CORRELATION BETWEEN SEDIMENT PROPERTIES AND SEAFLOOR CHARACTERIZATION MAPS BASED ON MULTIBEAM BACKSCATTER DATA FROM THREE REGIONS OFF THE COAST OF NORWAY

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Abstract: *Multibeam echo sounder data from Kongsberg EM 1002 and EM 710 (70–100 kHz) acquired between 2003 and 2014 were processed using QPS Fledermaus Geocoder Toolbox (FMGT) to produce backscatter mosaics and maps of estimated grain size. The regions surveyed (the Oslo fiord, the North Sea and off the coast of Mid-Norway) measured 36 000 km^2, with depths up to 600 m. Ground truth data acquired in 2004–2015 consisted of 64 gravity cores and 151 Van Veen grab samples. Particle size analysis was conducted on 125 sediment samples. Correlations between backscatter, estimated grain size and seabed sediment properties are examined in the paper. The Pearson's correlation coefficient squared was 0.46 between estimated and measured median sediment grain size in a subset of the data; the estimated grain size was in general coarser than measured. The 2 mm limit of the estimated grain size in the Angular Range Analysis of FMGT was reached in areas of coarse-grained sediments. The correlation between backscatter and the geoacoustic parameters (sound speed, density) averaged over the upper 20 cm of the cores varied significantly with region, from absent to strong. The correlation coefficient squared was 0.70 between estimated grain size and core density off the coast of Mid-Norway. To conclude, estimating the grain size using FMGT worked well as a method to characterize the seafloor of the surveyed regions.*

Keywords: *Multibeam echo sounder, seabed, backscatter, reflectivity, sediment, grain size, ground truth, angular range analysis, correlation coefficient, sound speed, density*

1. INTRODUCTION

During many years there has been an increasing interest in exploiting the possibilities of using multibeam echo sounder data to classify the seabed. The paper studies this question using data from Norwegian waters. In an earlier study single-beam echo sounder data from the northern North Sea has been investigated [1].

2. MATERIAL AND METHODS

2.1. The study area

The study covers three regions along the Norwegian coast: the Oslo fiord (2500 km^2), the northern North Sea (21 500 km^2) and off the coast of Mid-Norway (12 000 km^2), in total 36 000 km^2. All three regions have varying topography with depths up to 600 m.

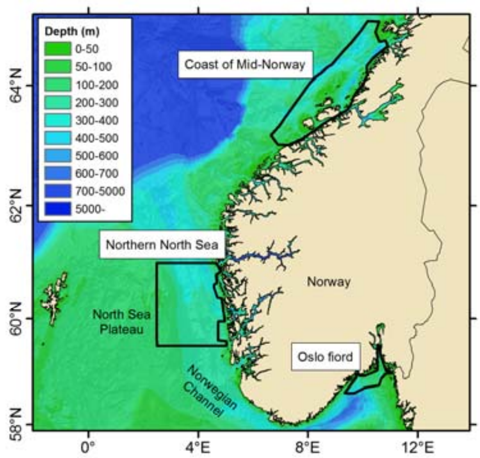

Fig. 1: Map showing the extent and bathymetry [2] of the three regions in the study.

2.2. Acoustic and ground truth data

In total 2 TB of multibeam echo sounder data has been acquired since 2003 in the three regions, and used to produce high-resolution bathymetric charts. The data was collected with Kongsberg EM 1002 at frequency 95 kHz and Kongsberg EM 710 at 70–100 kHz. The use of different versions of the processing unit software (1.2.0–2.3.7) and in the beginning different ping modes complicated the data analysis. Later shallow mode was default setting.

Backscatter data was processed using Fledermaus Geocoder Toolbox from QPS. The output was 20 m gridded raster maps of seabed reflectivity (backscatter mosaics), and estimated mean grain size using Angular Range Analysis (the method provides a single grain size value for each side of the swath). Ground truth was collected at 215 stations using a Van Veen grab sampler and two types of gravity corers. The sediment sampling took place in 2013 and 2015 in Mid-Norway, in 2013 in the Oslo fiord and between 2004 and 2008 in the northern North Sea.

Map values averaged in ArcGIS over circles of radius 20 and 100 m around each ground truth sample were correlated with sediment type and geoacoustic parameters of the seabed.

In total 60 sub-samples of 151 grab samples and 65 sub-samples of 64 sediment cores were analysed with respect to grain size distribution, using sieving to separate coarse and fine sediments. The mud fraction (grain size < 63 µm in diameter) was analysed with Micrometrics Sedigraph 5100, Micrometrics Sedigraph III 5120 or Malvern Mastersizer 3000 at the University of Bergen.

The sediment cores were sent through a GEOTEK Multi Sensor Core Logger for measurements of mainly gamma density, sound speed and sound speed amplitudes. The sound speed values were corrected to 25°C and 1 atm in the study. All the 151 grab samples were analysed rudimentarily.

Region	Min M_d (φ)	Max M_d (φ)	Mean M_d (φ)	Min SG (%)	Max SG (%)	Mean SG (%)	*n*
Oslo fiord	1	9.5	6.4 ± 2.7	3	90	26 ± 30	26
Northern North Sea	0.9	11	6.6 ± 2.6	1	100	27 ± 31	45
Mid-Norway 2013	−1	8.2	4.6 ± 2.3	6	79	47 ± 26	26
Mid-Norway 2015	−1	7.2	4.8 ± 1.9	3	100	36 ± 25	21

Table 1: The measured median grain size given as $M_d(\varphi) = -\log_2(D)/(1\,\text{mm})$*, where D is the particle diameter in mm, and fraction of sand/gravel SG for the 118 unimodal sediment samples analysed for grain size distribution. Mean values are listed with standard deviations; n is the number of samples.*

3. RESULTS AND DISCUSSION

The overall backscatter in the three regions varies from about −6 to 60 dB (Fig. 2). The EM 1002 values were manually adjusted in the North Sea to match the EM 710 data. The estimated grain size in two of the regions varies from −1 to 9φ, which are the lower and upper bounds in FMGT.

3.1. Correlations between acoustic and sediment parameters

The Pearson's correlation coefficient squared (r^2) gives the proportion of variability in the y values that is explained by linear relationship with x. There is a strong correlation between estimated grain size and backscatter with $r^2 = 0.71$ for 104 of the bottom stations in the Oslo fiord and off the coast of Mid-Norway (Fig. 3). The number also includes stations which grab samples have been analysed rudimentarily only. Stations with estimated grain size equal to −1φ and above 8.8φ have been removed, in addition to one outlier.

Including the stations with low/high estimated grain size, clearly the grain size boundaries are reached at 26 out of 130 stations (Fig. 3). The variation in backscatter is large for these stations. Photos of the five grab samples with estimated grain size above 8.8φ all show fine-grained sediments (mud), supporting the high estimated grain size. The measured median grain size of the six sediment samples (one from a grab sample and five from sediment cores) with estimated grain size above 8.8φ is coarser, between 6.2 and 8.2φ, while the backscatter varies significantly, from −35 to −25 dB. The small amount of coarser grains is affecting the backscatter, but apparently not the results of the FMGT Angular Range Analysis.

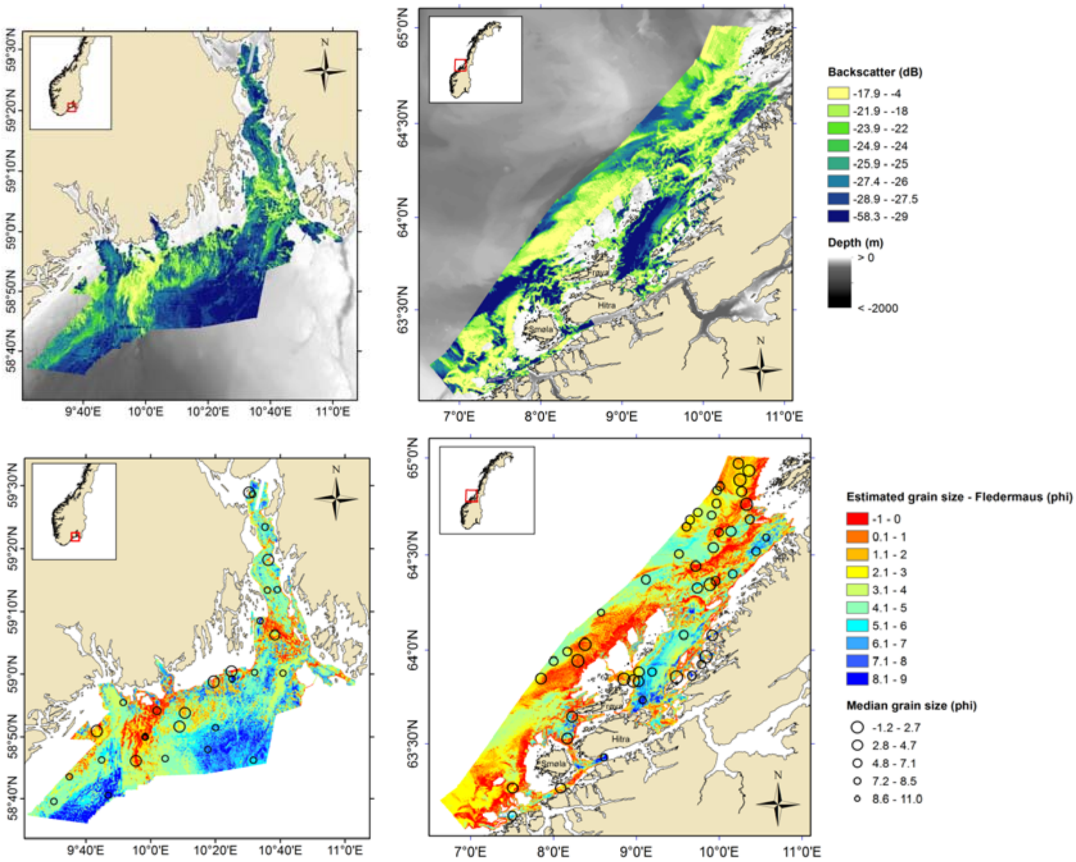

Fig. 2: Backscatter (upper) and estimated grain size (lower) in the Oslo fiord and off the coast of Mid-Norway (upper). The estimated grain size is compared with measured median grain size of the surface sediment samples.

The samples with estimated grain size equal to −1φ have backscatter > −20 dB. All the grab samples have stones at the surface, while the texture of the sediment varies significantly (Fig. 4). The fraction of sand/gravel in the sediment samples is from 14 to 100 %; the measured median grain size is from −1 to 7φ. Hence with the echo sounders used, the sediment layer is necessary not visible when the surface contains stones.

The outlier mentioned above has low backscatter (−29.1 dB) and low estimated grain size (−0.8φ). There was a 2 cm thick surface layer of muddy sand above a gravelly sand sediment layer. Unfortunately, no sediment sample was taken for particle size analysis. The backscatter is consistent with the surface layer, while the estimated grain size matches the sediment layer.

It is strong correlation between estimated and measured median grain size with r^2 = 0.46 (n = 50), when removing stations with estimated grain size equal to −1φ and above 8.8φ, and stations with backscatter standard deviation above 2.5 dB averaged over circles of radius 100 m (Fig. 3). In general the estimated grain size is coarser (lower) than the measured. The correlation is even stronger between the fraction of sand/gravel and the estimated grain size with r^2 = 0.53 (n = 50).

Estimated grain size versus water depth show moderate correlation with r^2 = 0.13 for the 104 stations.

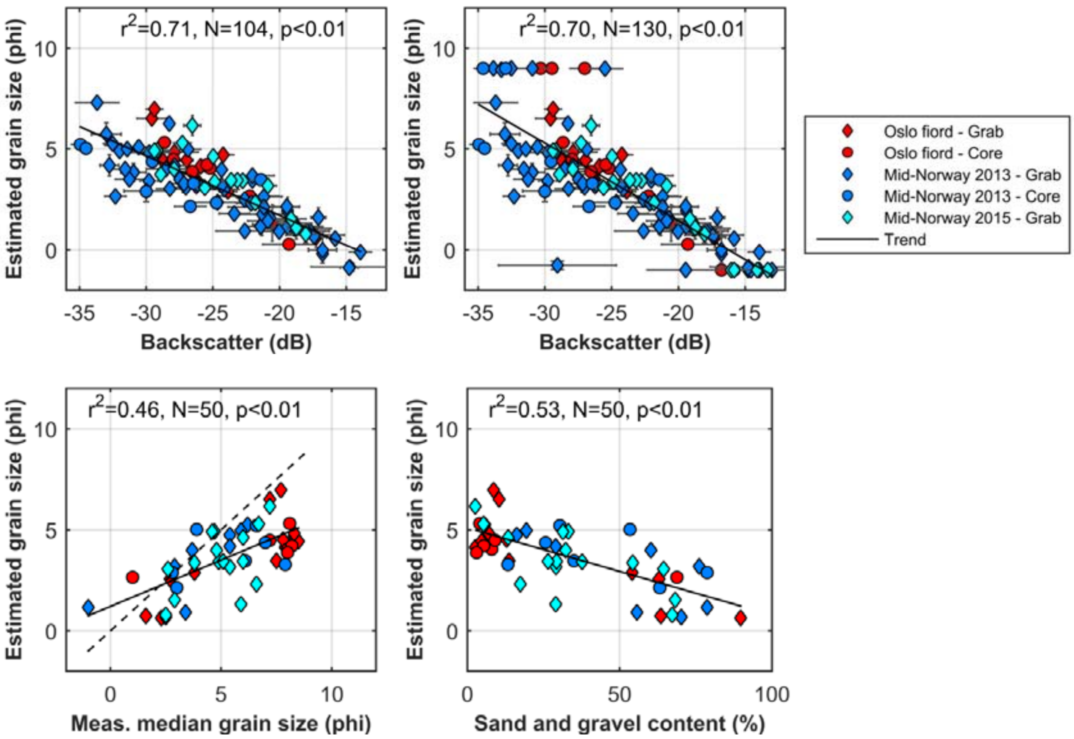

Fig. 3: Backscatter and measured median grain size versus estimated grain size for stations in the Oslo fiord and off the coast of Mid-Norway. The acoustic data are averaged over circles of radius 20 m

Fig. 4: Photos of grab samples from stations with estimated grain size equal to -1φ.

The correlation is varying with region for the selected parameter sets, as listed in Table 2. Strongest correlation is observed in the Oslo fiord. The correlation is much weaker off the coast of Mid-Norway, especially the correlation between backscatter and the sediment parameters.

3.2. Correlations between acoustic and geoacoustic parameters

The core sediment sound speed and density were averaged over the upper 20 cm and correlated with backscatter and estimated grain size for the three regions separately and overall (Table 3). The correlation is strong in the Oslo fiord, and varying from strong to absent off the coast of Mid-Norway, depending on which parameters are correlated. Overall, strongest correlation is experienced between core density and estimated grain size, and weakest between core sound speed and backscatter. Averaging the backscatter in circles of radius 100 m instead of 20 m, affects the overall correlation coefficients negligible.

Parameter set / Region	SG (%) BS (dB)	SG (%) M_z (φ)	M_d (φ) M_z (φ)	M_d (φ) BS (dB)	*n*
Oslo fiord	0.72	0.65	0.59	0.66	18
Northern North Sea	0.43	–	–	0.27	40
Mid-Norway 2013	0.12	0.47	0.46	0.18	16
Mid-Norway 2015	0.16	0.44	0.28	0.05	16
Overall	0.29	0.53	0.46	0.23	

Table 2: Pearson's correlation coefficient squared (r^2) between physical and acoustic parameters. SG − fraction of sand/gravel, M_d − measured median grain size, BS –backscatter, M_z – estimated mean grain size and n – number of samples. Estimated grain size for stations in the North Sea is excluded from the data set.

Parameter set / Region	ρ (g/cm^3) M_z (φ)	*c* (m/s) M_z	ρ (g/cm^3) BS (dB)	*c* (m/s) BS (dB)
Oslo fiord	0.55 (13)	0.43 (9)	0.61 (13)	0.47 (9)
Northern North Sea	–	–	0.00 (13)	0.38 (8)
Mid-Norway 2013	0.70 (9)	0.22 (7)	0.24 (9)	0.00 (7)
Overall	0.46 (22)	0.18 (16)	0.07 (35)	0.04 (24)

Table 3: Pearson's correlation coefficient squared (r^2) between geoacoustic and acoustic parameters (core density ρ and core sound speed c). The number of samples n is given in parenthesis.

4. CONCLUSIONS

Using Fledermaus Geocoder Toolbox has proven to be useful in seabed classification of three regions off the coast of Norway. Strong correlation is observed between estimated grain size and measured median grain size, and also between estimated grain size and core density averaged over the upper 20 cm. The correlation between backscatter (seabed reflectivity) and the sediment parameters varies with region.

REFERENCES

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[2] **EMODnet**, European Marine Observation and Data Network, www.emodnet-hydrography.eu, 2015.