

**MAPPING AND CLASSIFYING SURFICIAL SEDIMENT TYPES WITHIN  
THE MARYLAND WIND ENERGY AREA**

by

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A thesis submitted to the Faculty of the University of Delaware in partial  
fulfillment of the requirements for the Bachelor of Science in Geology with  
Distinction

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## **ACKNOWLEDGMENTS**

To my friends, family, and committee. Thank you for putting up with me over the past six months. Thank you for your support and direction.

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## **ABSTRACT**

In this thesis, a procedure for analyzing large-scale side-scan sonar projects was developed. Side-scan sonar is a geophysical acoustic tool that can be used to image morphological features, grain-size distributions, obstructions, and human-derived hazards on the seafloor. Using a dataset provided by the State of Maryland Energy Administration, side-scan sonar images within the Maryland Wind Energy Area (WEA), encompassing over 320 km<sup>2</sup>, were analyzed to better constrain the WEA's seafloor characteristics. The Maryland WEA is a proposed offshore region where wind energy projects could be developed. Offshore wind projects require a large capital investment. Up to 25% of total costs can be associated with wind turbine foundations that are directly influenced by seafloor conditions. Better understanding of the surficial and subsurface geology can aid in lowering costs by reducing uncertainty and allowing for optimal foundation design and siting in pre-construction planning.

The procedure developed involves data processing techniques such as: data import, tracking the bottom, identifying hazards, digitizing reflection boundaries, and creating a mosaic base map. As well as comparing automated (SonarWiz and ENVI) and manual reflection classification methods. The reflection classification methods were compared based on a measure of their accuracy, ease of use, and the relative time involved in analysis. Based on accuracy, the two automated classification methods produce more consistent results than the user defined method. Additionally, the user defined method was determined to be the easiest to use, followed by ENVI, and finally

SonarWiz. While the ENVI method required the shortest time investment to completion, followed by the user defined method, and again SonarWiz.

Furthermore, a geologic analysis was performed on the Maryland WEA. Although no sediment samples have been collected within the boundaries of Maryland WEA, various qualitative analyses have been performed in the vicinity of the study area. These studies verify the assumption that side-scan sonar reflection intensities captured within the Maryland WEA can be correlated to a general fine, medium, or coarse grain size scheme.

The results of this thesis provide a straight-forward procedure that can be used to analyze large-scale side-scan sonar datasets, like those that are/will be collected in geophysical surveys of offshore WEA's. When combined with sub-bottom investigations (e.g., chirp sub-bottom profiling), sediment sampling, and geotechnical measurements, the side-scan sonar data can be used to place constraints on the types and distributions of sediments that will be encountered in offshore WEA's. This information can be used by design engineers and planners to develop the most cost-effective foundations and thus aid in reducing the overall costs associated with offshore wind energy projects.



## **Chapter 1**

### **BACKGROUND INFORMATION & OBJECTIVES**

While Europe has a thriving offshore wind industry, the United States (US) has fallen severely behind with no industrial-scale offshore wind turbines currently deployed. Political, social (e.g., NIMBY, “not in my back yard”), regulatory, and/or commitment of investment capital issues have terminated or significantly delayed Delaware’s, New Jersey’s, and most recently Massachusetts’s efforts for offshore installations ( Herndon & Wade, 2012; Sullivan, 2014; McNamara, 2015). Though several states (e.g., Maine, Rhode Island, Virginia, and Oregon) have offshore wind projects in various stages of planning, none have yet to put “steel in the water”.

The importance of diversifying the sources of electricity production in the US cannot be understated. Multiple sources of electricity production decrease risks and ultimately, through market competition, keep electricity prices low. In the US, fossil fuels (natural gas, crude oil, NGPL, and coal) represent approximately 79% of the total domestic energy production while renewable energy sources (hydropower, geothermal, solar, wind, and various forms of biomass) and nuclear electric power represent approximately 11% and 10%, respectively (U.S. Energy Information Administration (EIA), 2015)(Figure 1).

Offshore wind projects have the potential to significantly reduce dependence on traditional fossil fuel coal-burning power plants, diversifying the US energy portfolio while providing a clean source of energy. The US has large population centers located in close proximity to coastal regions, especially in the Northeast and

Mid-Atlantic. Offshore wind projects in these regions provide an exceptional source of energy very close to the consumers that will use it. Virginia, Maryland, Delaware, New Jersey, New York, and Massachusetts consume approximately 455,479 gigawatt hours per year (GWh/Yr) of electricity (EIA, 2015). Assuming each state's US Department of Interior's Bureau of Ocean Energy Management (BOEM) designated Wind Energy Area (WEA) was fully utilized by installing one 5 megawatt (MW) wind turbine per square kilometer with an average capacity factor of 0.40 (Andrew, 2014), offshore wind farms along the Mid-Atlantic Bight could supply 13% of the locally consumed electricity or approximately 63,205 GWh/Yr. Figures 2 and 3 illustrate the electricity production and consumption breakdown on a state by state basis. Of particular interest for this study, Maryland consumes 61,916 GWh/Yr and has the potential to produce over 9% of that total, approximately 5,750 GWh/Yr, if its WEA was fully utilized.

Although BOEM has designated several potential offshore areas for wind energy development (i.e., WEA's) along the Mid-Atlantic Bight portion of the US eastern continental shelf (see Figure 2), several factors associated with offshore wind including the relatively high levelized cost of energy (LCOE), stability of federal and state policies, complex and long regulatory timelines, the necessity of developing local supply chains and the involved logistics associated with construction, operation and maintenance have served as obstacles (DOE, 2015). Offshore wind turbines, including the tower, blades, and nacelle (enclosing the hub, drive train, and electrical power systems), are supported by foundations, the majority of which extend into the subsurface (e.g., Manwell, 2009). Turbine size (and thus loading), water depth, and,

soil/sediment type and distribution govern the optimal type of foundation which may be used for a given project (Dean, 2010).

Foundations represent approximately 25% of the total expenditures for an entire offshore wind project (DOE, 2011). The need for the most effective foundation selection is becoming increasingly more important as the industry trends towards deeper, larger, and thus even more costly foundations (Westgate and DeJong, 2005; DOE, 2015). Minimizing the costs of foundations would aid in advancement of the offshore wind industry by lowering overall project costs, required initial capital expenditures (CAPEX), and the LCOE.

Geological, geophysical, and geotechnical investigations aid in the siting, type selection, and design of foundations (Feld, 2006). In this senior thesis, a desktop investigation of existing side-scan sonar data from the Maryland WEA was used to constrain the bottom sediment types and morphological features of the area. A comparison was made between two automated sediment classification techniques, specifically those found in the SonarWiz and ENVI software packages. Based on preliminary discussions with researchers familiar with the two software packages (DuVal, 2015, personal communication), ENVI has a user friendly interface that easily creates an accurate sediment distribution map while SonarWiz is capable of finely tuned and automated sediment classifications but is slightly more difficult to use. The procedures were compared based on accuracy, ease of use, and the time involved in data analysis. A standardized procedure for determining sediment and morphological distributions was developed to provide a model for analyses across the entire Mid-Atlantic Bight, specifically to be implemented prior to offshore wind project development. The results from this thesis project, when integrated with other

geophysical (e.g., sub-bottom profiling) and geotechnical (e.g., strength properties of sediments) data, can be used to provide constraints on the siting of potential wind projects and inform the selection of optimal foundation type for these projects.

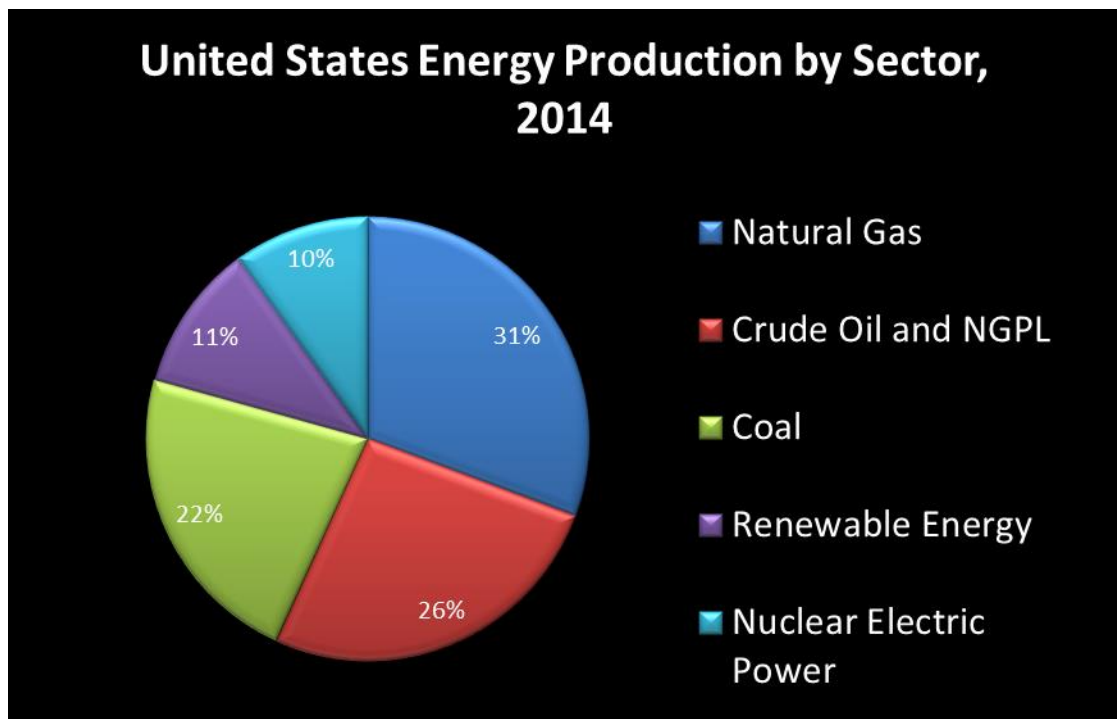


Figure 1 US energy production by sector, 2014 (EIA, 2015).

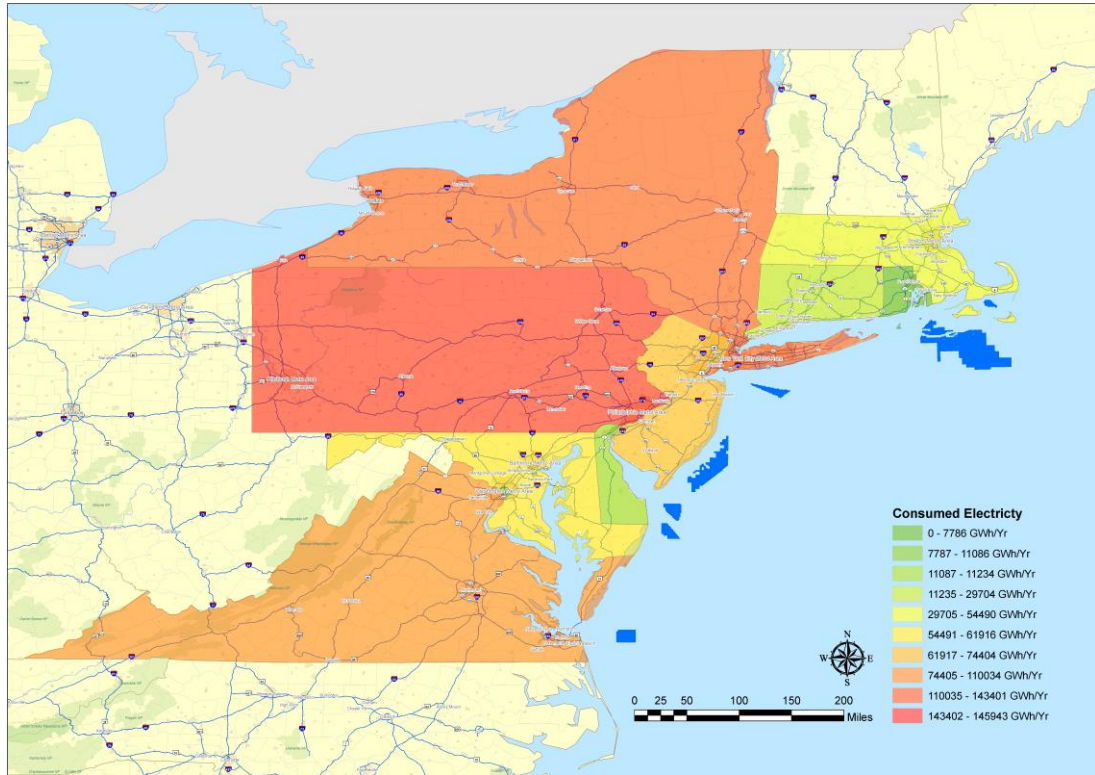


Figure 2 Map of electricity consumption by state bordering the Mid-Atlantic Bight. GIS shapefiles included in this map are from US Census, BOEM, and EIA databases. The offshore areas shown in blue are potential areas for offshore wind development (WEA's) as designated by BOEM, as well as, a New York state-designated area of interest off of Long Island and the Horseshoe Shoal Cape Wind project area in Nantucket Sound (Massachusetts).

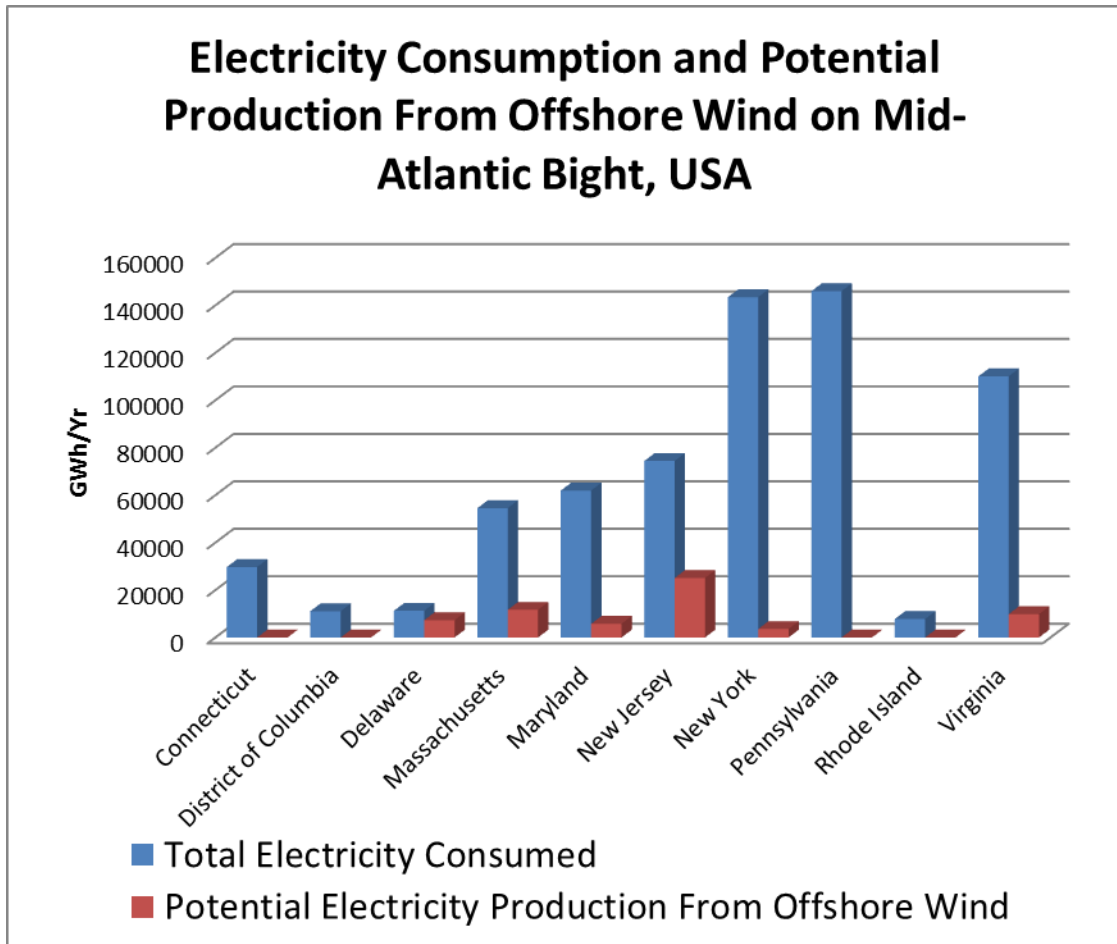


Figure 3      Energy consumption and potential production from offshore wind projects fully utilized in the WEA's along the Mid-Atlantic Bight.

## **Chapter 2**

### **METHODS**

#### **Data Acquisition**

The side-scan sonar data analyzed in this thesis were collected by Coastal Planning & Engineering, Inc., a CB&I Company, between July 4 and August 6, 2013 (Coastal Planning & Engineering, Inc., 2014). They used an EdgeTech 4200-HFL side-scan sonar system to collect the data (Coastal Planning & Engineering, Inc., 2014). This system consists of a towfish with 300/600 kHz dual simultaneous frequencies and a 4200-P Portable Topside Processor with EdgeTech's DISCOVER software. For georeferencing purposes, the towfish's position was recorded and coupled with USBL and C-Nav systems through Hypack navigation software (Coastal Planning & Engineering, Inc., 2014).

As summarized in the Coastal Planning & Engineering, Inc. report (2014), the Maryland WEA was surveyed by running North-South lines at approximately 150 meter spacing and East-West lines at approximately 900 meter spacing (Figure 4). The towfish recorded data in high definition mode which resulted in a 200 meter wide swath of data recovery (100 meters to starboard (right) and port (left) of the towfish). This provided an approximate 50 meter overlap of data coverage between adjacent North-South passes (Coastal Planning & Engineering, Inc., 2014).

## Maryland Wind Energy Area North-South Survey Trackline Map

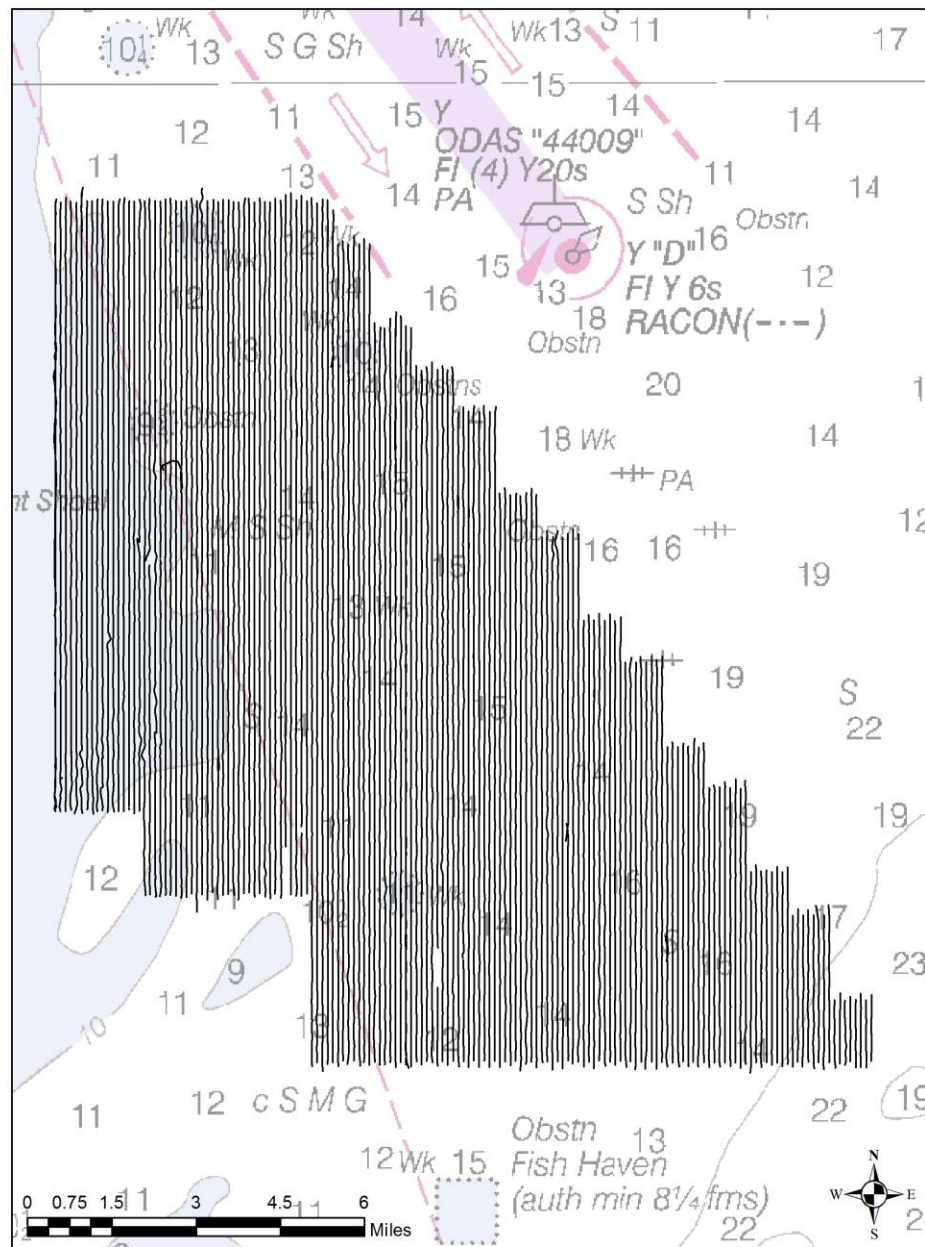


Figure 4 Track line map showing North-South lines collected by Coastal Planning & Engineering, Inc. in 2013 and used in the side-scan sonar processing and analyses in this thesis.



## **Data Processing**

The side-scan sonar data were processed using Chesapeake Technologies, Inc. SonarWiz software. A series of procedures were followed in the processing, that involved the following:

### **Data Import**

After starting a new project within SonarWiz and selecting the appropriate geographic projection (i.e., UTM 1983 18N), side-scan sonar files were brought into SonarWiz using the Import function under the post processing tab (Figure 5). Due to computer limitations, the entirety of the Maryland WEA was separated into adjacent groups of approximately 20-30 passes. These groupings were then further processed individually and joined together when completed.

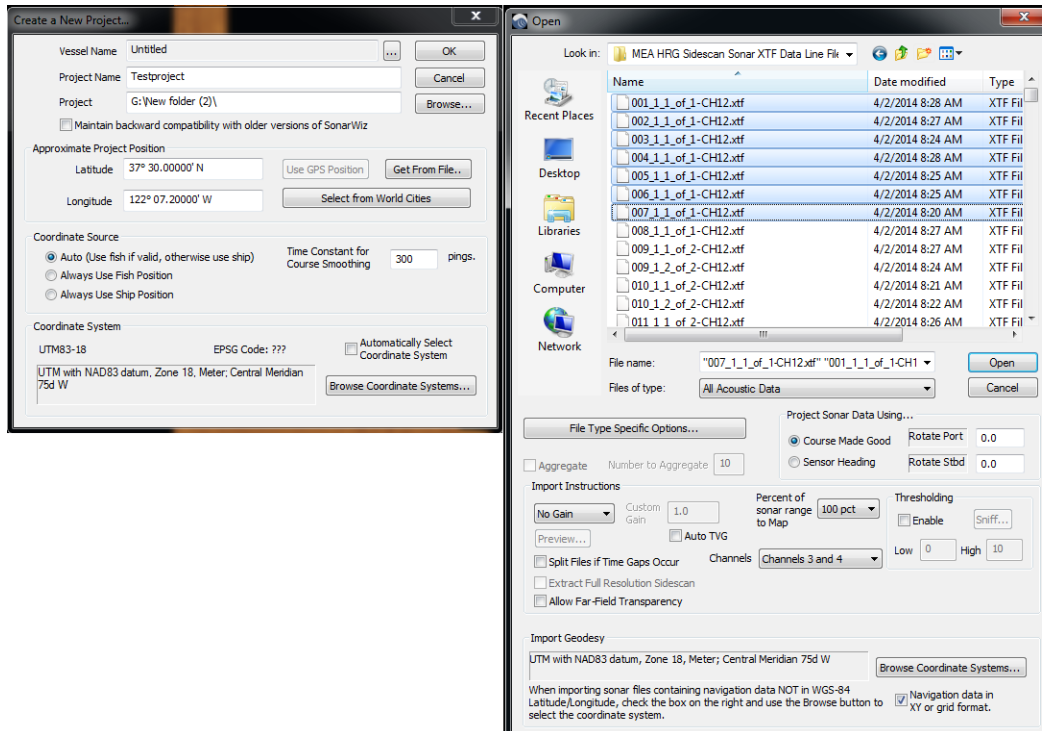


Figure 5 SonarWiz side-scan sonar import procedure: 1. Create new project, select folder to format and save changes in, and select projection. 2. Select desired files to import, preliminary gain adjustments (if necessary), desired frequency channels and projection.

## Bottom Track

After import into SonarWiz, the side-scan sonar files were processed using the bottom tracking function of SonarWiz. This function identifies the initial position of the bottom ensonified by the side-scan sonar towfish. By determining the proper distance from the towfish to the seabed on the port and starboard sides, bottom tracking allows for the geometric calculation of the position (latitude and longitude) of features (as represented by the sonar returns) on the seabed. SonarWiz has two methods for bottom tracking; automated and manual. Auto Tracking uses Blanking (the distance from directly below the towfish where SonarWiz will begin searching for

the initial bottom return), Duration (the number of continuous pings needed to identify the initial bottom return), and Threshold (compares the amplitude of bottom returns to a median value to identify highly probable initial bottom locations) parameters selected by the user to automatically determine the initial position of the seabed. Manual Tracking involves using visual inspection and “clicking” points to identify the initial position of the seabed along a side-scan sonar profile. In the side-scan sonar processing, Auto Tracking was always applied first, then, if during visual inspection, Auto Tracking did not “find” the appropriate bottom location, Manual Tracking was used. Figure 6 shows a representative side-scan sonar file before bottom tracking was applied. Figure 7 shows the use of Auto Tracking to identify the initial bottom return. Figure 8 illustrates the Manual Tracking procedure.

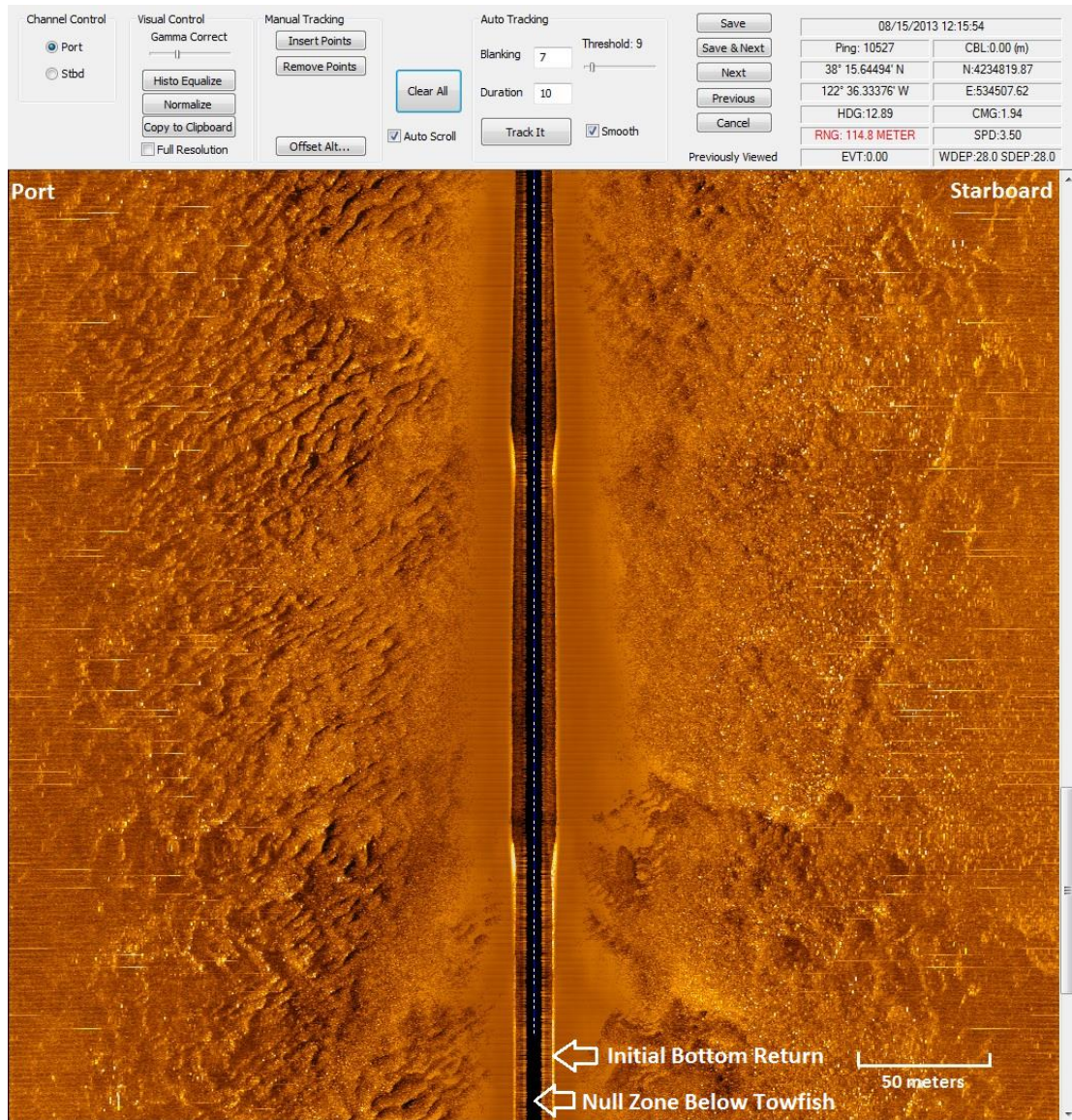


Figure 6 Example side-scan sonar image prior to bottom tracking.



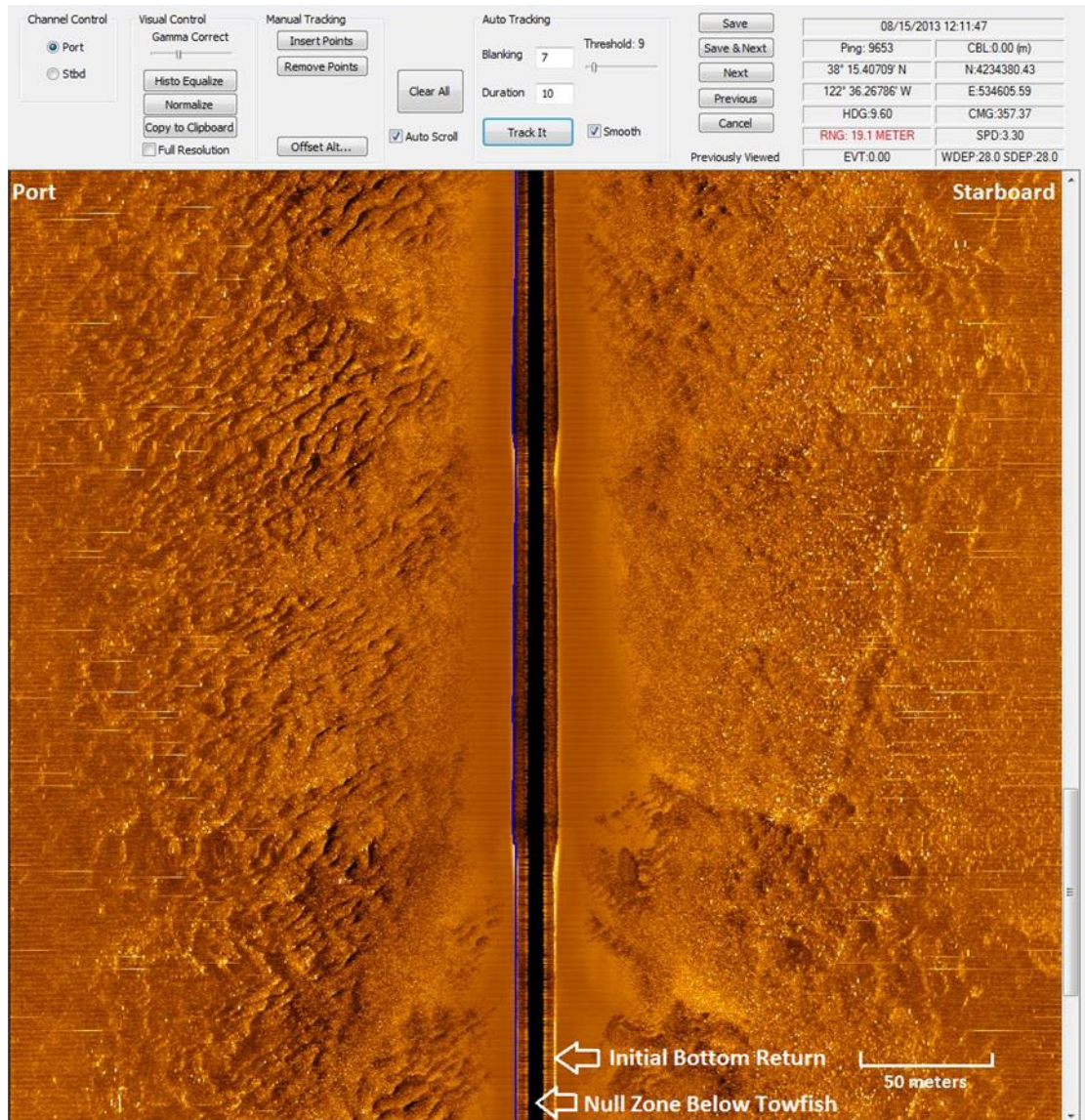


Figure 7 Example of applying Auto Tracking function in SonarWiz. Blue line identifies bottom track location as determined by this function. Note in this example as shown along the top of the image, Blanking was set to 7 meters, Duration was set to 10 pings, and Threshold was set to 9 (dimensionless value).

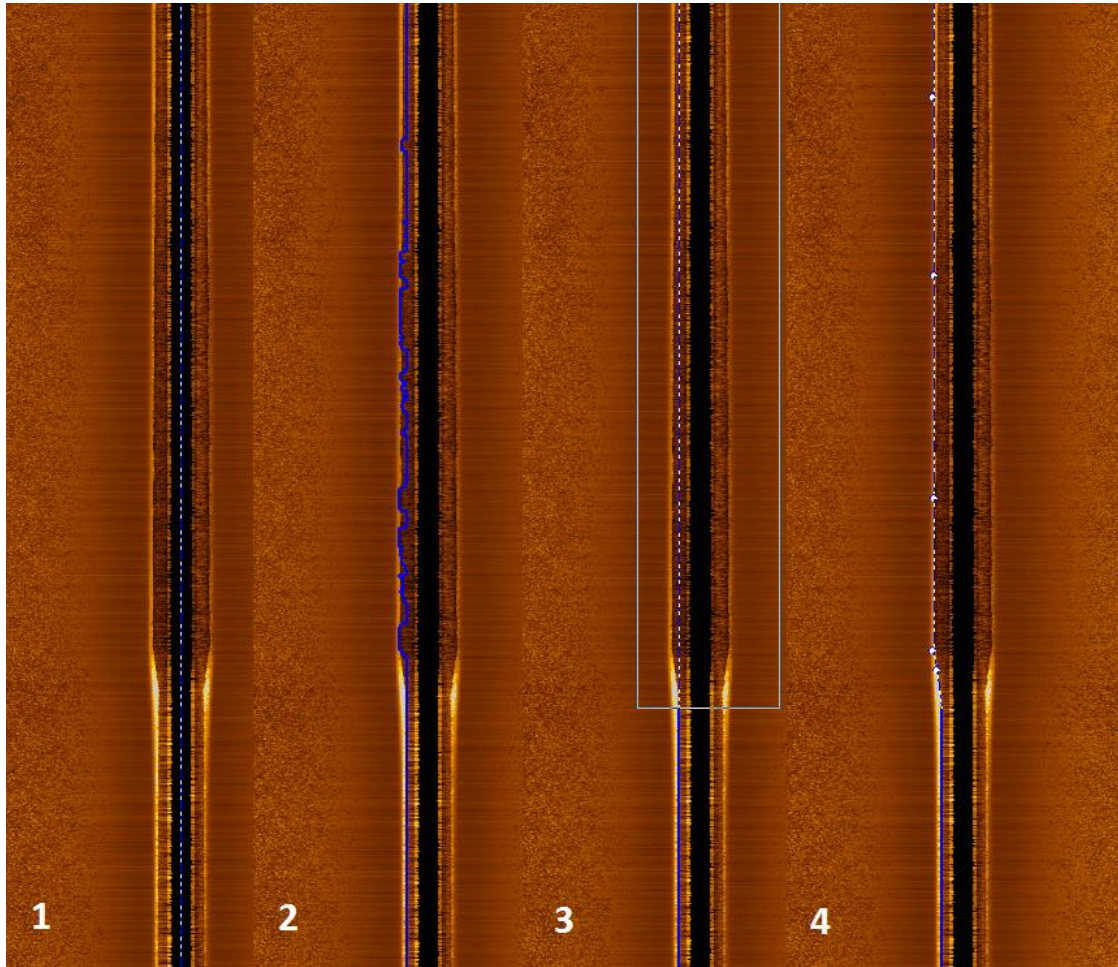


Figure 8 Example of application of Manual Tracking function in SonarWiz: 1. Baseline data before any bottom tracking has been applied. 2. Auto Tracking feature does not accurately capture the seabed's location. 3. Rectangle was drawn around the problem area using the right mouse button, erasing that section. 4. Appropriate location of the seabed was inserted where necessary by using the left mouse button.

### Identifying and Digitizing Bottom Features

This process of identifying and digitizing bottom features in SonarWiz is similar to the Manual Tracking procedure described earlier. Based on changes in

reflection intensity, it is determined if heterogeneous sediments, morphological features, or obstructions are present, and then digitized.

Sediment and morphological features were classified using the same procedure. First, a file must be selected, and then the Digitizing View function opened (Post Processing -> Sonar File Processing -> Digitizing View). Figure 9 depicts a typical view of the Maryland WEA seabed in Digitizing View while Figure 10 shows how this file would be classified using the “Insert Polyline or Polygon” feature in Digitizing View. Similarly, the sand ripples beside the outlined sediment would be classified based on their morphology being unique from the surrounding sediments.

If an obstruction was found on the seabed, it was named and then marked using the “Capture Contact Feature” function in Digitizing View. Figure 11 illustrates an obstruction found on the sea bed as well as the process of marking its location and naming it.



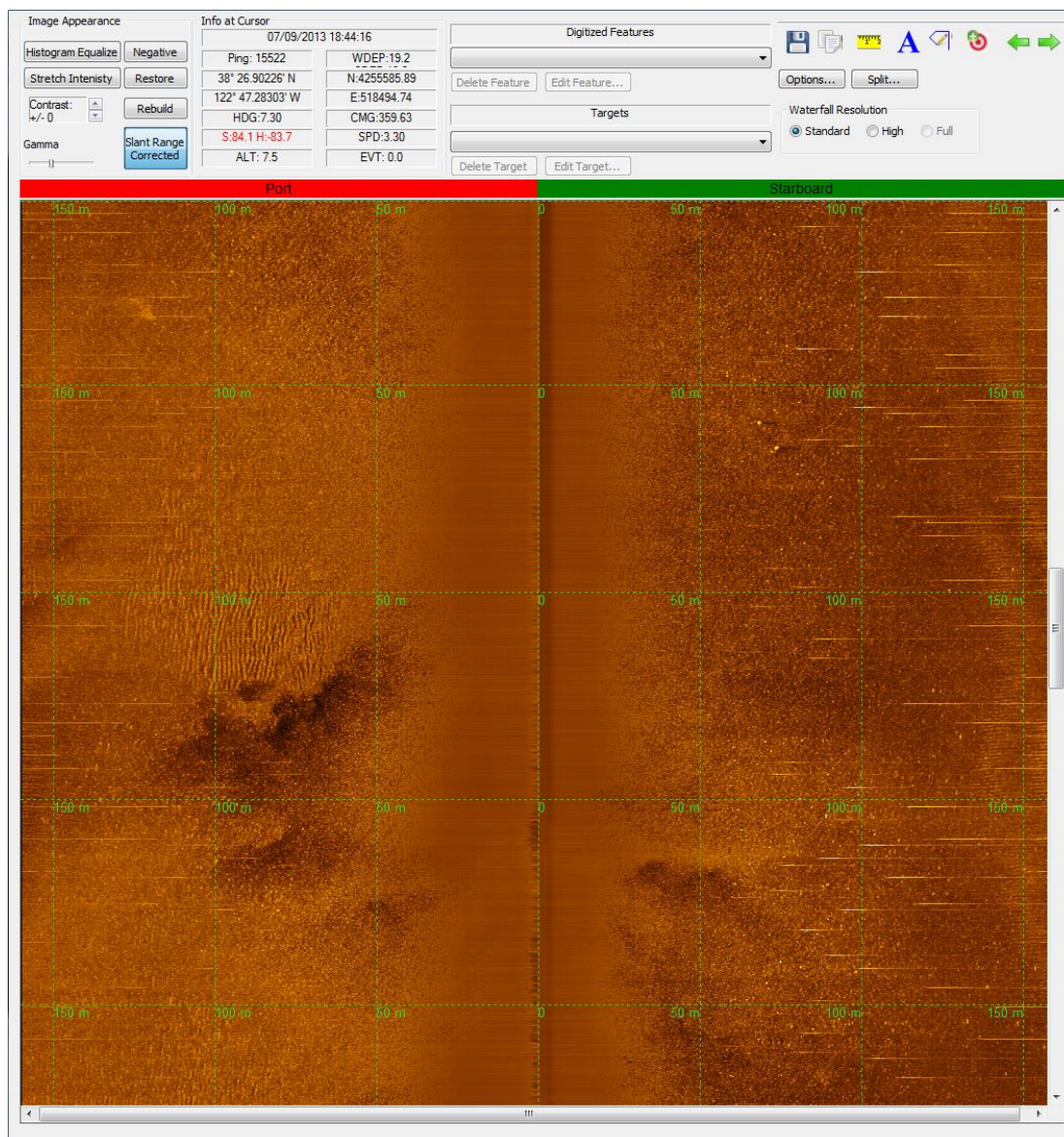


Figure 9 Initial image of Digitizing View.



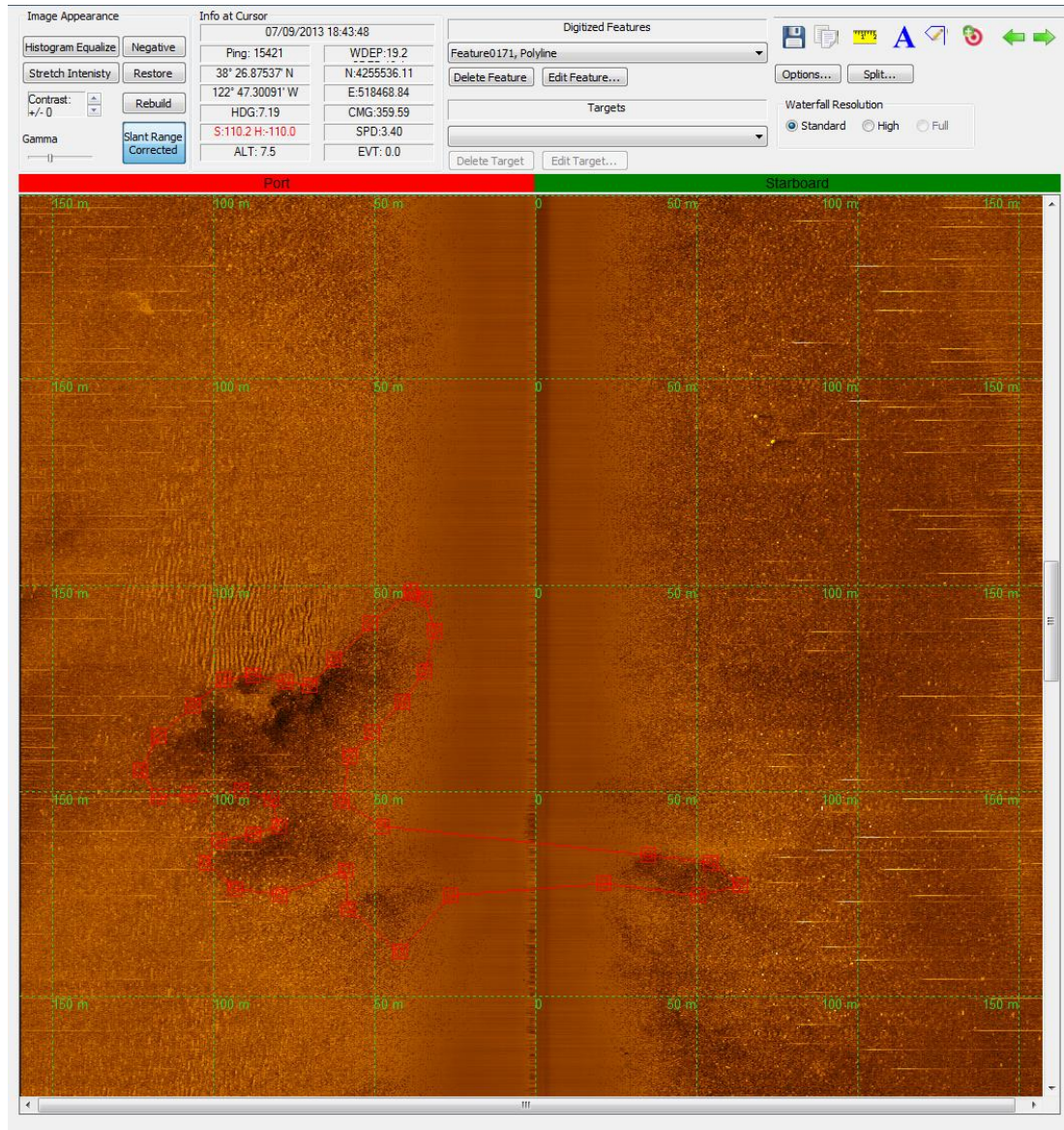


Figure 10 Digitizing view after using the “Insert Polyline or Polygon” feature (top of the window, fourth button from the right) to manually distinguish between different sediment types based on reflection intensity.



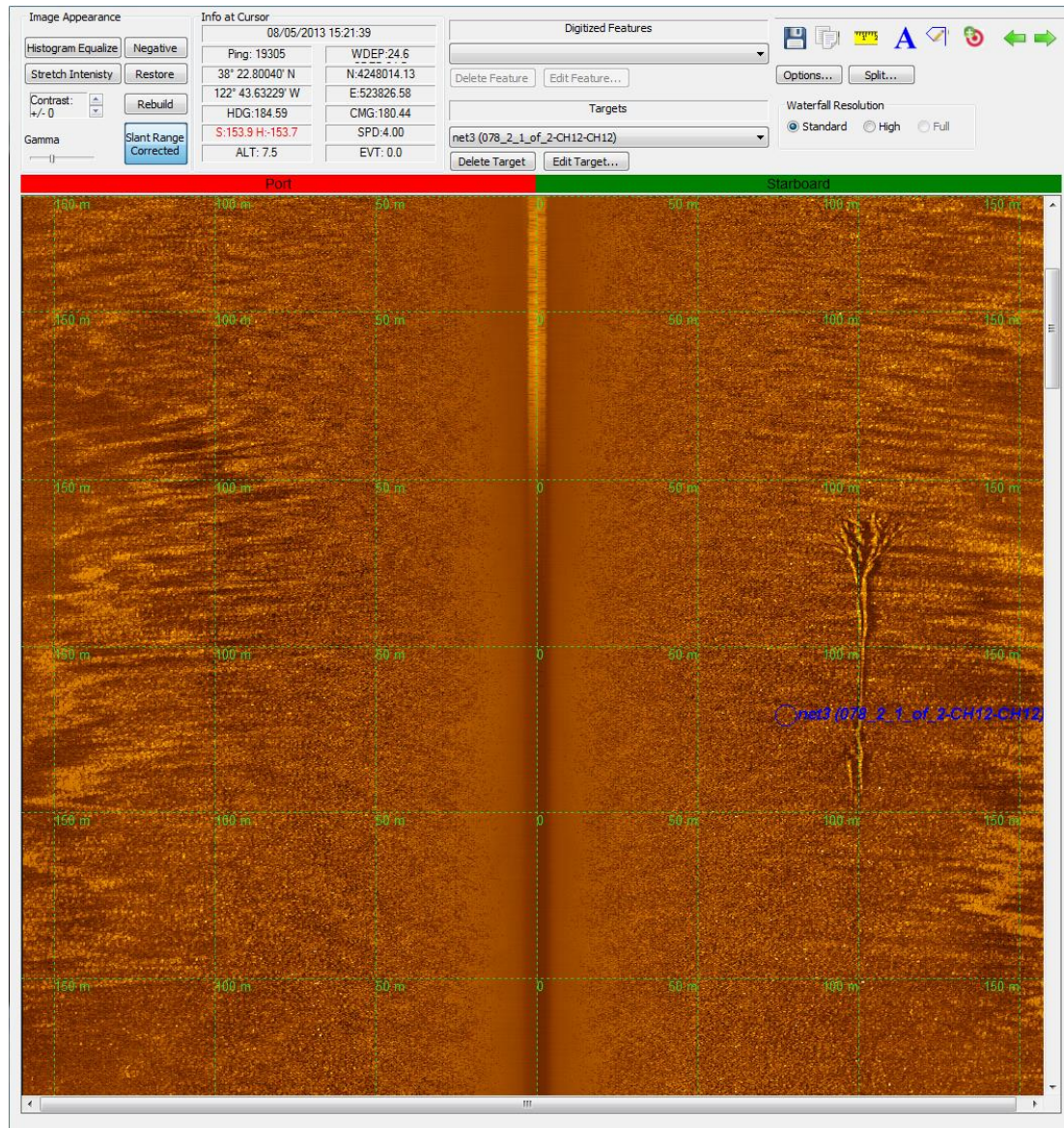


Figure 11 Typical “Capture Contact Feature” identification in digitizing view.

### ERDAS IMAGINE (.img) Base Map

A full scale Maryland WEA image map was made and used as a basis for the sediment classification techniques. To make this map, the Empirical Gain Normalization (EGN) function in SonarWiz was applied to each mosaic to raise

contrast levels and aid in identifying varying reflection intensities. The next step involved placing each project's side-scan sonar mosaic (consisting of about 30 complete and parallel track lines per project) into "average" view. This view calculates the value of each overlapping layer at a single point and outputs a final map that displays the mean value at each pixel. Two other view methods are available in SonarWiz: shine through and cover up. "Shine through" determines the value of each overlapping layer at a single point and outputs a final map that displays the sum at each pixel, while the "cover up" view treats each individual file as a layer. It begins from one side of the project, and builds an overlapped map where only sections that are not covered by the adjacent file are displayed (Figure 12).

"Average" view was chosen because it did not "smooth over" areas as in "shine through" or completely erases data as in "cover up". It produced a well-balanced map that retained contrast while not eliminating prominent features. The final post processing step involved reducing port/ starboard gain inconsistencies. After selecting the affected file, the file manager was used to access its gain settings. The port/starboard gains were desynced, then the starboard (almost all affected files in the project occurred on the starboard side) gain was adjusted so that inconsistencies between the port and starboard sides were resolved. Figure 13 illustrates an affected file before and after adjustment. The map was then converted into an ERDAS IMAGINE image file with 1 m/pixel resolution. The images were formatted so that their backgrounds displayed "NoData" and merged with their neighboring projects in GIS so that a full scale, surficial reflection intensity map was created.

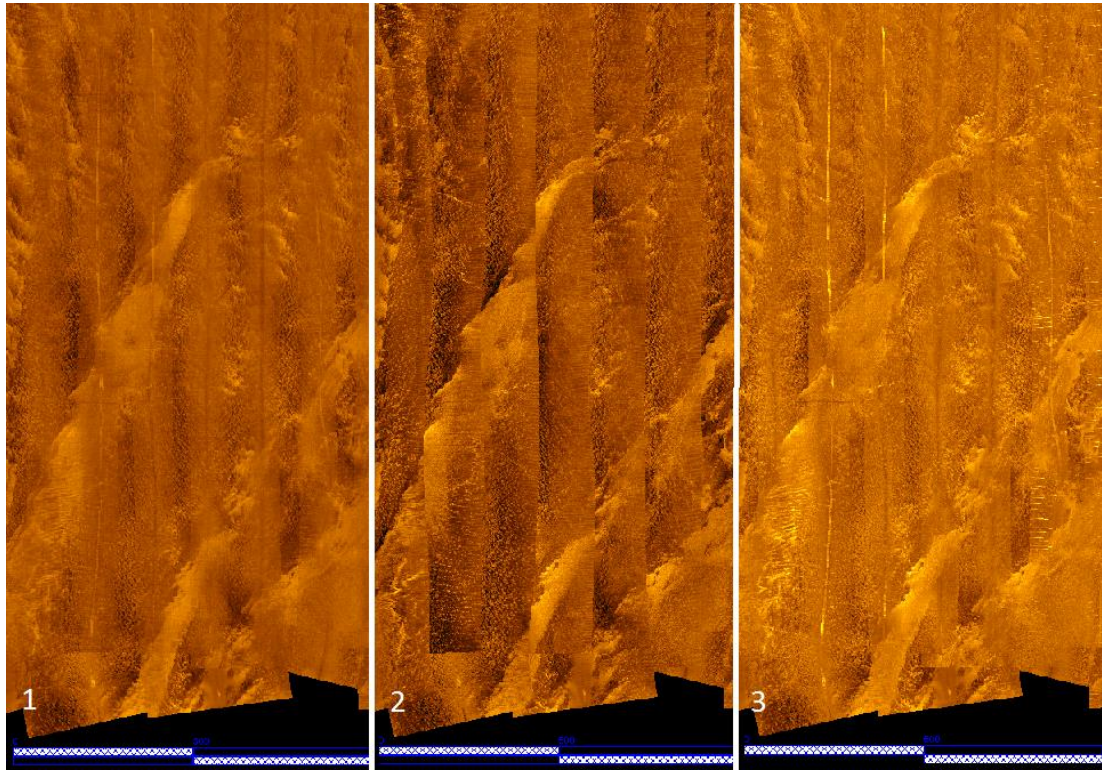


Figure 12 Illustrating the differences between “average” (1), “cover up” (2), and “shine through” (3) mosaic views after EGN has been applied.



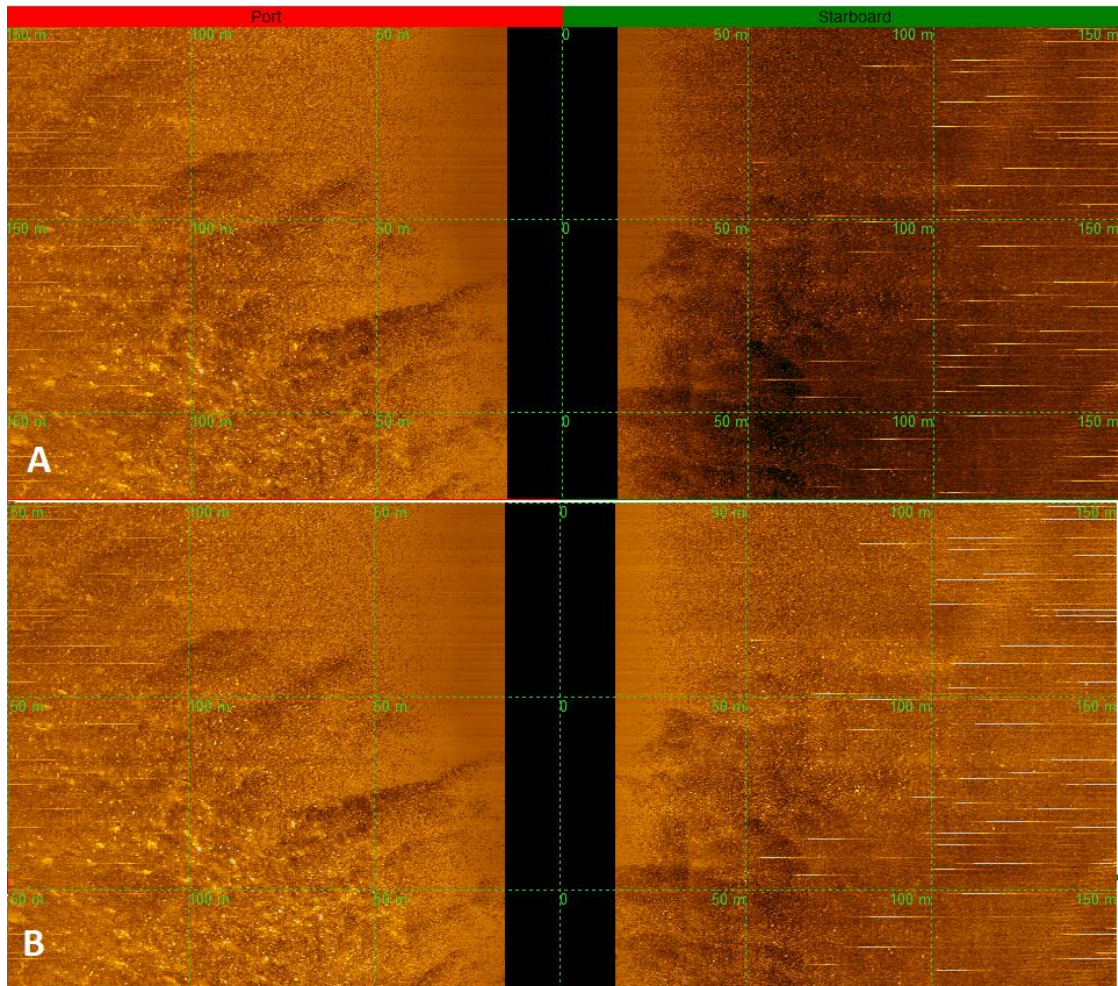


Figure 13 Adjusting port/starboard gain inconsistencies on affected profiles. A. before adjustments. B. after adjustments

### User Defined Sediment and Morphological Classification

After each side-scan sonar file was processed in the digitizing view procedure, the process of forming “hand drawn” maps began. The polylines that were drawn to signify sediment and morphological boundaries and features were then exported as GIS-formatted shape files. Both the ERDAS IMAGINE base map and the shape files

were then imported into GIS to view the Maryland WEA in its entirety (Figures 14 and 15).

Figure 14 shows the irregularities that arise when performing this type of analysis at such a high resolution. In order to fix these inconsistencies, a second map was drawn in GIS using the base map and the polyline shape files as references (Figure 15). Viewing the reflections at a larger scale makes identification between track lines easier and more laterally consistent though some resolution is lost. Figure 15 shows an example of the revised “hand drawn” sediment classification map. After the boundaries were classified, each distinct sediment and morphological section was assigned a color and two complete maps were created.

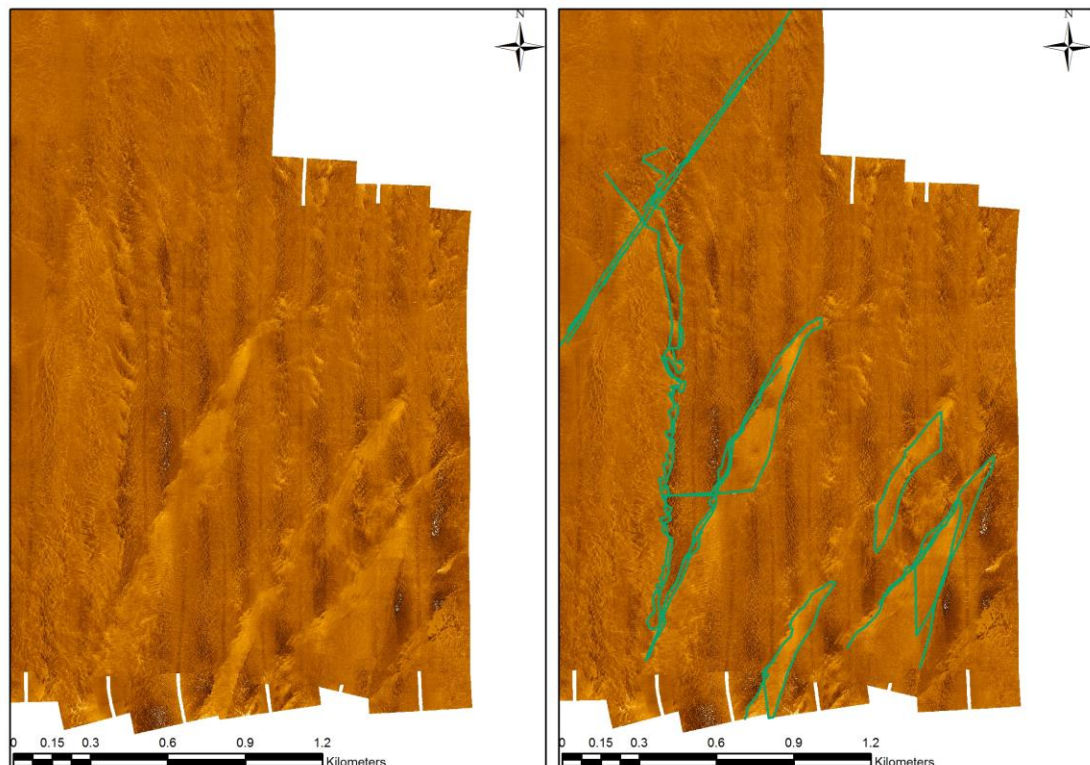


Figure 14 Base map comparison to unedited user defined reflection classification.

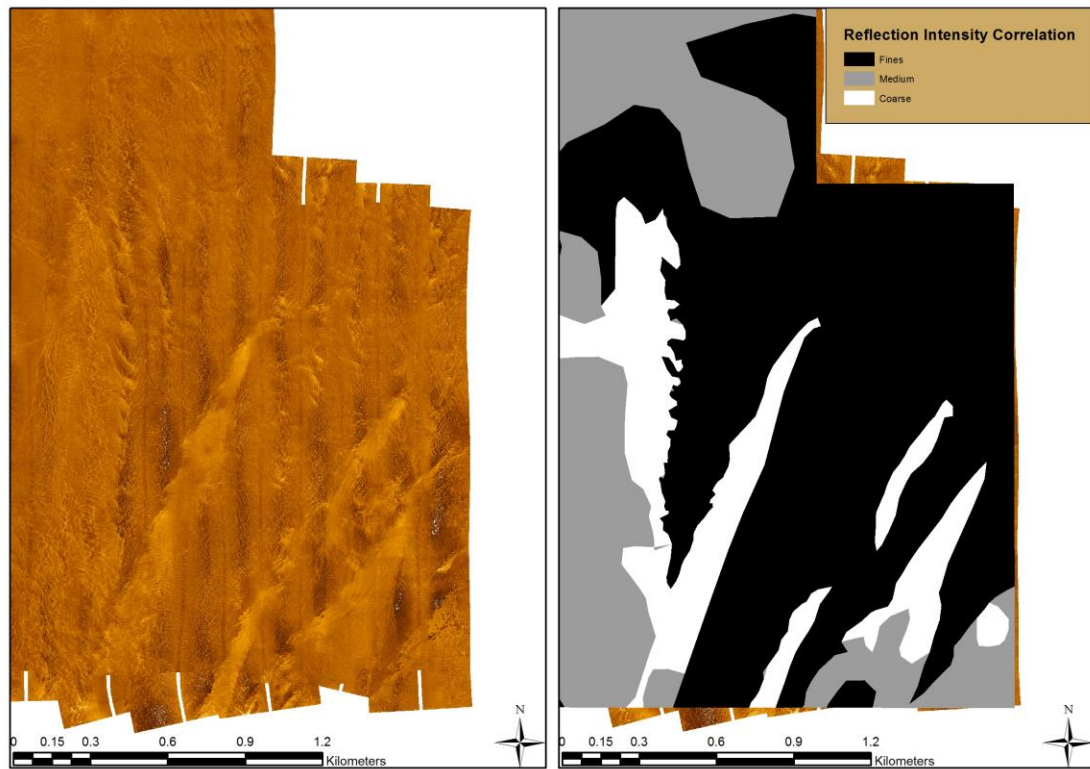


Figure 15 Revised base map and user defined reflection classification.

### Automated Bottom Classification

The SonarWiz sediment classification function builds an average range of values displayed by the side-scan sonar files. This range is grouped based on user defined variables including: number of categories (3), nadir and far range trim percentages (5% and 5%), window size (19), window step (15), and a single or combination of statistical analysis (Custom Selection 2). The groupings are displayed in different colors over the side-scan mosaic in two different versions: the first is the direct output from the classification function, and the second takes the direct output

and runs it through a filter algorithm that eliminates noise and generally “cleans” the image. The final filtered maps were then exported into GIS for final cartographic additions (Figure 16).

Figure 16 SonarWiz reflection classification (direct output (middle) and filtered (left)) side-by-side with side-scan sonar mosaic (right).

The ENVI sediment classification procedure uses the same ERDAS IMAGINE base map as that utilized with the User Defined classification. The “Classification Workflow” procedure which is found in the ENVI toolbox under Classification > Supervised Classification > Classification Workflow was used. First, the base map was selected, followed by selecting data to train where four classes were chosen: with three of the classes representing a different sediment type and one representing “NoData” areas. The values that correspond to each class were selected using a polygon creator tool where polygons were drawn around each reflection intensity. After multiple examples of each sediment type were chosen (Figure 17), the minimum distance algorithm was used to correlate between cells.

Using the range of pixel values defined inside each polygon, ENVI processed the base map and categorized local pixel clusters based on how well they fit into each sediment class grouping. The initial output contains noise and “sharp” edges between the different sediment types. A smoothing function is available in ENVI where kernel and aggregation size are variables that determine the amount of noise that can be eliminated. Figure 18 illustrates the difference between base map and the smoothed



output. To optimize resolution and correct sediment interpretation while minimizing vertical “streaking” between adjacent track lines, a 19 cell kernel size and 40 cell minimum aggregate size was used.

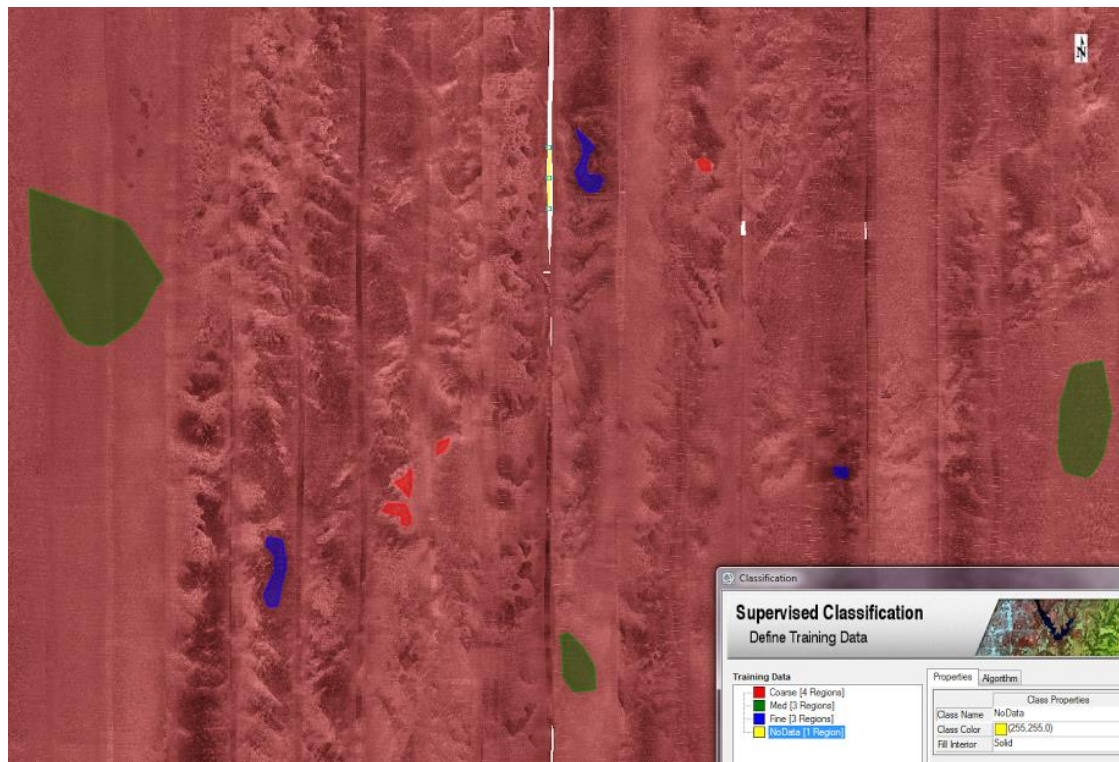


Figure 17 Illustrating reflection classification polygons in ENVI.

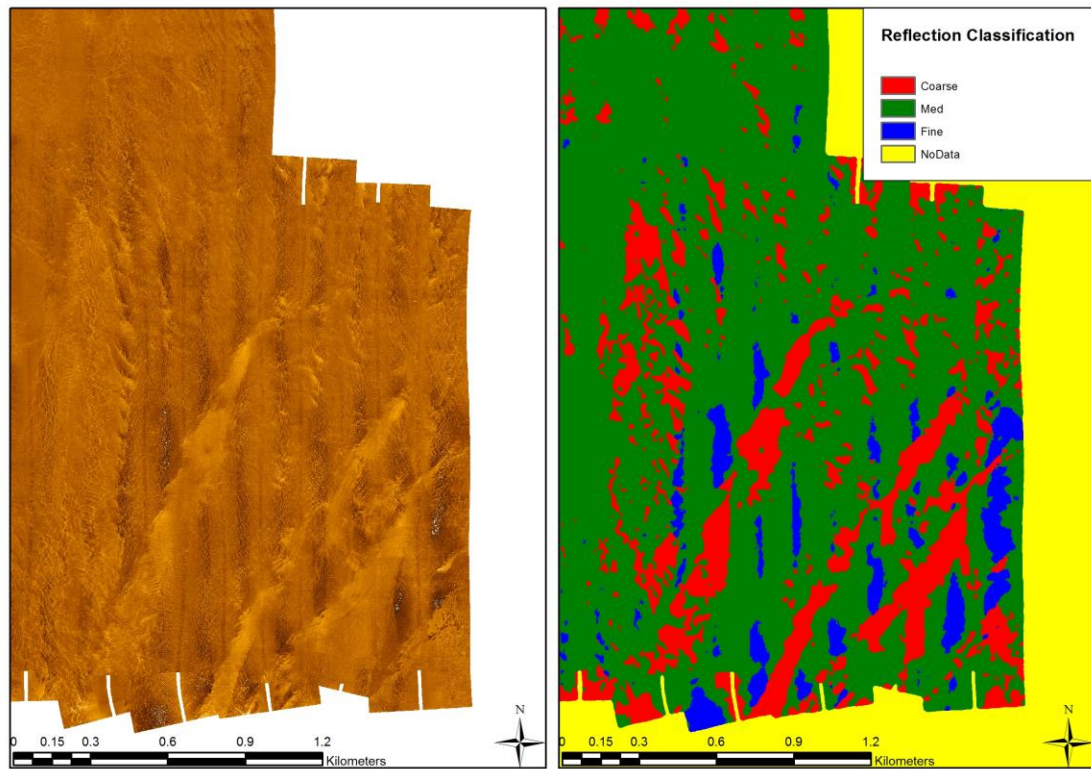


Figure 18 ENVI reflection classification comparison. Right is the base map, and left is the smoothed output.

## **Chapter 3**

### **RESULTS**

#### **Geologic Analysis**

The geophysical survey that collected the data used in this thesis did not also obtain “ground truth” sediment samples. No previous sediment samples were found inside of the Maryland WEA in a review of related literature, although there were historical geophysical and sediment samples found in the general region. To properly determine surficial sediment types without ground truth data, indirect analyses were performed. First, regional offshore geologic and geophysical studies were correlated and compared to the data found in the Maryland WEA. Then surficial and subsurface bed forms and bedding features identified within the Maryland WEA were characterized which allowed the grain size to be inferred.

#### **Literature Review**

Three regional studies offshore Delaware and northern Maryland’s inner shelf were used as geologic and geophysical references. Toscano (1989), Duval (2014), and Metz (2015) conducted studies examining the geophysical and grain size characteristics to the southwest and north of the Maryland WEA.

Toscano (1989) demonstrated that three distinct formations were outcropping southwest of the Maryland WEA; Q2, Q4, and Q5. The Q2 formation was deposited in a barrier marsh environment and consists of dark green grey dewatered silty clay with some sand laminae. The Q4 formation represents a transgressive tidal-stream or an estuarial depositional setting while containing muds overlain with sand and areas of fluvial gravels and light blue grey muddy sands. The Q5 formation represents

Holocene sand ridges typical of transgression induced shoal detachment (Toscano, 1989).

DuVal (2014) correlated side-scan sonar reflections to grab samples at the Redbird Reef site approximately 40 km north of the MWEA. That study found that muds, muddy sands, and clean sands with patches of gravel were related to dark, medium, and bright side-scan sonar reflection intensities, respectively. Metz (2015) identified the same subsurface formations as Toscano (1989) within the Redbird Reef site. These studies provided a basis for correlating grain sizes to side-scan sonar images in the Maryland WEA and surrounding region.

Duval (2014) and Metz (2015) confirmed that the sediments described by Toscano (1989) southwest of the Maryland WEA are very similar to those found north of the Maryland WEA both at the surface and in the sub-surface. Assuming formation continuity, the same sediments should be present in the Maryland WEA.

#### Bedform and Subsurface Analyses

Examining the surficial mosaic allowed large scale dunes and shore parallel features to be identified while examining individual side-scan sonar files allowed smaller scale bed forms to be identified. Figure 19 illustrates examples of each bed form as they were found in the Maryland WEA. In addition, Figure 19 (small scale) shows a prime example of where Toscano's (1989) stratigraphic sequence can be observed. The Q2 basal muds can be seen as dark reflections, which are directly overlain by Q5 Holocene sands while the northern and southern regions are typical of the Q4 muddy sand formation. Figure 19 also shows large continuous shore parallel ridge/depression sequences with an approximate 3 km wavelength.

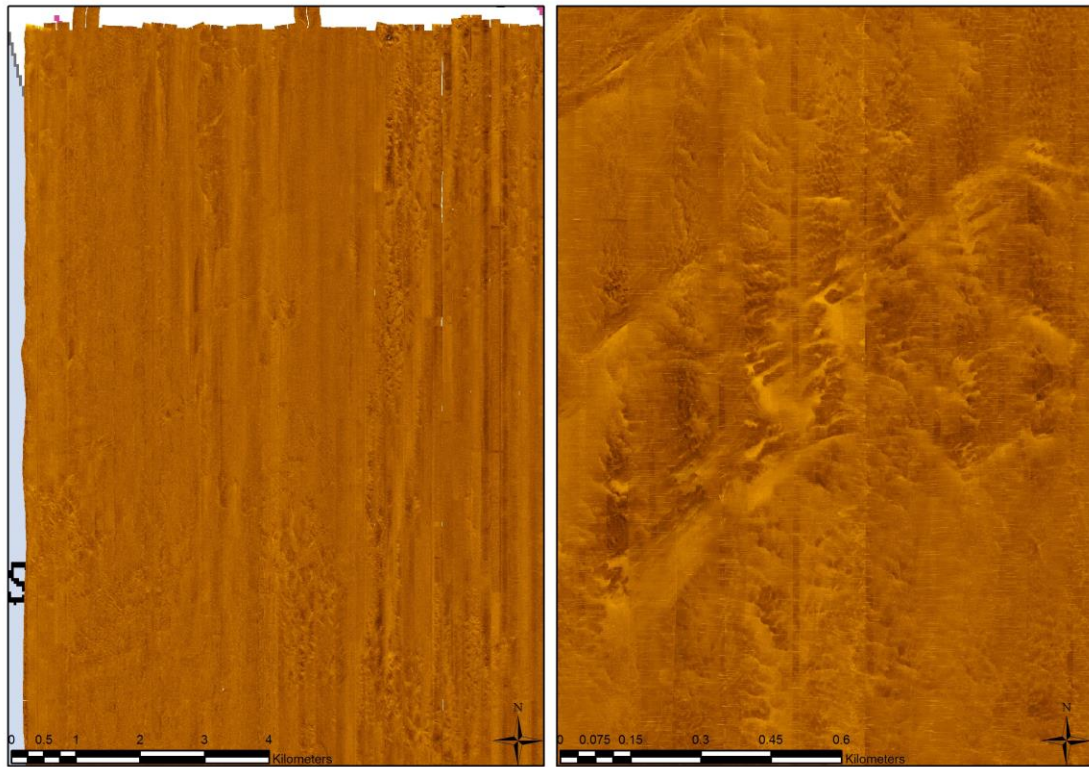


Figure 19 Illustrating large scale shore parallel ridges (left) and small scale shoreline oblique bed forms (right).

### **Presentation of Maps of Selected Areas**

Figure 20 shows the full scale Maryland WEA side-scan sonar mosaic. Figure 21 shows the user defined reflection classification, while Figure 22 shows the ENVI defined user classification. Due to computer issues, a full scale SonarWiz generated map could not be produced although a small sample area was provided in Figure 23.



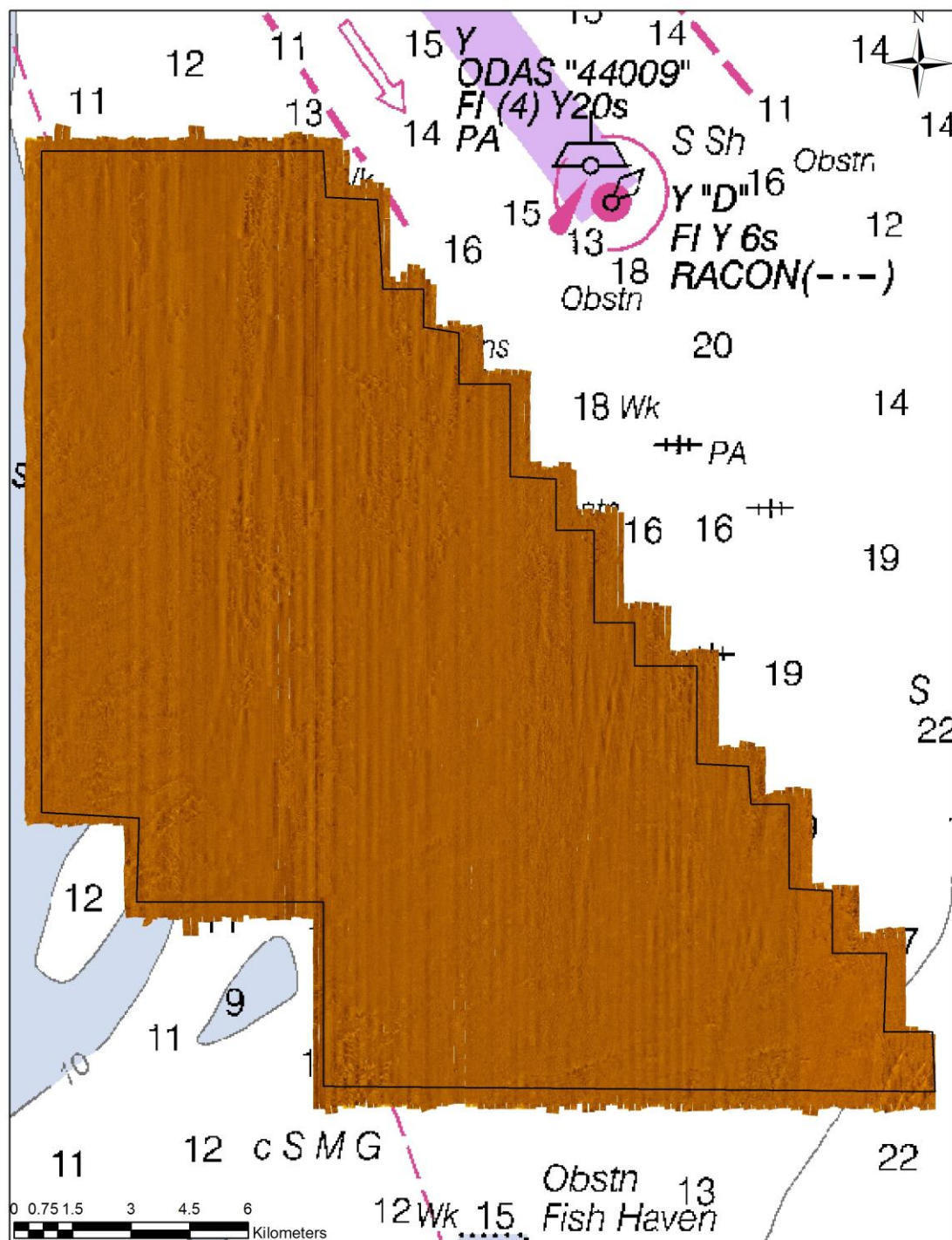


Figure 20 Side-scan sonar mosaic base map (.img).

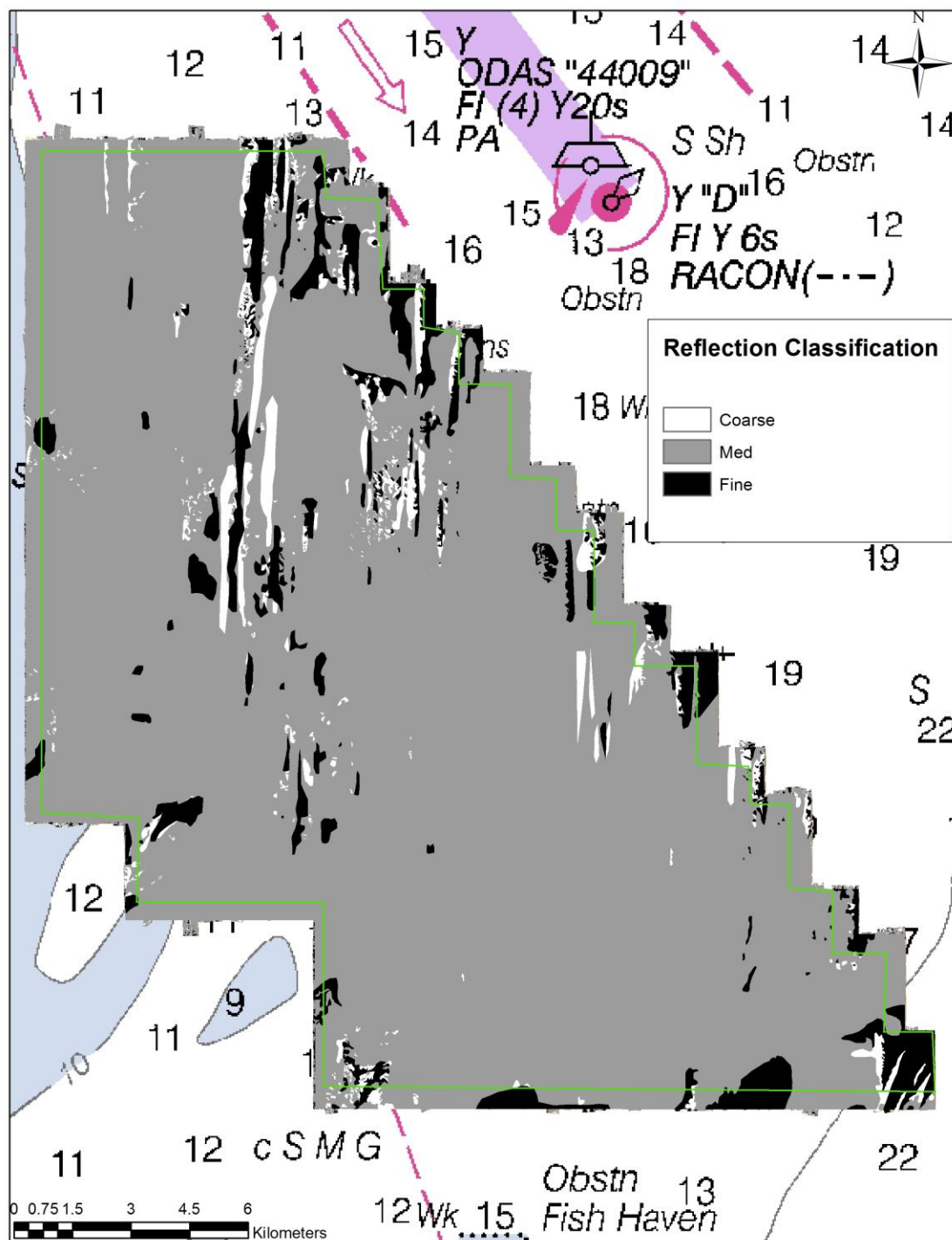


Figure 21 User defined sediment classification.

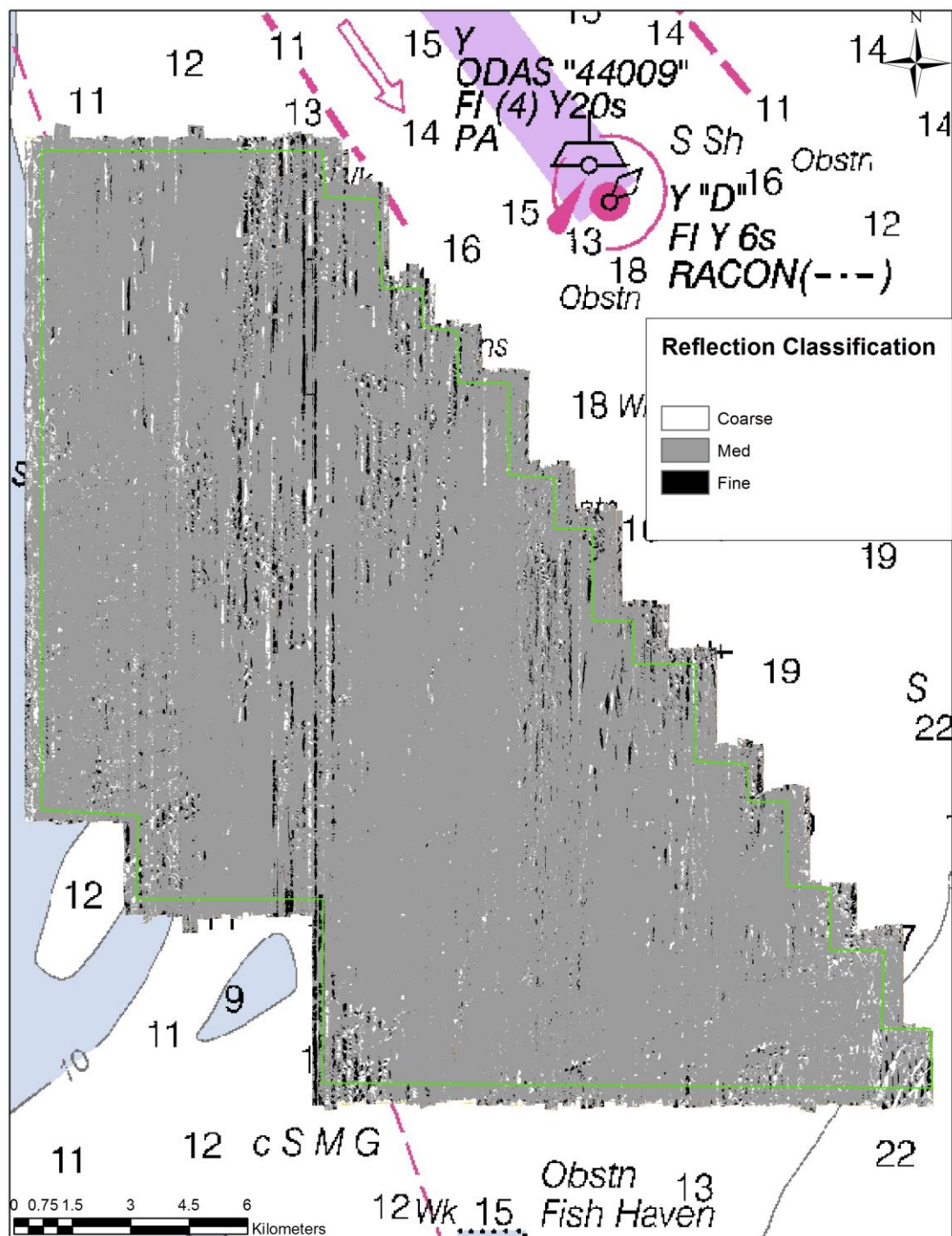


Figure 22 ENVI sediment classification.



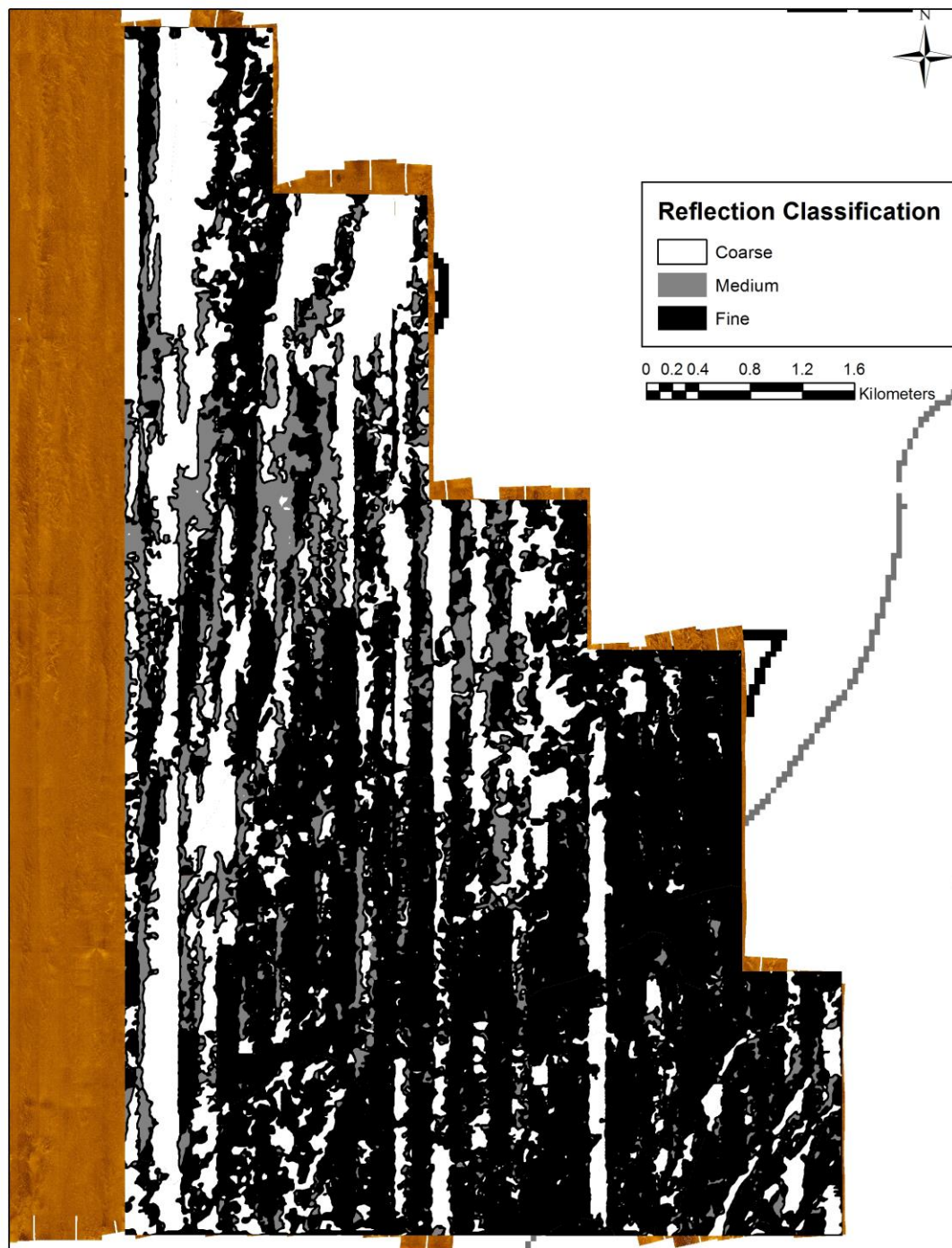


Figure 23 Partial SonarWIZ sediment classification.

## Analysis and Implications

### Sediment Classification Methodology Comparison

#### Accuracy

To properly determine the user-defined, ENVI, and SonarWIZ sediment classification's accuracy, each result should be compared to the actual sediment distribution. Since the actual sediment distribution was not available with the existing data, each classification result was compared to the others by measuring the difference in classification between the three methods. An example of the general formula used was:

$$\text{Diff. Analysis} = \sqrt{\frac{(\text{SW} - \text{ENVI})^2 + (\text{ENVI} - \text{SW})^2}{2}}$$

which is similar to a root mean squared error. Figure 24 shows the difference analysis results on a section of the eastern portion of the Maryland WEA. The red polygons indicate where maps disagree while the black polygons indicate agreement: the ENVI and User map differed by 20.5%, the SonarWiz and User map differed by 22.6% and the SonarWiz and ENVI map differed by 12.8% of the total area classified.

Intuitively it would be expected that the user defined map would have had the highest accuracy but, when comparing the three results, both comparisons of ENVI and SonarWiz sediment classification with the user map had higher disagreements

(20.5% and 22.6%) while comparing the two automated methods resulted in closer agreement (difference of 12.8%).

These unexpected results can be attributed to two main issues. First, the ENVI and SonarWiz automated classification systems are unable to look at the “big picture”. Their viewing windows are a maximum of 40 pixels, so they are limited in their scope. Making the viewing window’s size larger, say to 500 pixels, will increase their ability to identify large scale features, but will also drastically increase computing time and generalize all finer-scale details within the window. Secondly, the automated classification methods results are intrinsically linked to the quality of the initial data (and base map). These data sets, and thus the automated results, are hindered by limited overlap, system interference, port/starboard gain inconsistencies, and the lack of available time to fix these issues. These problems are mostly results created during the data acquisition phase, and are difficult and/or time consuming to rectify during post-processing.

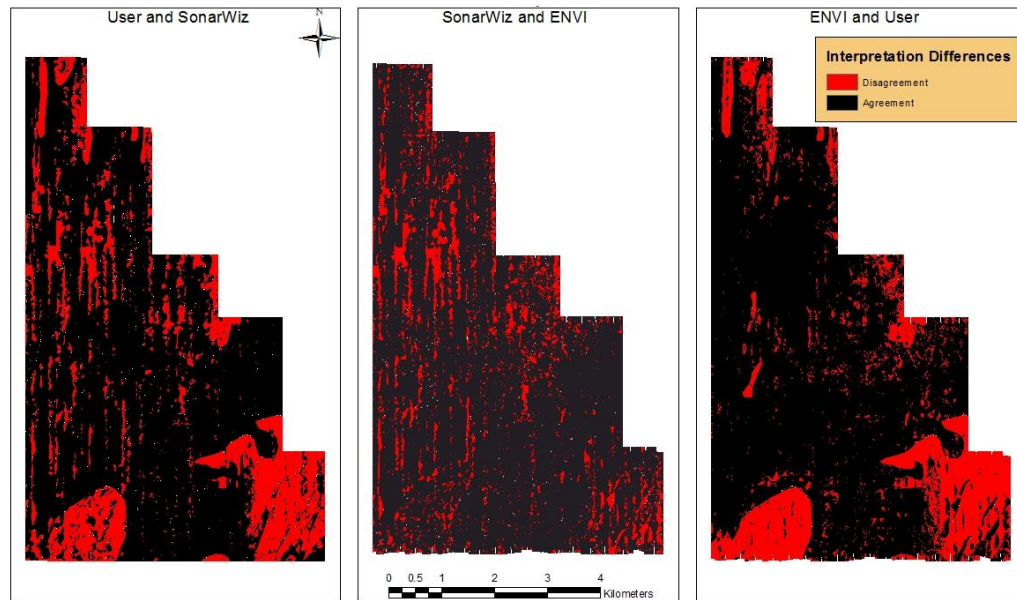


Figure 24 Difference analysis results illustrating areas of agreement and disagreement between each classification result.

### Ease of Use

After the .img base map was created, each methodology was compared based on its ease of use to produce a quality map. This was a user-subjective analysis and will vary slightly for different users based on their individual experience with the software employed and their geologic knowledge. As such, the following review is from the perspective of a user with little to intermediate experience using these software packages.

The user generate map was the easiest to create. Using a polygon creator in GIS software to create shapes around sediment types is as simple as outlining boundaries with a mouse. There is very little learning curve with this type of analysis. Slightly more difficult to use is ENVI. In addition to creating polygons, there are statistical analyses that must be selected from but they are very simple and well

defined in the user manual. The most difficult to use is SonarWiz because the only method of attaining useable results is through trial and error. This process takes hours to complete and can be very frustrating when, after hours of trials, no useable results have been produced.

### **Time Involved in Analysis**

After the .img base map was created, the time involved to produce an acceptable map was compared. It was also a subjective analysis and will vary slightly for different users based on their individual experience with the software and geologic knowledge. The following review is from the perspective of a user with little to intermediate experience using these software packages. It will also compare relative time involvement, instead of actual time to complete, so that the appropriate procedure may be applied future projects.

The ENVI generated map required the least time investment. The most time consuming aspect of this method was waiting for computer processes to run, both user and SonarWiz methods took much longer to complete. User required a large time investment to first process the "clean up" of the initial polyline output, and then an even longer period to create the new polygons; although the actual sediment analysis procedure was the quickest of the three methods. SonarWiz has similar computing limitations; processing and exporting require a large time investment. The necessity of trial and error methodology is, by far, the most time consuming aspect of any process described. Both the user generated map and ENVI map, in their entirety, were able to be produced in a shorter time frame than the final SonarWiz map.

## Sediment Classification Methodology Recommendation

When choosing a sediment classification methodology, individual projects must be evaluated independently based on the project's size, the user's available time commitment, and accessibility to software. As such, an idealized sediment classification procedure for WEA-sized projects will be proposed in detail which will limit time involvement, limit human error, and assume access to SonarWiz, ENVI, and GIS. Other procedures will also be discussed briefly where the initial variables are changed.

The idealized method is as follows: First, SonarWiz should be used solely as a sonar processing application with the goal of removing track line parallel striping. To do this, the user must apply overall gain adjustments to raise contrast levels, adjust to correct for individual port and starboard gain inconsistencies, and apply nadir transparency. Then the final project areas should be exported as .img files. Secondly, the base map mosaic must be created. To ease in processing large project areas, small sections should be created in individual projects. These individual projects should be imported into GIS where the side-scan mosaics can be isolated from their backgrounds, then merged using raster manipulation functions. Thirdly, the mosaic base map should be imported into ENVI for sediment classification. Based on recent sediment samples and historical studies of the project area and surrounding region, polygons should be chosen that are representative of the side-scan sonar reflection intensities correlating to grain size. The kernel and aggregation functions in ENVI should then be applied to remove "salt and peppering". Fourthly, the individual shape files for each classification type should be exported into GIS and laid over the base map. An experienced geophysicist should then examine each shape file for misinterpreted areas by switching between the classification shape file and base map.

Any improperly classified areas should be remedied using a GIS editor feature to create polygons. The final map should then be created using the cartographic features found in the GIS software.

A small project area can be defined as a region where it is not economically prohibitive (both in terms of cost and time) to process the data in detail. For such a project, SonarWiz, as a classification tool, becomes a viable alternative. The trial and error methodology is not eliminated, but computer limitations become more manageable and less time is consumed. ENVI and manual (user) definition would also receive the same performance increases with a smaller area size. As such, the ideal methodology could still be applicable to small study areas. The main advantage to using SonarWiz is its ability to process different types of geophysical data (e.g., side-scan sonar, sub bottom, magnetometer) resulting in an “all-in-one” software solution.

### **Conclusions**

In this senior thesis project, a side-scan sonar data set collected as part of a geophysical survey of the Maryland WEA was analyzed to constrain the bottom sediment types and morphological features of the area. A standardized procedure for determining sediment and morphological distributions was developed to provide a model that could be implemented prior to offshore wind project development in the Mid-Atlantic Bight region. The procedure, utilizing SonarWIZ, ENVI, and GIS software, involved processing side-scan sonar files (e.g. data import, bottom-tracking, digitizing features, and creating a base map), using ENVI to automatically classify reflection distributions based on grain size analysis, utilizing an editor function in GIS to “touch-up” ENVI’s output, and exporting a finalized base map.



As part of the thesis project, a comparison was made between a user-defined and two automated sediment classification techniques (SonarWIZ and ENVI). As a classification tool, SonarWiz was not user friendly. The trial and error methodology is time consuming and inconsistent, although for small projects, SonarWiz could be used more efficiently and accurately. ENVI is easy to use and produces accurate results. The most important consideration in using ENVI as a classification tool is having an artifact free base map with reflection consistency perpendicular to the track line direction. The user generated classification map is time consuming and prone to the same misinterpretations as the ENVI map. Although, this method is the only of the three that is able to identify large scale geologic and morphologic features.

Geophysical analyses by nature are indirect measurements of geologic properties, such as grain size. For example, side-scan sonar is a measure of sediment's ability to reflect a sonar signal, which is, to some extent, related to grain size. While unable to directly identify specific grain sizes, a general (e.g., fine versus medium versus coarse) distinction can be made as a function of side-scan sonar reflection intensity. Qualitative analyses (e.g., Toscano 1989, Duval 2014, and Metz 2015) of ground truth data collected in the vicinity of the study area suggest that these general grain size assumptions based on the observed side-scan sonar returns are to first-order reliable.

To quantitatively constrain the side-scan sonar sediment characterization results, various analyses could be performed. The most important would be to collect grab samples or shallow vibracores where there is existing side-scan sonar data. This would allow for direct grain size analyses to be performed and compared with side-scan sonar reflection intensities. In addition, overlaying high-resolution bathymetric

data on the side-scan sonar mosaic would allow the identification of morphologic features, and their side-scan sonar signatures to be identified. From the bathymetry, bed forms could be identified and associated grain sizes could be inferred.

## REFERENCES

If you want to number your bibliographic entries, change the style of the items to *Bib Entry - numbered*.

- Andrew, 2014, Capacity factors and Danish offshore wind farms:  
<http://energynumbers.info/capacity-factors-at-danish-offshore-wind-farms>  
(accessed March 2015).
- Coastal Planning & Engineering, Inc., (2014), Maryland Energy Administration High Resolution Geophysical Resource Survey (Project Number DEXR240005) Final Report of Investigations, Boca Raton, Florida: Coastal Planning & Engineering, Inc., a CB&I Company, 109p. (Prepared for the Maryland Energy Administration).
- Dean, E.T.R., 2010, Offshore Geotechnical Engineering: London, Thomas Telford Publishing, 552p.
- Department of Energy (DOE), 2011, A National Offshore Wind Strategy: Creating an Offshore Wind Energy Industry in the United States, (DOE/EE-0798), United States Department of Energy, Washington, DC, 42p.
- Department of Energy (DOE), 2015, Wind Vision: A New Era for Wind Power in the United States, (DOE/GO-102015-4557), United States Department of Energy, Washington, DC, 292p.
- DuVal, C.B., 2014, Hydrodynamic Variability and Bedform Dynamics at an Inner Shelf Artificial Reef [Masters Thesis]: Newark, University of Delaware, 161 p.
- Energy Information Administration (EIA), 2015, March 2015 Monthly Energy Review: United States Energy Information Administration, DOE/EIA-0035(2015/03), United States Department of Energy, Washington, DC, 225 p.
- Feld, T., 2006. Geotechnical Analysis Requirements: Soil Investigations for Offshore Wind Turbine Projects. *WindTech International* 22 – 25.
- Herndon, A., Wade, W., 2012, NRG Gets U.S. Lease for Delaware Offshore Wind Project: <http://www.bloomberg.com/news/articles/2012-10-23/nrg-s-offshore-wind-power-unit-gets-second-u-s-commercial-lease> (accessed March 2015).

- Manwell, J.F., McGowan, J.G., and Rogers, A.L., 2009, Wind Energy Explained: Theory, Design and Application: United Kingdom, John Wiley & Sons Ltd., 689p.
- Metz, T.L., 2015, Shallow Stratigraphy of the Mid Atlantic Bight: Constraints on Siting of Offshore Wind Projects [Masters Thesis]: Newark, University of Delaware, 146 p.
- McNamara, E. 2015, What really toppled Cape Wind's plans for Nantucket Sound: <http://www.bostonglobe.com/magazine/2015/01/30/what-really-toppled-cape-wind-plans-for-nantucket-sound/mGJnw0PbCdfzZHtITxqlaN/story.html> (accessed March 2015)
- Sullivan, S.P., 2014, N.J. whiffing on offshore wind despite environmental, economic benefits, report claims: [http://www.nj.com/news/index.ssf/2014/12/nj\\_stalling\\_on\\_offshore\\_wind\\_despite\\_environmental\\_economic\\_benefits\\_report\\_claims.html](http://www.nj.com/news/index.ssf/2014/12/nj_stalling_on_offshore_wind_despite_environmental_economic_benefits_report_claims.html) (accessed March 2015).
- Toscano, M. et al., 1989, Quaternary Stratigraphy of the Inner Continental Shelf of Maryland, Maryland Geological Survey, Report of Investigations No. 50.
- Westgate Z. J., and DeJong J. T., 2005, Geotechnical Considerations for Offshore Wind Turbines. Offshore Wind Collaborative pilot project. Civil Engineering Department, University of Massachusetts, Amherst.