INFLUENCE OF SHELLS AND SHELL DEBRIS ON BACKSCATTER STRENGTH: INVESTIGATION USING MODELING, SONAR MEASUREMENTS AND SAMPLING ON THE BELGIAN CONTINENTAL SHELF

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1   INTRODUCTION

Seafloor imaging technology is continuing to advance rapidly, though certain physical and biological processes, locally interacting with the acoustic signal, are still poorly understood. Especially, in the context of monitoring, when there is a tendency to compare absolute values of backscatter strength at high resolution (e.g., Lurton and Lamarche, 2015), very high understanding of the acoustic signal response mechanisms is needed.

The influence of discrete scatterers such as shells or shell fragments within the sediment and at the surface interface, has only been researched in a limited way. Several authors (e.g., Jackson et al., 1986; Stanic et al., 1989; and Zhang 1996) assessed the importance of the influence of shells on the scattering from the seafloor. Particularly, Zhang (1996) related shell type and dimension to their target strength at normal incidence. Stanton (2000) described scattering from both inclusions and partially buried shells in the sea-floor, whilst Ivakin (2009) studied scattering from shells as a potential mechanism explaining the scattering above 200 kHz. Lyons (2005) focused on the contribution of shell hash when modelling volume scattering mechanisms. He used single or multiple scattering models, depending on the abundance of shell hash in the sediment, for frequencies up to 100 kHz.

With our contribution, we aim at improving predictions of the influence of shells and shell debris on multibeam echosounder (MBES) backscatter results. We will use numerical models and simulations, calibrated with field results from sonar measurements, video imagery and seabed sampling. The methodological workflow will be discussed, as well as preliminary results.

2   METHODOLOGY

All the experiments are performed at sea. Our approach is to acquire very-high resolution multibeam data (MBES; Kongsberg EM3002; 300 kHz), and in particular backscatter, in combination with video imaging and ground truthing. A downward looking camera, mounted in a frame with a footprint of 1m by 1m, is used. Seabed samples are taken with a Hamon grab. For the experiments, the Belgian oceanographic vessel R/V Belgica A962 is used. During post processing analysis of the backscatter measurements acquired, raster maps with at different pixel scale were produced. One map with grid of 5 by 5m and one with a detail scale of 0.4 by 0.4m were considered to investigate the impact on the backscatter values by the presence of shells and shell hash at regional and local scale.

First experiments took place in April 2015 on the Smallbank, a sandbank in the Flemish Banks area of the Belgian part of the North Sea located at approx.. 51° 7'N, 2° 35'E (fig.1), where Ensis and Spisula shells are commonly found.

In June 2015, the experiments took place at a more offshore sandbank where a high concentration of shell fragments is found on the flanks of sandwaves ('Westhinder shell hash area'). The larger Westhinder Banks are located at approx.. 51° 27'N, 2° 30'E (fig.1), in water depths of 5-15m.

For both areas, multibeam recordings were acquired with a dual head EM3002 mounted on a pole, as well as ground-truthing by video, seabed samples and Sting measurements. Backscatter imaging of the area was related to the video recordings, as well as with the bathymetry and the seabed samples. The analyses of the latter were interpolated at different grid sizes.

Figure 1: Test areas where Multibeam recordings, video and seabed samples were performed; a) sample with high concentration of shell fragments collected at the Westhinder area; b) accumulation of shells of Ensis organism collected at the Small bank area.

To improve understanding of the field results, a collaboration was formed with a modelling program that is underway at FWG-WTD71 in Germany. That project has the goal of modelling the biological effects on a number of underwater naval operations. The form of the modelling is simulation, because an actual modelling scene is created, manipulated and analysed. The scene is of order 1m in size, and is embedded as a 1D, time-varying object in usual spatial coordinate systems. The simulation is of the bottom 1m of the water column and upper 0.5m of the sediments.

The bed sediments are characterized in the usual way by grain size and sorting, grain type (e.g., solid mineral or biogenic porous), density, etc. A consolidation profile is computed using relative density considerations (Bardet 1997). A periodic bedform surface and spatially correlated roughness are approximated with methods similar to those in Jaud et al. (2012). In making these compositions, the spectral parameters from published experimental studies (e.g., from Briggs 1994) were employed, appropriate in sediment type and environment.

Shell shapes were placed into and onto the sediment matrix as 3D imaged volumes. The images were based on advanced 3D scanning of real, recovered shells. The shell virtual models (Fig.2) were compiled using 3D scanner facilities (Nikon metrology K-Scan MMDx) of the Royal Military Academy of Belgium. Since the scanning resolutions were of order 0.01mm, shell roughness (i.e., ribbing, banding, breakage) is rendered. For first instance, Ensis remains from the Smallbanks area surveyed in April 2015 were used (Fig.1). Note that introduced Ensis species are currently reaching very high abundances – live and as shell litter - in the North Sea region (Gollasch et al., 2015). Using the combined elements, roughness statistics were computed on a spectral basis with

intercept and exponent. This is a necessary preliminary for subjecting the simulation volume to acoustic backscatter modelling for instance with the composite roughness model of Jackson et al. (1986).
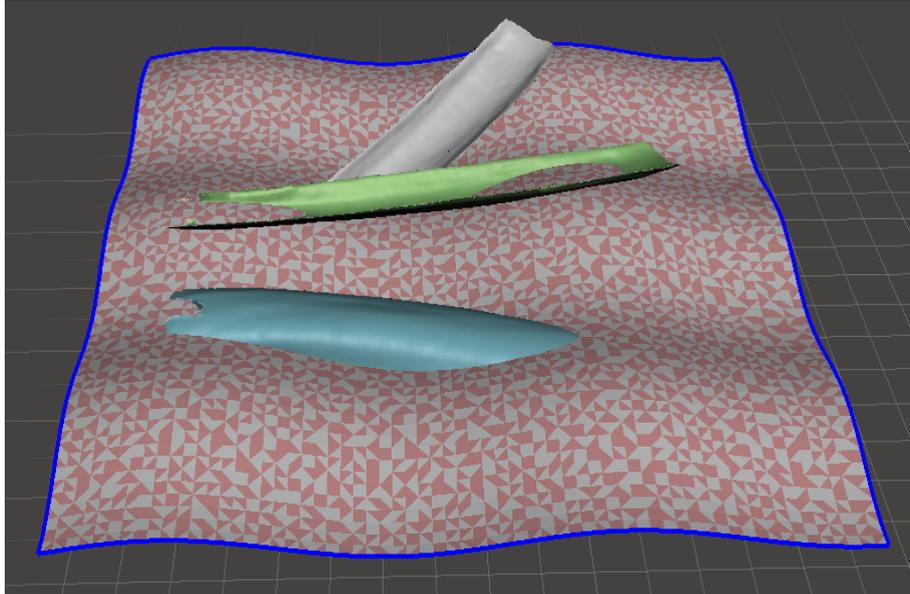
Figure 2: Visualization of a biological seabed with sediment bedforms, from the simulation box. Three Ensis valves (approx.1cm wide) are embedded in and on a sediment surface with mild bedform development.

3   PRELIMINARY RESULTS

3.1   Large-scale influences

Strong relation between backscatter and presence of shells was observed on the large scales (5x5m) at the multiple crested dunes area at the northern termination of the Westhinder bank.

The acoustic response of a seabed established on a large area covered by beds of whole and fragmented shells is observed in the northern part of Westhinder bank in the Belgian part of the North Sea (Fig. 1). The MBES data recorded on the top of the bank reveal a peculiar morphology of very large dunes with multiple crests. But even more, the MBES results show very high levels of backscatter (up to -15dB) on these dune areas compared to the common dune areas that shape the sides of the bank (-20 to -30dB). As measured on these very large dunes (fig.3b), amplitudes of -15dB are comparable to amplitudes of the coarser gravel areas of the Belgian part of the North Sea. By revealing accurately the nature of the seabed, photos provided by diver help explain the uncommonly high backscatter levels (fig 3c and 3d). A seabed covered with whole and fragmented shells gives an intense backscatter return for all angles of incidence.
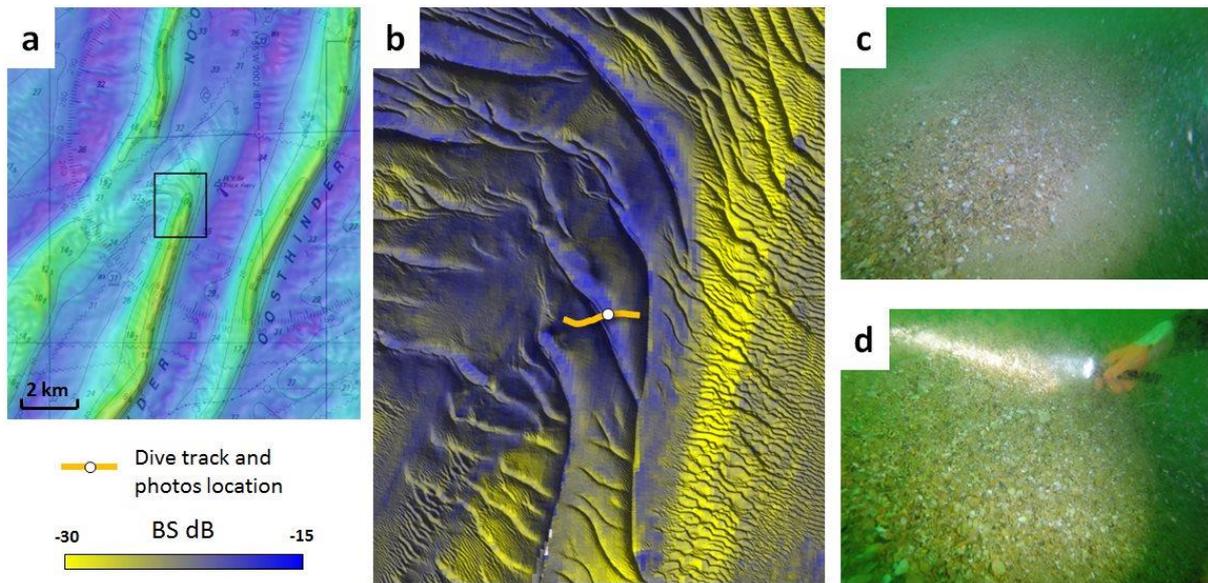
Figure 3: Example of high backscatter levels (blue) linked to a seabed consisting mainly of whole and fragmented shells. a: General location of the area; b: MBES seabed backscatter mosaic (5x5m) draped on a bathymetry DTM (5x5m); c and d: Diving photos (Scientific diving team, A. Norro) illustrating the occurrence of brownish coarse sand with lots of shell fragments and shell hash. Bivalve dimensions were up to 2cm.

3.2   Small-scale influences

The Westhinder sandbank area was further investigated at a smaller scale (0.4x0.4m). Lower backscatter levels were found on top of the sandwaves where ripples occurred (fig. 4 and 6). In the gullies, where shells had accumulated (fig 5), high backscatter values prevailed.
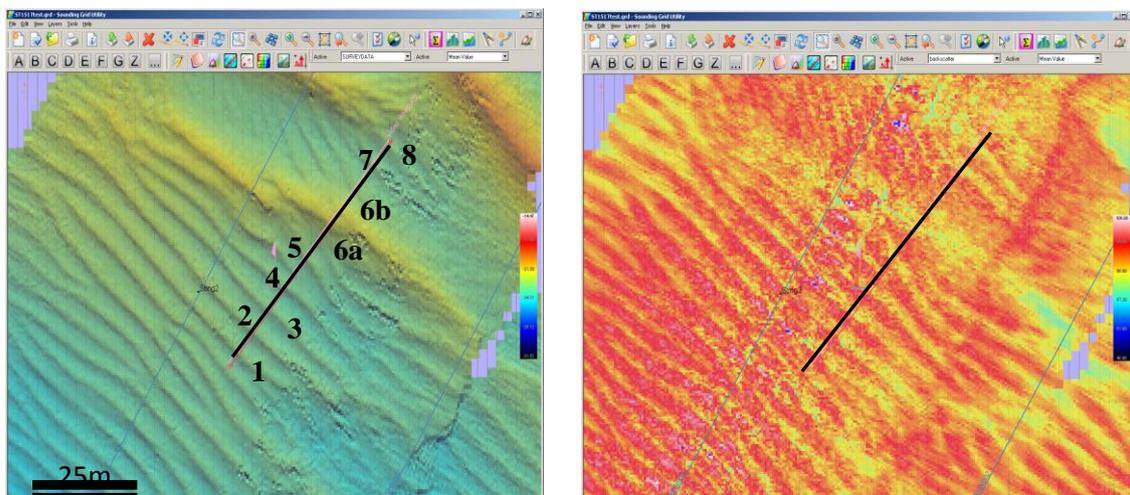
Figure 4: Bathymetrical and backscatter map of part of the westhinder shell hash area surveyed in June 2015. The black line illustrates the position of the video recording. Numbering refers to the sandwaves reported in figure 6.
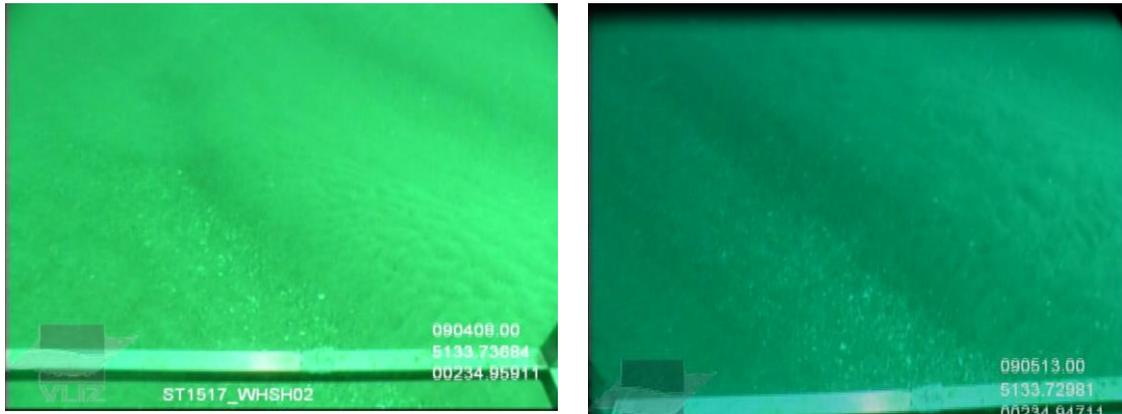
Figure 5: snapshot of the video recording made in June 2015 at Westhinder test area. Accumulation of sand is well visible in the hollow whilst ripples are superimposed on top of the sandwaves.
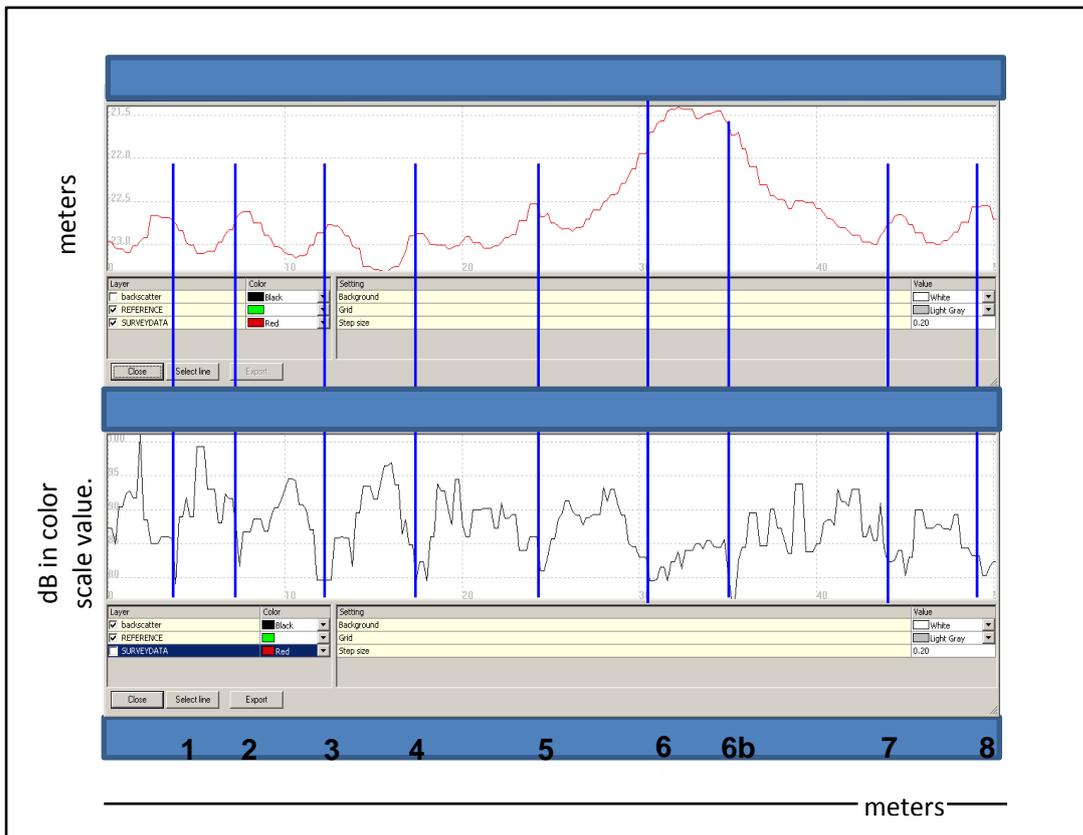
Figure 6: comparison between bathymetry and backscatter level recorded. Lowest backscatter values were measured on the crest of the sandwaves where ripples are superimposed.

3.3 Theoretical modelling

Although the modelling effort is in early stages, the results on roughness statistics suggest that the presence of shell complicates the spectral profile (Fig. 7). The presence of shell valves lowers the exponent of the spectral roughness characterization relative to simulations having just the sediment and bedforms. This implies that the response in backscatter of biological seafloor is not as simple as a rise in dB scattering strength such as with gravel – which is the result generally reported.
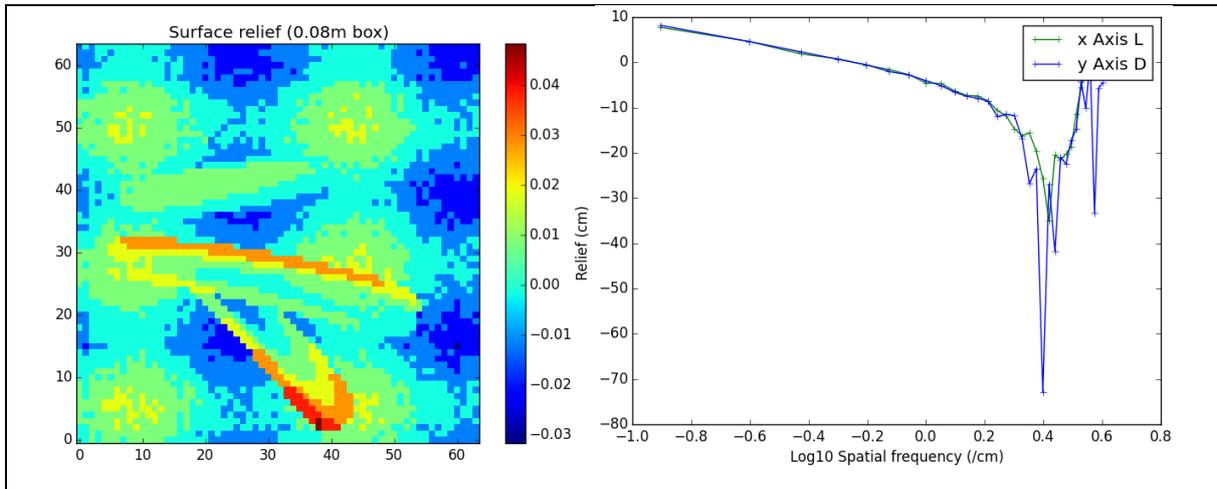
Figure 7: . Microtopography of the simulation box containing Ensis valves. (a) Gridded minimum elevations; (b) spectral surface roughness reduced to 1D. The simulated bottom in this case is very smooth overall and the spectral roughness is low (exponent -1.5..-2.2, intercept <1E-6 cm^3; see Briggs et al. 1994 for definitions).

4   DISCUSSION-CONCLUSION

From literature and field experiments, it is known that shells are key parameters in explaining the intensity of the acoustic response of the sediments. However, hitherto it is poorly known how much shells and shell hash contribute to acoustic backscatter and how important this is on both the large- and small-scale.

For both scales, some preliminary results have been presented using both experimental and bio-modelling approaches. The experiments included dedicated acoustic measurements, video imagery and seabed sampling, whilst the modelling uses advanced techniques and is able to incorporate realistic characteristics of shells and fauna and of the sediment matrix they live in.

First results showed that shell bed occurrences can be responsible for very high backscatter levels that are comparable to the presence of geogenic gravel. This work will be expanded by cartographic analyses that include coupling of acoustic to sampling data available in the Belgian part of the North Sea. From this exercise, it is aimed at highlighting large-scale trends and to assess whether the overall backscatter levels are correlated with the content of CaCO3 that reflect the abundance of shells. However, we realize that many factors, other than the abundance of shells, may play a role and must be unraveled. On the larger scale, the geology may play a role as also the compaction level of the sediments. On the smaller scale other influencing factors include shell morphology, size, level of fragmentation, orientation within the sediment, the nature of the sediment matrix (mud, sand ...) and will require quantification using *in-situ* observations by video or diving. Another issue is assessing differences between shell hash and coarse sand. Shell hash can indeed be part and modify the structure of the grain size of sand making the sand being coarse. But mostly shell hash at this dimension still has different structures and texture with sharp angularity. Further investigation is required.

On the level of the modelling additional research is needed. Clearly, the establishment of a model that quantifies the influence of the shells on backscatter levels is complex and requires both a theoretical approach and a detailed terrain validation with a strict *in-situ* control of the nature of the seabed. The preliminary modeling results indicate that shell complicates spectral roughness functions. Thus, acoustic response will vary by incident angle, sonar frequency and pulse type, particularly if the shell is sorted, ribbed, and/or thin compared to equant gravel. The backscatter

responses of biologically colonized seafloors then becomes quite a complex issue, but still computable at some level of practical accuracy.

Finally, it is our intention to quantify the level of variation in backscatter dB levels due to shells and shell hash, and to use this in a monitoring context.

5   ACKNOWLEDGMENTS

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