SOUTH CAROLINA'S INTERTIDAL OYSTER SURVEY AND REEF RESTORATION/ENHANCEMENT PROGRAM: USING NOVEL APPROACHES

Background

The Eastern oyster, *Crassostrea virginica*, forms intertidal reefs that are a dominant feature of many Atlantic and Gulf coast estuaries (e.g., Bahr and Lanier 1981, Burrell 1986, 2003, Dame 1996, ASMFC 2007), and provides viable recreational and commercial fisheries in many estuaries. Oyster reefs have a significant ecological role because they support a diverse assemblage of organisms in an otherwise soft-bottom environment. These reefs consist of vertical shell clusters built upon a fragile matrix of live and dead shell, and fine-grained sediments.

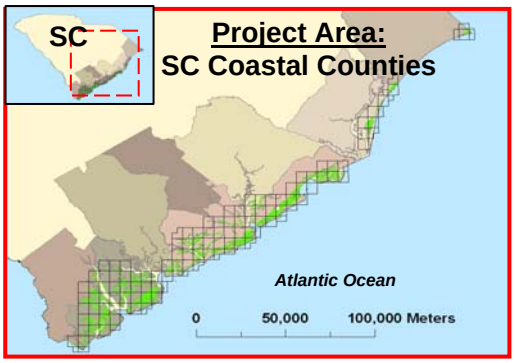
Beginning in the early 1980s, a multi-year, state-wide effort was undertaken to estimate the state's oyster resources using hand-digitized maps derived from field surveys and manual aerial photograph interpretation of a large portion of the state's harvestable resources. Approximately 900 hectares (or 2,000 acres) of intertidal oyster reefs (95% of the resource) were found growing along marsh shorelines, and in open areas, in the form of oyster flats. Potentially, shellfish growing waters (SCDHEC) may exceed 231,081 hectares (or 571,000 acres). This extensive information was placed in a GIS system. The 1980s efforts were labor-intensive and relatively costly for the time, using available surveying techniques and manual field surveys (see Jefferson et al. 1991) walking reef 'polygons' across the state. For many oyster flats, information on areal extent was captured by analog photography but not digitized for most areas. Other information collected in the original survey included: (1) bed areal extent, (2) oyster 'strata', (3) estimates of bushels/area, (4) live/total shell volume, (5) shell matrix depth, (6) bottom type, and (7) hard clam occurrence. Other intertidal approaches have used aerial photography interpretation of existing analog or digital imagery (e.g., Grizzle et al. 2002, Vincent 2006).

I. Using High Resolution Digital Multi-Spectral Imagery to Delineate South Carolina's Intertidal Oysters for Management and Restoration

The project objectives include: **(A)** mapping intertidal oyster reef boundaries (minimum overall accuracies of 80%); **(B)** classifying areas with high, medium, or low % vertical or "live" shell, to produce a numerical estimate of % vertical shell for each reef (minimum of 70% accuracy); and **(C)** delineating washed (bleached) horizontal shell (see Anderson et al. 1979). Although acceptable accuracy has been obtained for objective B in some DOQQs, it is apparent that this objective may not be achievable for much of the imagery obtained to date due to limitations in the image product.

In 2004, the South Carolina Department of Natural Resources (SCDNR) began a state-wide (over 300 km of shoreline) assessment of its oyster resources as part of a multi-year, collaborative effort with NOAA's Coastal Services Center (CSC) and the U.S. Geological Survey through funding provided by NMFS. This new effort involved analysis of multispectral (four-band, B,G,R,N), ¼ m digital imagery acquired by GeoVantage Inc.'s GeoScanner platform (~70%), and later Photo Science's DMC imaging platform (~30%).

Image mosaics of the study area for this oyster mapping project are being tiled to correspond to existing DOQQQ (1/16 of a U.S. Geological Survey digital orthophoto quad) boundaries. Imagery for this effort will be collected for a total of 122 DOQQs (see map above), but only the exposed (intertidal) areas within each DOQQ containing oyster reefs and 'washed shell' (see Anderson et al. 1979) are being mapped. Additional imagery, to include the remainder of the coast to the "freshwater-saltwater" line is being collected by SCDHEC's Office of Ocean and Coastal Resource Management (or OCRM).



Extent of Project. The black squares indicate orthophoto quarter quadrangles and green areas are SCDNR historic oyster data

Very restrictive flight acquisition constraints included collections at negative low tides only (~1.5 h acquisition window), no allowable cloud cover over intertidal areas, sun angle restricted to >45^{o} to lower glint, winds offshore at less than 8 km/h, and collecting limited to months (initially May to October) when the marsh growing (=green). CSC's role also included a rigorous imagery review process using a unique, dedicated Access database (contact Finkbeiner and Stevenson at CSC). Areas may be reflown in the future to update segments of the coast.

Finalized imagery is sent to Photo Science as digital orthophoto quarter quads (DOQQQs) for processing. Initially the oysters are stratified using a mask created for areas not containing oyster habitat through the use of buffers with ERDAS's Imagine®. Then Feature Analyst® is used to delineate (1) oyster reef location and (2) extent based on a training algorithm. Areas not containing oyster reefs are removed and the image is clustered into 20 spectral classes in ERDAS's Imagine® to derive an indirect measure of 'density' (percent of vertical shell coverage) within the oyster bed boundaries. Shadows cast from vertical clusters allow for an estimate of percent vertical shell.

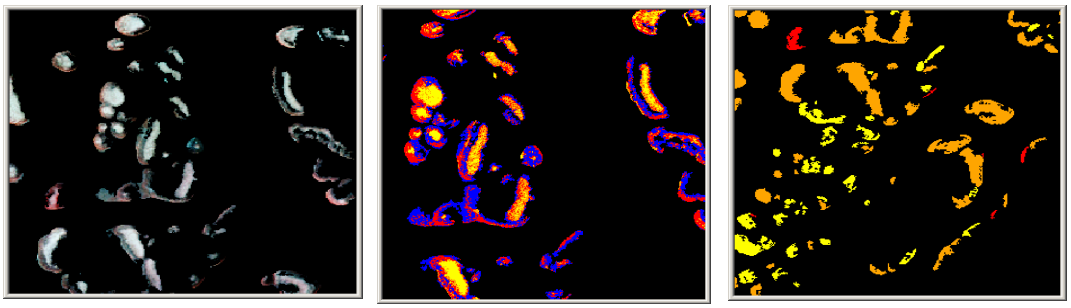


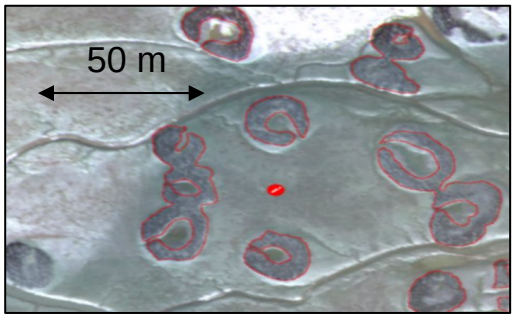
Image classification from the 20 spectral classes to areas of High (red), Medium (orange), Low (yellow) and mostly mud (blue) using ERDAS's Imagine®

Extensive ground-truthing is used to validate (and correct) oyster reef boundaries and associated characteristics. This included random surveys in portions of 60 DOQQs using shallow draft boats and low altitude digital imagery captured from a helicopter (see below) at or near MLW for verification of the processed imagery. The post-processed imagery is validated by identifying the number of beds that are correctly and incorrectly identified.

Ground-truthing involves using a Trimble Pathfinder Pro XR GPS (see at right) to record bed position, length, oyster strata (Jefferson et al. 1991), and an estimated average width of individual oyster reefs. Between 75 and 100 reefs are measured for each DOQQ depending on oyster presence and accessibility at low tide, and each reef was videotaped. Approximately 30 additional 'textured' mud or sand areas are also recorded to test for false positives (no reef presence). Data are collected during an approximate 4 h window, centered around a predicted negative low tide. Videos are viewed and paused every 5-10 sec depending on reef length. Percent vertical shell is estimated for each paused clip and averaged for each bed. All videos are reviewed by the same two people, one viewing the entire DOQQ, the other doing a QA/QC of 10% of the videos for comparison. Photo Science-classified polygons are verified with SCDNR's ground-

truthed transects in ArcGIS with a standardized protocol on a case by case basis for the three Objectives **(A-C).**

A helicopter is primarily used to verify areas inaccessible to boats (i.e. most flats) using low altitude (122 m) photographs are taken with an 8MP digital camera and a Trimble Pro XRS to obtain the geographic position. Oyster reefs observed in these photographs are used as reference to hand-digitize reefs onto the larger images (see below).



Reference photograph from helicopter (8MP) at 122 m (left). Hand-digitized oyster polygons are in red (right). The red dot denotes the GPS point taken from the helicopter.

Finally, Photo Science-classified polygons are verified with SCDNR's ground-truthed transects in ArcGIS (see Figure below) on a case by case basis with standardized protocol for the three Objectives **(A-C**) Objective B has met with limited success due to the variability of the imagery quality and variability in the appearance of similar oyster reefs due to factors such as: (1) height of the shell, (2) angle of sun and (3) degree of 'dryness' (exposure) of the shell-mud matrix.

This project, when completed, will enable us to be able to: (1) complete future evaluations of oyster resources using high-resolution imagery as a part of a longer-term monitoring plan to periodically assess broad scale changes in the condition of the state's shellfish beds; (2) provide governmental agencies and other interested users with hi-resolution imagery and maps (see future link at http:/ www.dnr.sc. gov/GIS /gisonline.html) of oyster resources, marsh, and other features within its coastal zone; and (3) allow us to focus our oyster restoration efforts relative to current state management plans and status and trends analyses.

At left: final classified polygons from contractor field transects are overlaid on imagery for QA/QC by SCDNR (polygons). Presence/ absence (base product), bed length, and % vertical shell are then graded to meet contracts specifications.

II. Restoration/Enhancement/Monitoring of Intertidal Oyster Reef Habitats

Part of the overall project is to use available funds to enhance the Department's existing reef restoration/enhancement program. NMFS funding has allowed us to purchase and plant additional shell in 2005 and 2006. To date a total of approximately 40,500 bushels of oyster shell were purchased using NMFS funds. Approximately 87,600 bushels of shell have been planted in Beaufort, Georgetown and Charleston Counties using a combination of NMFS and SCDNR funds. As a result of these plantings, ~6 acres (259,862 ft^2 or 24,142 m^2) of shellfish habitat have been created or enhanced. Funds also assist with the Department's shell recycling program (see http://saltwaterfishing.sc.gov/oyster.html).

Funding from this grant was used also to supplement the Department's South Carolina Restoration and Enhancement Program (or SCORE, http://score.dnr.sc.gov/) efforts. SCORE is 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. These (SCORE and OFM planting) programs were also featured in the Discovery Channel's 'Dirty Jobs' series in 2005.

Finally, a state-wide assessment of shellfish bed condition and shellfish recruitment patterns was initiated in 2005 (27 sites sampled) and continued in 2006 (32 sites sampled), in coordination with the Department's South Carolina Estuarine and Coastal Assessment Program (SCECAP, http://www.sc.gov/marine/scecap). This program is designed to evaluate the overall health of our state's estuarine habitat, but to date, has not included shellfish condition as one of the biotic components. Objectives of the oyster survey component include: (1) determining the incidence and intensity of oyster diseases; (2) evaluating the physiological condition of oysters as a measure of system health; (3) evaluating oyster recruitment potential; (4) assessing oyster population status at a subset of sites; and (5) measuring bacterial and viral densities in summer and winter.

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