

Megafaunal diversity associated with marine landscapes of northern Norway: a preliminary assessment

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The seabed of northern Norway was explored using video and multibeam surveys to assess the distribution of megafauna and examine associations of benthic organisms to their physical environment. The study area was initially divided into ten marine landscapes based on seabed morphology and general water mass distribution. In total 195 taxa were observed during video recordings. The highest number of taxa was found within fjord/coast and upper slope landscapes. Multivariate statistical methods were used to relate bottom environment and taxonomic composition and in order to find the relation between faunal groups and landscapes. Detrended Correspondence Analysis indicated four groups of video transects. The most important environmental factors influencing the groupings were depth, and the frequency of occurrence of mud along the transects. Video transects from canyons and the deep slope formed a distinct group based on faunal composition. The three other groups consisted of transects from banks, fans in outer trough areas, and upper slope/slope terraces respectively. Based on the groups defined by DCA a new set of five landscape classes could be defined. The results indicate that broad-scale topographic features and general hydrography are of relevance for the distribution and composition of megafauna. However to be able to define finer-scaled units of "nature types" more factors (quantitative substrate composition, current regime, etc) must be taken into account, and detailed analyses of the video records must be performed.

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Introduction

The seabed can be characterised and classified at different spatial scales ranging from local environment (habitat) with factors affecting individual organisms, to ecosystems and landscapes where the substrates, terrain and oceanographic settings influence biological communities or populations.

There are several approaches to seascape and habitat mapping. Greene et al. (1999) provide a classification scheme for deep seafloor habitats where the issue of scale is dealt with in a hierarchy of classes. The same approach is applied in the European Nature Information System (EUNIS) (Davies et al. 2004). Both classification systems take into account the biological components of the habitat classes. However, whereas the Greene et al. (1999) classification scheme use the biological components as modifiers of geological and geomorphological features at an intermediate level (macro and meso habitats) the EUNIS classification emphasises taxonomic composition at the lower levels (level 8-10). The main point of difference is scale and the application of ecological

knowledge in the habitat map. Mapping "habitat" normally requires knowledge of the benthic biota and ecosystem details that are not required for landscape approaches. The habitat approach offers most chance of success as prediction normally must involve integration of biota and statistical approach to habitats. In this paper we make use of broad-scale information about benthic communities to check which geomorphological features display faunal differences.

The concept of marine landscapes is a broad-scale classification of the marine environment based on geophysical features. It was first developed for Canadian waters by Roff & Taylor (2000). The landscape approach is well suited for offshore areas where biological information is often scarce. Roff & Taylor (2000) developed a classification system based on environmental factors such as water temperature, depth/light penetration, substratum type, exposure and slope. They termed the classes 'seascapes'. Currently, the term 'marine landscapes' is commonly used (see Golding et al. 2004). This level represents an intermediate scale between regional seas and habitats. A marine

landscape should have consistent physical and ecological characteristics and provide a practical scale related to the management of human activities such as fishing and hydrocarbon exploration.

This study is part of the MAREANO (Marine AREAdatabase for NORwegian coast and sea areas) programme which maps seabed topography, substrates, biodiversity, habitats and sediment pollution in Norwegian waters (see Thorsnes this volume). Use of a variety of sampling tools has ensured that both epifauna and infauna are represented, allowing MAREANO to offer a unique insight into the diversity of benthic species and habitats. MAREANO was initiated to fill knowledge gaps about the seabed and environment, and which are required for informed, sustainable management. The mapping programme includes acquisition of multibeam bathymetry and backscatter data together with a comprehensive, integrated biological and geological sampling programme.

The main goal of the study presented here is to explore the possibilities for meaningful characterisation of marine landscapes using data sets developed in real-time, collected, and assessed during surveys with towed video cameras to describe the association between faunal distribution and large-scaled topographic features at variable spatial scales of marine landscape classification. The study will be used to assess the degree to which marine landscapes can be subdivided over large areas using a method which relies on rapidly gathered field data. The results from the study will also provide a useful background for the development of Nature types in Norway (NiN) (Halvorsen et al. 2008).

NiN will serve as a standardised classification system for identification of units of nature at any scale from local substrate to landscape.

In this study, multivariate statistical methods were used to relate taxonomic composition with environmental factors and broad-scale topographic features. This approach will hopefully aid the analysis of finer scale variation by identifying sub-sets of data for further analyses.

Study area

The study area comprises an area of 28 330 km² off the counties of Troms and Nordland in northern Norway (Fig. 1). Three research cruises with the R.V. G. O. Sars were conducted in this area in 2007 and 2008 in connection with the MAREANO programme. However, this study will only utilise results from the spring cruise in 2008, when a new procedure for recording field observations was tested.

The offshore area off Nordland and Troms is important commercially for fisheries and potential hydrocarbon development sites. The area has been assessed as valuable and sensitive with respect to biological resources (Olsen & von Quillfeldt 2003, von Quillfeldt et al. 2003) by expert groups reporting to the Norwegian government. In areas such as this, where several potentially conflicting activities occur, nature type mapping is particularly important since it allows for informed and sustainable management. Knowledge about the spatial distribution

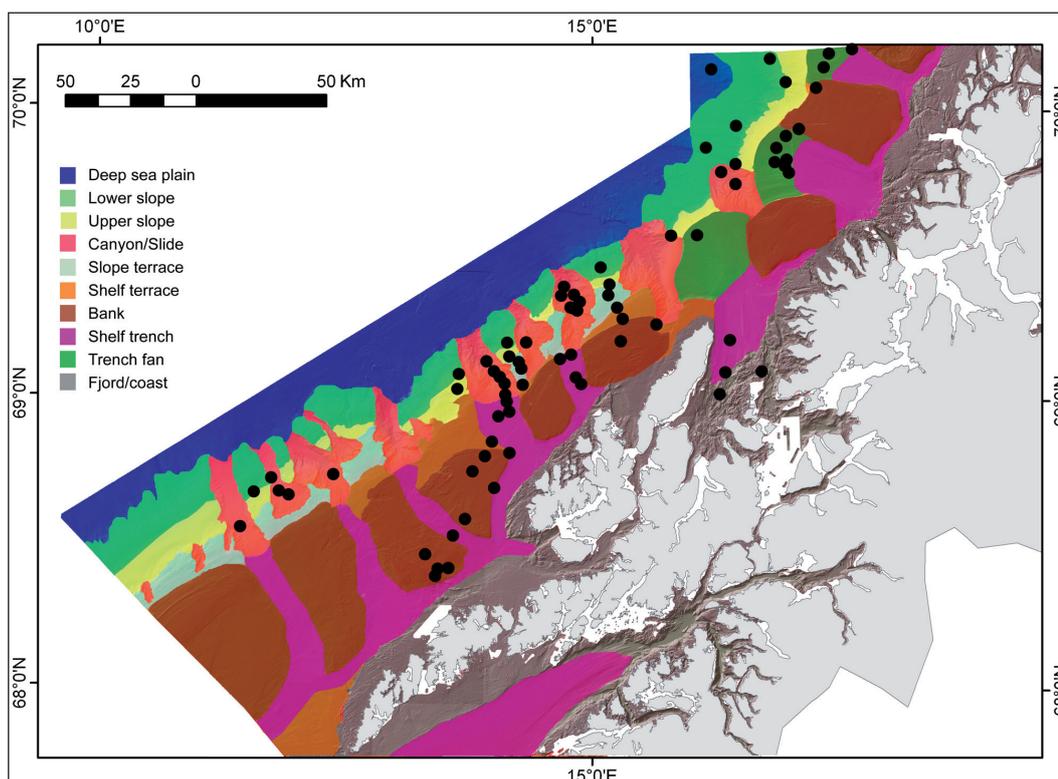


Figure 1. Map showing landscapes defined on the basis of broad-scale topographic features and general hydrography.

Table 1. Ten landscape units at different levels of classification based on broad-scale seabed topography and general distribution of water masses

	Marine landscape name	Definition
1)	<i>Fjord and coast</i>	Varied topography, with frequent occurrence of exposed bedrock, but also muddy level basins. This landscape is influenced by both Norwegian Coastal Water and North Atlantic Water. Only two locations in Andfjorden represent this landscape type.
2)	<i>Bank</i>	Glacial sediments dominate large parts of the banks and moraine ridges are also found. The banks are separated by troughs crossing the shelf commonly connected with fjords. Large parts of the banks have been heavily incised by iceberg ploughmarks (Bellec et al. 2008). Eleven locations represent this landscape type.
3)	<i>Shelf terrace</i>	Five locations represent terraces on the shelf. These are relatively level areas at depths between the shelf troughs and the banks. Within the study area this landscape mainly occurs between the shelf break and the banks.
4)	<i>Shelf trough</i>	Troughs were formed by erosion from ice flow during glaciations. The shelf troughs separate the banks and are often connected to fjords. The environment is variable with complex current patterns and occurrence of both sedimentation and erosion areas. This landscape is represented by twelve locations in the study area.
5)	<i>Trough fan</i>	Fans of sediments in the outer part of shelf troughs have been formed where the material transported by the ice reached the shelf break. This landscape differs from the connected troughs by being more exposed to the NWAC. Ten locations represent this landscape type.
6)	<i>Slope terrace</i>	Four locations occur in level areas below the shelf break. We termed this feature slope terrace. This landscape is part of the larger slope landscape complex which includes smooth slope, canyons and slide areas.
7)	<i>Upper slope</i>	This landscape represents smoothly sloping seabed down to 700 m, above the cold NSAIW. Only two locations represent this landscape type.
8)	<i>Canyon</i>	Canyons are valleys, or incisions in the continental slope comprising a fractural branching structure of smaller erosion channels meeting a central valley termed thalweg. The canyons often have areas where submarine slides have changed the shape of the erosion channels. The canyons cover water depths ranging from the shelf break down to the deep sea plain, having a variable hydrography with both the warm NAW, and the cold NSAIW and NSDW. This landscape is represented by the highest number of locations (19) in this study.
9)	<i>Lower slope</i>	This landscape has a relatively smooth sloping seabed similar to the upper slope, but is characterised by the cold NSDW and NSAIW below the NAW, at around 700 m depth. This landscape extends down to the deep sea plain at around 2400 m depth. Nine locations from this landscape were represented in the study area.
10)	<i>Deep sea plain</i>	The deep sea plain is a level muddy seabed occurring typically below 2400 m in the southern part of the study area and shallower in the northern part. Only one location was represented in the study area.

of different types of nature is the only background that can be used for the evaluation of areas. The amount of spatial information is greater at the lower levels i.e. at the scale of metres, termed “ecosystem level” in the nature type classification hierarchy. However, also higher classification levels operating at the scale of kilometres (landscape level) allow for the evaluation of areas based on a generalization of attributes such as diversity of habitats and species, ecosystem function and biological production, and how they differ from one another.

The study area has a varied seabed topography with plains and steeply inclined floors, and water depths ranging from around 80 m on the banks down to 3000 m in the Norwegian Sea. The oceanography of the area is influenced by four major water masses (Hansen & Østerhus 2000). The northward flowing Norwegian Coastal Current (NCC) comprises the low salinity Norwegian Coastal Water (NCW) with variable temperature. This water overlies the Norwegian Atlantic

Current (NWAC) (with Norwegian Atlantic Water - NAW) and is like a wedge thickest near the coast. The NAW extends down to about 500-600 m and is part of the relatively warm and saline North Atlantic Current (NAC). Below this depth two cold water masses are present: the Norwegian Sea Arctic Intermediate Water (NSAIW) and the Norwegian Sea Deep Water (NSDW). The former has temperatures between -0.5 and 0.5 °C, whereas the Norwegian Sea Deep Water (NSDW) typically has temperatures from -0.5 to -1.1 °C. The border between these two water masses occurs typically at around 1300 m depth off the Norwegian coast in the Norwegian Sea.

The study area was initially divided into ten units at different levels of landscape classification (see also Thorsnes et al. this volume) based on broad-scale seabed topography and the general distribution of water masses i.e., taking into account the border between NAW and NSAIW with different temperature regimes (Table 1).

Methods

Under the ongoing MAREANO programme, multibeam mapping surveys are followed up by comprehensive, multidisciplinary sampling cruises. Using a suite of remote sampling equipment including grab, beamtrawl, hyper-benthic sled and towed video platform, direct observations of the seabed were achieved. These observations are crucial for accurate mapping of seabed geology, biology, environmental status and habitats.

Data for this study comprised two main datasets: 1) topographic maps from multibeam echosounder data, and 2) field observation of benthic megafauna and bottom types made during video recording. The multibeam data were acquired by the Norwegian Hydrographic Service during several cruises in 2007 and 2008 as well as in earlier surveys by the Norwegian Defence Research Establishment (see Thorsnes et al. this volume for more details).

Registration of real-time seabed observations

Real-time observations of the seabed using video cameras were made at 75 locations during the fourth MAREANO sampling cruise in June 2008. The seabed and its epifauna were inspected with the video platform Campod. This is a tripod equipped with a high definition colour video camera (Sony HDC-X300) for inspection purpose, and an analog CCD video camera for navigation. During post-cruise analysis the video records obtained during this cruise are subject to detailed analysis of the seabed substrate and abundance of epibenthic megafauna. In this paper, however, only field observations noted during the video data acquisition were utilised for the initial broad-scale analysis.

During transects, each approximately 700 m long, CAMPOD was towed behind the survey vessel at a speed of 0.7 knots and controlled by a winch operator providing a near constant distance of around 1.5 m above the seabed. Geo-positioning for the field observations 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 about 2% of the water depth.

The video transects were divided into six sequences: two locations (start and stop of transect) with detailed inspection while Campod was stationary on the seabed, and four sequences of between 100 and 200 m long between start and stop. The occurrence of eight different bottom types (mud, sandy mud, sand, gravelly sand, sandy gravel, gravel, boulder, and bedrock) and organisms was recorded using the event-logging software 'Campod Logger' from the Institute of Marine Research. Navigational data (Date, UTC time, positions and depth) and bottom types were recorded automatically at ten seconds intervals using the last chosen bottom type.

When changes in the bottom type were observed the bottom type was changed manually accordingly. Each taxon was recorded upon its first occurrence within each video transect sequence. This provided a table of navigational data along with bottom type and records of the occurrence of taxa for each video transect.

Detrended correspondence analysis (DCA)

For the statistical analysis, relative abundance of megafauna for each video transect was calculated as the number of sequences with the occurrence of each taxon. The composition of bottom types from each video transect was calculated as the frequency of occurrence of eight different bottom types.

In order to identify species groups and the environmental variables that determine these groupings, multivariate statistical analysis is required. Several options are available and have been employed in previous habitat mapping studies to identify and visualise species groupings in relation to environmental variables, e.g. cluster analysis (Kostylev et al. 2001, Post et al. 2006) and canonical correspondence analysis (CCA) (Mortensen & Buhl-Mortensen 2005).

For this study we applied detrended correspondence analysis (DCA) to group video transects, based on species composition and relative abundance, using the software PC-Ord. The groups of video transects in this analysis reflect similarities based on species composition accumulated over a distance of 700 m. We believe this is an adequate scale for investigating patterns at a landscape scale. Different landscapes may have similar habitats with similar species compositions, but when studied at a broader spatial scale combined habitats provide different community "signals" that can be typical for specific landscapes. There is of course an alternative that the combined habitats "blur" the signal and spatial patterns become less clear. This is part of the problem of this study.

DCA has several advantages over alternative approaches. The basic approach is that DCA identifies species groupings first and then assesses the correlation of the environmental variables in relation to these groups along the various axes in multidimensional space. The axes of the ordination plot are given as eigenvalues, which is a measure of how much variation is explained by the axes. The sum of eigenvalues for all axes is called total inertia and reflects the overall variation in the data set. In total, ten environmental variables were used for this analysis i.e. depth and frequency of occurrence for each of the nine generic bottom types. In addition, the ten landscape classes defined in the study were used as a categorical variable to identify more easily groupings of video transects related to landscape. Only species occurring in three or more of the video transects were included which allowed 136 out of 195 taxa to be utilized for the

analyses. Analyses were made for both presence/absence data and relative abundance data (number of sequences with occurrence).

Results

The ten landscapes showed great differences in the relative composition of bottom types (Fig. 2). Large changes occurred when moving from fjord/coast to the deep sea plain. Bedrock was observed only in the fjord/coast landscape of Andfjorden. Gravel and boulders were most common on the banks. Below the upper slope the bottom type composition changed clearly, with increasing frequency of mud and sandy mud, while sand was absent.

A total of 195 taxa (identified species, and unidentified taxa at levels between genera and classes) were recorded. The highest number of taxa was found at depths between 200 and 300 m with 37 to 43 taxa at locations in fjord/coast and trough fan landscapes (Fig. 3). Below this depth the number of taxa per video transect decreased to between 7 and 20 taxa for locations below 1700 m. Thirty of the 195 taxa occurred only at one location, and 29 taxa only at two. These were not included in multivariate analyses.

Four groups of video transects were identified by using DCA based on species composition in the 75 video transects (Fig. 4A). The analyses of presence/absence data and relative abundance data revealed almost identical faunal patterns. Here we therefore

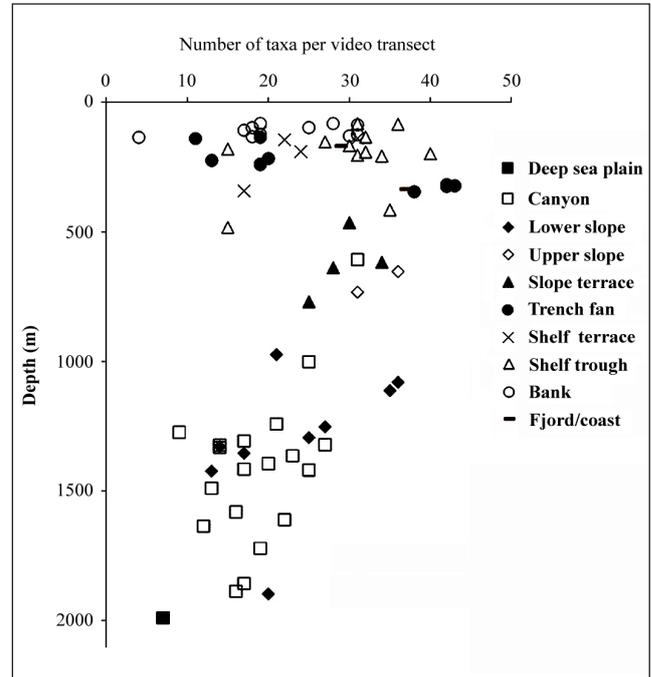


Figure 3. The relationship between number of taxa and depth for the ten different marine landscapes used in this study.

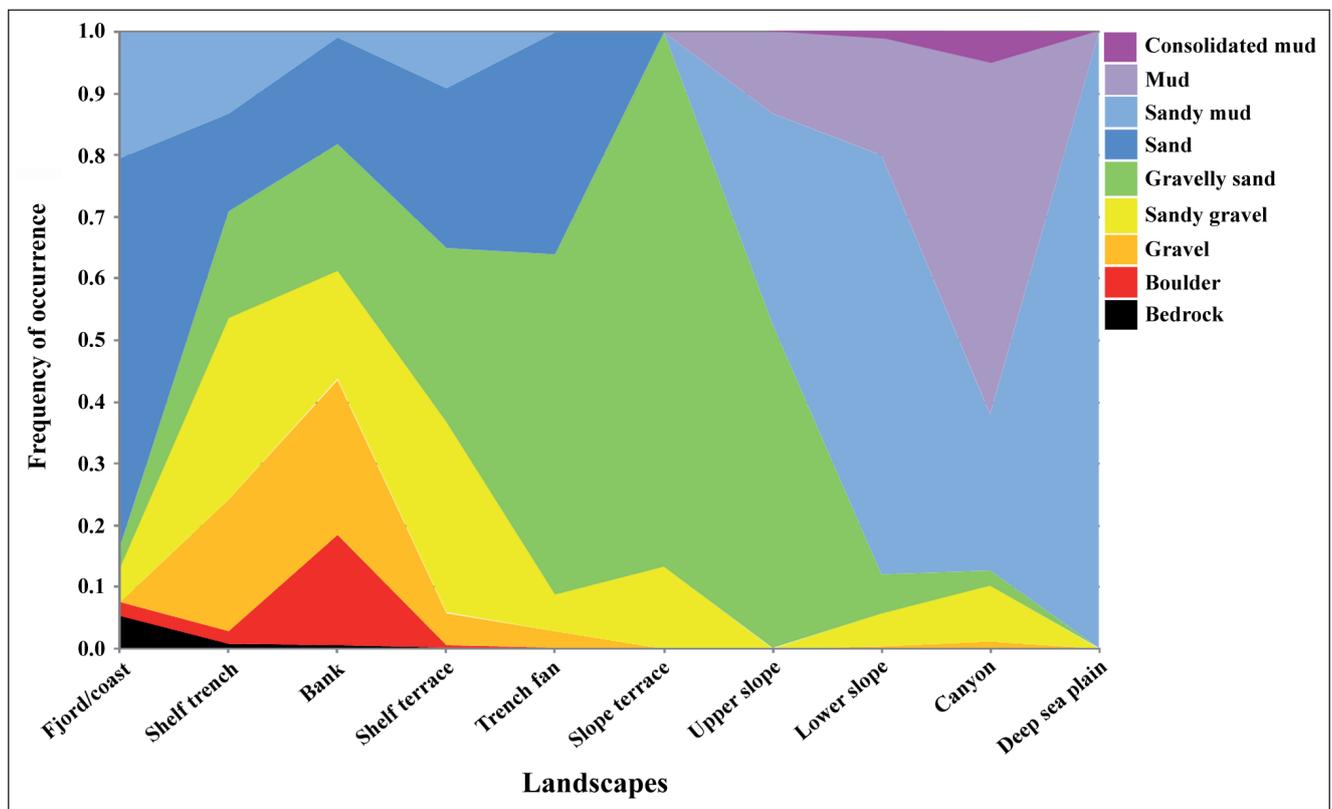


Figure 2. Relative composition (frequency of occurrence) of bottom types along a gradient from marine landscapes near the coast to the deep sea plain in the Norwegian Sea. The plot is made from average values for transects belonging to the different landscapes.

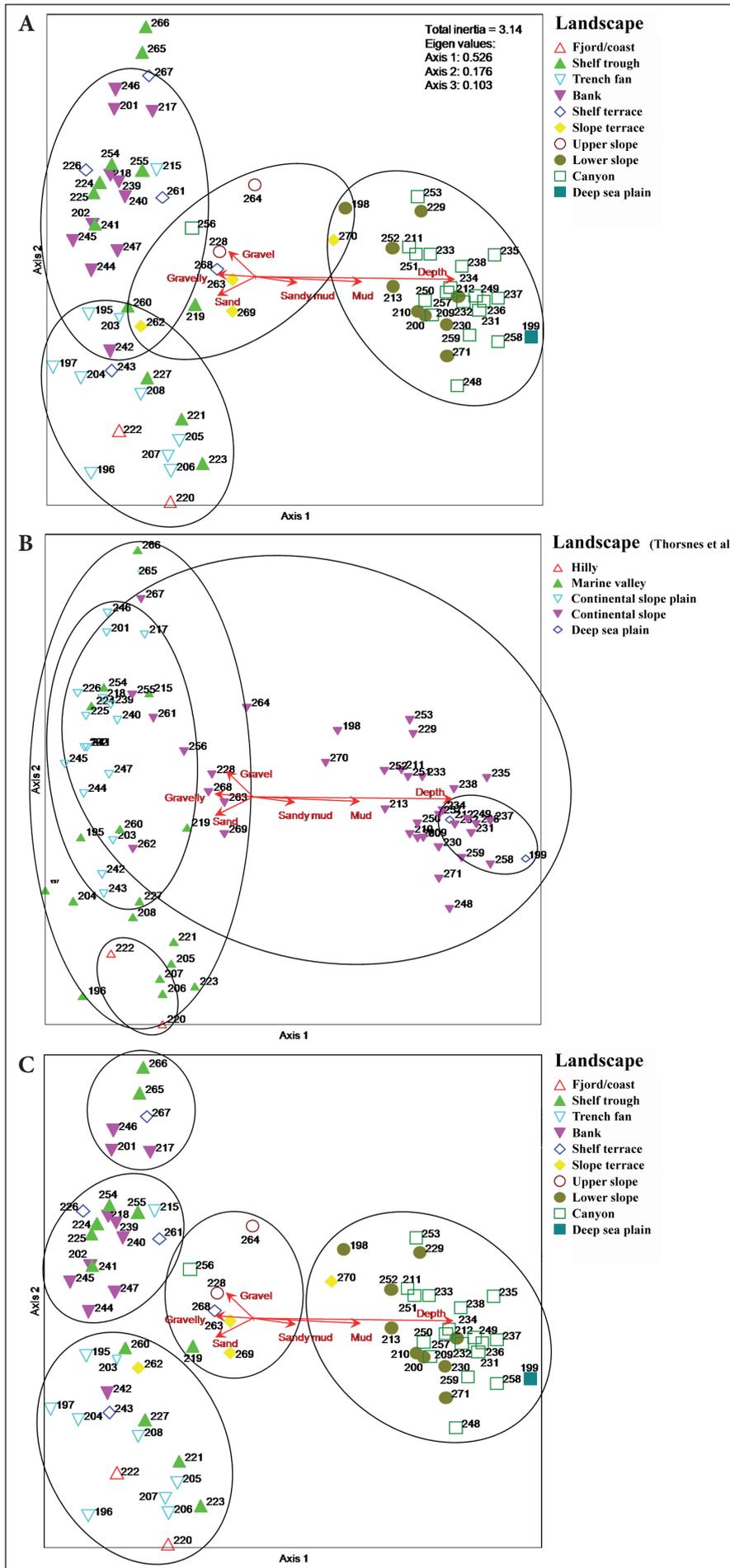


Figure 4. Plot of video sequences grouped by DCA based on species composition along 75 video transects along the seabed. The arrows indicate the relationship between the environmental variables and the ordination axes. The length of the arrows represents the strength of the correlations. A: groups of video transects identified from separation of landscapes defined in this study. B: groups of video transects identified from separation of landscapes defined by Thorsnes et al. this volume. C: groups of video transects identified and indicated by the DCA.

only present the results from the analyses of the relative abundance data because these contained more information. This was expressed as slightly higher eigenvalues for the DCA axes (0.04 higher for axis one). Most of the variation was explained by depth (correlation with first axis: $r^2 = 0.896$) and frequency of occurrence of bottom with mud (correlation with first axis: $r^2 = 0.45$). P-values are not provided for these correlations by the software, and as stated by McCune et al. (2002): "These correlations should primarily be used for descriptive purposes". The other bottom types were more weakly correlated with the ordination axes ($r^2 < 0.18$). The fauna of the lower slope and canyons was very different from the fauna on shallower areas on the shelf. One clear example was that of glass sponges (Hexactinellida) which were both more common and more diverse at the deep locations. Video transects from canyons and the lower slope formed a distinct group based on faunal composition. The three other groups separated transects from banks, fans in outer trough areas and upper slope/slope terraces (Fig. 4A). Transects from shelf troughs were widely distributed along the second DCA axis and showed faunistic similarities with both trough fan and bank transects. The two transects from the upper slope were more similar to bank transects than to lower slope and canyons.

Discussion

Methods for the collection and analyses of visual observational data from the seabed can be classified into analyses of frames (still images), georeferencing of occurrences of individual observations of organisms and seabed surface features and analyses of video sequences (Parry et al. 2003, Mortensen & Buhl-Mortensen 2005). Commonly, the observations are analysed from the playback of video records after the cruise. In this study we used field observations collected in a systematic way with the aid of the Campod Logger event-recording software. This can be regarded as a "quick and coarse" approach to seabed habitat analysis. However, the data lack detailed taxonomical precision and quantification, because they not allow for rewind or pausing of the record in order to study details. Nevertheless, we can assume that the precision was comparable for all locations because the taxonomically trained personnel were the same during the whole cruise. We are aware of this potential source of error, and the difficulty of assessing it. Hence, for future detailed studies of these video records one interesting task will be to compare the results of the preliminary visual seabed analysis with the post-cruise video analysis of the same material.

The classification of marine landscapes presented by Thorsnes et al. (this volume) was used to create a categorical variable representing an alternative classification. Using this categorical variable, video

transects from different landscapes had a great overlap with respect to the DCA (Fig. 4B). The classification by Thorsnes et al. (this volume) separates the shallow landscapes from the deep ones. However, the shallow landscapes overlap completely when based on faunistic similarities.

The DCA of both sets of landscape classes gives a clear indication that the marine landscapes on the shelf are more varied with respect to faunal composition than landscapes in deeper areas. This is most likely due to the higher habitat heterogeneity found in the different shelf landscapes providing many different microhabitats which in turn could lead to increased biodiversity (Warwick & Clarke 1998).

Our results indicate that broad-scale topographic features and general hydrography are of relevance for the distribution and composition of megafauna. However, in order to be able to define finer-scale units of nature-types more factors (detailed substrate composition, current regime, etc.) must be taken into account and the taxonomic data must be analysed more rigorously. For the characterization of nature-types on the ecosystem level (see Halvorsen et al. 2008) more information about infauna and epifauna from bottom samples is required. This aspect is the subject of ongoing analyses of material collected as part of the MAREANO programme.

Our approach of combining information from field observations of video transects (sediment characteristics and associated megafauna) with multibeam data in order to characterise marine landscapes proved, although rather crudely, to be successful. Different landscape types could be grouped based on their distinctive associated faunas and also on their main environmental factors.

Depth was identified as the environmental factor explaining most of the faunistic variation in the material. It is worth remembering that depth per se is not a factor influencing invertebrates but is a proxy for several environmental variables (e.g. temperature, pressure, light level, O₂ concentration). In this case depth reflects the changing temperature regimes in the shallow and deep water areas and the corresponding changes in, for example, current velocity and food supply. The transition between warm Norwegian Coastal water (NCW) and cold Norwegian Sea Deep Water (NSDW) occurs at a depth of approximately 700 m. This depth represent a major shift in benthic community composition in the Norwegian sea and has been documented in several studies (e.g. Dahl et al. 1976, Buhl-Jensen 1986, Gage 2001).

Most of the landscapes we defined on the basis of broad-scale seabed morphology have areas (here represented by our video transects) with species compositions not very different from one or more of the other landscapes. This could reflect habitat similarities between landscapes or irrelevant (with respect to faunal grouping)

classification of landscapes. Based on the grouping of locations provided by the DCA analysis we made a new classification separating the video transects into five groups (Fig. 4C). Plotted on a map (Fig. 5) the following revised landscapes include: 1) shelf troughs, 2) banks, 3) shelf break, 4) upper slope, and 5) lower slope. There are some exceptions regarding locations that do not occur within similar topographical features like the majority of the video transects within the DCA group. For instance, the video transect located at the outermost part of the fan of the Andfjorden trough at the shelf break is grouped together with bank locations. This may be because the fan is exposed to currents in a similar way to the banks. It is still in the same water mass as both the banks and the shelf troughs. There are also two video transects located in the trough west of Andøya that have more faunistic similarities with the upper slope than with other trough locations. Despite these exceptions, this revised classification (Fig. 4C) provides a means of establishing a coherent set of marine landscapes supported by both the biological and geological data sets. This is a useful background for selecting sub-areas to concentrate efforts aimed at further study to reveal finer spatial patterns of biology, surface geology and topography. The use of such landscape classes in management however, is probably limited without knowledge from lower levels nature types at lower levels. Lower level units (landscape elements, or mesohabitats and lower levels) will provide more differentiated information about biological resources such as biodiversity, sensitive habitats, commercially interesting species, etc.. More

detailed analyses of the seabed substrates and their associated epifauna from the video records together with a wider set of environmental data such as currents, bottom temperature, surface primary production, etc. will reveal clearer patterns that can better define marine landscape elements in this area. Mortensen et al. (submitted), and Dolan et al. (this volume) have shown that thorough analyses of video results with a finer spatial scale combined with information from multibeam bathymetry enable prediction of habitats at a finer scale with full areal coverage. Such analyses are more suitable for providing background information for management decisions, and represent one fundamental result from the MAREANO mapping programme. The valuation of habitats largely relies on information about the biodiversity as mentioned above. This information is provided by bottom samples.

This study, testing landscape classification in relation to fauna, together with testing of preliminary NiN landscape classes and geological structures (Thorsnes et al. (this volume)), will ultimately lead to better landscape level classification for Norway and will have clear relevance for future nature-type mapping activities.

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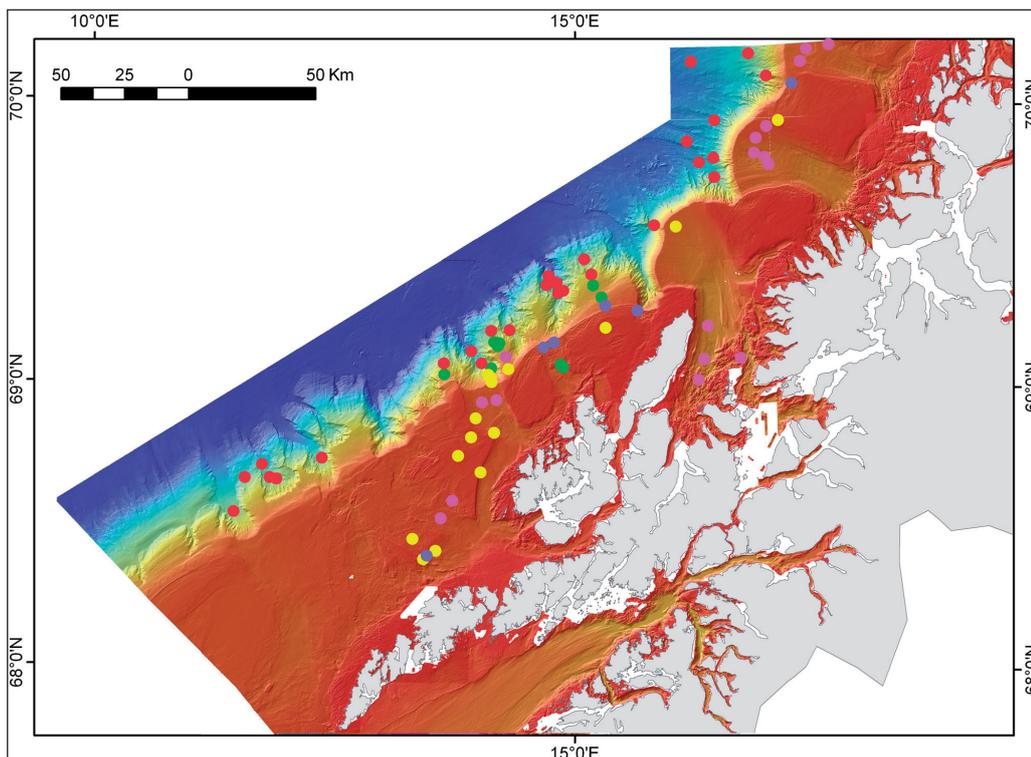


Figure 5. DCA groups of video transects plotted on a topographic map of the study area.

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