NGU Report 2012.030

Evaluation of alternative bathymetry data sources for MAREANO: A comparison of Olex bathymetry and multibeam data for substrate and biotope mapping

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REPORT

Report no.: 2012.030	ISSN 0800-3416	Grading: Open	

Title: Evaluation of alternative bathymetry data sources for MAREANO: A comparison of Olex bathymetry and multibeam data for substrate and biotope mapping			
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County:		Commune:	
Map-sheet name (M=1:250.000)		Map-sheet no. and -name (M=1:50.000)	
Deposit name and grid-reference:		Number of pages: 54 Map enclosures: 0	Price (NOK): 175,-
Fieldwork carried out:	Date of report: 31.05.2012	Project no.: 311702	Person responsible: Reidulv Bøe

Summary:

The MAREANO (Marine AREA database for NOrwegian waters) seabed mapping programme generates a wide range of products, including sediment and benthic biotope maps. Production of these maps relies heavily on full-coverage multibeam data (bathymetry and backscatter) which have revealed the seabed in unprecedented detail, and which form the basis for geological interpretations and the identification of seabed terrain of ecological relevance. The acquisition of multibeam data represents a significant proportion of the total annual MAREANO budget, and efforts to reduce this cost will help to maximize the cost-effectiveness of MAREANO in the future.

This report summarises a first study evaluating the potential use of one alternative full-coverage data source for MAREANO: regional bathymetry compiled from singlebeam echosounder data by Olex AS. The Olex data were used to simulate a potential future approach where only limited multibeam data are acquired, to complement existing bathymetry data. The composite Olex and multibeam dataset was used as basis for interpreting sediment distribution and for modelling the distribution of benthic biotopes.

This study shows that sediment maps at a regional scale (1:250 000) and biotope maps of acceptable quality can be produced using alternative bathymetry data sources combined with limited coverage multibeam data. The sediment maps show the same general trends in distribution, but are coarser and provide more generalised interpretations than the 1:100 000 maps currently produced by MAREANO. The biotope map based on the combined Olex and multibeam data also shows the same trends in biotope distribution as its multibeam-based counterpart, and the map seems adequate for regional-scale mapping. Despite these encouraging results we note several limitations of the combined Olex and multibeam and similar datasets, by comparison with full coverage multibeam. Two of these limitations are particularly important: (1) we found Olex data inadequate for detection of smaller topographic features, e.g. coral reefs and pockmarks; (2) the lack of backscatter information outside the multibeam transects will limit optimal planning of sampling stations, and the interpretation of surficial sediments in these areas, which may adversely affect the biotope maps that rely on this information. We conclude that a future approach with two levels of mapping scale (e.g. 1:250 000 and 1:100 000) can be envisaged for the MAREANO programme, with the option of producing even more detailed maps in smaller areas of special interest, if multibeam data are available.

Keywords: Marine geology	MAREANO	Olex
Multibeam bathymetry	Modelling	Maxent
Sediment mapping	Terrain variables	Biotope distribution

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NORWEGIAN SUMMARY/NORSK SAMMENDRAG

MAREANO (Marin AREAldatabase for NOrske kyst- og havområder, www.mareano.no) har siden 2006 arbeidet med å kartlegge dybde, bunnforhold, biologisk mangfold, naturtyper og forurensning i sedimentene i norske kyst- og havområder. Kostnadene knyttet til innsamling av nye dybde- og bunnreflektivitetsdata (backscatter) med multistråleekkolodd utgjør en stor del av MAREANOs budsjett (rundt 40 % i 2011), og hvis disse kan reduseres vil det kunne øke MAREANOs kost-nytte-verdi i fremtiden. Det finnes kun begrensede mengder tilgjengelige, eksterne multistråledata fra norske havområder, men mulighetene for å gjøre bruk av andre dybdedata (for eksempel enkeltstråledata og 3D-seismikk) til MAREANOs kartleggingsformål har vært diskutert.

Denne rapporten oppsummerer resultatene fra en evaluering av regionale dybdedata fra én mulig alternativ kilde: Olex AS, som produserer navigasjonssystemer og samler inn ekkoloddata fra sine brukere. Dataene sammenstilles i en database som brukerne får tilgang til, og i havområder med mye trafikk (for eksempel der fiskeriaktiviteten er høy) vil dekningen og kvaliteten på Olex-batymetrien være best. For å teste hvorvidt Olex-data vil kunne brukes til produksjon av kart over sedimentfordeling og biotoper på havbunnen, ble det gjennomført en simulert kartlegging av et område der MAREANO tidligere har samlet inn multistråledata (Oljedirektoratets delområder Nordland VII og Troms II, utenfor Lofoten, Vesterålen og Troms). Her ble Olex-batymetri supplert med multistråledata (batymetri og backscatter) i fire 10 km brede ”transekter” for å etterligne en situasjon der regionale dybdedata forsterkes med ny kartlegging av høy kvalitet i representative områder. Dette sammensatte datasettet dannet så utgangspunktet for tolkning av sedimenttyper og modellering av biotoper i henhold til MAREANOs metoder og standarder.

En sammenligning av resultatene fra tolkning og modellering basert på det sammensatte Olex/multistråle-datasettet og på MAREANOs heldekkende multistråledata viser at Olex-data under visse forutsetninger kan brukes til å produsere sedimentkart i regional målestokk (1:250 000) og biotopkart av akseptabel kvalitet. De nytolkede sedimentkartene viser de samme generelle trekk i utbredelse av sedimenttyper som dem man finner i MAREANOs publiserte kart i målestokk 1:100 000, men tolkningene basert på Olex-data er grovere og mer generaliserte. Biotopkartene modellert ut fra Olex/multistråle-datasettet er relativt like dem som modelleres med rene multistråledata, noe som skulle tyde på at Olex-data vil kunne være nyttige til dette formålet. Imidlertid er det viktige begrensninger knyttet til bruk av Olex-data, og vi vil spesielt påpeke at (1) Olex-data er ikke detaljerte nok til å påvise små topografiske elementer som for eksempel korallrev og pockmarks, og at (2) uten tilgang til flatedekkende backscatterdata (som ikke inngår i Olex-datasettet) vil optimal toktplanlegging bli vanskeligere, noe som igjen vil kunne få konsekvenser for sedimenttolkning og dermed også for kvaliteten på de modellerte biotopkartene.

1. INTRODUCTION

The MAREANO programme (www.mareano.no) has conducted mapping of the seabed off North Norway since 2005. Products generated by MAREANO include maps of bathymetry and topography, landscapes and landforms, sediment grain size and genesis, sedimentary environment, biomass, benthic biotopes and environmental status/pollution.

Production of sediment maps and benthic biotope maps relies heavily on full-coverage multibeam data (bathymetry and backscatter) which have revealed the seabed in unprecedented detail, and which form the basis for geological interpretations and the identification of seabed terrain of ecological relevance. Other data including video observations and bottom samples are also crucial inputs to the sediment and biotope maps. However, whilst MAREANO boasts an impressive number of video and sampling stations offering good representative coverage of the seabed, these data only cover a small percentage of the total mapped area. Full coverage multibeam data allows MAREANO scientists to bridge the gap between disperse video and sampling observations and a full coverage map, using expert interpretation and modelling.

During the first 6 years of MAREANO in 2005-2011, full coverage multibeam data were available for all mapped areas. Data were acquired across 76 000 km^2 of previously unmapped seabed, and MAREANO has also benefited from a significant volume of existing multibeam data made available to the programme by the Norwegian Mapping Authority and the Norwegian Defence Research Establishment (FFI), so that the total multibeam coverage now exceeds 90 000 km^2 (Figure 1). As MAREANO moves to further, previously unmapped areas, such a large volume of pre-MAREANO multibeam data does not exist. Whilst the value of multibeam data is well documented, obtaining data over large areas is expensive, and the acquisition of multibeam data for MAREANO represents a significant proportion of the total annual budget (about 40% in 2011). Efforts to reduce this cost will help to maximize the cost-effectiveness of MAREANO in the future.

Although the volume of existing multibeam data in the rest of Norway's offshore area is limited, there are other sources of data present that may help to provide full-coverage baseline data for future MAREANO mapping efforts. Data from a few multibeam surveys are available from commercial surveys, mainly for the oil industry, and these will provide a significant cost saving if they can be made available to MAREANO. Alternative sources of bathymetry data include compiled, single beam echosounder datasets such as Olex[1] bathymetry, or 3D seismic data, which are available for much of the Norwegian offshore area. Whilst lacking the backscatter information present in multibeam data, which is beneficial particularly for sediment interpretation, these alternative bathymetric datasets could reveal much of the seabed terrain and landscape if they were available with sufficient coverage and data resolution. Use of additional datasets would permit MAREANO to prioritize new multibeam data acquisition and target mapping to areas where the new data would best complement coverage and add new information to existing data.

[1] Olex bathymetry refers to the bathymetry dataset compiled by Olex AS and contributed by seafarers using the Olex navigation software (see Section 3.2).

1.1 Evaluation of Olex data for MAREANO

This report offers a summary of a first study evaluating the potential use of alternative full-coverage data sources for MAREANO. The report focuses on Olex bathymetry data and examines to what extent these data could facilitate the production of sediment and biotope maps. The study has been carried out in an area already mapped by MAREANO, comprising Norwegian Petroleum Directorate's sub-areas Nordland VII and Troms II off Lofoten-Vesterålen-Troms, Northern Norway. Olex data were combined with limited sections of multibeam data, simulating a potential future approach to MAREANO mapping where only limited multibeam data are acquired. This combined dataset was then used as basis for interpreting sediment distribution and modelling distribution of biotopes. This approach allows map products using contributions from Olex data to be compared with those based on full coverage multibeam data.

Although MAREANO is looking for ways to use alternative bathymetry data to facilitate cost savings in future mapping, it is envisaged that the use of alternative bathymetry data sources would only complement multibeam data acquisition in new study areas, not replace it entirely. Multibeam data, including bathymetry and co-registered backscatter, reveal the seabed in greater detail than the alternative bathymetry data sources, and the backscatter information is of tremendous value for the interpretation of surficial sediments. Having some multibeam in a study area helps expert interpretation of similar areas using other data of poorer quality.

The ratio of multibeam data to alternative bathymetry data that would be necessary for MAREANO product generation will vary from area to area depending on the complexity of the seabed and the quality of available data. This study simulates a ratio of multibeam to Olex data of approximately 1:7.

2. STUDY AREA

Figure 1 shows the total area mapped in the Barents Sea and Norwegian Sea by MAREANO during 2005-2011. The >90 000 km^2 of surveys span 5 degrees of latitude and more than 2500 m of water depth, comprising areas of continental shelf, continental slope and deep-sea plain. The width of the continental shelf differs greatly within the study area, narrowing to just 20-30 km off the Vesterålen archipelago and widening into the Barents Sea shelf sea to the northeast. Water depths on the continental shelf are 50-500 m, and the shelf break is found at around 300-500 m depth. Coinciding with the narrowest part of the shelf, the maximum gradient of the continental slope is at 69-70°N. Here, the slope reaches 5-8°, whereas the average continental slope gradient in the MAREANO area mapped to date is less than 3°. The base of the slope lies at ~2500 m water depth[2].

In addition to deep-sea plain and continental slope, several other marine landscape types have been identified in the MAREANO area and classified in accordance with the Norwegian Nature Types classification system (Halvorsen et al., 2009; www.mareano.no). Between 68.5°N and 70.5°N the variation in landscape types is particularly great, with continental shelf plains intersected by marine valleys and with deep canyons cutting into the continental slope.

[2] Slopes values in degrees computed from a 250 m regional grid using ArcGIS Spatial Analyst.

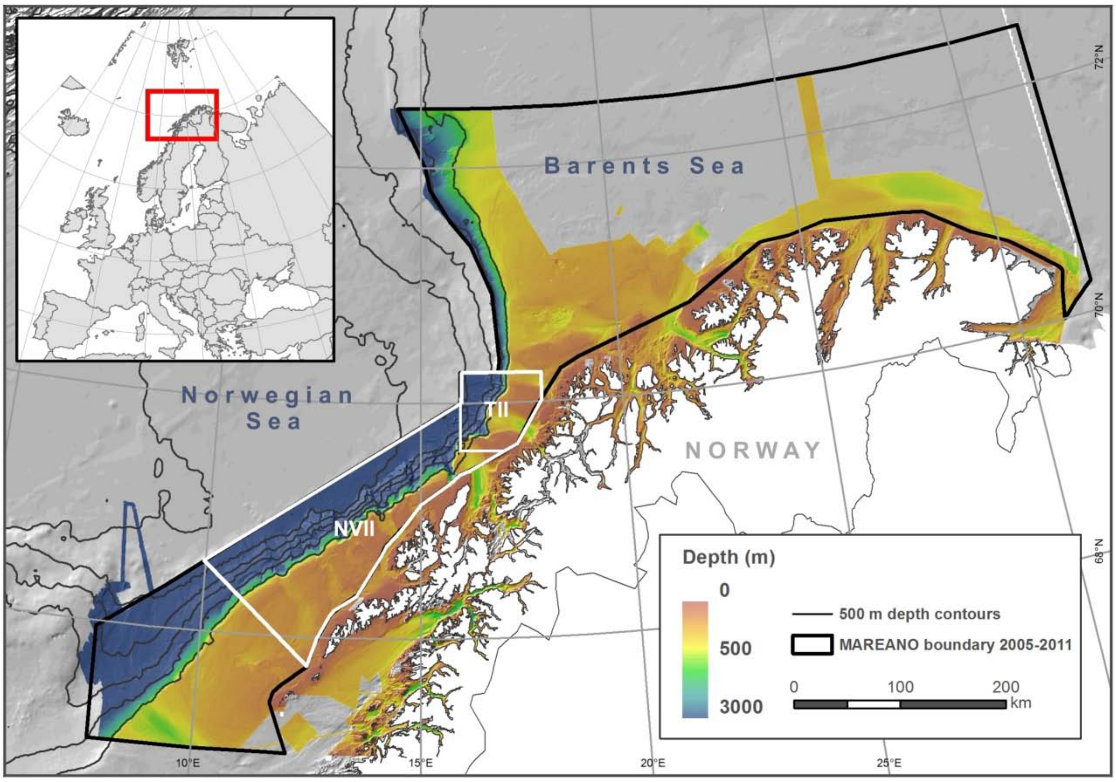

Figure 1. Status of multibeam mapping in the Barents and Norwegian Seas under the MAREANO programme at 2011, including multibeam data from surveys pre-dating the programme. Note that colour range of the bathymetry has been adjusted to emphasize features on the continental shelf. White outline indicates the focus area for this report. NVII – Nordland VII, TII – Troms II.

2.1 Oceanography

The oceanography of the MAREANO area is influenced by four major water masses: Norwegian Coastal Water, Norwegian Atlantic Water, Arctic Intermediate Water and Norwegian Sea Deep Water (Hansen and Østerhus, 2000). The relatively low salinity Coastal Water displays great seasonal fluctuations in temperature, whereas the Atlantic Water found further offshore has a higher salinity and a higher, stable temperature. The Arctic Intermediate Water underlying Atlantic Water has lower salinity and temperature, and the thermocline between these two occurs at 600-900 m water depth. Below this, the Norwegian Sea Deep Water occurs with temperatures from -0.5 to -1.1 °C.

The Norwegian Atlantic Current flows northwards parallel to the continental margin and branches into the Barents Sea, carrying Atlantic water. On the Norwegian continental shelf and the upper continental slope, circulation is affected by the bottom topography, with the highest current velocities being observed at the shelf edge and along bank slopes (Ersdal, 2001; Gjevik, 2000). Below the thermocline, current velocities are generally low, with the exception of density-driven downslope currents that can cause local erosion in steeper areas.

Observations of the benthic fauna suggest that oceanography has a significant influence on the species and communities found at different depths within the MAREANO area. The most profound fauna differences are found between the cold water mass of Arctic intermediate water and the warmer Atlantic water (Buhl-Mortensen et al., 2009a).

2.2 Geology

The seabed off Northwest Norway comprises alternating shallow banks (50-200 m deep) and deeper troughs (150-500 m deep) formed during the last glaciations (Bøe et al., 2009). Massive diamictic sediments are found on the continental shelf and in the troughs and outer fjords of the area. This indicates that ice streams advanced through fjords, onto the continental shelf and to the shelf edge during the last (late Weichselian) glaciation, which reached a maximum slightly before 18 000 ^{14}C BP. Deglaciation along this margin took place from ~15 000 ^{14}C BP on the outer shelf, according to the dated onset of glaciomarine and then open-marine sedimentation, and at 13 600 ^{14}C BP, the ice margin was located along the present coastal area of Vesterålen (Knies et al., 2007).

The sedimentary rock succession and bedrock of the continental shelf are covered by Quaternary sediments deposited during several glacial cycles (Bøe et al., 2009; Ottesen et al., 2005; 2002). The upper glacigenic sequence is dominated by muddy diamicton or silty sandy clay with scattered gravel. The diamicton is commonly overconsolidated, with only a very thin cover (<1 m) of sand/gravel in the bank areas, and 1-15 m of clay/silt/sand in the deepest troughs (Hald et al., 1990; Sættem, 1991; Vorren et al., 1989). This sediment cover was mainly formed during the deglaciation after 15 000 ^{14}C BP, and only small volumes of sediment have been deposited after the ice retreated from north Norway at c. 10 000 ^{14}C BP (Hald et al., 1990).

Many different sedimentary environments are found in the MAREANO area, resulting in diverse substrates (www.mareano.no - Maps). Generally, coarser sediment (sand to boulders) is found on the continental shelf and upper slope, while the lower slope and deep-sea plain are characterized by finer sediment (muddy sand to mud). However, there are numerous exceptions to this pattern, for instance areas with muddy basins on the shelf and occurrences of blocks and outcrops of consolidated sediment on the slope and in the deep sea.

2.3 Area selected for analysis and evaluation of Olex data

In order to best determine the usefulness of non-multibeam bathymetry data in marine biotope modelling, we have selected a study area where both MAREANO and Olex data of reasonable quality are available (outlined in Figure 1). The Nordland VII/Troms II area (hereafter referred to as NVII/TII) is located at the continental margin between 68°N and 70°N, and displays a wide range of landscape and bottom types within a depth range of 2500 m. Detailed observations of biology and sediment distribution are available from 222 video lines recorded through the MAREANO programme, and maps of sediment grain size and sedimentary environments in the area have previously been produced based on MAREANO data (www.mareano.no - Maps).

The Olex dataset comprises single-beam echo-sounder data recorded by numerous working marine vessels as they go about their daily operations. As the continental shelf of NVII/TII hosts important fishing grounds, marine traffic is high in the area where the fisheries occur. Below the upper parts of the continental slope, however, little data is available as few working vessels operate. Figure 2 shows the original Olex dataset this study is based on.

Figure 2. Olex data coverage in Norwegian waters.

3. DATA SOURCES

3.1 Multibeam data

The multibeam data in the MAREANO dataset for NVII/TII originates from multiple surveys carried out over a number of years using various multibeam echosounders. A large volume of existing multibeam data from the continental shelf was made available to MAREANO by the Norwegian Mapping Authority and the Norwegian Defence Research Establishment. These data were complemented by dedicated MAREANO surveys in 2007 and 2008 using the Kongsberg Maritime multibeam echo-sounders EM300 and EM710. The bathymetry data are available in horizontal resolutions as fine as 5 m on the shelf and 25 m in deeper areas. For the purpose of this study we use bathymetry gridded to 50 m resolution which has been shown to be effective for biotope mapping in offshore regions (Buhl-Mortensen et al., 2009b; Dolan et al., 2009) and which offers a realistic sized dataset to work with in terms of computation resources. Figure 3A shows the multibeam bathymetry data used for modelling in NVII/TII.

The multibeam surveys also provide high resolution acoustic backscatter data (seabed reflectivity). Backscattering at the seabed is a complex process that depends on many factors (Lurton, 2002), however major influences on the measured backscatter strength include the grain size of the seabed sediments and the degree of compactness of the seabed. In simple terms backscatter data give a rough indication of the distribution of hard and soft seabed. Using more detailed analysis, MAREANO backscatter data form the basis for the development of sediment distribution maps where they are interpreted together with detailed bathymetry and sediment observations from video transects and samples. Like the bathymetry data, backscatter for most of the study area on the shelf is available at 5 m or finer resolution. All the data have been 'levelled' as far as possible to help overcome unavoidable differences in the backscatter values recorded for similar sediments from different multibeam surveys, employing different vessels, multibeam systems, acquisition settings and weather/wave conditions. A full-resolution example of backscatter data from the NVII/TII area is shown in Figure 4D, although for this study a 50 m resolution grid of the backscatter data have been used (i.e. the same as the bathymetric data resolution).

3.2 Olex bathymetry

Olex AS is a commercial company based in Trondheim which specialises in the production of ship navigation systems. What makes the Olex product unique is that the navigation systems include a function for storing and sharing echosounder data. In return for gaining access to this pool of data, Olex users must agree to contribute data they acquire using on-board echosounders. This approach allows bathymetric data coverage to be built up line-by-line wherever the vessels operate, resulting in "collaborative" maps of accumulated bathymetry, where the quality of the map in terms of coverage and resolution increases with the number of Olex-using vessels navigating an area. More recently Olex AS has introduced a function to retrieve bottom hardness information from single beam data, giving information similar to multibeam backscatter. To date, however, this function is only available on a few boats that have purchased this extra functionality, and the coverage of the hardness data is therefore very limited. Hardness data coverage is almost non-existent within the NVII/TII study area and therefore cannot be used in this study.

Figure 3B shows the available Olex bathymetry in NVII/TII in 2010. The bathymetry data were gridded from the original Olex point dataset to a horizontal resolution of 50 m by the Norwegian Mapping Establishment. Examination of the dataset shows that coverage is fairly good down to about 800 m depth, and the morphology of the seabed can be recognized, at least at a broad scale. Below 800 m, there are only a few single ship-tracks which give just a rough indication of depth. On the continental shelf, where depths do not exceed 500 m, holes of up to 0.5 km^2 in the dataset are frequent in certain areas. Considering that the Olex system utilizes a method of 500 m swath extrapolation when creating datasets from single-beam data, actual data coverage may be even less extensive.

Close-ups of the Olex bathymetry data (Figure 4A) reveal numerous artefacts, mainly linear and following the ship paths. The artefacts are a consequence of using uncalibrated vessels of opportunity to collect the data and are often related to the fact that in building up data coverage Olex always preserves the shoalest registered depth. Despite the artefacts in the

Olex data a good number of topographic features are recognizable. Broad scale features such as banks and troughs are easy to see and the Olex data also reveal some finer structures such as moraine ridges. When compared to multibeam data of the same grid size, however, it is evident that the multibeam bathymetry shows more detail and has fewer artefacts.

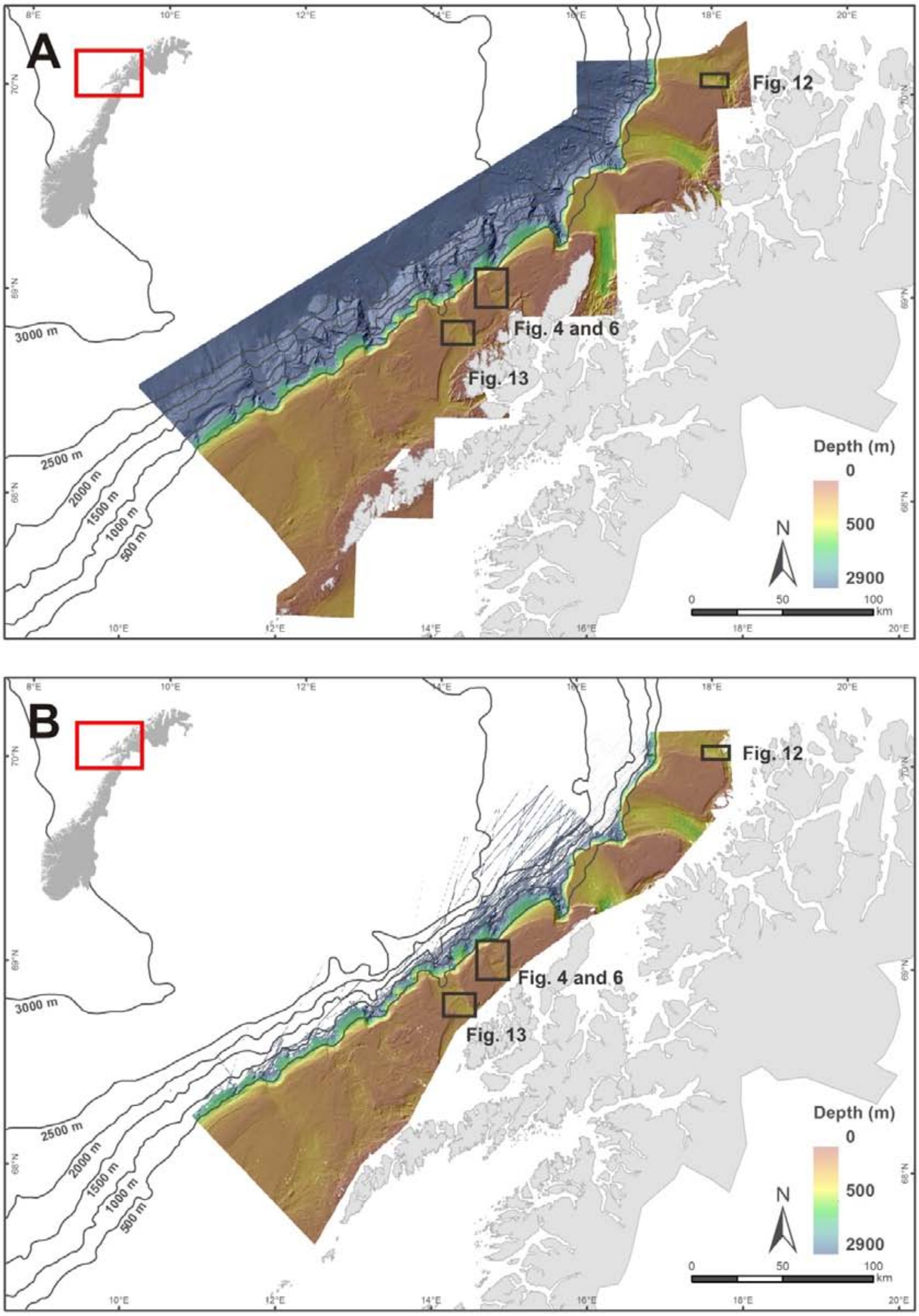

Figure 3. Bathymetry data from the study area, shown as colour shaded relief. Note that the colour range of the bathymetry has been adjusted to emphasize features on the continental shelf. A: MAREANO multibeam data. B: Olex data.

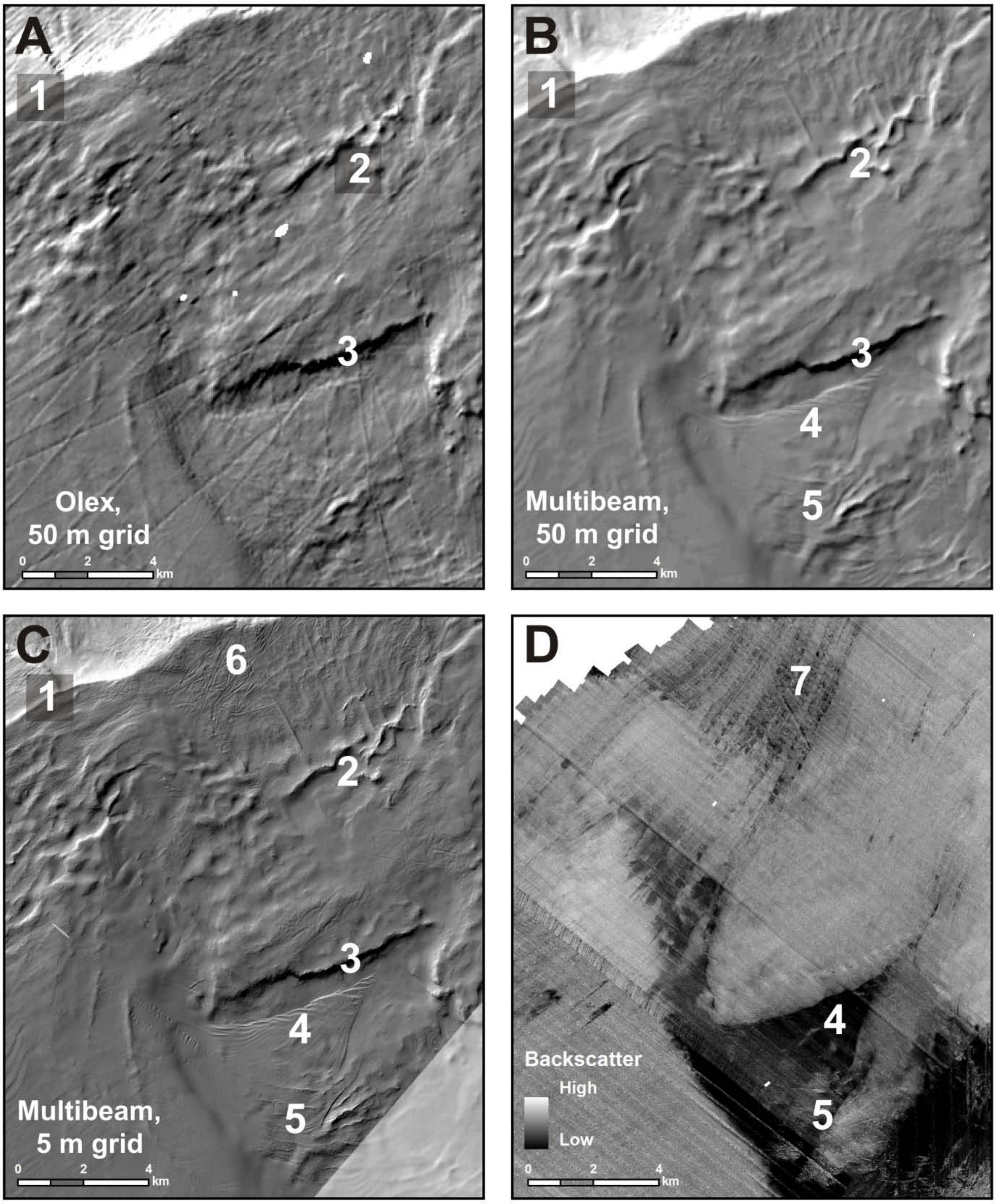

Figure 4. Detailed view of the MAREANO and Olex datasets showing seabed features recognisable in each dataset. A: Shaded relief image of Olex data, 50 m resolution. B: Shaded relief image of MAREANO multibeam data, 50 m resolution. C: Shaded relief image of MAREANO multibeam data, 5 m resolution. D: Multibeam backscatter, 5 m resolution. 1 – Shelf edge, 2 – Larger moraines, 3 – Escarpment, 4 – Sandwave field, 5 – Smaller moraines, 6 – Iceberg ploughmarks (5 m bathymetry only), 7 – Current lineations (backscatter only).

3.3 Video and sampling stations

Figure 5 shows the location of video stations acquired by MAREANO in NVII/TII. Station planning was mainly based on multibeam bathymetry and backscatter data and was designed to ensure good geographical coverage, to cover regions that are physically different in terms of their morphology and seabed sediments, and also to allow documentation of special features within the study area. In order to ground truth backscatter data (i.e. so that the acoustic response of the seabed can be matched with the surficial sediment type) and therefore facilitate interpretation of the sediment maps, video stations are often placed to capture the dominant sediments within the major backscatter classes from the various multibeam surveys across the area to be covered by the cruise.

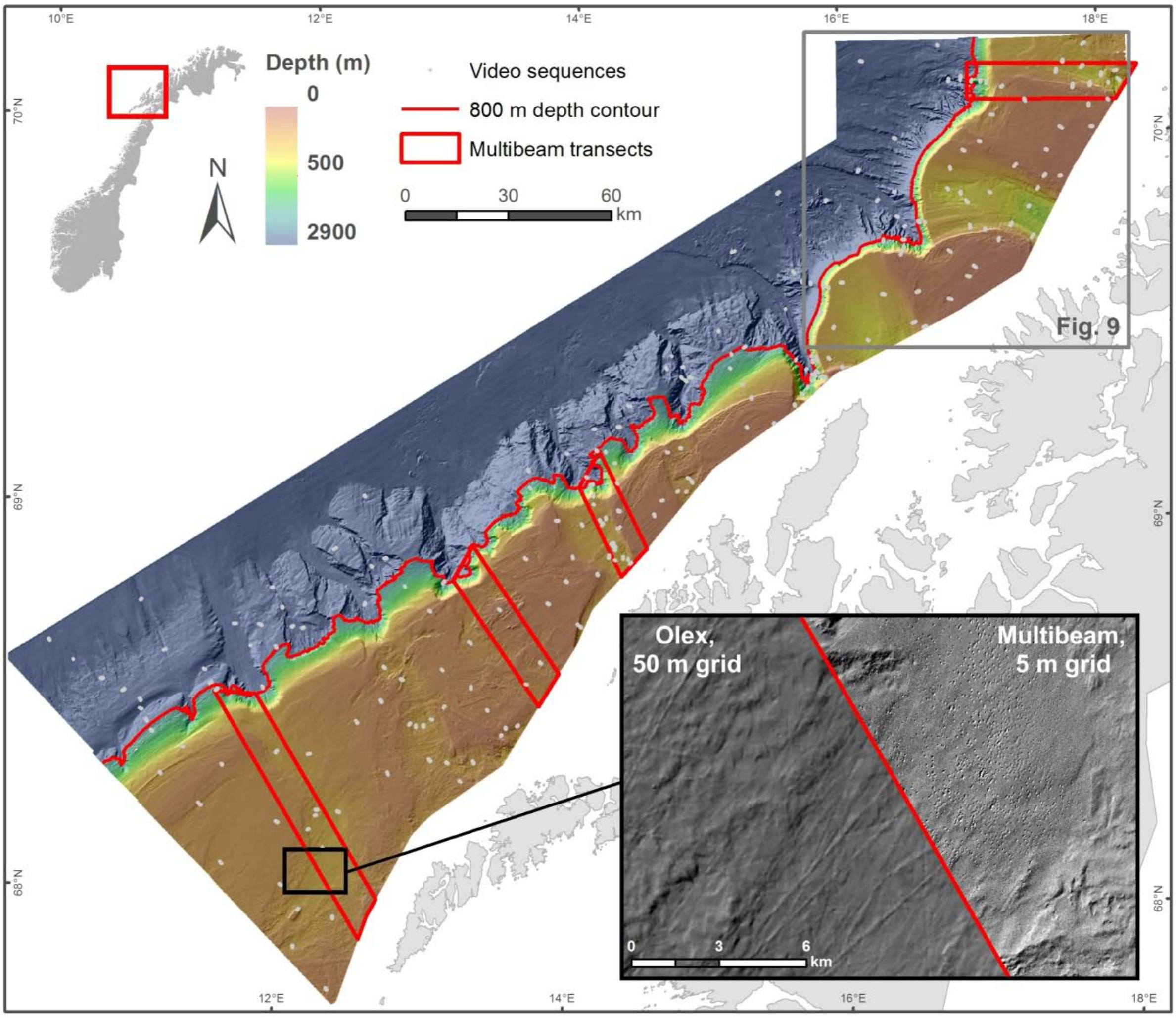

Figure 5. Colour shaded relief image of the composite dataset of multibeam and Olex bathymetry data (Olex-MB), showing the position of video lines. Note that colour range of the bathymetry has been adjusted to emphasize features on the continental shelf. Enlarged area shows difference between Olex 50 m resolution and multibeam 5 m resolution in shaded relief. Dashed grey outline indicates sub-area chosen for detailed study during model testing (Figure 9).

4. METHODS

This study simulates a situation where mapping is to be done in an area where multibeam coverage is less than 100%, but where some multibeam data are available. Olex data are available across the entire study area (down to 800 m depth). This approach allows us to create a study dataset that will be representative of potential future MAREANO datasets, utilizing a mix of Olex bathymetry and multibeam (bathymetry and backscatter) data. In order to assess the performance of Olex bathymetry data in biotope mapping we must first create a composite dataset of Olex and multibeam data, and use this to interpret new maps of the sediment distribution, based on limited backscatter information (multibeam areas only). This section details all the steps involved in data preparation and analysis, including preparation of baseline data, sediment interpretation, terrain variable calculation, video data analysis and classification and biotope modelling.

4.1 Preparation of the composite Olex and multibeam transect dataset (Olex-MB)

The first step in this simulation study was to produce a composite dataset comprising a mix of Olex bathymetry and limited multibeam data within transects. To avoid confusion with the original Olex or multibeam data, this composite dataset will be referred to as the Olex-MB data, and it is illustrated in Figure 5. The Olex-MB data comprise Olex data (bathymetry only) down to 800 m, together with four 10 km wide transects containing full high resolution multibeam data (bathymetry and backscatter). The multibeam data for the transects were cut from the MAREANO multibeam coverage, in order to simulate the scenario where a transect-based approach to multibeam data acquisition is adopted. The transects were positioned such that they captured both banks and troughs occurring along the continental margin, these being the dominant landscape features in the study area, identifiable from regional or Olex bathymetry. Below 800 m, where there is little Olex coverage, multibeam bathymetry data have been used in the Olex-MB dataset. The landward edge of the Olex-MB dataset was trimmed, in accordance with the inner MAREANO boundary, at 4 nautical miles offshore. Any holes in the Olex bathymetry were filled using a GIS method of extrapolation, in order to avoid data loss during the calculation of terrain variables as this would lead to gaps in the biotope map. The ratio of multibeam to Olex bathymetry above 800 m is about 1:7, with the total extent of multibeam data in transects adding up to 2000 km^2.

Backscatter and 5 m resolution bathymetry data in transects were used for sediment interpretation purposes (section 4.2). For biotope modelling, however, all bathymetry was gridded to 50 m resolution, and backscatter from transects was not included as modelling requires full-coverage datasets. In order to obtain directly comparable results from modelling with the Olex-MB versus the full MAREANO dataset, all sediment interpretation and modelling in the main study was carried out using the data extent shown in Figure 5. Biotope modelling results from the Olex-MB dataset were later clipped to include only the area above 800 m depth, where Olex bathymetry data are found.

4.2 Interpretation of surficial sediments

To realistically simulate a situation where high-resolution multibeam bathymetry and backscatter data are not available in most areas, we needed to re-interpret the sediment distribution, without reference to the published sediment maps (www.mareano.no – Maps) which use full multibeam coverage and supporting data.

The sediment maps interpreted in this study are based on the composite Olex-MB dataset (Figure 5), where backscatter and multibeam data are only available in transects and seawards of the 800 m contour. Numerous video lines have been recorded in the area; many of these have however been deliberately placed to aid the classification of backscatter data for sediment mapping. In an attempt to at least partially simulate the situation that video lines were planned without the availability of backscatter data to guide sampling, we randomly omitted some of the video data from consideration when interpreting the sediment maps from the Olex-MB data.

Inside multibeam transects, backscatter data were classified according to sediment observation from video lines. The classified backscatter, together with detailed bathymetry, forms the basis for sediment grain size polygons digitised by hand. Outside the multibeam transects with backscatter data, interpretation relies on bathymetry, video data and expert judgment to estimate the distribution of different sediment types. This may lead to a disparate level of detail (and likely also accuracy) across the map. Sediment grain sizes are classified according to SOSI standards (Bøe et al., 2010). Maps of the sedimentary environment were approximated through reclassification of the grain size polygons.

4.3 Terrain variables

Bathymetry data is much more than depth information. In addition to being used to produce shaded relief images that show the morphology of the seabed, the data can also serve as basis for computation of derived terrain variables which serve as quantitative descriptors of the seabed, many of which are relevant to benthic habitat (Wilson et al., 2007). In the absence of more directly relevant data, these terrain variables can serve as useful proxies to some of the effects influencing the distribution of benthic fauna, and since they are generated from full coverage bathymetry data they offer full coverage environmental predictor variables that can be used further in biotope modelling. By calculating the variables at multiple scales we have a better chance of capturing terrain information at the scales relevant to the benthic fauna. This is achieved by using a moving analysis window of variable size *n* x *n* raster cells rather than just the 3 x 3 cell standard analysis method available in most desktop GIS (for further details see Wilson et al., 2007). The largest analysis window size (49 x 49 cells) used in this study was set mainly due to computation time requirements, and to avoid excessive loss of data at the edges of a dataset during the calculation process which is inherent with multiple scale analysis (e.g. Wilson et al., 2007). Since we have no *a priori* knowledge of which variables will be the most important, i.e. ecologically relevant, in a given area, or at what spatial scales, we calculate a large number of different variables describing each type of property of the seabed terrain (*sensu* Wilson et al., 2007). To reduce the number of variables used in the final model, and prevent overfitting, we determine their relevance through statistical methods (section 4.6.2).

Table 1 shows the terrain variables computed in this study, together with details of the analysis windows used and a summary of the geomorphological and ecological relevance of each type of variable. All calculations were based on bathymetric data at 50 m resolution and were carried out separately on the multibeam and the composite Olex-MB dataset. Calculations were performed using the software Landserf (Wood, 2009, version 2.3) and ESRI ArcGIS with the Spatial Analyst extension (ESRI, 2010, version 10.0).

For the main study area, biotope classes summarised as points representing 200 m-long segments of video lines were available from the biological analysis (section 4.4). To ensure that terrain variables captured bathymetric variations along comparable length scales to the video analysis, the values of each of the variables (Table 1) were averaged (smoothed) using focal statistics in ArcGIS to obtain the mean and standard deviations for a 200 x 200 m area around each raster cell. This averaging process was also performed for all other continuous variables used in biotope modelling (bathymetry, backscatter (multibeam-based model only), and latitude). An example of smoothed bathymetry data is shown in Figure 6.

Table 1. Summary of terrain variables computed from 50 m grid of bathymetry data for the Nordland VII/Troms II study area.

Terrain variable type	**Terrain variable**	**Analysis window size** (*n* x *n* raster cells)	**Notes**	**Geomorphological relevance**	**Ecological relevance**
Slope	Slope	*n* = 3, 9, 21, 49	Computes the slope angle in the direction of steepest slope.	Stability of sediments (grain size). Local acceleration of currents (erosion, movement of sediments, creation of bedforms).	Stability of sediments (ability to live in/on sediments). Local acceleration of currents (food supply, exposure, etc.).
Aspect (orientation)	Eastness	*n* = 3, 9, 21, 49	Computes the orientation of the seabed, i.e. which direction it is facing.	Relation to direction of dominant geomorphic processes.	Exposure to dominant and/or local currents from a particular direction (food supply, larval dispersion etc.).
	Northness	*n* = 3, 9, 21, 49			
Relative position	Bathymetric position index (BPI,	*n* = 3, 9, 21, 49	These indices provide an indication of whether any particular pixel forms part of a positive or negative topographic feature with respect to the surrounding terrain. Plan and profile curvature measure this effect perpendicular and parallel to the slope.	Flow, channelling of sediments/currents, hydrological and glacial processes. Useful in the classification of landforms.	Index of exposure/shelter, e.g. on a peak or in a hollow (food supply, predators etc.).
	Curvature (mean, planar and profile)	*n* = 3, 9, 21, 49			
Terrain variability	Rugosity	*n* = 3	These indices provide a measure of how much the seabed terrain varies, or how rugged it is.	Terrain variability and structures present reflect dominant geomorphic processes.	Index of degree of habitat structure, shelter from exposure/predators (link to life stages). Structural diversity linked to biodiversity.
	Fractal dimensions	*n* = 9, 21, 49			

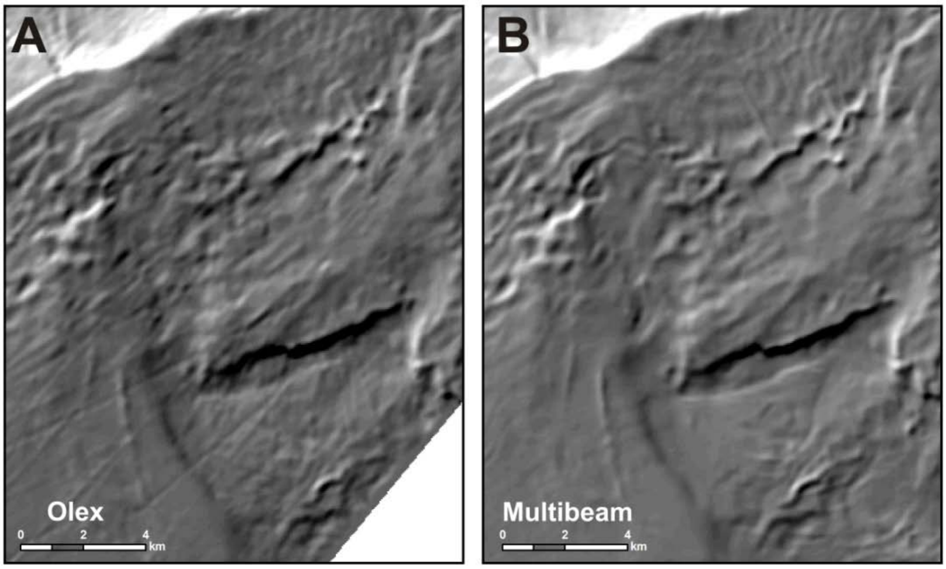

Figure 6. Shaded relief images of the Olex bathymetry dataset (A) and the MAREANO multibeam bathymetry dataset (B) after smoothing values to 200 x 200 m mean. Area identical to Figure 4.

4.4 Biology data

4.4.1 Video recording of the seabed

The biological data used in this study represent seabed observations of megafauna made through video-recording at 222 stations during 5 cruises from 2007-2009. Video was recorded with a High-Definition colour camera (Sony HDC-X300) tilted forward at an angle of 45° on the video platform CAMPOD (Figure 7). During recording of video lines, each ~700 m long, the 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 the CAMPOD, giving a position accurate to ~2% of water depth. Positions of the CAMPOD were logged to file.

4.4.2 Analysis of video records

Quantitative species data for 947 samples consisting of ~200 m long video sequences were obtained using the software Video Navigator (made at IMR; Figure 8). Areas for the 200 m sequences were calculated based on travelled distance and average field width. The distances were calculated from recorded geographical positions, and the field width was estimated from the ratio between measurements of the distance between two laser scales (10 cm apart) on the video screen, and the width of the screen, following the simple equation:

$$\text{Field width} = (\text{Screen width}/\text{Screen laser width})*10$$

All organisms were identified to the lowest possible taxon and counted, or quantified as percentage of seabed coverage following the method described by Mortensen and Buhl-

Mortensen (2005). Lebensspur, burrows, and bottom-trawl marks were also counted. 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.

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 video sequences. These detailed substrate observation data may provide valuable information regarding the preferences of bottom-dwelling organisms on a very local scale, and are not to be confused with the sediment maps (section 5.1) which are regional-scale interpretations of the dominant sediment distribution.

Figure 7. Photo of the CAMPOD video rig onboard R/V "G.O. Sars".

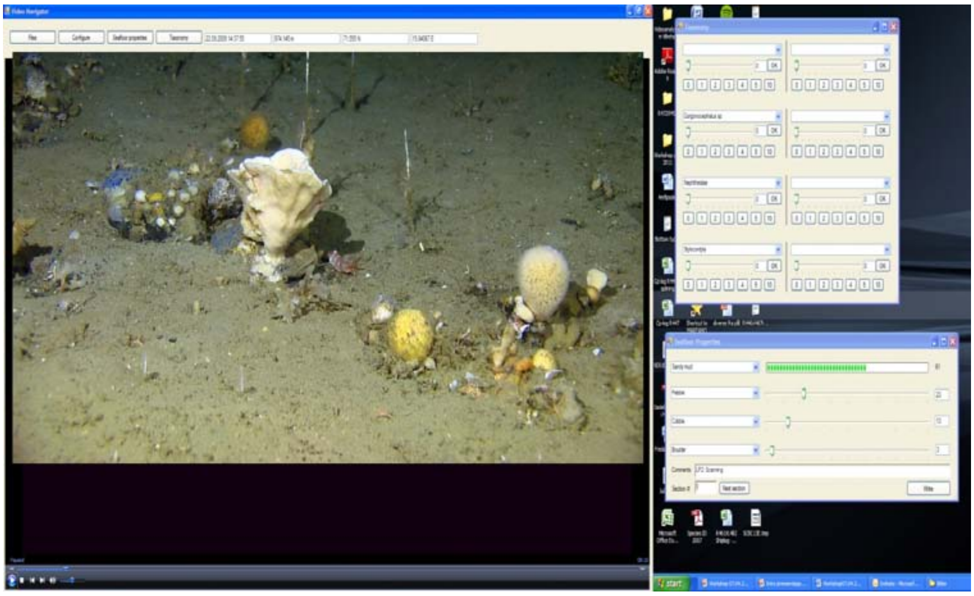

Figure 8. Screen shot from Video Navigator software developed by IMR.

4.5 Classification of video observations

In order to produce an input dataset for use in modelling, each 200 m video sequence must be considered one point, or sample, and assigned a class according to the biological observations made at that point. 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), 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. 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.

Only species found in more than four of the video sequences were included. This criterion left 291 taxa from the 947 video sequences for analysis. For each video sequence included in the analysis, corresponding values were extracted from all available environmental layers, i.e. bathymetry, backscatter (MAREANO multibeam only), latitude, interpreted sediment maps and terrain variables listed in Table 1. The extraction was performed separately on the Olex-MB-derived and the MAREANO multibeam-derived environmental layers. Environmental variables do not influence the result of the DCA classification, but were used to identify the strongest variables that could serve as reliable predictors. This was done by comparing the correlation coefficients for the variables in the ordination matrix, and by performing a forward selection procedure described in section 4.6.2.

Plotting the DCA results in three-dimensional space allowed us to identify clusters of points with similar species composition, and based on this assign a class to each point. The size and diversity of the point dataset necessitated that we conduct a succession of DCA analyses, where the most distinct groups identified in a 3D-plot were classified and removed prior to re-analysing the remaining point data. This hierarchical procedure facilitated classification of samples that would otherwise appear too closely spaced in a 3D plot of the full dataset to permit identification of clusters.

4.6 Modelling biotopes

In order to get from biotope point data observed from video to a full coverage map showing the overall distribution of biotopes, we require multivariate statistical techniques. In simple terms, the points where biotopes have been observed from video are used as training sites where the environmental predictor variables (bathymetry, sediment maps, terrain variables etc.) are examined statistically. The values of the environmental predictor variables at these points are then used by a model to predict the most likely biotope type occurring for all locations across the study area. Several alternative approaches are available for modelling. One relatively simple approach is supervised classification. This approach was used to produce the first biotope map under MAREANO for eastern Tromsøflaket (Buhl-Mortensen et al., 2009b; Dolan et al., 2009). However, following method development during biotope mapping of the Eggakanten area and all of Tromsøflaket it was found that habitat suitability modelling techniques, specifically Maxent (Phillips et al., 2006; Phillips and Dudik, 2008), produced superior results to those from supervised classification. In addition using Maxent provided more information about the relative importance of each predictor variable to the model, thereby helping us determine which variables are most ecologically relevant for each biotope.

Presently, marine biotope mapping in the MAREANO program involves combining observation data (classified video sequences based on quantitative species composition, resembling biotopes) with full-coverage environmental proxy variables derived from bathymetry and backscatter to model the spatial extent of the biological classes (biotopes). We predict the distribution of each biotope class using the presence-only modelling software Maxent (section 4.6.1). The model outputs are combined using ESRI ArcGIS to create a composite map showing which class has the highest probability of being present at a given location.

4.6.1 Maxent modelling

Maximum entropy modelling was introduced by Phillips et al. (2006, 2008) for species distribution modelling and implemented in the software program Maxent (Phillips et al., 2004, version 3.3.3e). Maximum entropy modelling itself is a general technique in statistics that could be used to model anything. However, several authors have shown that it is well suited to the prediction of species or communities/biotopes based on presence-only data, and that it performs well in comparison to other modelling approaches (Elith et al., 2006). In the context of this report, presence-only modelling simply refers to the fact that only observations of a biotope are required as input to the model, together with environmental predictor variables. Observations of where the biotope does not occur (absence data) are not required. This approach is well suited to marine data, particularly modelling of species distribution or habitat suitability from presence only data. In our approach, we have used Maxent as a habitat suitability modelling for biotopes identified from taxonomic composition (community characteristics). Thorough reviews of Maxent and its use in ecology is provided by Phillips et al.(2004) and Elith et al. (2011), and we will not repeat details here.

Preparation of data for Maxent involved extraction of terrain and other predictor variables for each classified biotope point using ArcGIS. Extraction and modelling was performed separately for the multibeam and the Olex-MB composite dataset and associated predictor variables. For the current study Maxent was run with default settings, although background data were obtained from the video transects rather than using the default random background. This is the target group background approach (Phillips et al., 2009), which helps to overcome bias from the video transects. In order to test the model, 25% of the observed biotope points were retained for cross validation.

4.6.2 Choosing predictor variables

Although it would be possible to run the model with all available environmental predictor variables, a selection of the best variables should be made in order to prevent issues of overfitting. Since many of the terrain variables may represent proxies for the same environmental factors that influence the distribution of taxa, care should be taken to avoid using inter-correlated variables. One way of testing variables for this issue is to perform forward selection with Monte-Carlo permutation testing. In this study we performed the testing using the multivariate analysis program Canoco for Windows 4.52 (ter Braak and Šmilauer, 2002, version 4.5). Monte-Carlo permutation testing can be viewed as an extension of multiple regression/analysis of variance models, the extension being that canonical ordination models explain a multivariate response (the community composition) by a set of explanatory variables (our potential predictor variables). One variable was tested at the time, starting with the variable that explained most of the variation in the biological data. By adding a variable to the canonical ordination model, the amount of remaining variance that the remaining variables could explain changed, thus also the ranking of the remaining variables based on remaining explanatory power. The selection of variables was stopped when the added variable did not add any significant explanatory power to the set of selected variables. By using this procedure, only the best of intercorrelated variables would be considered for modelling.

Forward selection will rank numerical variables only. To also get an idea of the relative importance of the categorical variables considered for modelling (i.e. landscape, sediment distribution and sedimentary environment), we made use of the Maxent modelling tool's output for each modelled class, which quantifies the contribution of all environmental variables. Running Maxent for all classes with all variables and aggregating the output provided us with a ranking of all variables, as well as information of which variables were particularly important to the distribution of specific classes. When deciding on the final selection of predictor variables, both the forward selection results and the Maxent results were taken into account.

4.6.3 Testing results

Since no independent test data were available within the study area, testing of the predicted biotope map was limited to cross-validation of the individual models for each biotope class, plus cross checking of the final composite biotope map with the observation points.

Cross validation in Maxent was performed by retaining 25% of the observed biotope points. The Maxent output provides indicators of how well the modelled distribution manages to represent the observed distribution of the class, including Receiver Operating Characteristics (ROC) curves (Phillips et al., 2006; 2004) where the area under the curve (AUC) gives an indication of how the modelled distribution compares with a random distribution, thus providing a measure of model performance. If the model is poor, this can indicate that the modelled class is poorly defined, and it may be necessary to go back and make adjustments to the classification and/or selection of environmental predictor variables.

Once satisfactory Maxent output from all classes have been combined to a single map, the accuracy of the modelling run is tested by finding the percentage of classified sample points that are predicted correctly by the model. The result can be further analysed to find out how well individual classes are predicted, or if incorrectly classified points are off by a distance smaller than the raster resolution. If the test reveals an unacceptably low model performance, variables or classification can be modified and Maxent run again until the result is satisfactory.

Detailed sub-area

The main focus of this study is on the comparison of Olex and multibeam data at scales that are consistent with video analysis and biotope mapping methods previously adopted in the MAREANO programme (Buhl-Mortensen et al., 2009b; Dolan et al., 2009), i.e. with biology observations being classified in 200 m segments (section 4.4) and terrain parameters smoothed accordingly (section 4.3). As an additional test and a cross-check on the models produced for the main study, we selected a sub-area for detailed analysis from the NVII/TII dataset to allow investigation of how modelling results may change if biotope classes are determined from video over finer distance intervals. The detailed sub-area is located at the northernmost part of NVII/TII, covering 6000 km^2 and amounting to 25% of the total study area (Figure 9). In the composite Olex-MB dataset, one multibeam transect falls within the sub-area.

Classified video samples were provided for every 50 m of video, rather than for every 200 m, and this amounted to 989 sequences from 60 video lines, with 165 taxa included in the DCA analysis. The same suite of environmental predictor variables were used in modelling as for the main study area, however within the detailed sub-area no averaging of the continuous terrain variables was performed since the raster data resolution and video points represent comparable distances. Preliminary biotope models for the detailed sub-area were produced using both the multibeam and the Olex-MB dataset together with their respective suites of environmental predictor variables. Only video samples and environmental variables from the area shallower than 800 m were included in the models, to facilitate a more direct comparison of results.

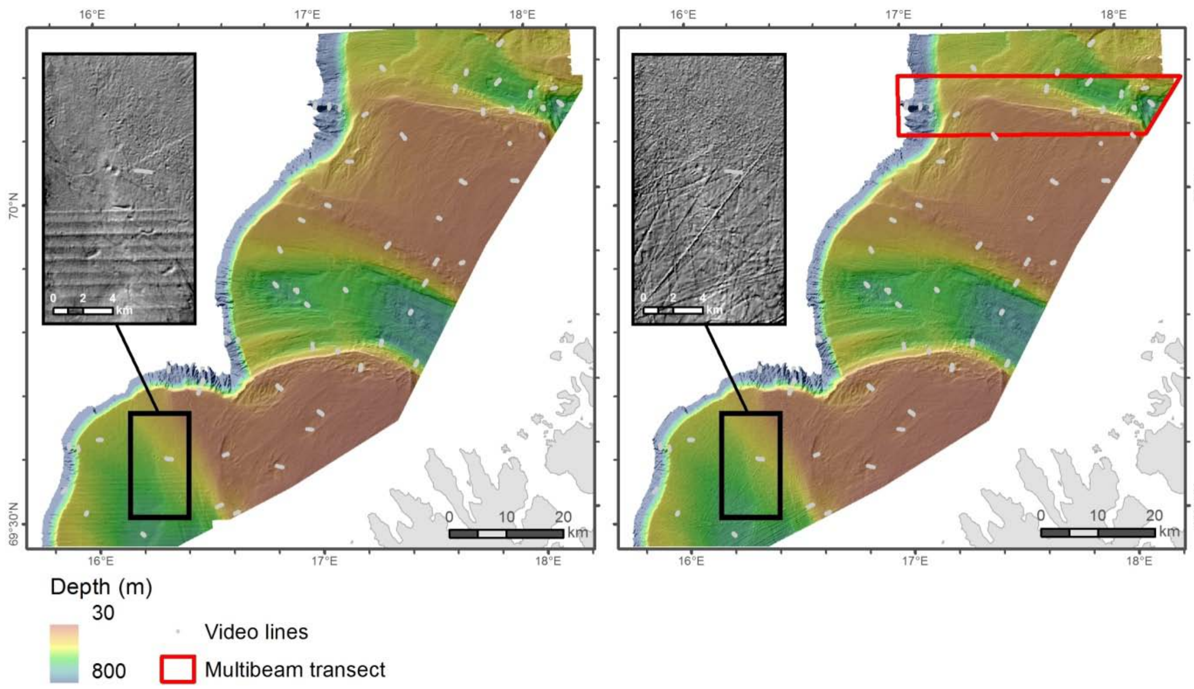

Figure 9. Colour shaded bathymetry of the detailed sub-area (location indicated in Figure 5), showing the position of video lines. A: MAREANO multibeam bathymetry. B: Olex-MB bathymetry. Note that colour range is not identical to previous figures. Enlarged areas show examples of artefacts in both datasets.

5. RESULTS

5.1 Sediment maps

Sediment grain size and sedimentary environment maps produced, as a result of this study, from the Olex-MB dataset (50 m resolution outside multibeam transects, 5 m resolution in transects) are shown in Figures 10 and 11. They are presented together with the published MAREANO maps (Bellec et al., 2009, www.mareano.no - Maps), based on full multibeam data (5-25 m resolution), to facilitate comparison. Sediment interpretation using the Olex-MB dataset could not be done to the same level of detail as it was for the published multibeam based maps (digitising at 1:50 000 for publication at 1:100 000) due to the lower resolution data. Within the multibeam transects, interpretation and digitising of grain size polygons from the Olex-MB data was possible close to the map scales used in the published MAREANO maps. Outside the multibeam transects, however, digitising was performed at 1:125 000 scale, i.e. suitable for publication at 1:250 000, where the map scale gives an indication of the level of generalisation/accuracy that should be expected from the map product.

From comparison of the maps based on high resolution multibeam data and the lower resolution composite Olex-MB data (Figures 10 and 11) it is clear that, although some general patterns are recognizable in both interpretations, the multibeam based sediment maps include considerably more detail than the Olex-MB based maps. This is not unexpected, since the Olex-MB based maps should be considered as 1:250 000 scale map products as opposed to 1:100 000 currently produced by MAREANO. Besides the differences in map scale there are differences in the morphological features visible between the Olex and multibeam datasets, which have important consequences for the identification and understanding of geological processes. In the multibeam data, sedimentary features can often be seen even in the 50 m resolution bathymetry. Lack of detail in the Olex bathymetry makes sediment interpretation difficult, as features indicative of sediment type (e.g. sandwaves or pockmarks) are rarely visible. Some examples are shown in Figure 4, where we see how only three out of seven features recognisable in high resolution multibeam can be identified from the Olex bathymetry. Five of the seven features can be identified in multibeam data resampled to 50 m (i.e. same as Olex resolution). Figures 12 and 13 provide additional examples of the differing level of detail across datasets, with Figure 12 showing how detection of separate coral reefs from bathymetry data is complicated by a reduction in data resolution and quality, and Figure 13 highlighting the poor Olex representation of a well-known coral area and the loss of prominent sedimentary features (sandwaves) in the Olex dataset.

Detailed interpretation of the sedimentary environment was not possible in the absence of backscatter data across so much of the study area, and the lack of detailed bathymetry data added a further challenge. Since erosional and depositional processes have a strong link to grain size, with coarser sediments generally dominating erosion areas and finer sediments dominating in deposition areas, we have used the grain size as a means to estimate the distribution of the different types of sedimentary environment. The Olex-MB based map presented here has been made by automatically translating values of grain size polygons to new values of erosion or deposition. No reinterpretation of the polygons has been performed. Comparison of the Olex-MB based map with the multibeam based map (Figure 11) shows how the main erosion and deposition areas are identified, but that distinction between the different types of erosional/depositional processes is not consistent between the two maps, with the Olex-MB based map offering a less accurate picture of the sedimentary environment.

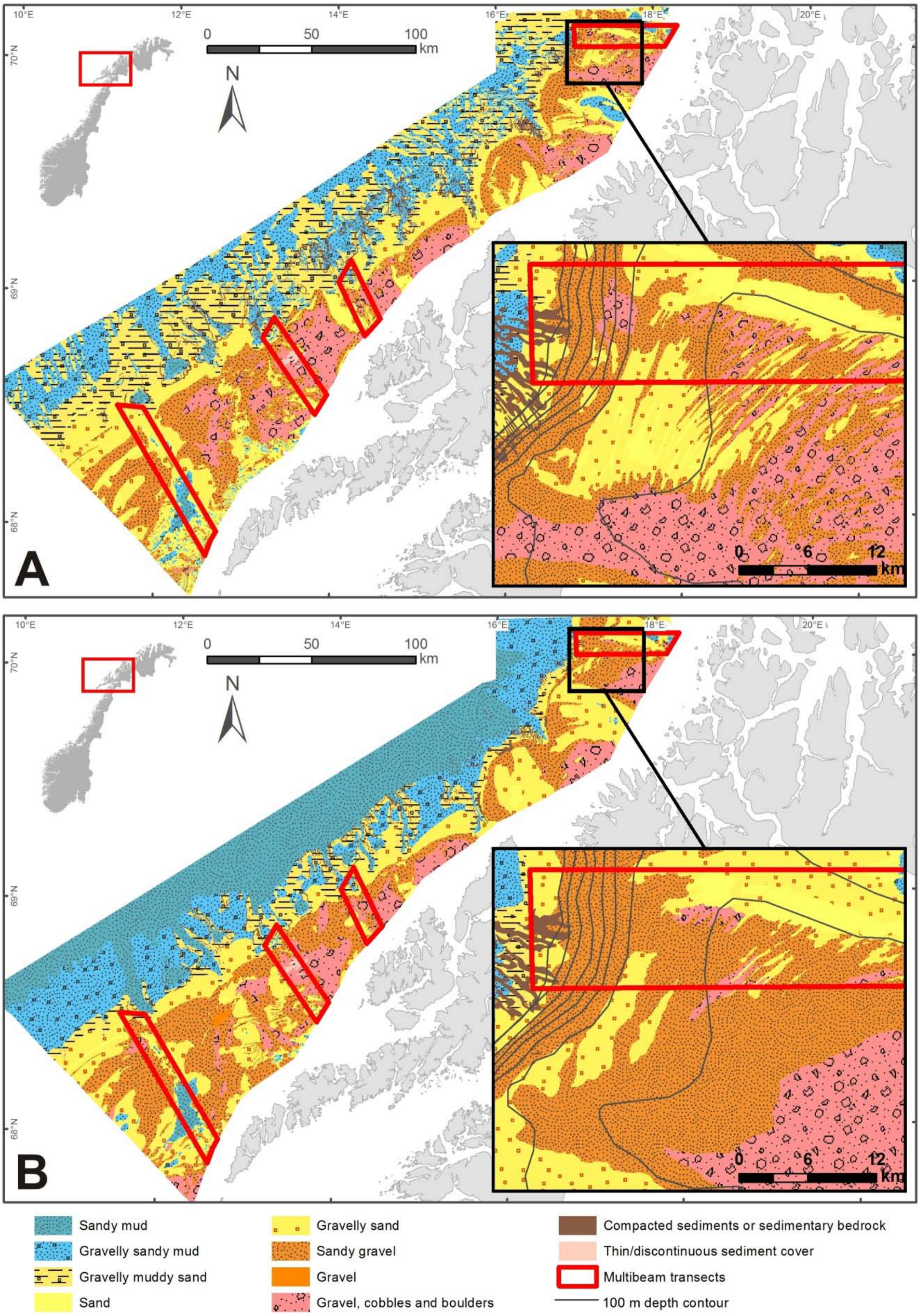

Figure 10. Interpreted maps of surficial sediment grain size. A: Published map based on MAREANO multibeam data with backscatter (www.mareano.no – Maps). B: Map interpreted from the Olex-MB dataset: Olex bathymetry data supplemented with MAREANO multibeam and backscatter data in transects (red).

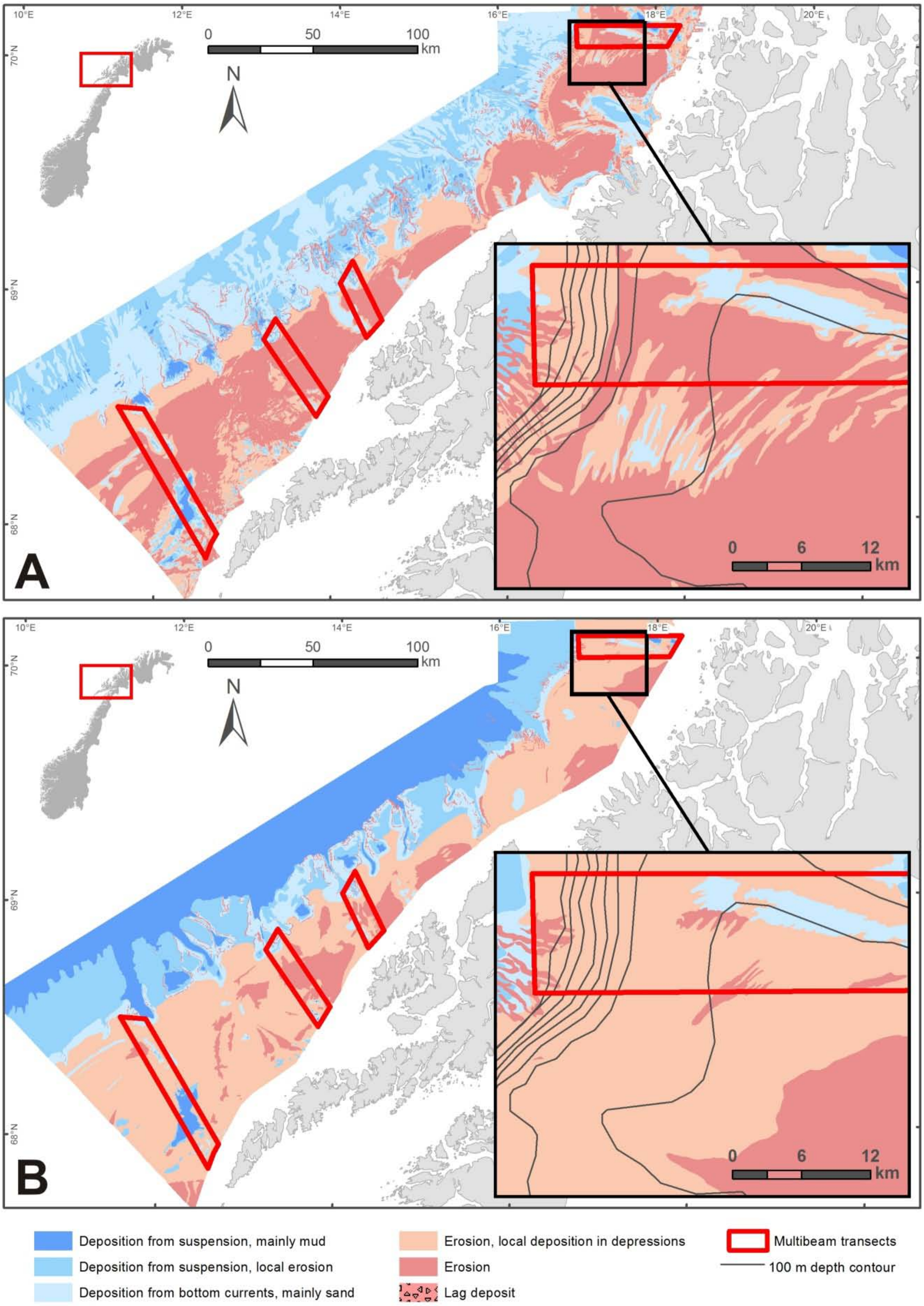

Figure 11. Interpreted maps of the sedimentary environment. A: Published map based on MAREANO multibeam data with backscatter (www.mareano.no – Maps, modification and re-interpretation of sediment grain size map) B: Reclassification of Olex-MB-based sediment grain size polygons into corresponding sedimentary environment classes (no re-interpretation).

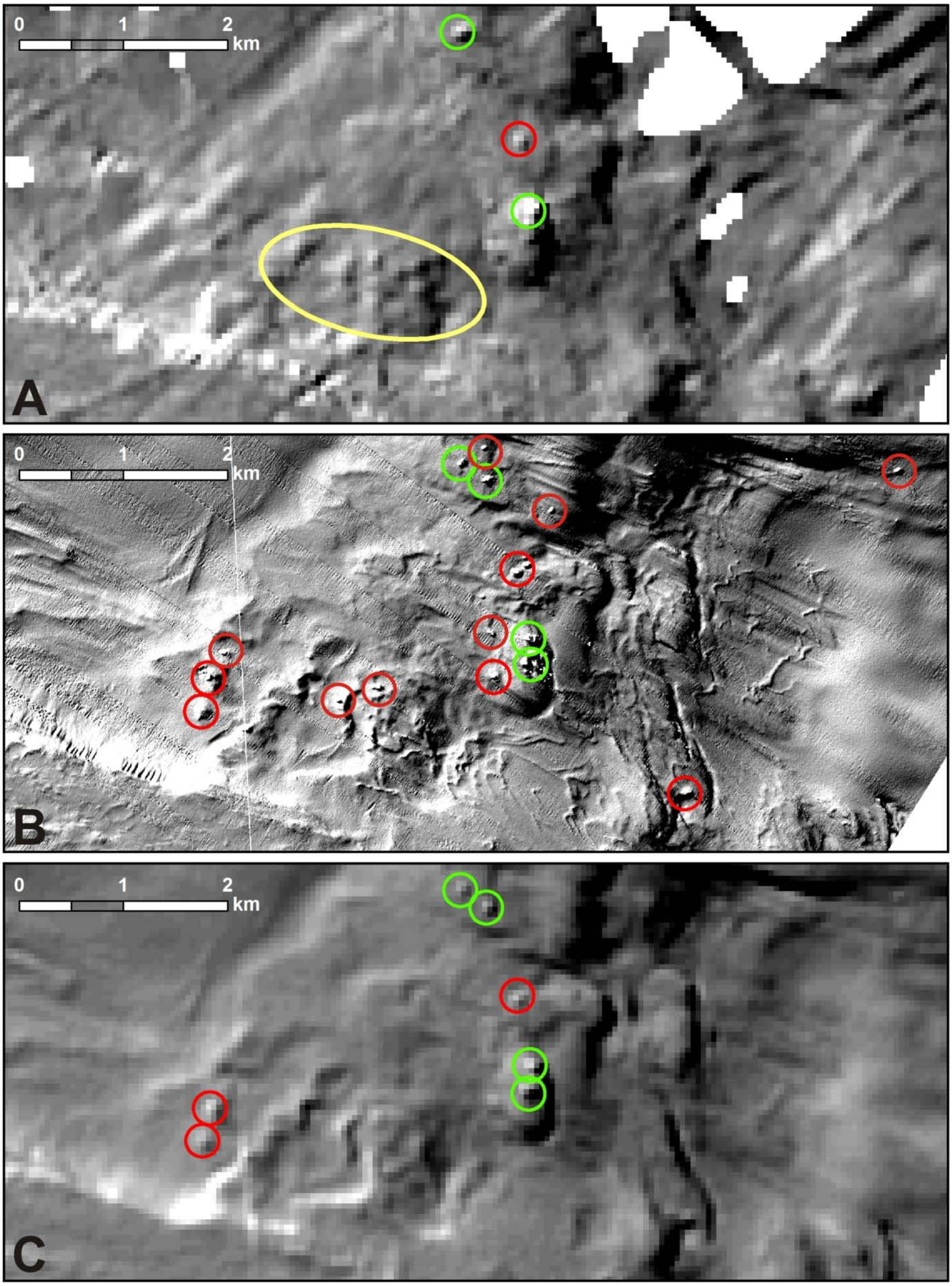

Figure 12. Shaded relief images of the Malangen coral reef area (location indicated in Figure 3). A: Olex bathymetry, 50 m resolution. B: Multibeam bathymetry, 5 m resolution. C: Multibeam bathymetry, 50 m resolution. Green circles – Inspected reefs, red circles – Expected reefs (based on morphology), yellow outline – Area of artefacts similar to reef morphology.

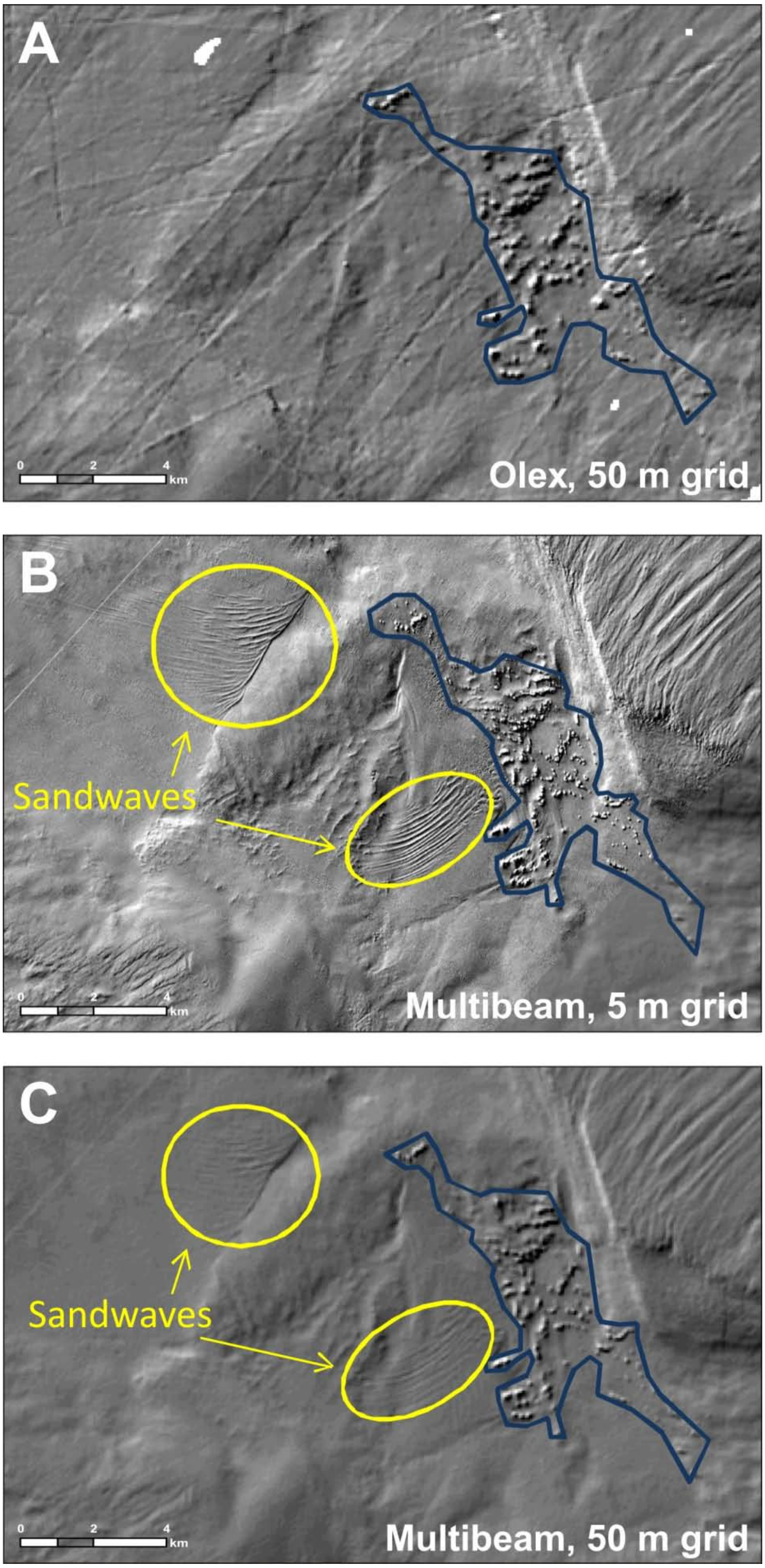

Figure 13. Shaded relief images of the Hola coral reef area (location indicated in Figure 3). A: Olex bathymetry, 50 m resolution. B: Multibeam bathymetry, 5 m resolution. C: Multibeam bathymetry, 50 m resolution. Blue outline – Interpreted reef area based on visual inspection of the datasets.

5.2 Ordination of video observations

The hierarchical classification of video-sequences using DCA (section 4.5) revealed 10 classes, three of which were predominantly found in areas deeper than 800 m. Figure 14 shows a two-dimensional representation of the 3D plot resulting from DCA analysis of the full dataset (947 sequences), classified through cluster identification at three successional stages of DCA (Figure 15) as described below.

In the initial ordination of the full data set containing 947 video sequences with 291 species included in the analysis, the total variance ("inertia") in species data was 10.484. Three distinct clusters of points were easily identified (Figure 15A), and labelled class 1-3. These three classes represent the deepest samples in the full dataset, located predominantly in areas of canyons, lower continental slope and deep sea plain, and were omitted from further analysis.

DCA was repeated with the remaining material. This analysis involved 244 species from 709 video sequences, and the total variance in species data was 7.809. Based on the new DCA 3D plot (Figure 15B) two clear classes could be identified (class 4 and 9). Following removal of the two classes from the dataset, DCA was again repeated with the remaining material. This amounted to 235 species from 635 video sequences, with a total variance in species data of 7.432. The DCA 3D plot from the final analysis was divided into 5 classes (Figure 15C, classes 5-8 and 10), and all points in the full, original dataset were subsequently labelled according to class identification from the three hierarchical levels. The values for total variance were relatively high for all three DCA analyses, reflecting the large number of samples and that the species data represent different environments with different species composition.

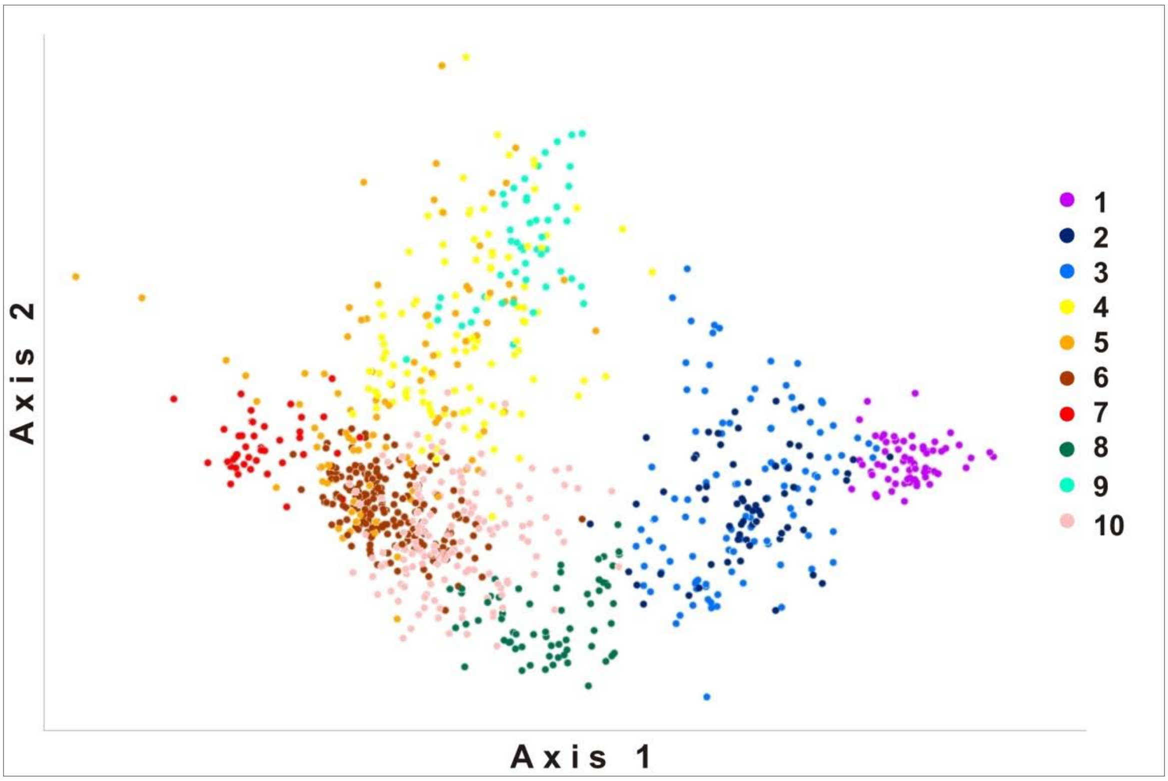

Figure 14. 2D representation of a detrended correspondence analysis 3D plot showing clustering of the 947 video samples used in this study. Colours correspond to the 10 final classes used in modelling.

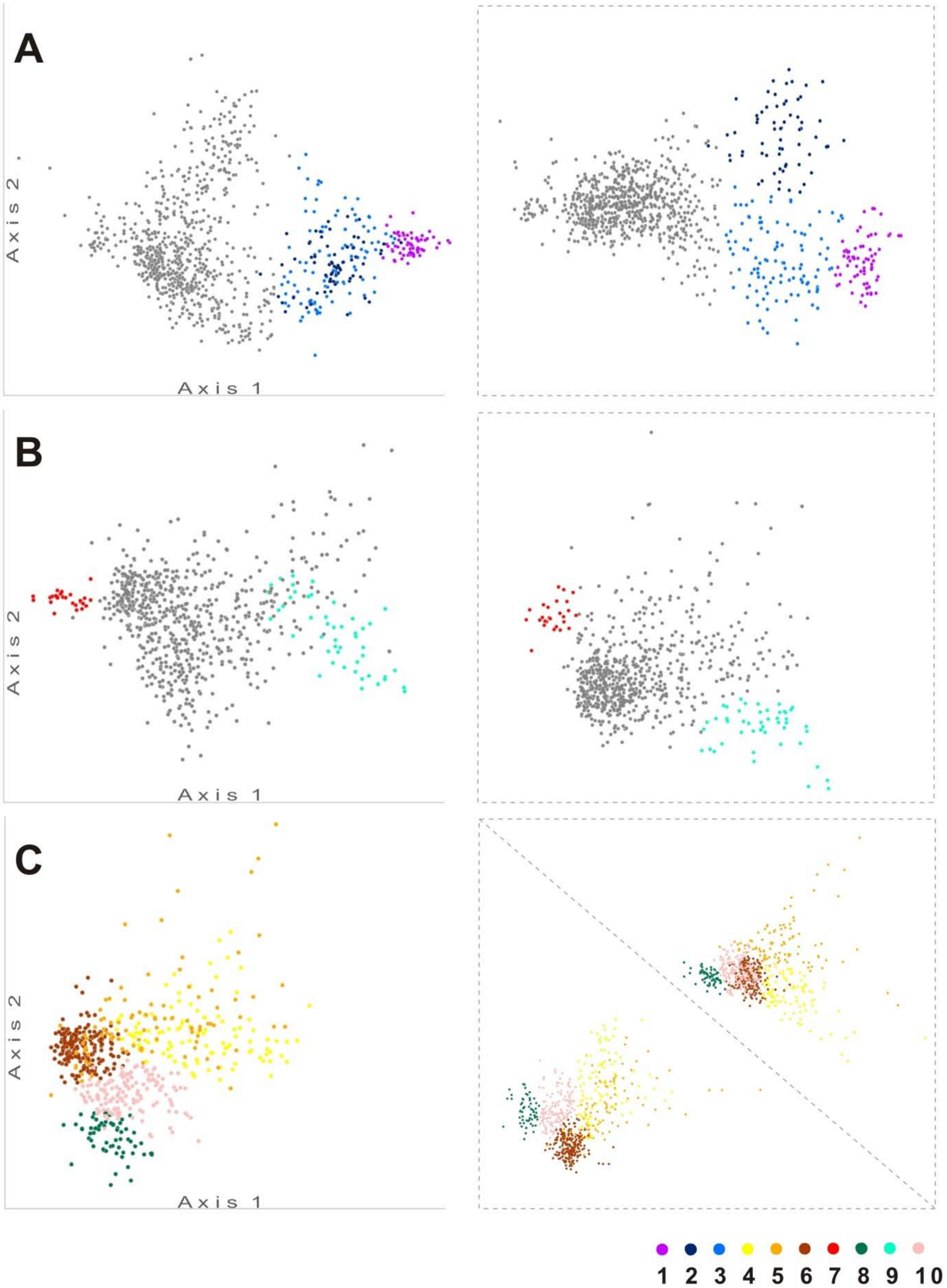

Figure 15. Stepwise identification of classes in DCA 3D plot. Left-hand column – original DCA output with classification of groups to be removed before re-analysis. Right-hand column – 3D plots shown from the angle that best illustrates class separation. A: Output from analysis of full dataset. B: Output from analysis after removal of Classes 1-3. C: Output from analysis after further removal of classes 7 and 9 (shown from two different angles in right-hand column to visualise all 5 remaining classes).

5.2.1 Class description

Figure 16 shows the spatial distribution of classified video sequences, plotted on a shaded relief image of the bathymetry of NVII/TII. Characteristics for the 10 classes are summarised in Table 2.

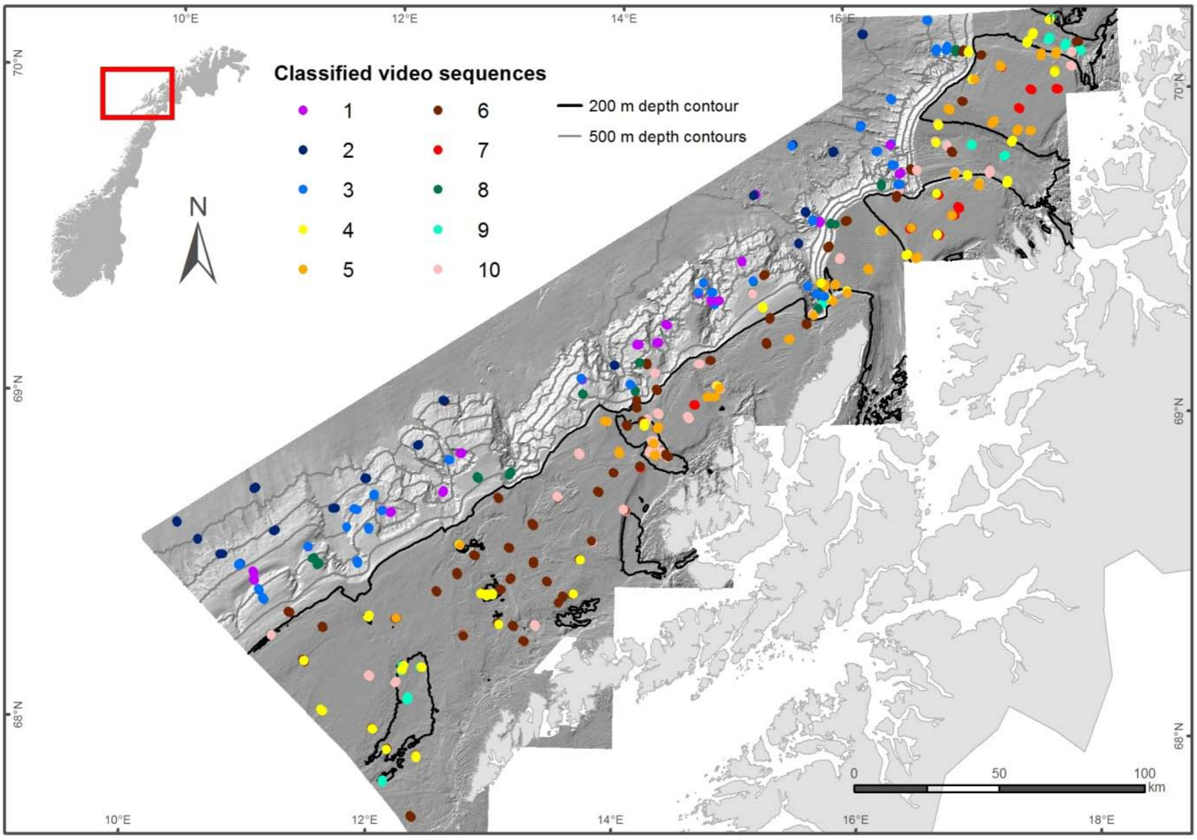

Figure 16. Distribution of classified video sequences – note that points from the same video line may be obscuring each other at this overview map scale.

The classes 1-3 are all predominantly found in areas deeper than the Olex coverage, and are thus not included in the comparison of biotope models for the two data sets (Olex-MB and MAREANO multibeam). Classes 4-6 are all from depths mainly between 164 and 237 m on the shelf, with moderate sloping bottom. In addition to the taxonomical composition they differ with respect to dominating bottom type (from field observations). On the sandy mud of class 4 the seapen *Funiculina quadrangularis* and the brittlestar *Asteronyx loveni* represent two characteristic species not observed in any other classes. Different seastars (*Pteraster sp.*, *Ceramaster granularis*, and *Hippasteria phrygiana*), the irregular sea urchin *Spatangus purpureus* and redfish (*Sebastes sp*.) were most common on the sandy gravel of class 5 locations. Class 6 represents the shelf plain area with gravelly bottoms dominated by 5 different sponge species (*Phakellia sp.*, *Craniella zetlandica*, *Geodia sp.*, *Stryphnus ponderosus*, and *Mycale lingua*). On the shallow bank areas (class 7) with an average depth of only 76 m, solitary sessile fauna dominates, with different gorgonians, the tubeworm *Filograna implexa*, white tunicates and sepulid tube worms. In addition, encrusting calcareous red algae (*Lithothamnion sp.*) are typical for this class. Class 8 is the deepest of the classes that are found within the area of Olex bathymetry coverage. The average depth of locations in this class is 747 m, representing the upper slope area. Here, the bottom is mainly gravelly with basket star (*Gorgonocephalus eucnemis*), the seastar *Crossaster papposus*, cauliflower corals (*Drifa glomerata*, and *Gersemia rubiformis*) and the bubblegum coral *Paragorgia arborea*. Class 9 represents deep shelf troughs with softer bottom (mud) than the other shelf trough class (4), where sand is mixed with mud. In class 9, two seapen species (*Kophobelemnon stelliferum* and *Virgularia mirabilis*), the common sea cucumber Parastichopus tremulus, pandalidae shrimps and the sponge *Steletta grubei* dominate. Class 10, also representing areas in shelf troughs, is characterised by sandy gravel and coral reefs. All of the five species (*Lophelia pertusa*, *Acesta excavata*, *Axinella infundibuliformis*, *Primnoa resedaeformis*, and *Protanthea simplex*) listed under this class in Table 2 are commonly found on *Lophelia* reefs.

Table 2. Characteristics for the 10 classes identified after three successional DCA analyses where clear classes were removed from the data set after each of the two first DCA runs. Class numbering corresponds to numbers used in Figures 14-16.

Class	Landscape element	Observed substrate	Mean depth (m)	Slope	Typical taxa
1	Mid slope	Soft	1389	Steep	Nemertini pink, Actiniaria small pink, Hexactinellida bush, *Lycodes* sp, *Bythocaris*
2	Lower slope /Abbyssal plain	Mixed	2114	Moderate	*Rhizocrinus/Bathycrinus, Elpidia, Hymenaster, Kolga, Caulophacus*
3	Canyon/Steep slope	Mixed	1390	Steep	*Chondrocladia, Lucernaria,* Pycnogonida, *Umbellula, Ophiopleura*
4	Shelf trough	Sandy mud	221	Moderate	*Asteronyx, Funiculina, Ditrupa, Flabellum, Pteraster*
5	Bank slope	Sandy gravel	164	Moderate	*Pteraster, Ceramaster, Hippasteria, Sebastes, Spatangus*
6	Shelf plain	Gravelly	237	Moderate	*Phakellia, Craniella, Geodia, Stryphnus, Mycale*
7	Shallow bank	Gravel	76	Flat	Gorgonacea, *Filograna*, Tunicata white, *Lithothamnion,* Serpulidae
8	Upper slope	Gravelly	747	Steep	*Gorgonocephalus, Crossaster, Paragorgia, Gersemia, Drifa*
9	Shelf trough	Mud	290	Flat	*Kophobelemnon, Parastichopus*, Pandalidae, *Virgularia, Steletta*
10	Shelf trough	Sandy gravel/Coral reef	263	Moderate	*Lophelia, Acesta, Axinella, Primnoa, Protanthea*

5.3 Environmental predictor variables.

Potential environmental predictor variables derived from available data and maps included the following:

- Continuous variables - bathymetry, backscatter, multiple scale terrain variables (Table 1), latitude (200 x 200 m means and standard deviations for main study area)

- Categorical variables - sediment grain size, sedimentary environment and landscape.

For the multibeam dataset this gave rise to a total of 73 variables, while the number was slightly lower for the Olex-MB composite dataset where some data were not available or difficult to compute.

5.3.1 Environmental predictor variables – multibeam-based model

Of the 73 potential environmental predictor variables that were generated, the 15 shown in Table 3 were used in biotope modelling based on multibeam data. The final set of selected variables is a synthesis of the variables indicated as most important by forward selection analysis at each step of the hierarchical classification, in addition to the three categorical variables that cannot be evaluated through forward selection (see sections 4.5 and 4.6.2). Forward selection analysis following DCA showed depth and backscatter to be the two variables that together explained the largest part of the variation in the video sequence dataset, with all bathymetry-derived terrain variables having less explanatory power. The final selection of variables also corresponds fairly well to Maxent’s own ranking of the importance of variables for each modelled class. All means and standard deviations have been calculated using a 200 x 200 m window following initial terrain parameter calculations.

5.3.2 Environmental predictor variables – Olex-MB-based model

The number of potential environmental variables is lower for the Olex dataset than it is for the multibeam, as there are no full-coverage backscatter data and as certain parameters were ignored and/or not calculated (for example, the sedimentary environment layer was left out as it is just a reclassification of the grain size layer). All in all 64 variables were considered for modelling, and the final 14 are shown in Table 4. The selection was done by means of combining the variables indicated by Maxent as important for each class. As for the multibeam data, means and standard deviations were calculated after producing the terrain parameter layers.

Forward selection analysis of the video sequence dataset with environmental values extracted from the Olex-MB dataset (section 4.6.2) revealed only small differences in explanatory power between the Olex-MB and the multibeam variables. As the variables landscape and sediment grain size are categorical, their explanatory power could not be quantified or compared between datasets. In the Maxent modelling output for the Olex-MB as well as the multibeam dataset, however, sediment grain size is listed as an important variable for many classes – often ranked above backscatter in the modelling results from the multibeam dataset.

Table 3. Environmental predictor variables used in biotope modelling based on multibeam data. Means and standard deviations were calculated over a 200 x 200 m analysis window.

Environmental predictor variable	**Analysis window** (cell size 50 m)
Mean depth	
Mean backscatter	
Landscape type (categorical)	
Sediment grain size (categorical)	
Sedimentary environment (categorical)	
Mean UTM latitude	
Mean slope	21 x 21 cells
Mean slope	49 x 49 cells
Mean of northness	49 x 49 cells
Mean bathymetric position index (BPI) value	49 x 49 cells
Standard deviation of BPI values	3 x 3 cells
Mean of mean curvature	49 x 49 cells
Standard deviation of mean curvature	3 x 3 cells
Mean of rugosity	3 x 3 cells
Mean of fractal dimensions	49 x 49 cells

Table 4. Environmental predictor variables used in biotope modelling based on Olex-MB data. Means and standard deviations were calculated over a 200 x 200 m analysis window.

Environmental predictor variable	**Analysis window** (cell size 50 m)
Mean depth	
Landscape type (categorical)	
Sediment grain size (categorical)	
UTM latitude	
Mean slope	49x49 cells
Standard deviation of slope	49x49 cells
Mean of eastness	3x3 cells
Mean of eastness	9x9 cells
Mean of northness	9x9 cells
Mean of northness	49x49 cells
Standard deviation of BPI	21x21 cells
Standard deviation of mean curvature	49x49 cells
Standard deviation of plan curvature	49x49 cells
Standard deviation of surface ratio	3x3 cells

5.4 Model results

Some example outputs from the Maxent modelling software are illustrated in Figure 17, 18 and 19. Figure 17 shows an example Receiver Operating Characteristic (ROC) plot showing training and test data for one biotope class. The Area Under Curve (AUC) provides a measure of model performance with a value close to one indicating a good model. Figure 18 illustrates how Maxent provides information on the relationship of the biotope class to the various environmental predictor variables. Values closer to 1 indicate the range of values preferred by that biotope. The map outputs from Maxent (Figure 19) show the suitability in percentage for each biotope across the study area.

For the current study we require a composite map showing the distribution of all habitats, rather than just one by one. To achieve this, individual maps were combined using a tool from ArcGIS's Spatial Analyst extention, which selects the highest value from the probabilities of each class to produce a composite map. This is not an exact approach as there can be differences in the relative probabilities. However, since there is good spatial separation between the distributions of many of the biotopes (examples shown in Figure 19) this is a reasonable approach. The composite map is also checked against the original observed data to check the accuracy of the model. If results are not satisfactory, the model can be refined by changing the biological classification or the selection of environmental variables.

Table 5a summarises the performance of the composite biotope maps produced by repeated Maxent modelling runs using different selections of multibeam and Olex-MB derived environmental predictor variables. Table 5b indicates how performance may increase if a buffer zone corresponding to the raster resolution of 50 m is included. The main effects of changing varying the environmental predictor variables are described below for the multibeam and Olex-MB based models in turn.

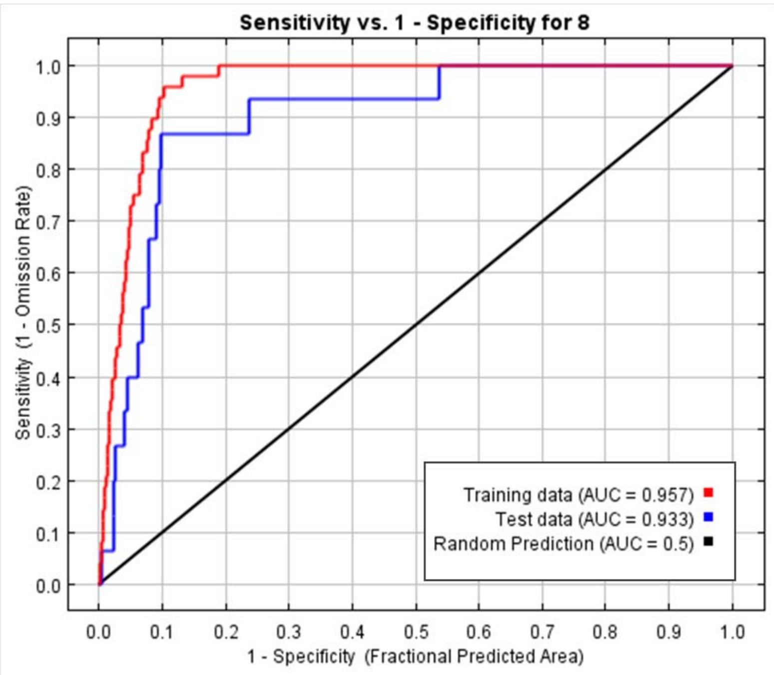

Figure 17. Maxent receiver operating characteristic (ROC) curve for Class 8 of the Olex-MB-based model results. The Area Under Curve (AUC) provides a measure of model performance, with values approaching 1 as performance increases.

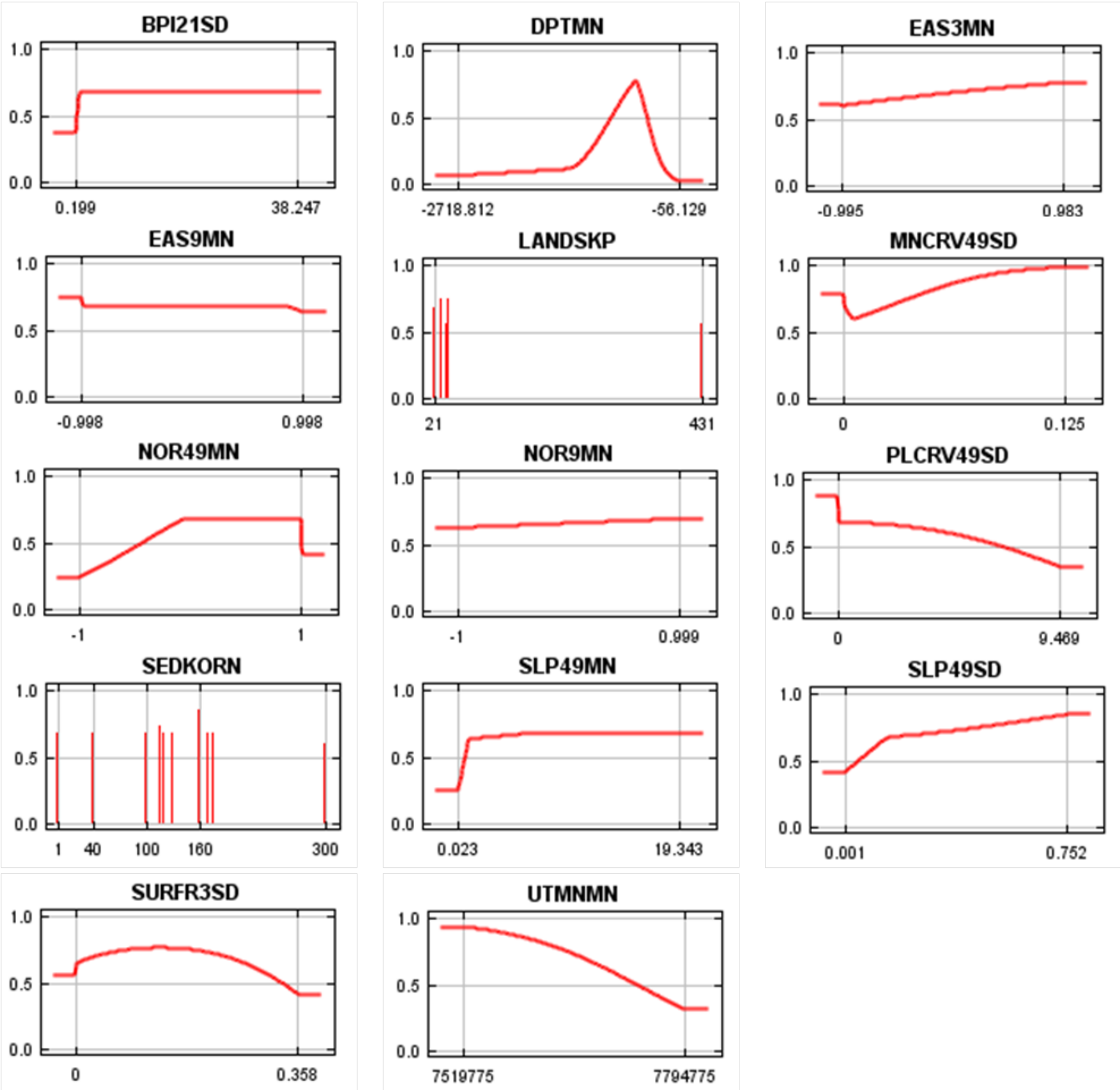

Figure 18. Maxent marginal response curves for Class 8 of the Olex-MB-based model results, showing how the individual predictor variables relate to the modelled class. Values closer to 1 indicate the preferred range of the class.

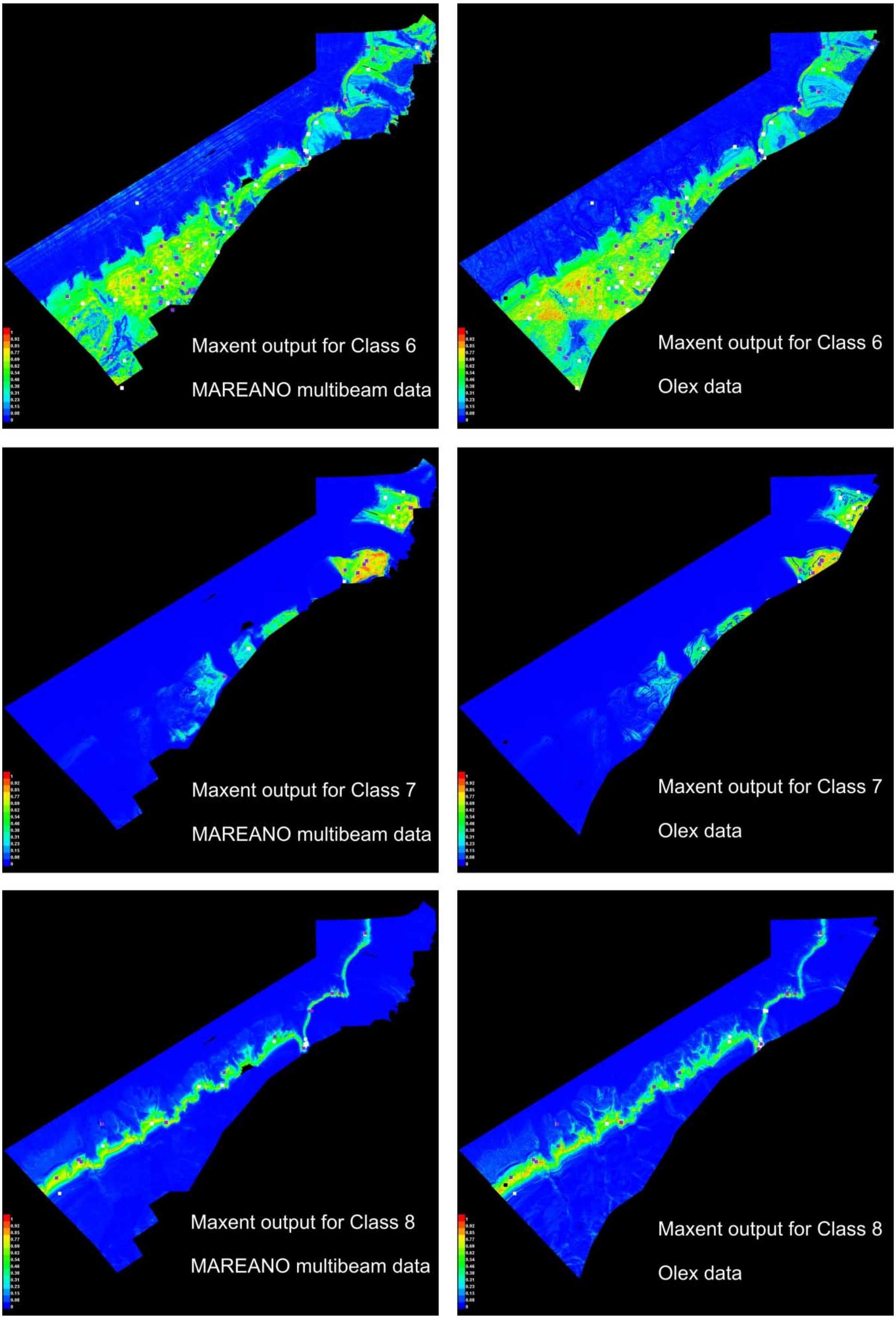

Figure 19: Maxent output showing the predicted distribution of individual classes 6, 7 and 8. Left-hand column – Model results from the multibeam dataset. Right-hand column – Model results from the Olex-MB dataset.

Table 5. Summary of model performances using different combinations of environmental predictor variables. Figures indicate percentage of points correctly classified in the composite biotope map with respect to observed biotope points.

a) Model performance for exact sample locations	**MAREANO multibeam**		**Olex-MB**	
	Entire study area	Area shallower than 800 m	Entire study area (based on MAREANO data below 800 m)	Area shallower than 800 m
Terrain variables, sediment maps, landscape, backscatter	**74,8%**	**71,5%**	*(no backscatter)*	*(no backscatter)*
Terrain variables, landscape, backscatter	74,7%	71,8%	*(no backscatter)*	*(no backscatter)*
Terrain variables, backscatter	72,6%	69,0%	*(no backscatter)*	*(no backscatter)*
Terrain variables, sediment maps, landscape	74,1%	70,1%	**72,3%**	**67,0%**
Terrain variables, landscape	71,7%	68,1%	70,1%	64,1%
Terrain variables only	70,7%	66,5%	69,1%	63,5%
One variable only: Depth	52,4%	*(not calculated)*	52,8%	*(not calculated)*

b) Model performance including 50 m buffer	**MAREANO multibeam**		**Olex-MB**	
	Entire study area	Area shallower than 800 m	Entire study area (based on MAREANO data below 800 m)	Area shallower than 800 m
Terrain variables, sediment maps, landscape, backscatter	**83,3%**	**82,7%**	*(no backscatter)*	*(no backscatter)*
Terrain variables, landscape, backscatter	83,5%	*(not calculated)*	*(no backscatter)*	*(no backscatter)*
Terrain variables, backscatter	81,6%	*(not calculated)*	*(no backscatter)*	*(no backscatter)*
Terrain variables, sediment maps, landscape	81,8%	*(not calculated)*	**84,1%**	**82,2%**
Terrain variables, landscape	80,5%	*(not calculated)*	82,7%	*(not calculated)*
Terrain variables only	79,6%	*(not calculated)*	81,4%	*(not calculated)*
One variable only: Depth	56,0%	*(not calculated)*	55,9%	*(not calculated)*

5.4.1 Predicted biotope map from multibeam data

Table 5a shows how the model based on multibeam-derived environmental predictor variables performs better with the inclusion of landscape types and of backscatter and/or interpreted sediment maps. Numerical variables alone or with landscape types give slightly lower performance, whereas modelling with the depth variable alone does not give a satisfactory result.

Figure 20A shows the final composite biotope map for the main study area. There is a clear division between continental shelf and slope/deep sea, with classes 1-3 and 8 dominating the latter. On the shelf, classes 4, 9 and 10 dominate troughs, while class 7 is predominantly found on the shallowest banks in the northern part of the study area and classes 5 and 6 occur on deeper banks. Examples of the predicted distribution of habitats for some of the individual biotope classes are shown in Figure 19, where we see that some biotopes have a very restricted distribution, whilst others are more general. Table 6 summarizes the characteristics of each class, based on statistics from their modelled distribution.

Testing of the performance of the composite biotope map from multibeam data reveals that 74.8% of all sample points are predicted to their correct class. If a 50 m buffer is included, the percentage rises to 83.3. Breaking down the data further, we find that classes 2, 3 and 8 are predicted best (>80% in exact location), whereas classes 5, 6, 7 and 10 are predicted below the average. For the area shallower than 800 m alone, the model performance is 71.5% without and 82.7% with a 50 m buffer.

5.4.2 Predicted biotope map from Olex-MB data

Table 5a summarises the performance of the composite biotope model based on Olex-MB-derived environmental predictor variables. For the Olex-MB dataset the inclusion of backscatter data is not an option, but the trend of increasing performance with inclusion of sediment and landscape information seem comparable to the multibeam results. Both datasets display a lower model performance if we isolate the area shallower than 800 m.

The final composite biotope map based on Olex-MB-based environmental predictor variables (Table 4) is shown in Figure 20B. The biotope map has been clipped to show only the area shallower than 800 m, which would be representative of results obtained using only Olex data and multibeam transects within this data (i.e. no additional deepwater multibeam survey). It is clear that the broad-scale distribution of biotopes is similar to the multibeam map, even though the general appearance is more fragmented and with certain artefacts from some of the environmental predictor variables (e.g. the sharp latitude-parallel boundaries in the southern part, originating from the UTM latitude predictor variable). For the area shown in Figure 20B, model performance is 67.0%, rising to 82.2% with the inclusion of a 50 m buffer as described above.

Table 6. Summary of the physical and biological characteristics of each biotope class represented in the final composite biotope map (Figure 20).

Biotope class	**Depth range**	**Landscape type** (Halvorsen et al., 2009)	**Sediments and terrain**	**Typical taxa** (from video observation)	**Other characteristics**
1	1200-1500 m	Continental slope/canyon	Variable sediment composition (mud to gravelly sand), regional/local topography uneven	Nemertini pink, Actiniaria small pink, Hexactinellida bush, *Lycodes* sp, *Bythocaris*	
2	>1500 m	Deep sea plain/ continental slope (lower)	Gravelly, sandy mud	*Rhizocrinus/Bathycrinus, Elpidia, Hymenaster, Kolga, Caulophacus*	
3	1000-1700 m	Continental slope (middle)	Variable sediment composition (mud to gravelly sand), regional topography uneven	*Chondrocladia, Lucernaria,* Pycnogonida, *Umbellula, Ophiopleura*	
4	150-300 m	Continental shelf plains/marine valleys	Sand/gravelly sand, flat areas	*Asteronyx, Funiculina, Ditrupa, Flabellum, Pteraster*	
5	70-180 m	Continental shelf plains/marine valleys	Variable sediment composition (sand to coarser), flat areas	*Pteraster, Ceramaster, Hippasteria, Sebastes, Spatangus*	Mainly north of 69°N
6	<300 m	Continental shelf plains/marine valleys	Variable sediment composition (gravelly sand to coarser), flat areas	*Phakellia, Craniella, Geodia, Stryphnus, Mycale*	
7	50-80 m	Continental shelf plains	Gravel, cobbles and boulders, flat areas	Gorgonacea, *Filograna,* Tunicata white, *Lithothamnion,* Serpulidae	North of 69°N, erosional environment
8	500-850 m	Continental slope (upper)	Gravelly and/or muddy sand, steep areas of uneven topography	*Gorgonocephalus, Crossaster, Paragorgia, Gersemia, Drifa*	
9	200-350 m	Marine/shallow marine valleys	Sandy/muddy sediments, flat areas	*Kophobelemnon, Parastichopus,* Pandalidae, *Virgularia, Steletta*	
10	100-500 m	Continental shelf plains/marine valleys/ continental slope (upper)	Variable sediment composition, variable topography	*Lophelia, Acesta, Axinella, Primnoa, Protanthea*	

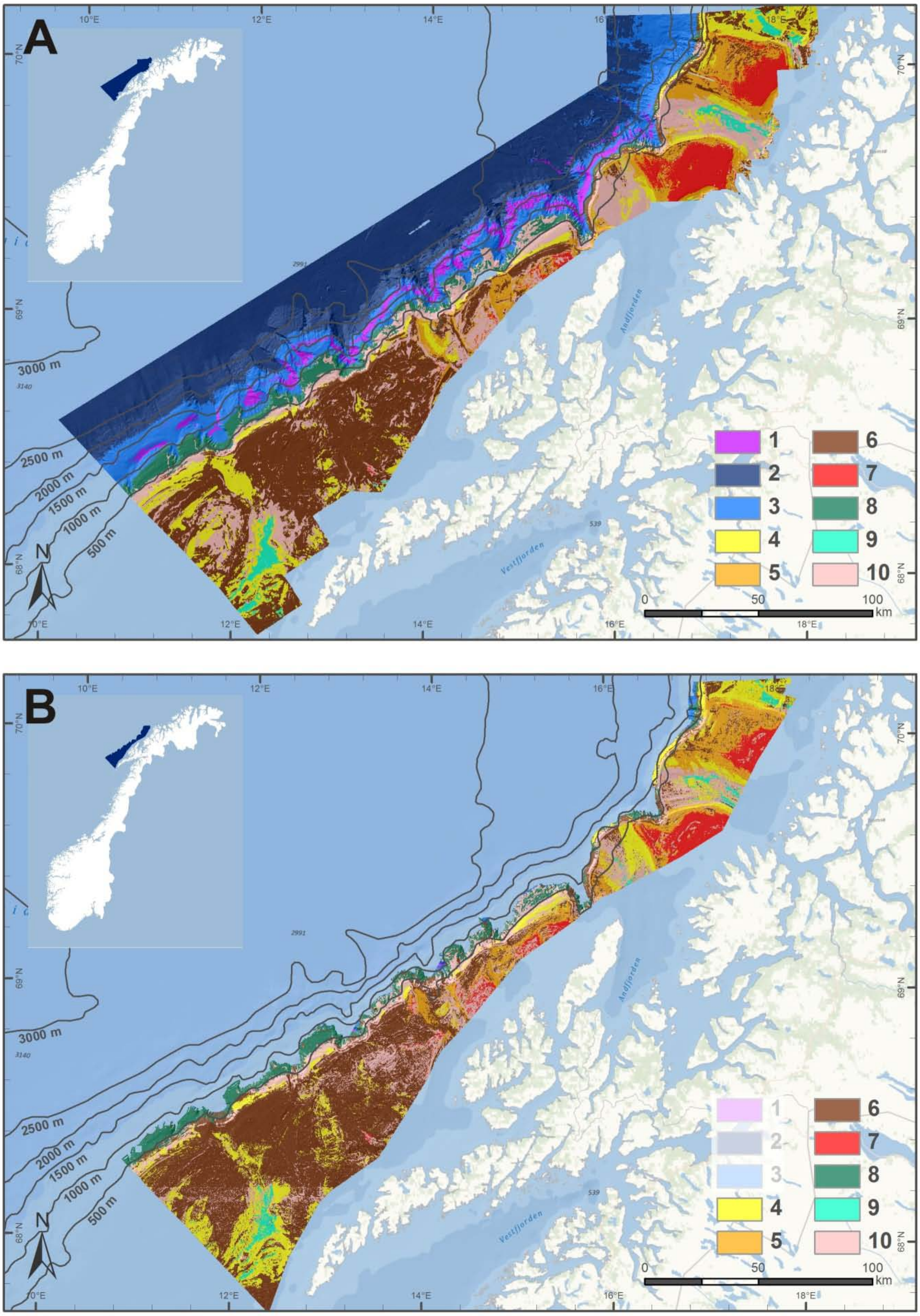

Figure 20. Modelled distribution of biotopes in the study area. A: Model results from the MAREANO dataset. B: Model results from the Olex-MB composite dataset (area below 800 m is disregarded due to lack of Olex coverage).

5.4.3 Test biotope maps from the detailed sub-area

Biotope maps for the detailed sub-area were produced only as a test and a cross-check on the main study area models, to study the effects of using biotopes classified over shorter segments of video transects. Detailed analysis of model performance in terms of statistics and accuracy was not conducted, since comparison of these performance metrics between models would be unrepresentative due to the different input data. Visual comparison of the results, however, is valuable, and Figure 21 shows modelled biotopes based on 200 m (A/C) and 50 m (B/D) classified biotope points using multibeam-based (A/B) and Olex-MB-based (C/D) environmental predictor variables. As classification of the 50 m video samples was done independently of the 200 m samples, the classes pictured in Figure 21A/C (200 m data) do not correspond directly to those pictured in Figure 21B/D (50 m data). Also, while only 7 out of 10 biological classes from the 200 m video samples are present within the detailed sub-area, the 50 m samples were grouped into more classes, reflecting the variation identified through DCA. Several class groupings were tested and 10 classes are shown in Figure 21 B/D for comparison of multibeam and Olex-MB based biotope maps.

The use of a greater number of classes from shorter video sequences resulted in more complex modelled biotope maps of for both the multibeam and Olex-MB datasets. However, visual inspection and preliminary statistical testing of results did not show major differences between multibeam and Olex-MB model performances using 50 m video samples. This seems to support the results from the main study area suggesting that there is little difference between multibeam and Olex-MB based biotope maps, however it should be noted that our findings for the sub-area are based only on preliminary results.

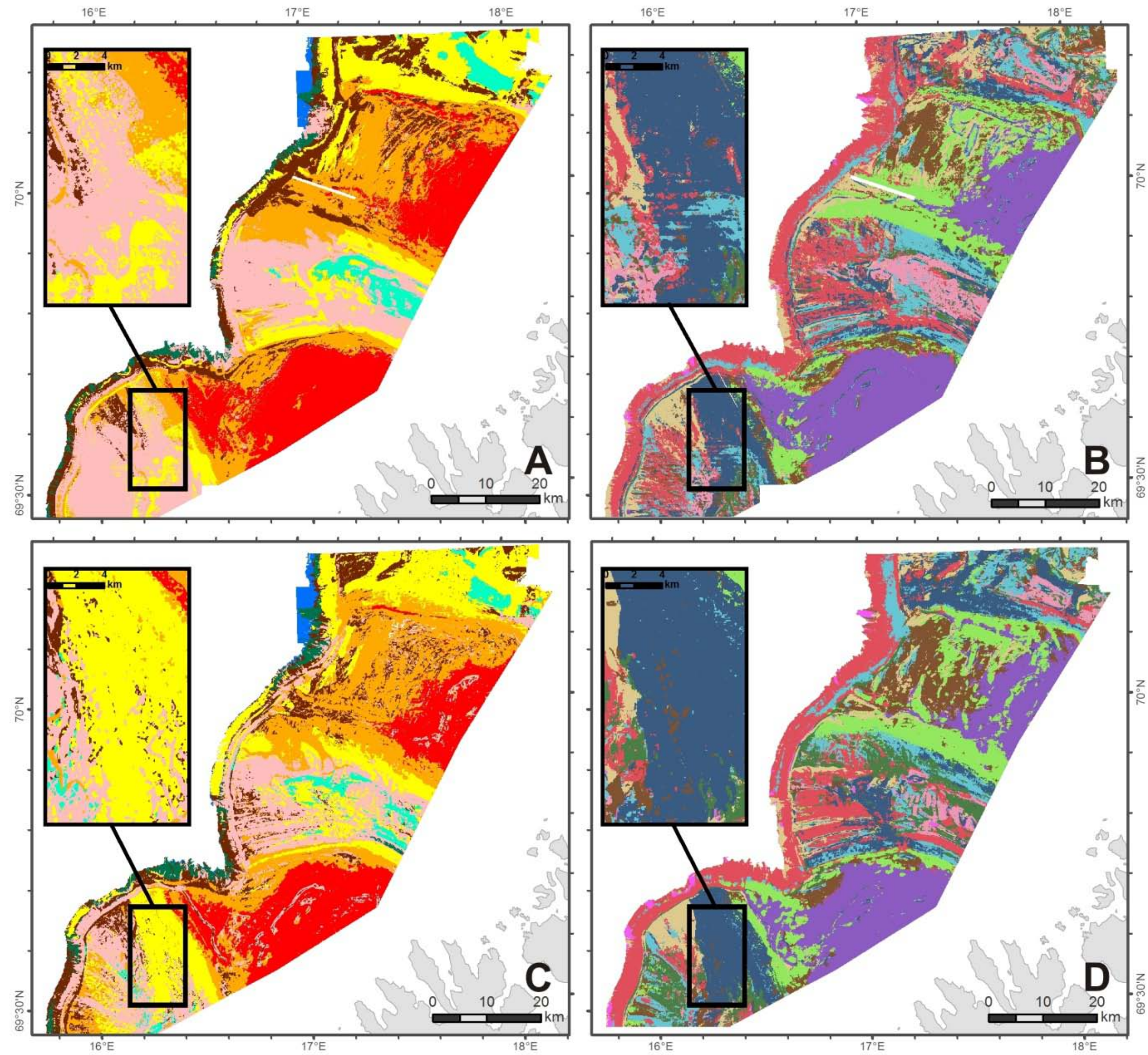

Figure 21. Modelled biotopes from the detailed sub-area (Figure 9). A: Final model result from point data representing 200 m segments of video lines and multibeam data averaged over 200 m. B: Example of model result from point data representing 50 m segments and non-smoothed multibeam data (50 m resolution). C: Final model result from the Olex-MB dataset (conditions as in A). D: Example of 50 m model result from the Olex-MB dataset (conditions as in D). Colours do not represent the same classes in A/C and B/D.

6. DISCUSSION

From the work undertaken in this study we see that a combination of Olex and limited multibeam data, as in the Olex-MB composite dataset, can be used for the production of regional sediment maps and for modelling biotopes. The results obtained using the Olex-MB for both the sediment maps and the biotope maps are broadly similar to those produced using full coverage multibeam data, however there are important differences in the level of detail achieved for the sediment maps and in the data available as environmental predictor variables for the Olex-MB based maps that have consequences for the final biotope map. We discuss each of the map products in turn and conclude by discussing some other consequences of using combined Olex and multibeam data in relation to MAREANO that have become apparent in the course of this study.

6.1 Sediment maps

Sediment grain size maps produced from the Olex-MB data are significantly less detailed than those currently produced by MAREANO using high resolution multibeam and supporting data. They should be considered 1:250 000 map products, rather than MAREANO's existing 1:100 000 maps. The reasons for the difference are the lower bathymetry resolution and quality across the entire Olex-MB dataset and the lack of backscatter data in the Olex-only areas: the bathymetry data used were at 50 m instead of 5 m resolution. Additionally it is important to note that the multibeam dataset also gives the potential for finer scale mapping, e.g. 1:25 000, in areas of special interest. We have seen in Figure 4 how the resolution affects the terrain features that can be recognised within the Olex-only areas of the Olex-MB dataset, and further examples are shown in Figures 12 and 13 where we see the impact of resolution and data quality on the identification of coral reefs and sandwaves which are important in sediment interpretation and for other MAREANO products as we discuss further below. Without the availability of full coverage backscatter data the identification of important terrain features and landscape elements such as sandwave fields, moraine ridges, pockmarks etc. becomes particularly important as the bathymetric signature of these features allows expert interpretation based on prior knowledge of the most likely sediments occurring on such features. It is important to remember also that the sediment distribution does not always correspond to changes in topography – an example of this is shown in Figure 4 where certain sedimentary structures (current lineations) are only discernible from the backscatter data. The multibeam transects greatly assisted the interpretation since they meant backscatter information were available for at least part of major landscape types in the study area (i.e. covering both banks and troughs).

Considering these limitations in the Olex-MB dataset, it is not surprising that the interpreted Olex-MB sediment maps turn out much less complex than the MAREANO sediment maps. Despite the lack of detail and some differences in interpretations, both maps from the Olex-MB dataset and the published maps show the same general trends in the distribution of sediments offshore. The comments above apply equally to interpretation of the sediment grain size and sedimentary environment maps. It is important to further point out that production of the sedimentary environment map from the Olex-MB data involved a different, much simpler and less accurate method than that in use for MAREANO today. The sedimentary environment map produced in this study using Olex-MB data was only a reclassification of the sediment grain size. Published MAREANO sedimentary environment maps have used some reclassification as an initial guide to interpretation of the sedimentary environment, but a considerable amount of re-interpretation and modification of polygons is applied, primarily guided by the backscatter data. In areas where seabed bedforms permit, e.g. where iceberg ploughmarks are present, multibeam data also allow the possibility for the interpretation of seabed processes such as bottom currents (e.g.Bellec et al., 2008). Interpretation of this type of additional information for MAREANO will not be possible within the Olex-only areas if composite multibeam and Olex datasets are used.

It should be noted that it is quite possible that the Olex-MB based sediment maps turned out better in the simulated study than what they might have done in a real situation. Interpretation was based on sediment information from video lines, and even though an effort was made to reduce the number of lines used in the simulation, the location of video lines is planned in order to give optimal coverage of bottom types. Without the aid of full-coverage backscatter in the planning process, line placement may have been less optimal, resulting in information not being available to the sediment interpreter. A real study where backscatter data were not available, however, could perhaps make use of external data such as sediment information from navigational charts to compensate at least partially for the lack of backscatter information. In an actual situation, data from other sources (e.g. modelled bottom currents) could also have helped to better translate a sediment distribution map into a map of sedimentary environment. Models of bottom current would also greatly assist sediment interpretation and biotope mapping even when full multibeam data are available.

6.2 Biotope maps

This study has demonstrated that it is possible to produce a reasonable-quality predicted biotope map at a regional scale (1:250 000 or coarser) using a composite Olex and multibeam dataset and derived environmental predictor variables. The biotopes represented by the map are the most likely dominant biotopes, on a regional scale, which we should expect to have a naturally patchy distribution within any particular biotope class. The Olex-MB based map is more limited in extent than the multibeam based map due to the lack of Olex data in deep water; however the general trends in the distribution of different biotopes on the continental shelf are broadly similar across the two maps. Since the biological input to each biotope map was exactly the same, any differences must be due to the number and quality of the environmental predictor variables that can be generated from each dataset, and the selection of these predictor variables used in the models.

6.2.1 Olex bathymetry and quantitative terrain variables

Both the multibeam-based model and the Olex-MB-based model use bathymetry and derived terrain variables from 50 m resolution data. The fact that there is no change in the data resolution used between the two models, in contrast to the situation for the sediment interpretation, can be one of the major reasons why there is not more variation between the models based on the different datasets and the overall level of detail is roughly the same. It is clear, however, from Figures 4, 12 and 13, that the Olex bathymetry data gridded to 50 m horizontal resolution do not achieve the same level of detail as the resampled 50 m multibeam data, and therefore do not provide the same opportunity for recognition of vulnerable habitats such as coral reefs which are important in biotope mapping and also documented by other MAREANO map products. It is also evident that the Olex-MB dataset is marred by linear artefacts in the Olex-only sections; these artefacts are prevalent across the entire dataset and are a result of the opportunistic method of data collection. It should be noted that the multibeam data also may contain artefacts (an example is shown in Figure 9A), particularly in areas where data come from older surveys; however the problems are much less extensive.

For biotope modelling at a regional scale, as done in MAREANO, a very high level of bathymetric detail is not essential. This fact, together with limitations on computation power, is why MAREANO biotope modelling to date has been done using only a 50 m, not the full 5 m or 25 m resolution multibeam data (although the availability of these higher resolution data do provide the potential for more detailed modelling at a local scale in areas of special interest). Artefacts can, however, cause problems when it comes to calculating terrain variables, and the lack of detail in the 50 m resolution Olex data as compared to multibeam data of the same resolution will mean that variations in terrain parameters corresponding to smaller, poorly resolved features will simply not be recognised. A naturally flat surface with artefacts will not be perceived as flat by the computation algorithms, and the resulting terrain parameters will have errors (particularly when smaller analysis window sizes are used – see Wilson et al 2007).

Some of these errors and crisp boundaries are likely to be smoothed out during the preparation of datasets, especially when we average the data to correspond with the 200 m biotope categories interpreted from video. We do not see the effect of erroneous terrain variables in the modelling results as might be expected, however, but as it turns out it does not seem to be very prominent, possibly due to the strong influence of depth, categorical variables and latitude in the models. It may also be that the reasonable Olex model results can be explained by sufficient smoothing of terrain variables (reducing artefacts) and by erroneous results being ranked as not relevant by the Maxent tool and having little impact on the result.

6.2.2 Selection of environmental predictor variables

Any biotope model result will depend upon how well the variables of choice reflect the complexity of the natural environment. In a case like the present study, where we lack full-coverage information about known, more direct influences on the distribution of fauna such as temperature and bottom currents, the identification and use of the best proxy variables is vital. Our approach within MAREANO has been to calculate a large number of terrain variables derived from the bathymetry data using a series of analysis windows (3, 9, 21 and 49 raster cells) in the computations, which provide an opportunity to obtain quantitative descriptors of different properties of the terrain at multiple scales. By considering multiple scales there is a greater chance that we capture most of the natural variation relevant to the distribution of biotopes – it is however possible that some variation will be under-represented, particularly on a regional scale. The inclusion of coarser categorically classified data including landscape and sediment maps helps to offset this effect to a certain extent, as we see improvements in the performance statistics when these variables are included (Table 5).

The terrain variables used in this study are consistent with and even more extensive (in terms of variable type and analysis scale) than many other biotope and habitat mapping and modelling studies (see e.g. summary by Brown et al., 2011). Since the study area is quite large, spanning several degrees of latitude, we included latitude as an environmental predictor variable in an attempt to capture bio-regional influences on the distribution of biotopes. Inclusion of this variable in preliminary model runs did indeed lead to a rise in prediction success in both the Olex-MB and multibeam based maps. We must therefore conclude that latitude influences biotope distribution in the study area, either directly or more likely as a proxy for other sources of variation which may be physically or biologically driven.

Although modelling with all available environmental predictor variables is feasible, it could be prone to overfitting issues and demands more computation time. A model based on so many variables also does not give such a clear indication of the key environmental drivers of biotope distribution, which is important for our increased understanding of benthic ecology. Selecting just the variables with best explanatory power for use in modelling helps to avoid this. The explanatory power of all continuous variables for this study was assessed in the first instance through forward selection. We cross checked this using Maxent, also assessing the importance of categorical variables. We have also experimented with a few different combinations of the best variables in order to test how the model predictions are affected by inclusion or exclusion of certain variables (Table 5). Based on our analysis it seems that the variables selected are the best available, however since we know the majority are only proxies to direct influences on the distribution of fauna, and that some key influences such as food availability cannot be quantified through available data, we must acknowledge that there are limitations on the predictive ability of the biotope models irrespective of the bathymetric dataset used.

In both forward selection analysis and Maxent, bathymetry comes out as the most important variable for both datasets in the study. It is clear from Table 5, however, that modelling with bathymetry as the only environmental variable does not give satisfactory results (barely exceeding 50% prediction success). When bathymetry is supplemented with backscatter and other terrain variables, the performance statistics increase for both the multibeam and the Olex-MB based models. There is clear indication that some measure of sediment properties is important for model performance, and is therefore a key driver in the distribution of fauna, as prediction is better when sediment distribution and/or backscatter are added to bathymetry and its derived terrain variables. We do not observe a prominent difference in results from modelling with interpreted sediment maps versus backscatter. This would seem to indicate that modelling will not suffer very much from having backscatter replaced with a high-quality sediment map as an environmental predictor variable, even though backscatter is rated among the more important parameters for biotope distribution, particularly by the forward selection analysis.

Considering the differences of the multibeam and Olex-MB based sediment maps, and given the above mentioned indications that sediment maps may replace backscatter in modelling with reasonable results, we might expect the Olex-MB model performance to be markedly lower than for the full-quality multibeam dataset. This, however, does not seem to be the case (best prediction success for the area above 800 m being 71.5% for multibeam data and 67.0% for Olex-MB data), and preliminary results from the high-resolution sub-area seem to support this finding.

It seems the quality of sediment maps interpreted from Olex data supplemented with multibeam transects including backscatter is indeed good enough for modelling biotope distribution at scales presently relevant to the MAREANO programme. This may also be due to availability of video data that were planned on the basis of high resolution multibeam data including backscatter data. This has consequences not only on the interpretations of sediments as discussed above, but also on the analysis and categorisation of biotopes from the video data. The number and representativeness of documented biotopes has a direct impact on modelling and hence on the predicted biotope map.

The implications of cruise planning without full multibeam data are hard to quantify, however it will remain vital that cruise planning efforts adopt a strategy that allow largest number, and broadest geographical spread of video and sampling stations across as many physically different areas of the seabed as possible within the limits of available the cruise time.

7. CONCLUSIONS

The conclusions of the present study can be summarised as follows:

1. This report is limited to the evaluation of bathymetry data compiled by Olex AS as one potential alternative to full-coverage multibeam data for use in MAREANO. The density and coverage of the Olex data are variable, but it was possible, with only limited interpolation, to produce a 50 m resolution bathymetric grid with just a few gaps in coverage across the study area, above 800 m depth. Existing Olex data provide no useable coverage in deep water (>800 m) within the study area. Multibeam data, by contrast, can typically be gridded to at least 5 m resolution on the continental shelf. Multibeam data coverage extends deeper than 800 m, mapping the lower continental slope and deep sea plain, where data are of sufficient density for gridding at 25 m resolution. Multibeam datasets include both bathymetry and backscatter data. Multibeam data therefore provide information on topography and also give an acoustic proxy to sediment properties. Olex data available within the study area are purely bathymetric and provide only information on topography.

2. The differences in data quality between multibeam and Olex have consequences for the topographic features that can be recognised in each dataset. Olex bathymetry at 50 m resolution is inadequate for mapping smaller, yet important, topographic features such as coral reefs and pockmarks which cover tens to a couple of hundred metres. Artefacts are also far more prevalent in the Olex data, and these often obscure features from visual interpretation and are also problematic in terrain variables computed from the bathymetry (e.g. slope) that are used further in MAREANO product development (e.g. biotope modelling).

3. The above limitations of Olex data will each have an impact on cruise planning. It has been difficult to realistically estimate the effects of this in our simulated study since the video data used here already had been acquired during cruises planned using both bathymetry and backscatter data. However, since we know that variations in backscatter, and hence variations in surficial sediments, often do not mirror changes in topography, it is likely that some sediment types will not be documented through video/sampling stations planned without backscatter. Due to the strong link between sediments and fauna it is therefore also likely that certain biotopes will not be documented. Since the level of bathymetric detail is not consistent across the Olex dataset, important features visible in multibeam data that would usually be investigated by video/sampling (e.g. coral reefs) can be missed entirely if they lie within an area of poor Olex bathymetric data coverage.

4. It is clear from this study that the addition of multibeam transects (bathymetry and backscatter data) to complement the Olex bathymetry data significantly improves the dataset. It is important, however, that these transects cover representative sections of the submarine landscape, thereby documenting in detail as much sediment/biotope variation as possible. The quality of the sediment map relies heavily on data interpretation within the multibeam transects where ground truth data can be directly linked to backscatter data. The ratio in the coverage of multibeam to Olex data used in this study (1:7) seems to have been sufficient. Since this study was limited to one study area it has not been possible to estimate the ratio of multibeam data to alternative bathymetry data that would be necessary for MAREANO product generation in other areas, where the complexity of the seabed and the quality of available alternative bathymetry data will be different.

5. Sediment maps are currently produced by MAREANO at 1:100 000 scale to meet regional mapping objectives, and the multibeam dataset gives the potential for finer scale mapping, e.g. in areas of special interest. Using the composite Olex/multibeam dataset it was not possible to produce sediment maps at 1:100 000 scale – the maps could only be produced at 1:250 000 scale or coarser. These maps reflect the same general patterns of dominant sediment distribution, but are more generalised than their 1:100 000 counterparts.

6. The biotope map based on the composite Olex/multibeam dataset is more limited in extent than the multibeam-based map, due to the lack of Olex data in deep water. The general trends in the distribution of different biotopes on the continental shelf, however, are broadly similar across the two maps. The biological input to each biotope map was exactly the same, therefore any differences must be due to the number and quality of the environmental predictor variables that can be generated from each dataset, and the selection of these predictor variables used in the biotope distribution models. In areas where the biology responds mostly to broad-scale changes in topography and sediment distribution, as they do in the Nordland VII/Troms II area studied here, there is less difference in the maps generated from each dataset than we would expect to get in an area dominated by finer scale changes in topography and sediments, where the dominant biotopes may exhibit less spatial separation and be more patchy.

7. Regional bathymetry available from commercial vendors such as Olex AS, in combination with multibeam data, can be used to produce sediment and biotope maps with acceptable quality at a regional scale – 1:250.000 or coarser. This represents a potentially huge cost reduction for the production of regional maps. For areas where more detailed maps are required, or where fine scale features such as coral reefs and pockmarks occur and are considered important, it is necessary to have full multibeam data coverage. A future approach to sediment and biotope mapping may therefore include two levels of mapping scale (e.g. 1:250 000 and 1:100 000), dependent on data availability.

Acknowledgements

This report is a product of the MAREANO programme (www.mareano.no) financed by the Norwegian government. The authors wish to thank Olex AS for making bathymetry data available for use in this study. We also thank all MAREANO partners, cruise participants, and the crew of RV G. O. Sars for their contributions.

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