KBWOT 2012: the use of an acoustic technique in mapping beds of razor clams (*Ensis* sp.)

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Summary

For the survey of shellfish in the Dutch coastal zone (WOT Ensis), a fixed stratified sampling grid is used. Stratification is based on expectation of occurrence, for which previously observations by *Spisula* fishermen were used. *Spisula subtruncata* has largely disappeared and was replaced by *Ensis* sp. However, the stratified sampling grid is still mainly based on expected occurrence of *Spisula* and on previous results of the survey for *Ensis*. The quality of the data would be improved with an entirely independent basis for the stratification. An improved accuracy of stratified sampling grids will increase the efficiency of the WOT surveys and will also increase the confidence level of stock assessments. This will benefit management of shellfish stocks and fishery and will also enhance the reliability of environmental impact assessment studies.

Acoustic techniques are increasingly applied for seafloor mapping and optimum allocation techniques for stock assessments. In the framework of the Belgian Science Policy project EnSIS (Houziaux et al., 2011) multibeam technology was successfully used to find an acoustic signal representative of dense *Ensis* sp. aggregations in Belgian waters. In this study however, only relatively few sampling stations were present in the areas with the acoustic signal. A plea was held for more ground-truthing, enabling applications in regular monitoring of *Ensis* sp. or other benthic species that form dense aggregations. Within the KBWOT Fisheries programme of 2012 we further studied the possibility to apply multibeam technology in the annual WOT stock assessment of *Ensis* sp. in cooperation with the Royal Belgian Institute of Natural Sciences – Management Unit North Sea Mathematical Models (RBINS-MUMM), that also performed the EnSIS project in cooperation with other institutes such as IMARES.

In an area in the Dutch Voordelta (Southern part of the Dutch coastal zone) where relatively high *Ensis* densities were found in the WOT survey of 2011, multibeam images of the seafloor were made by MUMM. In the same area, the WOT survey was repeated in June 2012. Additionally shellfish were sampled according to a very dense sampling grid in November 2012, within a different project commissioned by the Ministry of Economic Affairs. The latter project rendered highly relevant information on occurrence of *Ensis*, which was used in the current KBWOT project.

Processing of the multibeam data was done by MUMM as well. IMARES performed analyses, calculating parameters from the multibeam data. These were different parameters on texture, slope and reflectivity of the bottom. Sample-specific quantitative correlations with *Ensis* biomass and density were investigated. This yielded some significant although weak correlations.

The acoustic signal of *Ensis* sp. could be detected, but because of a high variation the predictive power and therefore generic applicability was still low. This may be improved using more advanced techniques for pre-processing of the backscatter data, and post-processing of both depth and backscatter data. Before acoustic techniques can be applied routinely, several steps need to be taken. Recommendations for these further steps are made in this report.

This project was financed by the KB-WOT Fisheries Programme of 2012.

Nederlandse samenvatting

Jaarlijks wordt in de Nederlandse kustzone een schelpdiersurvey uitgevoerd (WOT Ensis), welke is gericht op bestandsschattingen voor *Ensis* sp., *Spisula subtruncata* en overige commercieel interessante soorten. Er wordt gemonsterd volgens een gestratificeerd grid. Stratificatie werd gebaseerd op informatie van *Spisula* vissers, tot het bestand van *Spisula* instortte. Tegenwoordig is de stratificatie gebaseerd op deze oude informatie en op resultaten betreffende *Ensis* in voorgaande jaren. De kwaliteit van de survey, en ook de efficiëntie, zou enorm profiteren van een onafhankelijke basis voor stratificatie. Hoe accurater de stratificatie, hoe preciezer de uiteindelijke bestandsschatting is.

Akoestische technieken worden steeds meer ingezet om de zeebodem te karteren en voor zogeheten 'optimum allocation analyses' (dus stratificatie) voor bestandsschattingen. Binnen het Belgische EnSIS project voor beleidsonderzoek (Houziaux et al. 2011) is eerder gevonden dat hoge dichtheden aan *Ensis* sp. een specifiek akoestisch signaal lijken te geven. Om deze techniek echter direct toe te kunnen passen in de jaarlijkse WOT bestandsschatting is meer onderzoek nodig. Binnen het KBWOT programma van 2012 is verder onderzocht of multibeam sonar ingezet kan worden voor het karteren van ofwel *Ensis* banken ofwel bodemtypen waar de kans op aantreffen van *Ensis* sp. groot is. Dit is gedaan in samenwerking met het Koninklijk Belgisch Instituut voor Natuurwetenschappen, Management Unit North Sea Mathematical Models (MUMM), door wie ook het EnSIS project is uitgevoerd in samenwerking met andere instituten zoals IMARES.

In een deel van de Voordelta waar in 2011 in de WOT survey relatief grote dichtheden *Ensis* werden aangetroffen zijn door MUMM multibeam opnamen gemaakt van de zeebodem. In de WOT survey van 2012 zijn in juni dezelfde stations weer bemonsterd als in 2011. Daarnaast is binnen een ander project in opdracht van het Ministerie van Economische Zaken hetzelfde gebied bezocht in november 2012 en zijn schelpdieren waaronder *Ensis* sp. bemonsterd volgens een dicht monstergrid. Deze laatste campagne leverde veel bruikbaardere gegevens op dan de WOT survey van 2012, omdat het aantal monsterpunten vele malen groter was.

De eerste verwerking van de multibeam data (pre-processing) is gedaan door MUMM. Vervolgens zijn uit deze gegevens door IMARES verschillende parameters berekend (hellingshoek, textuur, reflectie). Kwantitatieve correlaties tussen deze parameters en biomassa en dichtheid van *Ensis* zijn onderzocht. Dit leverde enkele significante maar zwakke correlaties op.

Een akoestisch signaal van *Ensis* sp. kon gedetecteerd worden, maar vanwege een hoge mate van variatie is de voorspellende kracht van de correlatie laag en daarom nog niet algemeen toepasbaar. Dit kan verbeterd worden middels meer geavanceerde methoden voor pre- en post-processing van de multibeam data. Voordat multibeamtechnologie meer generiek kan worden toegepast moeten er nog een aantal stappen genomen worden, waarvoor in dit rapport aanbevelingen worden gedaan.

Dit project werd gefinancierd door het KB-WOT Visserij Programma van 2012.

1 Introduction

The Centre for Fisheries Research (CVO) of Wageningen-UR carries out statutory research tasks ("wettelijke onderzoekstaken", WOT) for the Ministry of Economic Affairs (EZ). These research tasks include stock assessments of exploited fish and shellfish species that are carried out by IMARES.

1.1 KBWOT Fisheries Programme 2012

The KBWOT Fisheries programme has an active policy of underpinning the key-expertise required to carry out the statutory tasks (WOT), and of encouraging the further development the expertise needed to complete those tasks. The programme operates through long term projects (multiannual) and annual projects in response to scientific and societal needs. It conforms to the wider Wageningen-UR strategic approach of Kennisbasis (KB, "Knowledge Basis") research being innovative, supportive and exploratory. Innovative and exploratory research is encouraged into integrated assessments of the ecosystem, impact of fishing, multispecies and maximum sustainable yield considerations in fisheries management whilst supportive research is maintained into acoustic survey techniques, biological parameters and ageing of fish and shellfish. The programme is administered by a panel of marine scientists, who review the programme each year, meet with civil servants from the Ministry of Economic Affairs (EZ) and circulate an annual report. This programme is part of the larger KB programme carried out by Wageningen UR and has been developed in consultation with the Ministry of EZ. The programme is mostly populated with projects resulting from an annual call for proposals. The core principles of the programme are maintaining expertise whilst being forward looking, ensuring value for money and strong collaboration with client ministries.

Themes addressed in 2012 were: 1. Ecosystem approach and fish descriptors in the MSFD; 2. MSY targets for North Sea flatfish; 3. Maintaining Quality; 4. International Exchange. This report shows the results of a granted proposal addressing Theme 3 "Maintaining Quality".

1.2 Aim of this project

For the survey of shellfish in the Dutch coastal zone (WOT Ensis), a fixed stratified sampling grid is used. Stratification is based on expectation of occurrence, for which previously observations by *Spisula* fishermen were used. *Spisula subtruncata* has largely disappeared and was replaced by *Ensis* sp. However, the stratified sampling grid is still mainly based on expected occurrence of *Spisula*. The quality of the data would be improved with an entirely independent basis for the stratification. An improved accuracy of stratified sampling grids will increase the efficiency of the WOT surveys and will also increase the confidence level of stock assessments. This will benefit management of shellfish stocks and fishery and will also enhance the reliability of environmental impact assessment studies.

Acoustic techniques are increasingly applied for seafloor mapping and optimum allocation techniques for stock assessments. In the framework of the Belgian Science Policy project EnSIS (Houziaux et al., 2011) multibeam technology was successfully used to find an acoustic signal representative of dense *Ensis* sp. aggregations in Belgian waters. In this study however, only relatively few sampling stations were present in the areas with the acoustic signal; a plea was held for more ground-truthing enabling applications in regular monitoring of *Ensis* sp. or other benthic species that form dense aggregations. Within the KBWOT Fisheries programme of 2012 we further studied the possibility to apply multibeam technology in the annual WOT stock assessment of *Ensis* sp. in cooperation with the Royal Belgian Institute of Natural Sciences – Management Unit North Sea Mathematical Models (RBINS-MUMM), that also performed the EnSIS project in cooperation with other institutes such as IMARES.

The aim of this project was fourfold:

1. study the ability to discern different types of seafloor (e.g. mud, sand, gravel, shellfish beds infaunal and epifaunal) using a high frequency multibeam acoustic sounding system;
2. assess the applicability of multibeam for stratified sampling in the coastal zone: will it optimize the sampling strategy and enhance efficiency?
3. determine what is needed to develop this innovative technique within IMARES and to apply it for stock assessments of shellfish and possibly other benthic communities (expertise, software, etc);
4. determine with whom to cooperate in future regarding availability of multibeam equipment and analysis techniques.

2 Methods

2.1 Acquisition of multibeam data

2.1.1 Planning

To evaluate the occurrences of *E. directus* in the Dutch coastal zone, individual tracklines were planned along locations where previously high densities of *E. directus* were found (Goudswaard et al. 2011). One area was chosen for full-coverage measurements; this area is at the extremity of a flood channel with a similar setting as where high densities of *E. directus* were found in the Belgian coastal zone (Van Lancker et al. 2012a). Surveying was restricted to areas deeper than 8 m, because of the draught of *RV Belgica*, the Belgian oceanographic research vessel used in this study (Van Lancker et al. 2012b).

Table 1. Start line (south) of the box where full-coverage multibeam has been sailed.

Track	Lat_wgs84		Long_wgs84	
Full_end	51	49.608	3	47.163
Full_start	51	48.014	3	42.245

Table 2. Start and end position of the single line multibeam tracklines.

Track	Lat_wgs84		Long_wgs84	
Track 1_start	51	52.617	3	52.186
Track 1_end	51	55.211	3	57.067
Track 2_start	51	46.520	3	37.181
Track 2_end	51	48.525	3	41.343
Track 3_start	51	38.076	3	22.079
Track 3_end	51	38.076	3	28.178
Track 4_start	51	28.141	3	9.892
Track 4_end	51	31.897	3	15.138

Apart from these lines the transit from the Dutch to Belgian coastal waters was sailed bordering the -10 m MLLWS (Mean Lowest Low Water Spring) depth contour.

2.1.2 Multibeam survey

RV Belgica’s Kongsberg-Simrad multibeam dual head echosounder EM3002D was used at a nominal frequency of 300 kHz. Standard procedures were chosen for its application (Van Lancker et al. 2012b). Position (UTM-31 WGS84), depth (m), and backscatter (dB) data were logged.

Compensations were made for the draught of the ship, sound absorption coefficient (temperature, salinity and pH dependent). Sound velocity was taken from the sensor next to the multibeam transducer. Due to well-mixed water masses, the surface values were taken for the corrections. Beam angles were set at 72°. High-density equidistance beam spacing was chosen.

A full system calibration (e.g. roll, heading, time delay) was carried out in May 2012. At the beginning of this survey results were evaluated from adjacent lines; no extra calibration was needed. A 10-20% overlap between the consecutive swaths was aimed at. Data were acquired at a speed of 8-10 knots. Weather conditions were excellent, resulting in a good data quality.

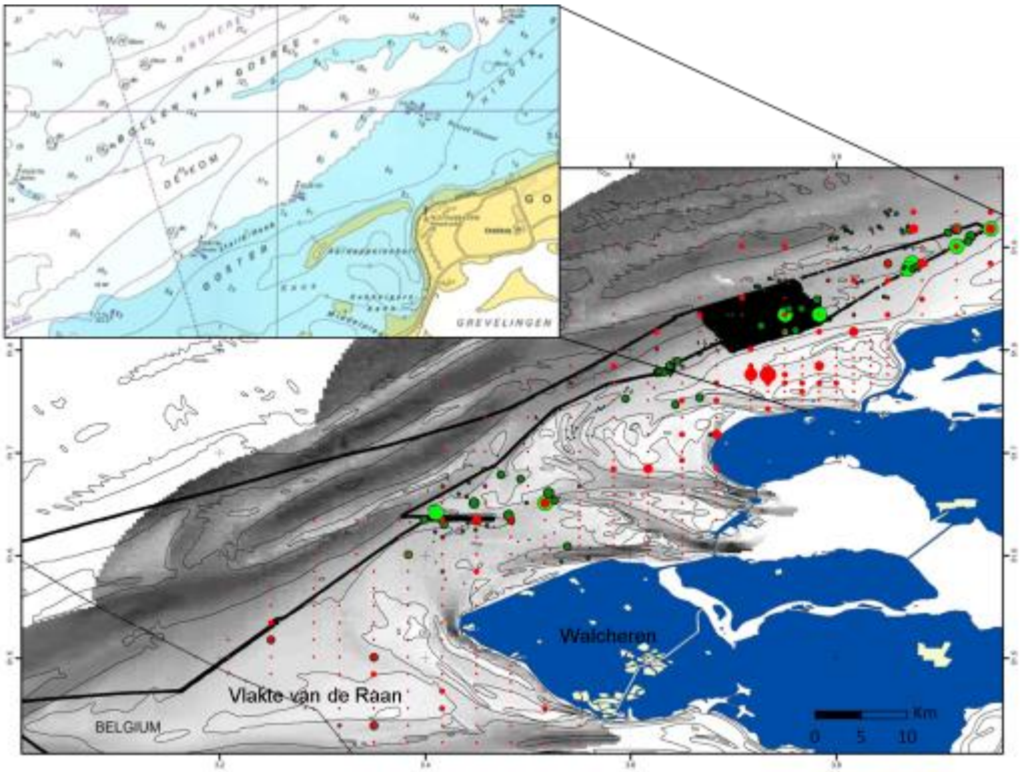


Figure 1. Multibeam recordings (black dots) in the Voordelta, Dutch coastal zone (RV Belgica ST1219, 2-6/7/12). Single line multibeam tracks were sailed and one full-coverage box in the area 'De Kom', 'Bollen van Goeree' (inset). Circles represent densities of E. directus (IMARES).

2.1.3 Tide correction

Time (Universal Time, UTC) and position data (UTM-31 WGS84, 1min interval) were extracted from RV Belgica's central data acquisition system (ODAS-II) and converted to a QinSY QTR file. This file was sent to the Hydrographic Service of the Dutch Royal Navy (Ministry of Defense) to obtain a tidal correction file (Lowest Astronomical Tide, LAT and Mean Sea Level, MSL). PREMOv3 (water level PREdiction MOdule) software was used (http://publicwiki.deltares.nl/display/PREMO/Technical+documentation).

2.1.4 Multibeam Processing

The EM3002D multibeam data have been processed with the IFREMER CARAIBES software release 3.8 (Linux). This included corrections for positional errors, tidal compensation and the creation of digital terrain models (0.5m and 1m grid resolution). A raw backscatter mosaic was produced at 1m resolution; no corrections were made for incident angle or absorption along depth.

From CARAIBES, depth (in m LAT, WGS84) and backscatter (dB) data were exported as floating grids (.flt), as well as NetCDF. Small gaps in the data were interpolated. As such, the 0.5m grids still provided a maximum of information in most of the survey areas. In the shoreface connected troughs, the 0.5m gridded data does not provide a full-coverage of the seafloor.

2.1.5 *Data storage and policy*

Data are stored at the Belgian Marine Data Centre (RBINS-MUMM). Data products and metadata are produced following Geo-Seas standards. Gridded data were exported as NetCDF. Data will be freely available for download (www.geoseas.eu). The data remain property of the Royal Belgian Institute of Natural Sciences, Management Unit North Sea Mathematical Models.

2.2 Distribution of *Ensis* sp.

The study area was based on the distribution of *Ensis* sp. found in the WOT shellfish survey of 2011 (Goudswaard et al. 2011). The survey data of 2012 were aimed to be used for field validation of *Ensis* occurrence. However, *Ensis* density in 2012 was dramatically reduced in comparison to 2011 (Goudswaard et al. 2012), and only few sampling stations in the multibeam box contained high densities of *Ensis* sp.. In November 2012 the multibeam box was sampled again for *Ensis* sp. and other shellfish species. This time for a project commissioned by the Ministry of Economic Affairs, focussing on monitoring for the Habitats Directive and the development of a methodology for monitoring of biogenic structures such as shellfish reefs. This offered the opportunity to use data from 179 sampling stations for field validation. All stations were sampled with a boxcore and a towed bottom dredge.

2.2.1 *WOT survey May – June 2012*

We use a standardized protocol for sampling methods, that is also used in the annual WOT *Ensis* survey as described by Goudswaard et al. 2012. Within the study area of the current project all samples were taken with a towed bottom dredge. More details are given in the following section.

2.2.2 *Survey for Habitats Directive November 2012*

The primary aim of this inventory was to (develop a method to) map shellfish beds, with a focus on *Ensis* sp. All bivalves encountered were counted and weighed. All intact individuals were measured to the nearest mm. Damaged individuals were counted if both hinge and meat remains were present. The weight of damaged individuals was estimated based on the weight of intact individuals.

Sampling was carried out in the periods 5 – 9 and 19 - 23 November 2012. The number of sampling stations was limited by adverse weather conditions. Sampling was carried out using the commercial fisheries vessel BRA 7 “Jade”. A sampling grid was chosen to be as dense as possible, while still covering a relatively large portion of the full-coverage box. Distance between sampling station was 350 m during the first sampling week. During the second week sampling stations were placed in between, resulting in a distance between sampling stations of only 175 m. All stations were sampled with two sampling gears: a boxcore and a towed bottom dredge. The boxcore sample was taken first, followed by a bottom dredge track. Methods used for sampling with the towed bottom dredge are the same as used in the annual WOT survey reported by Goudswaard et al. 2012.

We used a Reineck boxcore with a diameter of 31.4 cm and a sampling area of 0.0774 m^2. The samples were sieved over a mesh of 5 mm. We always processed the entire sample.

The towed bottom dredge is the same type as used in the annual WOT shellfish survey (Goudswaard et al. 2012). The dredge has a knife with a width of 10 cm that cuts to 7 cm depth. Towed distance is about 150 m, resulting in a sampling area of 15 m^2. The total distance towed is determined using a counting wheel on the dredge that logs the number of rotations during bottom contact. The logged distance between lowered and hauling is used to check these distances. The sample was sieved over a mesh of 5 mm. Samples with a large volume were subsampled. At least 6 litres of subsample was taken, which was processed entirely.

The data were stored in a central database at IMARES.

2.3 Analysis

2.3.1 Analysis of multibeam data

The multi-beam data, in resolutions of 0.5, 1.0 and 2.0 meters, were made available as ArcGIS ASCII grids and were further converted to raster format. The data contained values with X and Y coordinates and depth in meters or backscatter in decibels. The image pre-processing included contrast manipulation, filtering and histogram stretching to improve the overall visibility of the images.

The following parameters were analysed, for all three resolutions separately:

- Texture: *kurtosis*;
- Texture: *Moran's I*;
- Texture: *Slope*;
- Reflectivity: of the mean and standard deviation of the backscatter values (1.0 m resolution only).

These parameters were calculated for all sampling stations, at different spatial scales: we used boxes of 20x20, 50x50 and 100x100 m around each sampling station.

Texture: *Kurtosis*
Kurtosis is a statistical measure for the closeness of a distribution compared to the normal distribution. The value becomes 0 for a normal distribution and is increased for leptokurtic distributions. A distribution is called leptocurtic if it is more peaked about the mode than the normal distribution. Kurtosis expresses the slope differences of the seafloor in negative and positive numbers. The positive numbers indicate high slope and negative numbers depressions and basins. We used the kurtosis algorithm in the ERDAS IMAGINE software package to enhance and quantify the texture of the seafloor. This method is based on estimation and subtraction of means for the image values and then divides the remaining values to variance (the measure of how far a set of numbers is spread out) (ERDAS IMAGINE Field guide, 2011). We did the same analysis at different sample scales: 10x10, 20x20, 50x50 and 100x100 m of seafloor around each *Ensis* sampling station.

Texture: *Moran's I*
Moran's I is a measure for spatial autocorrelation. Like kurtosis it expresses differences from a normal distribution. Moran's I calculates the correlation in greyscale of nearby pixels. This spatial autocorrelation simplifies and quantifies the texture of the seafloor. Moran's I is a measure of the level of clustering of pixels, and can vary from -1 to +1. If pixels are randomly distributed, Moran's I is around 0. If pixels are evenly distributed (like a checker-board) the value is close to -1. If for instance all black pixels are located on one side of the image and all white pixels on the other side, Moran's I is close to +1. The results may be dependent on the chosen sample size and therefore we did the same analysis at different sample scales: 10x10, 20x20, 50x50 and 100x100 m of seafloor around each *Ensis* sampling station.

Texture: *Slope*
The slope of the seafloor was calculated for 0.5 and 2.0 m resolution data, in percentage (from 0 to 200% of slope) and in degrees (from 0 to 90 degrees). The calculated slope present changes in depth over the distance of one pixel (0.5 – 2.0 m). We calculated the average of all pixels within boxes of 10x10, 20x20, 50x50 and 100x100 m around each sampling station (e.g. 100x100 m boxes contained 200x200 pixels at 0.5 m resolution and 50x50 pixels at 2.0 m resolution).

Reflectivity

Reflectivity was studied by averaging the backscatter values for the chosen areas of interest around each sampling station (10x10, 20x20, 50x50 and 100x100 m). The resolution of the backscatter data was 1.0 m. The data were imported to ERDAS IMAGINE 2011. In order to improve the overall visibility and quality of the data, the Periodic Noise removal tool was used to reduce periodic noise- strips. This significantly reduced the stripes and smoothed the image (Figure 2). The method deletes artificial values and replaces them by average values of surrounding pixels using Fourier transformation. The applied algorithm is described in (Cannon et al. 1983) and (Srinivasan et al. 1988).

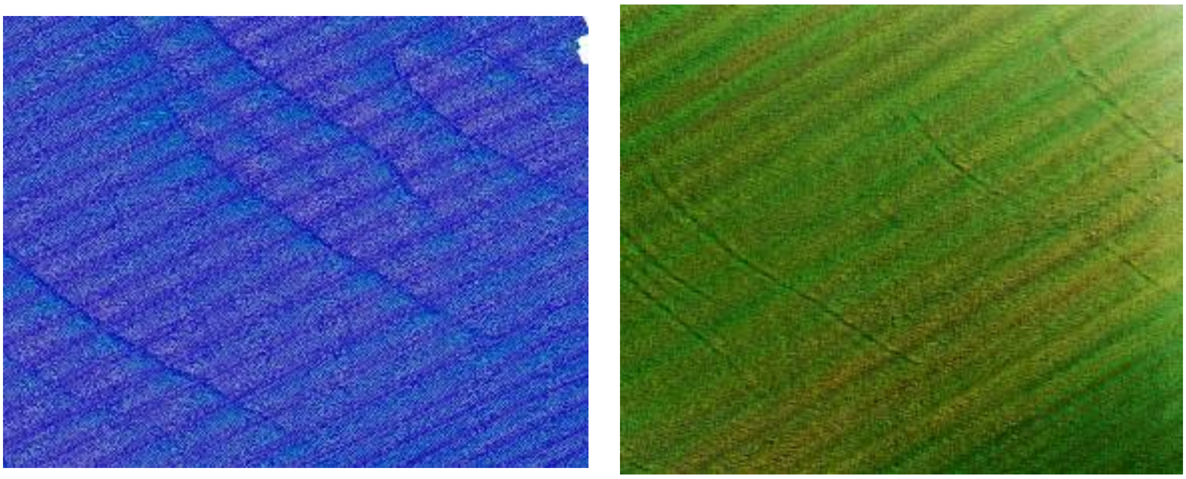


Figure 2. Backscatter image after pre-processing (left) with sharp striping, and the same image after Periodic Noise removal tool (more smooth) on the right.

After noise reduction, mean and standard deviations were calculated using the Focal analysis tool of the ERDAS IMAGINE 2011 program.

2.3.2 Correlation with presence of Ensis

Possible correlation between multibeam survey results and Ensis abundance were first explored visually by plotting Ensis abundance data on maps with depth and backscatter data. In the areas with most Ensis, acoustic imagery had a higher reflectivity than its surroundings (moderate level), a rough texture with (semi)-circular patterns. Ensis density and biomass was plotted against the different parameters for texture and reflectivity. Differences between small and large *Ensis* were explored. The strength of observed correlations was explored in Excel (R^2) and linear regression was tested statistically in IBM SPSS Statistics 19.

2.4 Availability of multibeam data in Dutch coastal waters

In the Dutch coastal waters, different parties map the seabed using multibeam echo sounding. Compared with other techniques multibeam survey is quite expensive, as such it is not applied in every bathymetric survey. The primary aim of this inventory was to have a quick overview of all companies applying multibeam echo sounding in the Dutch coastal waters. A list of multibeam experts (client and contractor) was generated by internet research. The most relevant parties were contacted by telephone or e-mail. The information was gathered based on a questionnaire. There were several questions, such as;

- Do you regularly perform multibeam surveys in the Dutch coastal waters?
- Who is your client for such surveys, or for which project was the survey?
- What was the size of the research area?
- How often will the survey be performed?

3 Results and discussion

3.1 Multibeam data

3.1.1 Maps

Maps were made of the texture parameter ‘kurtosis’, for slope, and for the backscatter data (after noise reduction). The kurtosis processing resulted in the map shown in Figure 3. The sand dunes are clearly visible. Besides these, clear differences can be seen between lighter and darker areas, more or less in bands parallel to the direction of the dunes.

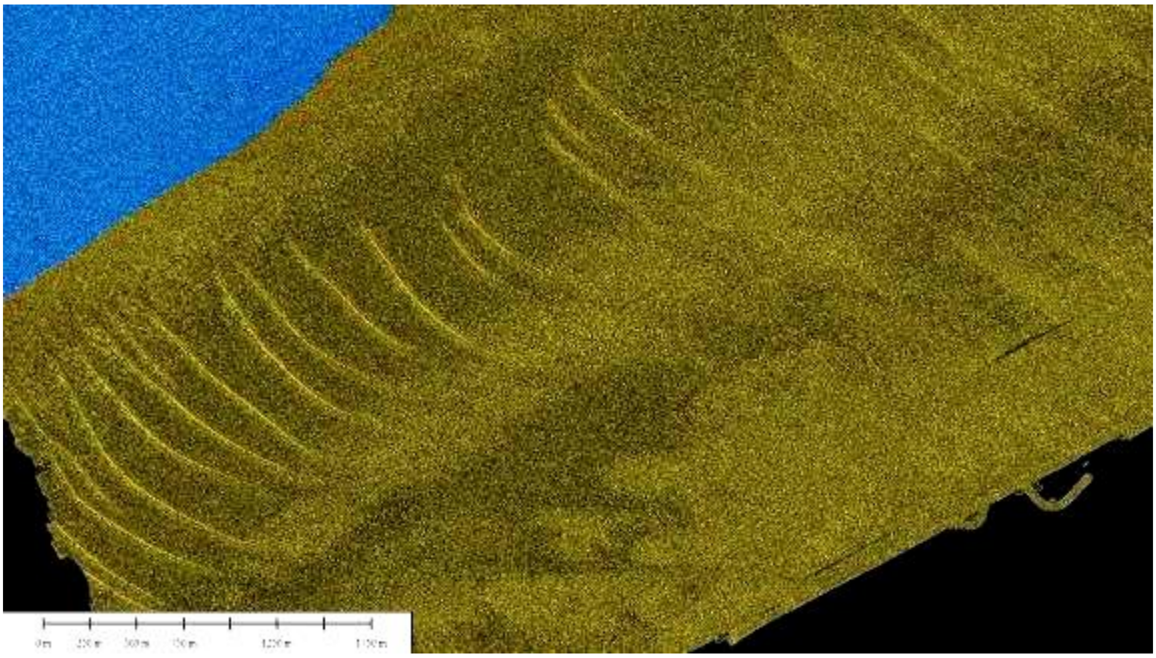


Figure 3. The image for kurtosis, calculated from the 2 m resolution multibeam data.

Also in the slope maps the sand dunes were clearly visible (Figure 4). A map showing backscatter is given in paragraph 3.2.

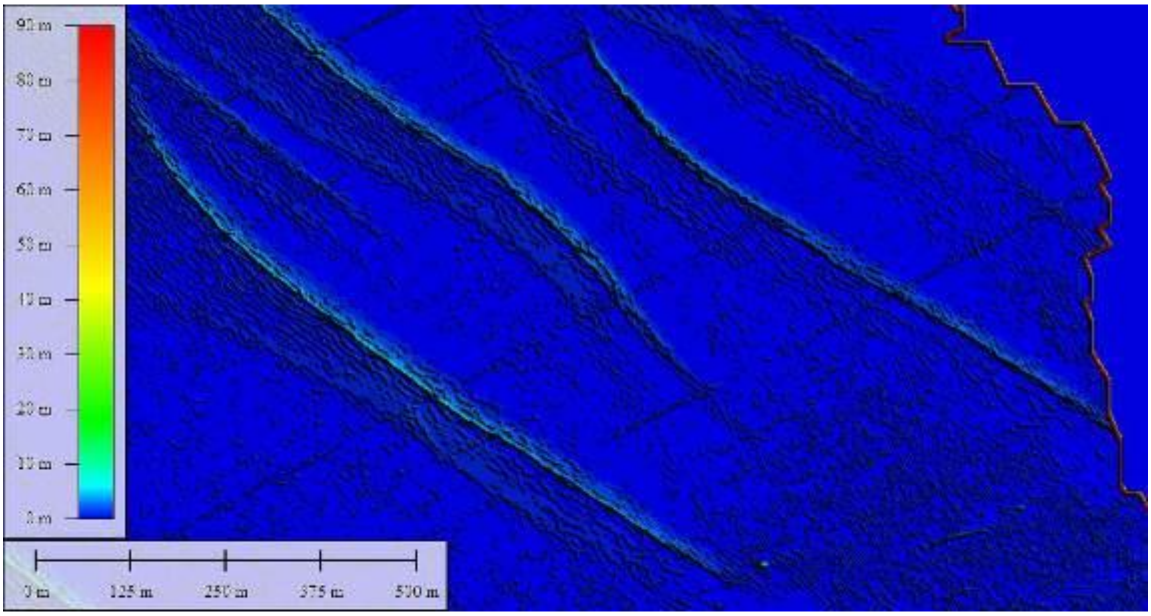
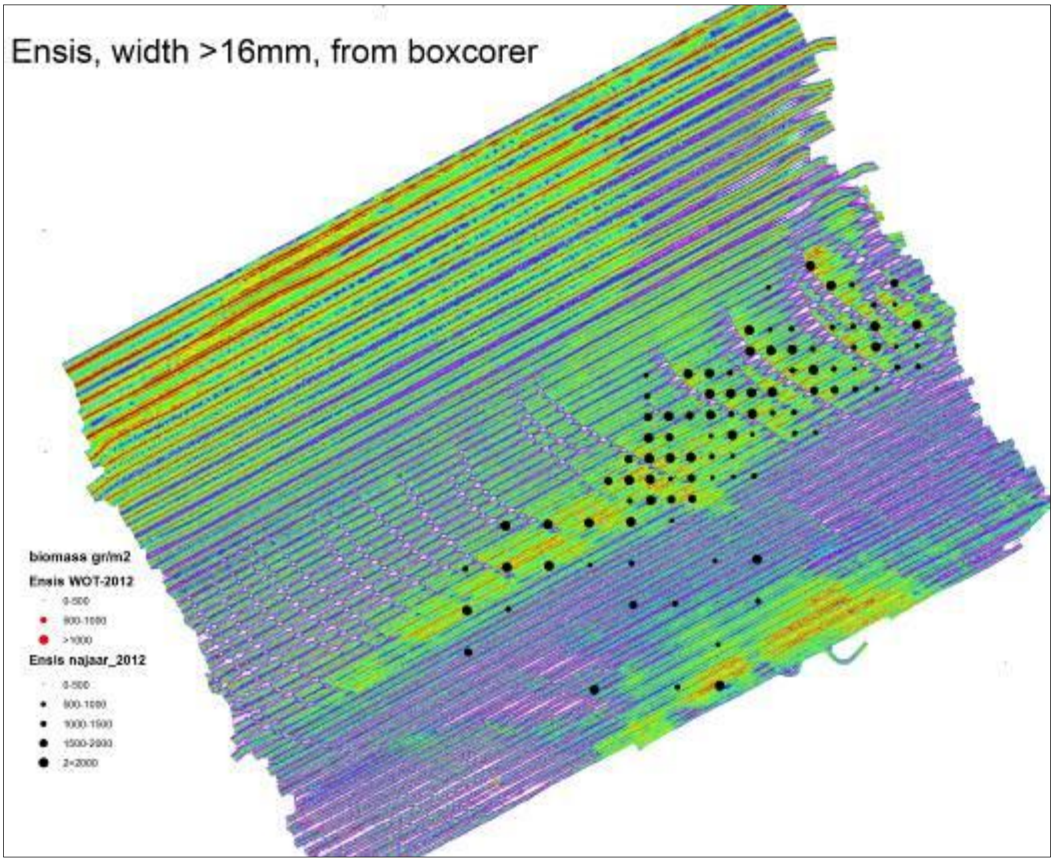


Figure 4. Example of a slope map. Slopes were calculated in degrees and percentage. Results are shown for only a smaller part of the full-coverage box in the area of the sand dunes.

3.2 Correlation between multibeam and Ensis occurrence

Ensis was sampled at 179 stations with boxcore and dredge. *Ensis* was found in 178 out of 179 dredge samples and in 123 out of 178 boxcore samples. This reflects the difference in sampling area. The dredge samples 15 m^2 per station and the boxcore only 0.08 m^2. Dredge results therefore give a value averaged over a larger area, and in the boxcore samples more extreme values are found and the variation between samples is larger. The average density found by dredge was 20.3 m^{-2} and the average density found by boxcore 44.0 m^{-2}. This difference is due to a difference in gear efficiency. The dredge only samples the upper 10 cm of the sediment and therefore misses more individuals (roughly by factor 2). The maximum density found per sampling station was 92.6 m^{-2} by dredge and 207.8 m^{-2} by boxcore. Mostly large individuals (shell width ≥16 mm corresponding with a shell length of ≥120 mm; Goudswaard et al. 2012) were found. In the dredge samples 4% of the animals consisted of smaller *Ensis* and in the boxcore samples 9%. Because of the time lag between the multibeam survey (July) and *Ensis* survey (November) we only show results for the larger *Ensis* individuals. Analysis results were however very similar for large *Ensis* only and the total of all *Ensis*.

The backscatter map appears to show different bottom types, roughly corresponding to the areas with different texture (Figure 5 Top). We can visually discern two bottoms, the one in purple hues and the one in green-orange. Figure 5 and Figure 6 show that most sampling stations were situated in an area with a similar backscatter signature and a depth between -10 to -15 meters. This is also the area where the sand dunes occur.



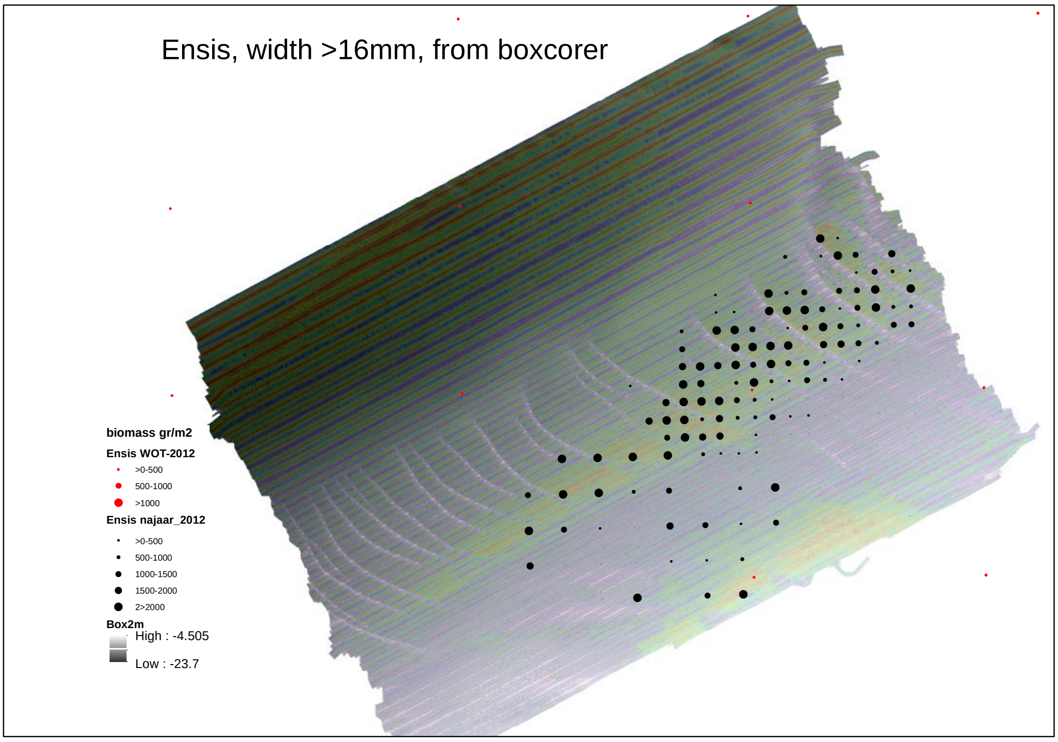


Figure 5. Top: map of the backscatter data after noise reduction, combined with large (>16mm width) Ensis biomass at all sampling stations (from boxcore samples). Bottom: combined map of depth (m) and backscatter (dB) with large Ensis biomass from boxcore samples.

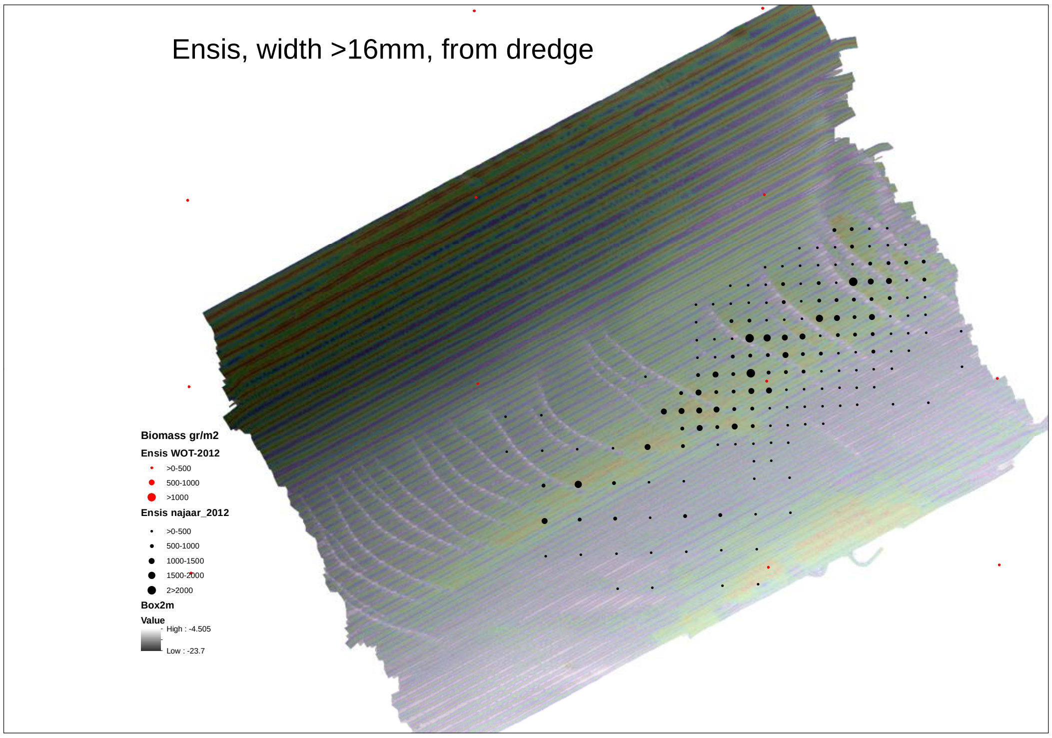


Figure 6. Distribution of large Ensis (width>16 mm), sampled by towed bottom dredge, projected on a combined map of depth (m) and backscatter (dB).

Differences found between results for the different scales (10, 20, 50 and 100m) were similar, but correlations were slightly stronger for 50x50 and 100x100. These results are therefore shown in Table 3. In general, bottom dredge data gave a slightly stronger correlation than boxcore data, and biomass data a stronger correlation than density data. In Table 3 the highest R^2 values found per parameter are given in bold. Per parameter, the combination of gear type, abundance unit (density of biomass) and analysis scale (50x50 or 100x100) with the highest R^2 value was tested statistically and p-values of linear regression analysis are given in the right column; corresponding graphs are shown below.

<u>Texture: Moran's I</u>

A correlation between Moran's I and *Ensis* occurrence was of similar weakness for 100x100 and 50x50 scale, biomass and density, and both gear types. Yet, linear regression analysis showed that the relation between Moran's I and *Ensis* occurrence was significant (Figure 7). The higher *Ensis* biomass was found at higher values of Moran's I. For Moran's I only values between 0.5 and 1.0 were found, showing that the distribution of pixels of different grey-scale was highly clustered. This may have been caused by a relatively strong depth gradient within the sample boxes (100x100 m), which may have obscured smaller scale texture patterns possibly caused by *Ensis* activity.

Table 3. R^2 values for different correlations, performed for the resolutions of 0.5 and 2.0 m (backscatter data 1.0 m) and at the spatial scales of 50x50 and 100x100, for density (n/m^2) and biomass (g/m^2) of large Ensis (>16 mm width). Per parameter the highest R^2 value found is given in bold. These correlations were shown in graphs. P-values from linear regression analysis are shown for the correlations for which the R^2 is given in bold.

			density		***biomass***		**p**
Parameter	**Gear**	**Resolution**	**50x50**	**100x100**	**50x50**	**100x100**	
Moran's I	**Boxcore**	**0.5 m**	<0.001	0.004	<0.001	0.005	
		2.0 m	0.05	0.04	0.05	0.05	
	Dredge	**0.5 m**	0.01	0.001	0.01	0.002	
		2.0 m	0.05	0.05	0.05	**0.05**	0.003
Kurtosis	**Boxcore**	**0.5 m**	0.01	0.002	0.01	0.002	
		2.0 m	0.11	0.16	0.12	0.17	
	Dredge	**0.5 m**	0.01	0.001	0.01	0.003	
		2.0 m	0.21	**0.26**	0.19	0.24	0.000
Slope (degrees)	**Boxcore**	**0.5 m**	0.06	0.04	0.07	0.05	
		2.0 m	0.01	0.001	0.004	0.002	
	Dredge	**0.5 m**	0.13	0.06	**0.13**	0.06	0.057 (*0.000*)*
		2.0 m	0.001	0.001	0.01	0.002	
Slope (percentage)	**Boxcore**	**0.5 m**	0.05	0.03	0.07	0.04	
		2.0 m	0.01	0.001	0.003	<0.001	
	Dredge	**0.5 m**	0.13	0.06	**0.14**	0.06	0.22
		2.0 m	0.002	0.001	0.01	0.002	
Backscatter	**Boxcore**	**1.0 m**	0.22	0.30	0.25	0.33	
	Dredge	**1.0 m**	0.29	0.44	0.33	**0.46**	0.000

*after ln-transformation

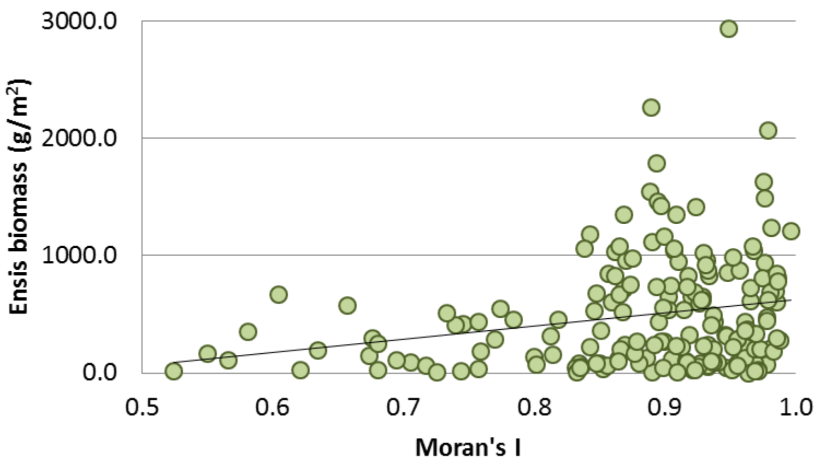


Figure 7. Biomass of large Ensis (>16mm) caught by dredge plotted against average values of Moran's I calculated from depth data in cells of 100x100 m around each sampling station (2.0 m resolution)(linear regression R^2 = 0.05; $p<0.05$).

<u>Texture: kurtosis</u>

A correlation between kurtosis and *Ensis* occurrence was the strongest for densities from dredge data at analysis scale 100x100 and resolution 2.0 m (R^2 = 0.26). These data were plotted in Figure 8. A significant linear relationship was found ($p<0.05$). The highest *Ensis* density was found at kurtosis values higher than 2.0. The kurtosis values also show that the texture is not entirely homogeneous. A value of 0 corresponds to a normal distribution. The values found, of between 1.8 and 2.3, may indicate (like Moran's I) that there was a depth gradient within the sampling area of 100x100 m.

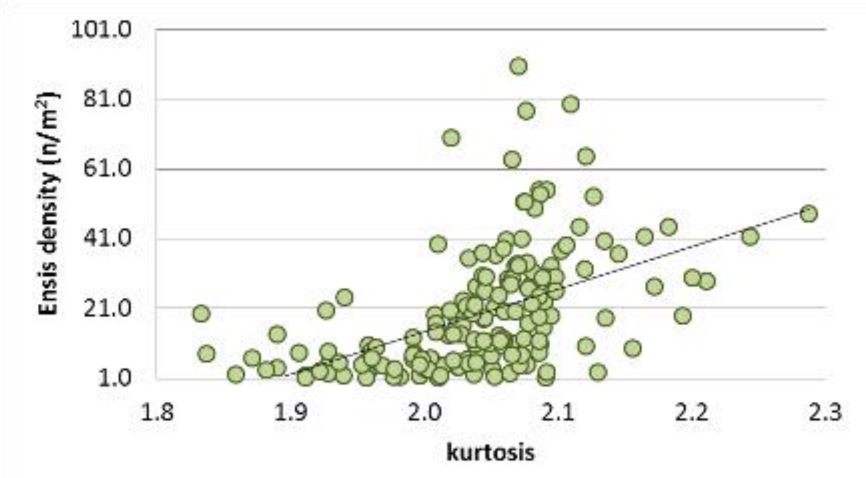


Figure 8. Biomass of large Ensis (>16mm) caught by dredge plotted against average values of kurtosis; values calculated from depth data in cells of 50x50 m around each sampling station (1.0 m resolution)(linear regression R^2 = 0.26; p<0.05).

<u>Texture: Slope</u>

Slope was expressed in degrees and in percentage, per pixel. Averages were calculated for larger areas (10x10 to 100x100 m), and therefore the slope results are also a measure of texture. Correlation was in both cases the strongest for *Ensis* biomass, caught by dredge, at scale 50x50 m and resolution 0.5 m. A significant positive relationship was only found for slope in degrees after ln-transformation of *Ensis* biomass (suggesting a logarithmic relationship). The highest *Ensis* biomass was found at values higher than 86 (pixel colour as a measure of slope in degrees).

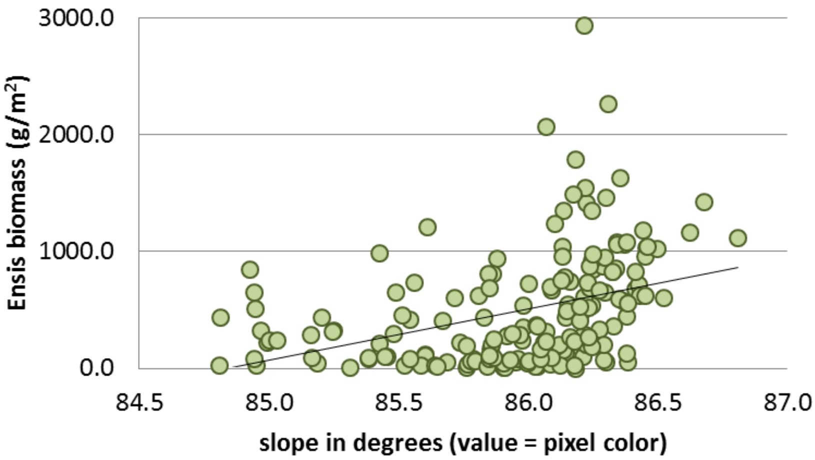


Figure 9. Biomass of large Ensis (>16mm) caught by dredge plotted against average values of the slope in degrees (expressed in values representing pixel colour due to an intermediate processing step) calculated from depth data in cells of 50x50 m around each sampling station (0.5 m resolution)(linear regression R^2 = 0.02; p=0.06. After ln-transformation R^2=0.08; p<0.05).

<u>Reflectivity: backscatter</u>

The strongest correlation between multibeam data and Ensis occurrence was found with backscatter values. Backscatter (in dB) was used as a measure for reflectivity of the seafloor. A correlation between backscatter and *Ensis* occurrence was the strongest for biomass from dredge data at analysis scale 100x100 (resolution 1.0 m)(R^2 = 0.46). A significant positive relationship was found (p<0.05)(Figure 10).

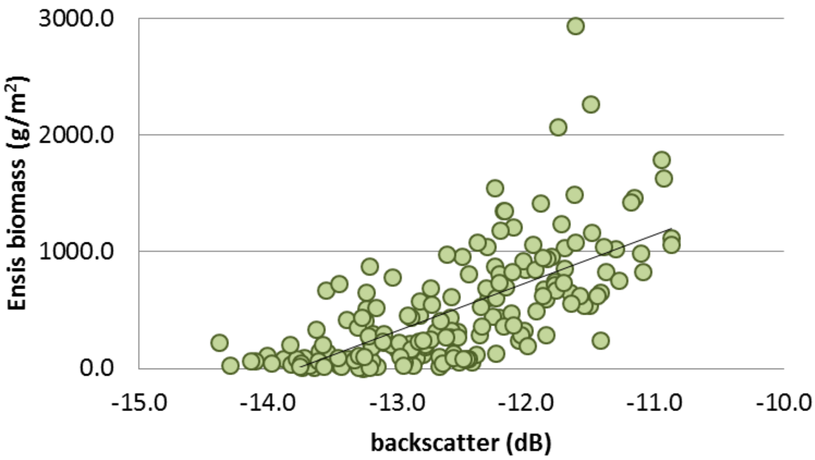


Figure 10. Biomass of large Ensis (>16mm) caught by dredge plotted against average values of the backscatter (dB) in cells of 50x50 m around each sampling station (1.0 m resolution)(linear regression R^2 = 0.46; p<0.05).

3.3 Availability of multibeam data in Dutch coastal waters

Table 4. Overview of companies that collect multibeam data in the Dutch coastal zone.

Company	Commisioned by / Project	Locations	Area (km2)	Frequency	Data available?
Deep	Econcern/Eneco	Amalia windpark	14	Every year	Yes*
	Noordzee wind	Windpark Egmond	27	-	Yes*
	Maasvlakte2	Near Maasvlakte2	-	-	-
Metaldec	-	Westerschelde	-	-	-
Geo+	Van Oord (sand nourishment)	Ameland	-	-	-
		Petten-Den Helder	-	-	-
		Texel-South	-	-	-
		Hoek van Holland	-	-	-
RWS	Bathymetry	Waddensea	-	5 years	Yes
		Zeeland	-	5 years	Yes
	(single beam)	Coastal zone (commissioned to districts)	-		
Port of Rotterdam	Archaeology	Maasvlakte 2	-	Once only	-
	Sand mining	Near Maasvlakte 2	-	Every year	-

* If client agrees
- Unknown / not available

Several companies were found to collect multibeam data in Dutch coastal waters (Table 4). However, in most cases only a specific area of interest is surveyed because of the high cost involved. Costs are estimated at €20.000 /day, nautical support excluded. In most cases backscatter data are not saved since this takes a lot of memory space and analysis of backscatter data is not straightforward. Saving backscatter will however not result in higher costs, but pre-processing of backscatter data will involve greater costs since this is more complicated and time consuming. As a rule, the costs increase with greater precision of pre-processing. For non-pre-processed multibeam data costs are the same whether backscatter is included or not. As for the bathymetry data collected by Rijkswaterstaat in the coastal zone: this is done using single-beam instead of multibeam, commissioned to the separate districts of which only Zeeland and Zuid-Holland save the backscatter data (but do not use it).

According to some companies the use of side-scan sonar could be a cheaper solution. Because of lower grazing angles and better bandwidth sampling they provide greater detail, though results are not quantitative (e.g. Degraer et al. 2008). Other techniques are available to detect cables and pipelines in the seabed (e.g. parametric echosounders, Missiaen et al. 2008). Perhaps these techniques can also be used for mapping shellfish beds.

4 Conclusions

4.1 Can Ensis be detected with multibeam?

As was found in the EnSIS project (Houziaux et al. 2011), *Ensis* sp. beds indeed appear to give a detectible acoustic signal. Qualitatively, areas with different acoustic signature (e.g. sedimentologically- or biologically-induced) can be depicted easily using multibeam technology and first quantitative delineations can be readily made based on a various parameters (e.g. from detailed terrain analysis or from backscatter. Similar to Van Lancker et al. (2012c), the areas with higher densities in benthos had a moderate reflectivity, a rough texture with (semi)-circular patterns. Correlations do become less obvious, if one attempts to quantitatively link sample parameters to acoustic data or their derived data products. Small-scale seabed heterogeneity becomes more important, as also noise and artefacts in the data.

We did attempt to quantify the acoustic signal and correlate it with abundance of *Ensis* sp. We found significant correlations, albeit rather weak. Backscatter intensity gave the strongest correlation and therefore this may be the most suitable parameter to detect *Ensis* beds. For the texture parameters used, kurtosis was the most useful one. Variation in the data was still high, possibly due to different causes:

- Pre-processing of the backscatter data was minimal and could be improved using more advanced software packages; these have recently become available at MUMM and also at IMARES;
- Post-processing may also be improved, if edge effects of the sweeps are better interpolated or avoided in the subsampling;
- Multibeam data were collected in July and *Ensis* abundance was monitored in November. In the time in between, *Ensis* densities may have been reduced at some stations because of mortality;
- Parameters acting at larger spatial scales may be more determining for the occurrence of *Ensis*, e.g. slope of the seafloor at larger scales, strength and direction of tidal currents, or sediment transport process knowledge in general. This was hypothesized in Houziaux et al. (2011).

4.2 Can multibeam sonar be applied to the annual shellfish survey?

Whether multibeam technology can be applied directly to the WOT survey is dependent on the availability of high-frequency multibeam data that include backscatter intensity, the costs and benefits of commissioning a multibeam survey specifically for the WOT survey, expertise available at IMARES or other institutes we can cooperate with, and primarily on the strength of the multibeam signal and the predictive power of it. We only surveyed a small part of the entire North Sea Dutch coastal zone, and a similar acoustic signal may also be related to dense aggregations of other benthic species. Ground-truthing, including sediment analyses, will therefore always remain highly necessary.

As for the availability of multibeam data, the largest areas are covered periodically by bathymetry surveys for Rijkswaterstaat. These are performed every 5 years in the Dutch Wadden Sea and Southwestern delta area (Oosterschelde, Westerschelde). In the coastal zone bathymetry maps are made using single-beam instead of multibeam, but backscatter data are recorded and stored in the Zeeland and Zuid-Holland districts. Whether these single-beam data can also be used is not certain. Commissioning a multibeam survey in the entire coastal zone will be very expensive and needs repeating regularly, with a frequency that depends on the rate of change.

Expertise in processing the (pre-)processed multibeam data has been developed within IMARES, but needs further developing if we want to apply multibeam technology in the WOT surveys. This can be developed further in cooperation with MUMM – Vera Van Lancker. Expertise in pre-processing will also be developed further within IMARES. Apart from cooperation with MUMM, further cooperation with Rijkswaterstaat is also advisable.

5 Recommendations for the WOT shellfish surveys

5.1 Applicability of the technique and recommendations for further development

Our results confirm that multibeam technology is suitable for detecting *Ensis* sp. beds, provided that ground-truthing takes place. However, before multibeam technology can be applied for optimum allocation of shellfish *(Ensis)* beds, it is advised to further test the acoustic signature, which is now attributed to dense aggregations of benthos, against other available multibeam datasets that are ground-truthed. To obtain better quantitative correlations with benthos data than in our study, it is recommended to:

- Repeat the pre-processing of backscatter data with more advanced software and test the strength of correlation again. The stronger the correlation, the higher the predictive power and therefore applicability to the surveys;
- Also test correlations with the rugosity parameter (ratio of surface area to planar area) which gave a good result in the EnSIS project but was not studied here;
- Additionally test correlations between Rijkswaterstaat multibeam data (including backscatter) and occurrences of high-density shellfish beds of any species in the Wadden Sea, Oosterschelde and Westerschelde estuaries.

5.2 Applicability to the coastal shellfish survey

As explained in the introduction, we wanted to investigate the potential of the multibeam technique for optimum allocation of shellfish beds in order to increase the efficiency and accuracy of stock estimates. We show that *Ensis* beds can be detected. However, *Ensis* sp. are relatively large shellfish species that may give a stronger signal than smaller species such as *Spisula* sp. The WOT survey is mainly targeted at *Ensis* and *Spisula* because of their commercial value, which is due to the fact that they are (or have been) relatively abundant. The strong decline that *Spisula subtruncata* showed, and the strong increase that *Ensis directus* showed, illustrate clearly that shifts in abundance may occur suddenly among any species. This will also have implications for the fisheries and what species are targeted. The WOT shellfish survey therefore always needs to be designed in such a way that results obtained are representative for all shellfish species (or at least the more dominant ones). The survey should not be stratified according to expected occurrence of *Ensis* sp. alone. It is therefore recommended to also study correlations between multibeam acoustic signals and occurrence of shellfish beds of other species, with the ultimate aim of being able to map shellfish occurrence in general and stratify the sampling grid accordingly.

5.3 Applicability to Natura 2000

The WOT surveys are commissioned with the purpose of assessing shellfish stocks for fisheries management. The data collected are also important for monitoring of Natura 2000 conservation goals in the North Sea. The WOT sampling grid covers three Natura 2000 areas in the coastal zone: "Noordzeekustzone", "Voordelta", and "Vlakte van de Raan". These areas are protected because of occurrence of the protected habitat type H1110 (Sandbanks which are slightly covered by sea water all the time) and because of the occurrence of foraging grounds for protected bird species. These bird species are diving ducks that forage on dense shellfish concentrations. These shellfish beds, as well as aggregations of the sand mason *Lanice conchilega*, are termed 'biogenic structures'. Where we confirmed that *Ensis* sp. can be detected by multibeam, Degraer et al. (2008) previously demonstrated that *Lanice conchilega* beds can be detected with very high resolution side-scan sonar. The multibeam technique is a very promising technique for an efficient mapping of biogenic structures. Without such means of narrowing down the search area for seafloor sampling, mapping of shellfish beds is nearly impossible to carry out for the entire coastal zone on a reasonable budget.

5.4 Availability of acoustic survey data

Our inventory of readily available multibeam data did not yield datasets that can be used on the scale of the entire North sea coastal zone. However, availability of acoustic data at the Royal Netherlands Navy was not investigated yet. Furthermore, Rijkswaterstaat has single beam acoustic survey data available for the North sea coastal area, but we are not sure whether single beam can also be used to detect shellfish beds. We therefore recommends to:

- Find out whether single-beam data can also be used, and study correlations between these data (including backscatter) as well as bathymetry data and *Ensis* occurrence from the WOT survey on a larger spatial scale (the entire coastal zone);
- Investigate whether acoustic seafloor information can also be obtained from the Royal Netherlands Navy;
- For application of Rijkswaterstaat survey data, backscatter data are probably essential. For the Zeeland and Zuid-Holland districts in the coastal zone backscatter data may already be available, although only for single-beam data. For the remainder of the areas it is recommended to ask Rijkswaterstaat to save the backscatter data and make it available after their first following bathymetry surveys.

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