

**PILOT INVESTIGATION OF REMOTE SENSING FOR INTERTIDAL
OYSTER MAPPING IN COASTAL SOUTH CAROLINA:**

A METHODS COMPARISON



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BACKGROUND

Introduction

South Carolina's oyster reefs are a major component of the coastal landscape. Eastern oysters *Crassostrea virginica* are an important economic resource to the state and serve many essential functions in the environment, including water filtration, creek bank stabilization and habitat for other plants and animals. Effective conservation and management of oyster reefs is dependent on an understanding of their abundance, distribution, condition, and change over time. In South Carolina, over 95% of the state's oyster habitat is intertidal. The current intertidal oyster reef database for South Carolina was developed by field assessment over several years. This database was completed in the early 1980s and is in need of an update to assess resource/habitat status and trends across the state. Anthropogenic factors such as coastal development and associated waterway usage (e.g., boat wakes) are suspected of significantly altering the extent and health of the state's oyster resources.

In 2002 the NOAA Coastal Services Center's (Center) Coastal Remote Sensing Program (CRS) worked with the Marine Resources Division of the South Carolina Department of Natural Resources (SCDNR) to develop methods for mapping intertidal oyster reefs along the South Carolina coast using remote sensing technology. The objective of this project was to provide SCDNR with potential methodologies and approaches for assessing oyster resources in a more efficiently than could be accomplished through field digitizing. The project focused on the utility of high-resolution aerial imagery and on documenting the effectiveness of various analysis techniques for accomplishing the update.

Remote Sensing Goals

Intertidal oysters in South Carolina occur in two reef configurations. Patch reefs are generally circular in shape, tend to be located in large mud flat areas, and often have a central zone of mud or dead oyster. They also form low mounds. Fringing reefs occur along tidal creek banks, tend to form narrow (<5 meter) strips, and are occasionally intermixed with smooth cordgrass (*Spartina alterniflora*) or clumps of eroded marsh mud. Fringing reefs are of greater interest to SCDNR due to the fact that most oysters in the state are in this category and they are more vulnerable to impacts such as harvesting and boat wakes. The presence of healthy fringing reef on tidal creek banks is also suspected of helping prevent marsh erosion.

South Carolina DNR determines the health or condition of oyster reefs on the basis of the amount of live shell present, the vertical relief of live shell, and the spatial density of shell clusters. Based on these parameters oyster reef areas are assigned by DNR to one of 9 categories or "strata". Strata classes range from dead washed shell to dense live clusters with vertical relief. These strata classes have been correlated with expected yields of oyster per acre and are used in managing commercial leases.

The goals of the remote sensing effort were established in partnership between SCDNR and the Center. These goals were based on SCDNR resource management needs and expectations for what remote sensing data could provide. Part of the methods and data sources evaluations were based on how well they met the following goals:

- Detect both fringing and patch reefs
- Determine perimeter of oyster reef habitat
- Identify some level of oyster strata

There was little expectation that any remote sensing approach would allow determination of all 9 of the SCDNR strata classes. Rather, a more generalized determination of oyster reef condition was anticipated. These more general condition classes might then be correlated with actual some of the strata categories at the conclusion of the project. It was also expected that remote sensing methods would identify some portion of the oyster resource but that field observation would still be required in certain areas.



Figure 1. Patch reefs in Gray Bay. Hamlin Creek study area.



Figure 2. Fringing reef along Hamlin Creek.

Pilot Sites and Image Data

Two pilot areas Broad Creek and Hamlin Creek were selected for image acquisition and methods testing. Broad Creek, on Hilton Head Island in Beaufort County, was chosen since field digitization work was already underway by SCDNR and the City of Hilton Head Island. This field data provided good comparative information for the remote sensing results. The area was characterized by a relatively narrow salt marsh environment with extensive suburban and urban development in the surrounding uplands.

Hamlin Creek, near Isle of Palms in Charleston County, was chosen because it had extensive oyster flats and a more open salt marsh setting. Boat traffic and some oyster harvesting were present in both pilot areas.

Two types of airborne high-spatial resolution imagery were collected for evaluation. An airborne platform was needed in order to collect imagery under the specific environmental conditions required to identify oyster beds. High-resolution imagery was needed to discriminate oysters from other intertidal features such as textured mud, and make determinations about oyster strata. Two image types showed strong promise for being capable of detecting the features of interest as well as being available for operational oyster mapping over the entire South Carolina coast; aerial photography, and digital multi-spectral imagery. All imagery was flown at negative low tides under calm wind conditions to optimize the opportunity to image all the oyster reefs.



Figure 3. Broad and Hamlin Creeks study areas and South Carolina location map.

Analog Aerial Photography

Aerial photography was selected for evaluation based on its proven utility for mapping aquatic habitat, its wide availability, and the limited technical infrastructure required for analysis. Conventional color (Kodak 2448) reversal film in 9" x 9" format was selected for the missions. Conventional color was selected on the belief that if any oysters were submerged at the time of the overflight, the blue-sensitivity of this film would maximize the ability to detect the submerged oysters. The film was flown at 60% overlap and 30% sidelap to allow for stereo analysis. The two pilot areas were flown at four photo scales, 1:8000, 1:5000, 1:3000, and 1:2000. This was to allow a determination of the optimal scale for detecting oyster strata while covering the widest swath possible per frame. All the photo missions were accomplished between April 23 and 24, 2002.

Individual film diapositives, scanned at an image resolution of 0.5 meters, rectified to the GeoScanner imagery, and were used to conduct most of the analysis.

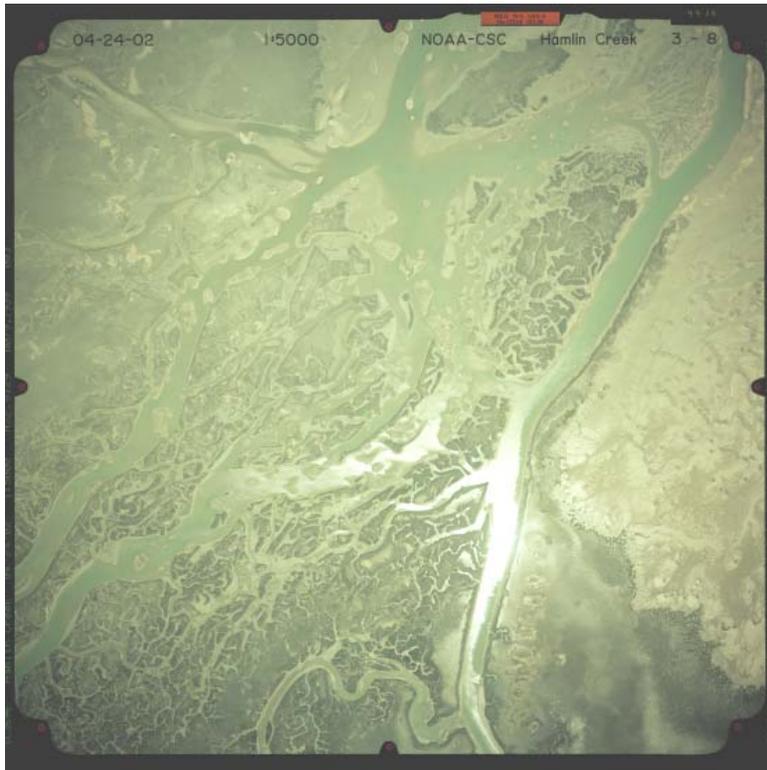


Figure 4. Conventional color aerial photograph of the Hamlin Creek area. Scale is 1:5,000. This photography has high spatial resolution but limited spectral information to guide automated processes.

GeoScanner Multispectral Imagery

Digital multi-spectral imagery (digital camera) imagery was also selected since this technology is becoming operationally feasible for benthic and coastal mapping. It has a number of advantages over traditional analog imagery that improve the ability to detect small natural features as well as make it more useable by coastal resource managers. The GeoScanner sensor package was flown at 0.5m spatial resolution over both pilot areas in January 2002. This imagery had four 80nm wide spectral bands (blue, green, red, near-infrared) and was delivered as orthorectified image mosaics and individual image frames. All data were corrected for solar illumination. Spatial accuracy of these image products was nominally ± 3 meters. The data are provided to the customer in a Windows bitmap (*.bmp) format with associated World files (*.bpw) that include the rectification information. This format is easily handled by image processing and GIS software but has some limitations for stretching and processing. To overcome these limitations the imagery was converted to ERDAS Imagine format (*.img). The imagine files are also handled well by many software.

The winter season of the 0.5m image acquisition resulted in a low infrared reflectance from the *spartina* marsh in both study areas. This negatively affected the ability of some automated clustering approaches for discriminating oyster reef from surrounding marsh.

Later, 0.25m imagery was flown over the Hamlin Creek pilot area in April 2002. This imagery showed significant improvement over the 0.5m imagery for detecting fringing reefs and the stronger infrared response of the *spartina* in the imagery improved the clustering results.



Figure 5. Near infrared composite GeoScanner image of the Hamlin Creek area. Pixel size is 0.25 meters. This imagery has four discrete spectral bands that support automated image processing algorithms. The image on the left is a mosaic of many individual image frames.

The different image sources were examined according to several criteria. These criteria included not only the individual image qualities, but also other factors related to putting useable imagery in the hands of an analyst that was ready for analysis. The criteria were:

- Cost of raw image acquisition
- Ability to collect imagery under demanding environmental conditions
- Level of detail that could be obtained from the image
- Extent of areal coverage
- File size and data manipulation issues
- Necessity for image post-processing
- Availability for subsequent missions.
- Quality and diversity of products available

General Hardware Requirements

The general hardware requirements for the digital imagery are driven by the need to handle the IDE removable hard disk drives that the GeoScanner data is typically delivered on, sufficient RAM to manipulate large image files in real-time, and a processor that can run automated algorithms in a reasonable time frame. The hardware requirements are also influenced by the needs of the processing software used in this comparison (ESRI ArcView 3.2, ERDAS Imagine, eCognition). The size of the GeoScanner mosaic file is dependent on the area covered but is normally clipped to produce files that do not exceed 500 Mb in size. The following hardware specifications should allow processing of these data and will support the digital processing methods described in the following sections:

Minimum required:

<u>Computer:</u>	Industry-standard personal computer with at least a Pentium or higher Intel-based microprocessor and a 20-gigabyte hard disk
<u>Memory:</u>	24 MB RAM (32 MB recommended)
<u>Operating System:</u>	Windows 98/ME, Windows NT 4.0, and Windows 2000, Windows XP-- Home Edition and Professional

Recommended:

<u>Computer:</u>	Industry-standard personal computer with at least a Pentium III or higher Intel-based microprocessor and an 80-gigabyte hard disk
<u>Memory:</u>	128 MB RAM
<u>Operating System:</u>	Windows NT 4

Unique hardware requirements for the individual methods are described in those sections.

Hardware requirements for working with the analog film are the same as for the digital GeoScanner imagery. However, there is a need to scan the photography in order to obtain a digital image. A photogrammetric quality scanner is recommended in order to preserve image integrity.

General Software Requirements

A variety of software was used to conduct the methods comparisons. General software requirements for the methods included the ability to display the imagery in the windows bitmap format in which the digital imagery was delivered, and the tiff format produced during scanning of the analog film. Other functions required are the ability to subset imagery, rectify scanned photos, adjust stretches, stack multiple image bands, superimpose other vector and raster data on the imagery, and run spectral clustering algorithms. Two software are especially well suited to these tasks, ERDAS Imagine and ESRI ArcView. A third software used in the image segmentation method test, eCognition has most of these capabilities but provides a unique approach to image processing. The software requirements for the most productive methods explored in this pilot project are:

Minimum required

- *ESRI ArcView 3.2*

Recommended

- *ESRI ArcView 3.2*
- ERDAS Imagine Essentials – for image mosaics, subsetting, and changing image format to allow histogram stretches.
- ESRI Image Analyst extension – for histogram manipulation
- NCCOS Habitat Digitizer extension – for streamlined digitization and attributing process

Unique software requirements or issues are described under each method section.

Approach for Methods Evaluation

Both image types were evaluated for their ability to detect oyster reefs and their suitability for operational mapping of intertidal oyster reefs over large geographies. Methods for analyzing the two image types were evaluated for a number of factors, especially whether they could be applied by staff at SCDNR. Determination of oyster strata normally occurs through field observation and a high degree of skill and experience is required to identify strata accurately. SCDNR staff are experts in this area and a goal of the project was to provide methods that could be applied by SCDNR staff that had this type of knowledge of oyster habitat. The following criteria were considered during the evaluation and exploration of different oyster mapping methods.

Technical approaches for mapping oyster habitat were evaluated with the overall goal of recommending a method that could be applied by SCDNR staff who have the greatest knowledge and familiarity with South Carolina's oyster reefs. The criteria for which analysis methods were evaluated were:

- Unique software environment
- Level of automation
- Dependence on ancillary data
- Ability to capture most detail about oyster reefs
- Time required
- Skill level required
- Repeatability and consistency
- Unique hardware requirements

The methods exploration and evaluation was an iterative process. Initially both manual and automated methods were tested. As varying levels of success were achieved with different methods. More effort was put into those that showed early promise. The final result of the methods exploration and evaluation is a menu of options available for SCDNR to pursue based on their needs and capabilities. The following methods were tested:

- Manual delineation
- Unsupervised spectral clustering
- Supervised spectral clustering
- Image processing incorporating image derived data
- Feature analysis
- Image segmentation

All these methods were tested in one or both pilot study areas. Summary ratings of level of effort and level of detail are presented at the end of each section. The ratings are based on a scale from 1 to 10.

A level of effort of 1 is considered to be a process that requires a low skill level, that runs quickly, and is simple in design. A 10 is a complex process that requires a high skill level and takes a long time to complete. For level of detail, a 1 is a process that only identifies the boundaries of some of the oyster reefs with low confidence. A 10 is a process that identifies all oyster boundaries and provides detailed strata information in all classes.

METHODS SUMMARIES

Manual Delineation

The GeoScanner 0.5-meter imagery of both the Hamlin and Broad Creek study areas was visually interpreted using the National Center for Coastal and Ocean Science's (NCCOS) Habitat Digitizer extension in ArcView 3.2. This extension allows the user to set several parameters such as minimum mapping unit (MMU) and a scale restriction that constrain the zoom capability to ensure consistent capture of detail while mapping. For this effort no MMU was set, all detectable features were mapped, and the mapping was conducted at a visual display scale of 1:1000 – 1:800. The interpretation was conducted primarily from the NIR image with the RGB image utilized sparingly. A two standard deviation histogram stretch improved the interpretability of both images considerably. The evaluation of this method and imagery was focused on the ability to accurately interpret fringing oyster beds located in the intertidal zone. These beds averaged 3-4 meters in width (6-8 image pixels) and strata ranged from A to G.

Source Imagery

GeoScanner 0.5 Meter Imagery

The Broad Creek GeoScanner imagery was collected early in the *Spartina* growing season (1/28/02), prior to real robust spring growth, negating the benefits of the near infrared information. Higher chlorophyll content in the *Spartina* results in a stronger near infrared response and makes discrimination between oyster and *Spartina*, one source of confusion, much easier. This impacted all methods but can be easily overcome by flying in the August or September time frame.

The Hamlin Creek imagery was acquired within 2 days of the Broad Creek imagery, but *spartina* in this site had a stronger infrared response that aided the interpretation. The Hamlin imagery also had fewer problems with shadows.

Features/information extracted from data

Heads-up digitization of the GeoScanner 0.5-meter imagery was appropriate for the visual extraction of the areal extent of both fringe and patch reefs. Figure 1 shows the results of the heads-up digitization method as compared to the field GPS polygons (this data set was collected by DNR and Town of Hilton Head personnel using differential GPS to walk the perimeter of beds and is considered the most accurate data set).

Interpreting the fringing beds proved challenging and required a thorough field evaluation to develop signatures. The oyster signature was most often confused with textured mud in the intertidal area and abutting *Spartina*. Patch reefs located on intertidal mud flats were much easier to interpret. These features with their relatively unique shapes and texture signature were more readily differentiated from *Spartina* areas. Information on strata was not reliably interpretable from this imagery using this method. However differences between washed shell and live oyster were evident.

The following table quantifies the differences between field GPS mapped and on screened digitized oyster polygons. The large difference in number of polygons mapped highlights the inability of the analyst to discriminate strata in the imagery. The closer agreement in area

highlights the ability of an analyst to visually discriminate the areal extent of oyster beds using the GeoScanner 0.5-m imagery.

Table 1 Comparison of polygon count and area – GeoScanner 0.5-m visually interpreted.

Data Source	Test Area		Difference Relative to GPS	
	count	area	count	area
Field collected GPS polygons	74	2691.939	**	**
GeoVantage .5 M Heads Up	22	2877.735	29.73%	106.90%

Level of Effort

The Broad Creek study area was mapped in a two-day period (~16 hours). This area is approximately 6 kilometers along the creek. In addition, a full day of signature development fieldwork was required to train the eye to break out the fringe oyster signature in the imagery. The Hamlin Creek area was mapped in a similar time-frame.

File Issues

The BMP file format is displayed quickly in the ArcView environment in which this method is applied; however histogram manipulation is not allowed in this software with this file format. The ability to manipulate the image histogram is critical for visual interpretation. The images were converted to the ERDAS *.IMG image format in ERDAS Imagine to allow for histogram manipulation using the Image Analyst extension in ArcView 3.2.

Software

- The NCCOS Habitat Digitizer tool is instrumental in this methodology.

Hardware

There are no unique hardware issues related to this method

Technical expertise/skill level

This method requires entry to mid level technical expertise. Skills required include basic image manipulation (image stretching) and basic understanding of digitization and attribution of shapefiles (this is minimized with the use of the NCCOS digitizing tool). The ideal candidate for this work would be more knowledgeable about the oyster habitat than GIS. Required training would include an introductory ArcView course such as that provided at CSC.

Project dependencies

For the Broad Creek study area, image interpretation required a significant amount of signature development for the interpreter to feel confident delineating the fringe oyster reefs. This was primarily a function of the increased shadowing in Broad Creek and the reduced *spartina* IR response. Less signature development was needed for Hamlin Creek.

Limitations of the method

This method is limited by the quality of the imagery and the ability of the interpreter to digitize for long periods of time. This method is one of the most time consuming. Manual delineation is also less objective and repeatable than more automated methods that rely primarily on the spectral information in the imagery.

Strengths of the method

This method allows the interpreter to apply their knowledge of the environment and make decisions based on collateral information in addition to the spectral information provided by the imagery itself. However, this level of interaction is time consuming

Summary from a user's perspective

This method is well suited for in-house production level work at SCDNR with existing infrastructure and staff. However, hand digitization of polygons is a tedious process and every effort should be made to maximize more automated techniques for the initial digitization of polygons. A hand digitization approach would then be used primarily for QA/QC.

Level of Effort = 7

Level of Detail = 7+

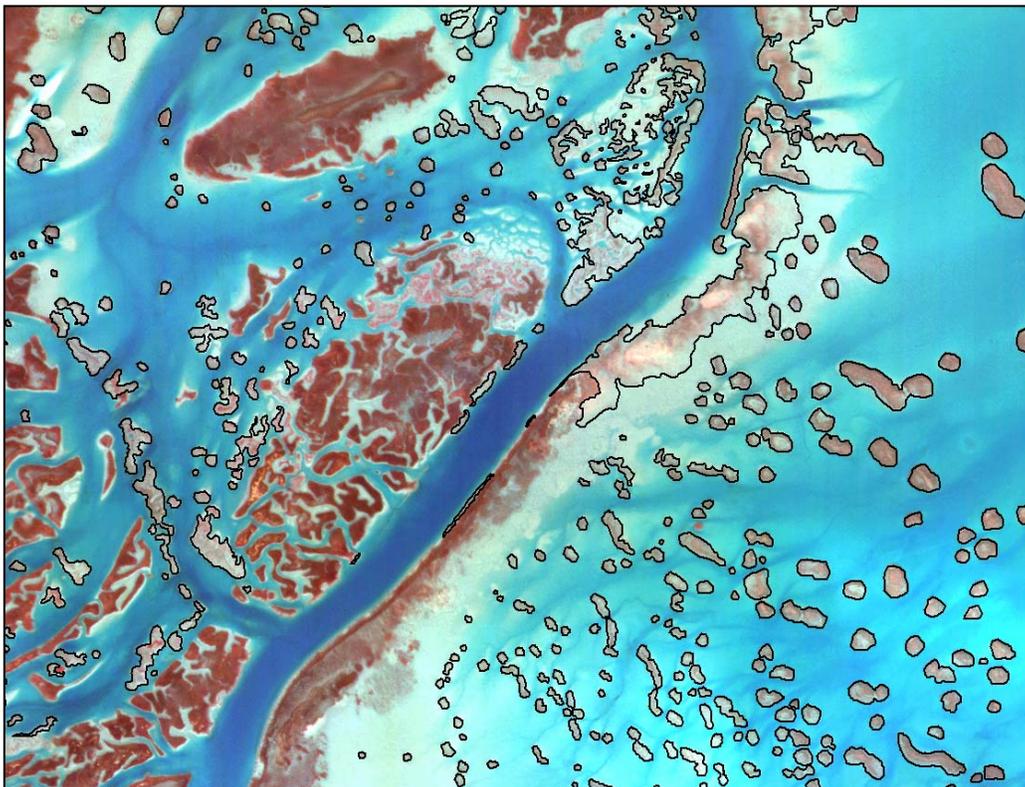


Figure 6. Manually delineated oyster reef polygons in northern Hamlin Creek on GeoScanner image. Reefs were mapped at level of detection with no minimum mapping unit

Image Segmentation

ECognition software uses textural information such as shape, linearity, and convexity as well as spectral information to generate image segments. Classes are then developed based on the parameters of like segments that encompass the desired feature. This sets up a rule based decision process that asks multiple if-then questions of each segment. This is a relatively new approach to image processing from more established methods that rely primarily on spectral response. The learning curve for effective application of this software is steep and the most appropriate characteristics for delineating oysters have not yet been completely identified. In addition, these parameters will vary based on the target (i.e. fringe reef vs. patch reef vs. washed shell).

Source Imagery

The digital multi-spectral imagery was used for this test due to its spectral integrity. GeoScanner 0.50 meter imagery in Broad Creek was used to test this approach.

Features/information extracted from data

The initial application of this method shows promise as segments representing the different oyster signatures were captured. However, much confusion exists in the current parameters included in the definition of these classes. This results in much of the water /mud interface and *Spartina* being classified as fringe oyster. The field GPS polygons were used as training sites for the initial creation of class parameters. It is believed that these parameters can be refined to produce a better classification. Figure 2 shows the classified data set with the GPS polygons overlaid.

One of the drawbacks of this approach is that it comprehensively maps the scene area meaning that each pixel must be classified. One approach to minimize the confusion that this creates is segmenting the raw image prior to importing into eCognition. Methods for isolating the intertidal area from water and *spartina*/uplands are being investigated. As mentioned previously, imagery collected in the *spartina* growing season will assist in differentiating the *spartina* from adjacent oyster beds.

Level of effort

A subset of the Broad Creek study area, primarily the island that was field delineated using GPS by SCDNR and Town of Hilton Head personnel, was mapped in a three-day period. Prior to the analyses, staff received a basic two-hour tutorial focused on the interface and basic principles. The learning necessary to fully implement and test this method is considerable and should not be discounted. In addition, processing time for large images is considerable and dependent on hardware. The table below shows required processing time for the initial segmentation of imagery similar to the GeoScanner on a PC with a Pentium IV CPU, 1.4 GHz, 2 GB RDRAM, a 40 GB SCSI Ultra 15.

File issues

A subset of the mosaic created for the Broad Creek study area was created for this method. The four-band ERDAS Imagine *.img file, a stacked composite of the individual RGB and NIR images, was 24 megabytes and the resulting classified image was 1 megabyte.

The GeoScanner imagery is delivered in a BMP file format. This format is compatible with eCognition.

Software

This methodology can only be performed using the eCognition software by Definiens. The software is node locked through a hardware key.

Hardware

The methodology requires the entire object structure to be kept in memory. Memory size therefore sets the upper limit for the size of image data to be processed. Systems with the highest available RAM are recommended for this method.

Technical expertise/skill level

This method requires an advanced technical understanding of imagery processing as well as advanced understanding of decision tree and rule based classification procedures. This method is not suited for a basic GIS technician. Manufacturer designed training is recommended for this software. In addition, many hours of trial and error are required to develop appropriate class definitions.

Project dependencies

Advanced training for remote sensing staff is needed to effectively utilize this software.

Limitations of the method

This method requires extensive investment in training. While the image segmentation shows promise for oyster delineation and characterization, further work is required to determine the true benefits and limitations of this approach.

Strengths of the method

Potentially, this method creates a “recipe” that is quantitative and repeatable, however this has not yet been proven. Further testing of this method is required prior to identifying its strengths and weaknesses.

Summary

This method requires strong remote sensing skills and training in the eCognition and is not well suited for in-house production level work at SCDNR with existing infrastructure and staff. Theoretically, a “recipe” of decision rules could be constructed to delineate oyster habitats then applied to the entire imagery set. However, radiometric differences in each GeoScanner image set would require a re-calibration of the “recipe” if spectral parameters were an integral component of the class definition.

Level of Effort = 7

Level of Detail = 7+



Figure 7. Ecognition initial segmentation of GeoScanner imagery, Broad Creek study area. Each polygon is an independent image object.

Unsupervised Spectral Clustering

The ISODATA clustering algorithm, available in standard ERDAS Imagine and the ArcView Image Analyst extension was used to conduct the clustering evaluations. This technique organizes image pixels according to the statistical similarity of reflectance in the various image bands. In an unsupervised classification the computer generates a predetermined number of classes based solely on the digital number values in each spectral band.

Once the statistical clustering process is complete an analysis assigns the clusters into some category. Normally this is an iterative process where each subsequent run of the algorithm is based only on the pixels that populate classes that contain the desired features. Thus at the end of the process only pixels representing the desired categories remain.

Source Imagery

GeoScanner 0.5-meter imagery was evaluated in Broad Creek and the GeoScanner 0.25 meter imagery of Hamlin Creek was also evaluated.

Features/information extracted from data

In Broad Creek, the unsupervised/ methods had limited success. The NIR image was used for this approach. This approach resulted in fringe oyster beds being represented by 10 to 15 classes with considerable confusion with non-oyster areas such as bare mud and spartina. As with all methods, patch reefs on mud flats were more easily distinguished than fringing reefs but still are represented by 5 classes. The patch reefs are most often confused with mud. The variable illumination, density, ratio of mud vs. oyster, and wetness/dryness seem to be the driving forces in confusion with mud.

More promising results were obtained for the Hamlin Creek area. This is mainly due to the higher spatial resolution of the imagery and the stronger IR response. Five classes represented oysters but as with Broad Creek there was confusion between mud and areas of sparse *spartina*. The errors were primarily errors of commission where oysters were adequately captured but additional features were picked up as well.

Early indications are that, in the Broad Creek study area; this method is less robust than others. However, further segmentation of the image prior to clustering, “mask” creation, should help reduce confusion among classes.

Level of effort

Approximately four days were spent exploring these methods in the Broad Creek study area. Tracking time and effort required with this method is difficult since the process is iterative and subject to local conditions and image quality.

File issues

The native GeoScanner format was converted into an ERDAS IMG file format for this method. A four band stacked image was created to provide more information for the unsupervised clustering algorithm.

Software

ERDAS Imagine software was used for this method evaluation. The same ISODATA algorithm is also available in the ESRI ArcView product with the Image Analyst extension; however, there is less ability to manage the clustering process in the ESRI environment.

Hardware

There are no unique hardware requirements needed for this method.

Technical expertise/skill level

This method requires mid-level GIS and Remote Sensing technical expertise. The Remote Sensing for Spatial Analyst course offered at CSC is designed to convey both the needed theoretical background and specific tool training to complete this type of analysis.

Project dependencies

None.

Limitations of the method

None have been identified at this time.

Strengths of the method

The real value of this technique is the ability to conduct mapping in a semi-automated approach that is somewhat repeatable. However, until further investigation is completed, this is an unproven method

Summary from a user's perspective

This method is marginally suited for in-house production level work at SCDNR with existing infrastructure and staff. This is based on the current uncertainty of success with this approach. This is an extremely iterative process that requires great attention to detail. However, it may prove to be well suited to quickly capturing the patch oyster reefs.

Level of Effort = 3

Level of Detail = 3

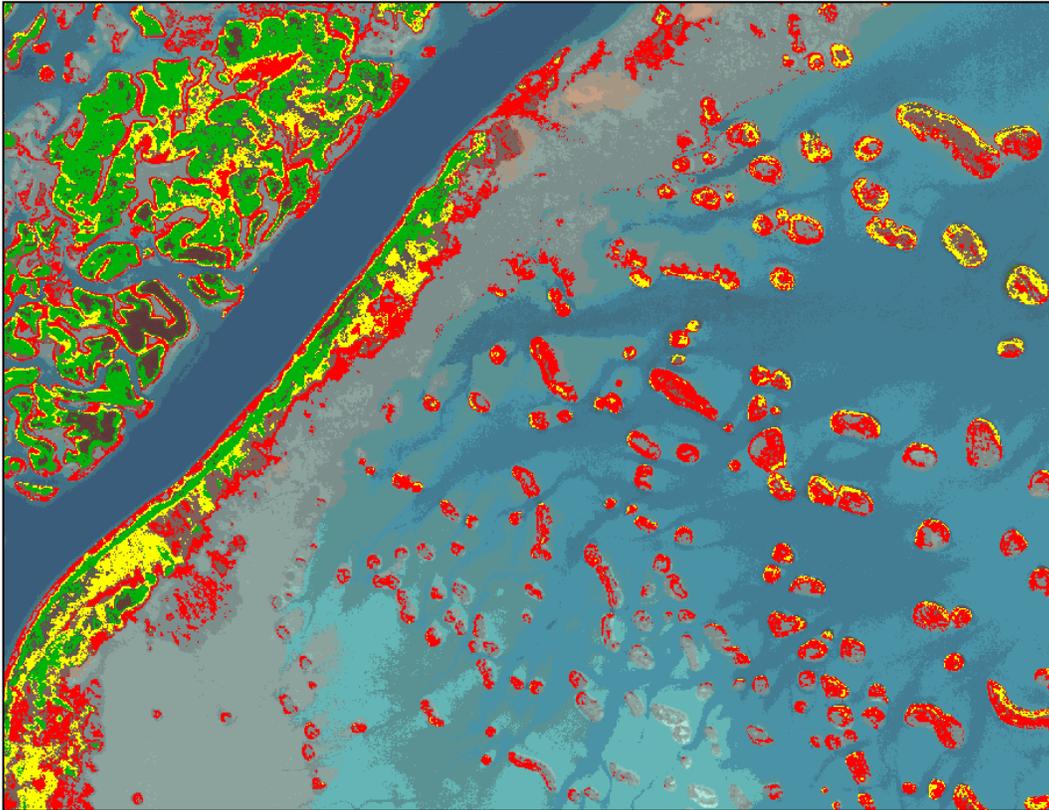


Figure 8. Unsupervised clustering result in Gray Bay and Hamlin Creek. Adjacent emergent marsh is also included in the classification. Emergent marsh is colored green, low profile oyster is colored yellow and high-profile oyster is red. The surrounding mud and water areas are not classified.

Supervised Spectral Clustering

As with the unsupervised analysis, the ISODATA clustering algorithm was used to conduct the supervised clustering evaluation. Unlike the unsupervised approach, in this process the analyst selects “training samples” that represent different habitat types or features. The spectral characteristics of these samples are used to organize the image data. Candidate pixels are assigned to classes based on their similarity one of the training samples. This approach is most effective when classes of interest are well understood, and distinct from the surrounding environment or other features.

Source Imagery

The coarse spectral resolution and variable spectral integrity of analog film severely limits the effectiveness of spectral clustering processes. Therefore this approach was only tested on the digital multi-spectral imagery. The supervised method utilized a stacked image, four-band composite with RGB and NIR bands.

GeoScanner 0.50 meter imagery in Broad Creek
 GeoScanner 0.25 meter imagery in Hamlin Creek

Features/information extracted from data

This image was clustered using 20 training sites derived from the field points. This resulted in a gross overestimation of oyster. Much of the intertidal mud banks were included in the multiple oyster classes. This method seemed to introduce more confusion than the unsupervised approach.

In both study areas, a challenge posed by the supervised approach was identifying homogenous training samples. With spatial resolutions as low as 0.25 meters, it was difficult to identify multiple pixel training samples that didn't contain a combination of either mud and oyster, *spartina* and oyster or other features. As a result there was often notable confusion in the resulting spectral classes.

Level of effort

Approximately four days were spent exploring this method in the Broad Creek study area. Tracking time and effort with this method is hard as the process is iterative and work was sporadic.

File issues

As with the unsupervised clustering approach, the native GeoScanner format was converted into an ERDAS *.img file format and a four band stacked image was created to provide more information for the supervised clustering. Stacking all the available GeoScanner bands is essential to successful use of the supervised clustering methods

Software

ERDAS Imagine software is needed to create the 4-band stacked image that can be clustered using the software listed below.

Hardware

There are no unique hardware requirements associated with this method.

Technical expertise/skill level

This method requires mid-level GIS and Remote Sensing technical expertise. The Remote Sensing for Spatial Analyst course offered at CSC is designed to convey both the needed theoretical background and specific tool training to complete this type of analysis. This method also relies on a strong understanding of the spectral response of target features by the analyst

Project dependencies

The supervised clustering approach is also dependent on good representative samples of the features of interest. The best training samples are drawn from direct field observations made under similar conditions as the image acquisition.

Limitations of the method

None have been identified at this time.

Strengths of the method

The greatest value of spectral clustering is the high level of automation in the method. This approach is also very quantitative and lends itself to repeated mapping efforts. However, the

importance of textural and spatial information in identifying oyster reefs reduces the effectiveness of spectral clustering alone.

Summary from a user's perspective

This method is marginally suited for in-house production level work at SCDNR with existing infrastructure and staff. This is based on the current uncertainty of success with this approach. As with unsupervised methods, this is an extremely iterative process that requires great attention to detail. However, it has shown some success in quickly capturing the patch oyster reefs.

Level of Effort = 5

Level of Detail = 3

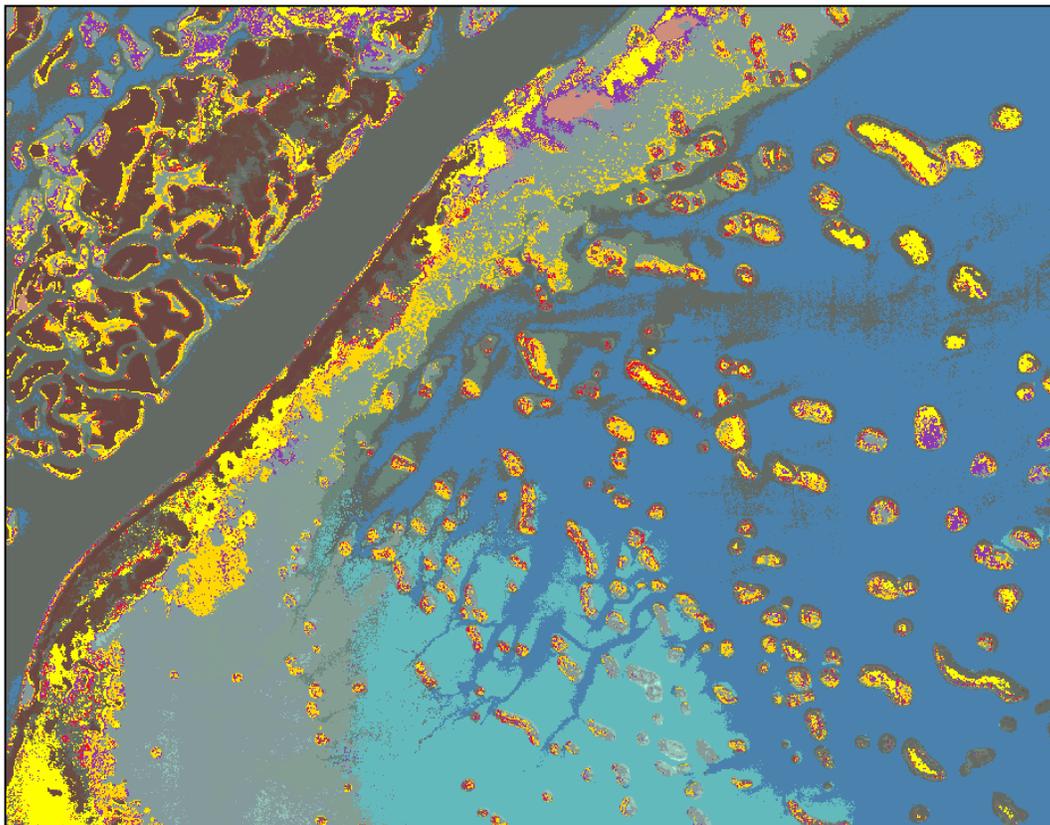


Figure 9. Supervised clustering result in Gray Bay and Hamlin Creek. Adjacent emergent marsh is not included in the classification. This result shows high-profile oyster in red and high-profile oyster with mud as yellow.

Feature Analysis

The Feature Analyst extension for ArcView, developed by Visual Learning Systems, was used to conduct oyster mapping in subsets of both the Broad and Hamlin Creek study areas. This software is similar to eCognition. In addition to spectral information, this software uses spatial context to differentiate features. Feature Analyst allows users to train the software to recognize specific types of features and to refine the definition over time. This is called "machine learning technology." Machine learning algorithms such as Nearest Neighbor, Neural Networks, Decision Trees and others are used to efficiently extract user-defined features. The software uses a hierarchical approach that iteratively allows the analyst to refine the classification. The analyst hand digitizes a representative sample of the target, allows the software to search for like features, and then interactively "teaches" the system which resulting polygons correctly capture the desired feature and which do not. This software is easy to learn and use.

Source Imagery

GeoScanner 0.5 meter imagery of Broad Creek and the 0.25 meter GeoScanner imagery of Hamlin Creek were both used to evaluate this method.

Features/information extracted from data

This software was explored using a 7-day temporary license. Initial results are extremely positive and justify a more complete evaluation of this software. Specifically its ability to quickly delineate the patch reefs with a high degree of accuracy is unique. A large mud flat to the east of Hamlin Creek was mapped in less than one hour as compared to 8 hours to manually delineate the same area.

Figure 10 shows an example of the detail obtained using FeatureAnalyst in comparison with the same area captured in the field.

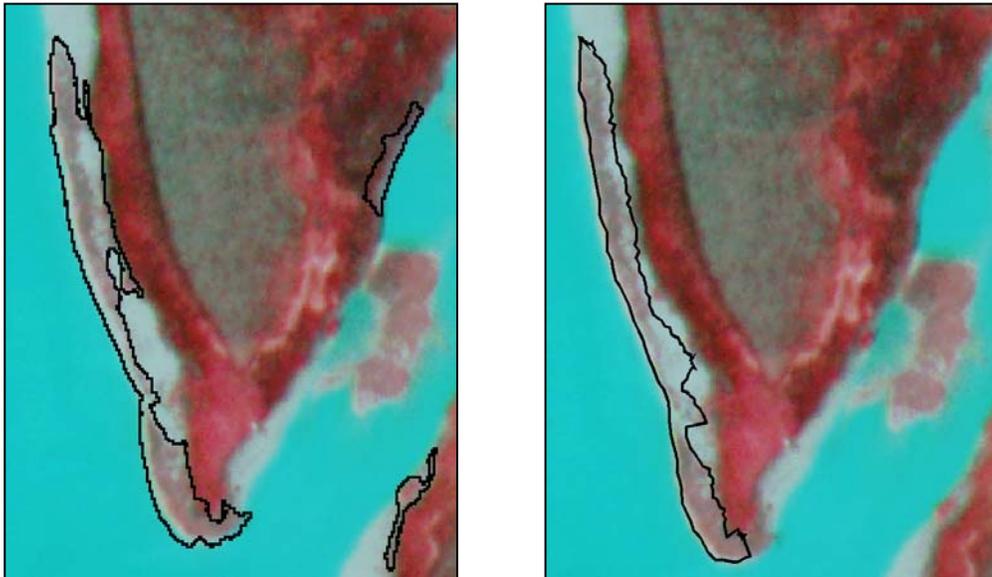


Figure 10. Fringing reef perimeter generated by FeatureAnalyst (left) and field digitization (right) in Hamlin Creek.

The fringe reefs were adequately captured although more testing of the spatial context search parameters is needed to further refine mapping this feature. Errors of omission in Broad Creek tended to be caused by shadows either obscuring the oyster or altering their spectral response. Errors of commission tended to be textured mud and *Spartina*. As with all methods tested, a late summer overflight will allow easier discrimination of *Spartina*.

The following table quantifies the differences between field GPS mapped and Feature Analyst derived polygons in Broad Creek. The large difference in number of polygons mapped highlights the inability of the software to discriminate strata in the imagery. The closer agreement in area highlights the ability of the software to discriminate the areal extent of oyster beds using the GeoScanner imagery.

Table 2. Comparison of polygon count and area – GeoScanner Segmented with Feature Analyst

Data Source	Test Area		Difference Relative to GPS	
	count	area	count	area
Field collect GPS polygons	74	2691.939	**	**
GeoVantage .5 M Feature Analyst	24	3230.5	32.43%	120.01%

Level of effort

Approximately two days were spent exploring this software in both the Broad and Hamlin Creek study areas by one analyst. An exact figure on effort to map a specific study area is not available. However, the comparison of approximately one hour vs. one day to manual digitize patch reefs on the mud flat in Gray Bay east of Hamlin Creek is a good indicator of the time savings offered by this software.

File issues

The feature analysis method works on all the common image formats supported by ArcView, including the GeoScanner .bmp format.

Software

The Feature Analyst extension is required for this method. It will operate in either an ESRI ArcView or ArcGIS environment. The software is node locked but can be passed between workstations on a network through a computer hand-shaking process. This avoids the need for a hardware key.

The cost of the single seat license of this software for this method test was approximately \$9500.

Hardware

There are no unique hardware requirements associated with this method.

Technical expertise/skill level

This method requires entry to mid-level technical expertise. This software is designed for a basic GIS technician. Knowledge of oyster habitat and the ability to delineate a representative sample of oyster in the study area is all that is required to begin the process. Training, if required, would be an introductory ArcView course such as that provided at CSC.

Project dependencies

Ability to interpret initial feature signatures for software to conduct segmentation.

Limitations of the method

None have been identified at this time.

Strengths of the method

This software is extremely intuitive with a simple workflow. Its ability to delineate patch oyster reefs is comparable to the results of hand digitization with a fraction of the labor and it is much easier to learn than eCognition. Of all the automated techniques, this promises to be the most efficient in terms of costs and skill required.

Summary from a user's perspective

This method is well suited for in-house production level work at SCDNR with existing infrastructure and staff. This software is capable of doing the majority of the “heavy lifting” of creating polygons around likely features. Iterative “training” of the software will eliminate many of the wrong features and should provide a relatively clean and accurate data set. Hand digitization/editing would be minimal and only needed for the final QA/QC step.

Level of Effort = 3

Level of Detail = 7

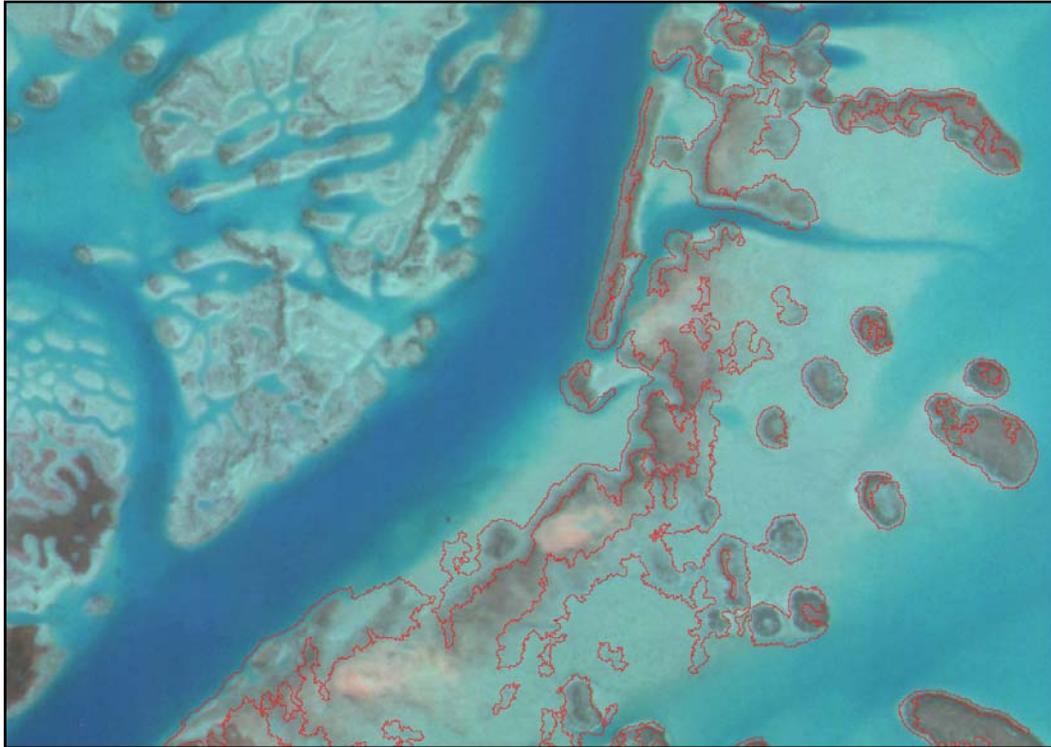


Figure 10. Oyster reef perimeter polygons in Gray Bay generated during the first pass of the FeatureAnalyst extension in ArcView. 3.2. These polygons are normally reviewed by the analyst and additional iterations are run. Each iteration builds on the prior results.

Analysis of Image-Derived Data

Based on the results of the standard clustering evaluations, it was clear that the results could be improved by segmenting the image and including other data derived from the imagery in the clustering process. Both the supervised and unsupervised methods were able to discriminate oyster classes, but too often included non-oyster areas. The objective of the analysis of image derived data approach was to remove these other confusion areas, primarily *spartina* marsh and water, and let the ISODATA algorithm focus on areas of intertidal mud where oyster reefs occur. A principle component analysis was done on the GeoScanner imagery. This produced an image with few useable principle components due to the limited band set of the GeoScanner imagery. A Normalized Density Vegetation Index (NDVI) was run on the GeoScanner imagery in an attempt to remove the *spartina* marsh. The NDVI approach used was the same used for Landsat Multi-Spectral Scanner imagery, which had a similar band, set to the GeoScanner data.

Source Imagery

GeoScanner 0.5 meter imagery in Broad Creek and the GeoScanner 0.25 meter imagery of Hamlin Creek was both examined using this approach. The lack of an IR band in the aerial photography precluded its use.

Features/information extracted from data

The NDVI was very successful in removing most of the confusion areas and improved the results of the clustering. Water and the higher biomass *spartina* were easily removed through this approach. Because of the lower IR response of the *spartina* in Broad Creek, the NDVI was somewhat less successful in this pilot area. Hamlin Creek had better results. Nevertheless, in both areas some *spartina* marsh was not removed in this process and required the normal cluster busting efforts to extract.

Once the major confusion areas were removed more reliable oyster class could be discriminated.

These methods require more attention to develop a sense of their applicability to a wide variety of environmental settings. Early indications are that, in the Broad Creek study area; this method is less robust than others. However, further segmentation of the image prior to clustering, “mask” creation, should help reduce confusion among classes.

Level of effort

This approach took comparable time relative to the other clustering processes, but was more efficient due to the reduced need for multiple mask development. The algorithms for generating Principle Component and NDVI data sets are easily accessible in ERDAS Imagine and can be run with little preparation. Some expertise is needed to make them as efficient as possible; however, these processes are well within the skill level of analysts with limited remote sensing backgrounds. Approximately four days were spent exploring these methods in the Broad Creek study area. As with the standard unsupervised and supervised approaches tracking the time and effort associated with this method is difficult as the process is iterative and subject to local conditions and image quality.

File issues

This method requires a stacked file containing all the image spectral bands. The ERDAS Imagine format was used in this case and this lent itself to the use of the automated processes available in Imagine. GeoScanner .BMP file format was converted into an ERDAS .IMG file format. A four band stacked image was created to provide more information for the supervised clustering.

Software

The ERDAS Imagine software was required for this method. The ability to produce image-derived products for inclusion in the processing could not be effectively done in any of the other software used in this methods comparison.

Hardware

There are no unique hardware requirements associated with this method.

Technical expertise/skill level

This method requires mid-level GIS and Remote Sensing technical expertise. The Remote Sensing for Spatial Analyst course offered at CSC is designed to convey both the needed theoretical background and specific tool training to complete this type of analysis.

Project dependencies

None.

Limitations of the method

The limitations of this approach are similar for the other spectral clustering approaches, in that a strong IR response from the surrounding marsh vegetation is needed to optimize the results.

Strengths of the method

This approach was good at reducing spectral confusion between oyster and other marsh features such as water and *spartina*. This allowed the clustering algorithm to identify more oyster classes more reliably than could be achieved with normal clustering methods

Summary from a user's perspective

This method is marginally well suited for in-house production level work at SCDNR with existing infrastructure and staff. While some iterative analysis is still required following the NDVI, the amount and complexity of this analysis is notably reduced. This is based on the current uncertainty of success with this approach. This is an extremely iterative process that requires great attention to detail. However, it may prove to be well suited to quickly capturing the patch oyster reefs.

Level of Effort = 7+

Level of Detail = 5

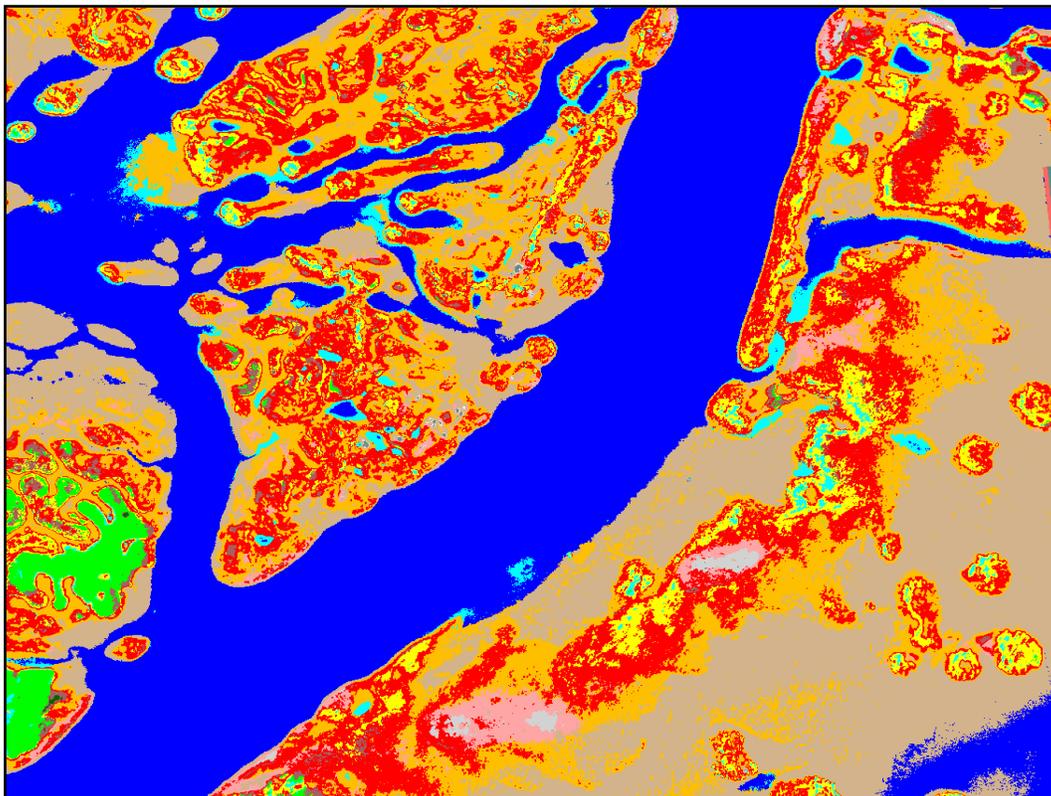


Figure 11. Unsupervised clustering result in Gray Bay and Hamlin Creek. This is a comprehensive classification of all habitats in the scene. Multiple oyster classes are detected.

SUMMARY AND RESULTS

All of the methods were evaluated for their ease of use, infrastructure requirements, level of effort, and level of detail that could be obtained. In addition, the two image sources were reviewed for their utility for mapping intertidal oysters over large geographies.

Data for both Broad Creek and Hamlin were developed based on these methods. The Hamlin Creek data was validated by field visit in March 2003 by staff from the Coastal Services Center and SCDNR. Both Feature Analysis and Clustering using Derived Imagery data were examined. The field validation relied on a stratified random sample that was drawn from both patch and fringing reefs, different reef orientation (to examine the effect of shadowing by adjacent marsh, and local setting. The field validation showed that both approaches produced results usable to SCDNR for large area mapping. Based on the lab and field evaluations, the following recommendations are proposed.

Source Imagery

The spatial resolution of the aerial photography is unsurpassed even by the 0.25 meter GeoScanner data. Even the 1:8,000 scale photos showed several oyster strata when viewed in stereo. The 0.5m GeoScanner imagery had marginal results in discriminating fringe reef and the automated clustering and feature analysis methods struggled to resolve oyster from surrounding features. The 0.25m GeoScanner imagery had markedly better results in all methods tested and although not as spatially resolved as the photography was suitable for automated processing methods.

The most promising image source overall was the GeoScanner 0.25 meter imagery. This had adequate spatial resolution as well as sufficient spectral resolution and integrity to support various automated data extraction methods. This data is also delivered in an ortho-rectified format with high spatial accuracy and can be within the hands of an analyst within days of acquisition. This maximizes the ability to review collected imagery and refly missions if the demanding environmental restrictions of intertidal oyster mapping have not been met for some reason.

Analysis Approaches

Both the aerial photography and the 0.25meter GeoScanner imagery supported manual delineation of both fringing and patch reefs. This method could be considered the last resort of an analyst and could be used in limited cases where the automated methods were unsuccessful or required too many iterations to produce desired results. The manual delineation process can also be accomplished in a variety of software environments.

Spectral clustering of the native multi-spectral imagery can identify both patch and fringing reefs and some level of oyster strata but is vulnerable to confusion. These methods have very limited use on the analog photography. The software requirements for these processes are slightly higher but still within the reach of most staff at SCDNR.

Image segmentation with eCognition shows promise but is a very complicated process and can only be accomplished in one software environment.

Feature analysis is a very promising approach to oyster delineation. Using the spectral and spatial information in the 0.25 meter GeoScanner data, this approach can identify both fringing and patch reefs and also several oyster classes. It also can be accomplished in the most

commonly used GIS software, has a short learning curve and can produce improved results through several iterations.

The spectral analysis using image-derived data such as an NDVI also has strong promise. This method could even be improved over the results achieved in this pilot evaluation if supporting ancillary data are available. Possible ancillary data that may be suitable might be high-resolution shoreline data to remove water, existing oyster polygonal data derived from field digitization, etc. The existing SCDNR oyster polygon data is unsuitable for direct image segmentation due to its coarse detail and spatial accuracy but may be useful as a general guide for visual analysis.

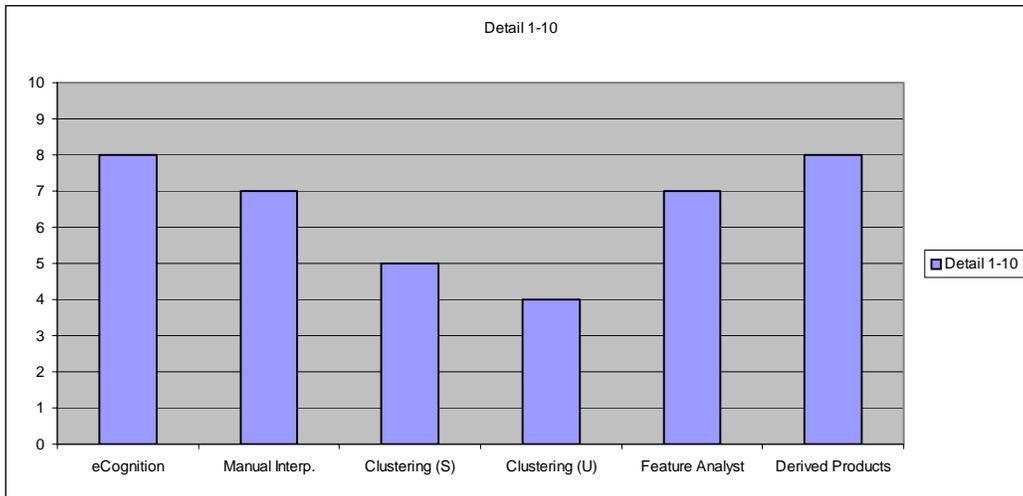


Table 3. General comparison between methods based on level of detail obtainable.

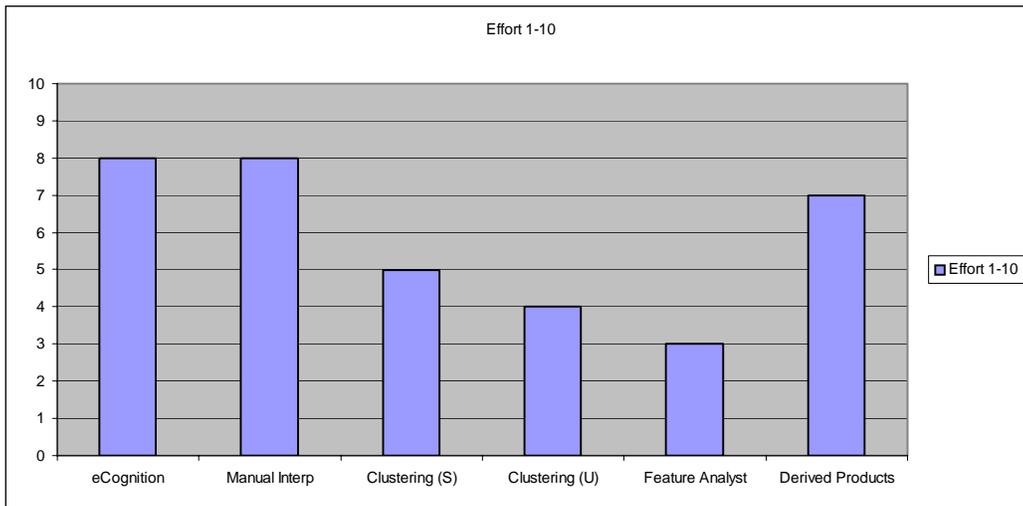


Table 4. General comparison between methods based on level of effort required.

Recommendations

Based on the results of these pilot tests the recommended approach for large-area intertidal oyster mapping using multi-spectral imagery involves a combination of two of the methods described above.

Feature analysis can be used to identify the location, extent and perimeter characteristics of both patch and fringing reefs. This will allow an accurate determination of the acreage present in South Carolina and some determination of loss or gain in extent of oyster over time. The bed edge configuration that can be obtained from this approach will support analysis of faunal utilization of oyster reefs.

Spectral analysis using image-derived products can be used to identify the individual components of the patch and fringing reefs and provides some information on oyster reef condition (strata). Four strata, as illustrated below, were reliably discriminated using this approach:

- A. High-Profile Oyster- These are areas with notable vertical relief and lots of live shell.
- B. High-Profile Oyster with Mud – These are areas with vertical, live shell but with intervening areas of mud
- C. Low-Profile Oyster – These are areas where there is little vertical shell, most shell is very low or actually dead
- D. Washed Shell – These areas consist of dead shell that has been bleached by the sun and water and has no vertical relief. This is perhaps the easiest class to distinguish, although some confusion with sand may occur in certain locations.

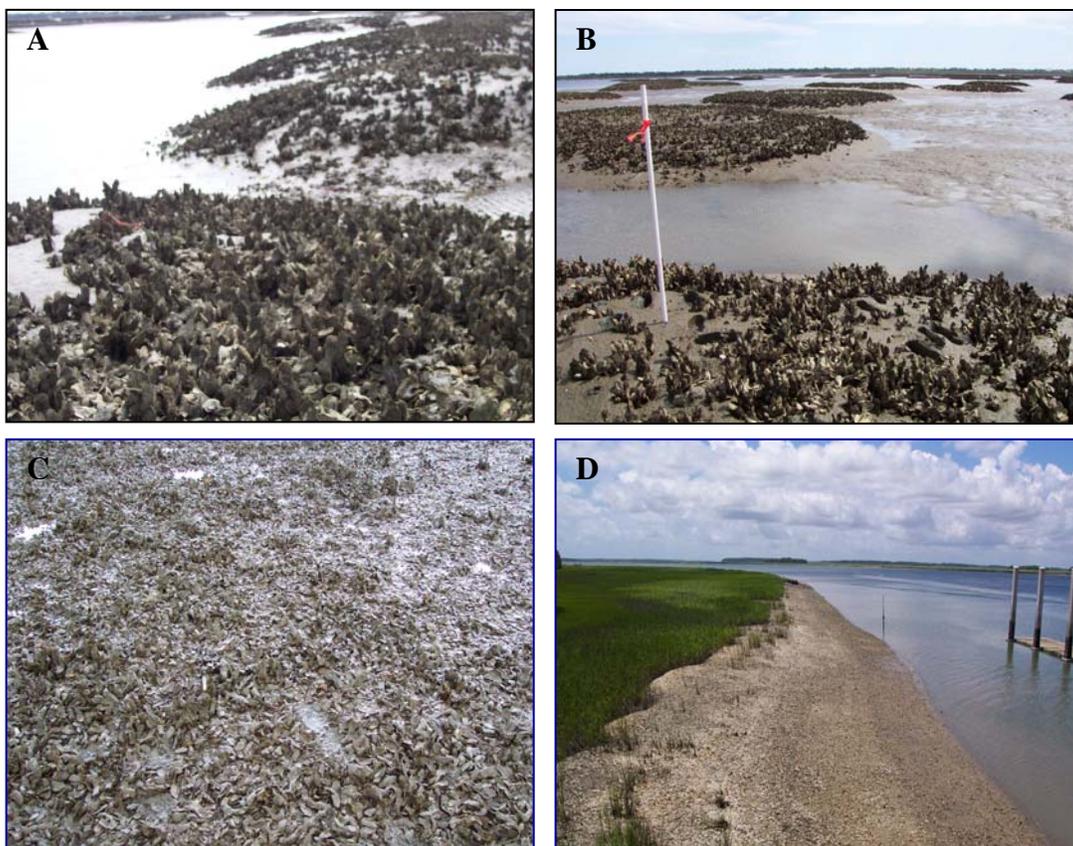


Figure 12. Four categories of oyster reef obtainable through remote sensing means.

Using both methods provides the coastal manager/researcher with the following information:

- Extent of oyster reefs
- Perimeter of oyster reefs
- Edge configuration of oyster reefs
- Amount of various reef components (live shell, mud, dead shell) in each reef.

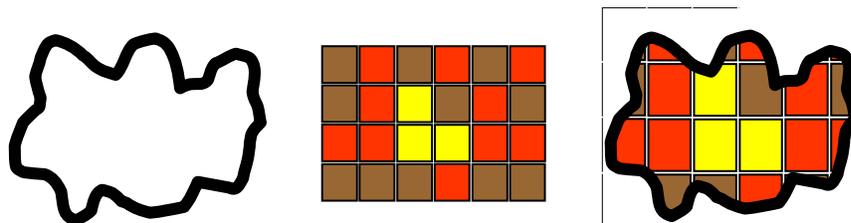


Figure 13. This figure shows a merge of the polygonal data generated by the Feature Analysis process and the raster data from the clustering to produce data on extent and condition of the oyster reefs.

In areas where both the automated methods have little success, manual delineation can be used.

Field Test of Recommended Approach

A field test of the two-part approach recommended above was conducted in Hamlin Creek in March 2003 by SCDNR and CSC staff. Two data sets were prepared for field validation, the oyster perimeter shapefile data derived from FeatureAnalyst and a classified raster derived from spectral clustering from a NDVI of the 0.25m 4--band GeoScanner imagery. The purpose of the visit was two-fold, first to determine whether the methods could reliably identify fringing reefs and develop an accurate boundary, and second to evaluate whether the four classes obtained from spectral clustering could be correlated to field observations and eventually to some of the 9 oyster strata classes used by SCDNR. The samples were stratified according to reef type (fringing vs. patch), and physical setting (creek banks, flats, and mud hummock areas). Efforts were made to collect points of each type.

Field observations were accomplished by driving a small boat along side fringing reefs and by walking to various points on patch reefs. A WAAS-enabled GPS receiver was used for navigation. The GPS coordinate string was recorded in a ruggedized laptop running FieldNotes software. This software allowed the GPS position to be displayed over the oyster perimeter vector and the classified raster. Field observations were recorded in a spatial database file for comparison to the digital data.

A total of 57 sites were visited in the field. Overall accuracies for detection of oyster reef are presented below in table 5.

Oyster Detection Error Matrix						
Lab\Field	oyster	washed shell	mud	vegetation	Totals	Commission
oyster	42		3		45	93%
washed shell					0	
mud	6		6		12	50%
vegetation					0	
Totals	48	0	9	0	84.2%	
Omission	88%		67%			
KAPPA = 47.7%		Total Observations 57				

Table 5. Error matrix showing thematic accuracy of aggregated oyster class and confusion with mud class.

In addition to determining the ability of the methods to identify oyster reef, the accuracy of the various oyster classes was also measured. Table 7 shows the results of the preliminary set of within-oyster categories

Oyster Character Error Matrix													
Lab\Field	textured mud	high-profile oyster/mud	water	washed shell	mud	high-profile oyster	low-profile oyster	compact shell/mud	wet oyster/mud	wet mud	vegetation	Totals	Commission
textured mud		1			1							2	0%
high-profile oyster/mud	1	28			2	1	2					34	82%
water												0	
washed shell												0	
mud		2			5		3					10	50%
high-profile oyster						7						7	100%
low-profile oyster							4					4	100%
compact shell/mud												0	
wet oyster/mud												0	
wet mud												0	
vegetation												0	
Totals	1	31	0	0	8	8	9	0	0	0	0	77.2%	
Omission	0%	90%			63%	88%	44%						
KAPPA = 63.3%												Total Observations 57	

Table 7. Oyster class accuracies in Hamlin Creek

Areas of Remaining Confusion

While the remote sensing methods showed good results and provide accurate spatial data on oyster in an efficient manner, there remain areas of confusion that will inevitably require field verification to resolve. All methods had difficulty discriminating oyster from textured mud. Textured mud in the pilot areas consisted of clumps of mud that eroded free from marsh edges and lay on the mud banks of tidal creeks. These clumps sometimes had a vertical relief of 0.3 meters. Another type of textured mud consisted of numerous shallow depressions on a creek bank. These depressions were usually approximately 0.3 meters in diameter and may have been caused by methane gas escaping from the sediment or feeding activities by stingrays or other animals.

Sparse *spartina* and other marsh plants and their shadows create a texture on the imagery that can be confused with low-profile oyster with mud. The relationship between the four remotely derived oyster categories and SCDNR strata classes still requires some examination. This will improve the use of data obtainable from remote sensing and may also provide a quantitative element to the existing strata classes obtained from field observation.



Figure 14. Shallow depressions on mud banks such as these on upper Hamlin Creek can sometimes be confused with oyster reef.



Figure 15. Short, sparse cordgrass shoots produce a texture on the mud that can mimic the appearance of oyster.

Figure 16. As marsh banks erode, blocks of mud and cordgrass drop onto the fringing bank where their appearance is similar to oyster reef.



Conclusion

Airborne remote sensing is a viable technology for producing high-detail oyster maps over large geographies. There is inevitably a trade-off between the detail obtainable from field observation and the logistics of that process; however, the approaches described above will complement and improve the efficiency of any field effort.

Further exploration of the relationships between remotely derived image components (oyster classes) and strata will hopefully allow a quantitative measure of oyster reef condition and anticipated yield.

These methods are appropriate for coastal management and natural resource professionals with knowledge of the oyster resource ecology/biology and with some experience in spatial data analysis. More exotic or complex methods may prove useful to a different user group and as technologies evolve these may supplant the methods recommended based on this pilot evaluation.