Final Report

2009 Atlantic Sea Scallop Research Set-Aside Program

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Executive Summary

We proposed this research first because there were no comprehensive sediment maps of the northwest Atlantic Ocean continental shelf. Habitat researchers and fishery managers were relying heavily on compiled geological point datasets and hand-drawn sediment maps to designate Essential Fish Habitat and develop area-based fishery management measures which have had strong implications for the sea scallop and groundfish fisheries (Poppe et al. 2003, Poppe et al. 2005, NMFS 1998, NMFS 2003).

Second, despite a large literature about the natural disturbance and transport of sediments by tidal and storm-generated forces on the continental shelf there were no shelf-scale maps delineating the regions where these conditions exist. Natural seabed disturbance information is critical for assessing the impacts of fishing gear on the sea floor, implementing and evaluating of Marine Protected Areas, and understanding the spatial ecology of commercial important fish and shellfish species.

We mapped the surficial sediment and natural substrate disturbance for the northwest Atlantic Ocean continental shelf in USA waters to a depth of 200m. The maps cover 238,400 km^2 of shelf stretching south from the US-Canada Border in the Gulf of Maine past Cape Hatteras, NC. After examining the sediment data in both the usSEABED and the SMAST Video Survey databases we used the sediment types observed at 138,844 sampling locations to map silt, sand, granule- pebble, cobble and boulder *dominated* sediments. Natural sediment disturbance was assessed for the Gulf of Maine, Georges Bank and northern Mid-Atlantic Bight regions using bi-weekly mean maximum shear stress fields derived from the Finite Volume Costal Ocean Model. Regions where model-computed mean maximum shear stress matched or exceeded sediment critical shear stress thresholds were mapped using hindcast model runs for 1995-2008. Regions of sediment disturbance due to winter storm events were inferred based on high-resolution depth data provided by the National Ocean Service and the SMAST Video Survey database.

This research was developed and conducted with direct input from the New England Fisheries Management Council's Habitat/ Ecosystems/ Marine Protected Area Plan Development Team. All the resulting data and map products were provided to the Team and presently form the base layers of the Swept Area Seabed Impact Model which are being developed to assess the adverse effects of fishing on Essential Fish Habitat (NEFMC 2010). In addition, these maps and analyses were used in education and outreach work with public primary, middle and high-school students and teachers. Maps were displayed at the New Bedford Working Waterfront Festival (25-26 Sept 2010), and at the Ocean Explorium at New Bedford Seaport for general public ocean education. Our research was conducted in cooperation with the scallop fishing industry. Fishing industry members provided important input during the data analysis and mapping phases of this work via the SMAST Scallop Industry Research Steering Committee which meets bi-monthly at SMAST.

Introduction

Surficial sediments play an important role in continental shelf marine ecosystems, and are frequently used to delineate benthic habitats (for regional examples see Kostylev et al 2001, Auster et al. 2003, and Harris and Stokesbury *In Press*). Since the mid-1900s researchers have studied northwest Atlantic Ocean continental shelf geology (for examples see: Shepard 1932, Stetson 1938, Wigley 1961,Schlee et al. 1973, Twichell 1983, Poppe et al. 1989, Stokesbury and Harris 2006). However, there were no comprehensive shelf-scale maps of the mud, sand, and gravel. The available maps were hand-drawn by experts and were intended to reflect very broad scale geological conditions (Poppe et al. 1989, 1994). Recent analyses have shown that these sediment type depictions are inaccurate (Harris and Stokesbury *In Press*).

Since the passage of the Sustainable Fisheries Act of 1996 and the subsequent Essential Fish Habitat (EFH) regulations the New England Fisheries Management Council habitat analyses have relied heavily on US Geological Survey (USGS) sediment datasets and the hand-rendered Continental Margin Mapping Sediment Grainsize substrate map (CONMAPSG, Poppe et al. 1989, Poppe et al. 1994, Poppe et al. 2000, Poppe et al. 2003, Poppe et al. 2005). The fisheries policy decisions made using these sediment data and map are substantial. For example, during Amendment 13 to the Northeast Multispecies Fishery Management Plan the Habitat PDT developed a set of ten closed area alternatives intended to minimize the adverse impacts of fishing on EFH. A primary factor in selecting the preferred alternative was the percent sediment composition and the relative percent area (nautical miles^2) represented by each sediment type within each proposed closed area based on digitizing the maps of Poppe et al. (1989, 1994). Harris and Stokesbury (*In Press*) found that most of the resulting Georges Bank EFH closed areas do not correspond well with the distribution of gravel sediments as intended.

Proposed Work (*From the Proposal)*

We propose to develop maps of benthic substrates and natural substrate disturbance for the northwest Atlantic Ocean continental shelf in USA waters, including the Gulf of Maine, Georges Bank, and the Mid-Atlantic. We will select appropriate data from both the SMAST and the usSEABED databases to map *soft* (silt, sand, granules and pebbles) and *hard* (cobbles and boulders) substrates. Natural substrate disturbance will be assessed for the Gulf of Maine and Georges Bank areas using mean maximum shear stress fields derived from the Gulf of Maine Finite Volume Costal Ocean Model (FVCOM-GoM). We will use hindcast model runs for 1995-2008 to determine regions where model-computed mean maximum shear stress matches or exceeds substrate thresholds at daily, seasonal, and annual scales. Substrate and disturbance maps will be constructed with scallop industry input and corroborated with data such as industry and NOAA trawl hangs. The proposed research is unique and not funded by any existing research grants.

Research Priorities Addressed by the Proposal

This proposal addresses important regional and national issues described in the 2009 Sea Scallop Research Set-Aside Program (NMFS-NEFSC-2009-2001472) and identified by the New England Fishery Management Council (NEFMC) Habitat and Scallop Plan Development Teams.

1. *Habitat characterization research (priority #6)*. Presently the relationships between benthic habitats and fishery species life stage and surplus production in the study area are poorly understood. Regardless, managers continue to rely heavily on substrate information for EFH designations and to predict the effects of fishing on EFH. This proposal uses the best available information to map substrates from Cape Hatteras to ME in USA Federal waters and will directly support the evaluation of present and candidate Essential Fish Habitat (EFH) closures and Habitat Areas of Particular Concern (HAPC) relative to their stated purposes and assist in understanding the benthic ecosystem processes occurring in these areas. Further, this analysis provides representative substrate base maps essential to understanding the relationships between fishery species and benthic habitats.

2. *Identification and evaluation of methods to reduce habitat impacts of scallop fishing (priority #5)*. Tidal, current and storm-driven water flow disturbs the seabed on short and long time scales. These natural disturbances provide the context for determining *if*, *how*, and *where* bottom-contact fishing adversely impacts the seabed of the northwest Atlantic Ocean continental shelf. Our analysis will define substrates based on the best available information and delineate regions where daily, seasonal, and annual mean maximum shear stress exceeds the thresholds of substrates present. The resulting maps of natural substrate disturbance are needed to make new and evaluate past management decisions regarding area-specific gear effects. The proposed work is essential to the ongoing NEFMC Habitat Plan Development Team's evaluation of adverse effects of mobile fishing gears on EFH, and will serve in determining the impacts of the Georges Bank Closed Areas on the re-distribution and concentration of the trawl and scallop dredge fisheries into open areas.

3. *Scallop biology*, *stock assessment, and population dynamics research* and *area management (priorities # 2, 8 & 9)*. The proposed analyses of substrate and natural disturbance are important to understanding apparent variability in adult scallop distribution, recruitment, natural mortality, shell growth and predator distributions. This information will be critical to successful sea scallop management, and the effectiveness of the area rotation program.

Methods

Substrate Data

Data from the Atlantic Coast usSEABED database and the SMAST video survey database were used to map the surficial sediments of the northwestern Atlantic continental shelf in USA Federal waters to a depth of 200m. The sediment data in both databases are classified into five particle sizes: mud, sand, granule/pebble, cobble, and boulder (Table 1, Wentworth 1922). However, the collection methods, sampling resolution, and ranges of sampled sediments vary between the data in these databases.

Table 1 Sediment classes by particle size range

Sediment	***Particle size range***	***Corresponding Wentworth class***
Mud	< 0.0039-0.0625 mm	Clays (< 0.0039 mm) and silts (0.0039 – 0.0625mm)
Sand	0.0625 – 2 mm	Sands (0.0625 – 2 mm)
*Granule/pebble	2-64 mm	Granules (2-4 mm) and pebbles (4-64 mm)
*Cobble	64 – 256 mm	Cobbles (64 – 256 mm)
*Boulder	> 256 mm	Boulders (> 256 mm)

** Gravel*

usSEABED database

The usSEABED database is a compilation of 150 published and unpublished sediment type and texture datasets from hundreds of projects. The USGS DS 118 Atlantic Coast data (a subset of usSEABED) covers the study area (Reid et al 2005). Both the *extracted* and *parsed* data were used in this analysis. The extracted data are from lab-based, numeric analyses. The parsed data are quantitative data obtained from verbal logs from core descriptions, shipboard notes, and photographic descriptions.

The strengths and limitations to this dataset for sediment mapping purposes are:

Strengths

- As a compilation, the usSEABED DS 118 data cover the entire study area.
- All the data are based on physical observations of sediment.
- Both the extracted and parsed data were suitable for estimating locally dominant sediment types based on sample volume or areal coverage.

Limitations

- The sampling designs, devices, and analytical methods used vary temporally and spatially between datasets.
- Few individual studies used a formal experimental design; most were observational.
- The methods used to assess the samples vary between studies. For example, extracted data grain-size analyses were sometimes done solely on the sand fraction, excluding coarse fractions such as gravel. Parsed data word descriptions of sediment samples may emphasize or de-emphasize the proportion of fine or coarse sediment fraction, or disregard other important textural or biological components (Reid et al. 2005, Per Com M. Arsenault USGS). Metadata describing these procedures were not provided in the database and were only available in the original reports. Given the scope of this analysis it was not feasible to assess the detailed procedures used in each of the datasets in our study area (N = 73).
- Benthic grabs and coring devices were used to collect 80-90% of the extracted data samples. Due to their size and sampling mechanisms these devices are often not capable of sampling large cobbles and boulders.

SMAST video survey

The University of Massachusetts Dartmouth School for Marine Science and Technology (SMAST) has sampled the shelf study area annually since 1999 using video quadrats in a two-stage sampling design. Stations were sampled on regular grids (stage 1) with four quadrats sampled at each station (stage 2, Krebs 1989). At each station the survey vessel stopped and a

700 kg steel pyramid was lowered to the seabed for 15-30 seconds, raised until the seabed was beyond view and then dropped again. This process was repeated until four samples were taken.

The pyramid housed three live-feed S-VHS underwater video cameras (Multi-SeaCam® 2050 or 2060, Deepsea Power & Light) which simultaneously viewed each quadrat. Two cameras sampled in plan-view (quadrats) and one in parallel-view. The plan-view quadrats were 2.84 m^2 and 0.59 m^2 respectively, with the smaller quadrat nested within the larger to provide a higher resolution video sample for identifying small sediments and organisms. The 2.84 m^2 quadrat size was selected to give the largest consistently viewable quadrat given water turbidity. The parallel-view camera (side camera) provided a cross-quadrat view of both the large and small camera sample areas. Multi-SeaLights (100 - 250 watt, Deepsea Power and Light) illuminated the quadrat; and four to eight lights were used depending on water turbidity and seabed reflectivity. As the pyramid landed on the seabed the latitude and longitude of the vessel was used as the quadrat position. The drift of the vessel during sampling determined the distance and direction between the quadrats. The position, date, time and quadrat identification were overlaid on the video which was recorded simultaneously to S-VHS and DVD (for survey details see Stokesbury 2002, and Stokesbury et al. 2004, 2009, 2010).

The presence or absence of the sediment types in each quadrat was recorded in real-time during sampling using all three camera views. In the laboratory all the video was reviewed, the sediment identifications were verified, and a digital still image from the large and small camera footage at each quadrat was archived (Harris and Stokesbury *In Press*, Supporting Document 1).

The strengths and limitations to this dataset for sediment mapping purposes are:

Strengths include:

- Formal sampling design with replication.
- Multi-view optic sample of mud to boulder substrates
- High spatial sampling frequency
- Annual sampling of Georges Bank and the Mid-Atlantic since 1999
- Detailed sediment sampling and mapping methods published in Harris and Stokesbury (*In Press*).

Limitations include:

- Database includes only surficial geology and does not include particles finer than silt.
- Surveys do not include depths greater than 150m and do not cover the inshore GOM or Mid-Atlantic Bight regions.

Dominant Sediment

To accommodate the limitations of both data sources we standardized all data to reflect the *dominant* sediment type in each sample. The *dominance* sediment type in each sample was the largest fraction determined by volume, area, or frequency of occurrence. Where two or more sediments had an equal fraction the larger type was considered dominant. Kosteylev et al. (2005) and Harris and Stokesbury (*In Press*) both examined sediment dominance and found strong spatial structure in the surficial sediments on Georges Bank.

Mapping Dominant Sediments
The positions (latitude, longitude) of the sediment sampling locations were mapped in ArcGIS® v. 9.3 (Environmental Systems Research Institute, ESRI, Redlands, California) and were projected with the Universal Transverse Mercator Projection for Zone 19 North using the North American Datum 1983 horizontal control.

Sediment Diagram Maps
The sediment data were tessellated to create a study area-wide Voronoi diagram. A Voronoi diagram is composed of convex polygons defined by the perpendicular bisectors of a Triangulated Irregular Network connecting all the sample points such that each polygon bounds the region closest to its data point relative to all others (Thiessen and Alter 1911, Gold 1991, Okabe et al. 1992, Legendre and Legendre 1998). Voronoi diagrams have been used in terrestrial and aquatic ecological studies and are particularly useful for creating a surface from point data without smoothing or predicting values between the points (Isaaks and Srivastava 1989, Fortin and Dale 2005). Harris and Stokesbury (2005) used Voronoi polygons to map sediments and macroinvertebrate distributions on Georges Bank and in the Mid-Atlantic.

The sediment diagram yields an unsmoothed map surface which retains the specific characteristics of the data point in each polygon. This allows direct assessment of the level of spatial data support for each polygon in the map, including a depiction of where spatial sampling resolution and representivity of the map inputs vary.

Comparison with Gear Hangs on Georges Bank
Mobile fishing gear is frequently damaged by cobbles and boulders so avoiding "hangs" saves fishers time and money. The New England trawl and dredge fleets have kept a list of hang locations since the 1970s. We acquired a copy from Eastern Fisheries, a scallop company in New Bedford, MA. Also, since 1948 the USA National Marine Fisheries Service (NMFS) Northeast Fisheries Science Center has maintained a list of gear hangs where their trawl survey net was damaged (Azarovitz 1981). The proportion of industry hangs designated as "rock" (n = 279), and of NMFS survey hangs causing significant gear damage (n = 348) inside and outside the gravel outcrops on Georges Bank were compared with a χ^2 test. This analysis was published in Harris and Stokesbury (*In Press*).

Natural Neighbor Maps
Sibson's Natural Neighbor interpolation was used to generate high-resolution (1 km^2) dominant sediment maps (Sibson 1981). The Natural Neighbor algorithm estimates the dominant sediment type $\hat{K}$ in each interpolated map cell as

$$\hat{K}(x, y) = \sum_{i=1}^{n} w_i K(x_i, y_i),$$

where $\hat{K}(x, y)$ is the estimate at location *x, y,* and $K(x_i, y_i)$ is the sampled data at locations x_i, y_i. The spatial weights w_i are determined by the areas of influence of the Voronoi polygons of x_i, y_i in each interpolated map cell (Sibson 1981, Isaaks and Srivastava 1989).

Natural Disturbance
As water flow increases over the seabed, the shear stress increases and the hydrodynamic forces acting on the bottom will eventually dislodge and start to move sediment particles. The relationship between water velocity and when sediment particles start to move is depicted by the Hjulstrøm Curve (Figure 2, Massel 1999). Using the properties of seawater the force (stress) exerted on the seabed can be calculated as a function of flow velocities. The force thresholds for substrate particle movement are termed critical shear stress and are given in units of force (e.g. N m^{-2}, Soulsby 1997).

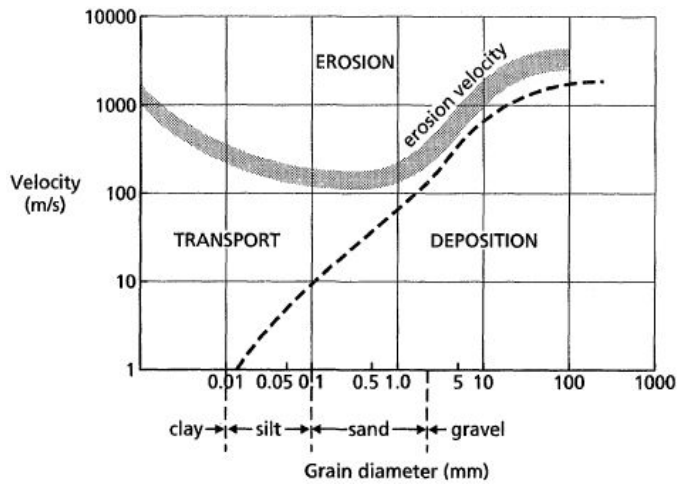

Figure 2. Hjulstrøm Curve with the grey line showing the velocity required to move the sediment and the dashed line showing the velocity required to keep the sediment in suspension.

Modeling Shear Stress
Shear stress was estimated using the Gulf of Maine module of the Finite Volume Coastal Ocean Model (FVCOM) (Chen et al., 2003, 2006, Cowles, 2008). FVCOM is an open source Fortran90 software package for the simulation of ocean processes in coastal regions run by the Marine Ecosystem Dynamics Modeling Group at the University of Massachusetts Dartmouth, Department of Fisheries Oceanography (http://fvcom.smast.umassd.edu/FVCOM/index.html).

FVCOM computes a solution for the hydrostatic primitive equations on an unstructured grid using a finite-volume flux formulation (for details see Chen et al. 2003, 2006, Cowles, 2008). The model mesh contains 30,000 elements in the horizontal and 30 layers in the vertical, and advances at a time step of 120s. A high performance computer cluster (32 processors) is used to run FVCOM, requiring about 8 hours of wall clock time for each month of simulated time. Boundary forcing in the Gulf of Maine module includes the five major tidal constituents at the open boundary, freshwater input from major rivers in the Gulf of Maine, and wind stress and heat flux derived from a high resolution configuration of the MM5 meteorological model. At the open boundary, hydrography is set using monthly climatology fields derived from survey data using optimal interpolation techniques. Assimilation of daily mean satellite-derived sea surface temperature (SST) into the model SST is included to improve the model temperature state. The model has been validated using long-term observations of tidal and subtidal currents and as well as hydrography (Cowles et al. 2008).

Ocean circulation on the northwest Atlantic continental shelf was simulated from 1995-2008. Hourly model hydrographic and velocity data fields were computed at each node the study area. Shear stress was computed from the model velocity fields using the "law of the wall" benthic boundary formulation with a depth-based estimate of seabed roughness (Chen et al. 2003, Cowles et al. 2008). Because the M_2 and S_2 tidal components compose about 80% of the kinetic energy in the study area (Butman 1987b) mean maximum shear stress magnitudes were derived from these tidal components. Outside the FVCOM model domain in the Mid-Atlantic Bight tidal flows are much less forceful and storm-generated surface waves are the primary source of sediment disturbance energy (Butman 1987a).

Critical Shear Stress Thresholds

The critical shear stress thresholds (τ_{cr}) for each dominant sediment type (Table 2) were estimated using Soulsby's (1997) formula:

$$\tau_{cr} = \theta_{cr}\, g(\rho_s - \rho)d,$$

where
θ_{cr} = Shield's parameter (constant = 0.055)
g = acceleration due to gravity (constant 9.81 m s^{-1})
ρ_s = sediment grain density (quartz = 2650 kg m^{-3})
ρ = seawater density (1027 kg m^{-3})
d = grain diameter (m)

Table 2. Minimum, median and maximum τ_{cr} values estimated using the sediment size ranges from Table 1.

	Critical Shear Stress(N m^{-2})		
Sediment	**Min**	**Mid**	**Max**
Mud	0.003	0.029	0.055
Sand	0.055	0.903	1.751
Granule/pebble[a]	1.751	3.503[b]	56.044
Cobble[a]	56.044	144.051	232.058
Boulder[a]	224.177	-	-

[a] = gravel, [b] = minimum value for granule - 4mm

Sediment Disturbance from Winter Storms
Annual winter storms create waves that generate orbital flows sufficient to disturb sediments in depth greater than 100m (Butman 1987b). Therefore, we assessed annually disturbed areas using high resolution digital depth soundings data queried from the National Geophysical Data Center of NOAA using the online National Ocean Service data portal (http://www.ngdc.noaa.gov/mgg/gdas/ims/hyd_cri.html), and the depth soundings recorded for each sample in the SMAST video survey database. These data were compiled and mean depth values were estimated in each sediment diagram polygon.

Mapping Sediment Disturbance

Within the FVCOM domain sediment type specific critical shear stress maps were created to show the locations where forces were sufficiently high to disturb sediments. Depth was used to infer the locations where winter storm wave generated forces were sufficiently high to disturb sediments. To determine a specific depth threshold for sediment disturbance we examined the depth ranges where flow induced bedforms (e.g. sand ripples) were observed in the SMAST video survey.

Spatial Data Support

In order to assess and map sediments over the 238,400 km^2 study area we had to merge data from many sources. The general level of sediment spatial data support (high, moderate or low) was determined for each sediment diagram polygon. Data support for sediment mapping was considered "*high*" when the sampling device was capable of detecting the full range of sediments (mud-boulder) *and* when the sampling frequency was high ($\geq$ 1 sample per 10 km^{-2}). "*Moderate*" data support indicates that only mud - granule/pebble sediments were detectable *or* that the sampling frequency was $\geq$ 1 sample per 100 km^2 but $<$ 1 sample per 10 km^{-2}. "*Low*" data support indicated that only mud - granule/pebble were detectable *and* sampling frequency was low ($<$ 1 sample per 100 km^2).

Results

Data

The usSEABED database provided sediment information from 27,477 sampling locations compiled from 73 datasets; the SMAST database provided 111,367 samples (Figure 3). The spatial sampling scales of these data sources are shown in Table 3.

Table 3. Spatial Scales

		Spatial Scale		
Input	**Data Source**	**Grain**	**Lag**	**Extent**
Geology	Video Survey	10-100 m^2	1.1 km	70,000 km^2
Geology	usSEABED	0.1 - 0.5 m^2	2.59 km	238,400 km^2

Mud and sand were the most common sediment in the study area accounting for 24% and 69% respectively (Table 4, Figure 4). Gravel sediments were dominant in only 7.1% of the study area and occurred primarily in outcrops on Georges Bank and in the Gulf of Maine.

Table 4. The number of samples, and area and percent area covered by dominant sediment types.

Dominant Sediment	Samples	Area (km^2)	Percent Area
Mud-Silt	3428	56904	23.6%
Sand	32898	167250	69.3%
**Granule- Pebble*	5078	13986	5.8%
**Cobble*	1330	2588	1.1%
**Boulder*	204	482	0.2%

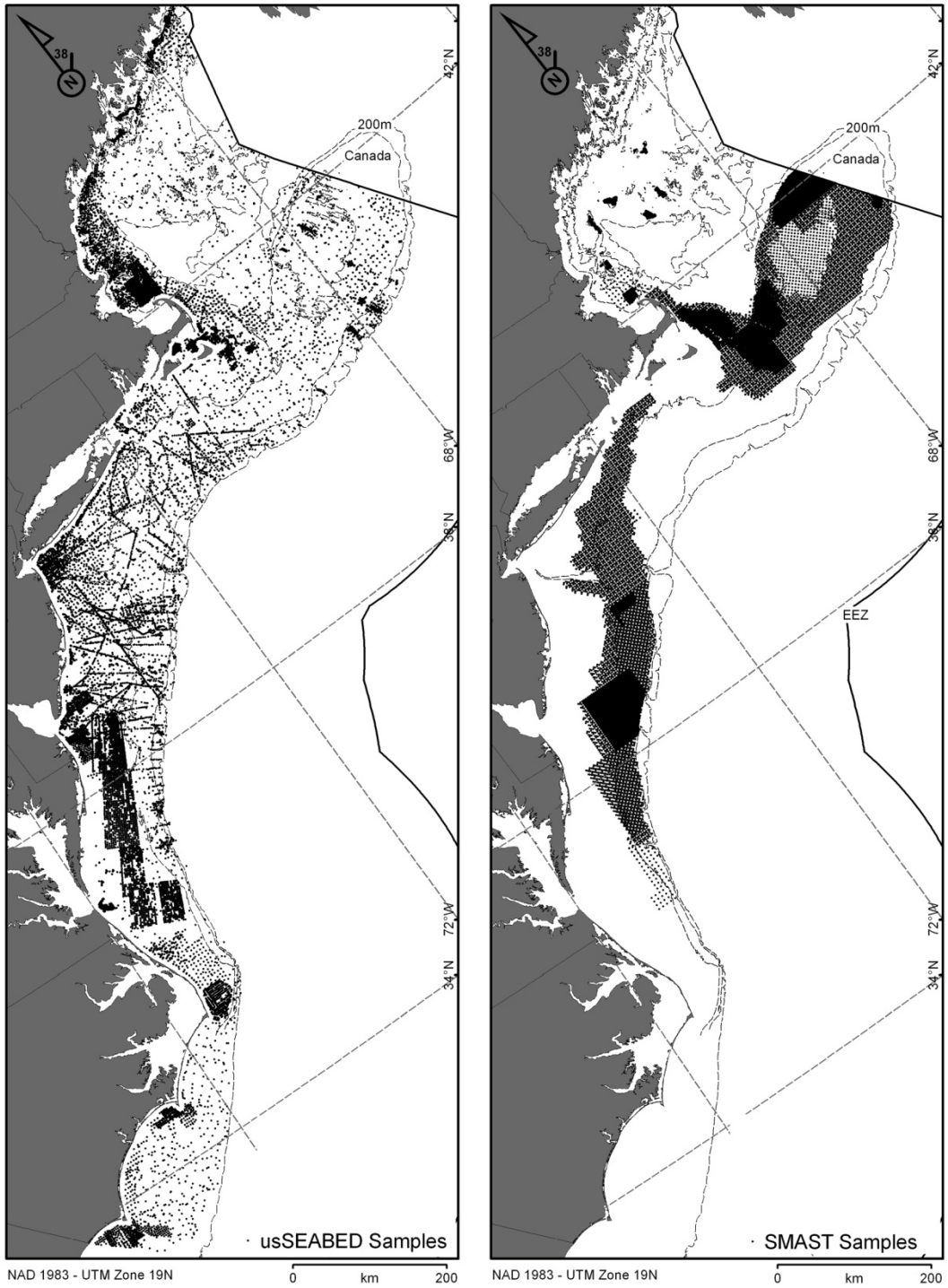

Figure 3. Sampling locations in the USGS usSEABED database (left panel) and the SMAST database (right panel).

Sediment Mapping - Sediment Diagram

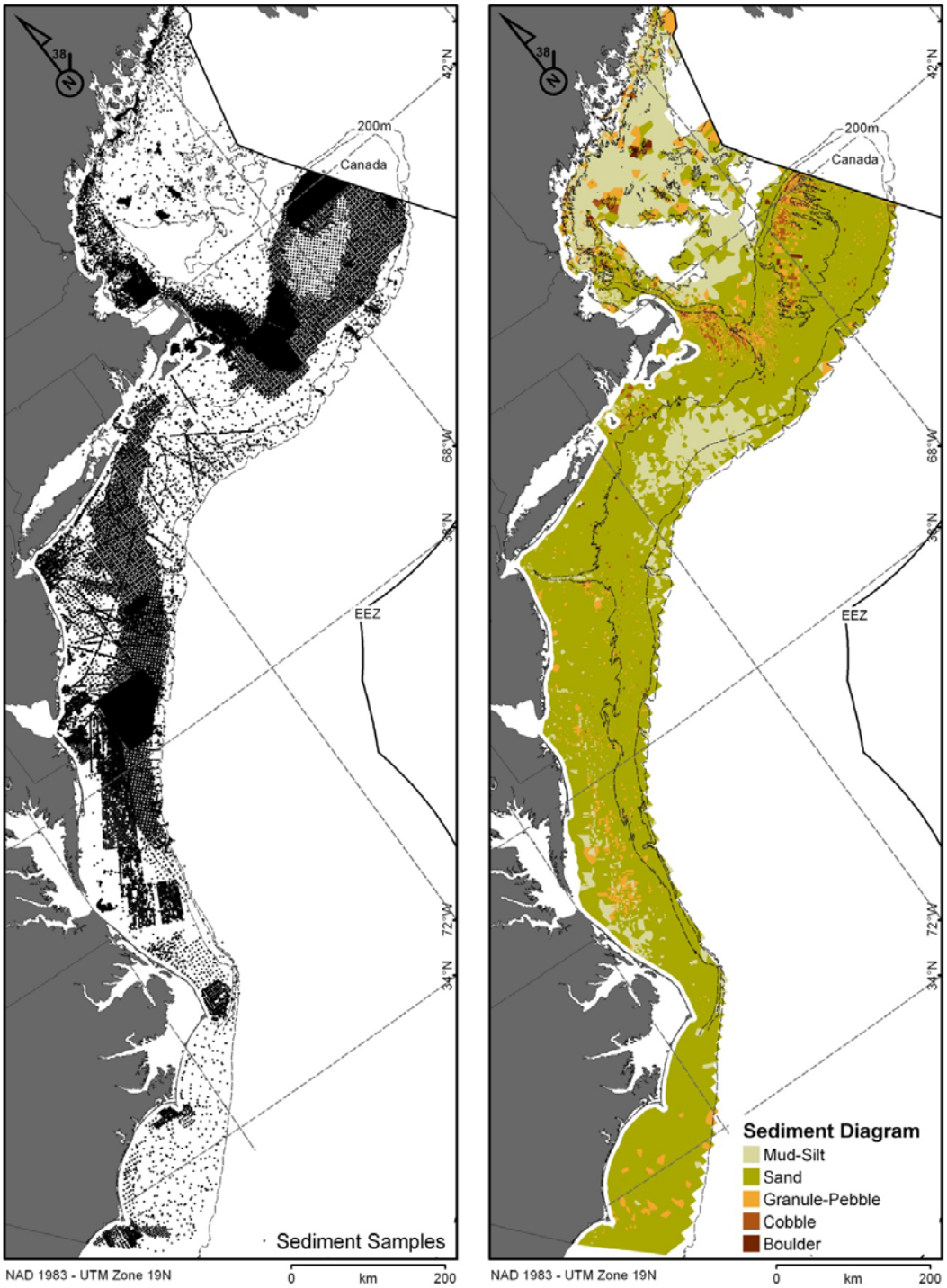

Figure 4. Combined usSEABED and SMAST sampling locations (left panel) and dominant sediment diagram (right panel).

Comparison with Gear Hangs
Hangs in both datasets concurred with the Georges Bank gravel sediments. Gravel outcrops covered only 12.8% of the Georges Bank study area but contained 42% and 45% of the industry and NMFS hangs, respectively (χ^2 = 184.9 and 273.7, $p < 0.0001$, Harris and Stokesbury *In Press*).

Natural Substrate Disturbance
There are 4,606 FVCOM prediction nodes in the study area and the spatial prediction resolution ranges from approximately 3km on Georges Bank to 15km near the open boundary in the Mid-Atlantic. The National Ocean Service provided depth sounding at 4,361,718 locations, and there were 111,367 depth records in the SMAST database (Figure 5).

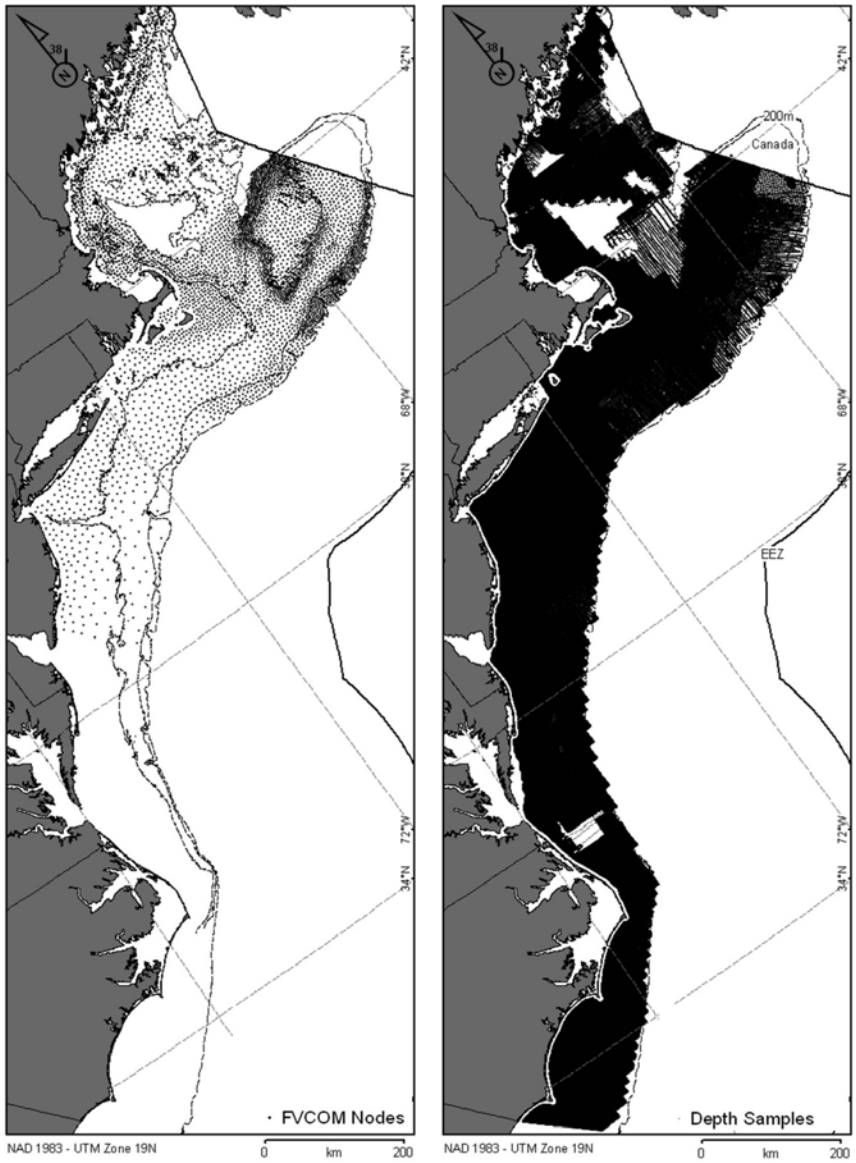

Figure 5. FVCOM prediction nodes (left panel) and National Ocean Service and SMAST depth data (right panel). The depth data maps appears dark because there are 4,473,085 data depth points.

Sand ripples were ubiquitous in the SMAST survey area regardless of depth. There were 1258 samples taken at depths from 100 - 145 m. Sand ripples were observed in more than 30% of these locations consistent with Butman (1987a,b) assessment. Therefore, we mapped shelf depths to 145m to depict the areas susceptible to disturbance from winter storms (Figures 6).

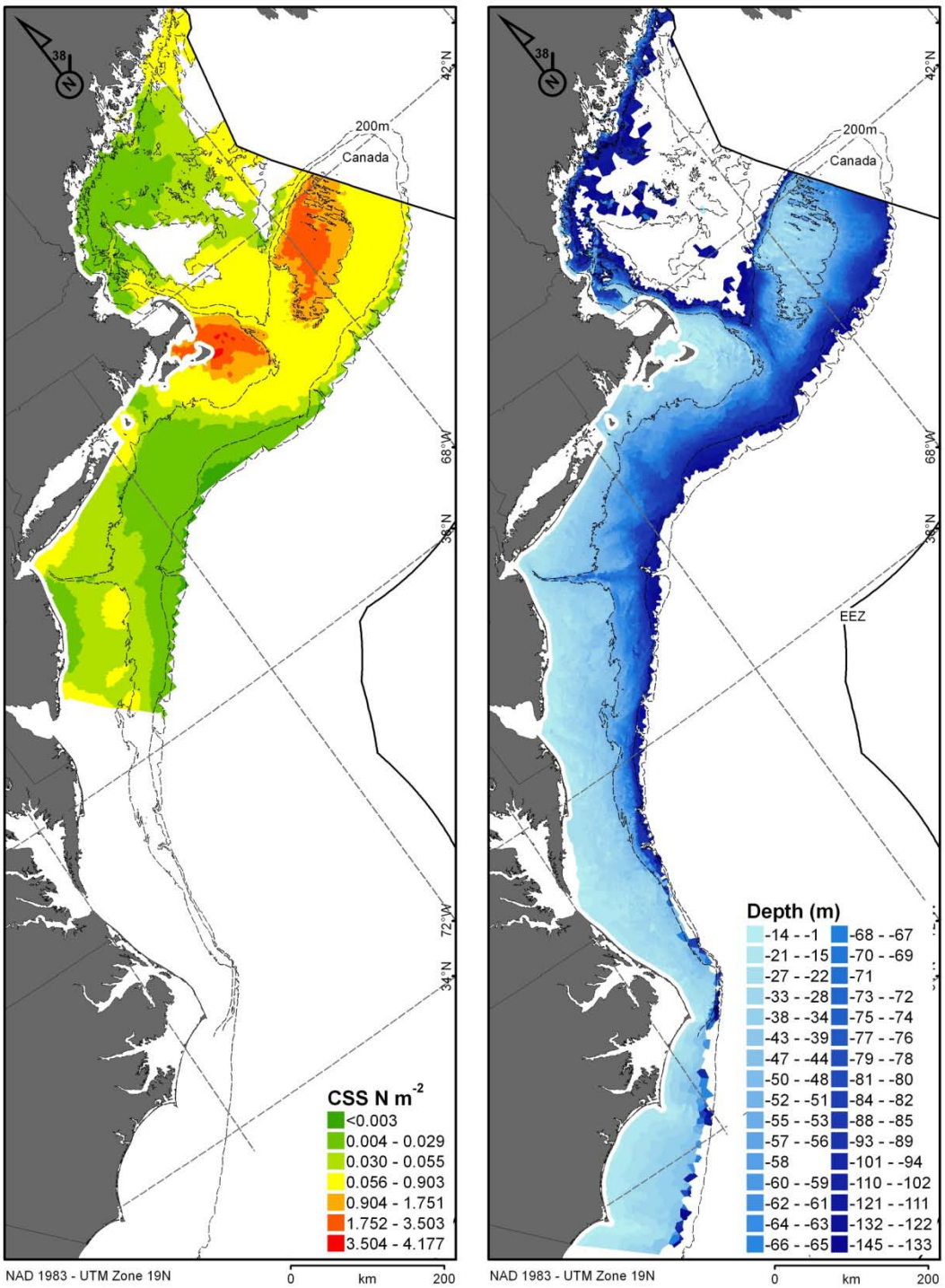

Figure 6. FVCOM Shear Stress predictions (N m^{-2}) (left panel) and depth (right panel) used to estimate locations with natural substrate disturbances due to tidal and wave generated forces.

Sediment Type Disturbance Maps

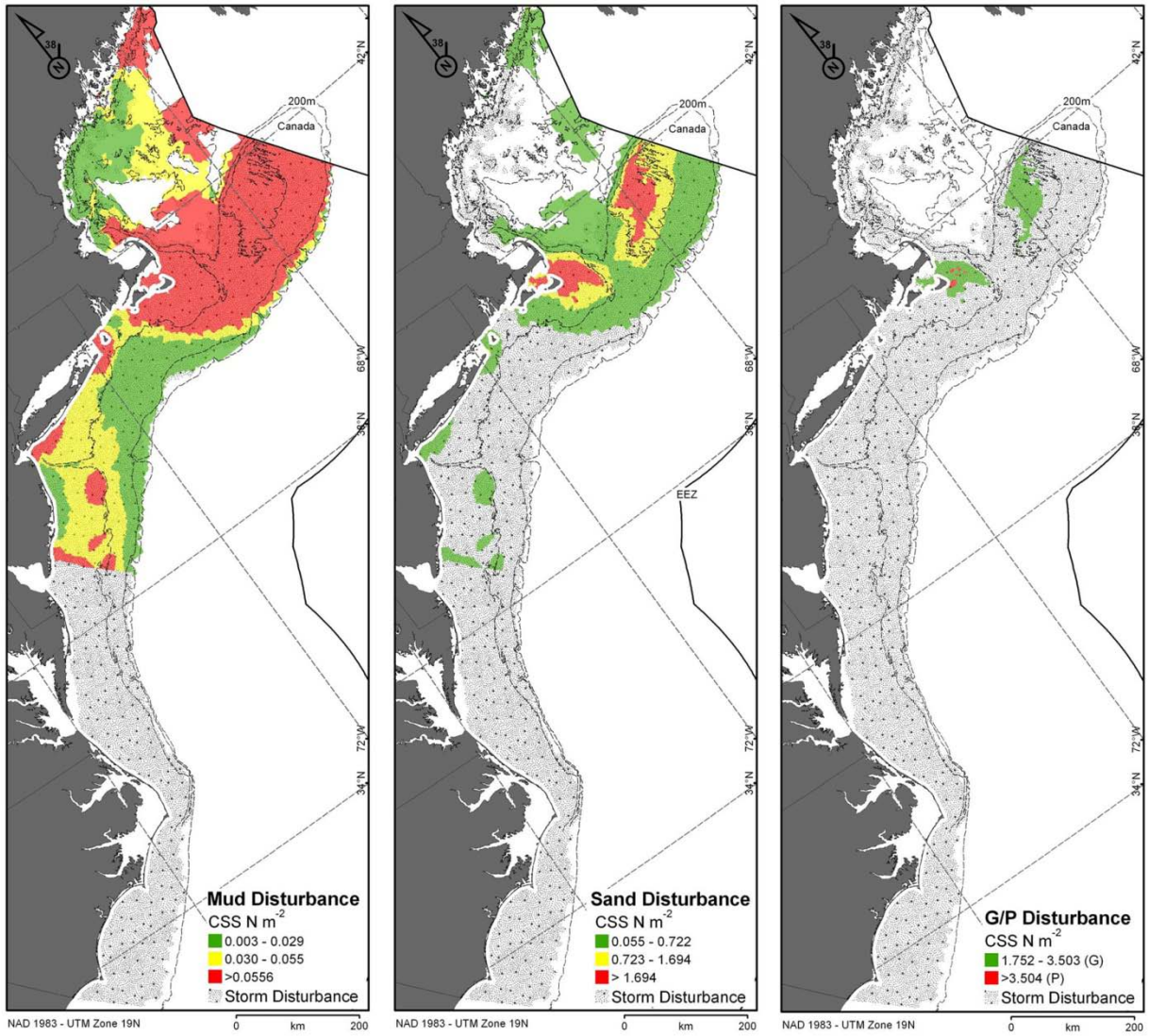

Figure 7. Sediment disturbance maps showing region where forces due to tidal and storm generated critical shear stress levels exceed the thresholds required to move mud, sand, and granule/pebble sediments. Thresholds are shown for minimum (green), median (yellow) and maximum (red) grain sizes. The granule/pebble thresholds correspond to minimum granule and minimum pebble values. Winter storms (stippled pattern) can disturb all these sediments to depths of at least 145 m.

Sediment Mapping - Natural Neighbor Map

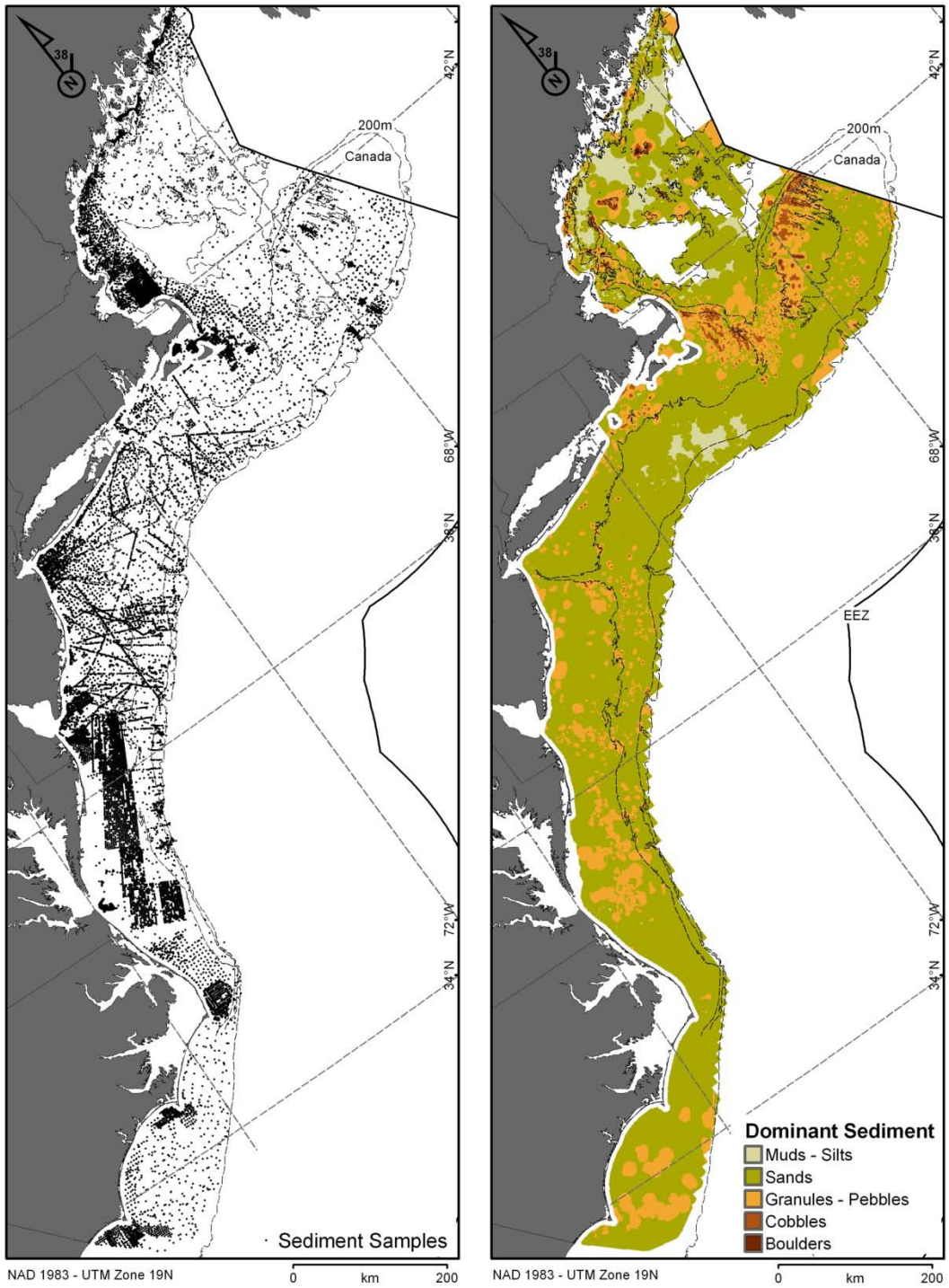

Figure 9. usSEABED and SMAST data (left panel) and resulting dominant sediment maps created via Natural Neighbor Interpolation (right panel).

Spatial Data Support

There was high spatial data support for sediment mapping in 53,125 km^2 (24.1%), moderate in 141,037 km^2 (64.1%) and low in 25,921 km^2 (11.8%) of the study area (Figure 10).

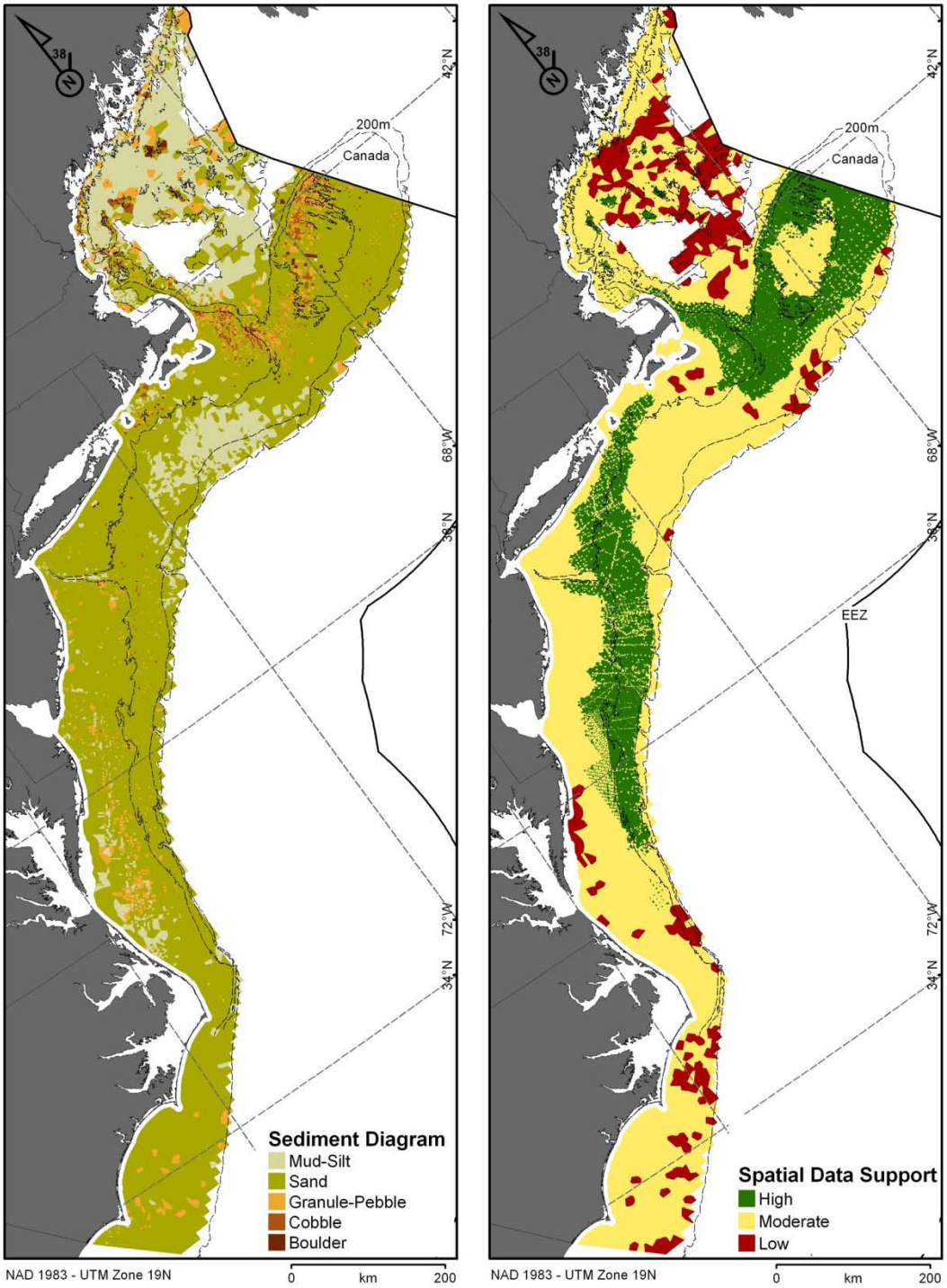

Figure 10. Map of sediment mapping spatial data support. *High* = mud - boulder sampled *and* sampling frequency ≥ 1 sample per 10 km^{-2}. *Moderate* mud - granule/pebble sampled *or*

sampling frequency ≥ 1 sample per 100 km^2 but < 1 sample per 10 km^{-2}. *Low* = mud - granule/pebble sampled *and* sampling frequency > 1 sample per 100 km^2.

Discussion / Conclusion

The US northwest Atlantic Ocean continental shelf supports federally managed commercial fisheries for more than 30 species with annual landings worth a billion US dollars (NOAA 2008). The data products, dominant sediment type and natural disturbance maps we created have substantially improved the information available for spatially specific habitat assessments and fisheries management.

Our analyses were designed with input from New England Fisheries Management Council Habitat/ Ecosystems/ Marine Protected Areas Plan Development Team (PDT) Members. The maps and data products have all been provided to the PDT and are being used in Phase 2 of the ongoing Habitat Omnibus Amendment. In a letter to the Dean of SMAST dated 11 March 2010, Paul Howard, Executive Director of the New England Fisheries Management Council wrote" *The video survey substrate data have increased the spatial resolution and quality of geological information available for habitat assessments by several orders of magnitude. These data provide the base layer for the PDT's Swept Area Seabed Impact Model (SASI). The FVCOM information is being used to distinguish the tidal energy regimes within the SASI model's domain allowing the assessment of fishing impacts on areas with high and low levels of natural disturbance. The high quality and spatial resolution of both these data sources have allowed the first quantitative geospatial assessment of fishing impacts on habitat*." (see Supporting Document 3).

Outreach and Education

Industry confidence in the map products and analyses is crucial for effective fisheries management. The work reported here was conducted in cooperation with the scallop fishing industry (see Supporting Documents 4 and 5). In addition to conducting harvest trips the fishing industry provided important input during the data analysis and mapping phases of this work via the SMAST Scallop Industry Research Steering Committee which meets bi-monthly at SMAST.

This project is part of Co-PI Bradley Harris' Ph.D dissertation work. He has presented these analyses at six scientific conferences (listed below) and published one related peer-reviewed journal article (see Supporting Document 1). In addition he used these maps and analyses in his continued education and outreach work with public primary, middle and high-school students and teachers via the Massachusetts Marine Educators, the Connecting Oceans Academy and the Education through Cultural and Historical Organizations. Maps from this analysis were displayed at the New Bedford Working Waterfront Festival (25-26 Sept 2010), and at the Ocean Explorium at New Bedford Seaport for general public ocean education.

Presentations

Harris, B.P. *Assessing the NW Atlantic Continental Shelf Benthos for US Fisheries Management*. International Council for Exploration of the Sea - Working Group on Fish Ecology. Sete, France. 8 Sept 2010.

Harris, B.P. *Assessing the NW Atlantic Continental Shelf Benthos for US Fisheries Management*. International Council for Exploration of the Sea - Working Group on the Northwest Atlantic Regional Sea. Woods Hole, MA. 22 April 2010.

Harris, B.P. *Surveying and Mapping the NW Atlantic Continental Shelf Benthos*. International Council for Exploration of the Sea - Working Group on the Northwest Atlantic Regional Sea. Woods Hole, MA. 21 April 2010.

Harris, B.P. *Surveying and Mapping the NW Atlantic Continental Shelf Benthos*. Massachusetts Oceans Plan - Coastal Zone Management Office. Boston, MA. 15 April 2010.

Harris, B.P. *SMAST Habitat Research*. Massachusetts Marine Fisheries Institute Programmatic Review. University of Massachusetts - Dartmouth, Department of Fisheries Oceanography. Fairhaven, MA. 07 January 2010.

Harris, B.P. and Arsenault, M. Merging Large Substrate Datasets: *usSEABED and SMAST data for Georges Bank.* US Geological Survey Seminar Series – Woods Hole, MA. 4 August 2009.

Future Work

Seventy six percent of the study area had moderate to low spatial data support for sediment mapping. To accurately map the sediments in these areas (167,000 km^2) requires new field studies using sampling designs and devices suitable for detecting sediments from muds to boulders. The *dominant sediment* approach used in this analysis resulted from the limitations of each data source. This perspective on the sediment yielded patters consistent with previous work and the geologic history of the region. However, future work should investigate other local sediment characteristics (e.g. maximum size types, and heterogeneity). Harris and Stokesbury (*In Press*) reported "*Apparent patterns in surficial sediment distributions depend heavily on the local characteristic being mapped. Maps of sediment type alone provide limited insight into local sediment spatial structure*".

As Reid et al. (2005) clearly state usSEABED database users should proceed carefully due to the myriad inconsistencies between datasets which were merged into the database. However, the structure of the database and the lack of detailed sampling device and design information make careful data selection difficult. The database is an extremely valuable resource and we suggest this information be added.

Supporting Documents

Supporting Document 1: Harris, B.P. and Stokesbury K.D.E. *In Press* The Spatial Structure of Local Surficial Sediment Characteristics on Georges Bank, USA. Continental Shelf Research. doi:10.1016/j.csr.2010.08.011

Supporting Document 2: NEFMC, 2010. The Swept Area Seabed Impact (SASI) Model: A Tool For Analyzing the Effects of Fishing On Essential Fish Habitat. New England Fishery Management Council, Draft Essential Fish Habitat (EFH) Omnibus Amendment. 19 August 2010.

Supporting Document 3: Letter from New England Fisheries Management Council Executive Director Paul Howard, 11 March 2010.

Supporting Document 4: List of Fishing Industry Participants.

Supporting Document 5: RSA Harvest Trip Weighout Sheets.

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