3-2005

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Investigation of Bottom Fishing Impacts on Benthic Structure using Multibeam Sonar, Sidescan Sonar and Video

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Abstract

Bottom fishing gear is known to alter benthic structure, however changes in the shape of the sea floor are often too subtle to be detected by acoustic remote sensing. Nonetheless, long linear features were observed during a recent high-resolution multibeam sonar survey of Jeffreys Ledge, a prominent fishing ground in Gulf of Maine, located about 50 km from Portsmouth, NH. These marks, which have a relief of only few centimeters, are presumed to be caused by bottom dredging gear used in the area for scallop and clam fisheries. The extraction of these small features from a noisy data set (including several instrumental artifacts) presented a number of challenges. To enhance the detection and identification of these features, data artifacts were identified and removed selectively using frequency filtering. Verification was attempted with sidescan sonar and video surveys. While clearly visible on the sidescan sonar records, the bottom marks were not discernable in the video survey. The inability to see the bottom marks with video may be related to the age of the marks, and has important ramifications about appropriate methodologies for quantifying gear impact. Results from multibeam sonar, sidescan sonar and video surveys suggest that the best methodology to deal with inspection of bottom fishing marks is to integrate data in a 3D GIS-like environment.

Introduction

Recent developments in multibeam echo sounding (MBES) offer the opportunity to broaden its use far beyond its traditional application of collecting data in support of navigational safety, port operations and marine geophysics. Foremost amongst these innovative applications is sea floor characterization, which has broad application in locating and characterizing Essential Fish Habitats (EFH) (Mayer et al., 1999). The ability of multibeam sonar to map the shape and structure of the sea floor in great detail provides fisheries managers with essential information about the depth structure of EFH. With additional information about the nature of the substrate (in some cases) and appropriate groundtruth, the spatial distribution of sea floor characteristics can be inferred while covering greater areas than possible with physical sampling methods. Sea floor characteristics, which are important to fisheries managers include, but are not limited to, depth, substrate type, stability, sea floor slope, bottom features, historical and cultural artifacts, natural disturbance (storms etc.) and anthropogenic disturbance (bottom fishing gear, pollution etc.) (Langton, 1995).

This paper describes part of a long-term effort aimed at exploring the viability of using remote mapping techniques to identify critical components of EFH and at gaining insight into the

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impacts of bottom fishing gear on sea floor structure and EFH. Bottom fishing gear includes otter trawls, beam trawls, hydraulic / non-hydraulic dredges and other gear. The interaction of these gear with sea floor depends upon type of the gear used and nature of the sea bottom (Collie et al., 2000). The physical remnants of bottom fishing are often times bottom marks, which may be just a few centimeters deep. Other notable effects on physical structure may be the leveling off the bottom structures (e.g. sand waves). This paper will focus on the development of approaches for improving the detection of these subtle bottom marks using multibeam sonar data.

Study Area

The sea floor off New England is considered one of the nation's richest fishing grounds. The decline of fisheries in the last few decades in this region is alarming and has led to a number of scientific studies aimed at identifying the causes and remedies of the declining fisheries. Several management measures have been implemented to preserve the integrity of fishing grounds including spatial and temporal closure of areas, which are considered essential fish habitat for spawning and stock recovery (Murawski et al., 2000). The largest of these is the Western Gulf of Maine (WGOM) closure area (Figure 1) bounded by $42^{\circ}15'$ N, $69^{\circ}55'$ W; $43^{\circ}15'$ N, $70^{\circ}15'$ W. This closure was implemented in 1996 covering upper and middle Jeffreys Ledge and the eastern portion of Stellwagen Bank (depth ranges 40 m – 200m). Scientists from University of New Hampshire (UNH) are studying this closure area to define the impacts of the closure on the over all ecosystem. In support of this effort several multibeam sonar surveys were carried out. The surveys were designed to cover both the open and closed areas in order to observe the differences between them. Sensors used included the Reson 8101 and 8125 multibeam sonars, a towed video camera and a Klein 5500 and Benthos 3D sidescan sonar.

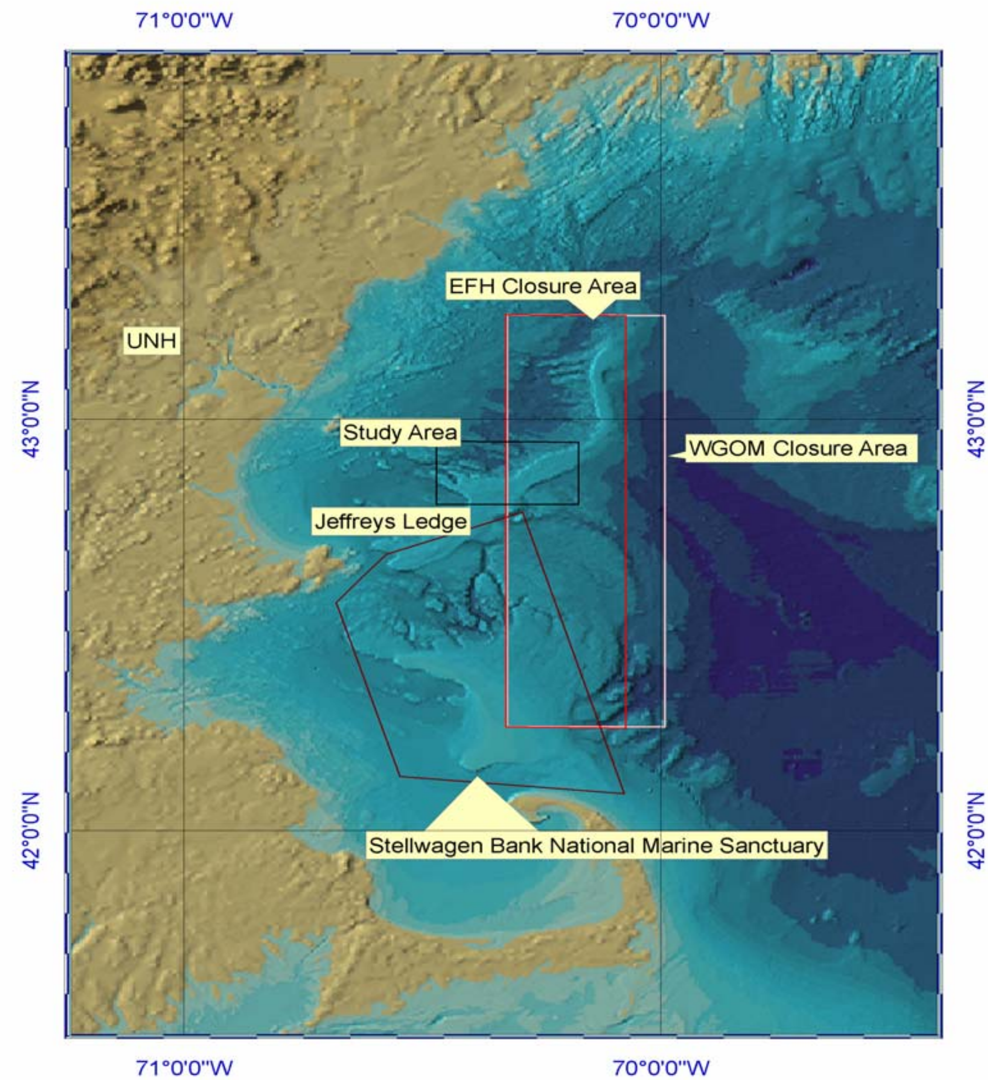

Figure 1: UNH / CCOM study area.

Data collection

Data for this study was collected in three phases. The first and largest survey was carried out by SAIC's Ocean Explorer (December, 2002) using a Reson 8101 multibeam sonar. The second survey was carried out by the NOAA ship Thomas Jefferson using a Reson 8125 and Klein 5500 sidescan sonar (October, 2003) concentrating on a small, 3 x 2 kilometer region in the middle of the earlier survey. An overview of bottom survey activities is shown in Figure 2. Data from both surveys were processed using CARIS HIPS/SIPS (Ver. 5.3). The processed high-resolution multibeam sonar (Reson 8125) data showed long linear features spread over both the open and closed areas of WGOM. These features were observed to have depth variations of a few centimeters and widths of 2.5 – 4 meters (Figure 3a and 3b). Surveys with the Klein 5500 sidescan sonar confirmed the presence of these long linear features (Fig 4a). An extensive survey was also carried out using the bottom video camera (June-October 2004) in areas where bottom features were detected by multibeam sonar, however the video survey did not detect the bottom features. A sidescan sonar survey (Benthos 3D) conducted after the video survey (September, 2004) re-confirmed the presence of the bottom marks on the sea floor (Figure 4b).

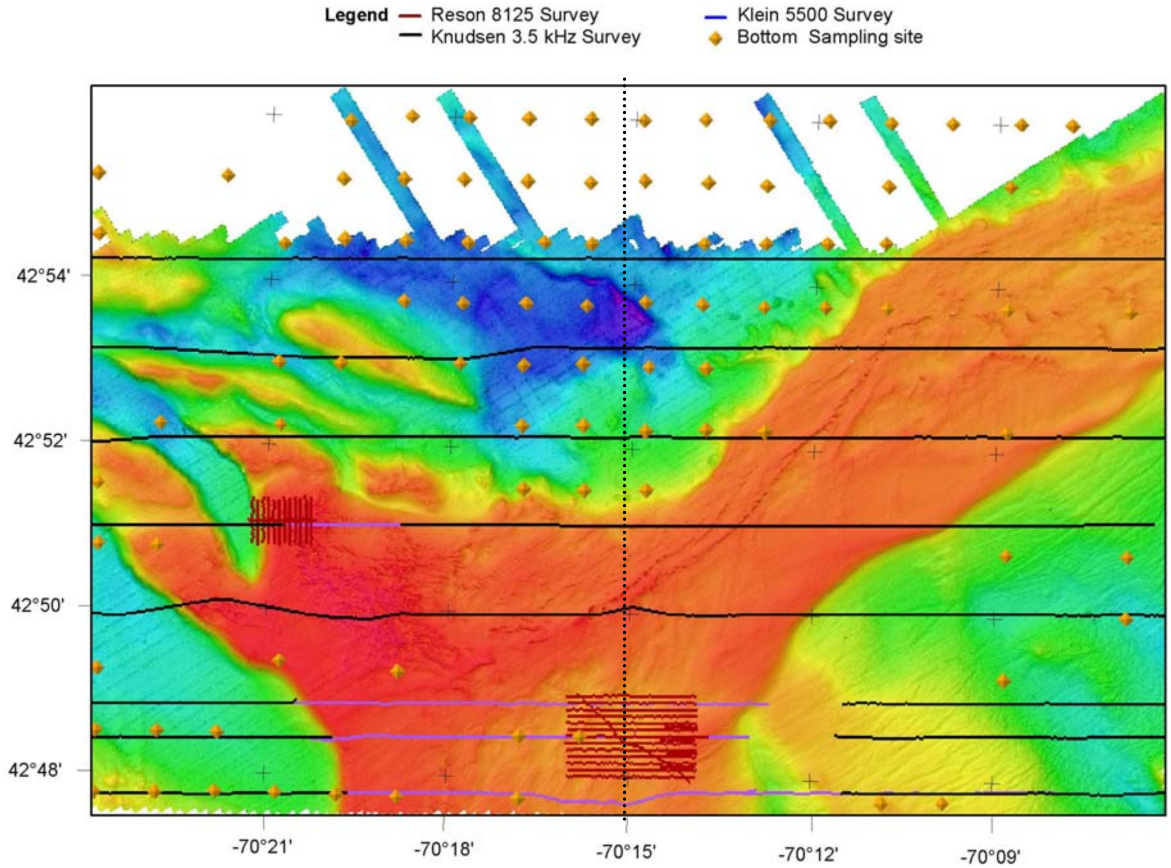

Figure 2: Overview of bottom surveys carried out by UNH / CCOM from 2002 – 2004. The background map of middle Jeffreys ledge was constructed from the Reson 8101 multibeam sonar survey. The bottom sampling sites shown are the preliminary bottom sampling sites. Dashed line in the center of the figure defines the boundary of closed area towards the right of the line.

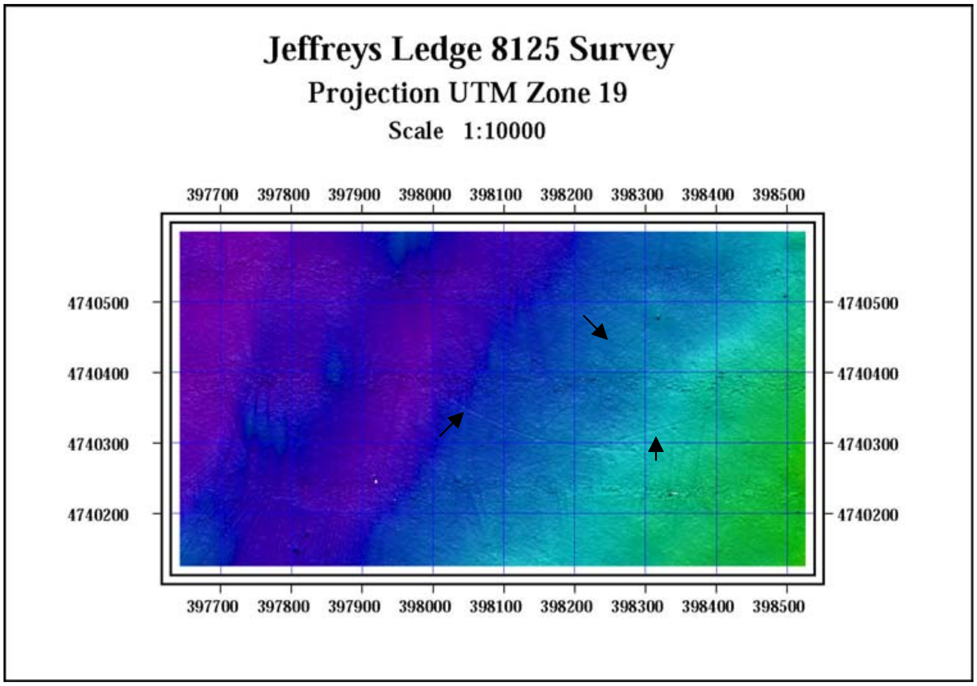

Figure 3a: An example of bottom marks observed in the Reson 8125 multibeam sonar survey.

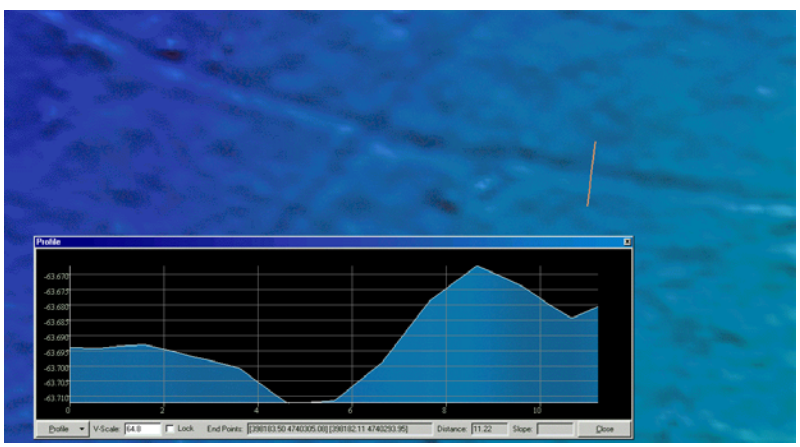

Figure 3b: An example of bottom mark and profile (as inset) as observed in the Reson 8125 multibeam sonar survey. The line drawn in the figure shows the location of the profile shown in inset. Width of the mark here is about 4 m and relief is about 2 cm.

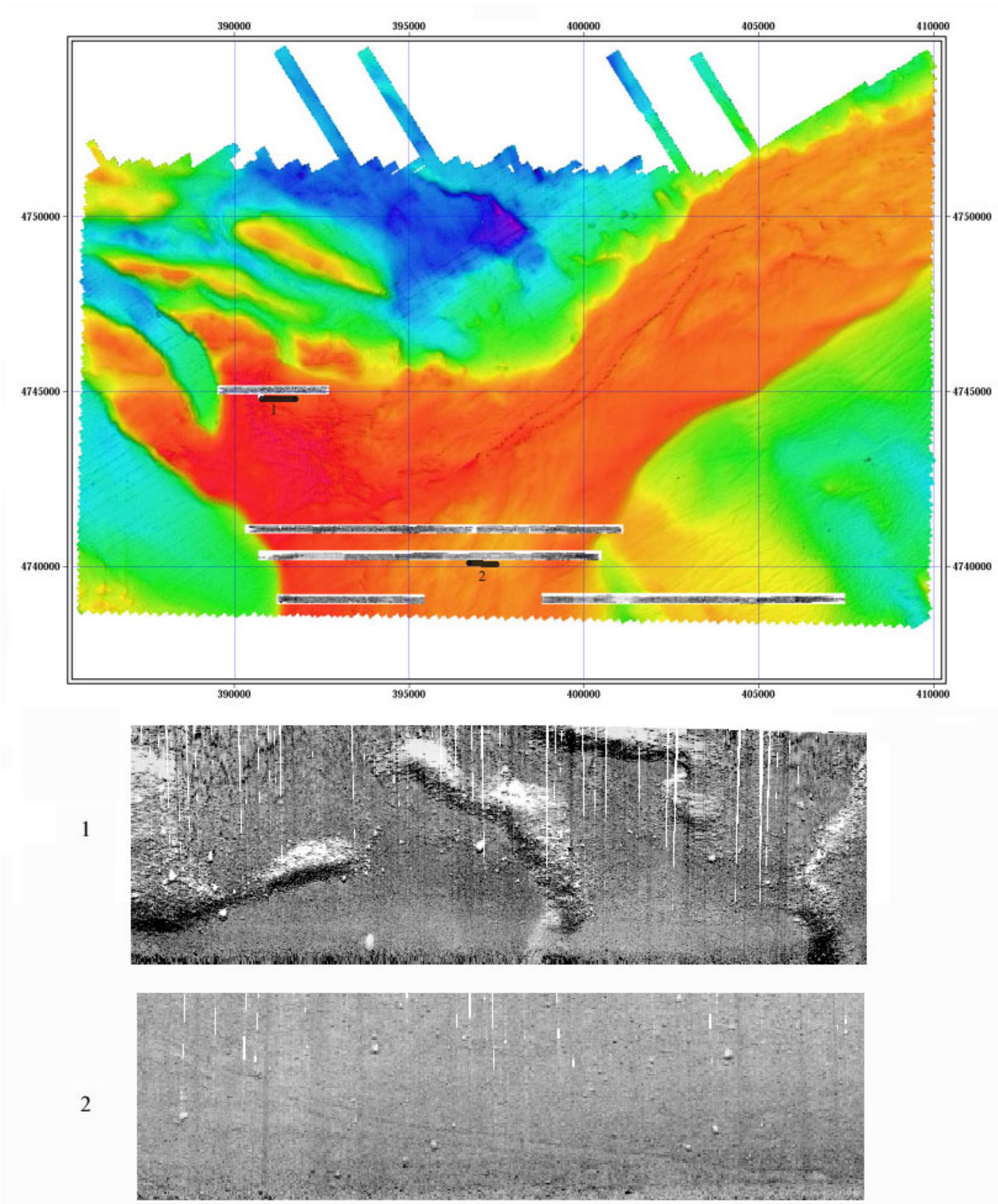

Figure 4a: Klein 5500 sidescan sonar survey results. Transect # 1 shows bedform features. Transect # 2 confirms the presence of bottom marks as observed in the multibeam sonar data.

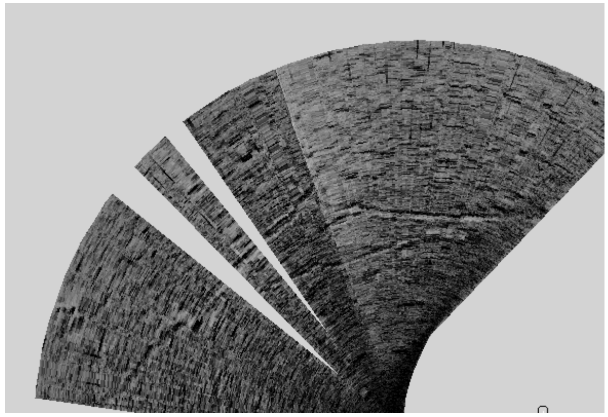

Figure 4b: Sidescan image from Benthos 3D sidescan sonar. Survey was undertaken in September 2004. Bottom marks are clearly visible. The same marks were shown in Figure 3 and 4.

Analyses:

Having demonstrated that at least three of our sensors (Reson 8125, Klein 5500 and Benthos 3D sidescan sonar) can detect features that appear to be related to fishing gear impact, we now explore the tradeoffs and limitations of our remote sensing systems as well as approaches to enhancing the detection of these subtle targets. The use of multibeam sonar in identifying areas, which have been impacted by bottom fishing gear, should require that the sonar detect changes in depth as small as a few centimeters. The ability of the sonar to identify such subtle features will be a function of both the vertical and lateral resolution of the sensor, as well as the degrading effects of noise and systematic artifacts.

The availability of two multibeam sonar systems (Reson 8101 and Reson 8125 sonars) operating at different frequencies (240 and 455 kHz respectively) and different beam widths (along/across track 1.5/1.5 and 1.0/0.5 degrees respectively) provided the opportunity to compare these systems with emphasis on their ability to detect the impact of bottom gear on the sea floor.

Figure 5 shows the comparison of a 125 x 200 meter area as observed with the two multibeam sonar systems. The highest spatial resolution achieved from the Reson 8101 survey in this area (depth ~ 50 m) was 2 m while the Reson 8125 data provided us with spatial resolution of 1 m. The depth resolution obtained by the Reson 8101 and Reson 8125 was estimated to be 4-5 cm and 1-2 cm respectively in this area. The notable difference in the two DTMs is the ability to resolve a linear feature in the Reson 8125 data.

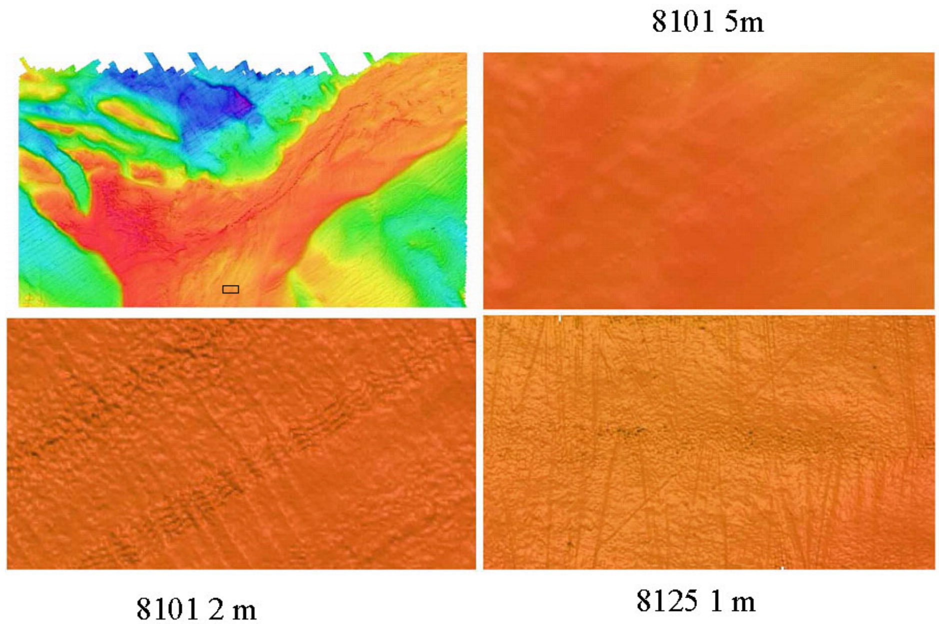

Figure 5: Comparison of the Reson 8101 and Reson 8125 multibeam sonar survey results from a 125 x 200 m rectangle shown in the top left figure. Sun illumination is from northwest at 45 degrees sun elevation.

In addition to the spatial resolution limitation of each sensor, we are also limited in our ability to resolve subtle gear impact features by the presence of systematic data collection artifacts. Subtle across-track artifacts are clearly visible when the data is presented with artificial sun illumination (8125 1m, Fig 5). These across-track artifacts, which are 3 - 10 cm high and up to 5 m wide are thought to be caused by an erroneous heave filter applied in the motion sensor during data collection (see discussion below). As has already been noted, their presence makes the visual identification of the bottom marks in the multibeam sonar data very difficult as they have the same order of relief as the target bottom marks.

Frequency filtering

To correctly locate all the possible observable bottom marks it was necessary to remove the heave-like artifacts from digital terrain model (DTM) of sea floor bathymetry. Given the consistent spacing of the artifacts, frequency filtering approaches were explored. To implement any frequency filtering method it is necessary to remove the absolute depth variations (e.g. de-mean the data). This was achieved by filtering out features with long spatial scales of variation (e.g. geological features). A high-pass filter was implemented by subtracting bathymetric grids constructed at two different resolutions. The results of application of the high-pass filter over the DTM are shown in Figure 6. As no a priori assumptions can be made about the spatial frequency of the bottom marks, this method provided an empirical approach to choosing which two sets of bathymetric grids produced the best results. A grid difference of 1 m and 2 m was chosen to best resolve the bottom marks. It is worth noting that in Figure 6 there is a considerable enhancement of the visual signature of the bottom marks in the figures towards right. As the relative depth differences rather than absolute depths are accentuated, the data collection artifacts also become more apparent.

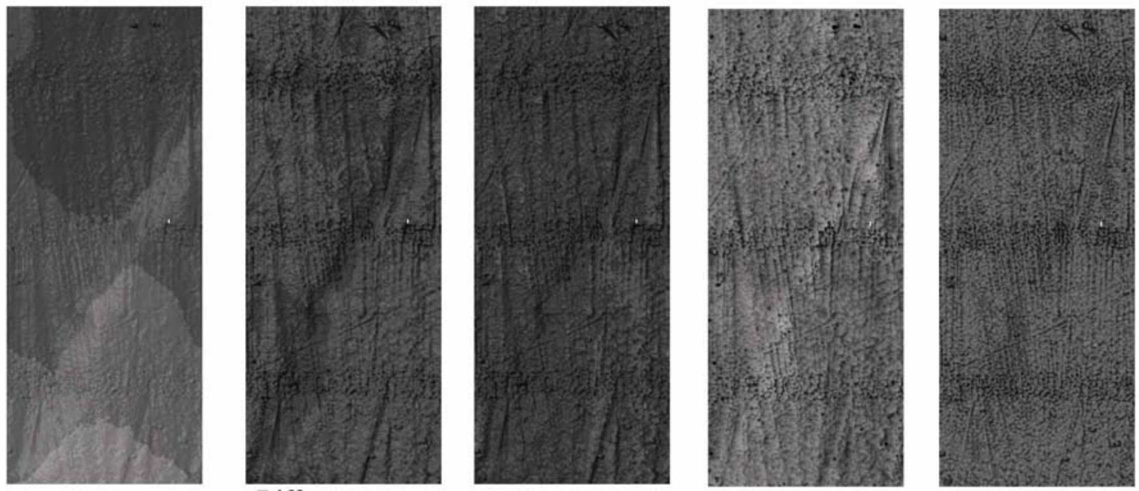

Figure 6: Example of surface differencing (high-pass filtering) using different grid sizes from Reson 8125 data. Sun illumination from NW at 45 degrees elevation. Tracklines running east west.

To further remove the artifact features from the DTM the identification of the frequency and cross-track consistency of the artifacts was necessary. This was achieved by comparing along-track profiles from near-nadir and outer beams. A comparison of near-nadir vs. outer beams showed that the profiles have a common frequency of 0.04 cycles/ meters (Figure 7). To confirm if this was attributable to the heave, the same line was used again to construct a frequency spectrum using one near-nadir beam and two outer beam profiles but this time without the application of motion compensation. The frequency analysis of the survey line showed that all beams had a similar behavior with a frequency near 0.04 cycles/m. The motion artifacts caused by heave should have the same effect on the near-nadir and outer beams as the heave causes the vessel to linearly move up and down affecting all the beams similarly (Hughes Clarke, 2003). Thus we concluded that the artifacts in the final DTM were caused by the residual heave errors.

Given that the spatial frequency of the artifacts was identified (Figure 7) a band stop filter (Chebychev filter, band stop 0.04 ± 0.005 cycles/m) was implemented to remove this frequency from the DTM. An example of the resulting DTM for a single survey track line is shown in Figure 9 along with the spatial equivalent of the data removed by frequency filtering. It should be noted that frequency filtering also removed some useful data, i.e. the frequency band of the heave artifacts overlaps the frequency band of useful data. We thus sought other approaches for removing the heave artifacts.

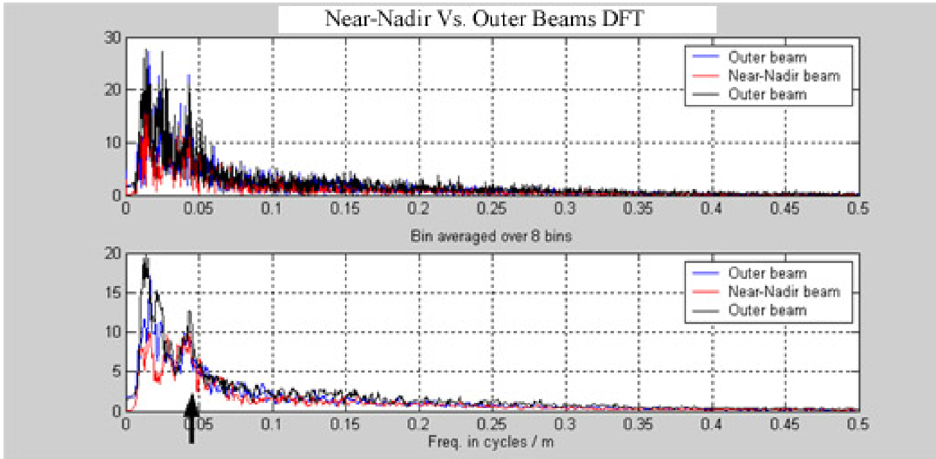

Figure 7: Near-nadir and outer beams Discrete Fourier Transform comparison. The arrow gives the location of the magnitude peak where frequency of the three series match.

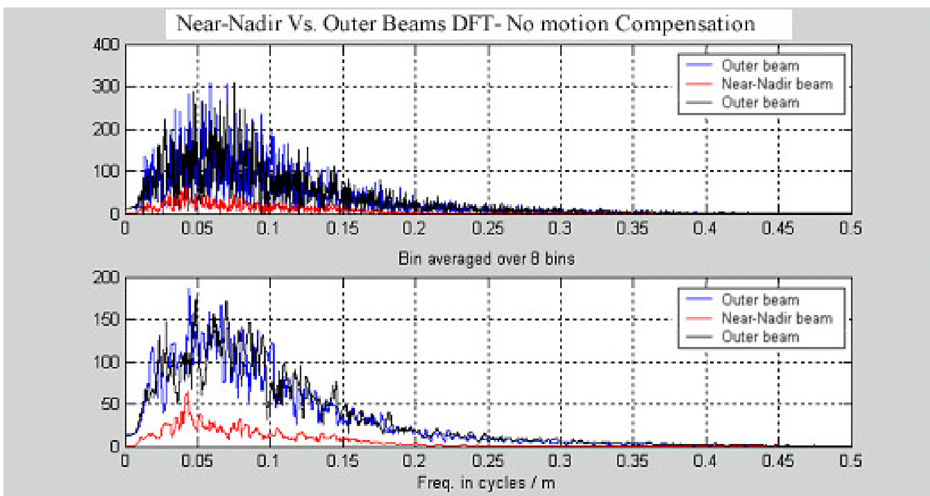

Figure 8: Data from a track line where no heave, roll and pitch correction have been applied.

Given the consistent direction that the survey lines were run and the fact that the artifacts appear orthogonal to the vessel heading, a directional filter can also be implemented to remove the heave artifacts. A two dimensional Discrete Fourier Transform (Figure 10a) of a track line confirmed this hypothesis as the predominant energy is located perpendicular to the vessel track line. The results of the directional filter (Fig 10b) show that the heave artifacts were removed to a greater extent (as compared to frequency band stop filter) without removing the actual features and thus greatly improving the visual recognition of the bottom marks.

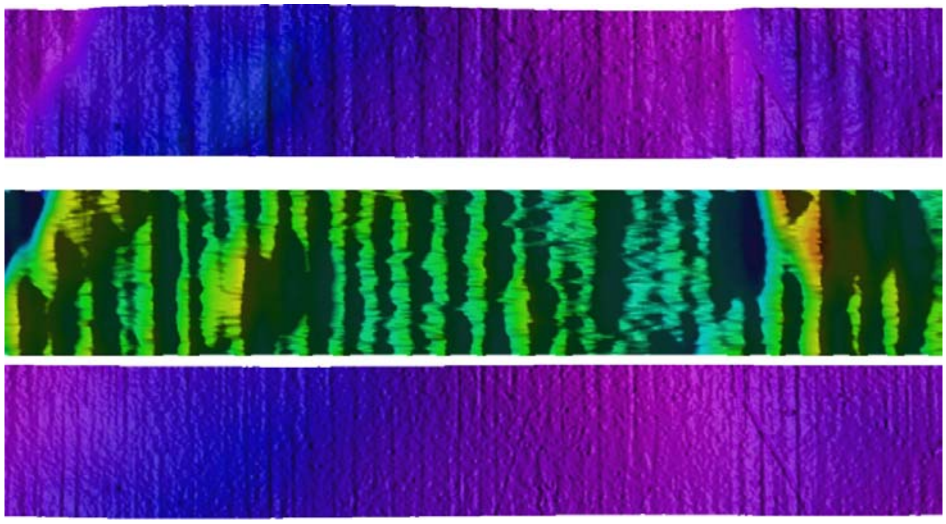

Figure 9: Results of frequency filtering using a near-nadir vs. outer beam analysis on a single track line from the Reson 8125 multibeam sonar. Top figure shows the original DTM; bottom figure shows the filtered DTM; middle figure shows the spatial equivalent of filtered frequency components.

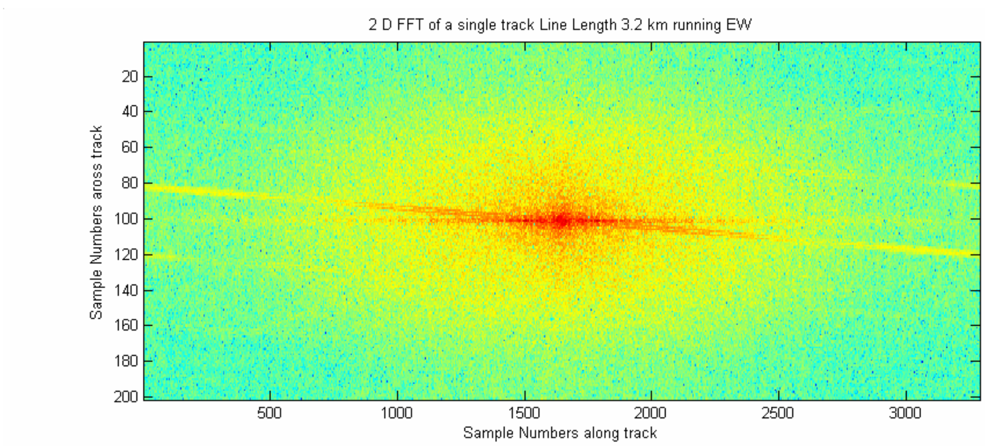

Figure 10a: Figure showing the plot of 2D Discrete Fourier Transform of the data from the Reson 8125 multibeam sonar data. Data comprised about a 3 km long track line.

A

B

C

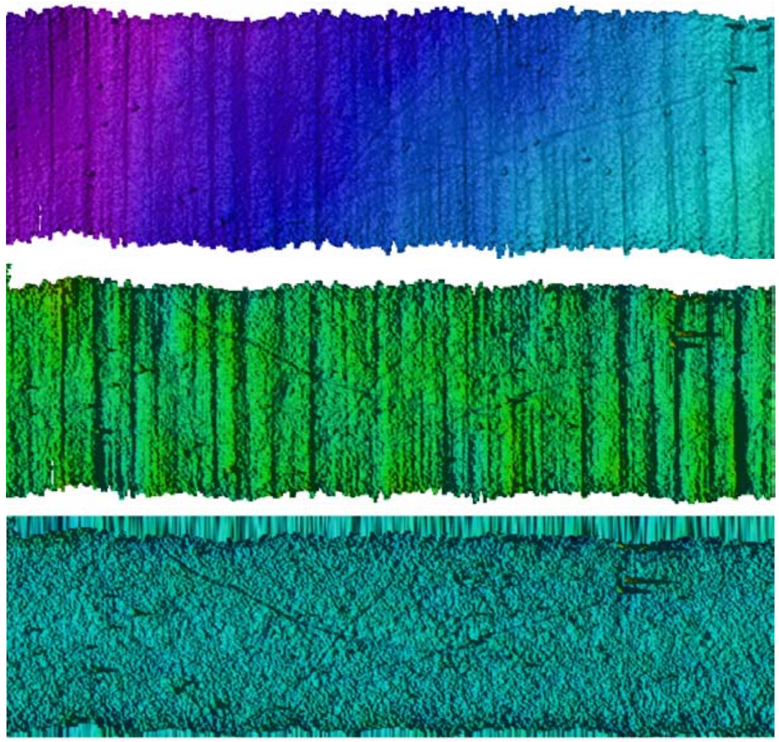

Figure 10b: The progression of frequency filtering by using original DTM shown in A, High-pass filtered surface shown in B and directional frequency filtering at C. Sun illumination is from west at 30 degrees sun elevation.

<u>Comparison with sidescan sonar and video data:</u>

The filtered surfaces were exported to Fledermaus (a commercial 3D GIS software package) where they were visually inspected in relation to the original DTM and a detailed map of the bottom marks constructed. The filtered DTMs enabled better visual identification of the bottom marks (Fig 10b). In exploring the data in this fashion, it also became apparent that small bathymetric highs and/or lows were often observed at the end of the bottom marks (Figure 12 and 13). The resultant map (Figure 11) shows bottom marks throughout the middle of Jeffreys Ledge with a large number of marks observed inside the boundary of area closed to bottom fishing under WGOM fishing closure.

A comparison of the sidescan sonar data with the frequency filtered DTM showed that all the bottom marks observed in the sidescan sonar survey were observed in the 8125 multibeam sonar data. However a comparison of the bottom marks observed in the Reson 8101 and Reson 8125 revealed that approximately only 10 - 20 % of the marks observed in the high resolution Reson 8125 data were successfully identified in the Reson 8101 data.

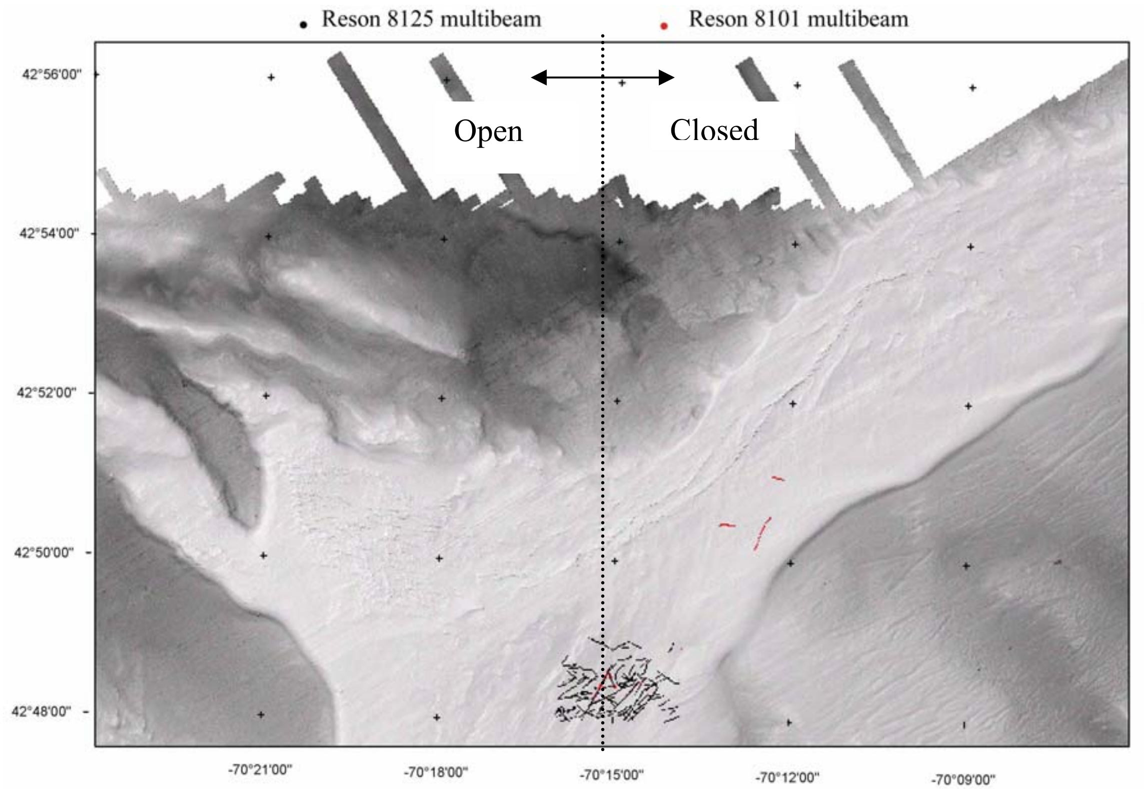

Figure 11: Bottom marks observed on Jeffreys ledge. Red lines show the marks observed in the 8101 survey while black lines represent marks observed in the 8125 multibeam sonar data.

A detailed video survey was conducted at the locations of bottom marks observed in the multibeam sonar survey. Attempts were also made to obtain video transects across the bathymetric highs/lows at the end of the marks. As it was necessary for the vessel to be stopped (to maintain the camera at an appropriate distance from the sea floor) the video transects were made by lowering the video camera from the UNH research vessel Gulf Challenger and letting the vessel drift across the bottom marks. The placement of the video camera accurately over the boulders, however proved challenging due to lack of steering control.

For accurate representation of bottom video with respect to the sea floor mapped by multibeam sonar, it was necessary to combine the video information with acoustic remote sensing (multibeam and sidescan sonar data). Each video frame was assigned the position at which it was looking at the sea floor so that it could be compared to the multibeam sonar DTM. While the video was collected at 30 frames per seconds, the positional information recorded (as text display on each frame from DGPS) was only updated to the third decimal of position (i.e. latitude and longitude updated every 0.001 degrees of position ~ 1.852 m) thereby assigning the same geographical position to more than one frame. A frame-by-frame analysis was done, assigning a position to frames every two meters; those frames between the two positioned frames were also analyzed but assigned an interpolated position.

The position accuracy of each frame was estimated to be 12 meters due to positional uncertainty (uncorrected GPS antenna offset of 8 m and uncertainty of the camera location on the sea floor of ~ 4 m). An example of such an analysis is shown in the Figure 14 and 15 where the bottom video has been frame-by-frame georeferenced and displayed in the 3D GIS environment on top of a boulder and a bottom mark. It may be possible that the due to the uncertainty in the reported position of the video frames, the bottom boulders have been missed (Figure 15), however, it is clear from Figure 14 that the video camera clearly passed over the bottom marks and yet there was no distinguishing features observable in the bottom video.

As video is most sensitive to any changes in bottom texture and is comparatively less sensitive to the depth variations it is safe to assume that the bottom marks do not represent a change in texture. This may mean that the impacted areas have been re-colonized or the movement of sediment has homogenized the area around the bottom marks. Video surveying therefore may not provide identification of areas that have been dredged/fished some time ago. How long after bottom fishing a video survey would discern bottom marks depends upon the ability of the camera to view the sea floor obliquely (to detect slight changes in the depth variation) and the rate of change of texture due to sedimentation / re-colonization.

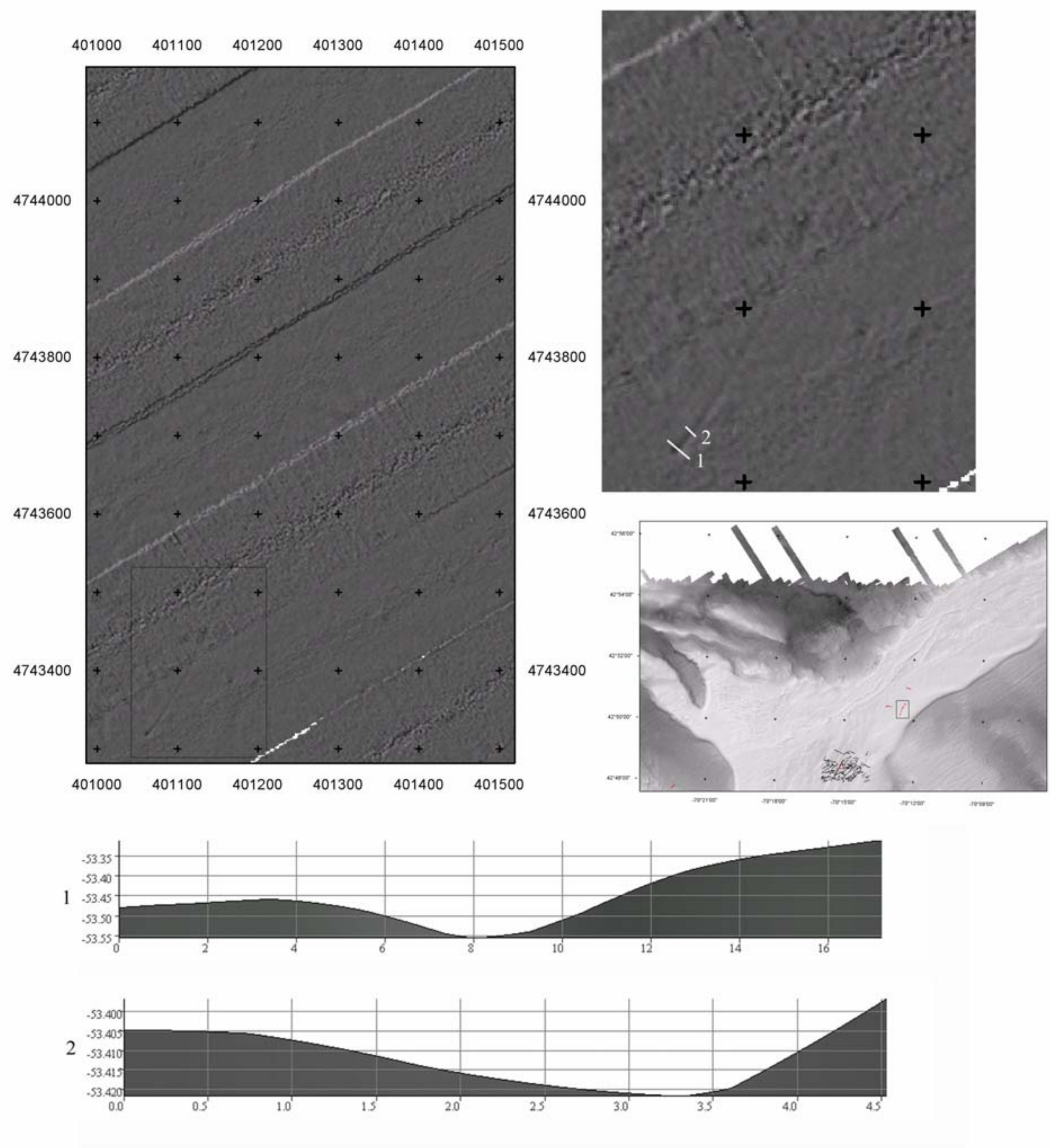

Figure 12: An example of a bottom feature observed in the Reson 8101 multibeam sonar survey. Note that at one end of the feature is a depression about 3-4 m wide and about 10 cm deep. (Profile 1). The width of the feature is about 2-3 m with 2-5 cm depth.

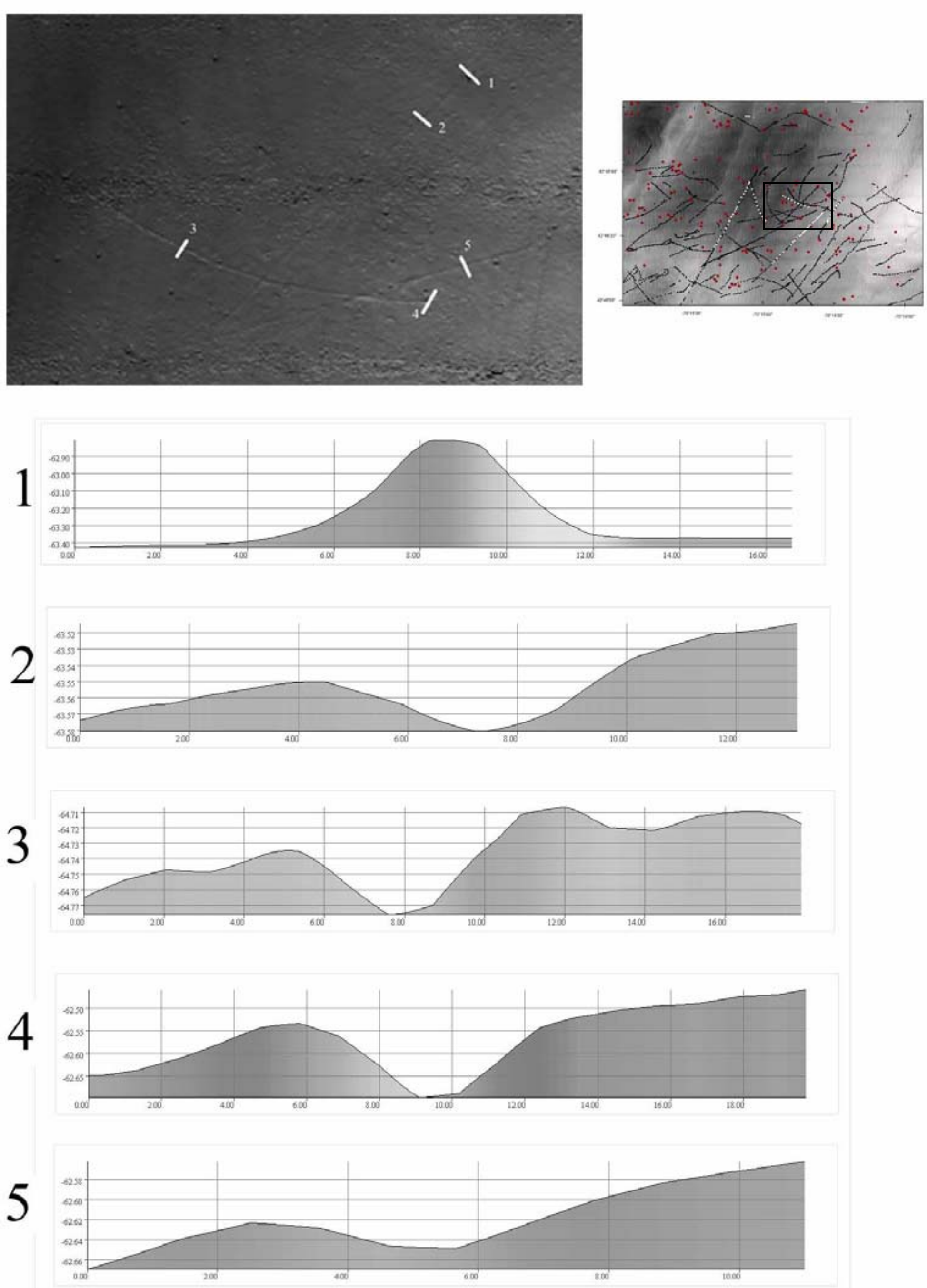

Figure 13: An example of bottom marks from Reson 8125 multibeam sonar survey. Profile 1 shows a boulder of width 3-4 m and about 0.5 m high. 2. Dredge mark associated with boulder in profile 1. Profile 3 shows width (3-4 m) and depth (4 cm) of a dredge mark. Profile 4 shows a depression at the end of the dredge mark. Profile 5 shows a dredge mark 2-3 m width with 2 cm depth. Figure on top right: White lines – Bottom marks from Reson 8101 data; Black line – Bottom marks from Reson 8125 data; Red dots - Inferred position of boulders from derived slope from the Reson 8125 data.

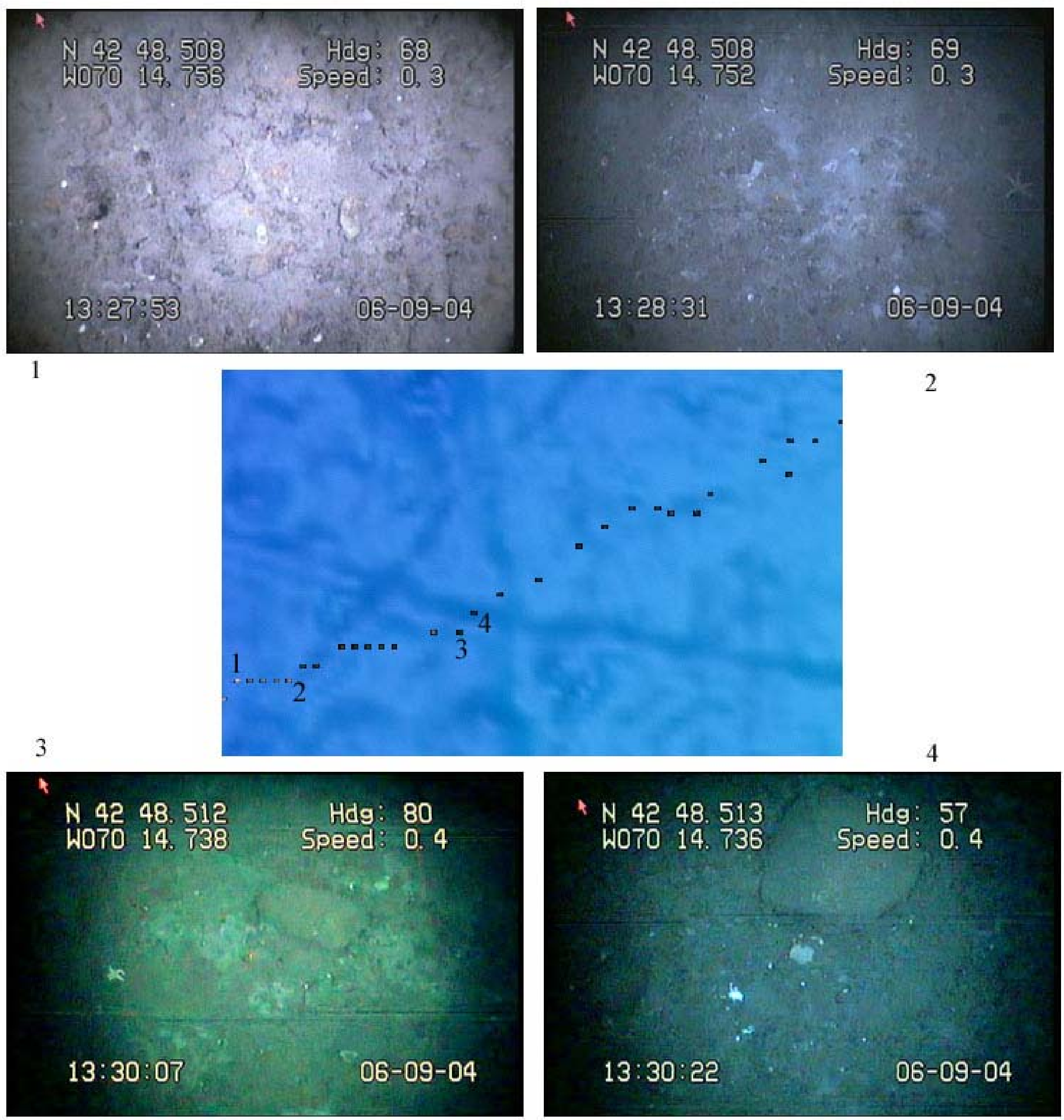

Figure 14: An example of video transect across a bottom mark. Individual frames around the bottom mark and the video do not show a distinct change in the bottom texture of bottom images as the camera passed over the bottom marks. The apparent change in the illumination in the lower images is due to change in distance of camera from the sea floor.

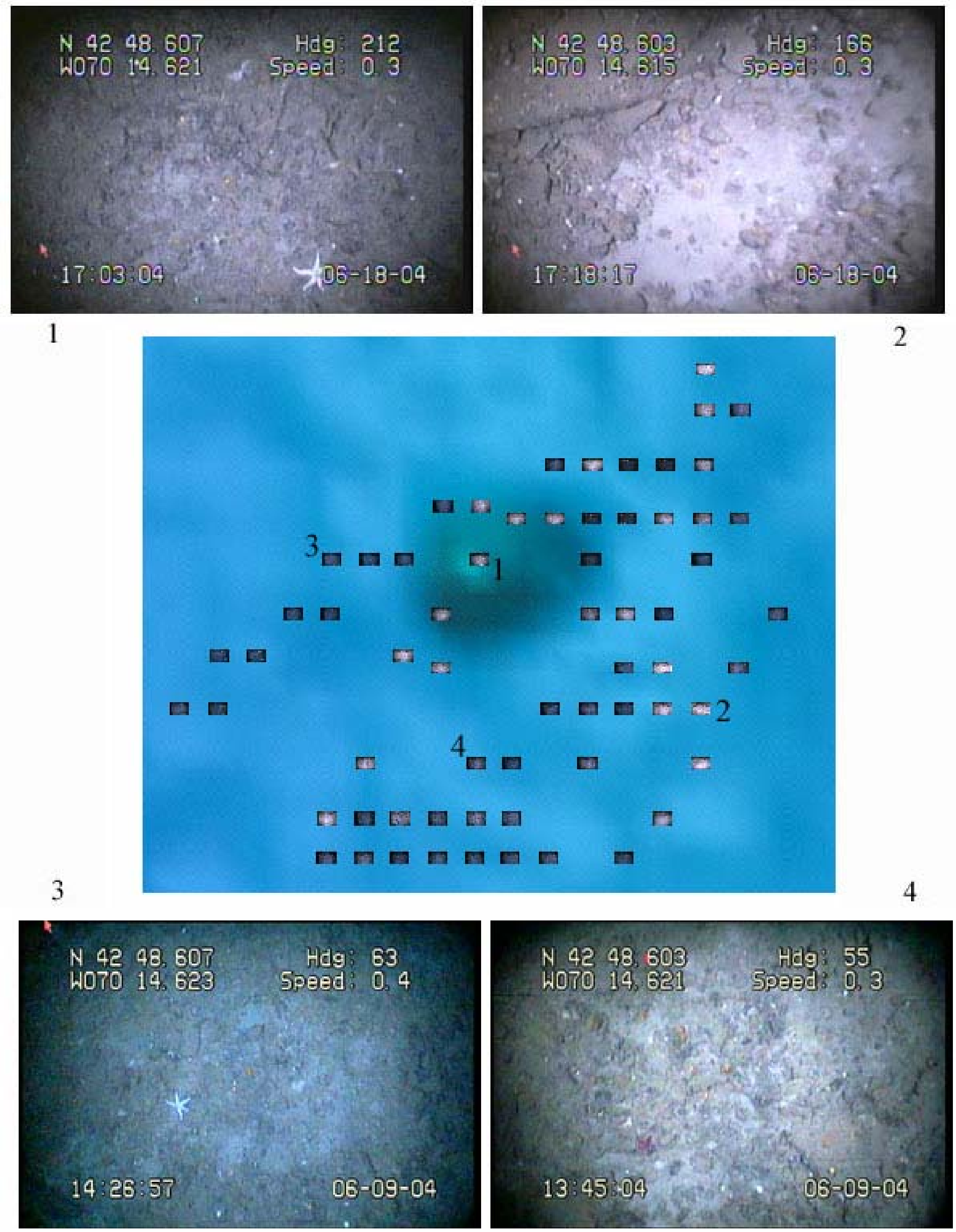

Figure 15: Figure showing the results of integration of georeferenced video frames in proximity of a boulder with multibeam sonar DTM.

Discussion

The presence of a large number of bottom marks in the area closed to bottom fishing raises some fundamental questions. There can be several explanations including the possibility that these marks were not created by bottom fishing gear (although there is little evidence to support this hypothesis). Here we present four possible explanations:

a. The marks are caused by some process other than bottom fishing e.g. anchor drag marks would also look similar to the marks found during this study. However the depth of the area (~ 50 m) and the absence of any known anchorages in the study area strongly suggest that these marks are not anchor drag marks.

b. The marks were caused by the direct interaction of the bottom fishing gear with the sea floor. As we did not observe two parallel marks (characteristics of bottom trawlers) it is likely that these marks were caused by bottom dredging gear (e.g. scallop dredgers) scraping the sea floor. The width (2.5- 4 m) and depth (few centimeters) correspond closely to that of the known impacts of New Bedford scallop dredging gear commonly used in this area. However as we did not observe the marks in the video survey these marks may have been made before the closure was implemented in 1996.

c. These marks were caused by the indirect interaction of the bottom fishing gear with the sea floor wherein boulders are dragged by bottom fishing gear leaving quasi-permanent features on the sea floor.

d. The implementation of the closure was compromised by illegal fishing in this area.

There is little quantitative information available on how long the physical impacts of bottom fishing gear stays on the bottom. To better interpret these results an investigation of the closure rules is necessary. Also as we were only able to identify the probable fishing gear causing these marks as dredgers (there were some dredging gear allowed in the closed area from 1996-2004!) a closer look at the closure rule would be helpful. The closure rule states:

"The western GOM closure area is closed year-round to all fishing vessels with the following exemptions: Charter, party or recreational vessels; vessels fishing with spears, rakes, diving gear, cast nets, tongs, harpoons, weirs, dip nets, stop nets, pound nets, pots and traps, purse seines, mid-water trawls, surf clam / quahog dredge gear, pelagic hook and line, pelagic long lines, single pelagic gillnets, and shrimp trawls" (Federal Register, 1998)

Given that there were some exemptions allowed in the period 1996-2004, it may be possible that these marks may have been caused by exempted (surf clam/quahog) dredgers (although their widespread use in this area is not known). Recognizing concern over the impact of these exemptions, NOAA made a significant change in the WGOM closure area rules in 2004. The new rule (Year around Essential Fish Habitat (EFH) closure) implemented in May, 20004 states:

"EFH Closure Areas are closed year-round to **all** bottom-tending gears. Bottom tending mobile gear is defined as the following: Gear in contact with the ocean bottom, and towed from a vessel, which is moved through the water during fishing in order to capture fish, and includes otter trawls, beam trawls, hydraulic dredges, non-hydraulic dredges, and seines (with the exception of a purse seine)" (Federal Register, 2004)

The new rule therefore provides essential protection to the habitat against physical disturbance by any bottom tending gear. In the context of the new rule, the detailed information about the location and extent of the bottom marks, would be essential in focusing future studies in this area thereby allowing a quantitative analysis of the fate of bottom marks, long term to medium term (15 to 5 years) effects on habitat structure, and scrutiny of the effectiveness of the area closure.

Another important observation was the presence of a bathymetric high or low at one end of some of the observed marks. Profiles taken across bottom marks in both multibeam sonar data sets are shown in Figure12 and 13. The bathymetric highs identified at one end of the marks are assumed to be boulders 3-5 m in diameter with heights up to 50 cm – 1 m. There are several possible explanations for the presence of these boulders at one end of the bottom gear marks. The most probable is that the fishing gear dragged these boulders. It may be possible that these boulders are piles of debris and shells formed at the end of dredge hauls, however the positive identification of these targets must await further video surveys. Given that these features are boulders, the depression at one end of the marks may be related to the position from where the boulder was removed. Another possible explanation is the impact of the dredging gear on sea floor while lowering the gear at the start of the haul.

Otter trawl doors normally leave two parallel marks on the sea floor, while dredges tend to leave a single bottom mark (National Research Council, 2002). In the course of this study we observed only single lines of bottom marks and thus otter trawl gear and beam trawl gear were ruled out as a cause for the marks. This leaves bottom dredges (e.g. scallop and clam dredges) and indirect interaction of fishing gear with bottom by dragging boulders, as the most likely cause of the marks. As there were some exemptions in the closure rule prior 2004 we cannot conclude that there has been illegal fishing in the closed area. Whatever fishing gear has caused these marks their detailed mapping will increase our understanding of how bottom gear interacts with the sea floor, how long these marks stay on the sea floor, and lay the groundwork for the unambiguous identification of illegal activity, should it be taking place.

Conclusion

We have demonstrated that high resolution multibeam sonar data with appropriate processing techniques can be used to identify the impact of bottom fishing gear on the sea floor of Jeffreys Ledge, a rich fishing ground that has been subject to closure for fisheries management. The features identified were long linear targets with depths of a few centimeters and widths of approximately four meters. The features are often associated with a bathymetric high (possibly a boulder) at one end and a bathymetric depression on the other end. These features are thought to be caused by the direct interaction of dredges (scallop or clam) with the bottom or by the indirect interaction of the dredge by dragging boulders. The mapping of such areas using sidescan sonar can also provide essential information about the general distribution of bottom impact features, however multibeam sonar provides the full 3-D context of a region including depth information. Video surveys can be useful for the benthic species identification and population count, however in the regions we studied, bottom impact features were not discernable in the video records. This may be due to the fact that the features we mapped were old enough to be covered by sediments or re-colonized by organisms. The ability to integrate and compare multibeam sonar, sidescan sonar and bottom video data in a single interactive 3-dimensional workspace greatly facilitated the analysis and interpretation of these complex data. The evidence collected during this study suggests that the bottom fishing activity causes longer than expected impacts on the benthic structure; future work will continue to monitor the fate of these features. Future studies on Jeffreys Ledge are expected to map the area for the distribution of demersal and benthic species. Comparison of these distributions with bottom impact maps will inevitably result in a better understanding of long-term changes in benthic species populations around the impacted bottom.

Acknowledgement

This research was carried out under the sponsorship of National Oceanic and Atmospheric Administration (NOAA) Grant Number NA170G2285. The authors also gratefully acknowledge the numerous contributions of Dr. Lloyd Huff with video and sidescan sonar data collection and processing and numerous fishermen who talked to us about fishing activities on Jeffreys Ledge.

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