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Final Report

to

National Marine Fisheries Service
Northeast Fisheries Science Center

Characterization of Scallop Abundance and Benthic Habitat Using Optical and Acoustic Imaging Technology

submitted by

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List of Acronyms

AST Applied Signal Technology, ProSAS synthetic aperture sonar (www.appsig.com)

CCOM Center for Coastal and Ocean Mapping, University of New Hampshire (ccom.unh.edu)

CLA I Closed Area I, groundfish closure area (1994), located in the Great South Channel
A portion of this area was reopened to the scallop fishery in 2000 and 2005

CLA II Closed Area II, groundfish closure area (1994), located on Georges Bank
The southern portion of this area was reopened in 1999, 2000, 2004-6, and 2009

DAS Days at Sea

DMV DelMarVa, Delaware Maryland Virginia scallop Access Area

ET Elephant Trunk scallop Access Area

HABCAM Habitat Mapping Camera System

HAPC Habitat Area of Particular Concern

HCAA Hudson Canyon scallop Access Area

NLSCLA Nantucket Lightship Closed Area, groundfish closure area (1994)

NEFMC New England Fishery Management Council

NEFSC Northeast Fisheries Science Center, Woods Hole

NOAA National Oceanic and Atmospheric Administration

NOS National Ocean Service

nm nautical mile, 1 minute of latitude

NMFS National Marine Fisheries Service

RSA Research Set Aside

SMAST School for Marine Science and Technology, Univ. of Massachusetts, Dartmouth

TAC Total Allowable Catch

UNOLS University - National Oceanographic Laboratory System (www.unols.org)

VIMS Virginia Institute of Marine Science, College of William and Mary

VMS Vessel Monitoring System

VPR Video Plankton Recorder

WGSC Western Great South Channel, an “open area” recently designated an HAPC

WHOI Woods Hole Oceanographic Institution

1. Abstract

Three cruises were conducted by the New Bedford scallop vessel F/V Kathy Marie during summer, 2008. The first cruise shipped the HABCAM instrument to the Elephant Trunk and DelMarVa Access Areas in the MidAtlantic and conducted comparative sea scallop (*Placopecten magellanicus*) survey tows with the University of Delaware (UNOLS) research vessel Hugh R. Sharp. The remaining two cruises included the Applied Signal Technology (AST) synthetic aperture sidescan sonar system mounted on a FOCUS-2 vehicle. These cruises collected both optical and acoustic data simultaneously within Stellwagen Bank National Marine Sanctuary, on Jeffreys Ledge, within the Closed Area II Habitat Area of Particular Concern (CLA II HAPC), Closed Area I, and the Western Great South Channel (WGSC) HAPC. Additional comparative tows were made at the locations of NOAA Fisheries survey tows often using the sonars to find and maintain a precise distance from the survey dredge tracks. Other towed equipment deployed during this project included the NMFS Video Plankton Recorder mounted on a batwing depressor towbody, for collecting data on plankton species throughout the water column, and an 8' scallop survey dredge for sampling in areas where NMFS survey tows were not conducted.

Overall approximately 1,400,000 m^2 of high resolution (~1mm pixel size) optical imagery were collected. Approximately 184 million m^2 of acoustic sidescan imagery was collected using the AST sonar system primarily in Closed Area I and the WGSC HAPC, but also within the Stellwagen Bank National Marine Sanctuary and on Jeffreys Ledge. Another 70 million m^2 of sonar data was collected using the Imagenix 991 (675 kHz) on the HABCAM vehicle.

Scallop counts and sizes were obtained manually by examining every 10th to 50th image (~5 to ~25m) along the optical transect path. Biomass estimates for Closed Area I were generated by using a kriging process at several different scales in order to compare results. The smaller cell size was considerably more computationally intensive; however, more accurately represented the data, and generated consistently higher biomass results. After adjusting for the variable altitude of the camera, optically derived shell heights were compared with the hand measured scallops obtained from the dredge tows. All data were provided to the NEFSC Invertebrate Subcommittee for the scallop Stock Assess Review Committee (SARC 50).

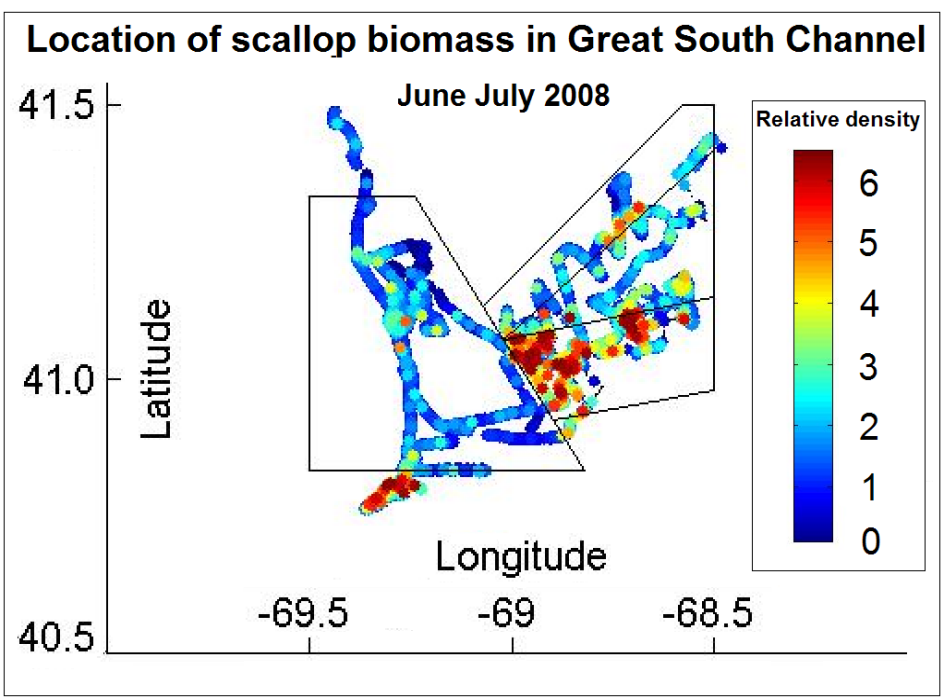


Figure 1. Location of high biomass areas from HABCAM transects in Great South Channel

2. Description of the problem addressed

2.1 Background on the management of the U.S. northwest Atlantic scallop resource

Over the last thirty years the annual scallop survey conducted by the NOAA/NMFS/Northeast Fishery Science Center (NEFSC), has served as the only broadscale snapshot of sea scallop (*Placopecten magellanicus*) populations over the U.S. range of the resource in the northwest Atlantic. Strata based on depth and bathymetric features were developed and have proven quite useful in measuring current, and predicting future, landings and trends. However a combination of changes to scallop management strategies has contributed to the necessity of improving our scallop resource assessment methods. Foremost among these changes was the shift from region wide management based on input controls (i.e. fishing effort or Days At Sea or DAS), to area management based on output controls (i.e. Total Allowable Catch or TAC) from specific areas. The situation became more acute as the landings from these relatively small rotationally fished areas with high density scallop populations have proven to be larger than previous annual landings from the entire continental shelf. In these areas, even a small error in the population estimate can lead to either foregone earnings worth millions of dollars, or short term windfall catches followed by depleted stocks. Both results are poor outcomes for commercial fishing businesses.

A more detailed history of the successive developments that have occurred must also include:

1. the institution of large areas closures for the protection of managed groundfish species in 1994: Nantucket Lightship (NLSCLA), Closed Area 1 (CLA I), and Closed Area II (CLA II),

2. the rapid rebound of scallop populations within those areas,

3. the first large closure specifically for scallop growout: Hudson Canyon (HCAA) 1997,

4. the reopening of portions of areas closed in 1994 with specific limits on fishery removals,

5. changes to regulations that required temporary closure of areas with large amounts of small scallops specifically for scallop growout purposes (Scallop Amendment 10),

6. massive reseeding of an area downcurrent from the Hudson Canyon closure requiring establishment of an additional scallop growout closure, Elephant Trunk (ET), and

7. another massive set of small scallop south of the ET area resulting in the establishment of yet another scallop growout area, DelMarVa (DMV).

Related changes within the fishery management regulations include the required use of Vessel Monitoring Systems (VMS) aboard each vessel for tracking Days At Sea (DAS) usage and for accurate vessel location in order to provide enforcement for the scallop growout areas. In addition, implementation of the 2% Research Set Aside (RSA) funding mechanism has allowed participating industry vessels to contribute to projects in diverse areas such as stock assessment, bycatch of flounders and skates, and protected species (e.g. sea turtles) that might interact with the scallop fishing gears. Other efforts include substrate and habitat deliniation, and other modifications to the scallop fishing gears.

There are a number of inherent uncertainties in the annual NOAA Fisheries scallop survey and in the survey method. Primary among them are a limited budget affecting survey vessel time and thus the spatial coverage or scope of the survey, and a highly variable efficiency in the catch rate of the survey dredge. The simple fact is that the survey was developed for broadscale sampling to produce an index and it served us well for that task. However, the current acute problem is developing a cost effective and accurate biomass estimate for the much smaller and more densely populated scallop access areas in order to determine the TAC.

2.2 Background on development and previous use of HABCAM instrument and system
The HABCAM system was designed as a towed instrument to collect both seafloor imagery and other environmental data (i.e., altitude, depth, temperature, pressure, salinity, fluorescence, vessel position, and velocity). HABCAM transmits the data directly to the vessel in real-time to enable on-the-fly changes to the line transect survey route. The original instrument and software were constructed in 2002 by the Woods Hole Oceanographic Institution in cooperative partnership with the commercial fishing industry with funding from the Northeast Consortium of Sea Grant Institutions. Initial images were obtained during March 2003 while towing the instrument from the WHOI R/V Oceanus.

Significant changes were later made to the original vehicle with support from the 2004 Scallop Research Set Aside program within the New England Fishery Management Council (NEFMC). Other changes included the refurbishing and installation of a fiber-optic winch, and construction and installation of an A-frame which have allowed the New Bedford commercial scallop vessel F/V Kathy Marie to efficiently handle all operational requirements for the HABCAM system. Additional funding was obtained from the NEFMC RSA program for the years 2006 and 2007. This significantly increased the capabilities of the system, especially in the areas of image processing and visualization of the rapidly expanding collection of data and data products (HABCAM GROUP 2006, 2008A, 2008B). All data products generated by all projects to date are available via the internet at http://habcam.whoi.edu.

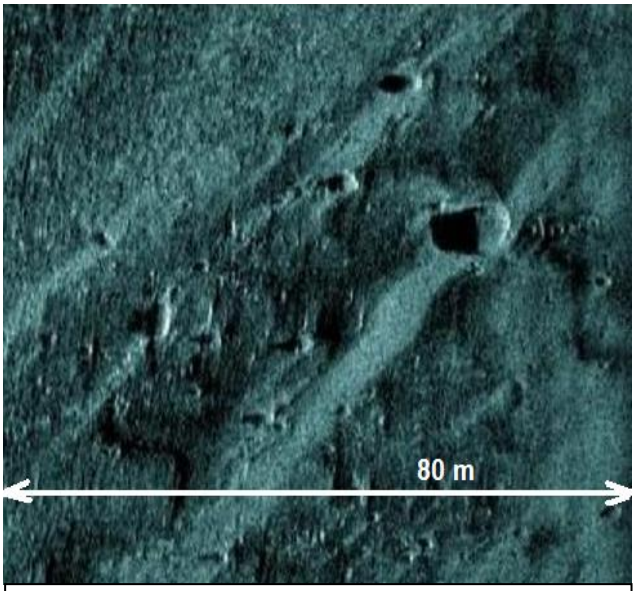


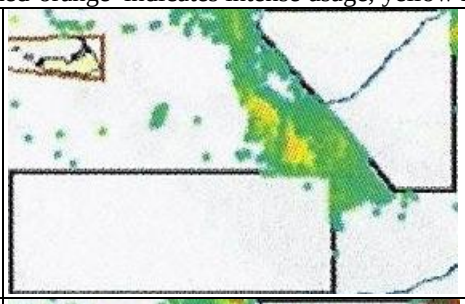
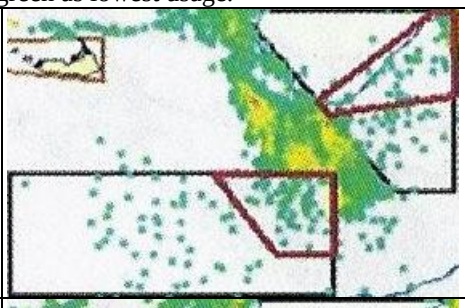
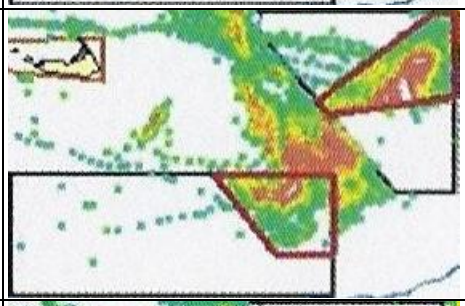
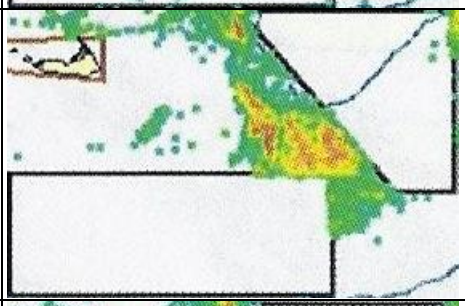
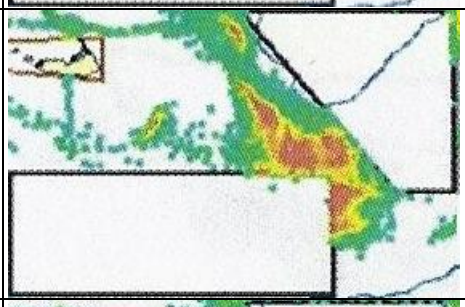
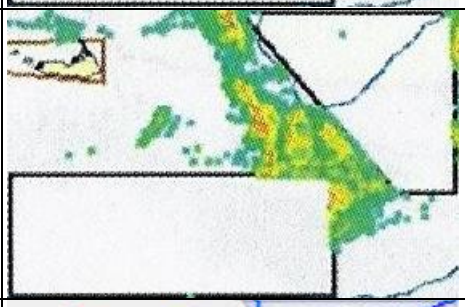
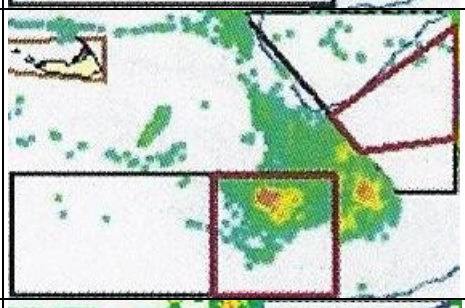
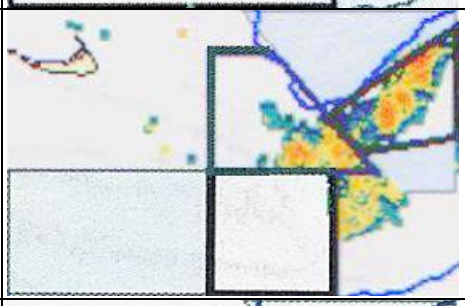
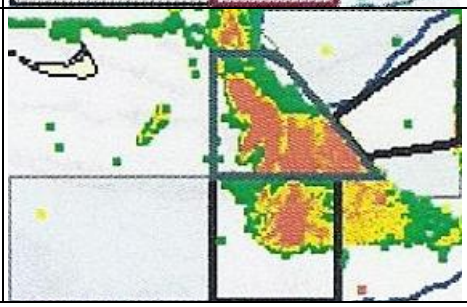
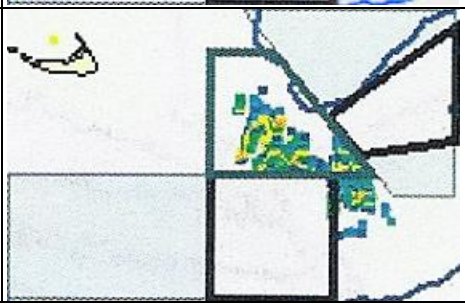
Figure 2. Backscatter differences are clear in areas of scour downcurrent of both large and small boulders.

The Applied Signal Technology (AST) (www.appsig.com) synthetic aperture sidescan sonar system is deployed on a MacArtney FOCUS-2 vehicle. This fibre-epoxy composite vehicle may be towed at up to 10 knots and is able to maintain a flight path of either constant altitude off bottom or constant depth, both within centimeters. The system as configured during this project was set to resolve targets of ~5cm at a range of 135 meters. However, perhaps of more interest and utility to our needs was the ability to image larger scale terrains and discriminate substrates with differing grain size.

2.3 Background on Closed Area I Access Area and the western Great South Channel HAPC
The rebuilding scallop population within CLA I was first reopened to the scallop fleet in 2000. The area was again reopened in 2005under the rotational management provisions within Scallop Amendment 10 (Fig. 3) Since that time the area has remained closed to scallop fishing because of NEFMC changes to the area boundaries, the resultant lawsuit from the environmental industries, and the court decision on the matter. Because there have been no fishery removals for the years 2006 to present there has been an unplanned opportunity for continued study of the area without the potentially confounding effects of fishing impacting the results. During this same time the WGSC has remained open to fishing and has been repeatedly recolonized with new year classes of scallop larvae. The southern portion of the area has recently been designated as an HAPC for small cod, however no management actions have been implemented to this time.

The WGSC HAPC has long been of significant economic importance to New England fishing communities as well, with estimates of current fishery landings from the area valued at $80 to 100 million annually for all species combined (NEFMC). Note the near continuous effort by the scallop fleet in the area as shown on the plots of Vessel Monitoring System (VMS) data below.

Figure 3. VMS based plots of scallop vessel landings in NLSCLA,CLA I and in WGSC HAPC, 1998 to 2007
Red-orange indicates intense usage, yellow moderate, with green as lowest usage.

1998 **First year VMS mandatory for Limited Access scallop vessels**		**1999** **Initial cooperative survey of NLSCLA and CLA I (SMAST, VIMS, NMFS)**	
2000 **NLSCLA and CLA I reopen for limited fishing with 18,000 lb. trip limits**		**2001**	
2002		**2003**	
2004 **NLSCLA reopens for 18,000 lb. trips**		**2005** **CLA I reopens for 18,000 lb. Trips with area shifted to the south**	
2006 **NLSCLA reopens for 18,000 lb. trips**		**2007**	

Images modified from A. Applegate, NEFMC

2.4 Project goals and objectives

There were three primary goals for this project:

1. Conduct 100 comparative scallop survey tows with the R/V Hugh R. Sharp during the 2008 annual NEFSC scallop survey. Of primary concern was determining relative dredge efficiencies and variability in multiple scallop resource areas.

2. Document scallop resource conditions in CLA I, an area that has not been open for fishing in recent years. Within this goal was an objective to determine the relative utility of different methods of conducting line transect surveys inherent in the use of the HABCAM system. Earlier efforts in CLA I had concentrated on making parallel transects (HABCAM GROUP 2006). In contrast, we proposed to look at the utility of both zig-zag and spiral transect patterns (similar to a man overboard search) in order to determine the most cost effective method of conducting linear transect surveys.

3. Document scallop resource conditions and substrate characteristics in the recently designated WGSC HAPC area, using both HABCAM and the AST synthetic aperture sonar. The addition and integration of an advanced sonar system while towing HABCAM was designed to significantly expand the quantity and value of the data collected for the same amount of fixed vessel costs, i.e. fuel and crew. Having the sonar look out 100 – 135 meters to each side gave greatly added insight into the local benthic terrain and surface composition both in terms of large and small scale features. For example, with the sonars we were able to observe sand waves of up to 10 m height, higher frequency sand ripples (Figure 15), and obtain backscatter data of surface (and near subsurface) composition. The combination of instruments is intended to provide both optical and acoustic data from the same area, in order to compare and visually calibrate the sonar return for the substrates in the area, i.e. sands, gravels, cobbles, and/or boulders.

2.5 Expected products

The workplan presented in the project proposal was designed to generate three products:

1. Dredge efficiency estimates from 100 comparative tows with the R/V Hugh R. Sharp;

2. A scallop biomass estimate for the CLA I Access Area, including areas beyond the current boundaries, which are currently undergoing review in the NEFMC process;

3. Optical imagery and approximately 50 square km of high resolution sonar imagery in the WGSC HAPC will be used to describe scallop abundance and fine scale substrate composition and larger scale distribution of substrate type in the transect areas.

3. Approach and methods

Three cruises were conducted by the New Bedford scallop vessel F/V Kathy Marie during summer 2008. The first cruise shipped the HABCAM instrument to the ET and DMV Access Areas off New Jersey and conducted comparative scallop survey tows with the University of Delaware UNOLS Research Vessel Hugh R. Sharp. Both remaining voyages included the AST synthetic aperture sidescan sonar system mounted on a FOCUS-2 vehicle. These cruises collected both optical and acoustic data simultaneously within Stellwagen Bank National Marine Sanctuary (SBNMS), on Jeffreys Ledge, the CLA II HAPC, CLA I, and within the WGSC HAPC.

Additional comparative tows were made at locations of NOAA Fisheries survey tows. During each tow we used the AST sonar to identify the NEFSC dredge track at long range and the Imagenix sonar to maintain a fairly constant distance from the track at close range. Other towed

equipment deployed during this project included the NMFS Video Plankton Recorder (VPR) mounted on a batwing depressor towbody, for collecting data on plankton species and location throughout the water column, and the 8' NEFSC scallop survey dredge for sampling areas where NEFSC survey tows were not made. The layout of the towing blocks allowed only three instruments to be set out at once.

3.1 Comparative tows with NOAA Fisheries scallop survey vessel, R/V Hugh R. Sharp

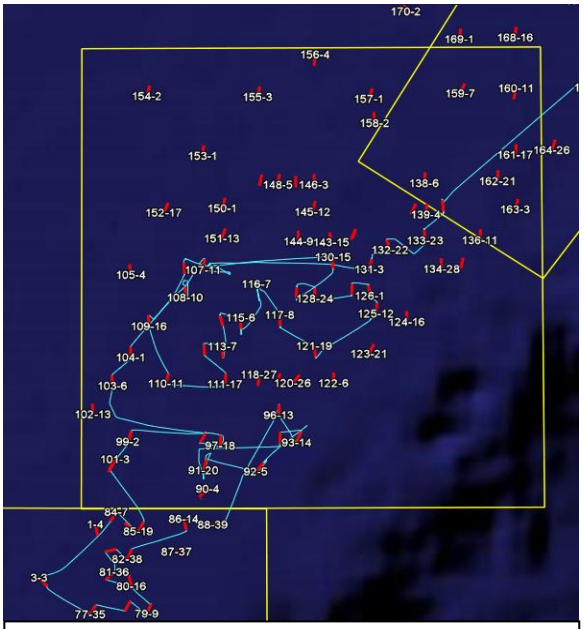


Figure 4. HABCAM trackline in DMV and ET showing path though 56 R/V Hugh R. Sharp survey tows (red). Many were sampled several times.

(25 June - 13 August 2008)
Optical data on scallop densities were collected at 56 NEFSC scallop survey station locations in the Elephant Trunk and DelMarVa scallop Access Areas. Additional comparative tows were conducted during the second cruise within the CLA II HAPC, CLA I, the WGSC HAPC. During the third cruise comparative tows were conducted within CLA I, the WGSC HAPC, and to the north along the eastern side of Nantucket Shoals.

3.2 Scallop resources in CLA I

(28 July - 4 August 2008)
Multiple strategies for conducting line transects were employed using the HABCAM system in the following areas: CLA II HAPC, CLA I, and the WGSC HAPC. In addition to the straight north-south transects conducted in 2006, grids, spiral, and zig-zag patterns were conducted to provide direct comparisons to both the optical data collected at locations of the NEFSC stratified random survey stations and the data that was collected between the survey stations.

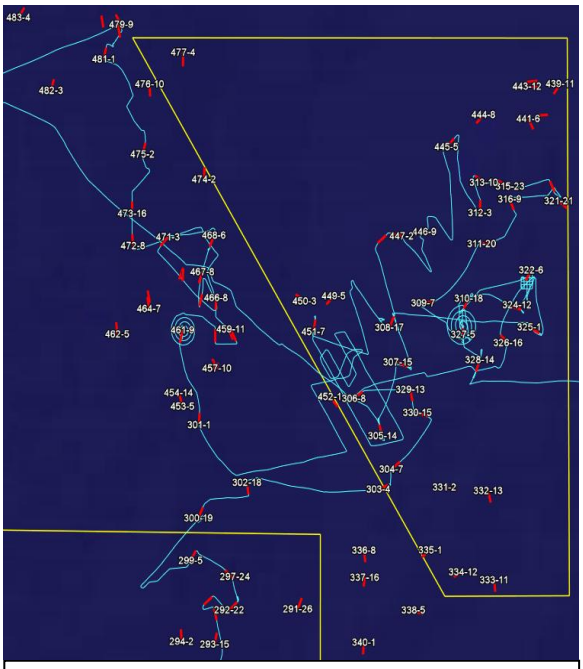


Figure 5. HABCAM trackline in Closed Area I and WGSC HAPC showing grid, spiral and zig-zag.

Initial efforts to tow two vehicles simultaneously were detailed in the 2007 RSA project final report (HABCAM GROUP 2008). In that report we described the development of routines for safely deploying, towing, and recovering the fragile carbon fibre epoxy FOCUS-2 vehicle, electronics bottles, and sonar antennae. After a short time both vehicles could be set or hauled sequentially within a few minutes, and towed simultaneously. In 2008, we repeated the same familiarization process with a third towed body, first with an 8' survey dredge, then with the VPR (Figure 14).

The timing of the AST sonar group's availability and the necessity of meeting the R/V Hugh R. Sharp at predetermined locations based soley on their progress through the survey stations meant we had to creatively juggle the multiple scheduled tasks. The cruise began with transects in SBNMS

and Jeffreys Ledge, before again meeting the Sharp in order to conduct comparative tows in the CLA II HAPC. Building on initial efforts in the 2007 RSA project, the final portion of this second trip utilized two of the four sonar instruments (i.e. the Imagenix and AST) to collect optical and acoustic data simultaneously in the CLA II HAPC, in CLA I, and in WGSC HAPC.

3.3 Scallop resources and substrate characterization in the WGSC HAPC

(7-13 August 2008)

Optical and acoustic transects were conducted in the WGSC HAPC using the HABCAM and FOCUS-2 vehicles. The remaining comparative tows were also conducted in this area and in the area just to the north. In order to compare the cost effectiveness of the two linear transect methods in one area, a spiral transect pattern was used to cover a 1 square nm area that had previously been surveyed using a ¼ nm rectangular grid pattern. The key question was how much time (and fuel and crew cost) does it take to survey an area, and with what level of precision.

4. Results and discussion

HABCAM trackline				length	length	~ area	~ area
	Year	Area		km	nm	km^2	nm^2
1A	2008	ET		429	232	0.429	0.125
1B	2008	DELMARVA		135	73	0.135	0.039
			subtotal	564	304	0.564	0.164
2A	2008	CLA2 HAPC		102	55	0.102	0.030
			subtotal	102	55	0.102	0.030
3A	2008	CLA1		127	68	0.127	0.037
3B	2008	CLA1		255	138	0.255	0.074
3C	2008	CLA1		89	48	0.089	0.026
			subtotal	471	254	0.471	0.137
4A	2008	WGSC HAPC		39	21	0.039	0.011
4B	2008	WGSC HAPC		57	31	0.057	0.017
4C	2008	WGSC HAPC		90	49	0.090	0.026
4D	2008	WGSC HAPC		47	25	0.047	0.014
4E	2008	WGSC HAPC		33	18	0.033	0.010
			subtotal	263	142	0.263	0.077
			total	1400	756	1.400	0.408

Table 1. Summary of optical transect lengths.

Optical transects were conducted in multiple areas to accomplish the three primary project goals. Overall approximately 1,400,000 square meters of high resolution (~1mm pixel size) optical imagery were collected during this project. All processed optical imagery and associated data is available on the project website at http://habcam.whoi.edu.

Approximately 184 million square meters of acoustic sidescan imagery was collected using the AST sonar system primarily in Closed Area I and the WGSC HAPC, but also within the Stellwagen Bank National Marine Sanctuary and on Jeffreys Ledge. Straight sections of the acoustic transects are available via the website using kml files. These kml files request the images over the network for display in a variety of viewers including Google Earth.

track	type	area	length_nm	length_m	width_m	area_m^2	area_km^2	area_nm^2
2008-1	AST	Closed Area 1	118	218,536	270	59,004,720	59	17
2008-2	AST	WGSC_HAPC	99	183,348	270	49,503,960	50	14
2008-3	AST	WGSC_north of HAPC	20	37,040	270	10,000,800	10	3
2008-4	AST	Northern Edge HAPC	55	101,860	270	27,502,200	28	8
2008-5	AST	SBNMS and Jeffreys	76	140,752	270	38,003,040	38	11
		subtotal	368	681,536		184,014,720	184	54
2007-1	AST	Closed Area 1	29	53,152	200	10,630,480	11	3
2007-2	AST	WGSC_HAPC_SE-NW	10	18,520	200	3,704,000	4	1
2007-3	AST	WGSC_HAPC_NE-SW	20	37,040	200	7,408,000	7	2
2007-4	AST	NLSCLA and west	6	10,186	200	2,037,200	2	1
2007-5	AST	Northern Edge HAPC	34	62,968	200	12,593,600	13	4
2007-6	3002	NLSCLA west	59	109,268	400	43,707,200	44	13
		subtotal	157	291,134		80,080,480	80	23

Table 2. Summary of Applied Signal Technology acoustic transects conducted in 2008 and 2007.

A second sonar, the Imagenix 991 (675 kHz), is mounted on the HABCAM frame and collects continuous sidescan data continuously looking out to the starboard side to a distance of 50 meters. The 1,400 km trackline implies an area swept of ~20 nm^2 (~68 km^2). This is most important in areas where the AST sonar was not deployed, where it is likely the only acoustic

data available. This imagery is currently not on the network as it has a proprietary format and viewer. Data can be reviewed at the WHOI Marine Research Facility Laboratory (MRF).

4.1 Comparative tows with NOAA Fisheries scallop survey vessel, R/V Hugh R. Sharp

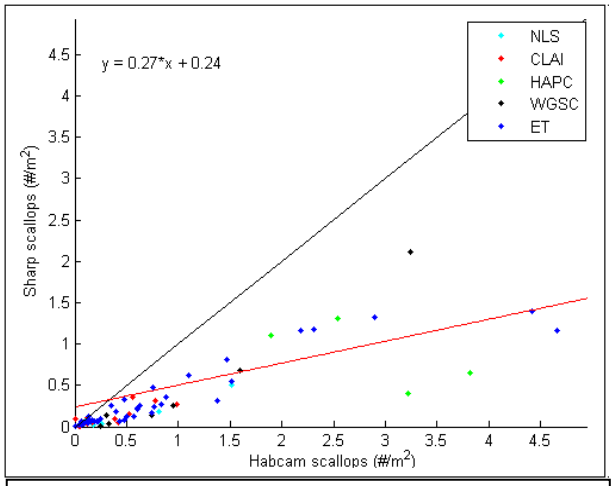


Figure 6. Plot of comparative tow results by area.

The HABCAM instrument was towed at the locations of 103 NEFSC scallop survey tows in the ET, CLA II HAPC, CLA I, and WGSC HAPC. Another 475 nm of optical data was collected while towing between the NEFSC survey stations.

Figure 7 is a plot of the sizes and counts of scallops seen during the HABCAM transects near a NEFSC survey dredge tow. Note that the ratio is clustered tightly and is fairly consistent for the more normal densities encountered below 3 scallop / m^2. For the large majority of comparative tows the raw ratio fell between 20 and 60% with most of the larger numbers coming from the ET Access Area.

Shell height measurements were plotted after correcting for the distortion inherent in the lens and the variable altitude of the HABCAM imagery. Multiple year classes were clearly evident in both efforts. The mean shell height was generally within 5mm for all tows with more than a minimal amount of scallops in the optical imagery. Differences are evident in shell heights at both the smallest and larger sizes, perhaps implying that the lens distortion is not fully compensated, and/or that the catch of the survey dredge varies with size.

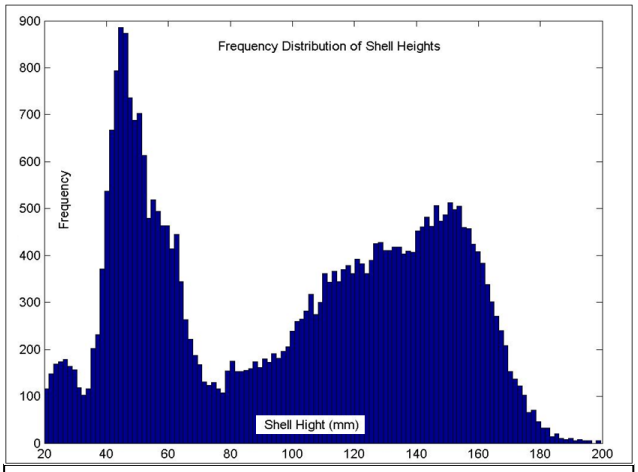


Figure 7. Shell heights within Northern Edge HAPC.

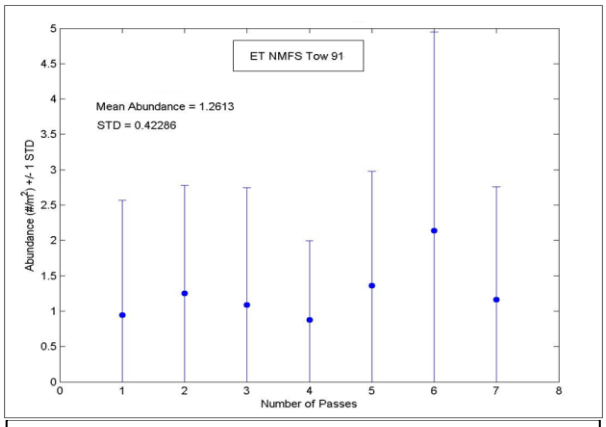


Figure 8. Comparison of multiple HABCAM passes over a single NEFSC scallop survey station. Over 50 comparative tows had at least 3 passes.

In order to generate data on the variability in counts of the 10 to 100 meter offsets in the optical transect, about half of the HABCAM comparative tows were replicated three times, and a few stations were replicated five to seven times. The simple fact is that the towed vehicle is not steerable in the normal sense. When we could see the dredge path in the AST or the Imagenix sonar imagery it could be used to visually steer the vessel, and often a fairly precise offset could be maintained. It was not possible in all cases to navigate with that level of precision, as it is an art not a science. The results from multiple passes suggest that, with few exceptions, offsets from the NEFSC tow

paths did not produce a wide difference in the scallop counts, as the variability along the tow path was much greater than that between the tow paths. Individual plots of the comparative tow results were produced for most of the 103 tows. A representative sample of these plots is included in the Appendix, section 9.2, Figure 18.

4.2 Scallop resources in Closed Area I

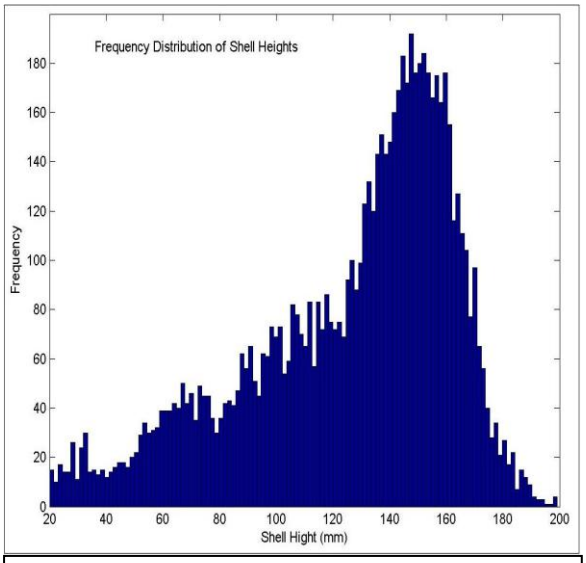


Figure 9. Shell heights within Closed Area I.

Multiple approaches were used to conduct optical transects within CLA I scallop Access Area including a spiral (with ¼ mile spacing between successive loops), a 1 nm square grid with ¼ nm spacing between both north-south and east-west transects, and various zig-zag spacings. The resulting irregular series of tracklines totaled 254 nautical miles in length (471,000 m^2), and were used to calculate scallop counts and derive a biomass estimate. Areas both north and south of the current iteration of the Closed Area I scallop Access Area were included in the transects as those scallop populations remain of continuing interest to industry as they have always been a significant portion of the Georges Bank scallop resource, as well as a key component of the NEFMC rotational fishing approach.

Manual counts were made of scallop in the HABCAM imagery collected within the Closed Area I then divided into subareas in order to understand the contribution of each area. These data were then kriged using cells of various sizes for the individual areas and for two combinations of two subareas. Neither the most northerly or most southerly portions were surveyed. Figure 10 plots the relative densities in the middle three of the five subareas where transects were made. The calculated biomass for subarea 4 alone was almost double that calculated for the combined biomass total within subareas 2 and subarea 3 (see Table 3, Appendix).

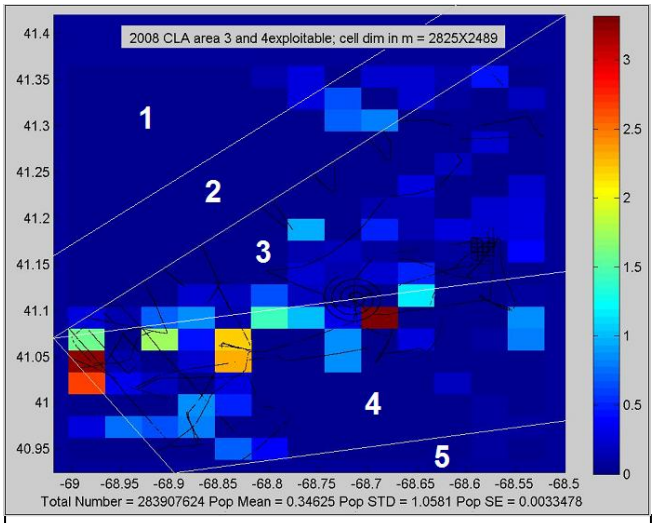


Figure 10. Map of kriged scallop counts in Closed Area I

4.3 Scallop resources and substrate characterization in the Great South Channel HAPC

The area of the WGSC HAPC is about 700 nm^2 or 9 10 minute "squares". In 2008 HABCAM was towed in the WGSC HAPC area and collected 142 nautical miles (263km) of optical data imaging an area of approximately 0.08 nm^2 (0.263 km^2).

The 2008 AST fieldwork was performed as a subcontract within this project. Additional work had been contributed in 2007 in experimental mode, where data from additional tracklines of ~30 nm were collected in the WGSC HAPC. In total the AST sidescan arrays were towed over a trackline of ~129 nm (238 km) looking out 100 - 135 meters to each side. Thus, neglecting

the few areas where the sonar transects crossed each other (and were useful for calibration purposes), the total imaged area using the AST sidescan was about 17 nm^2 (61 km^2) or about 20% of one 10 minute square, or about 2% of the entire area. Approximately 10% of the WGSC HAPC (primarily to the west) is in places quite shoal with sand ridges, wrecks, and underlying ledge, and thus difficult to survey safely with a 100' class vessel and problematical with any towed vehicle such as the FOCUS-2, as the towed sonar arrays need to be below the vessel wake.

Table 3. Calculated scallop counts for the Closed Area I subareas. Note subarea 3 and 4 results.

Scallop Abundance		cell STD	Cell Mean	Cell SE	pop mean	pop CV	pop STD	pop SE	Mean Variance
Areas 2 and 3									
Total	156,942,833	0.014196	8462	1.04E-04	0.1954	3.4103	0.66639	0.002607	0.33687
Area 3									
Total	92,015,590	0.014938	8177	1.41E-04	0.19427	3.4464	0.66954	0.002868	0.054842
Area 4									
Total	294,800,060	0.020837	15406	1.51E-04	0.57409	2.0783	1.1931	0.006405	0.49097
Scallop Biomass									
Areas 2 and 3									
Exploitable	12345	2.9043	1.4649	3.16E-02	8.3423	3.1735	26.4743	0.065753	0.17963
Areas 3									
Exploitable	2244	0.34719	0.19951	3.27E-03	4.6746	4.3076	20.1364	0.086257	0.08784
Area 4									
Exploitable	9880	0.71648	0.51633	5.18E-03	23.6933	2.27	53.7833	0.28874	1.1062

4.4 Contribution to management

Work accomplished during this project contributes to management in several ways. It has:

1. added to the body of knowledge concerning the efficiency of NOAA survey dredge in various scallop resource areas, useful in calibrating the optical survey method to historical time series;

2. provided scallop count and biomass estimates in CLA I, and the WGSC HAPC;

3. has collected high resolution sonar imagery for a representative portion of the WGSC HAPC as well as within the scallop access area of CLA I and the CLA II HAPC; and

4. provided internet access to all of the optical and much of the acoustic imagery, the latter in areas where generally there is no existing or publically accessible backscatter data.

Results from items 1 and 2 above have been presented and reviewed by the Invertebrate SubCommittee at the NEFSC during the weeks of February 8th to 12th, March 15th to 19th, and April 26th to 30th 2010. These meetings have been conducted in preparation for the scallop Stock Assessment Review Committee (SARC 50) held in early June at the NEFSC.

4.5 Opportunities for further work

Applied Signal Technology synthetic aperture sonar

The inclusion of the Applied Signal sonar system in this project was to provide a "first look" at substrates in selected areas using these new technologies. It was not meant to be a systematic survey effort and could not be because of cost alone. Technical problems were encountered with the ProSAS system during the effort degrading spatial accuracy; however the somewhat lower

resolution data and imagery collected, approximately equivalent to a 175kHz sidescan, gives an adequate indication of capabilities and of the results possible.

Representative samples of the straighter sections of the AST sonar imagery have been saved in .jpeg format, and roughly georeferenced (within 30 m or about the accuracy of fishing vessel GPS at 5 knots) for viewing in a variety of no cost applications including Google Earth. While not having the full capabilities or spatial precision of dedicated sonar processing and viewing software the result provides a web accessible overview of the bottom backscatter and terrain readily apparent in the imagery of the WGSC HAPC and other areas. The .kml format files with web enabled links to this imagery are available on the HABCAM GROUP website at http://habcam.whoi.edu for individuals who are interested. However, due to the large size of the image files, a high speed internet connection is necessary. The website is currently undergoing rapid change and expansion in order to increase functionality.

A short list of logical next steps regarding the acoustic imagery includes the following:

1. comparison of the optical and acoustic results for specific target areas in order to document and better understand what the acoustic data represents. While this is ongoing it will require a long term effort in conjunction with the UNH Center for Coastal and Ocean Mapping (CCOM).

2. automated segmentation of areas with differing grain size (note the long streaks in line with the strong north-south currents in the WGSC in Figure 2). This effort will require repeat visits to determine persistence of these features, and for those of dredge and door tracks. Initial observations coupled with data from VMS plots suggest that dredge tracks do not persist in high current areas such as the WGSC HAPC. This is based on the fact that they are only present in the acoustic data in small areas when the VMS records indicate considerable scallop fishing activity in each of the 10 years between 1998 and 2007.

3. counting, sizing, and delineating areas where targets are classified as cobbles and boulders.

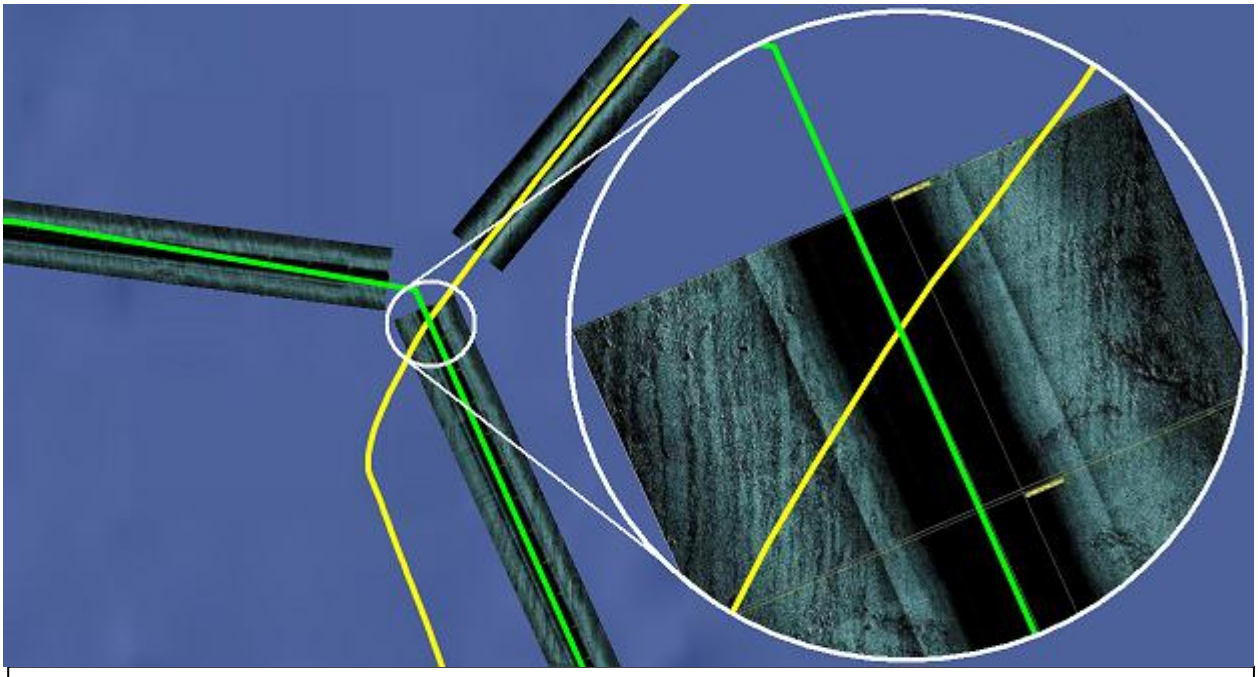


Figure 11. High resolution insert of an area where AST sonar crosses a previous trackline in WGSC HAPC.

Representative imagery is available online and may assist the NEFMC Habitat Committee in the ongoing substrate/habitat description process.

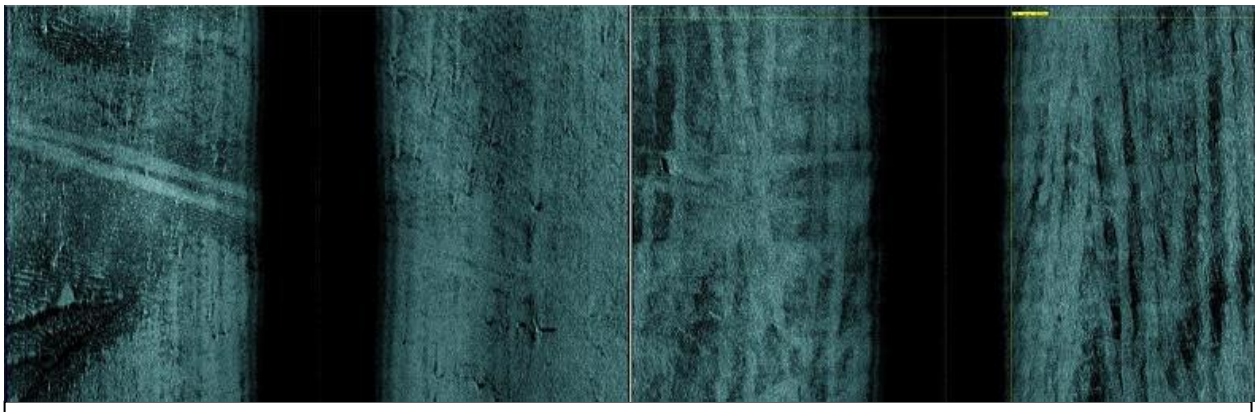


Figure 12. Scallop dredge tracks evident in the AST sonar imagery. In the left panel note the single pair of tracks, and the many tracks in the right. Wide areas of the WGSC HAPC exhibited no tracks at all though VMS data for the preceding 10 years indicates substantial scallop fishing activity in the area for the entire period.

Linear transect survey design

In order to generate the greatest amount of useable data in the shortest time given the large area to be surveyed, considerable savings in fuel and personnel costs can likely be realized by determining the most cost effective survey method. One method suggested is synchronizing survey patterns with the tide as much as possible in order to minimize fuel while maintaining speed over the seafloor. This would steady the vehicle pitch and roll. Another approach is to minimize tight turns in order to more reliably fly the towed vehicle in the lighting "sweet spot" of 1.5 to 2.5 meters reducing the number of images that are not useful (Vine, pers. comm.).

5. Participating organizations and individuals

The HABCAM GROUP is a partnership with individuals from the Woods Hole Oceanographic Institution (Gallager, Howland, York, Lerner), Arnie's Fisheries, Inc. (Rosonina, DeMello), and independent researchers (Vine, Taylor). Additional individuals contributed greatly in at-sea data collection and shoreside data processing tasks (Bolles, Keating, Fallon, Tyler and many others).

Applied Signal Technology, Inc., located in Sunnyvale, California, provided the advanced sonar equipment and data collection and processing technologies for their contribution, including initial planning and logistics (Wilby, Walden, Barrett), scientists-programmers and technicians for the at sea deployment (Matt, D. Simmonds, R. Patton, Shivesh).

6. Acknowledgements

The Northeast Consortium provided funding for initial camera and vehicle development in 2002. Particular recognition is given to Jonathan Howland, Lane Abrams, and Andy Girard of the Woods Hole Oceanographic Institution for their contributions to instrument and vehicle design, construction, and testing.

NEFMC/NMFS Scallop RSA program grant (NOAA Award NA05NMF4540009) for funding further camera system development in 2005. This funding allowed the system to become fully functional and included major vehicle modifications, installation of a fiber optic winch and A-frame.

NMFS Advanced Technology Working Group, Deborah Hart P.I., for providing additional funding for software development specifically focused on color correction and segmentation of targets, a computer for data processing, and a dedicated server.

NEFMC/NEFSC Scallop RSA program grant (NOAA Award NA06NMF4540264) for funding to conduct survey transects in 2006. This funding also allowed for further system development, integration of software improvements, and progress in comparing survey designs.

NEFMC/NEFSC Scallop RSA program grant (NOAA Award NA07NMF4540030) for funding to conduct survey transects in 2007. This funding also supported additional sea time for imagery collection, further development and integration of software improvements.

SBNMS for a contract to collect imagery of an archeological resource on Stellwagen Bank.

NOAA/NOS Integrated Ocean Observing System IOOS program funding (FY 2007) which allowed repeated visits to many of the same areas where scallop transects have been conducted in order to document changes in benthic community structure over time.

Kathryn Ford of the Massachusetts Division of Marine Fisheries provided the generator to power the McArtney winch used to tow the FOCUS-2 vehicle.

Special thanks are due to Arnold DeMello, owner of the F/V Kathy Marie, Captain Paul Rosonina, and the rest of the crew for being willing to modify their fishing schedule and make the vessel available for the science cruises. In particular, Antonio Melo, the engineer, must be singled out for making necessary changes and repairs to equipment on the fly, while making it seem as if it is all in a day's work.

7. Presentations

Scallop Survey Advisory Panel, Coonamessett Farm, Falmouth, MA, 20071220
NEFSC Noon series, Woods Hole, MA, 20080123
Scallop Survey Advisory Panel, Industrial Park, Falmouth, MA, 20080304
National Shellfish Association meeting, Providence, RI, 20080410
Scallop Survey Advisory Panel Meeting, Holiday Inn, Mansfield, MA, 20090903

All Powerpoints and posters are on the website at URL http://www.habcam.whoi.edu

8. References

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HABCAM GROUP (2008) Evolution of a Benthic Imaging System from a Towed Camera to an Automated Habitat Characterization System, MTS/IEE Oceans08, Quebec, CA, 7pp.

HABCAM GROUP (2008A) Final Report RSA 06-SCA-010, Adaptive Characterization of Scallop Populations Using High Resolution Optical Imaging, NOAA Award NA06NMF4540264, 21 pp.

HABCAM GROUP (2008B) Final Report RSA 07-SCA-002, Adaptive Characterization of Scallop Populations Using High Resolution Optical Imaging, Phase 2, NOAA Award NA07NMF4540030, 29 pp.

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Sanderson, Melissa A. (2004) CHARACTERIZATION OF SCALE IN COMMERCIAL FISHERIES DATA, Masters thesis, http://dukespace.lib.duke.edu/dspace/handle/10161/248, http://dukespace.lib.duke.edu/dspace/bitstream/10161/248/1/Sanderson%20MP%202004.pdf

Stein, M. L. (1999) Interpolation of Spatial Data: Some Theory for Kriging (Springer Series in Statistics). Springer.

Stiene, S., K. Lingemann, A. Nuchter, J. Hertzberg (2006) Contour-Based Object Detection in Range Images, Third International Symposium on 3D Data Processing, Visualization, and Transmission (3DPVT'06) pp. 168-175.

Zhang, J., and L. Gruenwald (2006) "Opening the black box of feature extraction: Incorporating visualization into high-dimensional data mining processes." IEEE Computer: 6th International Conference on Data Mining, p. 1188.

9. Appendix

9.1 Selected images

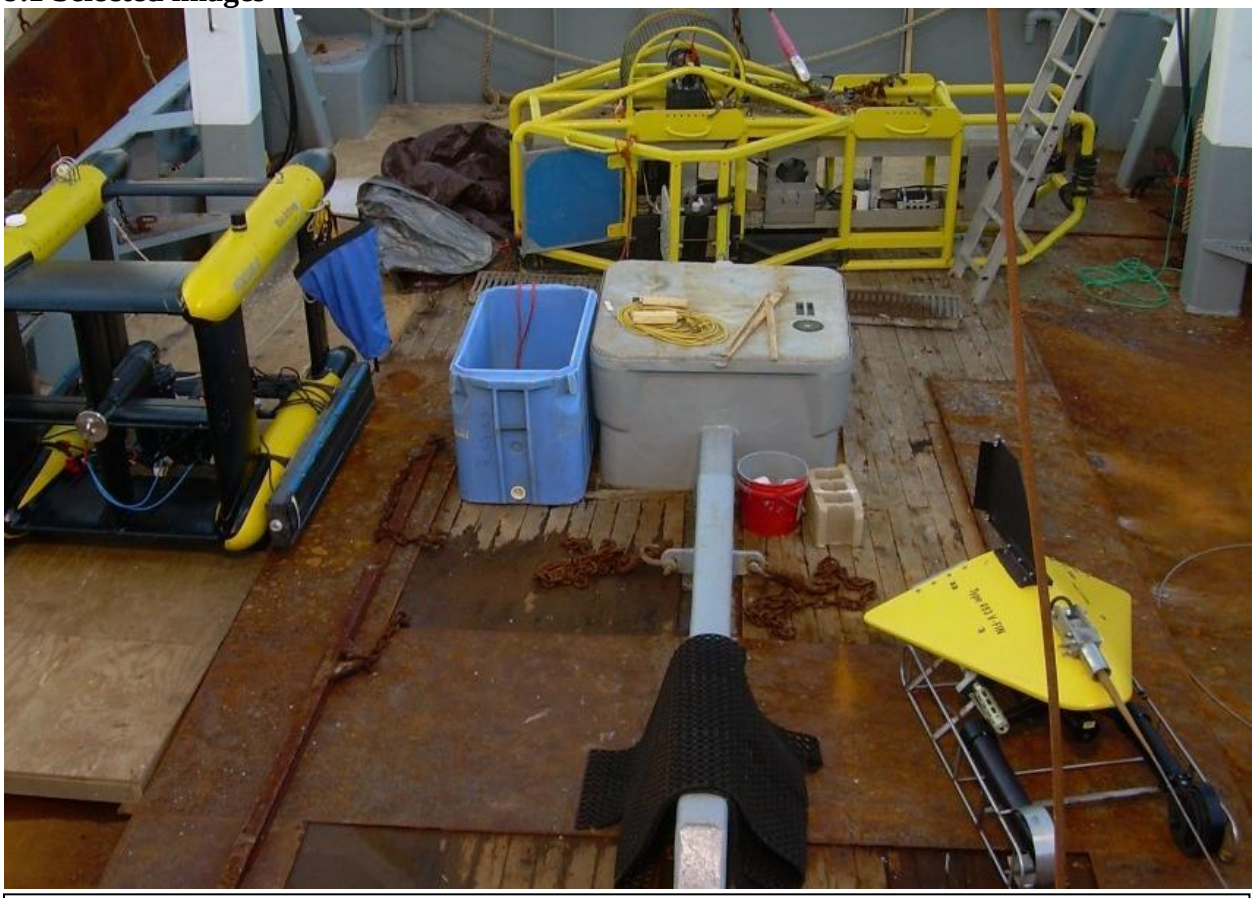


Figure 13. Three of 4 instruments towed by F/V Kathy Marie during this project. NEFSC survey dredge not shown.

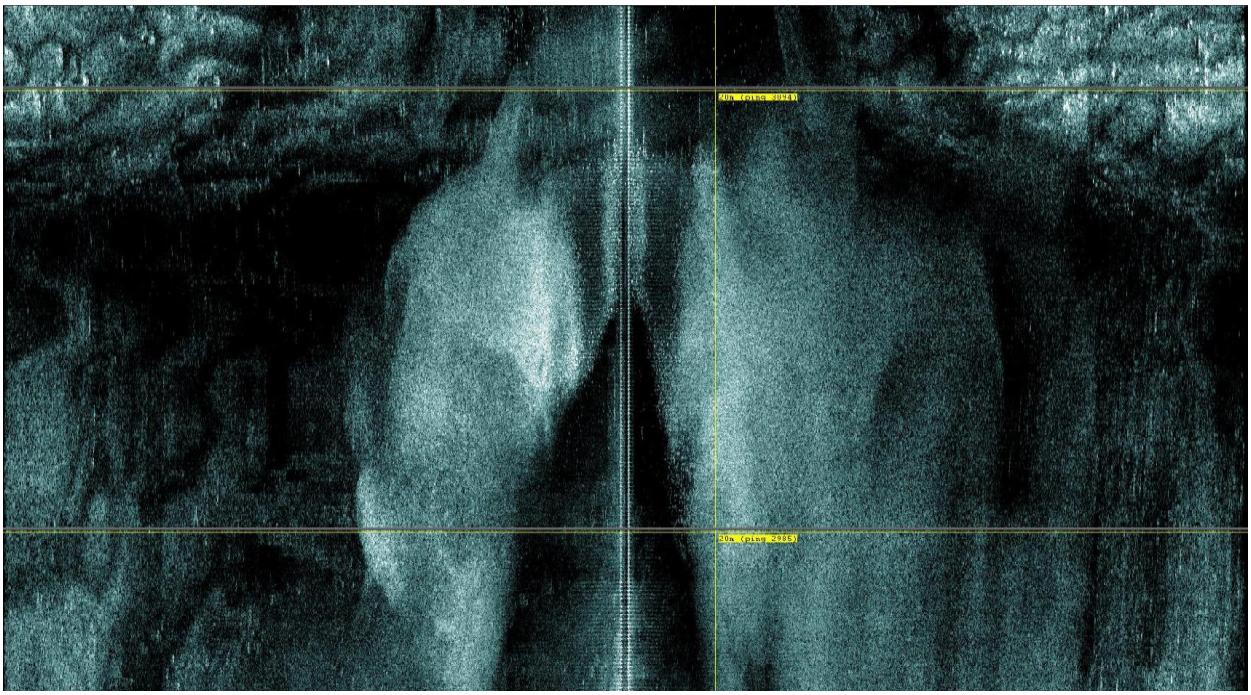


Figure 14. Midwater clouds of plankton imaged when setting out the AST sonar in Western Great South Channel. Total depth ~70m, vehicle altitude ~40m, total image width ~270 meters, resolution 1 pixel = ~3cm.

Figure 15. AST sonar sand wave mosaic, 270m total image width. Note sand waves of differing scales.

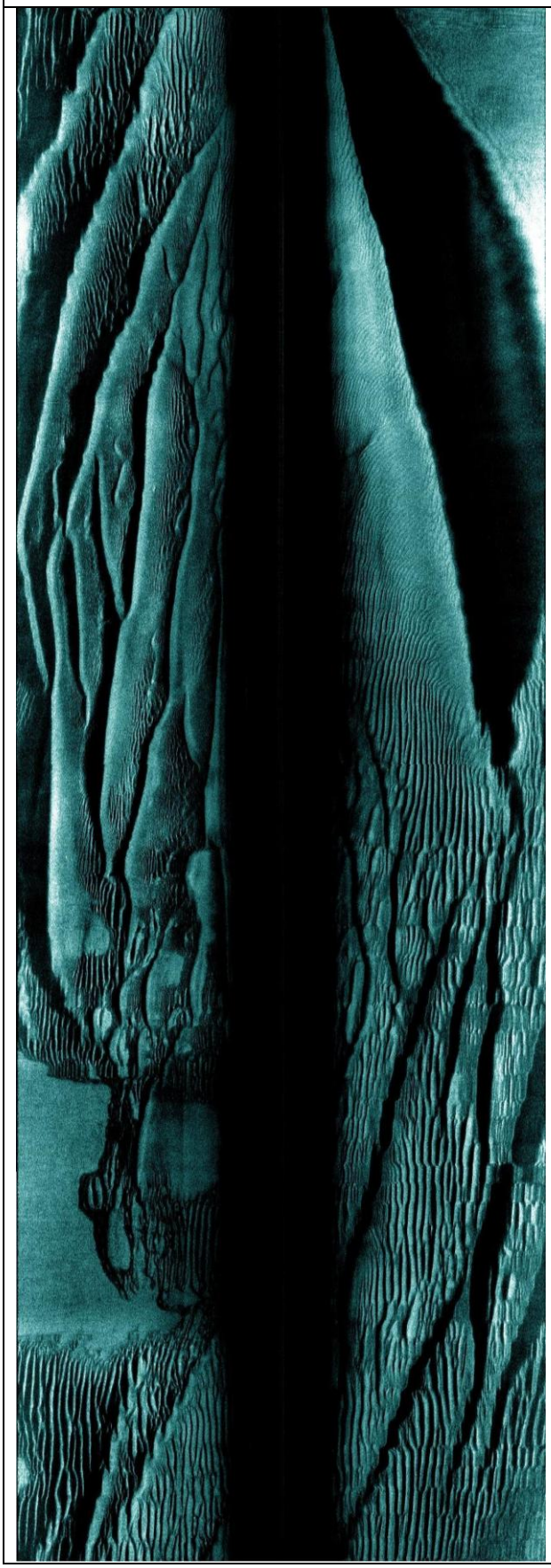


Figure 16. AST imagery of 8' NEFSC dredge. Note faint NEFSC survey track left. Image width ~100 feet.

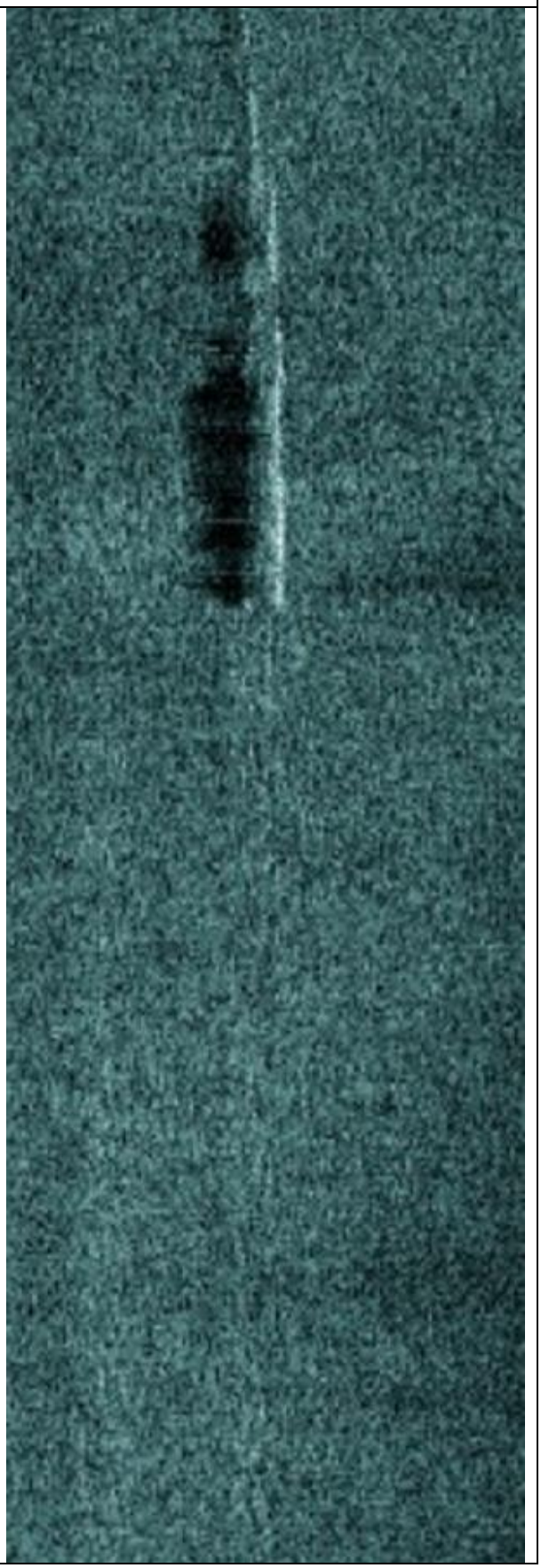


Figure 17. Sequential screenshots from Google Earth as seen when zooming in to AST sonar transects. Over 14 nm^2 of imagery was collected in the WGSC HAPC.

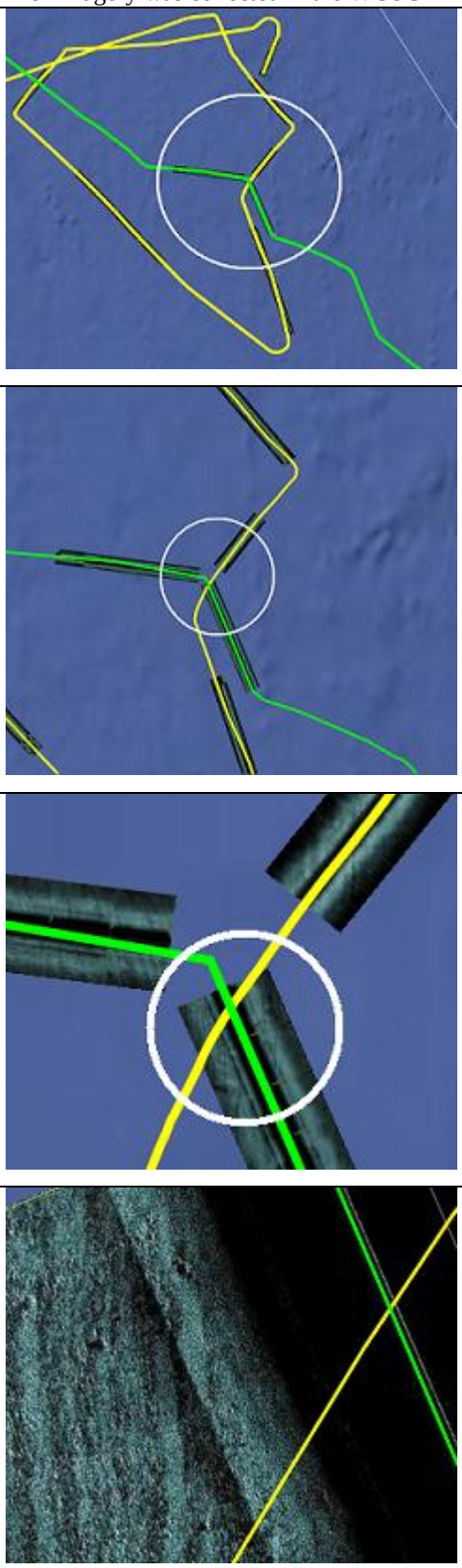
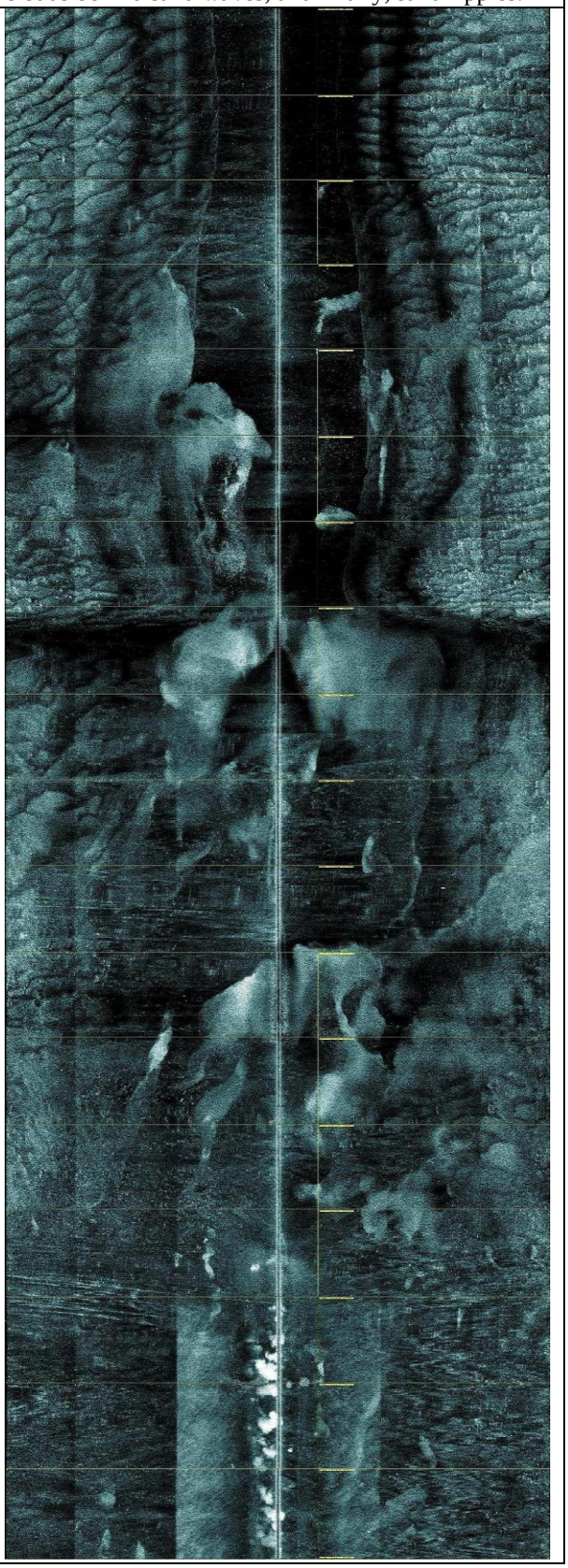
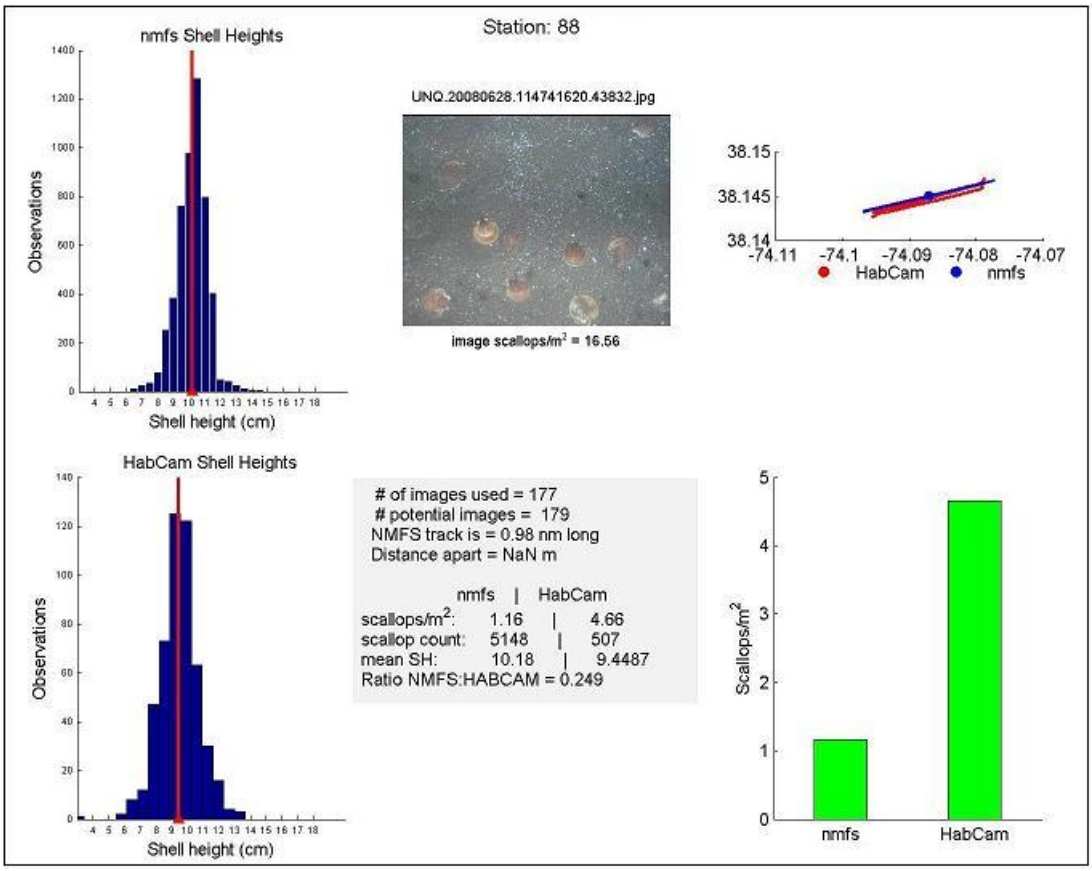
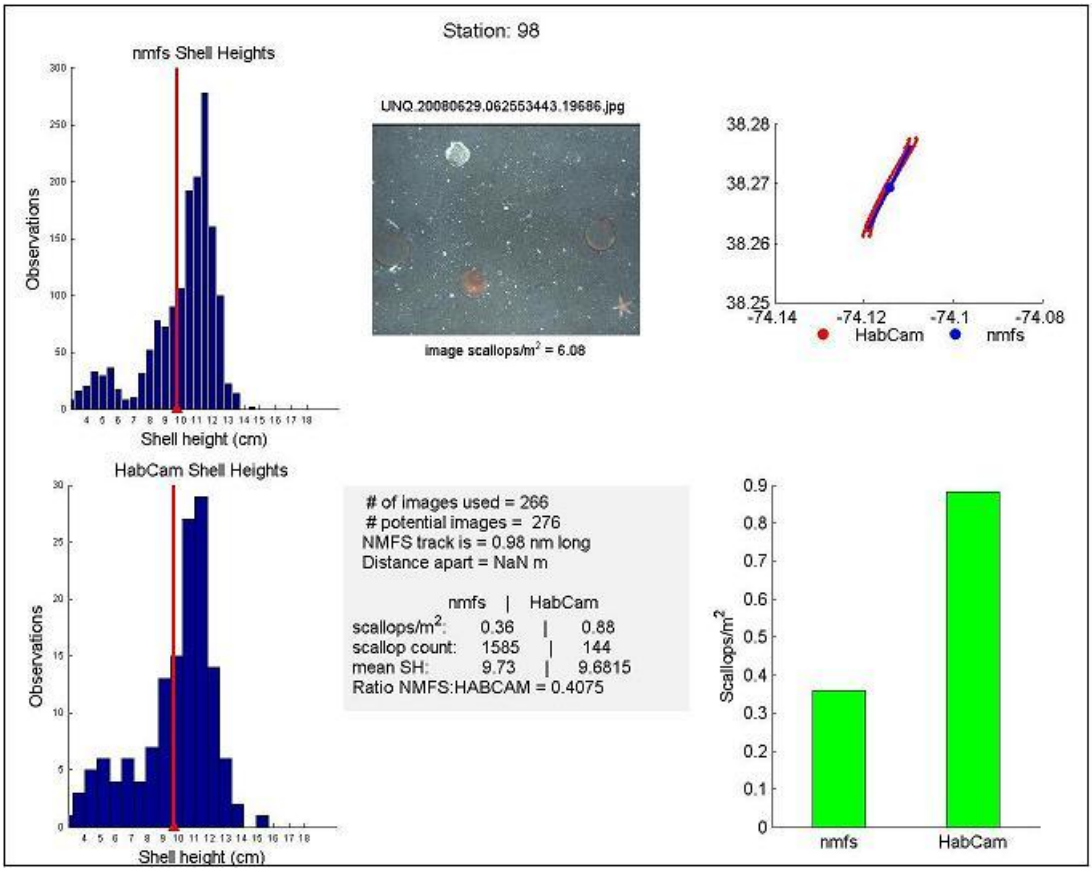


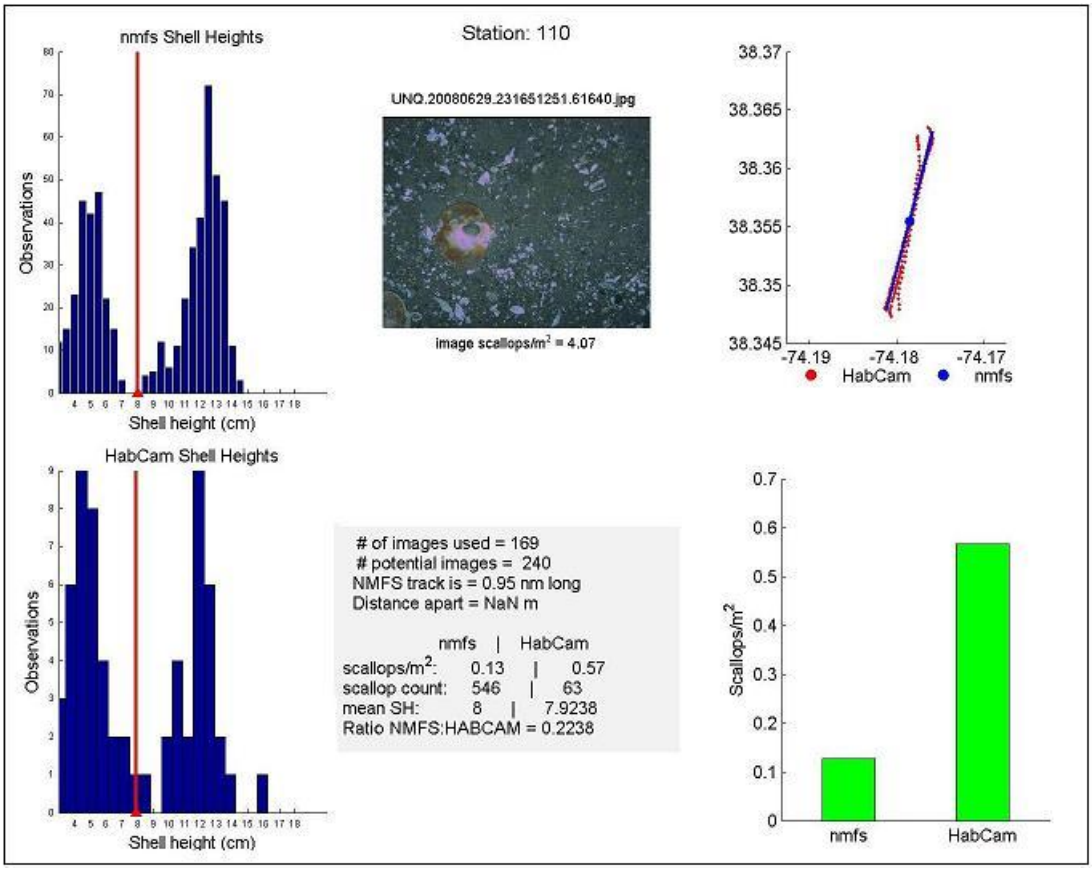
Figure 18. AST sonar setting out. Note progression of returns: vessel propwash (bottom), midwater plankton clouds behind sand waves, and finally, sand ripples.



Figures 19a–19d. Individual plots of data and comparative results from four representative tows






Station: 110
nmfs Shell Heights
Observations
Shell height (cm)
UNQ.20080629.231651251.61640.jpg
image scallops/m² = 4.07
HabCam
nmfs
HabCam Shell Heights
# of images used = 169
potential images = 240
NMFS track is = 0.95 nm long
Distance apart = NaN m
nmfs | HabCam
scallops/m²: 0.13 | 0.57
scallop count: 546 | 63
mean SH: 8 | 7.9238
Ratio NMFS:HABCAM = 0.2238
Scallops/m²

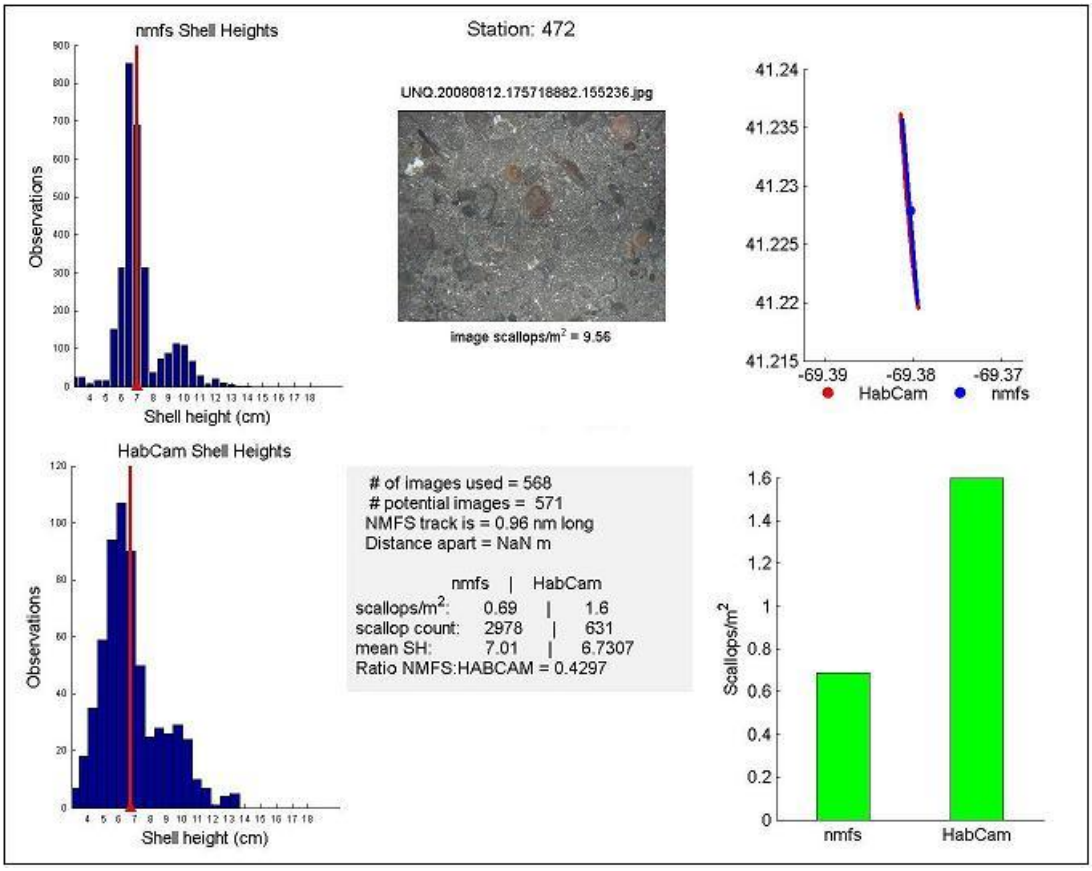
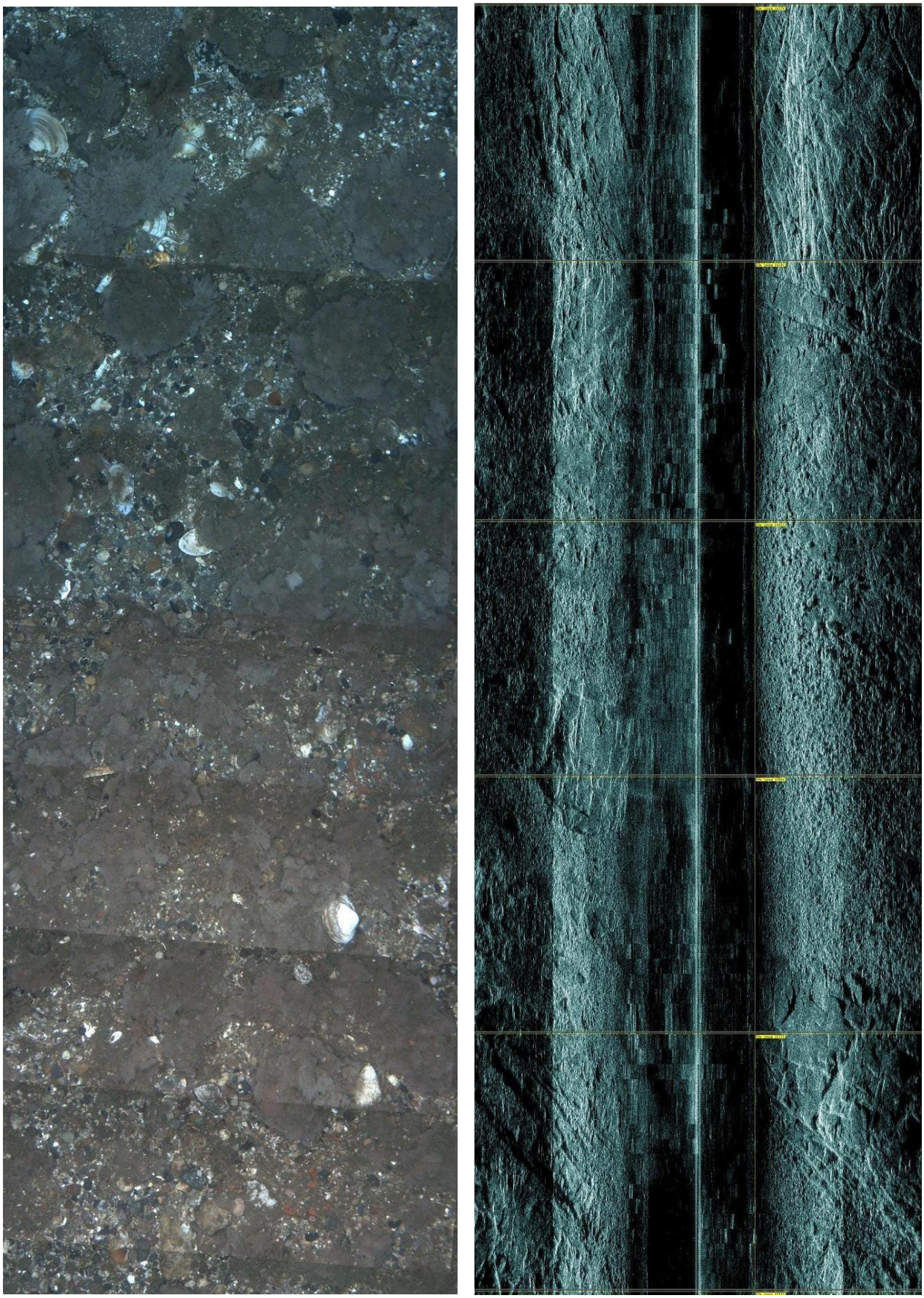

Station: 472
nmfs Shell Heights
Observations
Shell height (cm)
UNQ.20080812.175718882.155236.jpg
image scallops/m² = 9.56
HabCam
nmfs
HabCam Shell Heights
# of images used = 568
potential images = 571
NMFS track is = 0.96 nm long
Distance apart = NaN m
nmfs | HabCam
scallops/m²: 0.69 | 1.6
scallop count: 2978 | 631
mean SH: 7.01 | 6.7307
Ratio NMFS:HABCAM = 0.4297
Scallops/m²

Figure 20. Mosaics from two areas: bryzoans on Georges Bank, and exposed ledge in SBNMS



9.2 Table 4. List of species identified in HABCAM imagery as of 20080901

PHYLUM	GROUP NAME	*GENUS*	*SPECIES*	COMMON NAME
Porifera	sponges	*Haliclona*	*oculata*	finger sponge
Porifera	sponges	*Isodictya*	*palmata*	palmate sponge
Porifera	sponges			Tan branched sponges
Porifera	sponges	*Microciona*	*prolifera*	red beard sponge
Porifera	sponges	*Suberites*	*ficus*	fig sponge
Porifera	sponges			unknown sponge
Porifera	sponges	*Halichondria sp.*		halichondria
Porifera	sponges	*Haliclona*	*urceola*	tubular sponge
Porifera	sponges	*Hymedesmia*	*spp.*	Hymedesmia
Porifera	sponges	*Iophon*	*spp.*	Iophon erect
Porifera	sponges	*Iophon*	*spp.*	Iophon encrusting
Porifera	sponges	*Iophon*	*spp.*	Iophon on brachiopod
Porifera	sponges	*Ciocalypta*	*penicillus*	thin brush sponge
Porifera	sponges			encrusting sponge
Porifera	sponges			erect sponge
Porifera	sponges			Polymastia
Porifera	sponges	*Mycale*	*spp.*	Mycale
Cnidaria	jellyfish			jellyfish
Cnidaria	anemonies /coral			cerianthid
Cnidaria	anemonies /coral	*Metridium*	*senile*	frilled anemone
Cnidaria	anemonies /coral	*Urticina*	*felina*	northern red anemone
Cnidaria	anemonies /coral			unknown anemone
Cnidaria	anemonies /coral	*Bolocera*	*tuediae*	deeplet sea anemone
Cnidaria	anemonies /coral	*Alcyonium*	*spp.*	dead mans fingers
Cnidaria	anemonies /coral	*Edwardsia*	*spp.*	burrowing anemone
Cnidaria	hydrozoan	*Tubularia*	*spp.*	tubularia
Cnidaria	anemonies /coral	*Pennatula*	*aculeata*	sea pen
Cnidaria	anemonies /coral	*Edwardsia*	*spp.*	burrowing anemone
Ctenophora	comb-jellies			ctenophore
Brachiopods	lamp shells	*Terebratulina*	*septentrionalis*	lamp shell
Mollusca	snails	*Buccinum*	*undatum*	waved whelk
Mollusca	snails	*Busycon*	*canaliculatum*	knobbed whelk
Mollusca	snails	*Busycon*	*carica*	channeled whelk
Mollusca	snails	*Lunatia*	*heros*	moon snail
Mollusca	snails			conical gastropods
Mollusca	snails			round gastropods
Mollusca	snails			sand collar
Mollusca	snails	*Calliostoma*	*spp.*	Calliostoma
Mollusca	snails	*Neptunea*	*decemcostata*	ten-ridged whelk
Mollusca	snails	*Colus*	*spp.*	Colus
Mollusca	snails	*Epitonium*	*spp.*	wentletrap
Mollusca	snails	*Nudibranchs*		nudibranchs
Mollusca	bivalves	*Chlamys*	*islandica*	iceland scallop
Mollusca	bivalves	*Ensis*	*directus*	razor clam shell
Mollusca	bivalves	*Modiolus*	*modiolus*	northern horsemussel
Mollusca	bivalves	*Placopecten*	*magellanicus*	sea scallop
Mollusca	bivalves	*Spisula*	*solidissima*	atlantic sufclam
Mollusca	bivalves			clam shape
Mollusca	bivalves			dead scallop
Mollusca	bivalves			other mussels
Mollusca	bivalves			unknown mollusk
Mollusca	bivalves			unknown siphon
Mollusca	bivalves	*Astarte*	*spp.*	Astarte
Mollusca	bivalves	*Cyclocardia*	*borealis*	northern cardita
Mollusca	squid/octopus			squid
Mollusca	squid/octopus			octopus
Mollusca	squid	*Loligo*	*pealei*	long-finned squid

Annelida	marine worms	*Aphrodita*	*hastata*	sea mouse
Annelida	marine worms	*Filograna*	*implexa*	lacy tubeworm
Annelida	marine worms	*Serpulid*	*spp.*	serpulid worm
Annelida	marine worms	*Spirorbis*	*spirorbis*	Spirorbis
Annelida	marine worms			Fan worms
Annelida	marine worms			unknown worms
Arthropoda	crustaceans	*Balanus/Semibalanus*		barnacle colony
Arthropoda	crustaceans	*Homarus*	*americanus*	northern lobster
Arthropoda	crustaceans			unknown crab
Arthropoda	crustaceans	*Pagurus*	*spp.*	hermit crab
Arthropoda	crustaceans			shrimp
Arthropoda	crustaceans			jonah or rock crab
Arthropoda	crustaceans			mantis shrimp
Arthropoda	crustaceans			spider crab
Arthropoda	crustaceans	*Lithoides*	*maja*	northern stone crab
Arthropoda	crustaceans			squat lobster
Echinodermata	seastars	*Asterias*	*forbesi*	common sea star
Echinodermata	seastars	*Asterias*	*vulgaris*	northern sea star
Echinodermata	seastars	*Astropecten*	*spp.*	armored sea star
Echinodermata	seastars	*Crossaster*	*popposus*	spiny sunstar
Echinodermata	seastars	*Henricia*	*sanguinolenta*	blood star
Echinodermata	seastars	*Henricia*	*sanguinolenta*	pale henricia
Echinodermata	seastars	*Leptasterias*	*polaris*	polar sea star
Echinodermata	seastars	*Solaster*	*endeca*	smooth sunstar
Echinodermata	seastars			unknown sea star
Echinodermata	seastars	*Leptasterias*	*tenera*	Leptasterias tenera
Echinodermata	seastars	*Ophiopholis*	*aculeata*	daisy brittlestar
Echinodermata	seastars	*Gorgonocephalus*	*agassizi*	northern basket star
Echinodermata	seastars	*Hathrometra*	*spp.*	feather star
Echinodermata	seastars	*Luidia*	*spp.*	Luidia
Echinodermata	seastars	*Hippasteria*	*phrygiana*	horse star
Echinodermata	seastars	*Pteraster*	*militaris*	winged seastar
Echinodermata	seastars	*Porania*	*insignis*	badge star
Echinodermata	sea urchins/sand dollars	*Arbacia*	*punctulata*	purple sea urchin
Echinodermata	sea urchins/sand dollars	*Echinarachnius*	*parma*	sand dollar
Echinodermata	sea urchins/sand dollars	*Strongylocentrotus*	*droebachiensis*	green sea urchin
Echinodermata	sea cucumbers	*Cucumaria*	*frondosa*	orange footed sea cucumber
Chordata	tunicates	*Boltenia*	*ovifera*	stalked tunicate
Chordata	tunicates			poss didemnum
Chordata	tunicates	*Molgula*	*spp.*	sea grapes
Chordata	tunicates			unknown tunicate
Chordata	tunicates	*Halocynthia*	*pyriformis*	sea peach
Chordata	tunicates	*Ascidia*	*spp.*	tunicate
Chordata	hagfish/lamprey	*Myxine*	*limosa*	atlantic hagfish
Chordata	sharks	*Squalus*	*acanthias*	spiny dogfish
Chordata	sharks	*Scyliorhinus*	*retifer*	chain dogfhish
Chordata	skates/rays	*NA*	*NA*	skate egg case
Chordata	skates/rays	*Raja*	*eglanteria*	clearnose skate
Chordata	skates/rays			winter and little skate
Chordata	skates/rays	*Raja*	*laevis*	barndoor skate
Chordata	skates/rays	*Raja*	*radiata*	throny sk
Chordata	skates/rays			unknown skate
Chordata	bony fish	*Ammodytes*	*americanus*	american sand lance
Chordata	bony fish	*Centropristis*	*striata*	black seabass
Chordata	bony fish	*Citharichthys*	*arctifrons*	gulf stream flounder
Chordata	bony fish	*Conger*	*oceanica*	conger eel
Chordata	bony fish	*Gadus*	*morhua*	atlantic cod
Chordata	bony fish	*Glyptocephalus*	*cynoglossus*	witch flounder
Chordata	bony fish	*Lophius*	*americanus*	goosefish
Chordata	bony fish	*Macrozoarces*	*americanus*	ocean pout
Chordata	bony fish	*Melanogrammus*	*aeglefinus*	haddock

Chordata	bony fish	*Merluccius*	*bilinearis*	silver hake
Chordata	bony fish	*Myoxocephalus*	*octodecimspinosus*	longhorn sculpin
Chordata	bony fish	*Myoxocephalus*	*scorpius*	sea raven
Chordata	bony fish	*Omochelys*	*cruentifer*	snake eel
Chordata	bony fish	*Paralichthys*	*dentatus*	summer flounder
Chordata	bony fish	*Paralichthys*	*oblongus*	fourspot flounder
Chordata	bony fish	*Peprilus*	*triacanthus*	butterfish
Chordata	bony fish	*Pholis*	*gunnellus*	rock gunnel
Chordata	bony fish	*Pleuronectes*	*americanus*	winter flounder
Chordata	bony fish	*Pleuronectes*	*ferrungineus*	yellowtail flounder
Chordata	bony fish	*Priontus*	*carolinus*	northern sea robin
Chordata	bony fish	*Scomber*	*scombrus*	atlantic mackerel
Chordata	bony fish	*Scophthalmus*	*aquosus*	windowpane flounder
Chordata	bony fish	*Stenotomus*	*chrysops*	scup
Chordata	bony fish	*Tautoga*	*onitis*	tautog
Chordata	bony fish	*Tautogolabrus*	*adspersus*	cunner
Chordata	bony fish	*Urophycis*	*chuss*	red hake
Chordata	bony fish	*Urophycis*	*tenuis*	white hake
Chordata	bony fish			unknown flounder
Chordata	bony fish			other hake
Chordata	bony fish			small roundfish
Chordata	bony fish			unknown fish
Chordata	bony fish	*Lepophidium*	*profundorum*	blackrim cusk-eel
Chordata	bony fish			unknown worm
Chordata	bony fish	*Brosme*	*brosme*	cusk
Chordata	bony fish			altantic wolf-fish
Chordata	bony fish	*Myoxocephalus*	*scorpius*	shorthorn sculpin
Chordata	bony fish	*Lopholatilus*	*chamaeleonticeps*	tilefish
Chordata	bony fish			unknown gadid
Chordata	bony fish	*Anarhichas lupus*	*lupus*	wolffish