata could not be assessed for accuracy.

One problem with the assessment procedure is that the units were not interpreted at the same tide level as the imagery was taken. The imagery was collected at low tide as close as possible. Some effort was taken to collect the validation units at low tide but this was not always the case. This led to interpretation differences regarding the Strata categories because often an oyster bed was being described by the whole bed in the imagery but only a top non-inundated rim during the assessment. Since there is often variation of density and verticalness within an oyster bed, and this is particularly true over vertical space because of the different amounts of time the oysters are exposed to the water, the validation Strata category may not be a fair judgment of the Strata Classification Product. This is a factor that is being revisited. Also there was probably some difference in opinion of density and verticalness of oysters within a bed because of the different perspective of collecting the field information from a boat looking horizontally at the features and collecting the airborne image data from an aerial or vertical perspective. The same oyster bed looks sparser and the context material (i.e. mud) is more apparent from above. Also the horizontalness of the bed is more apparent from the aerial view, whereas from a boat, the vertical oysters are more obvious.

The accuracies are listed in Table 7.

Table 7. Accuracies for Ft. Moultrie and St. Phillips DOQQ's as Reported by SCDNR.

DOQQ	Extent	Verticalness	Strata
Fort Moultrie SE	76%	N/A	57%
St. Philips NE	88%	90%	59%

CONCLUSIONS

Our initial conclusions upon the completion of this pilot study are that the procedures developed for oyster bed delineation and characterization of verticalness and characterization of strata are accurate. The processes are repeatable as well because the subjectivity of interpretation is limited as much as possible. The rules developed during the oyster bed delineation, verticalness characterization, and strata characterization are objective processes. The subjective portions of this mapping process are in the placement of training points and the labeling of ISODATA clusters to create the clump analysis file, which is the base of the modeled verticalness and strata layers.

The accuracy of the products rely heavily on the rulesets. The validation of these data must take into account how the categories are modeled. For example if the PSI team determined that highly vertical oyster features means > 66% high and medium vertical pixels in the pixel-based product, but in the field SCDNR considers that > 50% high and medium verticalness in an oyster bed warrants the highly vertical label, then both parties may be correct in their assessment, but are not synchronized. In this case the error would be due to a lack of understanding of the client's preference for rule establishment as opposed to an inaccurate mapping procedure.

The strength of this procedure is that it is a syncretic approach. It blends the strengths of vector analysis, particularly regarding the delineation of features, with the power of raster spectral processing, such as with ISODATA classification. It also blends the subtlety of expert interpretation with the automation of modeling. This is a procedure that utilizes the strengths of many techniques. It is a procedure that is semi-objective and yet has the flexibility for experts to improve accuracies as the relationship between ground features and their associated categories are understood better.

Appendix 3

QA/QC Rule Sets – SCDNR

There are four parts to the following Rule Sets developed by SCDNR to score the accuracy of the oyster mapping process. The "Remote Sensing QA/QC Grading Key" was formalized into a dichotomous key for assessing presence/absence of oyster reefs and reef extent through the use of GPS transects captured by boat ground-truthing. Following the grading key are the final rules developed to score attempts for Option 1 (percent vertical oyster) and Option 2 (oyster strata type). The final set of scoring rules was developed for use with low altitude helicopter photos. All visible reefs on the helicopter photos were hand-drawn onto the multispectral imagery using the helicopter photos as reference. These hand-drawn reefs were used to assess reefs in areas inaccessible to boats.

Remote Sensing QA/QC Grading Key (Base Option)

> ***General Notes***
> -Minimum mapping unit = 10 m^2
> -Continue through the key until both the P/A and Length columns give an answer
> -When recording one grade for multiple transects, record it on the data sheet in the spaces
>   after the largest transect.
> -Be aware that there is an error of 3-4 m in the positional accuracy of the images, so the transects
>   may appear to be improperly placed. Take that into account when grading it against the
>   polygons and make sure you are comparing the correct polygon/transect pair. If the polygon is
>   in the low intertidal or far upper bank region, check the width of the transect, the polygon may
>   be capturing something completely different than was intended by the ground-truthing transect.

Relationship

One Shell Transect : No Polygon I
One Shell Transect : One Polygon.. II
One Shell Transect : Multiple Polygons III
Multiple Shell Transects : One Polygon IV
Multiple Shell Transects : Multiple Polygons V
One Mud Transect : No Polygon VI
One Mud Transect : One Polygon VII
One Mud Transect : Multiple Polygons.. VIII
Multiple Mud Transects : One Polygon... IX
Multiple Mud and Shell Transects : One Polygon......................... X
Multiple Mud and Shell Transects : Multiple Polygons XI

	Grade[1]	
	P/A	Length
Relationship I		
One Shell Transect : No Polygons	FN	not graded
Relationship II		
One Shell Transect : One Polygon		
A. Polygon length is < 25% of the transect length...	FN	not graded
B. Polygon length is ≥ 25% of the transect length		
1. Polygon length is < or > the transect length by ≤ 10 m. on either side..	CP	Pass
2. Polygon length is < the transect length by > 10 m. on either side.......	CP	Fail
3. Polygon length is > the transect length by > 10 m. on either side.......	CP	Fail or no grade[2]
Relationship III		
One Shell Transect : Multiple Polygons		
A. Combined length of polygons is < 25% of the transect length	FN	not graded
B. Combined length of polygons is ≥ 25% of the transect length		
1. All spaces between polygons are ≤ 10 m. and polygons differ from either transect end by ≤ 10m.	CP	Pass
2. At least one gap between polygons is > 10 m.	CP	Fail
3. The transect is longer than the edge polygon by > 10 m......................	CP	Fail

4. The transect is shorter than the edge polygon by > 10 m ....CP   Fail or
....   no grade[2]

Relationship IV
Multiple Shell Transects : One Polygon
    A. The polygon is <25% of the combined widths of the transects.................FN   not graded
    B. The polygon is ≥ 25% of the combined widths of the transects
        1. At least one transect extends beyond the polygon by > 10 m..............CP   Fail
        2. A gap between the transects is > 10 m. or the polygon
        extends > 10 m. beyond a transect..CP   Fail or
        ....   no grade[2]
        3. All gaps between transects are ≤ 10m. and the end transects are
        within 10 m. of the ends of the polygon ....CP   Pass

Relationship V
Multiple Shell Transects : Multiple Polygons
    A. Two shell transects : two polygons
        1. Gap between transects is ≤ 10m and
        the gap between polygons is ≤ 10m..Go to II
        2. Gap between transects is ≤ 10m and
        the gap between polygons is > 10m..Go to III
        3. Gap between transects is >10m and
        the gap between polygons is ≤ 10m..Go to IV
        4. Gap between transects is > 10m and
        the gap between polygons is > 10m
            a. Both polygons overlap one transect by ≥ 25% of the
            transect length, the other transect covers < or > 25%
            of one polygon (combine transects) ....CP   Fail
            b. One transect is overlapped by two polygons; one polygon
            overlaps it by ≥ 25% of the transect length, the other polygon
            overlaps it by < 25%. The other transect overlaps
            only one polygon (two grades recorded)
                - The transect touching two polygons is graded using
                the polygon that covers ≥ 25% ....CP   Fail
                - The transect overlapping only one polygon is graded..............Go to II
            c. Both polygons each overlap one transect by <25% of
            the transect length, and ≥ 25% of the length of the
            second transect is overlapped by one of the polygons (2 grades)
                - The transect overlapped by < 25%..FN   not graded
                - The transect overlapped by ≥ 25%..Go to II
            d. Neither polygon comprises > 25% of the length of
            either of the transects (2 grades) ....2FN   not graded
    B. More than two shell transects : more than two polygons
    - Start at the first pair of transects and give temporary grade based
    on relationship IV or V.A.
    - Go to the next transect and see if it or the next polygon can be
    incorporated into the temporary grade or if it needs to be graded
    separately based on the rules in V.A. If separated, start a new grade
    with the next set of transects/polygons. If combined, the temporary grade may
    be changed if the added transect is large.

<u>Relationship VI</u>
One Mud Transect : No Polygons..CN Pass

<u>Relationship VII</u>
One Mud Transect : One Polygon
 A. Polygon is > 75% of the mud transect length...FP
 B. Polygon is ≤ 75% of the transect length (25% or more of the transect
 is correct with no polygon presence).
  1. Polygon covers ≤ 10m of the mud transect...CN Pass[3]
  2. Polygon covers > 10 m of the mud transect..CN Fail

<u>Relationship VIII</u>
1 Mud Transect : Multiple Polygons
 A. Combined length of the polygons is > 75% of the mud transect length....FP
 B. Combined length of the polygons is ≤ 75% of the mud transect length
  1. All polygons are ≤ 10 m ....CN Pass
  2. At least one of the polygons overlaps the transect by >10m ....CN Fail
  3. At least one of the polygons overlaps the transect by ≤ 10 m
  but is > 10 m in length ....CN Pass[3]

<u>Relationship IX</u>
Multiple Mud Transects : One Polygon
 A. There is ≤ 10 m between mud transects treat as one transect....................Go to VII
 B. There is > 10 m between mud transects, but the shoreline is
 continuous mud, combine transects...Go to VII
 C. There is > 10 m between mud transects and there appears to be
 Shell or something other than mud between them, grade separately ....Go to VII

<u>Relationship X</u>
Multiple Mud and Shell Transects : One Polygon
 A. Mud transect(s) on the end(s) of the polygon (multiple grades)
  -The mud transect(s) individually graded for the portion
  of the polygon covered ....Go to VII
  -The shell transect(s) are graded for the polygon portion they cover ......Go to IV
 B. Mud transect(s) located between shell transects (multiple grades)
  -The mud transects are graded separate from shell transects for the
  portions of the polygon they cover.
   - A single mud transect ....Go to VII
   - Multiple contiguous mud transects ....Go to IX
   - A single shell transect...Go to II
   - Multiple contiguous shell transects...Go to IV

<u>Relationship XI</u>
Multiple Mud and Shell Transects : Multiple Polygons
 A. Two transects (1 shell, 1 mud): two polygons
  1. Shell transect touches both polygons, mud touches one polygon
  Draw an imaginary line through the polygon at the ends of the transects
  Grade the transects for the portions of the polygon they cover, and if
  there is a gap > 10m between transects of questionable
  composition, it is ignored.
   - The shell transect ....Go to III

- The mud transect ....Go to VII
2. The mud transect touches both polygons, shell transect touches one
Draw an imaginary line through the polygon at the ends of the transects
Grade the transects for the portions of the polygon they cover, and if
there is a gap > 10m between transects of questionable
composition, it is ignored.
    - The shell transect ....Go to II
    - The mud transect..Go to VIII

  B. More than two shell and mud transects : multiple polygons
    Start with the first pair of transects and polygons, give them a temporary grade,
    Then look to the next transect to see if it needs a separate grade or is combined.
    If combined, the temporary grade may need to be changed if the added transect
    is larger than the others.
        - For pairs of shell transects and polygons..Go to V
        - For pairs of mud transects and polygons ....Go to IX
        - For a pair of one mud and one shell transect ....Go to XI. A.

Footnotes

1. There are two parts to grading the Base option: Presence/Absence and polygon length.
    Presence/Absence (P/A) has 4 grading options: Correct Positive – correct shell (CP), Correct
    Negative – correct absence of shell (CN), False Positive – shell incorrectly identified as being present
    (FP), and False Negative – shell not identified when it is present (FN).
    Length has three options: Pass, Fail, and no grade. Length is not graded if Presence/Absence fails, or
    if the polygon is larger than the transect and the validity of the extra length is uncertain.

2. As mentioned in the first footnote, there is an option to not grade the length if the polygon is larger
    than the transect by more than 10 m. If there is any uncertainty as to if what the polygon is capturing
    is shell, it should not be graded. Notes from the field, recollection of the area , or video can enable
    you grade these types of polygons sometimes. Sometimes in the field, the tide may be up high
    enough to obscure the full width of the bed, especially in the middle.

3. This relates to note #2. Generally for mud you should only grade the area within the transect since
    the transect was often randomly placed on a long mud bank, but sometimes was ended due to debris
    or a section of shell less than 10m long. If the polygon extends beyond the transect by more than 10
    m and there is a note somewhere in the notes or on the map that it is clearly all mud, a failing grade
    on length can be issued.

Option 1: Percent cover of complex shell matrix.

The purpose of this option is to determine the density of complex shell within the oyster polygons identified by Photo Science and DNR ground truthing.

- The Photo Science percent cover data will be provided as percents.
- Percent cover estimates will be considered to be correct if they are within 20% of DNR's estimate of percent vertical.

- The DNR average value will be compared with the Photo Science average value for each Photo Science polygon, or for a collective set of polygons when several are present within one DNR transect. When multiple polygons have a variable percent cover estimate, make an estimate of PS average %vert keeping in mind that larger areas are weighted heavier in an average. If an average is difficult to attain, use video records and the intermediate raster file to determine if the areas are classified correctly.

DNR Bed #1 – 65% vert.

P.S. – 85 %   P. S. - 30 %

P. S. – Passes on % vertical (avg~67%). (The 85% bed is twice the size of the 30% bed)
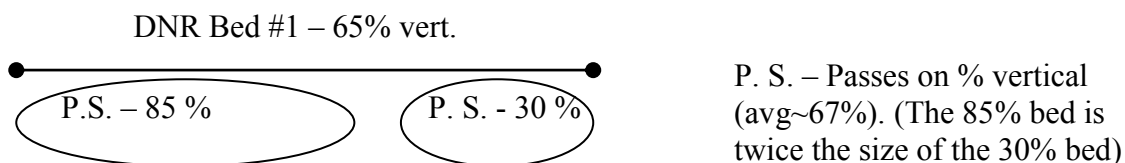
- When DNR identifies multiple transects of different percent coverages, within a single large Photo Science polygon, the score is assigned to the transect used to grade the base option(the largest). If PS has passed on length, average the DNR transects(weight them when necessary) to grade the PS percent vertical.

DNR #2 = 25%   DNR #3 = 65%   DNR #4= 55%   DNR #5= 90%

P.S.= 70 %

P.S. – Passes on % vertical (~58%) and the grade is recorded for DNR #2 (largest single transect)
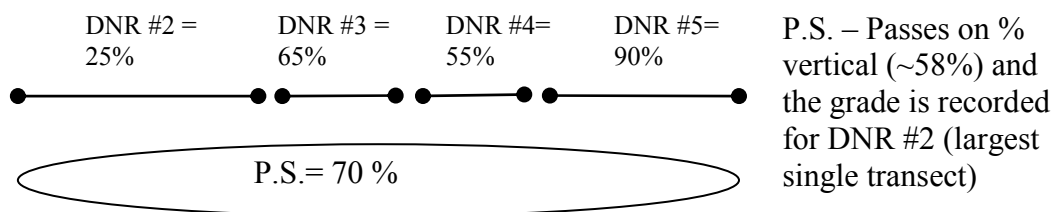
- If PS captures a larger polygon than DNR, use the intermediate file to assess if the area DNR captured appears to be classified correctly. If the bed looks homogeneous in % vertical coverage (not patchy), use the PS % to grade the polygon. If the polygon is patchy the intermediate file can be used to make a judgment call (ideally that section should be cropped and recalculated by PS for a new percent). Make a note.
- If high tide occurs and there is a discrepancy in % cover or strata, the bed should not be scored positive or negative.

Option 2: Strata classification

- The DNR strata classification (grouped) will be compared with the Photo Science classification (grouped) to obtain the percentage of correct classifications.
- When there are multiple Photo Science polygons compared to a single DNR transect, the predominant classification of the multiple polygons will be used for the comparison. In these cases, the multiple polygons will be considered collectively as a single polygon for classification purposes.
- When DNR identifies multiple transects of different strata, within a single large Photo Science polygon and the majority of the large polygon is correctly classified, the sections of the polygon where transects strata disagree will not be scored. The grade gets entered for the longest bed as in above.
- When there is a DNR transect with low % vertical shell (≤30%) classified as either D or F1, Photo Science will get a correct score if they have either D or A,E,F,F1 and if they have passed with the % vertical rules.
- When there is a DNR transect with a high % vertical (>70%) classified as either a G or an F, Photo Science will get a correct score if they have either a G,C or an A,E,F,F1 and have passed with the % vertical rules

Helicopter QA/QC Rules

- To grade Base:
    - Grading Presence/Absence (P/A) is similar to transect rules, except you'll be estimating if there is more than 25% overlap of PS polygons with DNR polygons unless one is completely inset in another.
    - You can grade (P/A) for CP, FP, and FN, but not CN (we have no specific "mud" polygons)
    - To grade extent, add a 1 m. buffer on either side of each polygon for both sets of polygons. If there is an area (excluding the buffer) that Photo Science missed or captured in excess of 10 m^2 (with a 1m width minimum), they fail extent. This can be estimated using the "ruler" tool for most instances, if it is too close to call, no grade can be given or the polygons can be intersected to calculate these areas time permitting.
- To grade Option 1:
    - Strata were recorded by DNR, use the "Range of % Vertical Shell" developed for each strata for the DNR % vertical estimate. These ranges will be listed on the bottom of the data sheet.
    - If PS calculated a % vertical that falls in the range for the strata recorded for that polygon, they pass.
    - If there are multiple PS polygons per one DNR polygon, it can be graded if there is one large dominant PS polygon and use the % from the large polygon for the grade, otherwise you can choose to do a "no grade".
    - If there are multiple DNR polygons, but there is a dominant strata either in one large polygon or among several smaller polygons, use the range for that dominant strata for the grade. If there isn't a dominant strata do a "no grade".

Ranges of % Vertical Shell for Strata (10 - 90%)

Strata	Range
A,E,F	55 - 83.6%
F1	36.38 - 62.5%
G	51.05%- 73.3%
C	26.73 - 50.77%
D	5 - 22.5%
W	< 5%

Appendix 4

DOQQ Summary Table

This table reflects the information known on the status of the SC Dept. of Natural Resources oyster reef data set (SCoyster2008) as of December 3, 2008. It will be updated as the data set changes. Oyster reef areas were processed at the USGS DOQQ boundary level. Reef counts and total reef area have been summarized for each DOQQ. Sixty DOQQs were assessed for accuracy and the data is listed below. GPS transects were collected by boat and compared to digitized vector polygons of oyster reefs. For scoring correct oyster (presence) vs correct mud (absence) classification: An area parallel to a transect is considered correct if 25% of the length of the transect is classified correctly. The Extent is the length of the reef along the measured transect. It is considered a correct extent if no more than 10 consecutive meters were incorrectly classified. Editing status is listed by DOQQ for areas where SCDNR has conducted final edits and corrections for 2008 ("Y" indicates completion) . Improvements were made using available data and knowledge of the resource. Some sections (quadrants) of DOQQs have also been flown over by helicopter "F" and fully photographed at altitudes of 200-400 feet. Reefs in these areas are currently being edited using these photos. They are marked with a "D" when completed. **Accuracy scores are not changed to reflect any edits completed, so all accuracy scores listed should be considered minimum scores.

DOQQ	Presence/Absence	Extent	SCDNR 2008 Edits Complete	NE	NW	SE	SW	# Reefs	Total Acreage	# Reefs	Total Acreage
	Accuracy Scores** (% Correct)		**Edit Status** SCDNR	Helicopter Edits				**Reef Measurements** Live Shell		Washed Shell	
Adams Run NE			N			F	F	260	5.55	5	0.02
Adams Run NW			N			F		70	1.22	4	0.03
Adams Run SE	95	94	Y	F	F	F	F	3025	60.38	63	1.70
Adams Run SW			Y	F		F		213	2.26	10	0.19
Awendaw SE	84	82	N	F		F		640	53.23	108	6.88
Awendaw SW			Y					187	12.41	54	1.33
Beaufort NE			Y					1193	15.56	71	1.46
Beaufort NW			Y					501	5.30	9	0.06
Beaufort SE	75	87	N					1435	41.56	127	3.23
Beaufort SW	93	88	Y					1840	26.35	0	0.00
Bennetts Point SE	89	72	N					1291	39.03	47	1.53
Bluffton NE	81	62	N					4156	372.72	132	10.78
Bluffton NW			N					1721	32.80	244	11.02
Bluffton SE	85	81	N					1104	48.86	237	23.89
Bluffton SW	95	95	Y					820	32.62	184	39.48
Brookgreen NE			Y					190	8.25	23	0.28
Brookgreen SE	88	59	N					2127	119.46	183	3.45
Brookgreen SW			Y					77	2.47	0	0.00
Bull Island NE			Y					0	0.00	0	0.00
Bull Island NW	91	89	Y					868	42.29	48	2.61
Bull Island SW			N	D				361	29.96	52	2.93
Cainhoy SE			N					480	16.33	8	0.11
Cainhoy SW	93	75	Y					438	25.24	83	3.39
Calabash SW			Y					67	1.60	61	2.92
Cape Romain NW			Y				D	162	7.97	13	10.24
Cape Romain SW			N					509	35.77	26	1.77
Capers Inlet NE			Y					58	1.18	0	0.00
Capers Inlet NW	85	66	Y					6196	186.84	566	23.86
Capers Inlet SW			Y					41	0.37	0	0.00
Charleston NE			Y					241	11.92	88	3.40
Charleston NW			Y					109	2.70	9	0.15
Charleston SE			Y					178	6.56	146	8.93
Charleston SW	75	88	N					178	12.25	111	4.68
Dale SE			Y					737	16.47	74	2.64
Dale SW	95	95	Y					1933	16.78	0	0.00
Edisto Beach NE			Y					4	0.03	0	0.00
Edisto Beach NW			N					174	4.49	3	0.08
Edisto Island NE			N					1942	46.96	10	0.17
Edisto Island NW	74	88	N					625	11.35	367	8.36
Edisto Island SE	80	87	N					478	8.16	0	0.00
Edisto Island SW	85	94	N					1142	42.79	111	4.29
Fort Moultrie NE	93	78	N					4525	152.43	2	0.15
Fort Moultrie NW	94	90	Y					482	13.37	80	4.69
Fort Moultrie SE	96	92	N					1602	50.86	82	3.77
Fort Moultrie SW	77	92	Y					1470	36.49	98	3.84
Fort Pulaski NE			Y	D	D	D	D	0	0.00	0	0.00
Fort Pulaski NW			Y	D	D	D	D	0	0.00	0	0.00
Fort Pulaski SE			Y	D	D	D	D	0	0.00	0	0.00
Fripps Inlet NW	87	80	N					1967	103.89	5	0.07
Frogmore NE	91	74	N					1136	53.84	89	5.49
Frogmore NW	95	83	Y					2193	45.53	46	8.77
Frogmore SE			Y					1655	60.96	0	0.00

| | Accuracy Scores** | | Edit Status | Helicopter Edits | | | | Reef Measurements | | | |
| | % Correct | | SCDNR | | | | | Live Shell | | Washed Shell | |
DOQQ	Presence/ Absence	Extent	2008 Edits Complete	NE	NW	SE	SW	# Reefs	Total Acreage	# Reefs	Total Acreage
Frogmore SW	91	80	N	F	F	F	F	2813	63.24	0	0.00
Hilton Head NW			N					894	29.07	6	0.21
Hilton Head SW			N					307	15.47	6	0.85
James Island NE	73	73	N					3311	102.19	0	0.00
James Island NW	78	84	Y					803	15.09	0	0.00
James Island SE	88	85	N					740	29.96	0	0.00
James Island SW	89	97	Y					1733	53.54	55	2.18
James Island OE E NW			Y					2	0.30	0	0.00
Jasper NE	95	87	N					1870	36.72	1	0.00
Jasper SE			N					359	10.86	1	0.00
Johns Island NE			N					248	4.98	18	0.27
Johns Island SE			N					251	10.28	15	0.27
Johns Island SW			Y					48	1.55	0	0.00
Kiawah Island NE			Y					186	1.60	0	0.00
Kiawah Island NW	90	89	N					1554	103.46	0	0.00
Laurel Bay NE			Y					902	25.41	38	0.71
Laurel Bay NW	86	90	N					813	25.24	81	2.73
Laurel Bay SE			Y	F	F	F	F	1004	2.73	262	5.76
Laurel Bay SW	95	97	Y					3461	79.82	59	9.35
Legareville NE			N					225	4.74	0	0.00
Legareville NW			Y					139	1.35	0	0.00
Legareville SE	96	65	Y					774	40.87	64	2.00
Legareville SW			N		D	D	D	935	24.50	1	0.02
Little River NE			Y		F			1090	18.93	121	21.44
Little River NW	76	75	Y	F	F		F	480	9.52	180	18.24
Magnolia Beach NW			N	F	F		F	375	4.09	6	0.03
Magnolia Beach SW			Y		F			147	1.22	0	0.00
McClellanville NE	88	82	Y					596	13.99	0	0.00
McClellanville NW			Y			D		236	6.88	96	6.02
McClellanville SE	96	83	N					1198	59.50	0	0.00
McClellanville SW	79	69	Y	F	F	F	F	800	24.14	281	26.38
North Charleston SE			N					335	12.26	17	0.29
North Island NE	96	90	N				F	2312	35.74	10	0.06
North Island NW	99	91	Y					772	20.47	0	0.00
North Island SE	92	91	Y		F		F	768	12.71	0	0.00
North Island SW			N	F		F		234	5.73	1	0.00
Parris Island NE	94	86	N					977	52.67	102	6.97
Parris Island NW			Y	D	D	F	F	1717	45.39	285	9.10
Parris Island SE	96	84	Y			F		607	23.15	203	11.09
Parris Island SW			N					525	77.44	71	10.24
Pritchardville NE	86	91	Y					716	14.39	0	0.00
Pritchardville SE	96	97	Y					502	9.46	37	1.23
Ravenel SE			N					104	4.70	8	0.20
Ridgeland SE			N					182	2.94	0	0.00
Rockville NE	86	88	N					1094	21.44	188	4.09
Rockville NW	89	93	Y					3449	39.14	162	16.41
Rockville SW			Y	D	D			595	4.99	0	0.00
Saint Helena Sound NE			Y	D	D			420	19.55	1	0.01
Saint Helena Sound NW			Y	D	D		D	196	35.97	143	26.15
Saint Helena Sound SE			Y			D	D	62	0.64	0	0.00
Saint Helena Sound SW	90	73	Y	D	D	D	D	4010	229.56	20	2.55
Saint Phillips Island NE	94	93	N					10916	572.66	0	0.00
Saint Phillips Island NW	79	96	N					1553	39.26	198	5.65

| DOQQ | Accuracy Scores** % Correct | | Edit Status SCDNR 2008 Edits Complete | Helicopter Edits | | | | Reef Measurements Live Shell | | Washed Shell | |
	Presence/ Absence	Extent		NE	NW	SE	SW	# Reefs	Total Acreage	# Reefs	Total Acreage
Saint Phillips Island SE	87	86	N					503	17.90	3	1.74
Saint Phillips Island SW	89	95	N			F	F	1753	54.88	165	37.73
Santee Point NW			Y					0	0.00	0	0.00
Sewee Bay NE	63	84	N					478	20.68	5	0.16
Sewee Bay SE	80	76	N					5361	160.68	206	15.46
Sewee Bay SW	77	75	N					1124	36.47	31	4.91
Sheldon SE			N	F	F	F	F	1657	25.33	0	0.00
Spring Island NE			Y	F	F	F	F	1973	103.62	296	21.55
Spring Island NW	99	96	Y					2858	52.13	15	0.43
Spring Island SE	91	81	N					2245	138.00	103	18.64
Spring Island SW	90	92	Y					1631	46.53	40	1.79
Wadmalaw Island NE			Y	F	F	F	F	442	4.41	0	0.00
Wadmalaw Island NW			Y			F	F	2698	41.72	45	1.59
Wadmalaw Island SE	90	72	N					554	6.07	2	0.01
Wadmalaw Island SW	71	89	Y	F	F		F	2475	27.51	216	4.93
Wampee NE			Y	F		F		131	3.47	0	0.00
Waverly Mills SE			Y	F		F		142	1.74	0	0.00

Appendix 5

SCDNR System of Classification of Intertidal Oyster Reefs
Intertidal Oyster Strata Descriptors

Examples of the nine oyster reef descriptors (strata), are provided to assist with interpretation of strata distribution graphs and tables.

Strata A
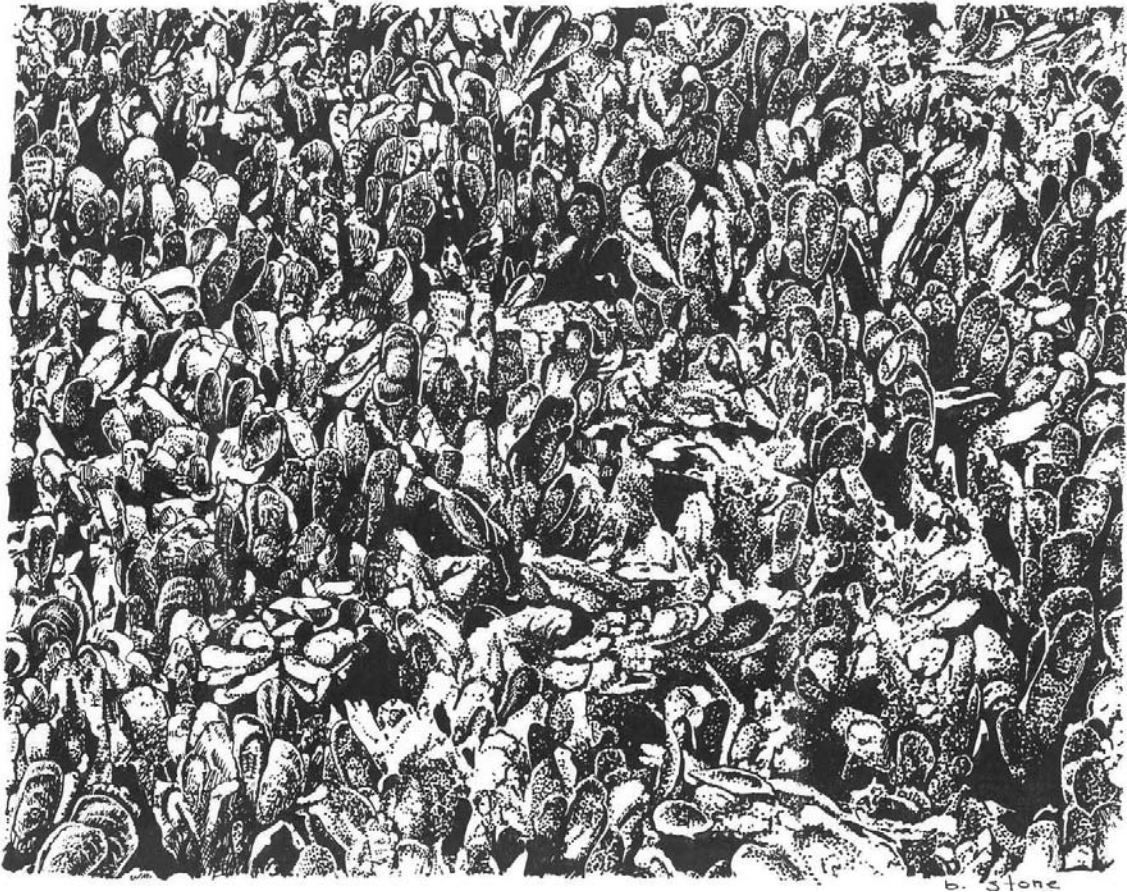
<u>Strata"A"</u>   One of the most productive oyster strata found in the intertidal zone, it has the greatest yield per acre of densely clustered live oysters. This strata exhibits little exposed dead shell or mud and the shell matrix is not visible.

Strata B

Strata "B"   Characterized by having no vertical, or very few clusters in the standing crop. Found mostly in the lower intertidal zone, oysters are frequently single. These populations are located on heavily shelled grounds with thin shell matrices.

Strata C
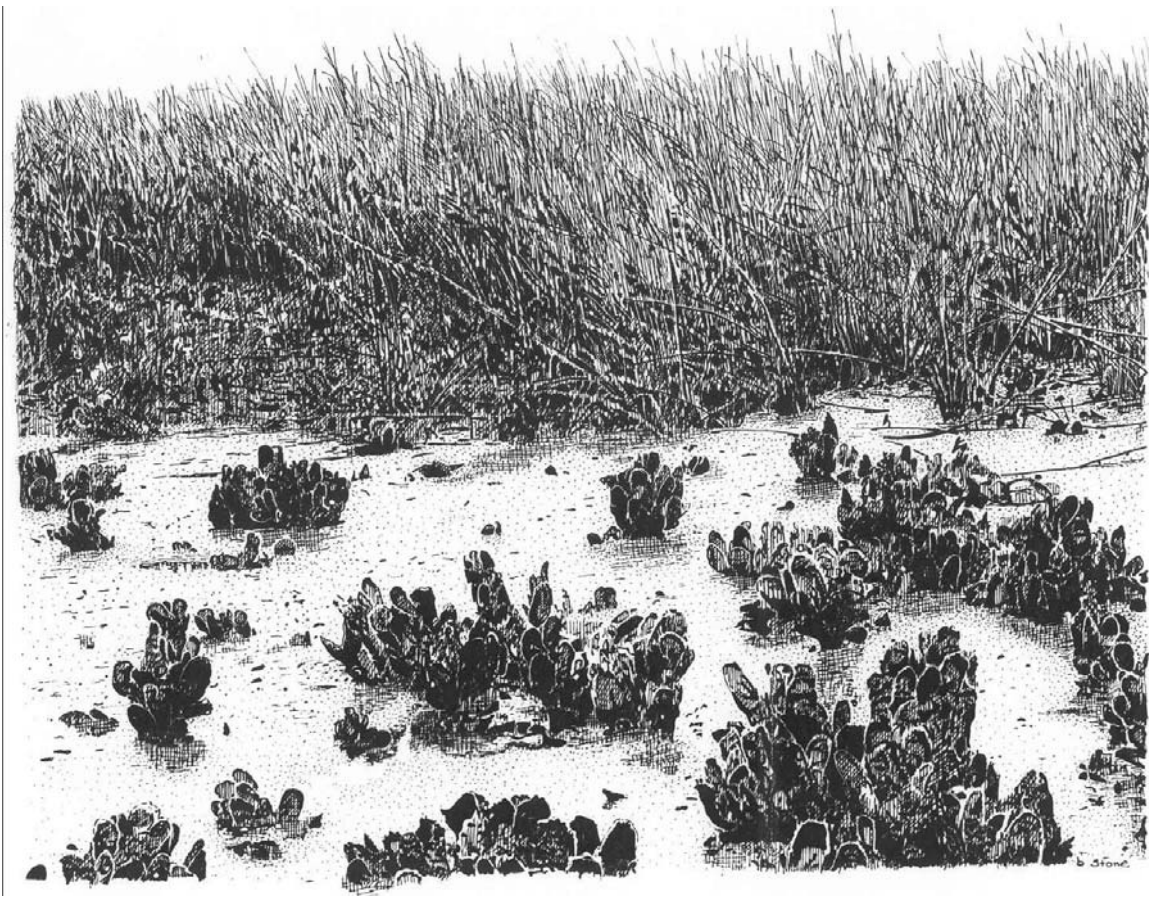
Strata "C".   Characterized by vertical clusters with spatial separation. Substrate is usually mud with little or no surrounding shell. Spatial separation between clusters ranges from a distance equal to the height of an individual cluster to approximately one meter.

Strata D

Strata "D"   This strata consists of scattered live oysters usually integrated with large quantities of "washed" or dead shell. Characteristically found in the lower intertidal zone on hard substrate, the "D" strata habitat is a productive area for cultivating and harvesting.

Strata E
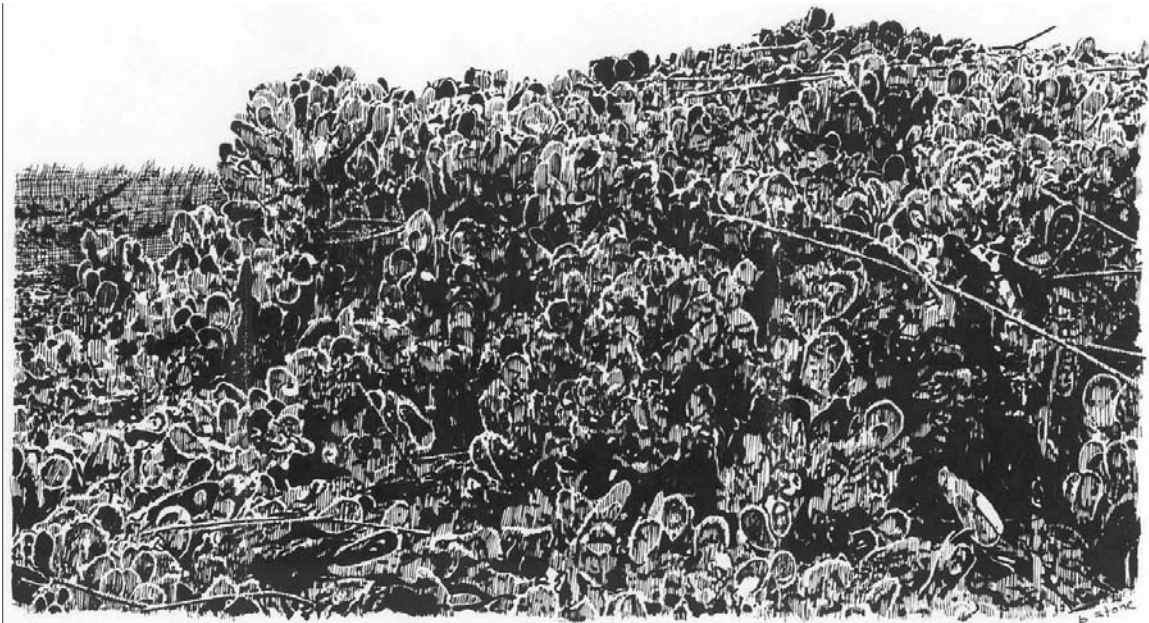
Strata "E"   Oysters characterized by overgrowth. This strata is difficult to harvest and has negligible immediate commercial value. Oysters are tightly clustered, totally covering the substrate. Occasionally "E" strata may show signs of siltation with mud or sand encroaching within spaces between clusters. *Spartina alterniflora* is periodically observed growing within the silted area of the strata high in the intertidal zone. "E" strata is usually found at the highest oyster growing elevation and is further characterized by small oysters with sharp, thin shells.

Strata F

Strata "F"   Spatial separation between clusters ranges from a distance equal to the height of the individual standing crop to as much as one meter. However, unlike "C" strata, the underlying substrate consists of shells with few horizontal live oysters and very little mud. This strata is one of the most ubiquitous in the intertidal zone.

Strata F1
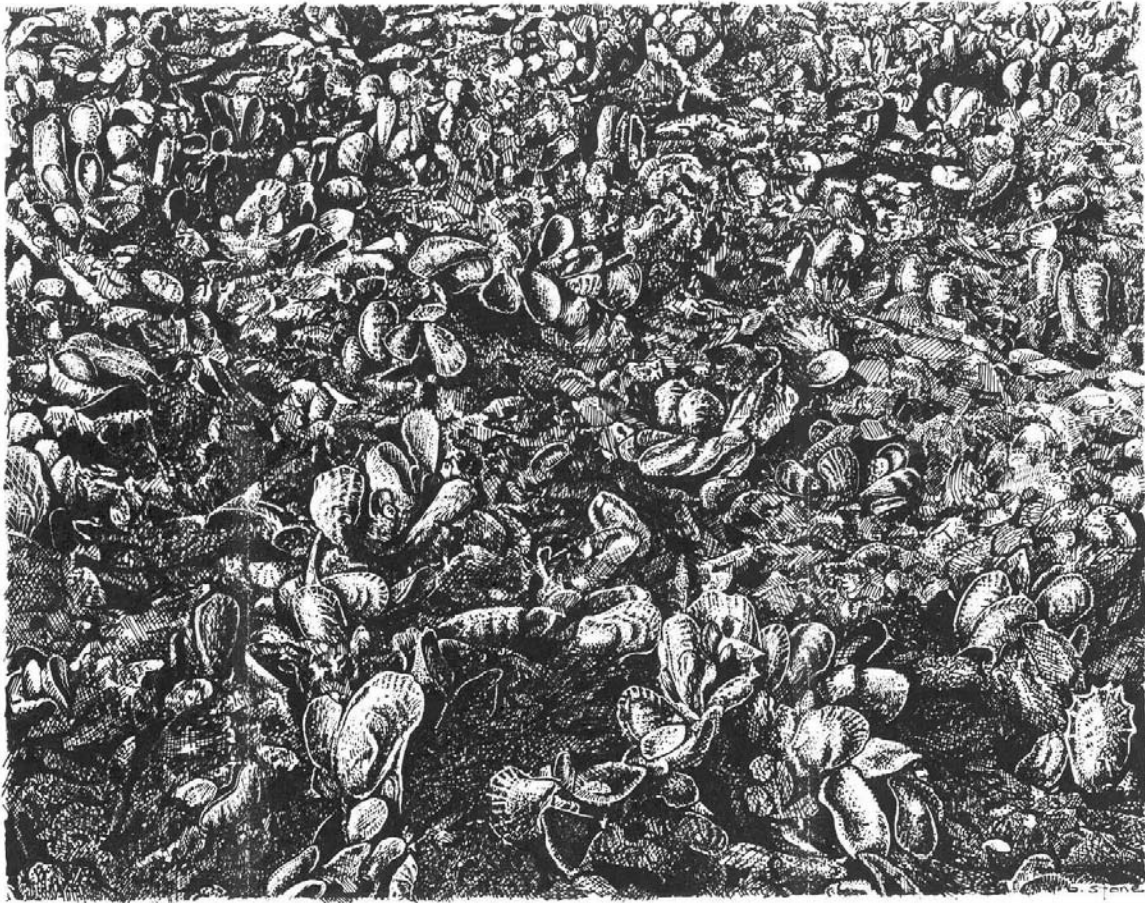
Strata F1".   Characterized by small, vertical clusters evenly dispersed within a substrate of small, single horizontally oriented oysters. Very little exposed mud is associated with "F1" strata. These populations are the most dominant strata in northern South Carolina.

Strata G
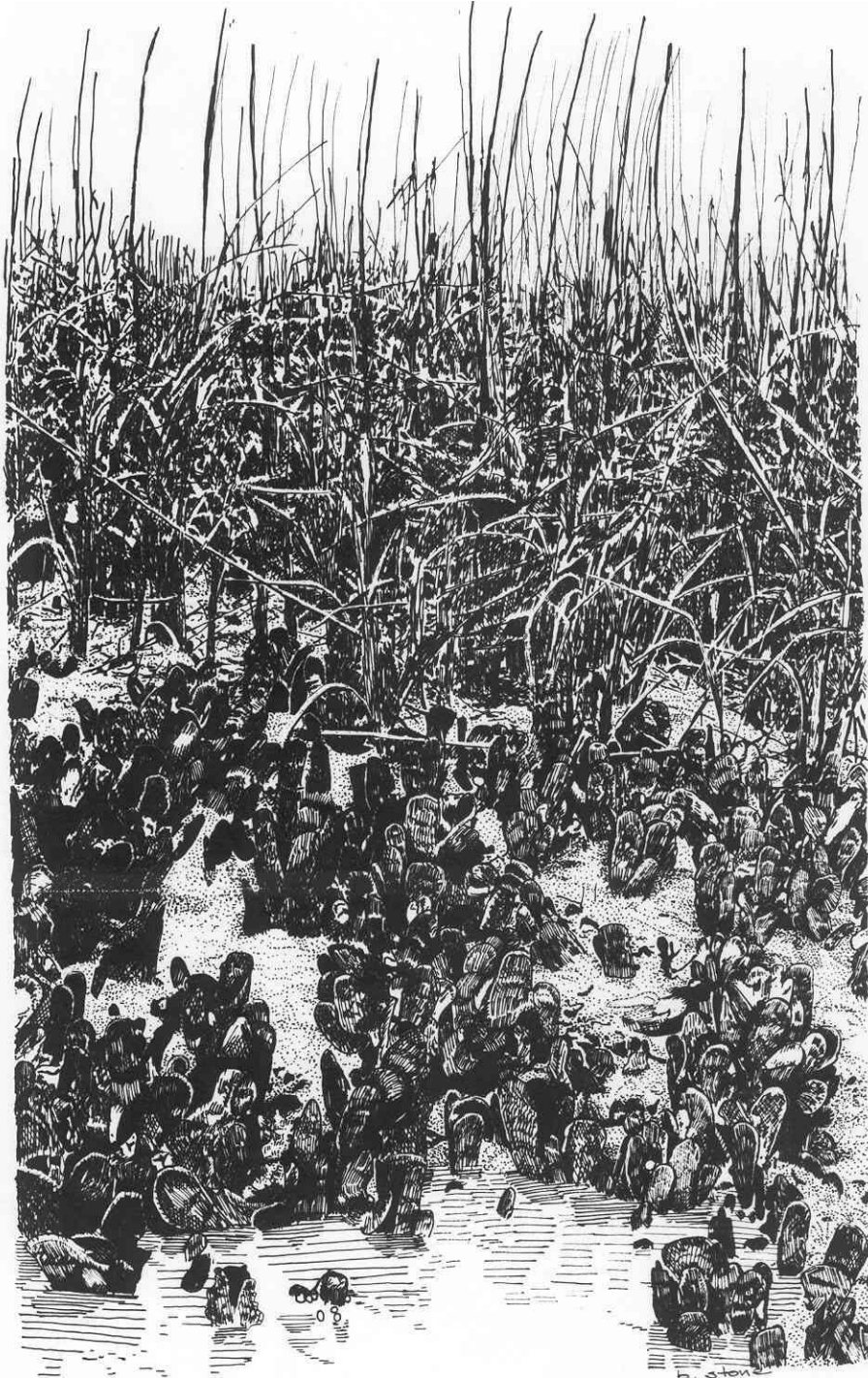
Strata "G"   "G" strata is characterized predominantly by vertical, clustered oysters. The spatial separation between clusters is approximately a distance equal to or less than the height of the standing crop. The substrate habitat is mud with little or no shells or single live oysters.

Strata M

Strata "M"   Scattered live oysters are present, but are generally small and show negligible aggregation. The strata is further characterized by a highly permeable surrounding mud substrate and is difficult to harvest and cultivate because of inaccessibility. "M" strata falls below the 10 m² minimum mapping unit of this project.

Appendix 6

Bacterial Concentrations in Oyster Tissue

Bacterial concentrations within oyster tissue were measured in the summer and winter at a subset of randomly selected SCECAP monitoring sites, and six permanent SCDNR oyster disease monitoring sites, in 2005 and 2006.

Station	Station Type	Latitude Decimal Degrees	Longitude Decimal Degrees	DHEC Classification 2006	Fecal coliform (MPN/100g)		Enterococcus (MPN/100g)		Vibrio vulnificus (cfu/g)		Vibrio parahaemolyticus (cfu/g)	
					summer	winter	summer	winter	summer	winter	summer	winter
RO056092	Open	32.88686	79.87643	A	50	60	300	16	360	30	500	210
RO056093	Open	32.57146	80.22095		0	260	500	180	40	300	160	180
RO056096	Open	32.32822	80.52306	A	8	46	1600	26	90	80	120	90
RO056100	Open	33.09634	79.39247	R	26	60	340	4	400	10	1300	20
RO056102	Open	32.15794	80.80637	A	46	480	34	8	100	160	490	120
RO056104	Open	32.30936	80.76254	A	26	100	94	18	70	140	240	0
RO056105	Open	32.36655	80.64191	A	8	60	400	4800	0	2600	170	0
RO056106	Open	32.29963	80.84103	A	8	60	440	815	40	300	2600	130
RO056107	Open	32.35050	80.81168	A	34	100	127	26	40	350	380	70
RO056112	Open	32.99827	79.91013	P	34000	5600	6000	366	160	100	580	900
RO056114	Open	32.66459	79.93485	A	14	100	10000	52	90	230	80	100
RT052094	Creek	32.93901	79.63921	A	46	60	18000	34	60	90	650	80
RT052095	Creek	32.60793	80.21160	A	80	1000	700	340	200	500	2000	200
RT052096	Creek	32.32364	80.48735	P	340	140	80	100	80	160	540	80
RT052100	Creek	32.86558	79.82256	R	46	160	60	26	1000	110	2900	105
RT052104	Creek	32.26831	80.63504	A	60	46	240	1400	20	200	110	60
RT052106	Creek	32.16005	80.84331	A	46	100	1800	160	180	600	1000	40
RT052110	Creek	33.55408	79.01981	P	46	100	260	4	100	60	1000	60
RT052118	Creek	32.71365	80.08588	R	80	1000	80	120	800	60	900	80
RT052198	Creek	33.34641	79.18391	A	46	60	460	34	100	140	1400	200
RT052200	Creek	32.31447	80.84546	A	22	260	1600	34	60	500	300	150
MLT06	Creek	33.57880	79.00450	R	140	480	280	4	100	120	200	80
OLT06	Creek	33.58333	79.19302	R	60	260	340	22	800	100	1500	195
PLT06	Creek	32.88330	78.35000	A	160	46	10000	140	120	40	900	300
ILT06	Creek	32.78410	79.84960	P	480	60	4800	46	640	60	460	10
TLT06	Open	32.79868	79.82810	A	46	160	4800	260	200	50	1200	90
WLT06	Open	32.43730	80.60909	R	46	60	3400	100	200	60	810	60

Station	Station Type	Latitude Decimal Degrees	Longitude Decimal Degrees	DHEC Classification 2006	Fecal coliform (MPN/100g)		Enterococcus (MPN/100g)		Vibrio vulnificus (cfu/g)		Vibrio parahaemolyticus (cfu/g)	
					summer	winter	summer	winter	summer	winter	summer	winter
RO06305	Open	32.13280	80.89194	A	160	260	4800	280	100	60	260	20
RO06312	Open	32.92805	79.65802	A	100	46	6000	68	70	10	30	50
RO06315	Open	32.63713	80.20726	A	480	60	820	18	120	10	80	50
RO06320	Open	32.79245	79.91029	P	460	260	6000	120	160	390	380	20
RO06321	Open	32.21142	80.83881	A	100	340	6000	140	40	20	40	20
RO06324	Open	32.86528	79.88023	R	100	600	18000	100	180	145	600	30
RO06325	Open	32.52419	80.82480	A	480	46	10000	160	160	115	2000	50
RO06326	Open	32.45163	80.60735	A	480	480	4800	240	80	150	270	40
RT06002	Creek	32.27398	80.62653	A	260	46	4800	12	550	80	120	70
RT06006	Creek	32.35752	80.50870	A	60	160	4800	100	50	70	60	<10
RT06007	Creek	32.49724	80.37920	A	60	60	14000	82	300	55	220	100
RT06008	Creek	32.78627	79.83340	A	480	160	4800	1000	400	150	1000	<10
RT06013	Creek	32.30275	80.81205	A	160	600	48000	140	500	90	220	10
RT06014	Creek	32.38805	80.59650	A	100	46	48000	68	210	10	120	100
RT06018	Creek	32.30811	80.58398	A	60	100	34000	1800	180	130	400	20
RT06020	Creek	32.65852	79.96515	P	260	480	4800	3200	220	550	60	<10
RT06024	Creek	32.81405	79.75846	A	480	480	4800	1000	60	90	575	50
RT06027	Creek	32.55611	80.23526	A	480	46	820	160	120	60	90	<10
RT06028	Creek	32.90037	79.68524	A	480	46	4800	68	90	20	730	<10
RT06031	Creek	32.61168	80.12521	A	160	480	4800	560	220	60	65	50
RT06032	Creek	33.04429	79.46753	A	480	60	4800	480	180	55	300	<10
RT06033	Creek	33.34778	79.17606	A	480	46	6000	160	690	105	400	<10
RT06035	Creek	32.43852	80.51772	R	1600	260	14000	3400	260	100	390	30
RT06036	Creek	32.67282	79.92780	A	260	480	4800	140	350	30	270	40
RT06037	Creek	32.45024	80.88676	A	480	46	6000	8	80	105	140	50
SCA06	Open	32.79085	79.92524	P	60000	1000	6000	530	240	600	90	10
MLT06	Creek	33.57880	79.00450	R	1000	160	480	480	290	40	95	50
OLT06	Creek	33.58333	79.19302	R	1000	60	6000	65	430	170	125	105
PLT06	Creek	32.88330	78.35000	A	480	100	4800	8	320	40	40	50
ILT06	Open	32.79868	79.82810	A	480	600	4800	1800	140	110	120	10
TLT06	Creek	32.78410	79.84960	P	480	100	4800	240	160	330	70	50
WLT06	Open	32.43730	80.60909	R	480	100	6000	700	60	250	40	20

Appendix 7

Metals Concentrations in Oyster Tissue

Metals concentrations within oyster tissue were measured in the summer and winter at a subset of randomly selected SCECAP monitoring sites, and six permanent SCDNR oyster disease monitoring sites, in 2005.   In 2006, metals concentrations were measured at all sites except for four of the SCDNR disease sites.

Station	Station Type	Latitude Decimal Degrees	Longitude Decimal Degrees	DHEC Classification 2006	Oyster Metals (µg/g dry wt.)									
					As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Se	Zn
RO056092	Open	32.88686	79.87643	A	12.40	1.75	2.68	125.00	0.48	29.90	0.08	1.88	10.80	3920
RO056093	Open	32.57146	80.22095		22.50	1.94	3.95	86.25	0.33	46.30	0.07	1.90	17.95	1565
RO056096	Open	32.32822	80.52306	A	21.40	1.97	3.15	63.30	0.33	31.50	0.10	2.06	18.70	1430
RO056100	Open	33.09634	79.39247	R	8.13	1.41	2.31	72.40	0.26	34.70	0.07	1.77	10.30	1550
RO056102	Open	32.15794	80.80637	A	19.20	1.98	2.67	73.40	0.35	25.20	0.07	1.64	14.90	1380
RO056104	Open	32.30936	80.76254	A	15.50	4.04	3.12	61.10	0.28	28.70	0.07	1.72	15.60	1440
RO056105	Open	32.36655	80.64191	A	15.90	2.95	3.01	123.00	0.31	35.90	0.10	2.19	17.30	2640
RO056106	Open	32.29963	80.84103	A	14.20	4.27	2.88	106.00	0.23	32.20	0.07	2.22	19.70	2780
RO056107	Open	32.35050	80.81168	A	13.75	3.90	3.10	82.80	0.30	20.20	0.07	2.08	19.35	2175
RO056112	Open	32.99827	79.91013	P	20.20	1.31	2.46	300.00	0.45	28.40	0.05	2.15	10.10	3300
RO056114	Open	32.66459	79.93485	A	25.30	1.51	2.48	48.90	0.28	23.30	0.08	1.55	15.40	960
RT052094	Creek	32.93901	79.63921	A	28.00	1.43	2.79	45.90	0.40	44.40	0.12	1.77	15.30	639
RT052095	Creek	32.60793	80.21160	A	18.00	1.78	2.89	187.00	0.44	39.20	0.06	1.72	14.80	3060
RT052096	Creek	32.32364	80.48735	P	19.10	1.78	2.74	41.95	0.28	23.45	0.07	1.70	15.25	989
RT052100	Creek	32.86558	79.82256	R	11.30	2.15	2.52	224.00	0.41	21.60	0.10	1.64	11.40	5600
RT052104	Creek	32.26831	80.63504	A	21.00	2.89	3.27	46.00	0.34	24.50	0.08	1.41	20.80	807
RT052106	Creek	32.16005	80.84331	A	17.80	2.30	2.23	48.05	0.32	21.60	0.06	1.63	13.15	1030
RT052110	Creek	33.55408	79.01981	P	56.90	0.88	2.42	50.30	0.32	18.80	0.06	1.41	13.10	1420
RT052118	Creek	32.71365	80.08588	R	8.62	1.25	2.45	90.60	0.38	26.30	0.10	1.89	12.70	2540
RT052198	Creek	33.34641	79.18391	A	38.60	1.01	1.88	26.00	0.24	17.10	0.07	1.45	8.61	679
RT052200	Creek	32.31447	80.84546	A	12.10	3.84	2.30	120.00	0.29	25.10	0.08	2.76	14.80	3150
MLT06	Creek	33.57880	79.00450	R	33.20	0.65	2.73	142.00	0.44	20.60	0.07	1.72	17.10	4050
OLT06	Creek	33.58333	79.19302	R	26.40	0.71	2.99	54.35	0.41	30.05	0.08	1.64	15.75	1920
PLT06	Creek	32.88330	78.35000	A	48.50	2.15	2.91	32.80	0.28	23.20	0.08	1.44	16.30	464
ILT06	Open	32.79868	79.82810	A	22.70	1.32	3.05	46.20	0.33	26.90	0.08	1.50	15.20	1160
TLT06	Creek	32.78410	79.84960	P	18.00	1.03	2.78	371.00	0.46	24.50	0.06	1.28	11.60	3010
WLT06	Open	32.43730	80.60909	R	11.60	3.55	2.56	86.20	0.29	32.00	0.06	1.52	14.40	3090

Station	Station Type	Latitude Decimal Degrees	Longitude Decimal Degrees	DHEC Classification 2006	Oyster Metals (µg/g dry wt.)									
					As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Se	Zn
RO06305	Open	32.13280	80.89194	A	16.9	2.23	14.6	67.9	0.287	19.7	0.0578	2	12.9	2200
RO06312	Open	32.92805	79.65802	A	24	1.53	10.1	50.4	0.393	26.4	0.0945	2.77	10.6	743
RO06315	Open	32.63713	80.20726	A	18.6	1.96	16.4	116	0.421	30.7	0.0803	2.18	15.4	2280
RO06320	Open	32.79245	79.91029	P	18.2	1.7	8.64	177	0.351	18	0.0582	2.71	10.4	2350
RO06321	Open	32.21142	80.83881	A	17.1	2.36	10.1	109	0.265	24.1	0.0956	2.21	10.1	1970
RO06324	Open	32.86528	79.88023	R	14.5	1.71	7.26	237	0.342	22.1	0.0544	2.71	8.47	4600
RO06325	Open	32.52419	80.82480	A	8.35	4.94	7.81	56.8	0.388	23.3	0.0436	2.37	7.83	3770
RO06326	Open	32.45163	80.60735	A	10.8	3.46	9.81	133	0.326	20.5	0.0601	3.22	10.4	3680
RT06002	Creek	32.27398	80.62653	A	17.8	1.92	8.71	48	0.341	21.3	0.0615	1.93	9.31	1280
RT06006	Creek	32.35752	80.50870	A	17.7	1.88	8.4	68.4	0.219	15.6	0.0952	2.03	8.4	1220
RT06007	Creek	32.49724	80.37920	A	19.9	2.03	14.8	62.1	0.296	16.1	0.0568	2.19	13.6	1340
RT06008	Creek	32.78627	79.83340	A	21.3	1.39	11.4	66.6	0.35	22	0.0729	1.89	9.78	1100
RT06013	Creek	32.30275	80.81205	A	15.1	4.16	11.1	106	0.285	21.9	0.133	1.49	12.6	3800
RT06014	Creek	32.38805	80.59650	A	11.3	2.19	7.27	63.1	0.358	28.7	0.0758	2.47	9.32	2710
RT06018	Creek	32.30811	80.58398	A	18.4	1.78	9.49	66.5	0.296	30.8	0.099	2.13	10.7	1390
RT06020	Creek	32.65852	79.96515	P	25.3	2.41	8.9	59.3	0.272	17.1	0.0836	1.68	9.69	1140
RT06024	Creek	32.81405	79.75846	A	23.2	1.33	11.5	111	0.32	16.3	0.122	2.17	5.85	1450
RT06027	Creek	32.55611	80.23526	A	15.9	2.06	11.1	99.7	0.442	22.1	0.0772	2.55	11.1	2180
RT06028	Creek	32.90037	79.68524	A	22.5	1.67	9.3	40.2	0.348	27.5	0.09	1.81	8.51	628
RT06031	Creek	32.61168	80.12521	A	15.4	1.86	9.11	70.2	0.409	24.7	0.108	2.36	10.3	1600
RT06032	Creek	33.04429	79.46753	A	22.8	1.45	7.32	70.9	0.313	22.8	0.0816	2.35	9.03	749
RT06033	Creek	33.34778	79.17606	A	33.1	1.36	11.5	26.5	0.349	21.9	0.0815	1.79	10.9	555
RT06035	Creek	32.43852	80.51772	R	14.2	2.22	10.8	83.4	0.361	33.6	0.0446	2.75	12.2	3180
RT06036	Creek	32.67282	79.92780	A	19.4	1.73	13.6	78.1	0.382	22.2	0.0993	2.21	14	1480
RT06037	Creek	32.45024	80.88676	A										
SCA06	Open	32.79085	79.92524	P	20.1	1.45	8.59	274	0.424	26.7	0.0571	2.89	9.95	3070
MLT06	Creek	33.57880	79.00450	R										
OLT06	Creek	33.58333	79.19302	R										
PLT06	Creek	32.88330	78.35000	A	31.4	2.3	10.6	43.4	0.259	20.8	0.131	1.51	10.6	530
ILT06	Open	32.79868	79.82810	A										
TLT06	Creek	32.78410	79.84960	P										
WLT06	Open	32.43730	80.60909	R										

Appendix 8

Metals Concentrations in Sediment

Metals concentrations from sediment samples were measured in the summer and winter at a subset of randomly selected SCECAP monitoring sites, in 2005 and 2006.

Station	Station Type	Latitude Decimal Degrees	Longitude Decimal Degrees	DHEC Classification 2006	Sediment Metals (µg/g dry wt.)									
					As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Se	Zn
RO056092	Open	32.88686	79.87643	A	3.07	0.05	28.70	0.00	13.10	67.60	0.02	6.03	0.00	27.10
RO056093	Open	32.57146	80.22095		2.81	0.04	11.90	0.00	7.33	74.50	0.00	3.30	0.00	16.90
RO056096	Open	32.32822	80.52306	A	5.47	0.04	22.30	0.00	10.50	89.10	0.02	7.46	0.24	23.80
RO056100	Open	33.09634	79.39247	R	5.47	0.04	22.30	0.00	10.50	89.10	0.02	7.46	0.24	23.80
RO056102	Open	32.15794	80.80637	A	2.84	0.07	12.50	0.00	7.20	95.10	0.00	2.12	0.00	0.00
RO056104	Open	32.30936	80.76254	A	1.96	0.18	33.80	0.00	8.68	196.00	0.00	2.77	0.32	16.20
RO056105	Open	32.36655	80.64191	A	4.59	0.20	19.20	0.00	9.90	169.00	0.01	4.30	0.41	19.60
RO056106	Open	32.29963	80.84103	A	3.32	0.10	22.60	0.00	8.90	151.00	0.01	3.98	0.19	17.80
RO056107	Open	32.35050	80.81168	A	4.05	0.24	28.50	0.00	11.60	91.60	0.01	5.24	0.23	18.80
RO056112	Open	32.99827	79.91013	P	3.04	0.12	20.70	0.00	13.30	113.00	0.01	4.91	0.44	20.90
RO056114	Open	32.66459	79.93485	A	4.56	0.07	15.50	0.00	9.31	106.00	0.01	4.91	0.29	26.90
RT052094	Creek	32.93901	79.63921	A	17.40	0.05	32.40	12.50	18.70	319.00	0.03	15.90	0.53	54.50
RT052095	Creek	32.60793	80.21160	A	6.95	0.06	25.10	0.00	12.60	130.00	0.02	8.27	0.30	27.80
RT052096	Creek	32.32364	80.48735	P	3.37	0.06	24.10	0.00	8.01	81.00	0.01	4.25	0.22	0.00
RT052100	Creek	32.86558	79.82256	R	8.10	0.02	39.30	0.00	13.30	88.20	0.01	11.00	0.22	41.60
RT052104	Creek	32.26831	80.63504	A	16.40	0.12	42.55	12.45	21.45	337.00	0.04	17.80	0.71	60.65
RT052106	Creek	32.16005	80.84331	A	5.79	0.10	24.80	0.00	10.60	117.00	0.01	7.38	0.26	26.90
RT052110	Creek	33.55408	79.01981	P	1.16	0.01	8.50	0.00	2.59	28.10	0.00	0.00	0.00	0.00
RT052118	Creek	32.71365	80.08588	R	1.43	0.03	16.00	0.00	6.62	88.40	0.00	1.70	0.00	0.00
RT052198	Creek	33.34641	79.18391	A	1.93	0.01	5.26	0.00	3.23	34.00	0.00	0.00	0.00	0.00
RT052200	Creek	32.31447	80.84546	A	4.36	0.06	22.50	0.00	9.63	81.90	0.01	5.23	0.20	24.60
MLT06	Creek	33.57880	79.00450	R										
OLT06	Creek	33.58333	79.19302	R										
PLT06	Creek	32.88330	78.35000	A										
ILT06	Open	32.79868	79.82810	A										
TLT06	Creek	32.78410	79.84960	P										
WLT06	Open	32.43730	80.60909	R										

Station	Station Type	Latitude Decimal Degrees	Longitude Decimal Degrees	DHEC Classification 2006	Sediment Metals (µg/g dry wt.)									
					As	Cd	Cr	Cu	Pb	Mn	Hg	Ni	Se	Zn
RO06305	Open	32.13280	80.89194	A	2.03	0.08	9.06	0.00	5.70	61.30	0.00	1.64	0.00	0.00
RO06312	Open	32.92805	79.65802	A	10.00	0.03	26.00	6.43	15.70	205.00	0.02	10.30	0.22	66.00
RO06315	Open	32.63713	80.20726	A	5.99	0.06	26.40	0.00	13.55	123.00	0.03	8.10	0.37	49.75
RO06320	Open	32.79245	79.91029	P	4.84	0.13	27.70	18.10	15.90	134.00	0.03	6.85	0.45	35.20
RO06321	Open	32.21142	80.83881	A	2.96	0.51	6.46	0.00	5.26	69.10	0.00	1.14	0.20	0.00
RO06324	Open	32.86528	79.88023	R	2.91	0.04	16.80	0.00	33.80	91.90	0.02	3.57	0.00	21.80
RO06325	Open	32.52419	80.82480	A	7.18	0.30	38.90	13.10	14.30	114.00	0.05	10.60	0.46	40.90
RO06326	Open	32.45163	80.60735	A	4.21	0.11	27.40	0.00	11.10	131.00	0.01	5.23	0.28	21.10
RT06002	Creek	32.27398	80.62653	A	2.90	0.04	17.90	0.00	7.57	75.90	0.01	3.55	0.00	54.00
RT06006	Creek	32.35752	80.50870	A	6.28	0.04	20.20	0.00	10.30	180.00	0.01	6.58	0.35	23.20
RT06007	Creek	32.49724	80.37920	A	2.07	0.04	12.90	0.00	5.31	60.10	0.00	1.71	0.17	0.00
RT06008	Creek	32.78627	79.83340	A	4.03	0.03	18.10	0.00	8.91	97.00	0.01	3.92	0.00	18.80
RT06013	Creek	32.30275	80.81205	A	3.30	0.10	18.80	0.00	9.00	70.60	0.01	3.37	0.00	0.00
RT06014	Creek	32.38805	80.59650	A	0.80	0.04	7.82	0.00	3.71	40.10	0.00	0.00	0.00	0.00
RT06018	Creek	32.30811	80.58398	A	3.64	0.04	19.45	0.00	10.03	107.00	0.01	4.37	0.19	0.00
RT06020	Creek	32.65852	79.96515	P	4.45	0.04	18.50	0.00	11.30	126.00	0.01	4.18	0.21	17.10
RT06024	Creek	32.81405	79.75846	A	12.10	0.05	30.00	9.17	16.30	194.00	0.02	12.10	0.39	38.70
RT06027	Creek	32.55611	80.23526	A	4.19	0.03	18.50	10.40	8.93	84.30	0.01	4.68	0.00	0.00
RT06028	Creek	32.90037	79.68524	A	6.47	0.03	22.20	0.00	11.60	136.00	0.01	5.78	0.22	20.40
RT06031	Creek	32.61168	80.12521	A	4.41	0.03	18.40	0.00	10.45	102.00	0.01	5.70	0.18	19.30
RT06032	Creek	33.04429	79.46753	A	4.50	0.02	13.60	0.00	9.04	175.00	0.00	3.90	0.16	0.00
RT06033	Creek	33.34778	79.17606	A	2.88	0.02	14.40	0.00	6.31	70.70	0.00	1.97	0.00	0.00
RT06035	Creek	32.43852	80.51772	R	9.81	0.09	35.30	7.33	14.80	207.00	0.04	13.10	0.43	45.80
RT06036	Creek	32.67282	79.92780	A	12.90	0.07	34.60	19.30	18.90	173.00	0.03	14.00	0.60	58.60
RT06037	Creek	32.45024	80.88676	A	2.00	0.15	17.90	0.00	8.59	82.70	0.00	3.54	0.00	0.00
SCA06	Open	32.79085	79.92524	P										
MLT06	Creek	33.57880	79.00450	R										
OLT06	Creek	33.58333	79.19302	R										
PLT06	Creek	32.88330	78.35000	A										
ILT06	Open	32.79868	79.82810	A										
TLT06	Creek	32.78410	79.84960	P										
WLT06	Open	32.43730	80.60909	R										