Marine Acoustics and Habitat Mapping in the Peconic Estuary, NY

A Thesis Presented

by

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to

The Graduate School

in Partial Fulfillment of the

Requirements

for the Degree of

Master of Science

in

Marine and Atmospheric Science

Stony Brook University

May 2015

Stony Brook University

The Graduate School

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Abstract of the Thesis

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As coastal populations grow, there is an increasing need for better spatial management of the seafloor. Multibeam backscatter data can be a powerful tool for habitat mapping and segmenting large areas of the seabed, based on similar physical characteristics. In order to increase the effectiveness of backscatter data sets, MBES data from the Peconic Estuary, NY, is reprocessed using newly developed software. These mosaics are less noisy compared to prior results. The relationship between grain size and backscatter is found to have a good correlation in the Peconic Estuary and a simple regression is used to predict mean phi size based on backscatter. ARA results are examined and found to have a weak correlation with grain size compared to backscatter. Overall this study hopes to provide tools to improve the ability to classify areas of the seafloor in the Peconic Estuary.

Dedication Page

To Nan and Gram.

Table of Contents

Page

List of Figures/Tables/Illustrations

List of Abbreviations

SBES: Single beam echosounders, sidescan sonar

MBES: Multibeam Echosounder

NYSDEC: New York State Department of Environmental Conservation

ARA: Angular Range Analysis

AR: Angular response

GIS: Geographic Information Systems

LOI: Loss on Ignition, an estimation of organic content

NAD: North American Datum

SoMAS: School of Marine and Atmospheric Sciences

FIPS: Federal Information Processing Standards

Acknowledgments

New York State Sea Grant through the Sea Grant Scholar Program (Project 90-2) and the New York State Department of Environmental Conservation funded this research; their support was greatly appreciated. Processing work was also supported by the Long Island Sound Pilot habitat Mapping Project, Columbia University Award 2GG006832. Original survey and sediment data acquisition and interpretation was funded by: Award LIC 2005 080105 A from the Long Island Chapter of The Nature Conservancy and awards HSV525823511100000001 and HSV001440545600000031 from the Department of Health Services of Suffolk County NY. Thanks to Dr. Henry Bokuniewicz whose unending help in academic advising and as a scientific mentor made this thesis possible. Thanks to Dr. Robert Cerrato for his gift of enthusiasm and encouragement throughout the project. Thank you to Dr. Roger Flood whose expertise in the field of marine acoustics and technical support was critical to this thesis. Thank you to Mom, Dad, Aunt GG and Tim for their infinite supply of emotional and physical sustenance. Thanks to Molly for her patience and unconditional support. Thanks to SoMAS faculty, staff and administrators.

Part I

Introduction:

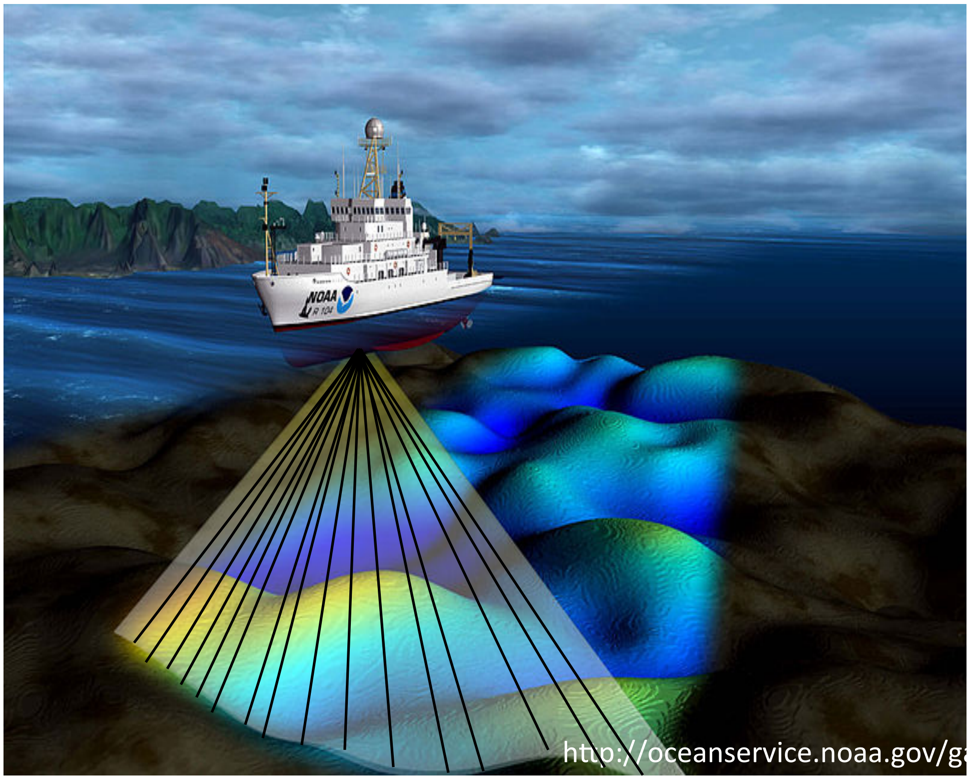
Coastal zones contain a significantly higher population compared to inland areas and future trend suggests the rate of migration to coastal areas will only increase due to the potential for economic growth (Neumann et al., 2015). The increase in human density propagates the all too often deleterious effects humans have on the coastal environment. With this rising pressure there is a great need for better spatial management of shallow water marine environments. On Long Island this need is obvious as future land planers and litigators will continue to dictate the use of the seafloor. These decisions may include where to locate an electric cable line that avoids crucial commercial fisheries habitat, zoning of aquaculture areas, wind farm placement or the allocation of land permits for a floating liquid natural gas barge. In any case informed and knowledgeable management decisions require accurately mapped seabed characteristics, including bathymetry, submerged geology, and benthic habitats.

Compared to most terrestrial habitats, most marine habitats (excluding, for example kelp forests and coral reefs) are defined and structured by two-dimensional geomorphological characteristics. Satellites are now used to map the Earth's surface, but due to the lack of light penetration, they cannot be used to map and describe the seafloor. Over the last several decades, researchers have been using acoustic instruments to map the seafloor. Along with more powerful computers, new developments in marine acoustic imagery and processing capabilities have allowed marine scientists to accurately describe and illustrate these characteristics (Brown and Blondel, 2009). Acoustic data has been applied to integrate a number of seafloor parameters (e.g. Ferrini and Flood, 2006). Variations in the return signal of echosounders can be used to quantitatively describe these features and determine their distribution (e.g. Brown and Collier, 2008; Brown and Blondel, 2009). It can also be used for the identification of geomorphological features such as sand waves, dunes and ripples (Lamarche et al, 2011). Acoustic data can also detect and monitor anthropogenic features like subaqueous cable lines and shipwrecks (Masetti and Calder, 2012).

Acoustic data acquisition can be broken down into two systems: SBES or sidescan sonar and Multibeam Echosounders (MBES). While valuable high-resolution backscatter imagery can be acquired from SBES for interpretation and classification, MBES have the distinct advantage of acquiring multiple measurements of depths and backscatter simultaneously. With increasing processing capabilities and the availability of more powerful computers and software, MBES are now the preferred choice of many researchers (e.g. Pickrill and Todd, 2003). MBES systems can provide both high resolution bathymetry and backscatter and offer certain advantages for the acquisition of data, such a faster speed of the survey and the accurate positioning of data (Le Bas and Huvenne, 2009)

High-Resolution Multibeam Echosounder:

A multibeam transducer is often mounted to the hull of a ship emits a fan shaped transit pulse that is narrow in the along-track direction and wide in the across track direction. The receiver array then uses a bottom finding algorithm to record the return signal as a series of multiple beams that are wide in the along-track directions and narrow in the across track direction (Figure 1). For modern MBES systems advanced bottom-finding algorithms form hundreds of distinct beams (Brown and Blondel, 2009). Depending on the ping frequency and the rate of data collection, this could mean hundreds or thousands measurements every few seconds. This design allows for the real-time acquisition of many separate measurements in a wide swath.



Multibeam Echosounder Survey

http://oceanservice.noaa.gov/g

Figure 1: Illustration of the acquisition of MBES data. A fan shaped pulse is emitted from a hull-mounted transducer. A beam forming algorithm then forms distinct beams within the transducer, allowing for up to 250 individual measurements of the seafloor with each ping. For the device used to acquire the data in this present study, a Dual Head Simrad 3000, up to four 300 kHz pings a second can be emitted. A time varied gain is applied to compensate for signal loss.

High quality soundings require accurately measuring the installation geometry with respect to the transducer and navigational devices (Le Bas and Huvenne, 2009). Additional radiometric and geometric corrections are also required, whether done during acquisition or post processing. The resolution of MBES systems is a function of several factors. Horizontal resolution depends on the sound frequency and the physical characteristics, most importantly length, of transducer array. A wider beam width offers less lateral resolution since the size of the insonified area is also increased. Vertical beam resolution is dependent on the pulse length and beam angle. By taking into account the angle and direction of the transducer and beams, the motion of the ship, the sound speed velocity profile of the water column, and the time elapsed between pulse origin and beam return, high resolution MBES data can be collected.

MBES Backscatter:

Backscatter is the measure of the intensity of acoustic energy that is returned to the transducer. When the transmit beam is emitted from the transducer some sound is lost to absorption in the water column and some is lost to spherical spreading as sound waves travel. A time varied gain is applied internally in the transducer to compensate for loss. The remaining energy makes contact with the seafloor, where some is absorbed and some is reflected either back towards the receiver or scattered away from the receiver where it is lost.   Some sound that enters the seabed is eventually absorbed, but can be scattered off of particles or reflect off of layers. Backscatter is the sound that is scattered back in the direction of the transducer. Backscatter is related to both acoustic impedance and roughness. The intensity of sound that returns to the ship is a function of the contrast in impedance, a product of sound velocity times desnity, and strength of reflectivity (Hamilton, 1971). Reflectivity is the difference in impedance divided by the sum of the layered impedances. Higher acoustic impedance results from acoustic mediums with larger density ratios, causing higher reflection coefficients and thus, higher amplitudes of the acoustic backscatter. For example, a higher acoustic backscatter would result from the propagation of sound energy through the water column only to be reflected at the sediment-water interface by solid bedrock. The high acoustic contrast as a result of the large difference in the densities of the acoustic mediums - water and bedrock – and the strength of reflectivity would yield a higher return.

Other than interactions with the water column and the sediment-water interface, variations in the backscatter can also be consequences of instrument configuration and pulse geometry (Ryan and Flood, 1996). Examples that will affect backscatter during acquisition include altering the transmit frequency and pulse length. Variations in the angular response of the seafloor can also affect signal acquisition (Foneseca and Mayer, 2007). In the outer swath, away from the transmitter, the signal can be scattered. Directly under the transmitter, known as the nadir or near nadir, backscatter tends to be high since the signal is reflected directly back to the receiver. Backscatter intensity generally decreases as the angle of incidence increases of to the side of the track. This variation of backscatter with the angle of incidence is known as the angular response (AR) and can be a diagnostic of seabed character. This will be discussed later as a modeling parameter.

Backscatter and Seafloor Parameters:

This report is principally concerned with the relationships between backscatter and physical characteristics of the seafloor. If one can relate backscatter to specific physical parameters then patterns in backscatter can be used to efficiently segment the seafloor based on physical characteristics and ultimately submerged habitat. There are a large number of variables that can contribute to the acoustic nature of the seafloor, including but not limited to grain size, sorting, porosity, pore filling, seabed roughness, existence and orientation of bed forms, subaqueous vegetation, and the presence of large clasts.

Compared to other methods of seafloor analyses, MBES data sets offer several distinct advantages. MBES impact on the environment is low, being non-invasive with respect to the benthic habitat. Improving the quality of the processed data means more accurate qualitative and quantitative analysis and enables researchers to more accurately examine the spatial distributions of seafloor characteristics (Clarke et al, 1996). While shipboard time of acquisition of MBES data is expensive, the cost versus information obtained is low; a single survey may contain tens of gigabytes of information describing large areas of the seafloor. Backscatter can be a useful tool in highlighting relatively small heterogenic features and patterns in what can otherwise be considered largely homogenous areas (Ryan and Flood, 1996).

Researchers have commonly linked backscatter to the grain size of the insonified area (e.g. Ryan and Flood, 1996; Brown and Collier, 2008). This relationship has received much attention for two reasons. First and foremost, grain size can be easily measured, through the acquisition by grab or core sample and then quantification in a laboratory by a variety of methods. Compared to other in-situ parameter measurements, for example porosity or seabed density, measuring grain size is relatively inexpensive and straightforward.

The second reason the relationship between grain size and backscatter has received attention has been the well-documented correlation between them. The conventional wisdom is that larger grain sizes produce higher intensity backscatter since the contrast in impedance is greater and smaller grain sizes absorb more of the transmitted energy, producing a lower backscatter intensity (e.g. Goff et al, 2000; Jackson and Briggs, 1992). Flood and Ryan (1996) found a linear correlation between grain size and acoustic signal. At an artificial reef site, researchers also found a positive relationship between grain size and backscatter, though poorly sorted sediments had the most variable backscatter (Collier and Brown, 2005).

Backscatter Models and Mapping:

The parameters used to predict backscatter can change regionally and temporally. Temporal changes may be the result of storm events or changes in ecological community structure. Regionally, backscatter may be driven by different seafloor properties such as grain size (Collier and Brown, 2005) or bioturbation (Urgeles et al, 2002). For any one area however, it is reasonable to assume that geospatially proximate areas with similar acoustic properties have similar geologic and biologic characteristics. Because of the connections between the geologic and biologic properties of sediment and their influence on acoustic characteristics and the link between surficial sediments and faunal composition of distinct habitats (e.g. Gray, 1974), one can use a combination of acoustic, sediment, and faunal data to segment areas of the seafloor into discrete geophysical provenances.

As GIS programs and capabilities become more ubiquitous and more powerful, investigators can more effectively combine various layers based on their geospatial relationships. Researchers have found that using several layers of data to classify areas of the seafloor leads to increased spatial resolution of each data set; increased spatial resolution means increased confidence in discreetly classified areas (Freitas et al, 2011). Kostylev et al (2001) identified distinct habitats based on photographic and sediment data and then used acoustic data as a tool to extrapolate benthic habitat characteristics leading to increased confidence in the final biotype map. They also found a strong correlation between habitat and backscatter boundaries and concluded areas of similar backscatter intensity coincided with discrete benthic assemblages. Textural image analysis and ground truth data have been used to classify acoustic data, which were then assigned physical characteristics and used to identify specific geomorphological features such as save waves and dunes (Preston, 2009; Blondel et al, 1998).

Study Area:

The Peconic Bay Estuary system is a series of semi-enclosed bodies of water located between the North and South forks of Long Island New York (Figure 2). The Peconics are a tidal estuary that is fed with freshwater primarily from the west from the Peconic River and submarine ground water discharge, as well as a few other tidal creeks on the North Fork. Brackish water is exchanged with the Atlantic Ocean to the east. The western part of the Peconic Estuary can be separated into two areas divided by Robin's Island, the Great Peconic Bay to the west and the Little Peconic Bay to the east. The Great Peconic Bay is circular shaped, with a bowl shaped bottom morphology. The Little Peconic Bay is oval shaped and has a relatively more complicated bottom morphology. Relatively shallow, <10 m, the Great Peconic Bay the Great Peconic Bay can generally be characterized by unconsolidated benthic substrates ranging from gravels to fine clays. The Little Peconic is deeper, >20m, and while it does feature some unconsolidated substrates there are large areas of shell in the Little Peconic Bay in the form of relict oyster reefs (Kinney, 2012).

In 2001, the Peconic Estuary Program found that the Peconic Estuary had "significant biodiversity" and that it "may require an extra level of protection" (Peconic Bay Estuary Program, 2001). Historically, the Peconic Bay Estuary has been the location for a variety of commercial benthic fisheries. Notably these included clams, oysters, bay scallop and winter flounder. Almost all of these fisheries are in decline (in the case of winter flounder have essentially collapsed) as a result of an assortment of factors, including over fishing, nutrient loading, algal blooms and habitat loss. The NYSDEC and other government agencies are currently leasing areas of the seafloor for aquaculture for several shellfish species. The Cornell

Cooperative and Suffolk County have also lead reseeding efforts to help ecologically restore the Peconic System.

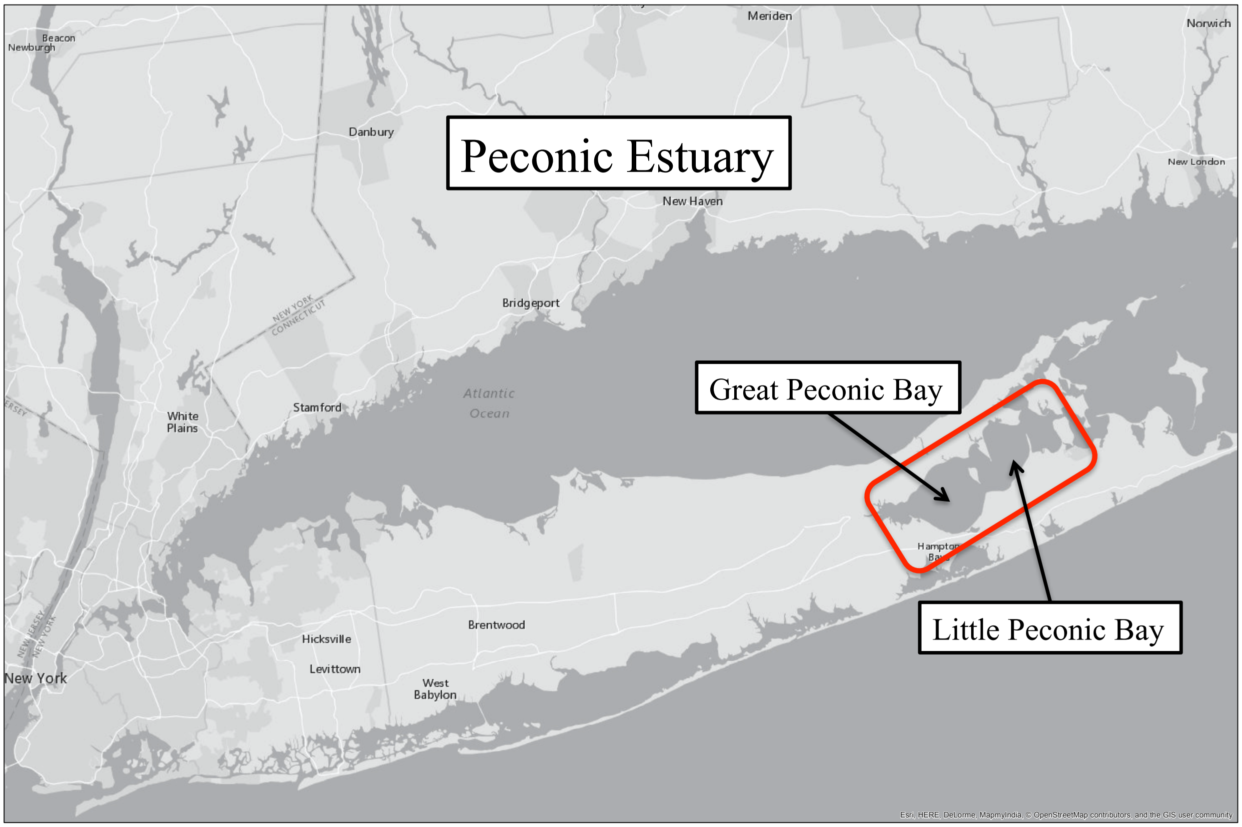


Figure 2: Peconic Estuary outlined in red.

MBES in the Peconic Bays:

In 2002 a series of efforts began to segment, identify and map benthic habitats of the Peconic Bays (Cerrato and Maher, 2007; Cerrato et al, 2009; Cerrato et al, 2010). Acoustic mapping was used as a foundation from which similar geophysical provinces could be identified. The original backscatter mosaics where processed using in-house software at SoMAS. Each of the mosaics for the Great Peconic Bay (Figure 3) and the Little Peconic Bay (Figure 4) were completed by merging smaller geographic surveys as the surveys where completed. The final data set for the Great Peconic Bay included 59 gigabytes of raw MBES data. For the Little Peconic Bay, there was 35 gigabytes of raw MBES data. The surveys themselves were done between 2002 and 2010. Once the acoustic surveys where interpreted to reveal suspected similar bottom types and boundaries between dissimilar areas, samples for macrofauna and sediments would be used to ground truth these seemingly similar acoustic regions. Figure 5 shows the original geophysical provinces that were interpreted based on the original backscatter mosaic and the sample locations for the Great Peconic Bay. These provinces were used to focus sample collection. Figure 6 displays the original geophysical provinces for the Little Peconic; again, these provinces were drawn based on the original backscatter mosaics, which were

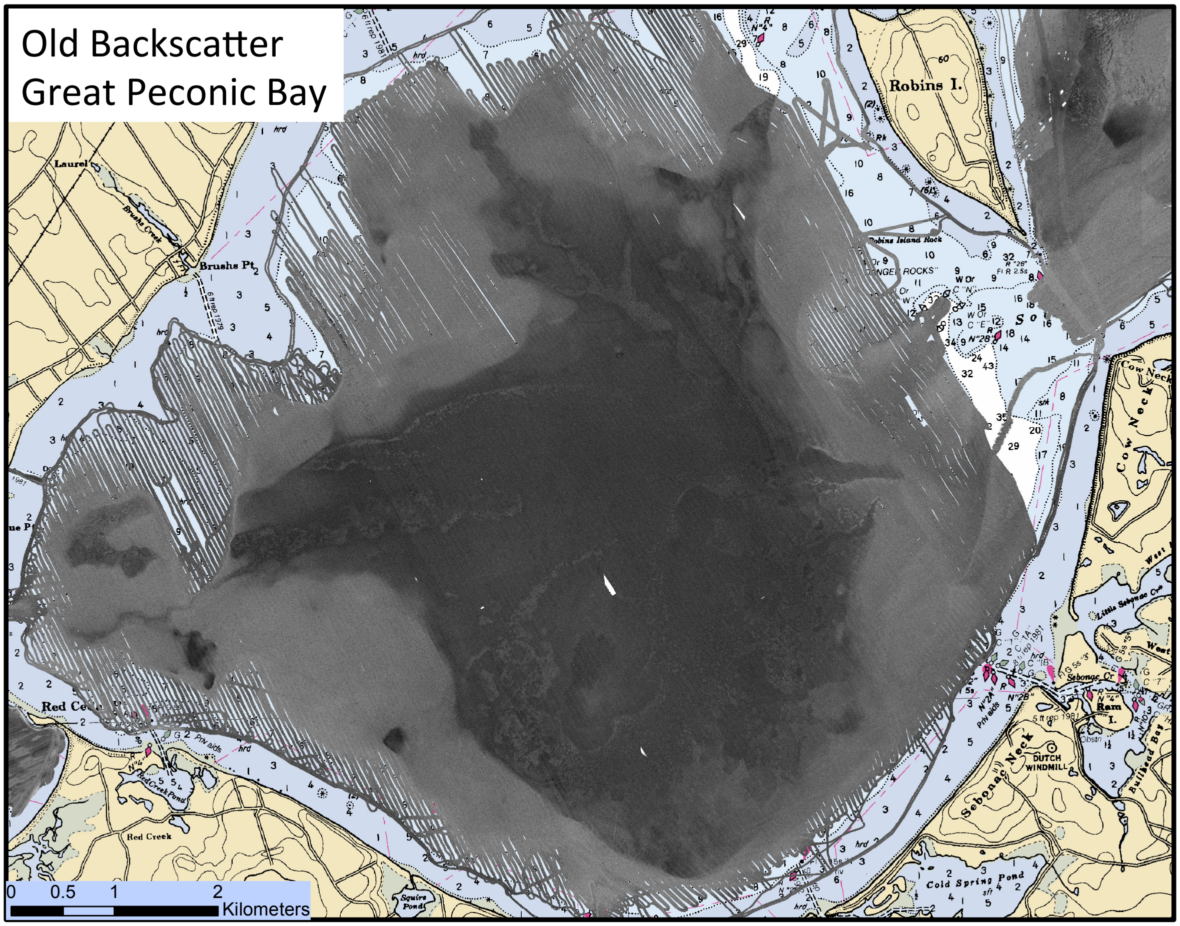


Figure 3: Original backscatter mosaic for the Great Peconic Bay. Mosaic was processed using in-house software at SoMAS. Final mosaic was merged from 4 individuals surveys.

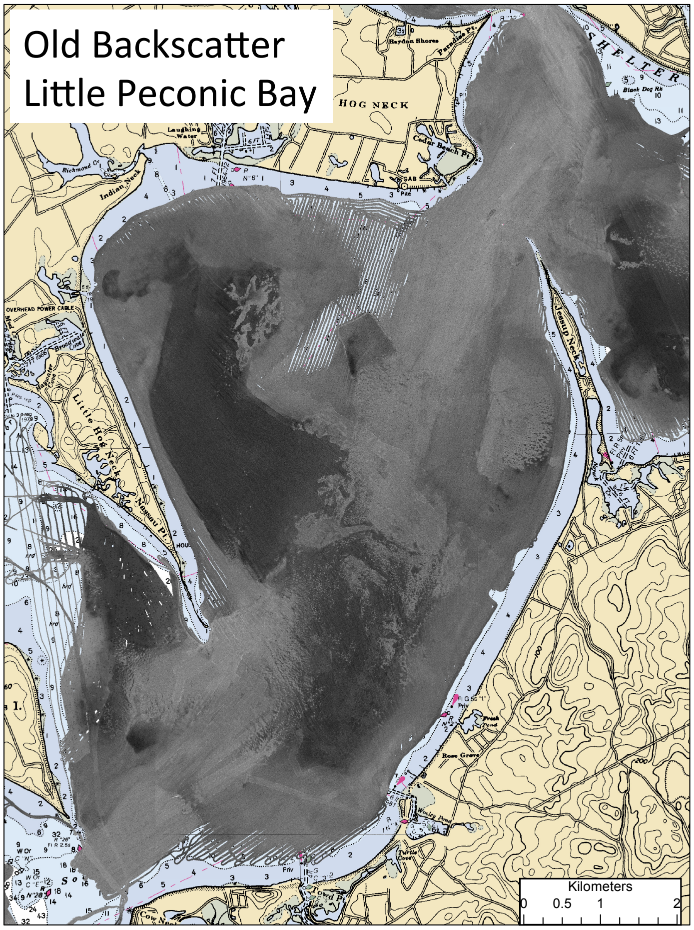


Figure 4: Original backscatter mosaic for the Little Peconic Bay. Mosaic was processed using in-house software at SoMAS. Final mosaic was merged from 5 individual surveys.

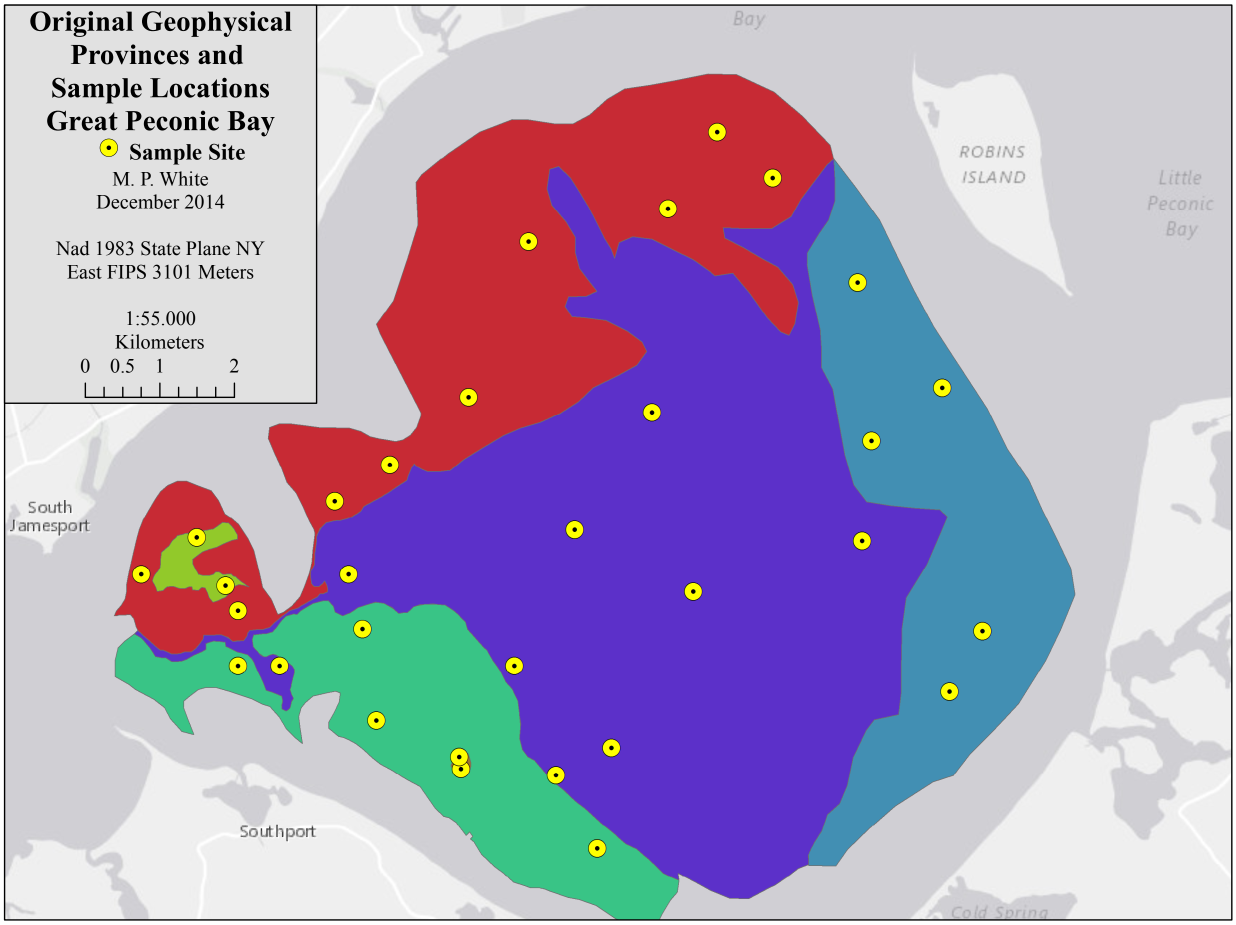


Figure 5: The original geophysical provinces for the Great Peconic Bay. Provinces were drawn based on the original survey data and were then used to target ground truth samples for sediment and fauna analysis. Yellow circles with black dots are used to show the sites for samples with fauna and sediment data.

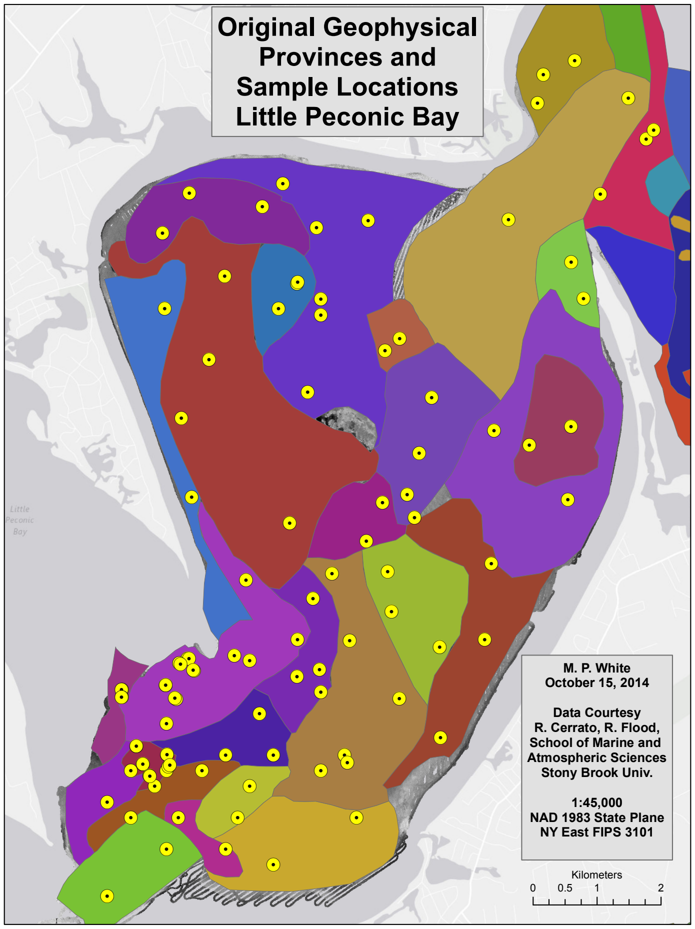


Figure 6: The original geophysical provinces for the Little Peconic Bay. Provinces were drawn based on the original survey data and were then used to target ground truth samples for sediment and fauna analysis. Yellow circles with black dots are used to show the sites for samples with fauna and sediment data.

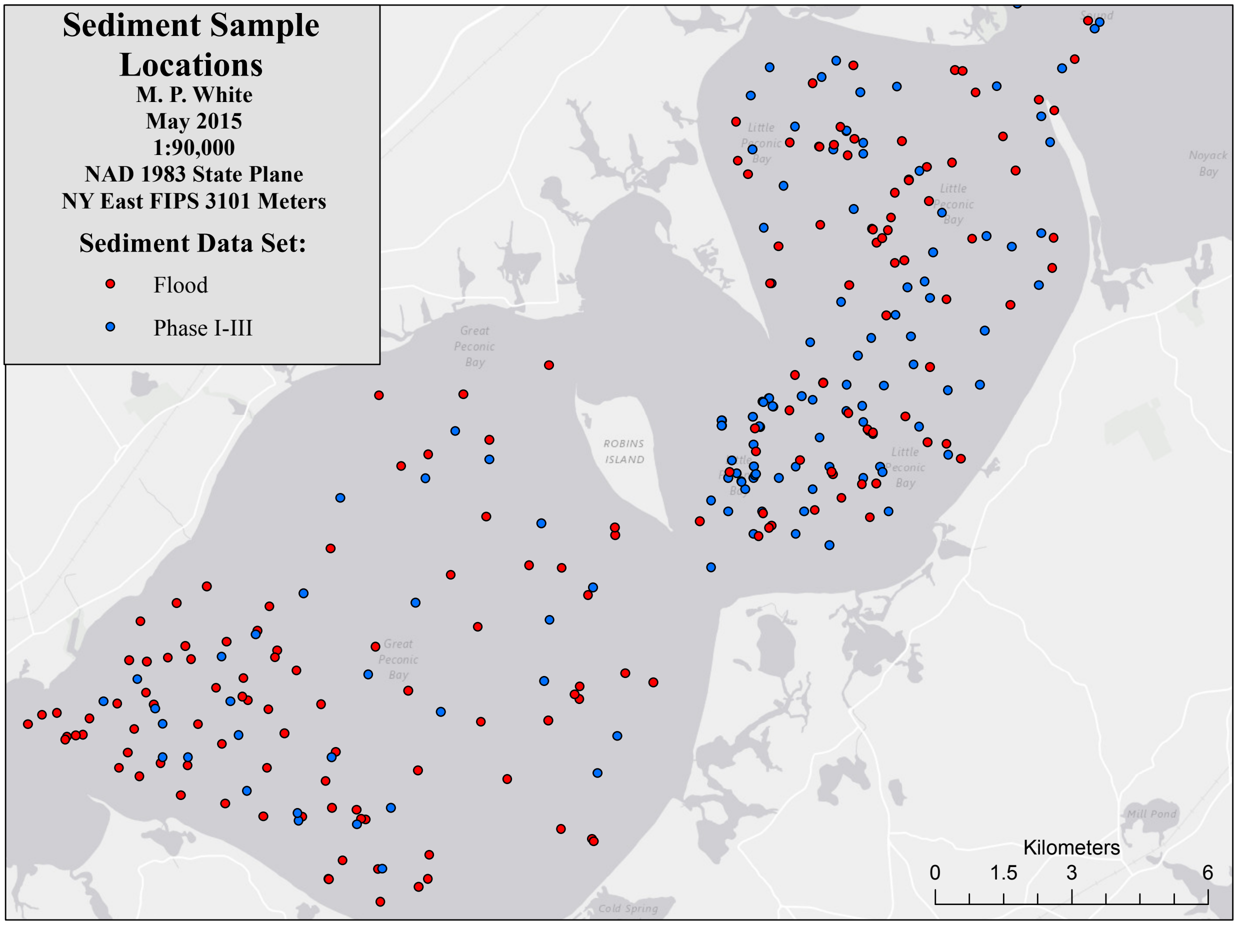


Figure 7: Sediment Sample locations for the Peconic Estuary. Samples in blue were collected and published in a series of phases (Cerrato and Maher, 2007; Cerrato et al, 2009; Cerrato et al, 2010). R. Flood of SoMAS, acquired during acoustic surveying, supplied samples in red. Collectively these data sets will here on out be referred to as PhaseI-III/Flood.

completed at different intervals based on geographic location. To ground truth the sonar data a modified Van Veen Grab, overall there were 31 samples for the Great Peconic Bay and 102 samples for the Little Peconic Bay. These samples were analyzed for sediment composition and faunal characteristics as described in Cerrato and Maher (2007). An additional 163 samples were also collected with the acoustic data, and analyzed for sediment composition and grain size (Flood et al., 2009; personal communication with R. Flood, SoMAS). The combination of these sediment data sets will from here on out be referred to *Phase I-III/Flood* sediment samples, shown in Figure 7. In a series of reports (Cerrato and Maher, 2007; Cerrato et al, 2009; Cerrato et al, 2010), researchers meticulously described how acoustic data could be used as a foundation to which faunal and sediment data could be added to identify specific biotopes; these spatial distinctions could later be used to improve management efforts.

One common theme through these reports is the ability of MBES backscatter to highlight heterogeneities in sediment and faunal characteristics in regions that would otherwise be considered relatively homogenous. Phase I (Cerrato and Maher, 2007) concluded that while physical variables (e.g. grain size) were a good predictor of acoustic boundaries, they where less important for discriminating biological communities. Identifying backscatter boundaries was determined to be a good foundation for later habitat and biotope characterization (Cerrato et al, 2009), although acoustic segmentation alone was not sufficient without extensive groundtruh efforts (Cerrato et al, 2010). Another key element of the reports was the use of acoustic data to focus sampling. Once sonar maps were produced, specific geophysical areas were identified and sampling efforts were targeted in these areas. Logically, it follows that improved sonar maps would lead to better targeting of sample targeting and subsequent analysis, a typically prohibitively technique.

These reports were done in three phases, divided by geographic regions based on the availability of funding. Both the Great Peconic Bay and the Little Peconic Bay were split into several distinct regions and acoustic surveys were done separately for each region. Thus, for each body of water, several different sets of acoustic mosaics were combined to produce one final coverage. Instead of combining separate mosaics, I will attempt to create two individual mosaics, one for the Great Peconic Bay and one for the Little Peconic Bay. In doing so, the backscatter maps will be normalized for each body of water. Hopefully, this will lead to increased accuracy in identifying distinctly similar acoustic regions. The reprocessed backscatter data, along with the ARA will be used to redraw boundaries between acoustic provinces.

Here is noted a word of caution: mapping and sampling efforts were undertaken over several years (2002 – 2010) and in different seasons (Cerrato et al, 2010). Since benthic sediment properties and communities can change on inter-annual scales (e.g. Cerrato, 2006), there may be changes in the data that are not presented here.

Part II

Objectives:

1) To reprocess acoustic data from prior surveys using updated algorithms and commercial software

The initial objective of this study was to reprocess old MBES data. Since the original acquisition of the data presented here, there have been new developments in the processing and analysis of multibeam backscatter. In particular new algorithms and processing software have been developed which may significantly improve the quality of the backscatter mosaics created and allow additional sonar parameters to be derived from the backscatter data (Fonseca et al, 2007 and 2009). The successful reprocessing of older surveys using new techniques ensures that the substantial amount of archived acoustic data will continue to provide valuable new information to researchers. There is then significant worth not only scientifically, but also economically, to improve upon the ability to reprocess old acoustic data. Improved mosaics will lead to more clearly defined boundaries between geophysical distinct areas and highlight the intricacies of heterogeneous areas. Increased confidence in the acoustic segmentation of the seafloor would also lead to more systematic groundtruth targeting. Combined with ground truth efforts such as coring, grab samples, and photography, improved MBES products can be used to extrapolate point source data over large lateral extents.

2) Explore the relationship between backscatter and grain size for the Peconic Bay areas

As described above, many factors can influence backscatter. In some areas, backscatter can be correlated with grain size, while in others backscatter is primarily driven by other characteristics such as the presence of bioturbated sediment. For the Peconic Bays, one of the questions this report will try to answer is: Is there a correlation between grain size and backscatter, i.e., do larger mean grain sizes produce more intense backscatter and finer mean grain sizes produce less intense backscatter? By gridding the backscatter mosaic to less than 4 m^2 per pixel, the reprocessed data should help answer this query. Additionally I will attempt to predict phi size from backscatter using a simple linear regression.

3) Create new interpretive maps showing areas of similar geophysical characteristics using reprocessed acoustic data and compare with ground truth data.

Once the acoustic data has been reprocessed and products exported, the acoustic, sediment, and faunal data will be coalesced and layered to identify areas with similar characteristics. Using a GIS, several data sets can be combined in order to increase each spatial resolution of each and the acoustic data will be used to extrapolate groundtruh sediment and faunal samples over large lateral areas.

Methods:

The Fledermaus software suite from QPS contains several interactive modules for 4D interactive geospatial processing, visualization and data analysis. Capable of handling large geographic data sets, Fledermaus contains a myriad of tools that can be used in seafloor classification (www.qps.nl/fledermaus; June 2013). This software suite has several advantages for the purpose of habitat mapping and acoustic segmentation, including flexible but advanced backscatter mosaic creation and wizard based importing and exporting of data and products. These modules offer high quality data visualization and can seamlessly integrate a number of seafloor parameters from an assortment of sensor, software and agency specific formats including XYZ, Floating Point GeoTIFF, ASCII, LAS, Caris HIPS & SIPS HDCS, Hypack HS2, Kongsberg ALL and Esri's ArcGIS grids and shapefiles. The Fledermaus software suite can also help shorten processing time and can rapidly produce seafloor models and mosaics from unrefined surveys.

There are several distinct advantages in using commercial software. While it does increase overhead for projects, the developers of this product have an inherent motivation to remain competitive in a relatively niche but highly competitive market. This competiveness is associated with frequent product and software updates along with new tools and module capabilities. In addition to regular reviews of the software, there exists copious online and personnel support for academic and research troubleshooting and workflow inquires. Such an extensive support system would later become helpful as unique challenges presented themselves in using new software to reprocess old data.

Reprocessing of MBES Data

Reprocessing began with loading the original sonar data from the Peconic Bays into the Fledermaus software suite. The data sets for the Great Peconic Bay and the Little Peconic Bay were each treated as separate schemes. The Peconic Bays multibeam data set, the Fledermaus license and the computer on which the processing was done were all provided by Dr. Roger Flood (SoMAS). The raw data files from the Dual Head Simrad EM3000 MBES are Kongsberg (.all) files and contain both depth and beam time series data. FMGeocoder (FMGT) is the specific module used for the processing of backscatter data to produce mosaics. These files can be loaded directly into FMGeocoder Toolbox without any ancillary files or pairs. A projected coordinate system was used as a reference grid for all FMGT products to later be re-projected in another GIS. Source files that were corrupted or encountered error messages were removed. Once the entire data set was loaded, processing parameters where set. The toolboxes found in FMGT enable users to edit processing parameters and mosaicing styles, depending upon the sonar device used for acquisition and mosaic preferences (i.e. pixel size, pulse length, absorption, sampling rates, beam width, different line blending styles). The default processing parameters were set for a Dual Head Simrad EM 3003. Manual processing parameters where also set for primary frequency, pulse length, primary sampling rate and secondary sampling rate. Transmit power and receiver gain were set at 1 dB. The architecture of FMGT has been set up such that at each stage of pre-processing and processing, products are created as the data move through the entire workflow. This structure allows for selective data re-processing and product rebuilding without have to load and pre-processing the data.

While initial reprocessing seemed promising, certain obstacles began to present themselves. Certain parts of the data in the layers created were being left out indiscriminately because the computers using the new software simply did not have enough processing memory to process and edit all of the data, whether it was part of a survey or the whole area. Transferring the data to a new workstation helped, and I not only gained the capability to process whole surveys - an important ability since the gridding algorithms employed could use values relevant to the whole survey as opposed to portions – but could also produce mosaics occur at finer resolutions. Instead of gridding individual pixels at >5m, layer resolution could be calculated at ≤1m. The production of higher resolution mosaics allows investigators to identify and describe fine scale features that would otherwise be undetectable at coarser resolutions.

After improving the hardware associated with reprocessing there continued to be issues loading raw data into any of the Fledermaus modules. The multibeam data was collected with a Kongsberg dual head Simrad 3000 Multibeam that writes raw.all files during data acquisition. The dual head raw.all files, however, were not compatible with any modules. As a result, half of the survey area was deleted during loading, erroneous backscatter values and incorrect depth calculations (>6000m in the Peconic Bay), and effectively ceased all reprocessing of archived multibeam data.

When data reading errors were identified in the software, communication and troubleshooting were begun with QPS. Individual files were chosen for processing and results were compared. It became clear the dual head files were being read incorrectly. Ultimately, the software does not count heads but individual beams. The Feldermaus software had not been used to processing the specific set-up and datagram structure, which were used to acquire the sonar data. QPS developers, prompting a new software version that was released to all users, fixed this bug. By June 2013and the dual head Simrad 3000 data was successfully being reprocessed.

The staged-based processing allows for the selection of individuals lines that can be shorten or removed form the project completely. After removing or editing of survey lines FMGT re-calculates the mosaic. All samples are preserved in the mosaicking process, which ensures a full data resolution and along with an applied anti-aliasing algorithm, allows researchers to reprocess the data at different resolutions. Each backscatter value in the data set is assigned a priority based on the distance from the nadir and the transducer. Low quality samples are given lower priorities if they are located very near the nadir or far from the nadir. Higher quality samples are given higher priority if they are mid-range from the nadir. Instead of averaging values in a single cell together or selecting the last mapped value, FMGT selects the best sample based on relative distance.

Each acoustic data set went through a rigorous manual editing process. Track lines were turned on and off in the software and evaluated to determine if they contained quality backscatter data. During acoustic surveys there are erroneous lines that can occur as a result of many variables, such as gas bubbles under the transducer, traveling lines from port to survey areas where the ship is traveling too fast to acquire good quality data and obstacles like lobster or crab traps in the track line that obstruct the survey. These can produce artifacts. By comparing individual track lines to their neighbors and examining the raw image using the Beam Pattern Viewer, erroneous lines were identified and removed. Lines were blended at 50% based on dB mean and the option of no nadir is possible was selected for the smoothing of near nadir values. Several mosaics were created for both the Great Peconic Bay and the Little Peconic Bay. The final mosaics were chosen based visual comparison and exported as SD files (Fledermaus specific viewing files which contain the raster data) into the Fledermaus viewer module. In the Fledermaus module, backscatter values for each sample site were assigned for both the individual pixel backscatter and the mean pixel backscatter. Finally, the mosaics were exported as ArcView Grid Files and loaded as raster features in ArcCatalog.

From the raw data FMGT can also produce many statistical layers, including mean, median, mode, minimum and maximum - several or all of which may be utilized for further statistical analyses of the seafloor. In addition to these functions, FMGT can apply the Angular Range Analysis (ARA) algorithm, another tool used to acoustically segment the seafloor and remotely estimate surficial sediment properties. MBES systems acquired backscatter from a large range of incidence angles, depending on ship and seafloor orientation. Typically, the angular response of the seafloor is disregarded during standard backscatter processing. However, Fonesca and Mayer (2007) developed and approach that preserves the angular information and uses it for the remote estimation and characterization of seafloor properties. ARA stacks a series of consecutive pings and corrects for seafloor slopes, beam pattern time and angle varying gains. These parameters are used to estimate acoustic impedance, which is then compared to empirically derived measurements acoustic impedance of seafloor sediments (Fonseca and Mayer, 2007). ARA provides another tool used to describe and aid the seafloor by remotely classifying the seafloor not based on backscatter alone (Fonseca et al, 2009). This process results in a model that can be used to segments the seafloor based on the remote estimation of surficial seafloor properties. The ARA patches are assigned indices based on grain size. The ARA files were also exported as ArcView Grid Files and loaded as raster features in ArcCatalog

GIS database swere created in ArcCatalog version 10.1 (ESRI, 380 New York Street, Redlands, CA 92373-8100) for the Great Peconic Bay and the Little Peconic Bay. The fauna data was broen down into mollusk, polychaetes, and crustaceans and plotted as point feature classes. Natural jenks were used to symbolize counts to show a deductive assignment of breaks and show natural groupings of values. The PhaseI-III/Flood sediment data was combined and a point feature class was created. All products from the FMGT software were imported as raster features. All features were displayed using a projected coordinate system, NAD 1983 State Plane NY East FIPS 2104 (meters) using the “Project” tool in ArcToolbox. The PhaseI-III/Flood sediment data was symbolized as stacks and colored by percent composition of four grain size classes and projected on top of the reprocessed backscatter mosaics.

Part III

New Mosaics:

The reprocessed backscatter for the Great Peconic Bay is shown in Figure 7. Each pixel on the mosaic represents 1x1m of seafloor. For the Little Peconic Bay, the reprocessed backscatter is displayed in Figure 8. In the mosaic for the Little Peconic Bay each pixel represents 2x2 m of the seafloor. The granule texture present in the original mosaic has been removed and boundaries between dissimilar acoustic areas are clearer.

The reduction in noise (excess noise produces the granular texture) is a result of the applied radiometric and geometric corrections. Radiometric corrections included the removal of variable acquisition gains, power levels, pulse widths and incidence angles. Corrections for slant-range distortion and transducer altitude are also applied. Speckle removal and reduced clutter in the near nadir region also allows for better distinct and more confident segmentation of acoustically distinct areas.

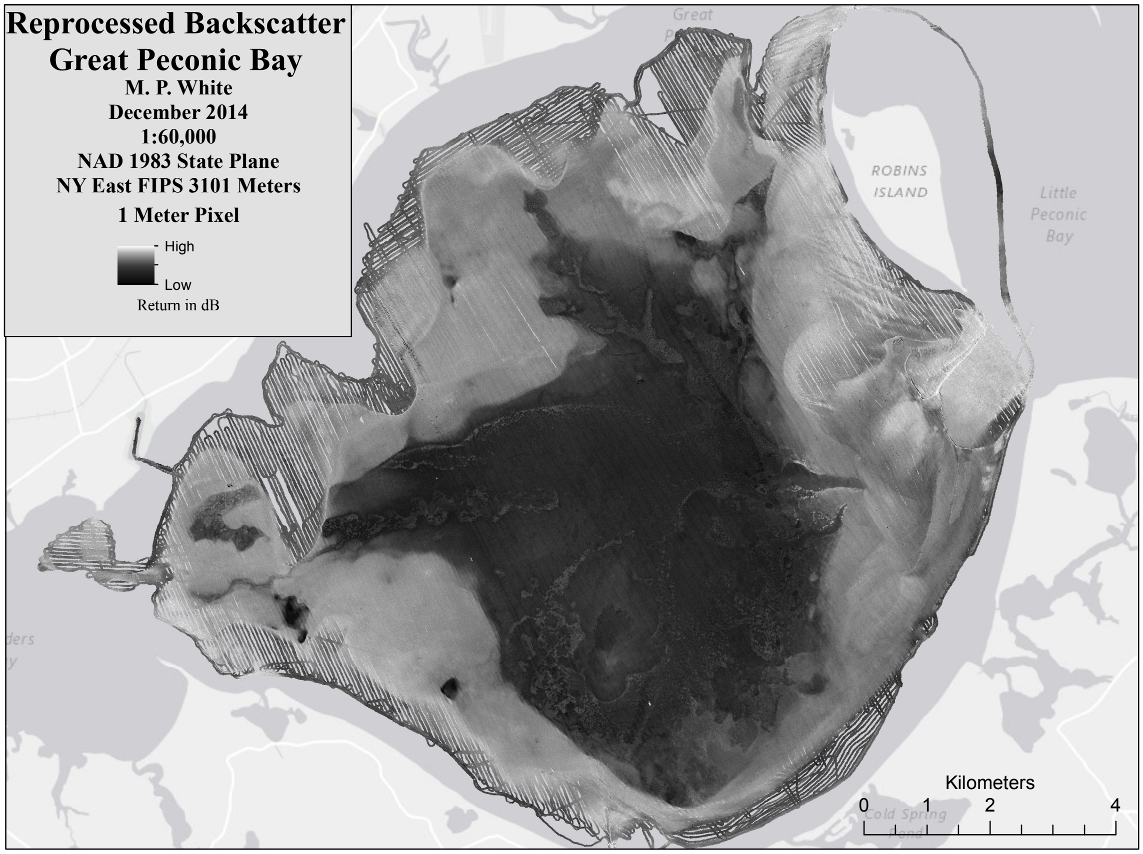


Figure 8: Reprocessed backscatter mosaic for the Great Peconic Bay. Each pixel for the mosaic represents 1 x 1m. Brighter areas represent more intense backscatter; darker areas represent less intense backscatter. Mosaic was created using all of the data available for the Great Peconic Bay, therefore values are normalized over the entire area.

Figure 9: Reprocessed backscatter for the Little Peconic Bay. Each pixel for the mosaic represents $4m^2$.

Sediment data was layered on top of backscatter data to record the backscatter in the cell the sample was located in. Figure 10 shows the spatial distribution of samples with bar graphs representing grain size distribution and the reprocessed backscatter for the Great Peconic Bay. Samples containing coarser grain material, the gravels and sands represented by blue and green, are located in areas of brighter, more intense backscatter return. This correlation is the result of a higher acoustic contrast as a result of larger grain sizes. Finer grain material, silts and clays represented by orange and red, are located in areas of darker, less intense backscatter return. The less intense return is due to lower acoustic contrast.

Figure 11 illustrates sample location and grain size distribution for the Little Peconic Bay. As in the Great Peconic Bay, samples containing coarser grain material, the gravels and sands represented by blue and green, are located in areas of brighter, more intense backscatter return. This correlation is the result of a higher acoustic contrast as a result of larger grain sizes. Finer grain material, silts and clays represented by orange and red, are largely located in areas of darker, less intense backscatter return. The less intense return is due to lower acoustic contrast. Unlike the in the Great Peconic, some samples with coarser material are located in areas of less intense backscatter return (Figure 11a). This may indicate the presence of paleo-oyster reefs.

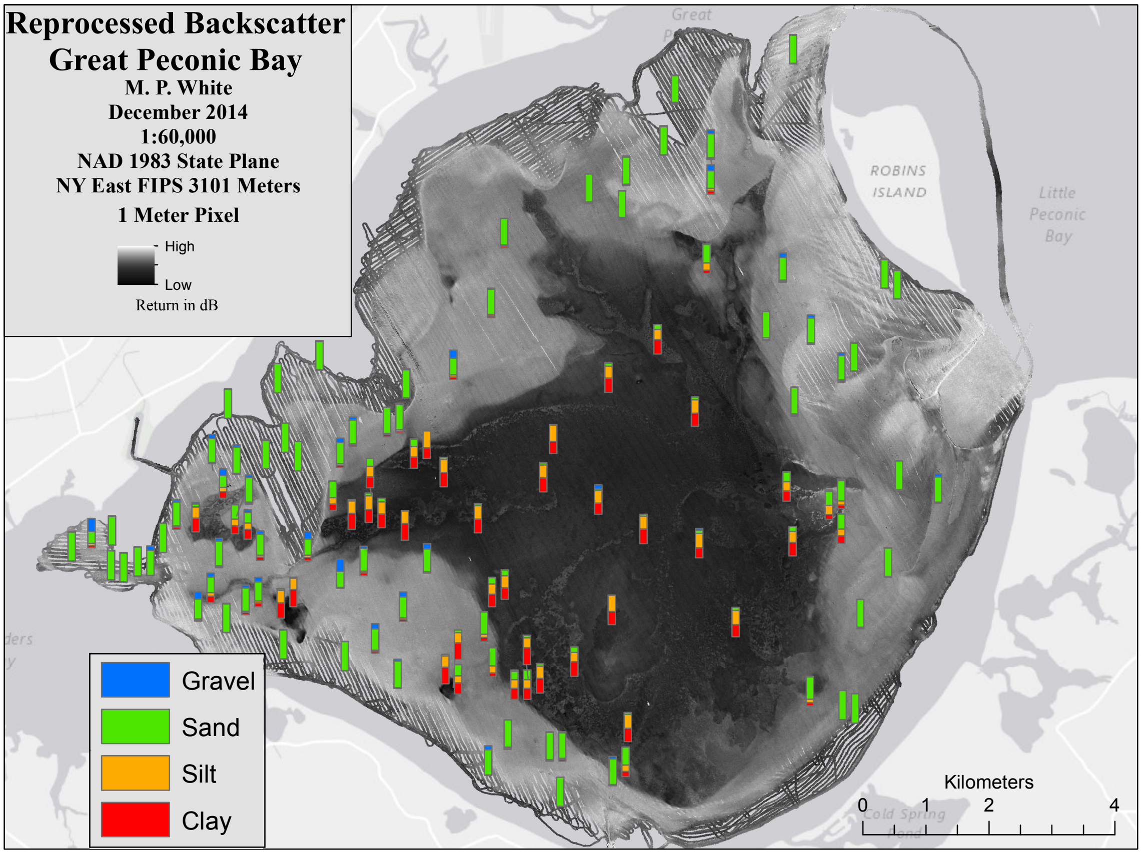


Figure 10: Sample locations and reprocessed backscatter for the Great Peconic Bay. Sediment samples are from PhaseI-III/Flood. Stacked bars represent the composition of each sample by percent grain size.

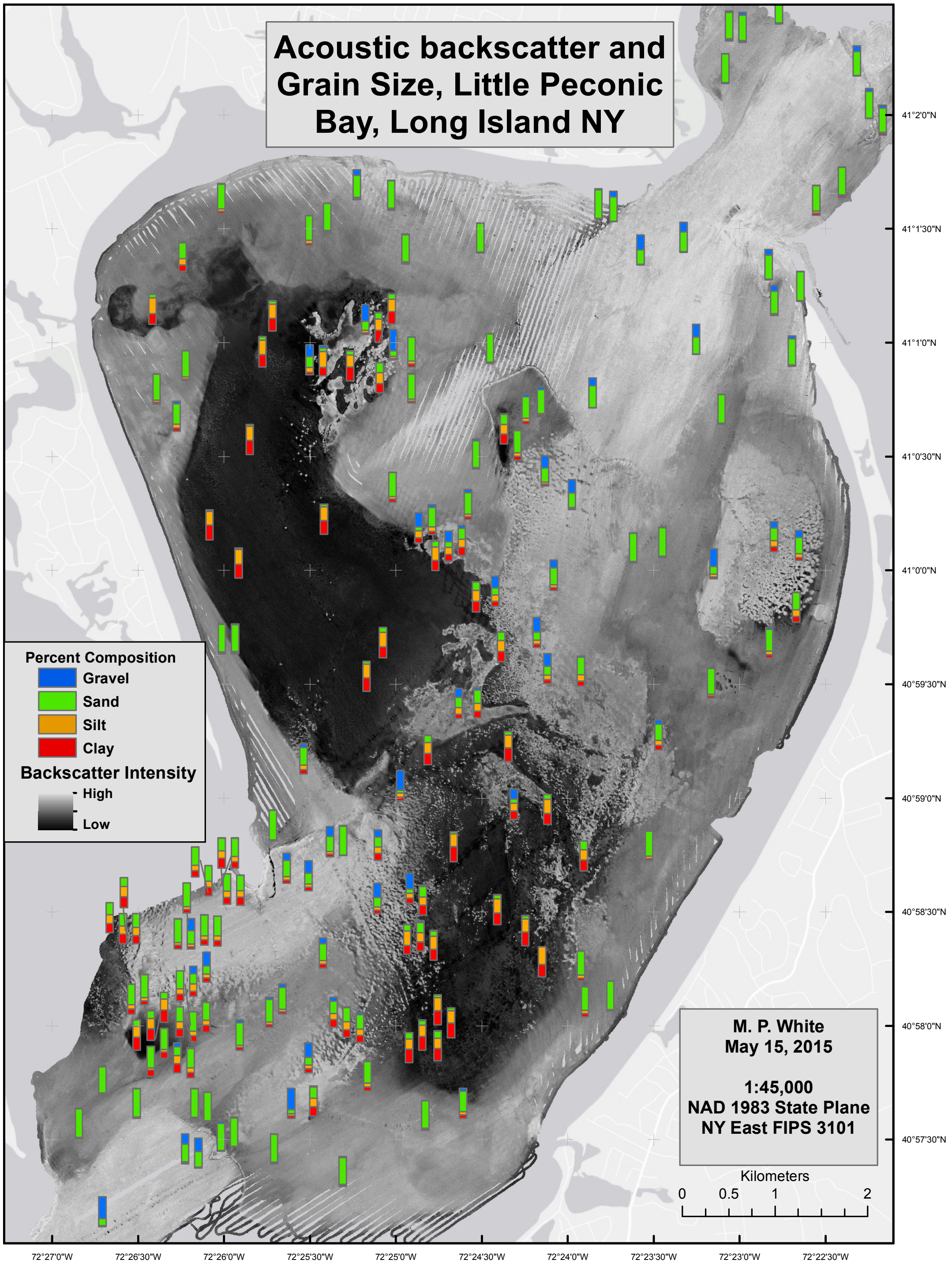


Figure 11: Sample locations and reprocessed backscatter for the Little Peconic Bay. Additional sediment samples, acquired during the acoustic survey, were added. Stacked bars represent the composition of each sample by percent grain size.

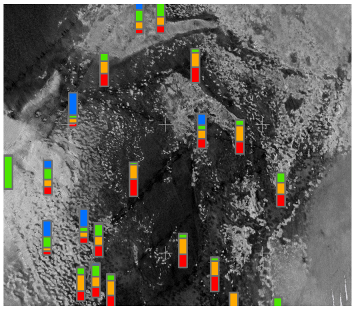


Figure 11a: Close up of Little Peconic Bay, middle.

Single Pixel Correlation

As discussed earlier, there is a well-documented relationship (e.g. Brown and Collier, 2005; Ryan and Flood, 1996) between grain size and backscatter. One of the objectives of this study was to examine this relationship in the Peconic Estuary. Figure 12 graphs the relationship between the mean phi size for each sediment sample and the backscatter intensity. The backscatter intensity was taken from the single pixel each sample was located in. The correlation is $r^2= 0.59$. Because of the re-projected data and the fact that sample location was recorded on a moving ship, the single pixel a sample is located in may lack some accuracy. Given the high resolution of each mosaic, moving even a few meters in any direction would change the backscatter value.

Mean Pixel Correlation

A mean backscatter value for each sample location was calculated by averaging the nearest 20 pixels in a circular array and was compared to the mean phi size for each sample (Figure 13). The correlation between mean phi size and the mean backscatter intensity is $r^2 = 0.64$. Mean backscatter might be a more accurate measure of backscatter for each sample, since it would smooth variability in the backscatter.

Loss of Ignition (LOI) was also originally calculated for each sample (PhaseI-III/Flood) in order to estimate organic content. Backscatter and organic content (Figure 14) have a weak correlation compared to backscatter and grain size ($r^2 = 0.20$).

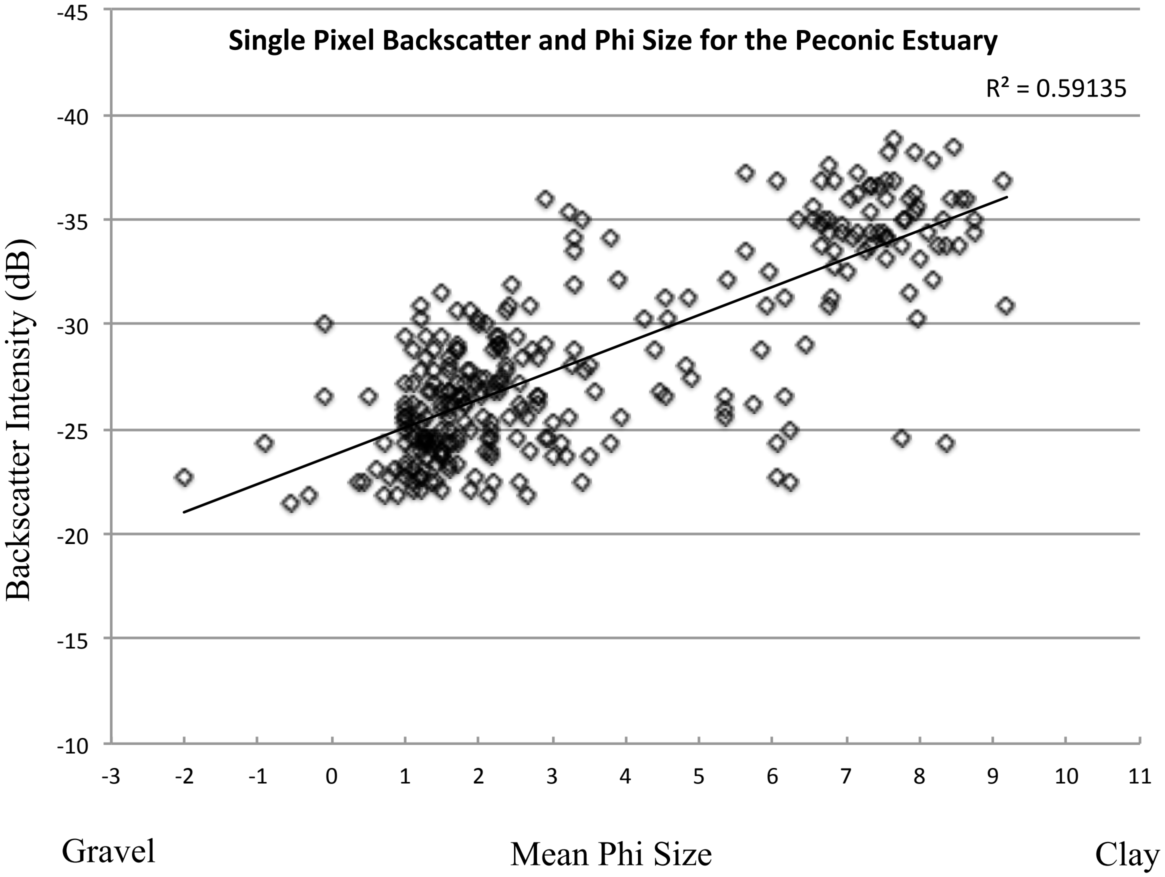


Figure 12: Single pixel backscatter and mean phi seize correlation for the Great Peconic Bay and Little Peconic Bay data (PhaseI-III/Flood). The value for backscatter was derived from the single pixel corresponding to the sample location.

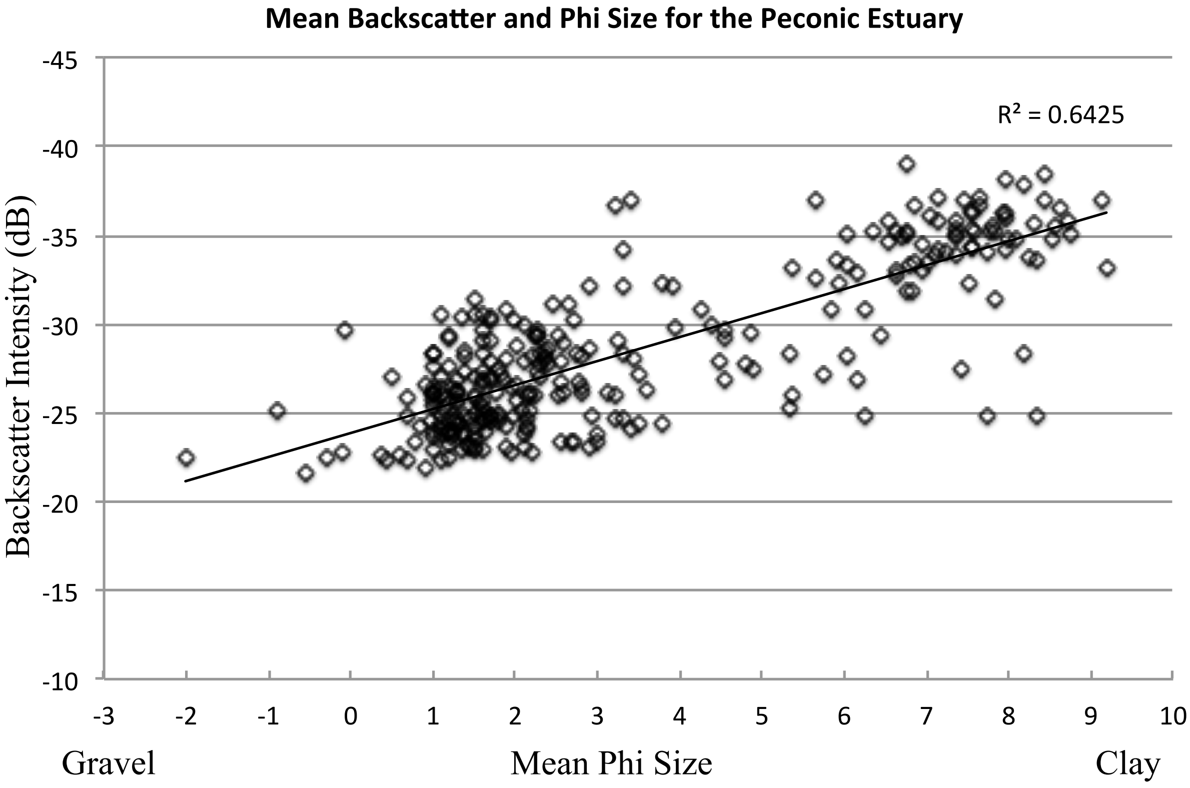


Figure 13: Correlation of mean backscatter and phi size. Mean backscatter was obtained by averaging the backscatter of the nearest twenty pixels in a circular array.

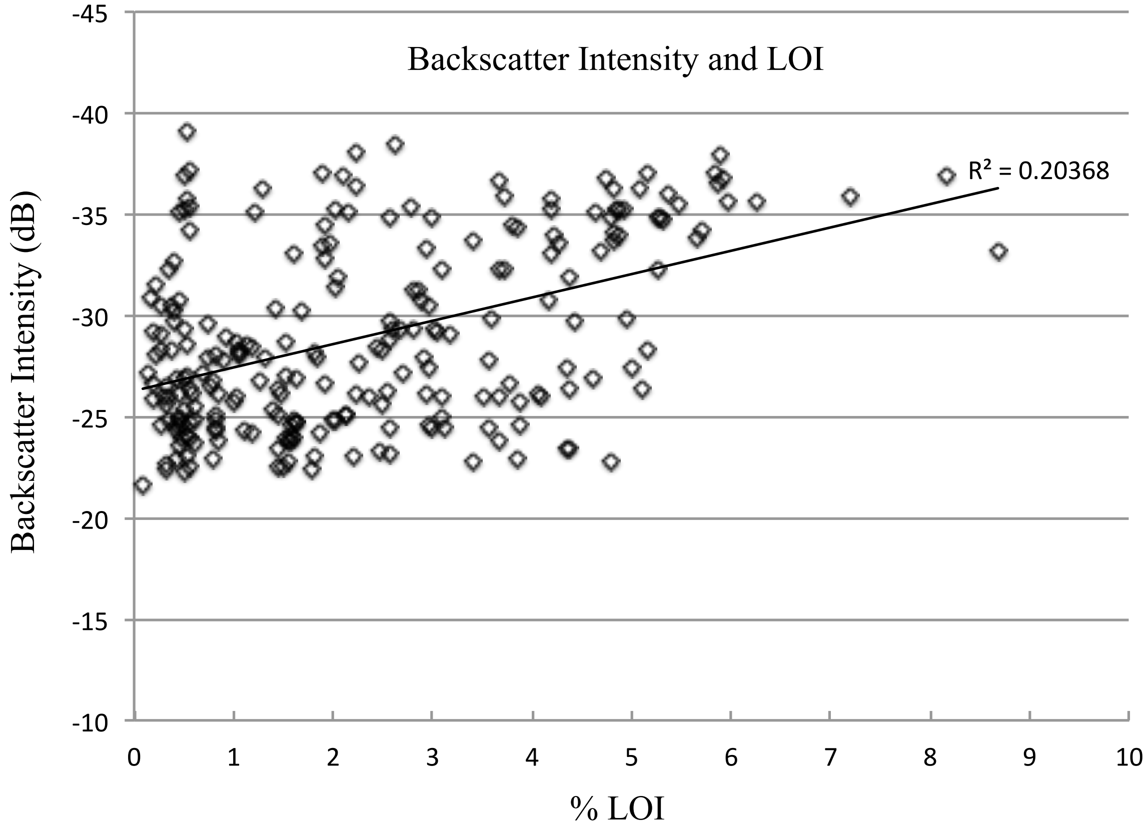


Figure 14: Percent LOI and backscatter intensity for Phase I-III/Flood. Loss on Ignition is an estimate of the amount of organic material contained in each sample.

Angular Range Analysis (ARA)

Figure 15 shows the ARA layer for the Great Peconic Bay and Figure 16 shows the ARA layer for the Little Peconic Bay. Segmented areas with the same ARA indices are assumed to have similar sediment grain sizes (Fonesca and Mayer, 2007; Fonseca et al., 2009). Indices are represented by color, reds being finer grained material and blues coarser grained material. For example in the Great Peconic Bay (Figure 15) the small patches of blue in located in the bottom left, while separated, should have comparable properties. Figure 17 graphs the relationship between the ARA scalar and phi size, $r^2 = 0.41$.

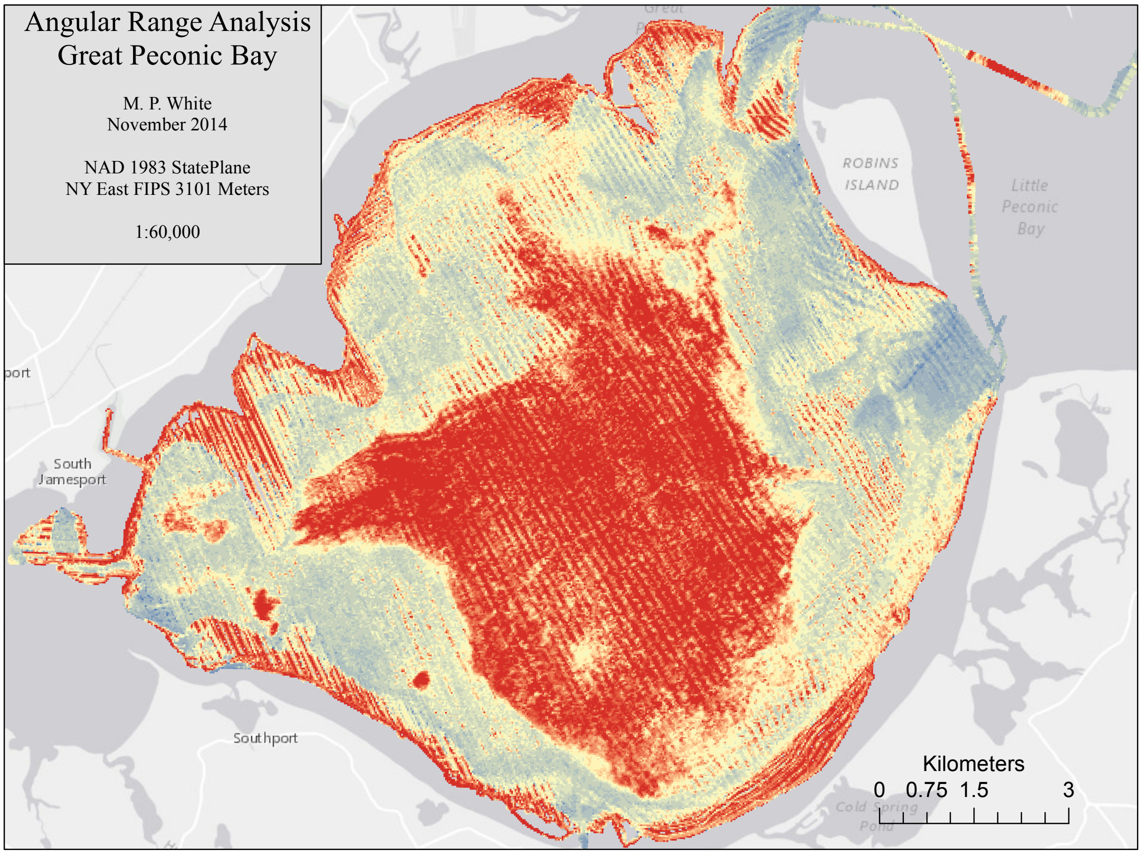
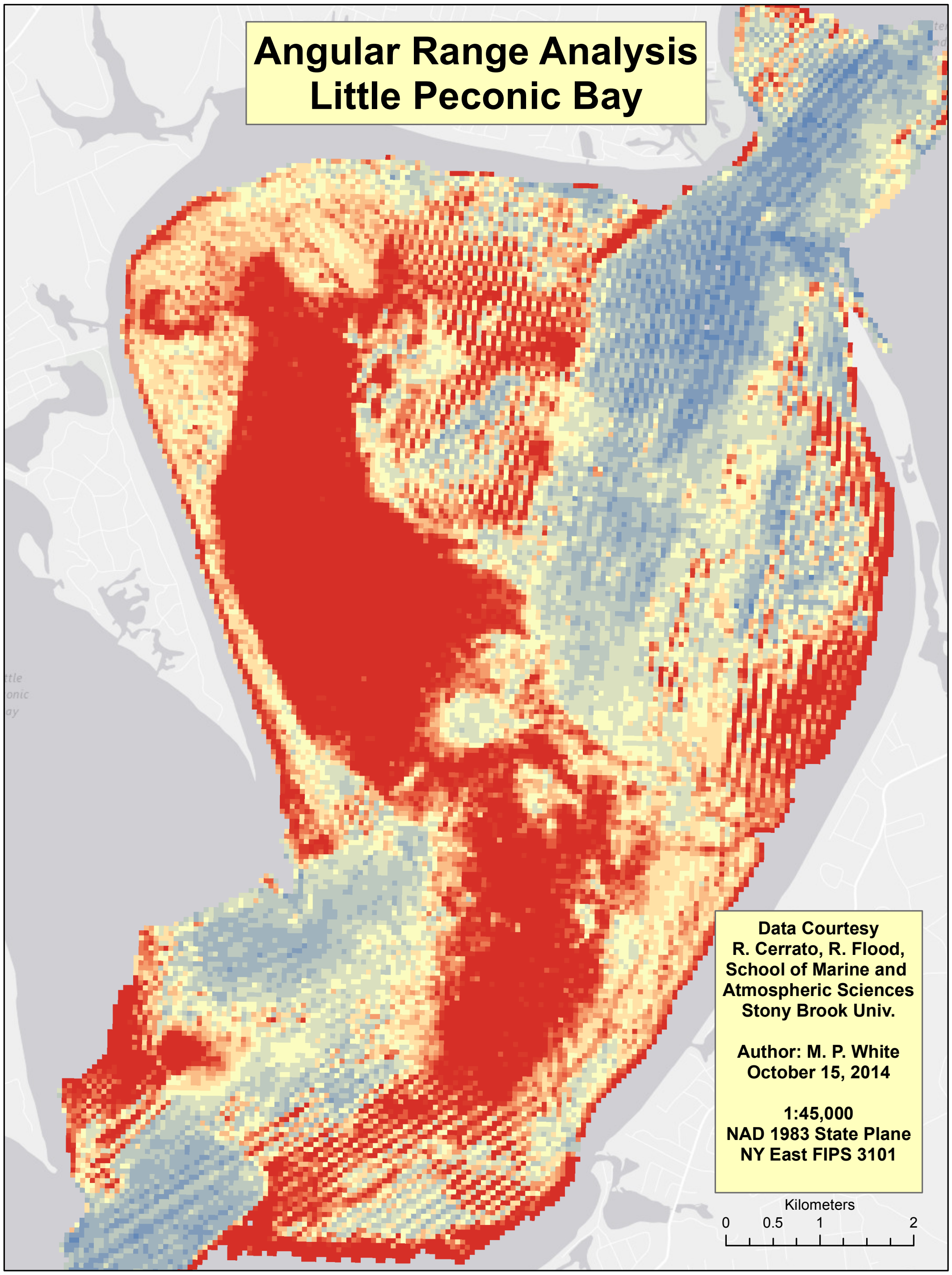


Figure 15: ARA layer for the Great Peconic Bay.



Angular Range Analysis
Little Peconic Bay

Data Courtesy
R. Cerrato, R. Flood,
School of Marine and
Atmospheric Sciences
Stony Brook Univ.

Author: M. P. White
October 15, 2014

1:45,000
NAD 1983 State Plane
NY East FIPS 3101

Figure 16: ARA layer for the Little Peconic Bay

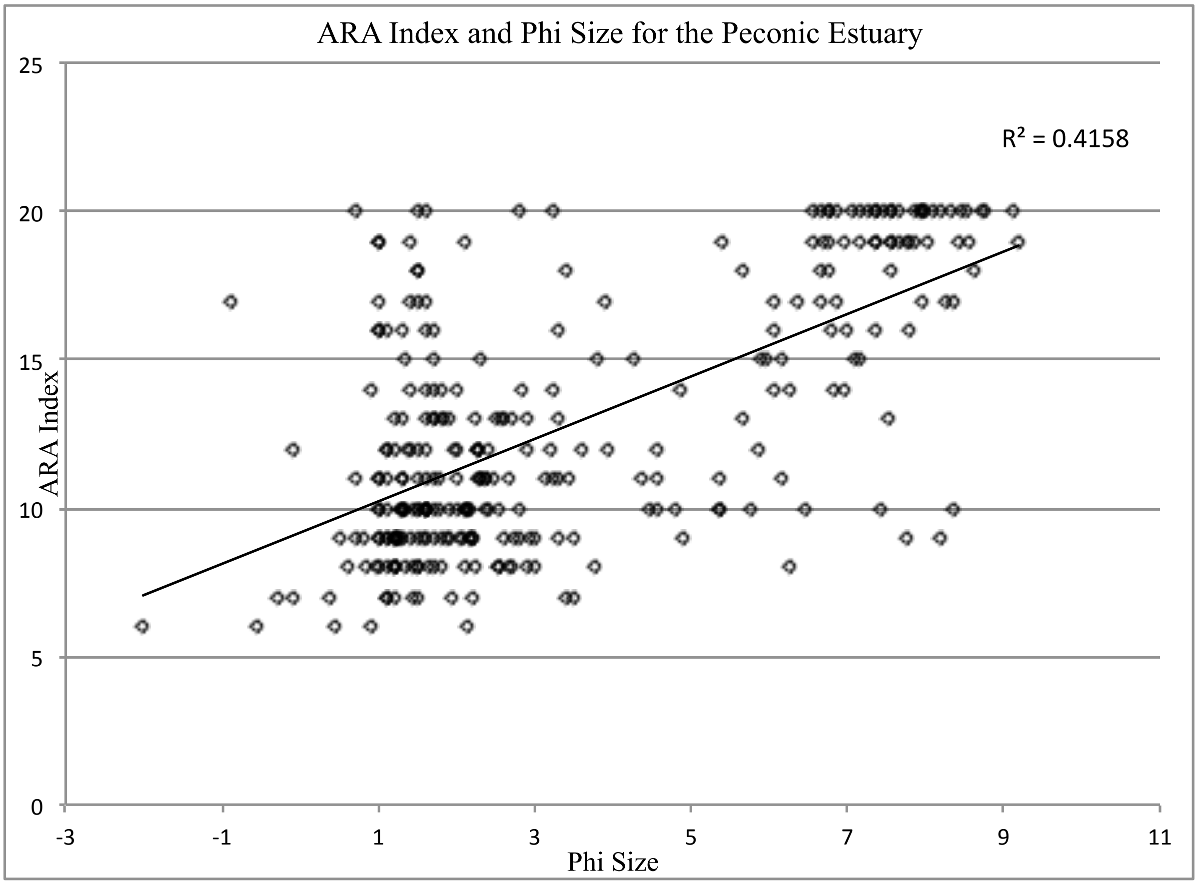


Figure 17: ARA index from FMGT and phi size from PhaseI-III/Flood.

New Geophysical Provinces:

Using the newly processed backscatter and ARA model, new geophysical provinces were visually drawn for the Great Peconic Bay and the Little Peconic Bay (Figures 18 and 19). As references, Figures 20 and 21 display translucent layers of the new geophysical provinces on top of the reprocessed backscatter.

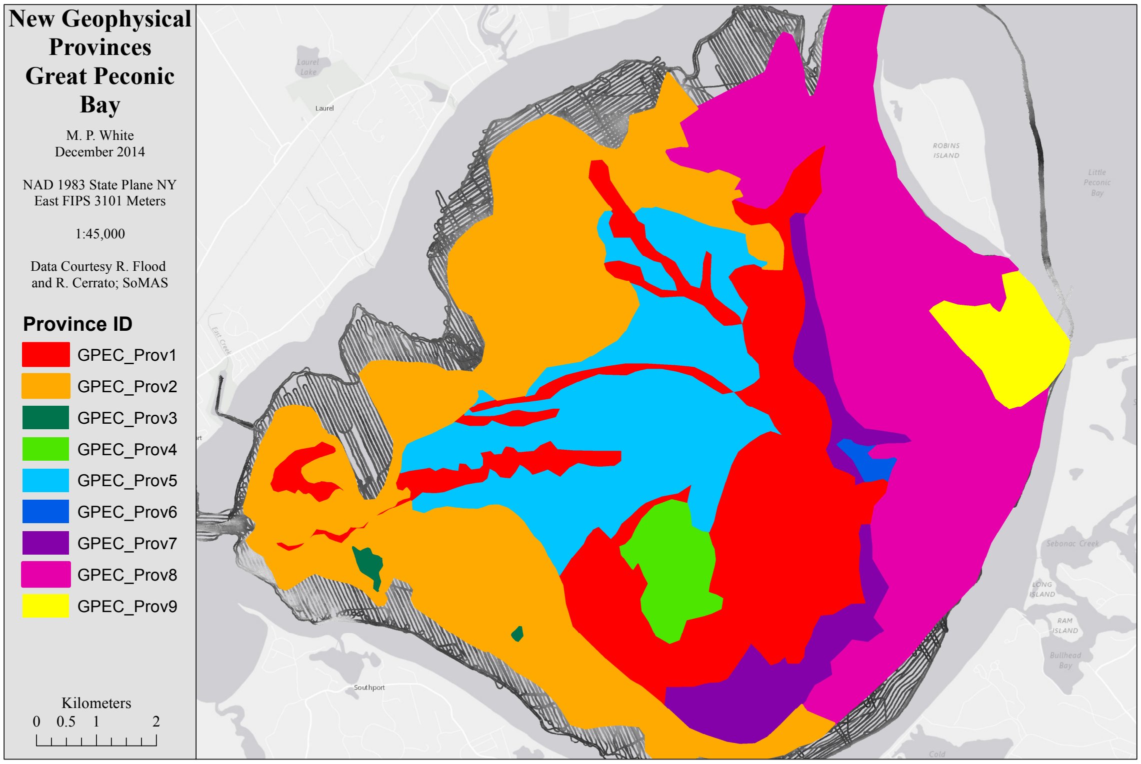


Figure 18: New geophysical provinces for the Great Peconic Bay. Provinces were drawn visually based on the reprocessed backscatter mosaic and the ARA analysis.

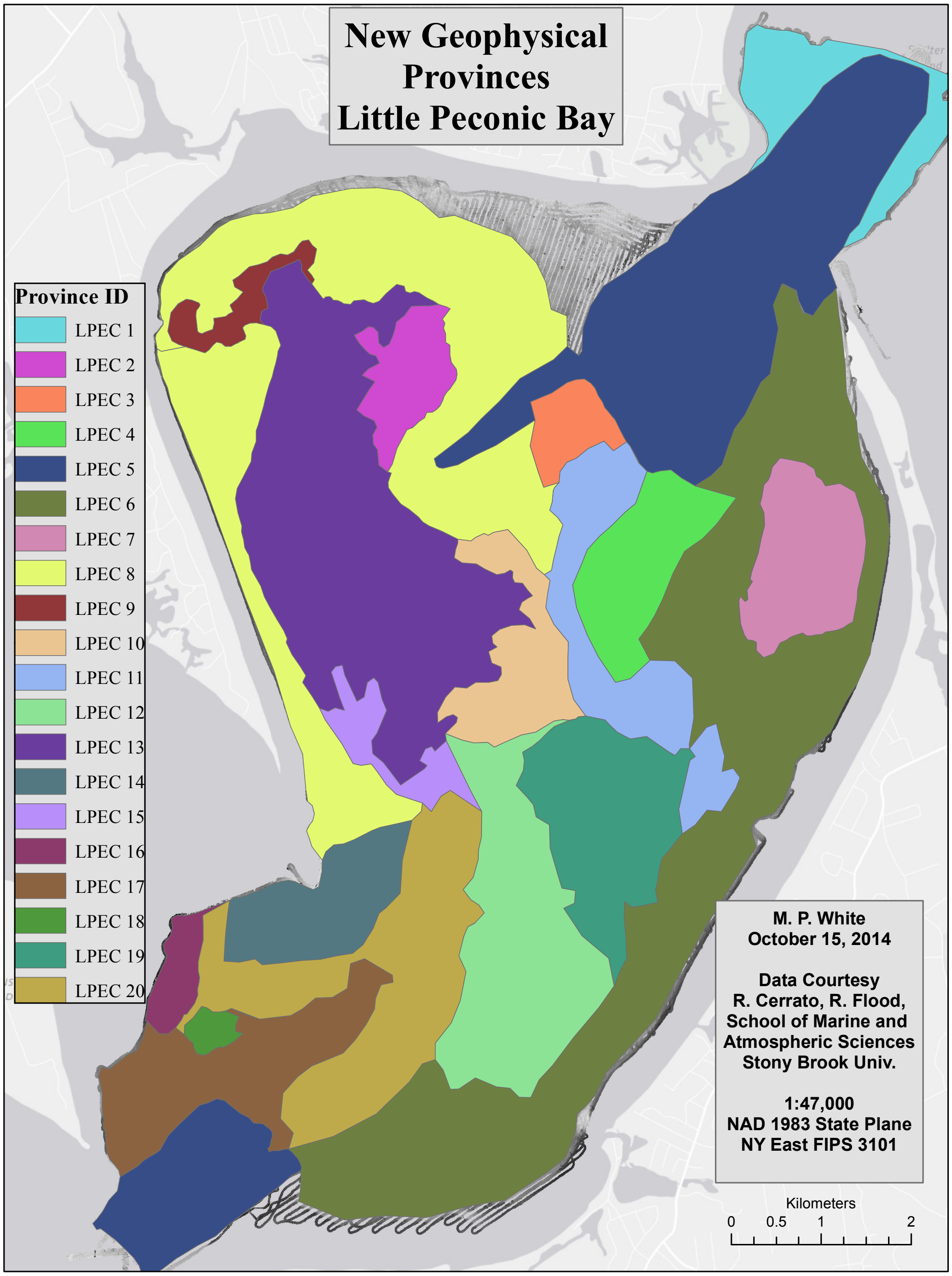


Figure 19: New geophysical provinces for the Little Peconic Bay. Provinces were drawn based visually on the reprocessed backscatter mosaic and the ARA analysis.

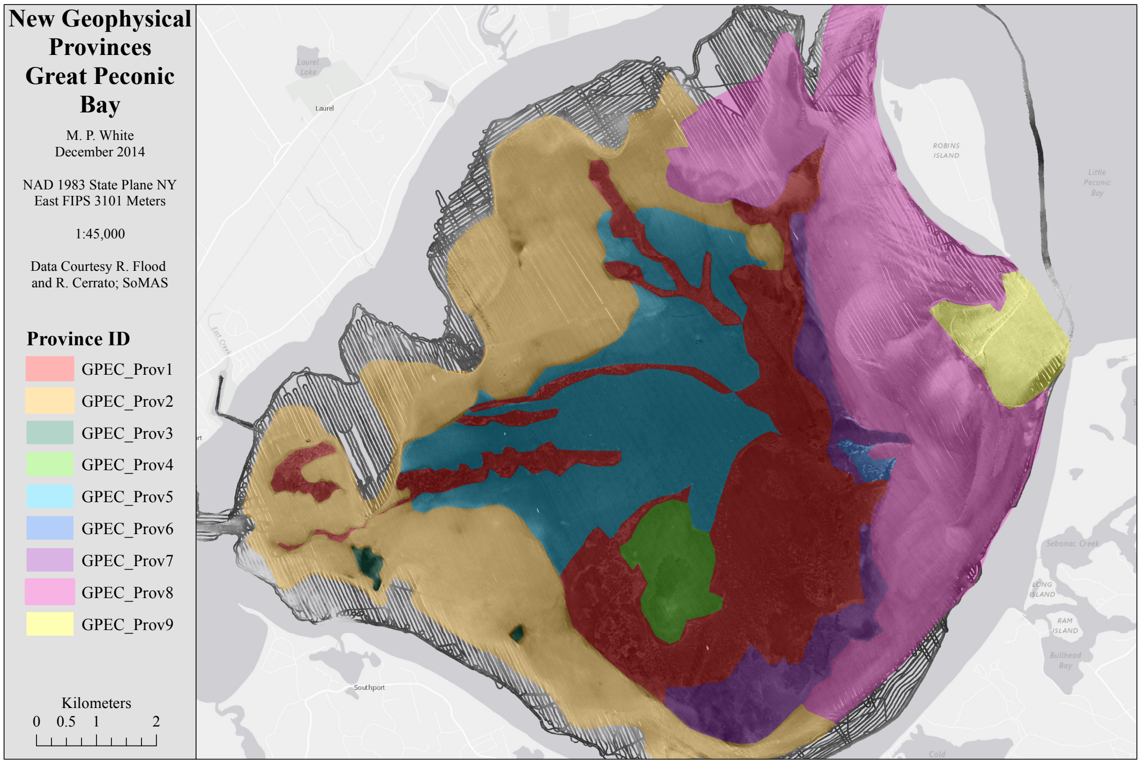


Figure 20: Semi-transparent layer of the new geophysical provinces for the Great Peconic Bay layered on top of the reprocessed backscatter.

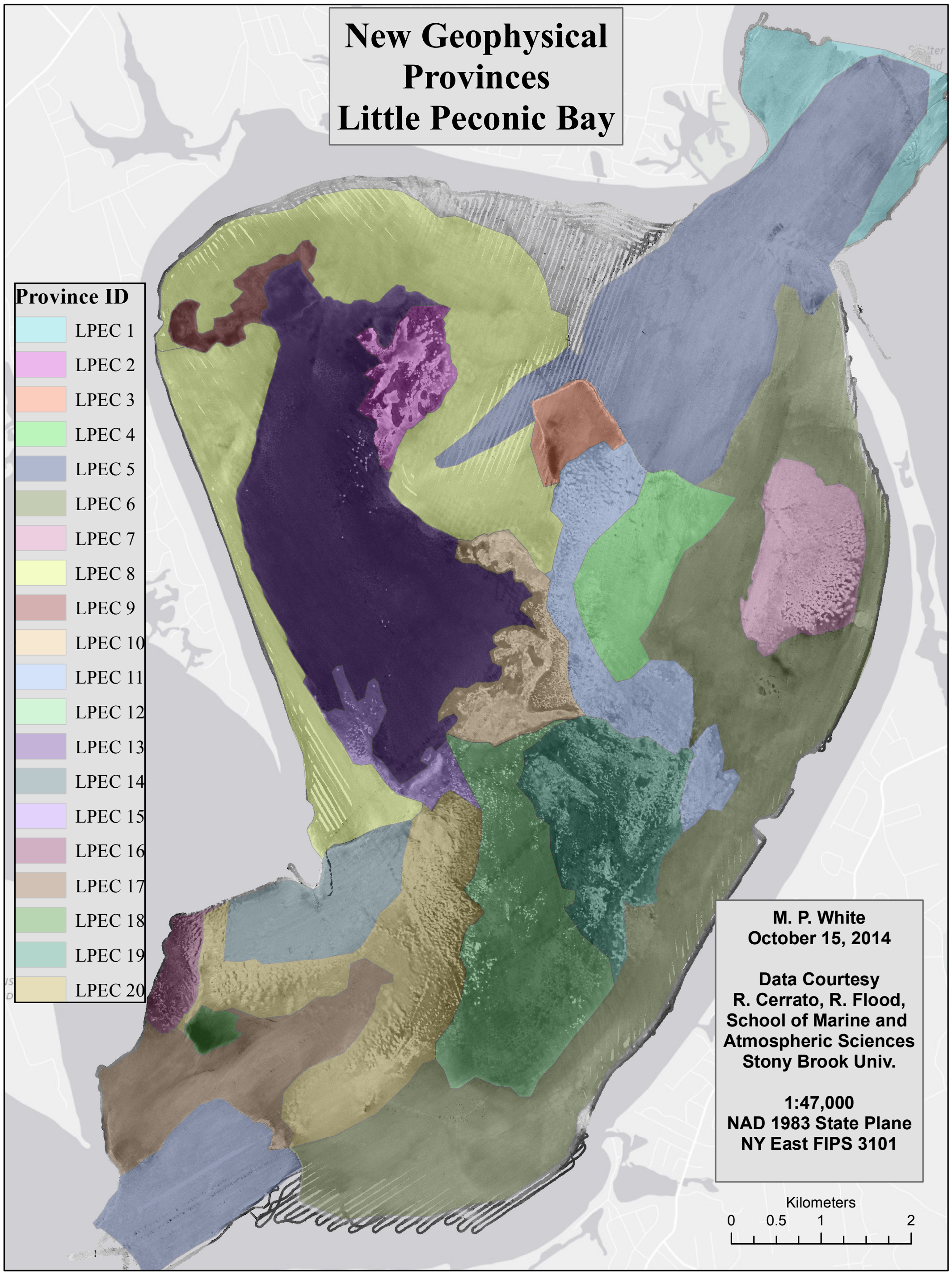


Figure 21: Semi-transparent layer of the new geophysical provinces for the Little Peconic Bay layered on top of the reprocessed backscatter.

Predicted Phi Size:

For the entire Peconic Estuary, a simple linear regression was plotted (Figure 22) in order to estimate mean phi size from backscatter intensities. Using the “Raster Calculator” tool in the Spatial Analyst Toolbox the expression was used to approximate mean phi size based on backscatter intensities. Figure 23 displays the result for the Great Peconic Bay and Figure 24 shows the result from the Little Peconic Bay.

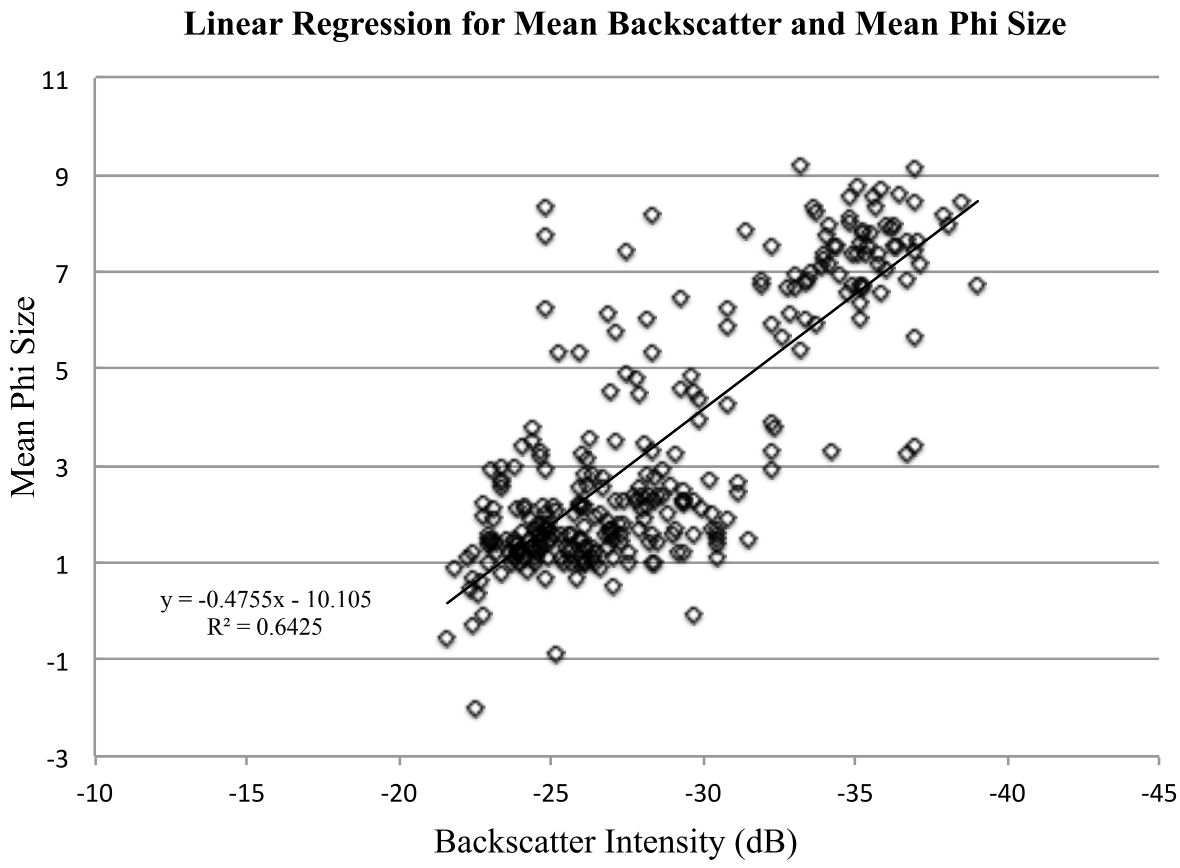


Figure 22: Linear regression for mean phi size and mean backscatter intensity for PhaseI-III/Flood.

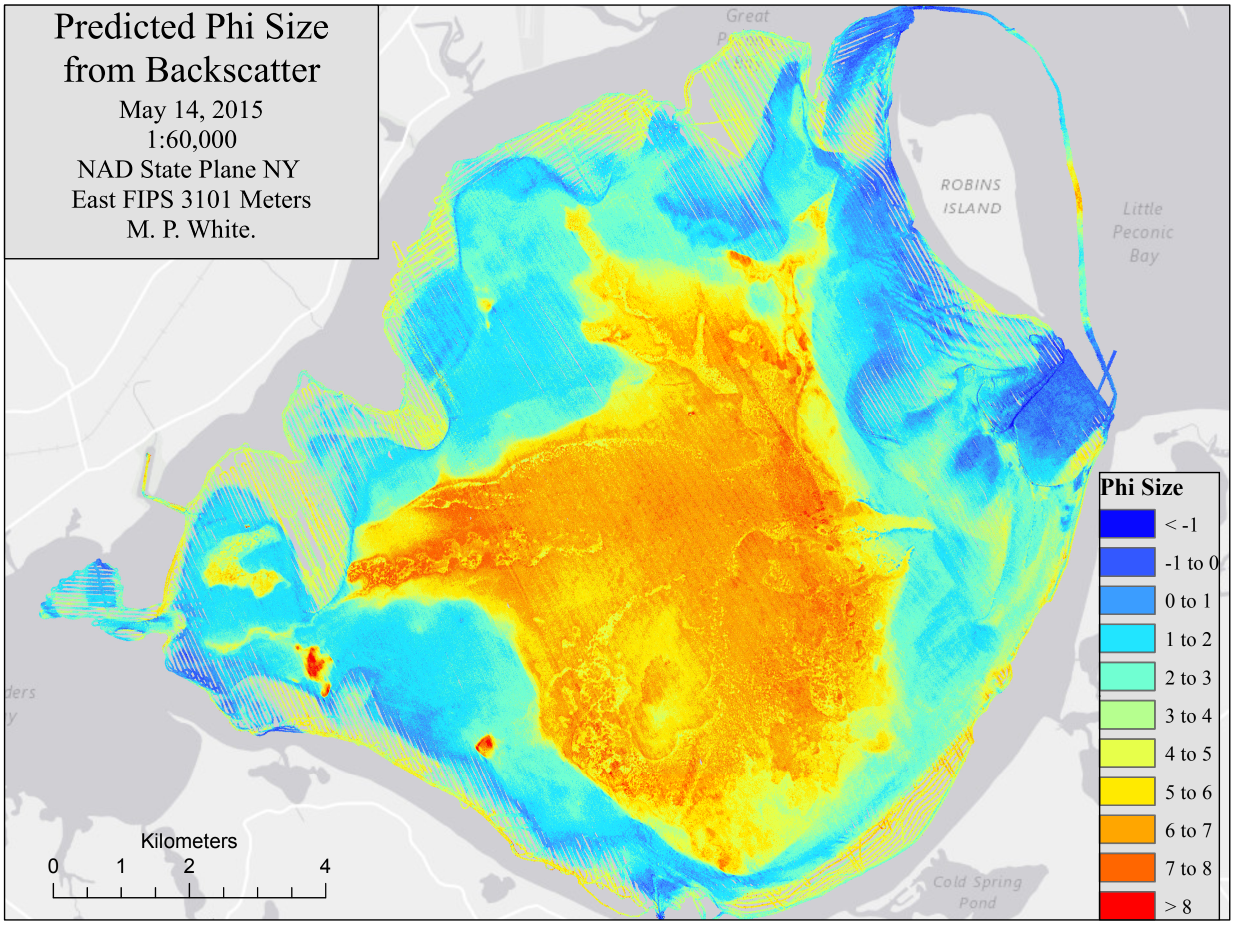


Figure 23: Predicted mean phi size from backscatter for the Great Peconic Bay.

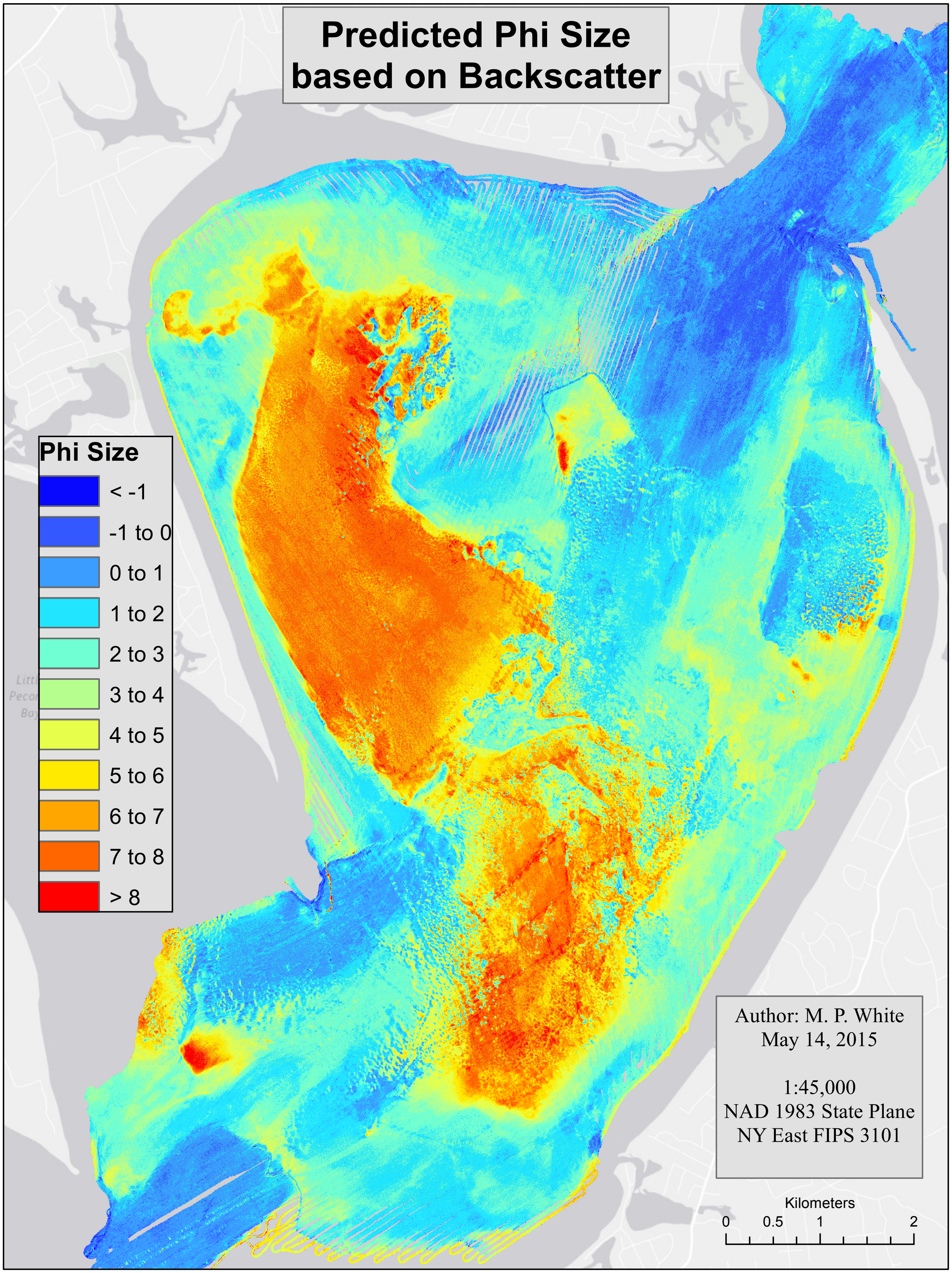


Figure 24: Predicted mean phi size from backscatter for the Little Peconic Bay.

Discussion:

Faunal Samples and New Geophysical Provinces:

The faunal data from the ground truth samples was overlaid on top of the new geophysical provinces to see if there was any spatial correlation between the fauna data and the new provinces. Figures 25, 26, and 27 display the fauna data broken down by phylum: mollusk, polychaetes and crustaceans for the Great Peconic Bay. Figures 28, 29 and 30 illustrate the fauna data broken down by phylum: mollusk, polychaetes and crustaceans for the Great Peconic Bay.

There exist some visual correlation between the new provinces and the fauna data. In the Great Peconic Bay, Province 8 contains the highest amounts of mollusks and crustaceans. Provinces 2 and 8 contain the highest amount of polychaetes. Other Provinces, such as 5 and 3 contain relatively low amounts of all three categories. Some of the new geophysical provinces do not contain any fauna samples. If investigator wanted to effectively characterize habitats and map biotopes in the Peconic Estuary, the density of sampling is not high enough.

Any visual correlation between faunal data and the new geophysical provinces should be taken with some caution. Data were collected over the coarse of several years and in different seasons, resulting in changes in community structure. What is clear however, if that with the new provinces based on the reprocessed acoustic data, both the Great Peconic Bay and the Little Peconic bay are under sampled in order to accurately describe all provinces.

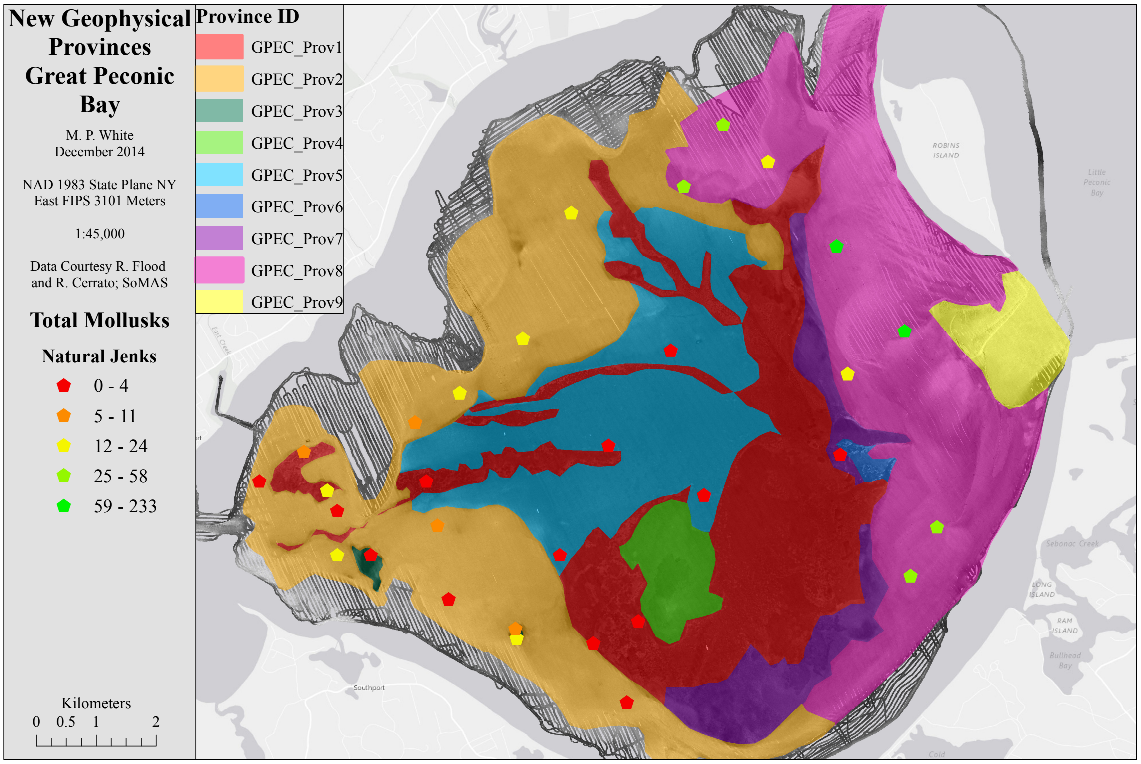


Figure 25: Mollusk counts symbolized by natural jenks for the Great Peconic Bay.

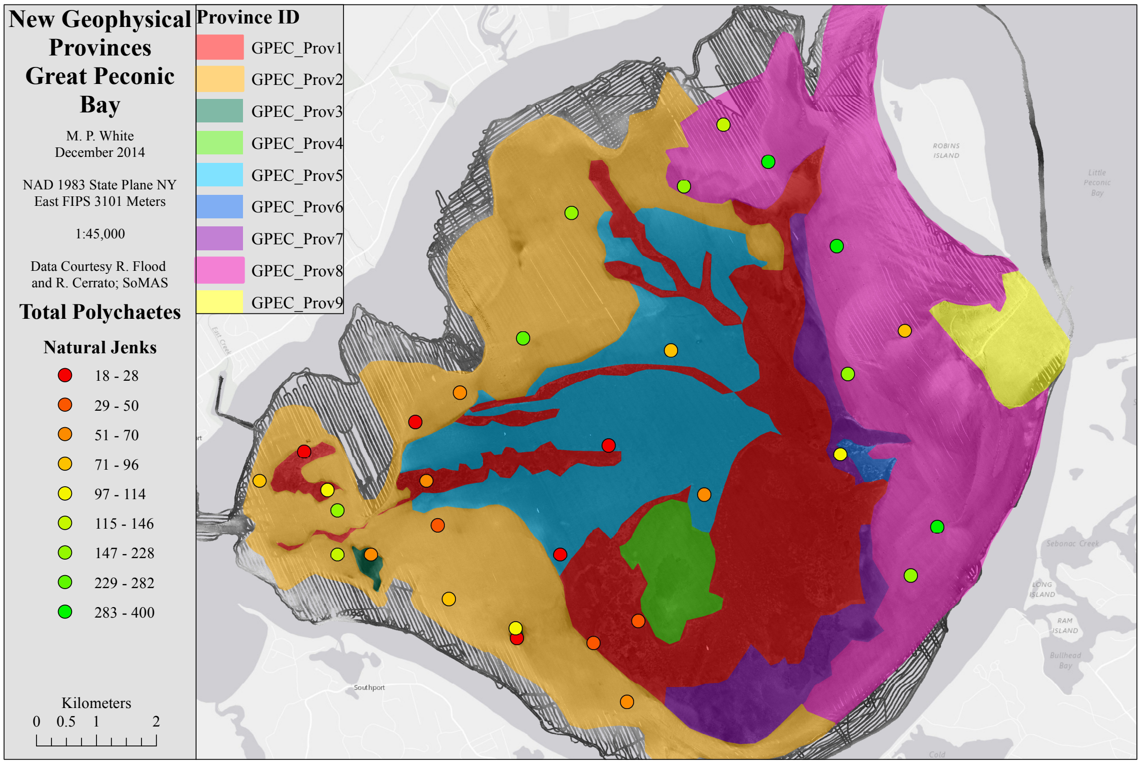


Figure 26: Polychaete counts symbolized by natural jenks for the Great Peconic Bay.

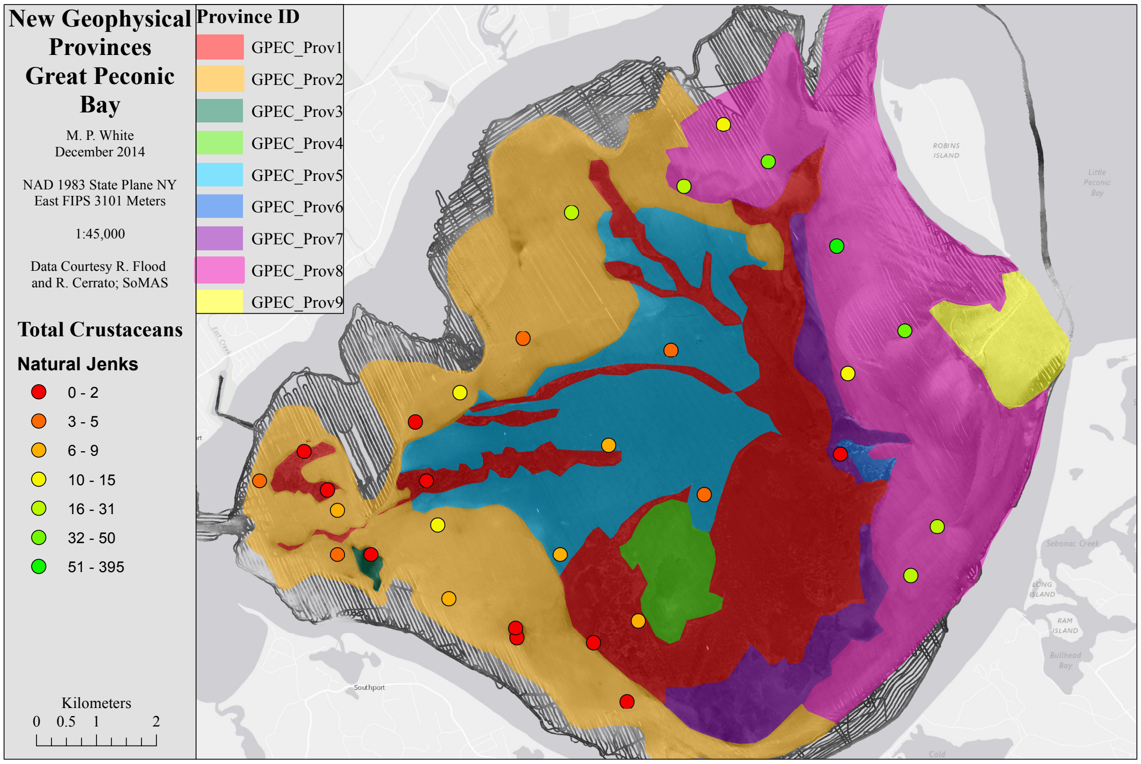


Figure 27: Crustacean counts symbolized by natural jenks for the Great Peconic Bay.

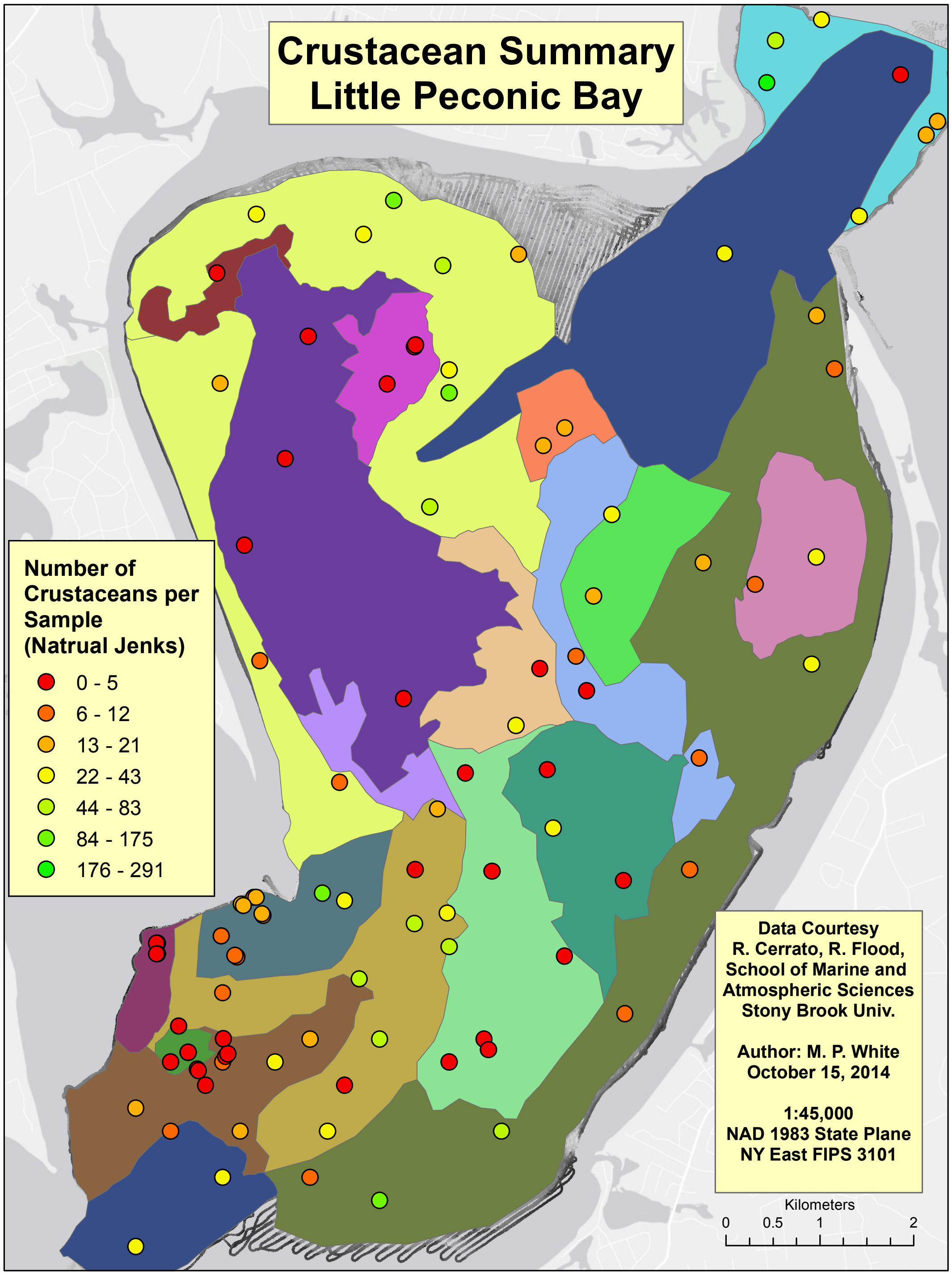


Figure 28: Crustacean counts symbolized by natural jenks for the Little Peconic Bay.

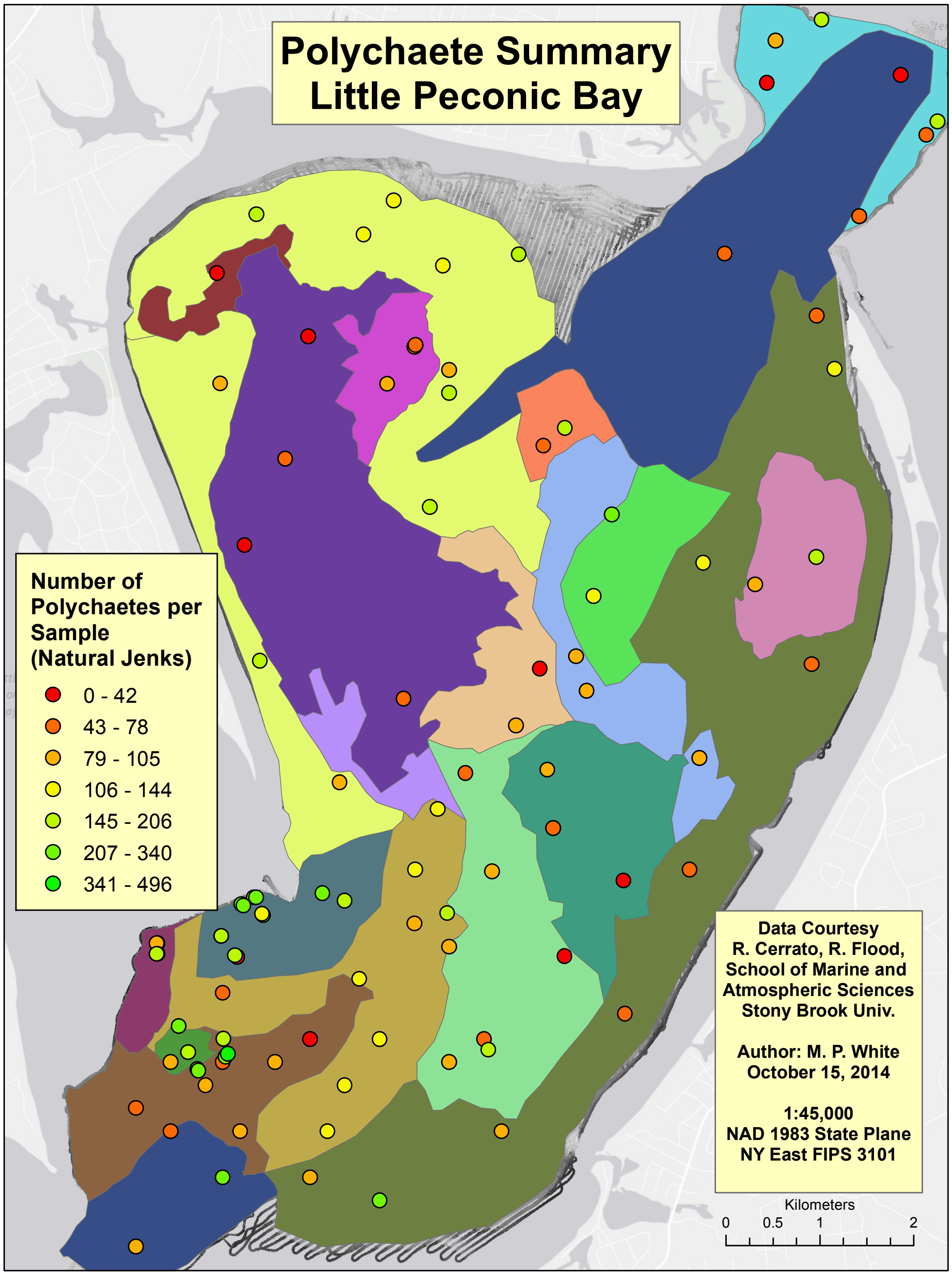


Figure 29: Polychaetes counts symbolized by natural jenks for the Little Peconic Bay.

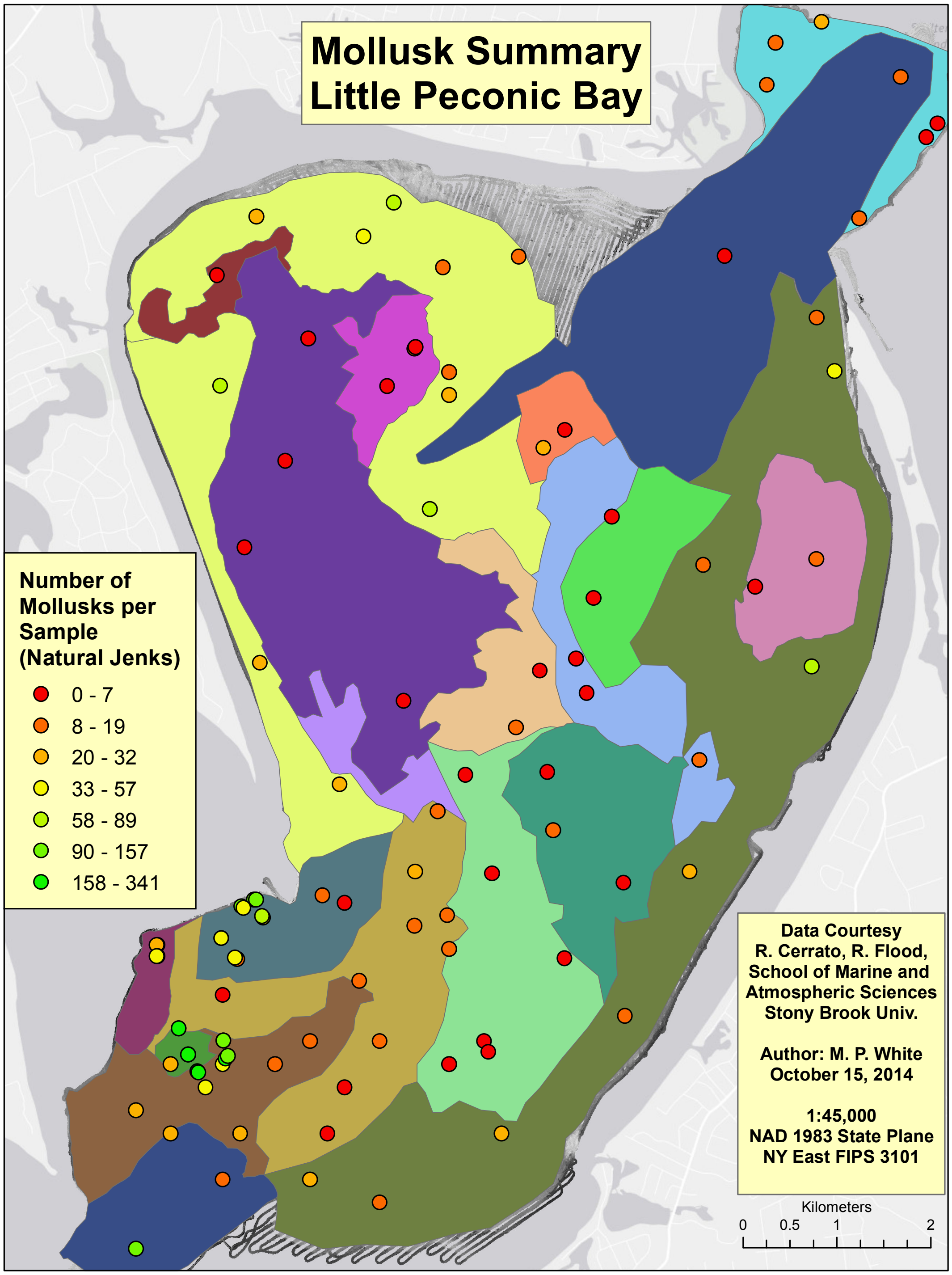


Figure 30: Mollusk counts symbolized by natural jenks for the Little Peconic Bay.

New and Old Backscatter Mosaics:

Compared to the original backscatter mosaics (Figures 3 and 4) the reprocessed mosaics (Figures 8 and 9) provide several advantages to those attempting to characterize the seafloor. The granular texture of the old mosaics has been decreased while finer scale features have been preserved. These features are evident in several places. In the new mosaic for the Great Peconic Bay (Figures 31) the sinuous features had clear boundaries with well-defined internal texture. These sinuous features may be extinct river channels, which were active during the last glaciation, when see level was lower. In the bottom of Figure 31, clearly defined dark patches are present in the new backscatter. Some of these textures may result from burrowing organisms that are transporting deeper material to the surface, telegraphing the properties of stratigraphically deeper sediments. Also in Figure 32 in the bottom right hand corner there are lines of oscillating bright and dark backscatter. This pattern suggests these features are sand waves; the brighter areas are the crests representing coarser grained material and the dark areas are the troughs, representing finer grained material. In the Little Peconic, the scaly pattern in the middle bottom show clear boundaries between areas of bright and dark backscatter, displaying small features (2-3m). In Figure 33 scaly textures in the south, with alternating areas of dark and bright backscatter likely represent paleo-oyster reefs. The bright areas are the result of more intense backscatter from the hard surfaces while the dark, less intense areas are where finer grain sediment has been deposited onto of the paleo-reefs (Kinney, 2012).

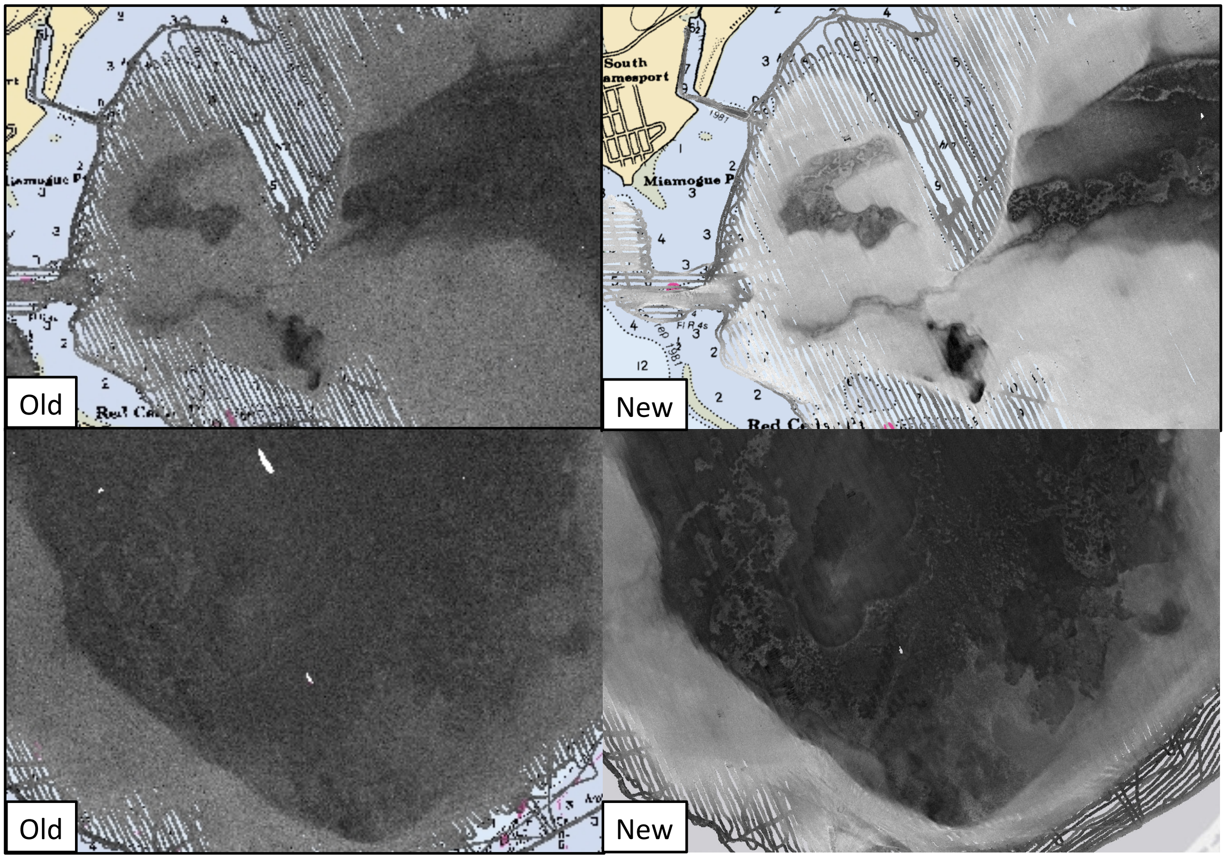


Figure 31: Panels showing comparison of zoomed in areas for the Great Peconic Bay. Panels from the old mosaic are on the left, panels from the new mosaic are on the right.

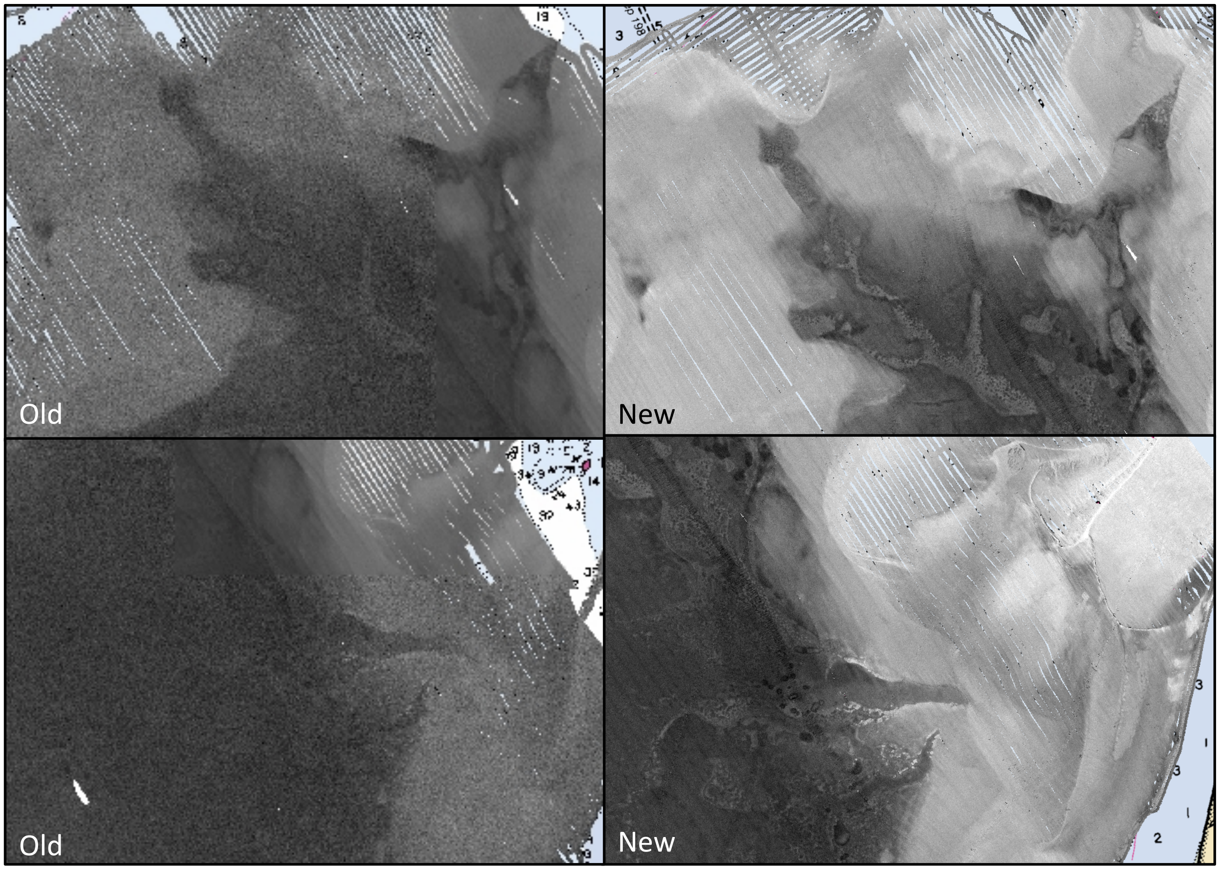


Figure 32: Panels showing comparison of zoomed in areas for the Great Peconic Bay. Panels from the old mosaic are on the left, panels from the new mosaic are on the right.

New and Old Geophysical Provinces:

Figures 33 and 34 compare the old and new geophysical provinces for the Great Peconic and Little Peconic Bays. While some of the provinces are similar in each map, new provinces have been added and some old provinces have been merged together. Again, it should be noted the old provinces were drawn over a period of years and the new provinces were drawn based on the entire preprocessed mosaic. The new provinces have more complex boundaries between are of dissimilar acoustic response. While the new provinces provide a finer delineation based on the reprocessed backscatter, increased sampling within individuals provinces would help explain the distribution of physical characteristics.

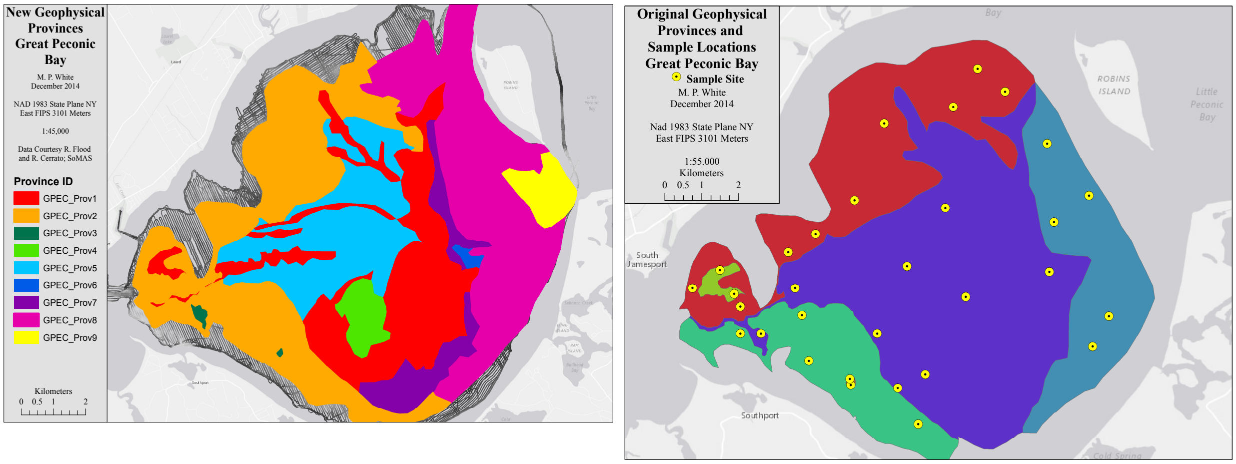


Figure 33: Comparison of New and Old Geophysical Provinces for the Great Peconic Bay

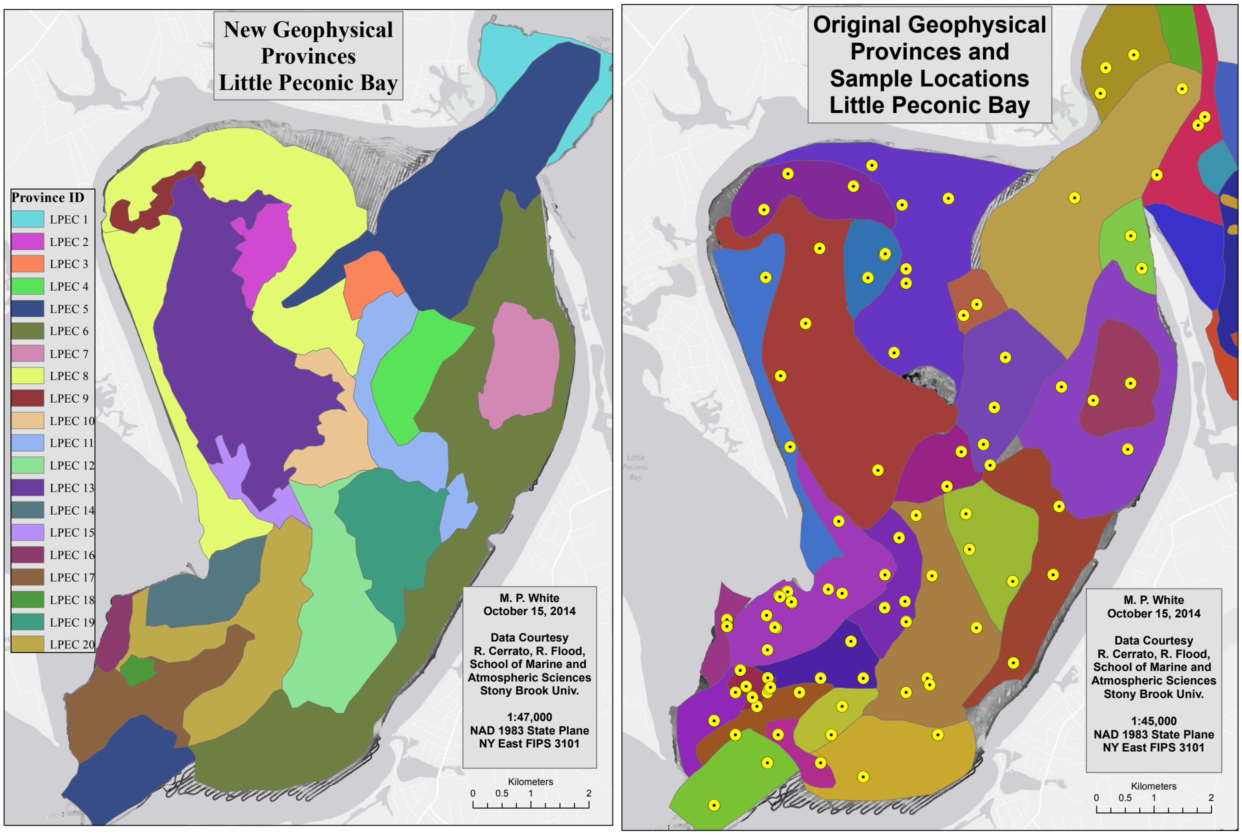


Figure 34: Comparison of New and Old Geophysical Provinces for the Little Peconic Bay

Grain Size, Backscatter and ARA:

The correlation between grain size and backscatter in the Peconic Estuary was relatively strong. But this relationship has nuances and reasons why the correlation is not stronger. Working in the Hudson River Estuary, Nitcshe et al (2004) found patterns in the backscatter that could not be explained by grain size. The grain size variation was too small to be explained by the difference in acoustic backscatter. Instead they found the patterns in the backscatter were the result of changes in roughness, compaction and thickness of the surficial sediment layer on top of the bedrock. These characteristics determined by depositional environment, were all used to explain the variation in the backscatter (Nitcshe et al, 2004). If one can relate backscatter to local depositional environments, one can also use patterns in the backscatter to predict environmental energy and can make inferences about how geologically dynamic it is. In one fjord that continually experienced flooding events, researchers found an inverse correlation between the backscatter and grain size; the larger the grain size actually produced a lower intensity backscatter (Urgeles et al, 2002). The coarser flood deposits were less bioturbated compared to the finer grained material because most organisms do not do well if flood deposits are continually burying them. The bioturbation increased sea surface roughness and altered the porosity of the sediments. Ferrini and Flood (2006) found a positive correlation of median grain size and backscatter but concluded that in addition to grain size, sorting, the standard magnitude of seabed roughness were all significant in predicting backscatter.

Other than the geologic properties already mentioned (grain size, sorting, roughness, porosity, and compaction) many biologic factors can also influence sediment properties and therefore affect backscatter. Biologic factors may include nutrient supply, trophic interactions, percent organic matter and microbial content. Organic content did not have as good of a correlation compared to grain size in the Peconic Estuary. Another example could involve the presence of benthic vegetation. Areas covered by seagrass in shallow marine environments around Long Island, NY are typically characterized by high intensity backscatter due to the presence of gas in the grass. In additional to finding that similar acoustic areas had similar geological properties, Brown and Collier (2008) found that areas of similar biological properties also had a similar acoustic response.

Using a simple linear regression to predict phi size based on backscatter is a straightforward, but effective method of characterizing the seafloor. Given the strong correlation between backscatter and grain size for the Peconic Estuary this is an effective way of predicting mean phi size based on mean backscatter.

The ARA indices and grain size had a weaker correlation compared to grain size and backscatter. It may be the ARA does not have a high enough resolution and groups dissimilar areas together. Based on the results presented here, assuming that ARA classifies areas of similar sediment grain size may not be appropriate. However, in geographically larger data sets this coarseness may even out.

<u>Future Work:</u>

I have shown here backscatter and grain size have a relatively good correlation in the Peconic Estuary. How factors such as porosity, compaction, roughness and bioturbation effect backscatter in the Peconic Estuary remains unclear. Future studies should include in situ measurements of these properties and to explore their relationship with backscatter in the Peconic Estuary.

While the new geophysical provinces can be used to more accurately target future ground truth efforts, there does not exist sufficient density of samples to segment and map biotopes. In the Great Peconic Bay, more geophysical provinces were drawn. More samples are needed to describe these provinces. In the Little Peconic Bay, while some provinces were merged together, some of the new provinces do not have any samples. Mapping of specific biotopes would necessarily involve a larger sampling effort.

As already noted, the surveys and the data presented here were collected here were collected at different times of year in different years. This allows for changes in sediment distribution and community structure. In order to more accurately describe a region, sampling and acoustic surveying should occur within a smaller time window. Instead of breaking naturally distinct regions down geographically, surveyors should try and collect the data for an entire region. This ensures the acoustic data will be continuous through the area.

Conclusion:

Acoustic data, backscatter in particular can be a powerful tool when attempting to segment and classify the seafloor. The successful reprocessing of MBES backscatter data let to improved mosaics can be used to redraw provinces based on distinct boundaries. New provinces can be used to target future ground truth efforts. Regionally, areas of similar acoustic response are assumed to have similar physical characteristics. In the Peconic Estuary, there exists a good correlation between backscatter and sediment grain size. This relationship was used to map predicted phi size. By reprocessing data sets using improved software, these data sets remain viable and important sources of information.

List of Citations

Blondel P, Paroson LM, Robigou V. TexAn: textural analysis of sidescan sonar imagery and generic seafloor characterization. IEEE 1998;98:419-23.

Brown CJ, Blondel P. Developments in the application of multibeam sonar backscatter for seafloor habitat mapping. Applied Acoustics 2009;70:1242-47.

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