Prediction of benthic biotopes on a Norwegian offshore bank using a combination of multivariate analysis and GIS classification

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This study is part of the multidisciplinary seabed mapping programme MAREANO (Marine AREAdatabase for NOrwegian coast and sea areas). The mapping programme includes acquisition of multibeam bathymetry and acoustic backscatter data together with a comprehensive, integrated biological and geological sampling programme. The equipment used includes underwater video, boxcorer, grab, hyperbenthic sled, and beam trawl. The Tromsøflaket offshore bank was used as a case-study area to develop suitable methods for mapping habitats and biotopes. A procedure for producing maps of predicted biotopes is described that combined information on the distribution of biological communities with environmental factors and indicators. Detrended correspondence analysis (DCA) was used to relate bottom environment [including multiscale physical descriptors of the seabed derived from multibeam echosounder (MBES) data] and faunal distribution to find the best physical biotope descriptors. DCA of 252 video samples (sequences 200 m long) revealed six groups of locations representing different biotopes. These were characterized by different compositions of species, substrata, depths, and values for terrain parameters. Prediction of biotope distribution was performed using a supervised GIS classification with the MBES-derived physical seabed descriptors with the strongest explanatory ability (depth, backscatter, and broad-scale bathymetric position index) identified by the DCA. The species diversity of the identified biotopes was described from the content of the bottom samples. For future MAREANO cruises, an important task will be to ground-truth predictions of habitat and biotopes and to test the reliability of these predictions in the wider MAREANO area.

Keywords: benthic biodiversity, habitat mapping, habitat prediction.

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Introduction

Information about benthic habitats and biological communities is important in implementing ecosystem-based management of the sea and in assessing the consequences of human activities. This study is part of the MAREANO programme (Marine AREAdatabase for NOrwegian coast and sea areas; www.mareano.no), which maps seabed topography, substrata, biodiversity, habitats, and sediment pollution in Norwegian waters. MAREANO is a multidisciplinary mapping programme, focusing on offshore areas in the southern Barents Sea. It was initiated to address the lack of knowledge of the seabed and environment, which is required for informed, sustainable management. The mapping programme includes acquisition of multibeam bathymetry and acoustic-backscatter data together with a comprehensive, integrated biological and geological sampling programme. Mapping outputs from the project consist of bathymetric data, geological maps (morphology, hard and soft seabed, sediment grain size distribution, sedimentary environment, geological genesis), biological maps (including biodiversity and faunal distribution), and benthic biotope maps. A biotope is defined as an area of uniform environmental conditions providing habitats for a specific assemblage of species (Dahl, 1908). It can be regarded as the habitat for a specific biological community.

Using a variety of sampling tools to ensure that organisms on all types of seabed are represented, MAREANO offers a unique insight into the diversity of benthic species and habitats. Maps of benthic habitats and biotopes are produced based on visual inspection, mapping of environmental conditions, and interpreting the data collected through multibeam mapping. However, because of the great expense and time needed, it is virtually impossible to produce full-coverage habitat maps from large areas based on samples and observations only. Therefore, relationships between environmental proxies with full spatial coverage and distributions of biological communities are used here to predict the distribution of biotopes.

When characterizing biotopes, it is logical to regard the environment as the structuring force controlling what species can live within an area, therefore defining what can be regarded as similar or dissimilar in nature. Climatological, hydrological, topographic, and geological conditions are decisive in that respect. Moreover, to characterize a biotope, the species that live there must be included in the evaluation.

Biotopes and habitats can be characterized at different spatial scales, ranging from the local environment with factors affecting the vicinity of individual organisms to ecosystems and landscapes where the substrata, terrain, and oceanography influence biological communities or populations. In this study, we concentrate on an intermediate scale (grid size 200 m) for practical reasons, covering ecosystems and landscape elements rather than small-scale habitats.

Many biotopes are linked to marine landscapes such as offshore banks, deep-water channels, canyons, submarine slide fields, and abyssal plains, characterized by very different environmental conditions. Therefore, a limited area with few marine landscapes was selected for the first step of MAREANO's seabed mapping. A manuscript already published from the MAREANO programme describes how systematic field records can be used to identify broad-scale units (marine landscapes) that are suitable for separate detailed analysis at a more local scale (Mortensen *et al*., in press).

The main goal of the study was to explore the possibilities for meaningful prediction of benthic biotopes utilizing information interpreted from video records and multibeam echosounder (MBES) data. Here, we present a novel procedure for biotope prediction involving classification of seabed locations based on species composition and supervised GIS analysis of MBES data and terrain indicators.

Material and methods

The study area is situated on the Tromsøflaket bank of the continental shelf off northern Norway (Figure 1). This was the first area mapped and sampled under the MAREANO programme in 2005/2006 and was used for testing and developing methodologies. The area was chosen for several reasons. It is an important area for fisheries, and it contains potential hydrocarbon development sites as well as dense sponge habitats. The area has been assessed as valuable and sensitive with respect to biological resources by expert groups reporting to the government (Olsen and von Quillfeldt, 2003; von Quillfeldt and Olsen, 2003). In areas such as this, where there are several potentially conflicting activities, habitat and biotope mapping is particularly important. The area is relatively small (2200 km^2) and consists of just two marine landscapes: offshore bank and marine valley (trench).

Tromsøflaket is a relatively shallow bank in the southern Barents Sea, with a relatively level plateau 150–200 m deep. Glacial sediments dominate much of the bank, and moraine ridges are also found (Bellec *et al*., 2008). Much of the bank has been heavily incised by iceberg ploughmarks. The eastern part of the study area covers a deeper area that is part of Ingøydjupet, with softer sediments and a contrasting sedimentary environment including an extensive pockmarked field (Chand *et al*., 2008).

The oceanography of Tromsøflaket is influenced by two major current systems. The north-flowing Norwegian Coastal Current contains relatively cold, low-salinity Norwegian coastal water. The Norwegian Atlantic Current, which is part of the North Atlantic Current, brings relatively warm, saline water north, and splits into two branches at Tromsøflaket (Skarðhamar and Svendsen, 2005).

Under the MAREANO programme, multibeam mapping surveys are followed-up by comprehensive, multidisciplinary sampling cruises, using a suite of remote sampling equipment including grab, beam trawl, hyperbenthic sled, and towed video platforms.

Data for this study comprise two main datasets, MBES and video. In addition, results from benthic macrofauna samples bring data to describe the general biodiversity of the biotopes identified. The multibeam data (bathymetry and backscatter) were acquired using a Kongsberg Simrad EM1002 (95 kHz) multibeam system and have been processed to produce bathymetry and backscatter raster grids with a cell size of 10 m, which have been converted to the ArcGIS format for use in this study.

Video recording and analysis

Video records were acquired from 48 locations during the first MAREANO sampling cruise in June 2006. Video was recorded with a high-definition colour camera (Sony HDC-X300) tilted forward at an angle of 45° on the video platform "CAMPOD". During transects, each ~1 km long, "CAMPOD" was towed behind the survey vessel at a speed of 0.7 knots and controlled by a winch operator providing a near-constant altitude of ~1.5 m above the seabed. Geopositioning for the video data was provided by a hydroacoustic positioning system (Simrad HIPAP and Eiva Navipac software) with a transponder mounted on "CAMPOD", giving a position accurate to ~2% of water depth.

In all, 48 video records were analysed in detail initially using sequences 30 s long (average length 12 m). Distances were calculated from recorded positions, and the field width was estimated from the recorded altitude (acoustic altimeter) converted to field width based on the relationship between measurements made using a laser scale and the height above the seabed. All organisms were identified to the lowest possible taxon and counted, or quantified as % seabed coverage following the method described by Mortensen and Buhl-Mortensen (2005). Lebensspur, burrows, and bottom-trawl marks were also counted. The percentage cover of six classes of bottom substrata (mud, sand, pebbles, cobbles, boulders, and outcrops) was estimated subjectively at a scale of 5% intervals in the same video sequences. To standardize the sample size, the 30 s sequences were pooled into distances of 50, 200 m, and 1 km (whole transect). Following initial analyses, it was decided that the 200-m distance segments provided the most appropriate level of data for nature-type mapping. This is similar to the strategy suggested by Orpin and Kostylev (2006), who suggest that "data should be collected at the highest practical resolution but be reduced to a resolution meaningful for statistical analysis, in accordance with the total sample population". Abundance data (the number of organisms counted divided by the area observed) for solitary organisms were standardized as the number of individuals per 100 m^2.

Deriving environmental descriptor variables from multibeam data

Multibeam echosounding data provide excellent data on bathymetry and can be used to generate quantitative variables describing the terrain. A recent summary of the variables that can be computed is provided by Wilson *et al*. (2007). A suite of terrain variables was derived, including slope, aspect, curvature, bathymetric position index (BPI; Lundblad *et al*., 2006), and rugosity (Jenness, 2004). Each variable was computed from the 10-m bathymetry grid using ArcGIS tools employing a 3×3-cell rectangular analysis window, except the broad-scale BPI, which was additionally calculated using an analysis window of 49×49 cells from a 50-m

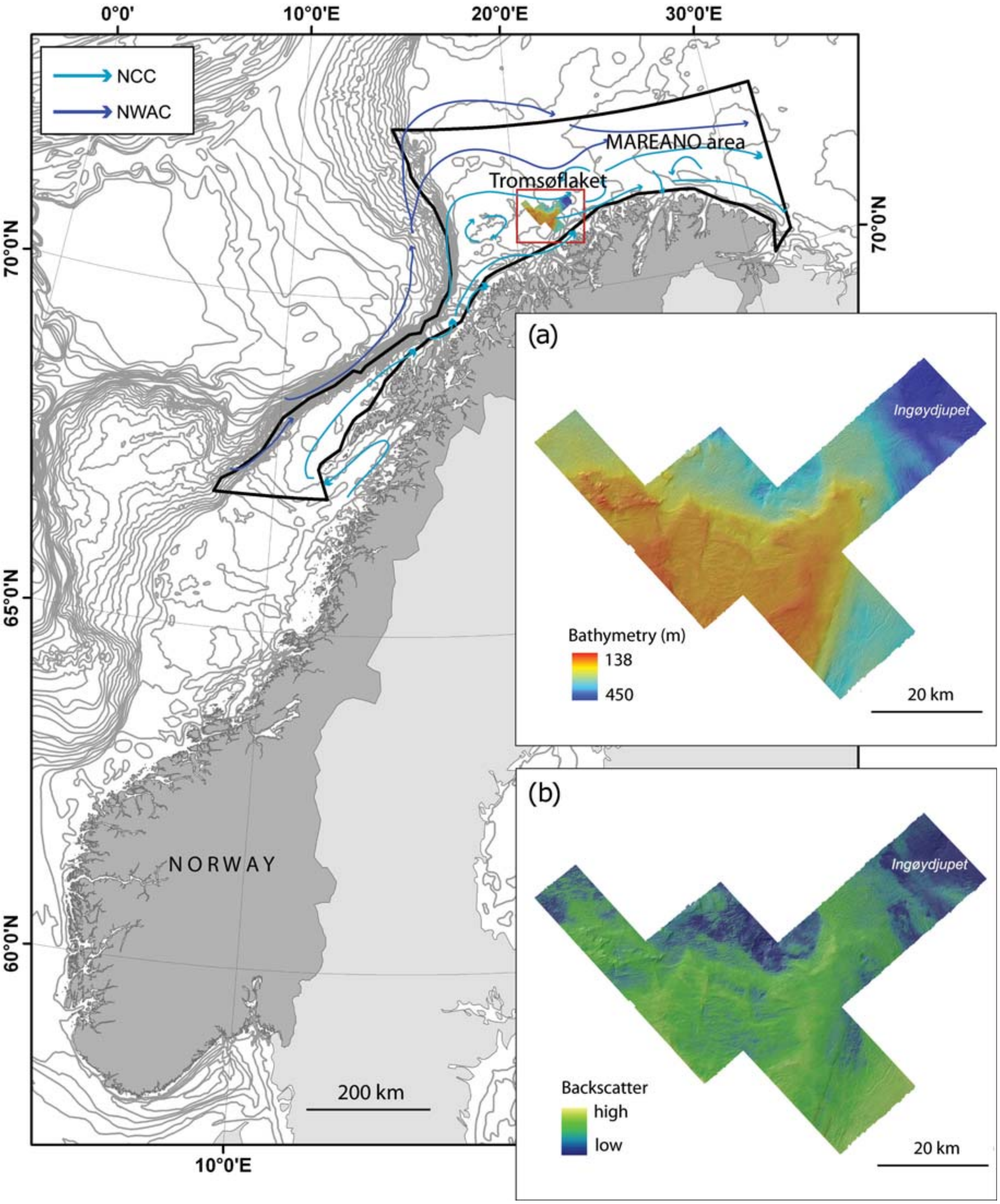

Figure 1. Overview map showing the Tromsøflaket study area within the MAREANO area of offshore northern Norway. Inset maps show (a) the multibeam bathymetry, and (b) the backscatter data for eastern Tromsøflaket. Regional bathymetry is indicated by 100 m contours. The main current patterns for the two main water masses, the Norwegian Coastal Current (NCC) and the Norwegian Atlantic Current (NWAC), are indicated by arrows.

bathymetry grid. In this analysis, we also used the multibeam backscatter data, which allow us to include some proxy to the general sediment substratum type. Rather than simply using the values of each terrain parameter derived directly, the mean and standard deviation of each terrain variable were computed within a square of 200 m. This distance was chosen to correspond to the distance over which the video data were pooled. Values for each terrain variable were extracted at points every 200 m along each video transect.

Detrended correspondence analysis

To identify sample groupings based on species composition and to characterize the groups with respect to controlling environmental factors, we applied detrended correspondence analysis (DCA),

Table 1. Correlation of the variables used in DCA with the first two ordination axes.

	Axis 1		Axis 2	
Variable	***r***	**R^2**	***r***	**R^2**
Depth (from video)	0.696	0.484	0.391	0.153
BATHYMETRY_MEAN	0.683	0.467	0.385	0.148
BACKSCATTER_MEAN	−0.652	0.425	−0.644	0.414
Mud/sand (% cover)	0.341	0.116	0.446	0.199
Stones (% cover)	−0.341	0.116	−0.446	0.199
Pebble (% cover)	−0.318	0.101	−0.386	0.149
BPI (broad)_MEAN	−0.092	0.008	−0.383	0.147
SLOPE_MEAN	−0.313	0.098	−0.146	0.021
Boulder (% cover)	−0.306	0.094	−0.366	0.134
BPI (local)_s.d.	−0.278	0.078	−0.081	0.007
Cobble (% cover)	−0.235	0.055	−0.433	0.188
SLOPE_s.d.200	−0.233	0.054	−0.13	0.017
RUGOSTY_MEAN	−0.217	0.047	−0.098	0.010
CURVATURE_s.d.	−0.216	0.047	−0.032	0.001
RUGOSITY_s.d.	−0.186	0.034	−0.097	0.009
BATHYMETRY_s.d.	−0.159	0.025	−0.133	0.018
BACKSCATTER_s.d.	−0.093	0.009	0.215	0.046
BPI (local)_MEAN	−0.070	0.005	−0.135	0.018
CURVATURE_MEAN	−0.067	0.004	−0.124	0.015
ASP_MEAN	−0.028	0.001	−0.208	0.043
ASP_s.d.	0.014	0.000	−0.085	0.007

Variables in italics were observed from video data and are used for comparison with full coverage environmental variables from multibeam data (in capitals), which can be used for the GIS-based classification.

using the software PC-Ord (McCune and Mefford, 2006). Several other methods have been employed in previous habitat mapping studies to identify similar locations based on species composition in relation to environmental variables, e.g. cluster analysis (Kostylev *et al*., 2001; Post *et al*., 2006) and canonical correspondence analysis (CCA; Mortensen and Buhl-Mortensen, 2005).

DCA is an eigenanalysis ordination technique based on reciprocal averaging (Hill, 1973). It can be considered an indirect gradient analysis, where environmental data are overlain on the ordination plot. This differs from CCA, which can be termed a direct gradient analysis, where ordination of the species matrix is constrained by a multiple regression on variables included in the environmental matrix. DCA of quantitative video data should be an effective way of identifying community patterns of larger areas and offers advantages over alternative approaches when species–environment relationships are not well known. The basic approach is that DCA identifies groups of samples with similar species composition first, then assesses the correlation of the environmental variables in relation to these groups along the various axes in multidimensional space. In all, 17 environmental variables were used for the analysis (Table 1): depth (mean for the 200 m sequences), backscatter (mean and s.d.), slope angle (mean and maximum), aspect (direction of slope), topographic indices (rugosity and curvature), percentage cover of the six types of seabed substratum, and the frequency of trawl marks. Only species found in more than two of the video sequences were included. These criteria left 99 taxa and 252 video sequences for the analysis.

Supervised GIS-based classification

The groups of video sequences and their associated environmental settings which emerge from the DCA represent distinct biotopes across the study area. Once classified by group, the location of video sequences was displayed in ArcGIS, showing the spatial variation in biotopes along the video transects. This type of map, showing classification of actual observations, represents the first stage of biotope classification. To produce a full-coverage map, we require a method for classifying the seabed and predicting the biotope distribution across the entire study area. As is common in many remote-sensing classifications, training data were used to define class signatures based on other layers of data. The strongest correlated environmental variables derived from the MBES data were used as signature variables for the identified groups of video sequences. These signatures were then used to predict the geographical distribution of classes across the entire study area. The geographic locations of biotope groups served as training data. The "create signatures" function in ESRI's Spatial Analyst extension for ArcGIS was used to relate the biotope groups to the various raster layers. At each training location (polygon), this function drills down through the GIS layers and provides a statistical summary (a.gsg file) of the values of the various rasters that correspond to that class, including the number of samples, the means, and the covariance matrices. In ArcGIS, this spatial classification can be done using the standard statistical technique of maximum likelihood classification. This produces a raster map for the entire study area, with each cell assigned to a class from the original training data based on the multivariate properties of the predictor variables (terrain variables).

Sampling macrofauna

To document infauna, epifauna, and hyperfauna within the habitats, grabs, beam trawls, and a hyperbenthic sled were used at ∼25% of all stations documented by video (Table 2). The faunistic results from the bottom samples are the topic for other work currently underway, so are used here in brief only to support the information on identified biotopes. It was not possible to deploy all gear types at all stations because the seabed was sometimes too coarse/rough. Therefore, the different habitats are not equally well sampled. At selected stations where sampling was possible, three replicate grabs were taken, along with one beam trawl haul and two replicate hauls of the hyperbenthic sled (RP sled). Grab samples were sieved over a 1-mm mesh and fixed in 5% buffered formalin until sorting and identification in the laboratory. Epifauna (fauna on the surface of the seabed) were sampled with the beam trawl (2 m width, 5 min hauls) and hyperfauna (fauna in the water just above the seabed) with the RP sledge (1 m width, 10 min hauls). Trawled distance over the seabed was determined by the navigation data; it varied between 113 and 437 m for the beam trawl and 427 and 851 m for the RP sledge.

Results and discussion

In all, 113 taxa were observed on the video records. Of these, 42 were identified to species, 20 to genus, and 49 to higher taxonomic levels. Of those taxa, 14 were seen in fewer than three of the video sequences and were not included in the DCA.

The DCA plot of the 252 video sequences (Figure 2a) indicated six groups with different taxonomic composition. The arrows in the plot indicate affinities of the environmental variables with the strongest correlations with the ordination axes. The direction of the arrows indicates the main direction of the environmental gradients, and the length of the arrows indicates the strength of the correlation. The cut-off level for variable included in this plot is $r = 0.3$.

Table 2. Comparison of the diversity of taxa in biotope groups between the results from a van Veen grab, video, a beam trawl (BT), and a hyperbenthic sled (RP).

Biotope	Gear	Number of stations	Number of species	Average number of species per sample
Fine-grained mud in shelf basin	Grab	8	117	26.9
	Video	8	45	17.4
	BT	3	51	23.0
	RP	2	70	46.0
	All gear		148	
Sandy mud in areas with iceberg ploughmarks/sponge grounds	Grab	2	120	77.5
	Video	4	78	32.5
	BT	2	81	27.0
	RP	1	49	49.0
	All gear		172	
Sandy sediments in level areas	Grab	3	149	65.0
	Video	8	68	24.3
	BT	1	32	29.5
	RP	2	109	72.0
	All gear		197	
Gravelly sand on gently sloping seabed	Grab	5	257	85.4
	Video	11	89	30.1
	BT	6	110	35.7
	RP	2	108	69.5
	All gear		289	
Sandy gravel with cobble in areas with iceberg ploughmarks	Grab	9	333	90.7
	Video	15	96	32.3
	BT	6	195	51.2
	RP	2	103	64.5
	All gear		372	
Sandy gravel with cobble and boulder on morainic ridges	Grab	0	–	–
	Video	4	85	26.5
	BT	1	48	–
	RP	1	73	–
	All gear		177	

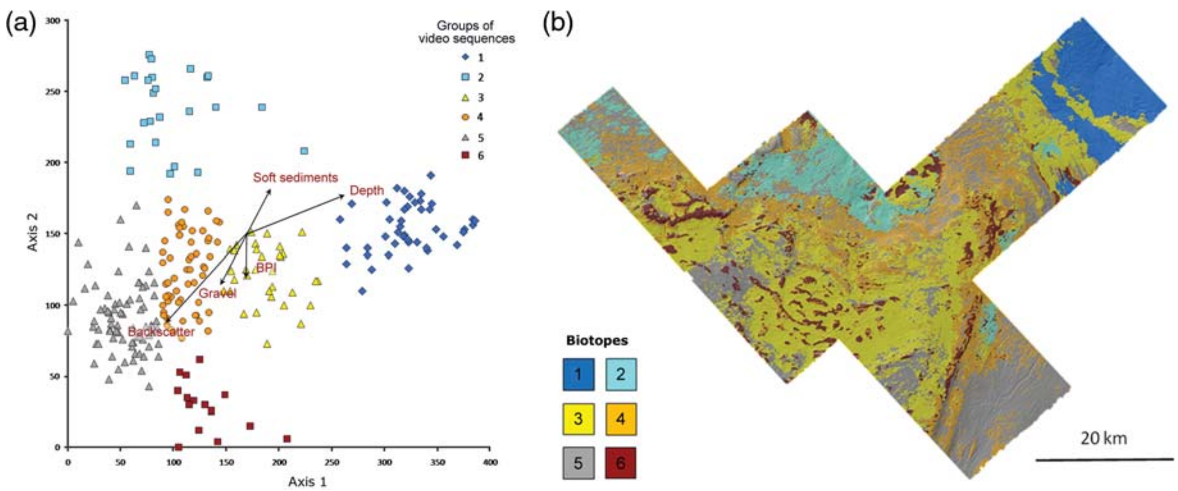

Figure 2. (a) DCA plot of video sequences based on species composition in 252 video sequences from 48 video transects along the seabed. The arrows indicate the relationship between the environmental variables and the ordination axes. The length of the arrows represents the strength of the correlations. BPI is the bathymetric position index (one of the terrain indices). (b) Provisional biotope map for the eastern part of Tromsøflaket. A brief description of the six biotopes is given in text.

Table 3. Summary of biotopes on Tromsøflaket.

Biotope	Short description	Typical species
1	Fine-grained mud in shelf basin	*Pelosina arborescens* (Foraminifera), *Asbestopluma pennatula* (Porifera)
2	Sandy mud in areas with iceberg ploughmarks/sponge grounds	*Geodia* spp., *Aplysilla sulfurea* (Porifera)
3	Sandy sediments in level areas	*Ceramaster granularis* (Asteroidea), *Stichopus tremulus* (Holothuroidea)
4	Gravelly sand on gently sloping seabed	*Stylocordyla borealis* (Porifera), *Aphrodita* sp. (Polychaeta)
5	Sandy gravel with cobble in areas with iceberg ploughmarks	*Phakellia* sp., *Axinella* sp. (Porifera)
6	Sandy gravel with cobble and boulder on morainic ridges	*Polymastia* sp. (Porifera), *Poraniomorpha* sp. (Asteroidea)

The most important environmental factors correlated with the groupings were depth (measured with the video platform and with MBES), acoustic backscatter, and percentage cover of soft sediments (mud and sand combined; Table 1). The last was inversely correlated with the sum coverage of stones (gravel). The three strongest correlated environmental variables derived from the MBES data were mean bathymetry, backscatter, and broad-scale BPI.

Using the classified video data as a training dataset, we identified the multivariate signatures on a spatial basis within GIS, then used this to develop a predicted classification of the entire area (Figure 2b). On that map of predicted biotopes, the groups of video sequences (Figure 2a) are located within areas with similar colours to those used in the DCA plot.

The biotopes identified on Tromsøflaket (Table 3) can be described by combining substratum, terrain, and typical taxa. The two typical taxa provided for each biotope were identified based on the combination of frequency of occurrence and abundance. Biotope #2 is the only one where the biota plays a significant structuring role. In that biotope, sponges were so dense that they could be termed sponge grounds, resembling the Eunis habitat "deep-sea sponge aggregations".

Further refinement of the biotope classification and methods will be ongoing under MAREANO, as other areas are also analysed and additional biotopes encountered. Combining bathymetric and backscatter-derived variables has shown promise in other studies related to habitat classification (e.g. Dartnell and Gardner, 2004; Whitmire *et al*., 2004, 2007).

Our results indicate that substratum type, broad-scale topographic features, and depth (indicating general hydrographical gradients) are of relevance to the distribution and composition of megafauna. The broad-scale topographic features do not represent environmental variables in themselves, but may modify the environment by influencing the currents and can often be related to the distribution patterns of different substrata.

To compare species diversity in the video results with the results from the different bottom sampling gear, the video-transects were classified as the most frequent biotope. The number of stations representing each biotope varied for the different sampling gears. Biotope 6 (morainic ridges) could not be sampled with a grab, and just one sample with the beam trawl and hyperbenthic sled was successful. In general, habitat complexity increased with an increasing amount of stones in the sediment. The total number of species observed and sampled within the biotopes increased with habitat complexity (Table 2). Morainic ridges are probably more architectural complex than areas with smaller gravel and finer particles. However, in this study, the number of species observed on video was only at an average level. The two samples collected with the hyperbenthic sled and beam trawl contained a large number of species, indicating that video may not record all species in this complex biotope, either because the species occupy microhabitats more hidden on the video record or because the video platform on average is higher from the bottom over rough topography with large boulders. Biotope 2 (sandy mud in areas with iceberg ploughmarks and fields of large sponges) had a large number of species in both grab samples and video records. This can be explained by the high densities of sponges in this biotope. Sponges are known to increase biodiversity by providing microhabitats for mobile species.

The predicted maps present the distribution of biotopes characterized by a combination of bottom substratum type, landscape elements, and biological communities. Such maps are useful for managing marine areas, especially in deeper water where direct methods are not a realistic option. However, it still remains to be demonstrated how well this method will work in other areas. One can expect that the same predictors found in this study will provide useful information in similar landscapes (banks on continental shelf) in the same region. Most likely, other landscapes and regions have different environmental settings with different factors controlling the distribution of communities. The continuing mapping under the MAREANO programme will provide material for testing how well this procedure for prediction will work in different landscapes, regions, and depths (water masses).

The general procedure for characterization and prediction of biotopes can be summarized into five steps:

(i) multivariate analysis of species data from bottom video surveys to find groups of locations that are similar with respect to composition of species;

(ii) identification of environmental variables (e.g. depth, surface sediment composition, topography) that best explain the composition of species identified on video records;

(iii) comparison of the explanatory ability of variables derived from the MBES dataset and parameters collected by visual inspection;

(iv) "supervised" GIS analysis for classification with full spatial coverage;

(v) presentation of the general biodiversity of biotopes based on species composition in samples collected with different bottom sampling gears.

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