DATA SETS, PRODUCTS AND METHODS
USED FOR MAP PRODUCTION
IN MAREANO BY NGU –
CURRENT STATUS

(*Last updated 24.08.2017)*

Content

1. INTRODUCTION

This document contains a summary of data sets, products and methods used for mapping and scientific studies in MAREANO by the Geological Survey of Norway (NGU). The document provides some short and some longer descriptions of data sets, products and methods and also references and links to important publications, reports, web pages and technical documents.

The areas to be surveyed with acoustic methods, visual tools and physical sampling are chosen by the MAREANO Programme group and Steering group. This is usually concluded the year before the surveys, following long-term planning spanning over several years.

2. ACOUSTIC DATA

2.1 Multibeam echosounders

Data on bathymetry, backscatter and the water column are collected by multibeam echosounders mounted on surface vessels (figure 1).

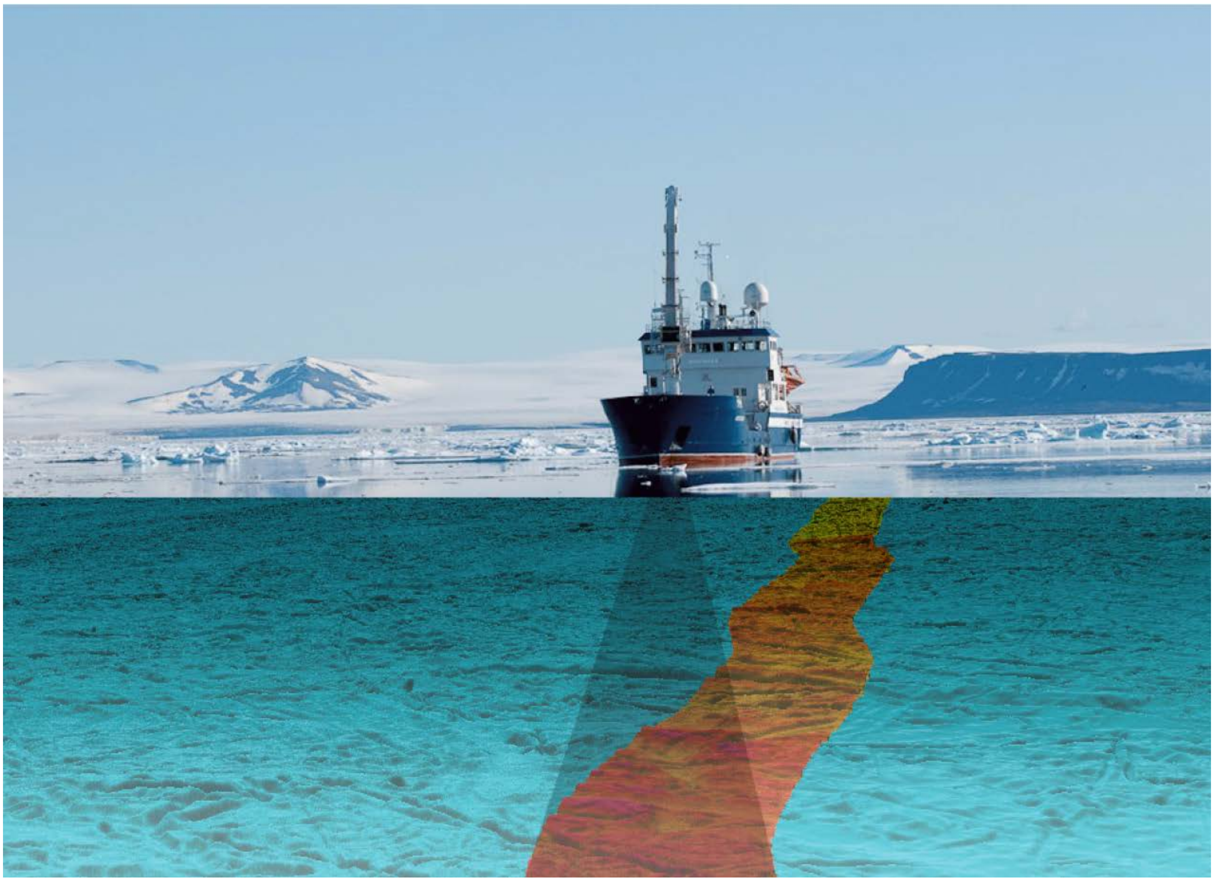

Figure 1. Illustration of surveying using multibeam echosounder.

2.1.1 Multibeam swath bathymetry

Bathymetry data are collected, processed and managed by the Norwegian Hydrographic Service. Bathymetry data are used to produce digital terrain models (DTM) of 5, 25, and 50-metre resolution (figure 2). In some areas it may be possible to produce DTMs with even higher resolution depending on the depth, multibeam echosounder used and the resulting sounding density. Inside the territorial boundary, the resolution is limited to 50 metres in compliance with Norwegian military classification regulations.

Bathymetry data give important information on the general seabed topography, as well as all seabed features (like iceberg ploughmarks, coral reefs, pockmarks, sand waves, boulders etc.). Both the surveying and processing must be done in a careful manner to preserve all the seabed information, yet facilitate removal of any faulty soundings. Data artefacts can occur; it is important that seabed features are not camouflaged by artefacts, or that artefacts appear as false seabed features. Despite cleaning, some motion-related artefacts may persist in otherwise clean data, especially when the surveys have been conducted in poor sea conditions.

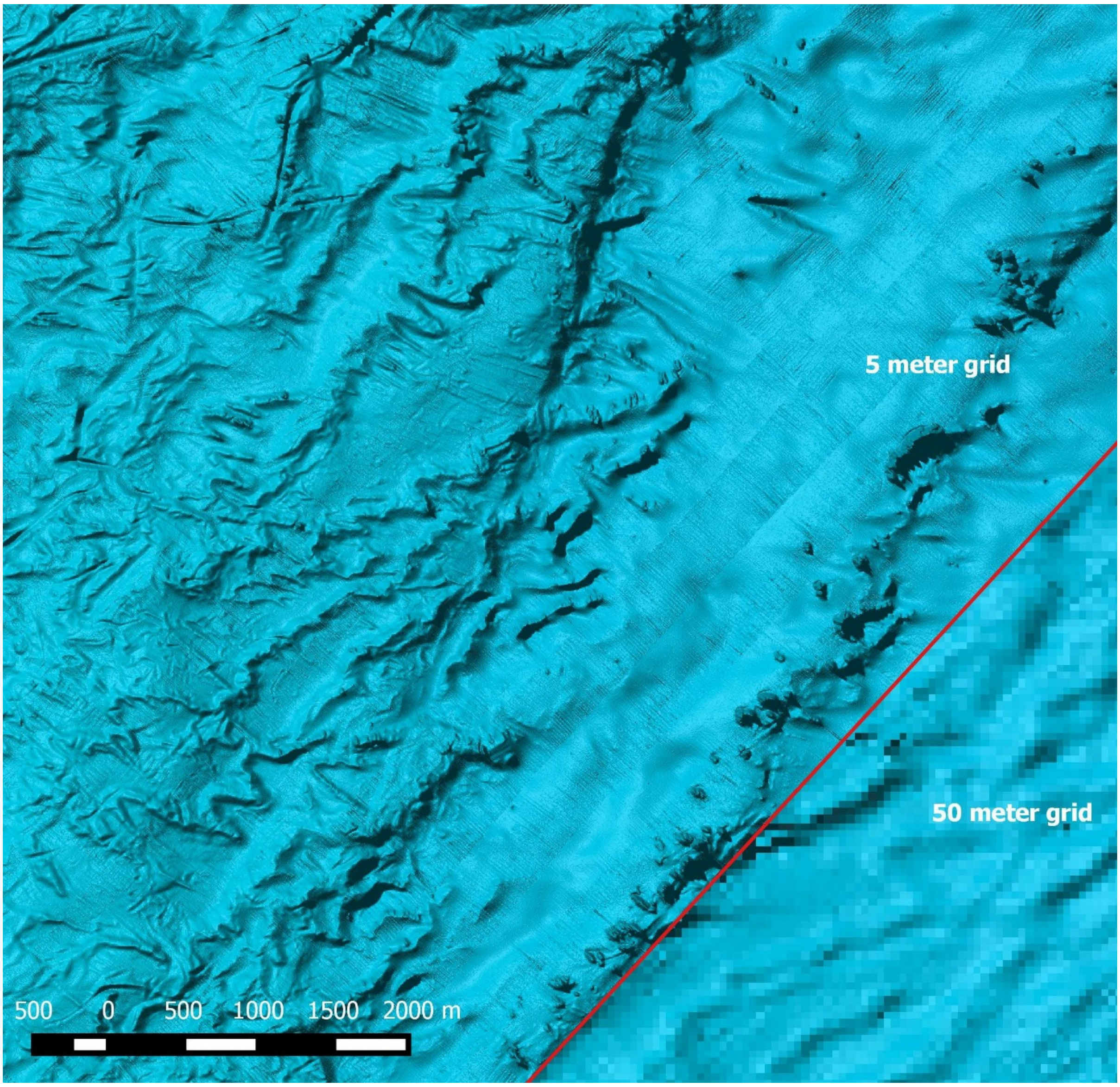

Figure 2. Digital terrain models from Sularevet with 50 metres resolution (down to the right) within the territorial border, and 5 metres resolution (up to the left) outside the territorial border. Coral reefs, moraines and iceberg ploughmarks can be identified using 5 metres resolution, but not using 50 m.

2.1.2 External and non-standard bathymetry data

If bathymetric data of adequate quality and resolution exist, these are used by MAREANO. Sources of existing data are the Norwegian Mapping Authority (Norwegian Hydrographic Service, NHS), the Norwegian Defence Research Establishment (FFI), the Norwegian Petroleum Directorate, Olex AS, the petroleum industry, universities, research institutes and other bodies. Olex data (figure 3) is a compilation of mostly single beam echosounder data acquired by working vessels using the Olex vessel navigation system. Use of Olex for sediment and biotope mapping has been evaluated (Elvenes et al. 2012), showing a considerable potential, with some important limitations. Data provided by Olex to MAREANO have been used at Mørebanken. The coverage varies, and in areas with good coverage (important fishing areas), it is possible to produce a DTM with a resolution of 50 metres. Olex data do normally not have backscatter or water column data, nor do some of the older multibeam surveys.

Collection of bathymetry and backscatter data using AUV was tested in October 2015, using the HUGIN 3000 AUV equipped with an EM2040 multibeam echosounder. In addition, Synthetic Aperture Sonar data, colour imagery and methane sniffer data were collected, along with standard environmental parameters. These data are currently evaluated, and will be reported during 2016.

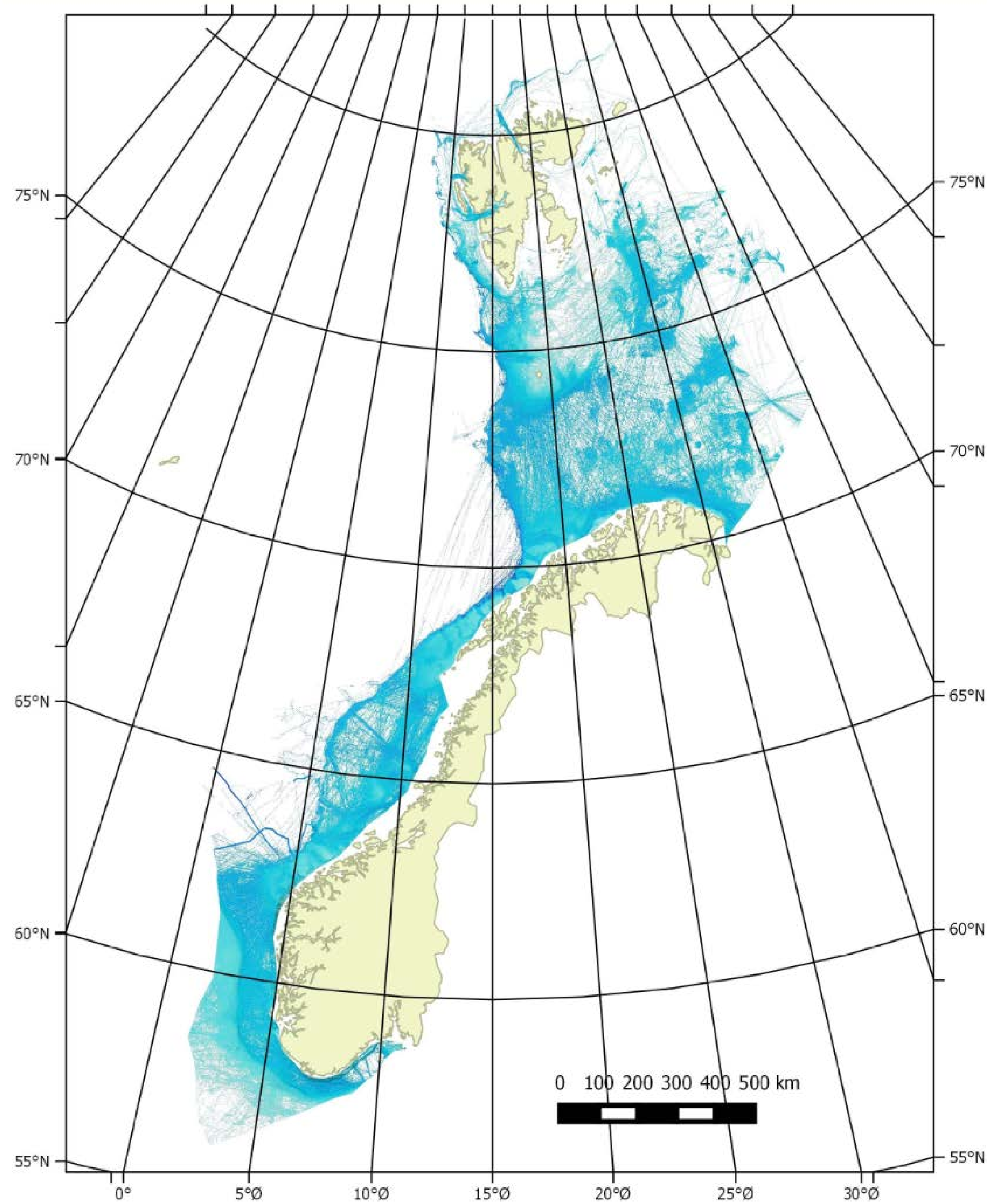

Figure 3: Coverage of Olex data in Norwegian sea areas (2010).

2.1.3 Multibeam backscatter data

NGU is responsible for processing and archiving of processed multibeam backscatter data (figure 4) under the MAREANO programme. Raw multibeam data, incorporating backscatter information, are managed by the Norwegian Hydrographic Service (NHS). Following multibeam data acquisition by the Norwegian Hydrographic Survey (or contractors) raw multibeam data are sent to The Geological Survey of Norway for backscatter data processing. From here the data are taken directly into the workflow for geo-bio cruise planning and sediment interpretation (post-cruise). Backscatter data are also published in map format on www.mareano.no and included as an inset map in NGU's pdf map series.

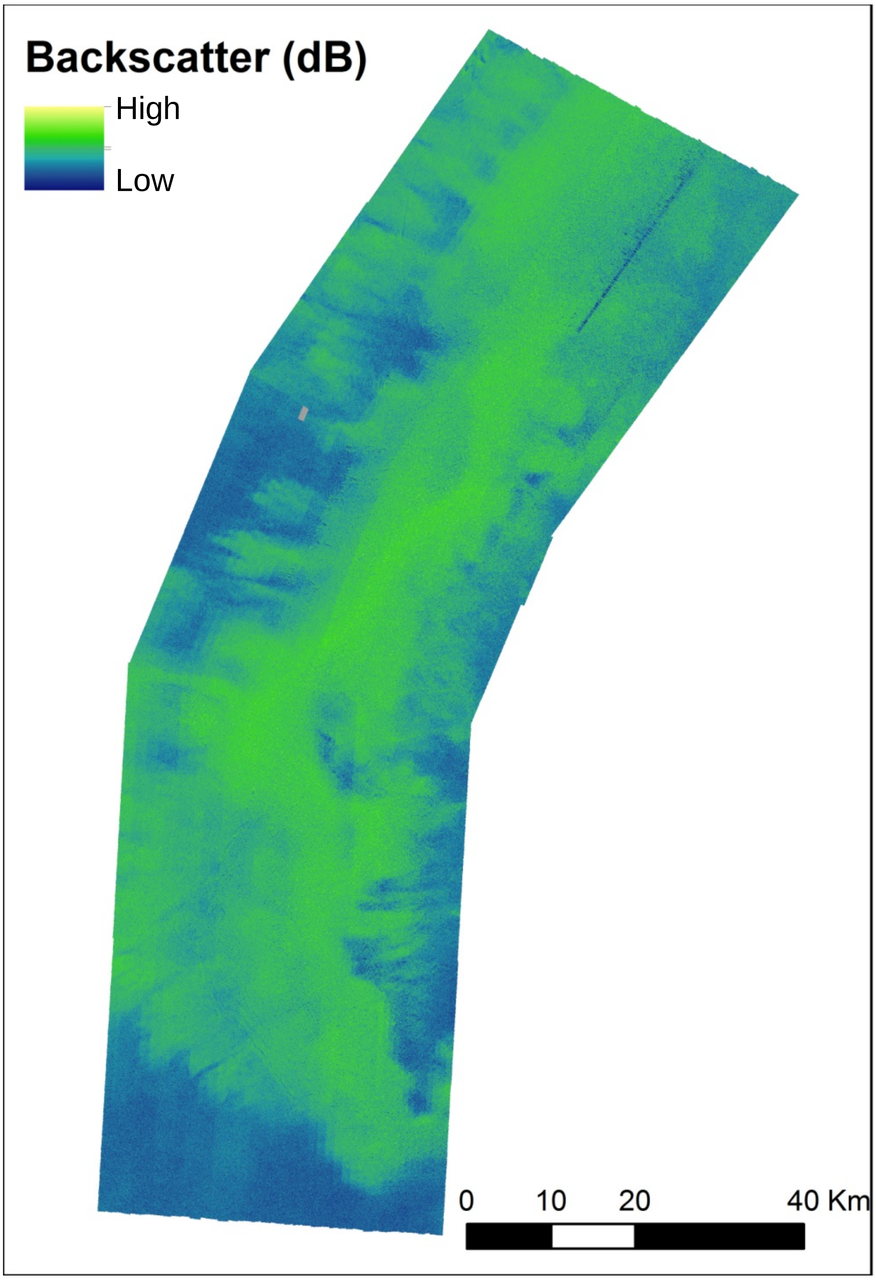

Figure 4. Example of multibeam backscatter data from Skjoldryggen, Norwegian Sea. Data were acquired using a Kongsberg EM710 multibeam echosounder and processed using QPS-Fledermaus FMGT to produce backscatter mosaics with a resolution of 3 metres.

Multibeam echosounder data include backscatter data, which are invaluable for interpreting seabed sediments. Backscatter provide a first indication of the hardness of the seabed and thus the sediment type, but represent only an acoustic proxy to sediment properties. Backscatter must therefore be ground truthed – i.e. verified by visual and/or physical sampling. Together with bathymetry and ground truthing information, acoustic backscatter data provide the basis for interpretation of sediment distribution. However, it is worth noting that there are several challenges associated with the use of backscatter data. They are usually not calibrated, meaning that absolute backscatter values (in dB) cannot be compared directly from one area to another. Also, the backscatter value for a given sediment varies if echosounders with different frequencies are used. The backscatter is texture dependent, meaning that an uneven seabed may give a different response from an even seabed. Finally, the acquisition-specific modes and settings of echosounders vary, being an additional source of variations not related to sediment variability. For these reasons, extra care must be taken when interpreting backscatter data (see below). Successful use of backscatter data is dependent on sufficient ground-truthing and qualified expert interpretation.

Further details on backscatter data are available in the internal working document *Multibeam backscatter procedures for the MAREANO programme, Geological Survey of Norway (NGU).* This provides an overview of procedures that are followed by all staff when processing the data using the various software currently available at NGU. After more than a decade of MAREANO multibeam data acquisition, these data, together with several pre-MAREANO surveys, constitute a considerable data holding. The procedures document provides a summary of the measures NGU is taking to manage the ever-growing volume of backscatter data. Due to a re-organisation of the data storage facilities at NGU during 2015 and ongoing developments in ESRI image management software the new in-house backscatter data management system is currently in development, but promises to offer a more manageable long-term solution than its predecessor, with a simplified workflow through to web-publication.

References

Multibeam backscatter procedures for the MAREANO programme, Geological Survey of Norway (NGU).

Lurton and Lamarche (2015) Backscatter measurements by seafloor-mapping sonars, guidelines and recommendations: http://geohab.org/wp-content/uploads/2013/02/BWSG-REPORT-MAY2015.pdf

2.1.4 <u>Water column data</u>

Since 2010, water column data have also been acquired using multibeam echosounders. These are reflections of the sonic pulse as it travels through the water, before it reaches the seabed. Such data can be used to detect objects or anomalies in the water column, for example to detect gas bubbles rising from the seabed (figure 5).

After data acquisition, the water column data are managed by the Norwegian Hydrographic Service, which will forward the data to the Geological Survey of Norway. The MBE data are processed using Fledermaus FM Midwater for water column anomalies, and manually scrutinized for gas flares, similar to the procedures described in Chand et al. 2012. The water column data are evaluated parallel and perpendicular to the tracklines to identify anomalies. The coordinates of potential gas flares are recorded, along with the survey name and line ID. A subjective assessment of the apparent strength is done. Potential, but uncertain flares which may be fish schools is assigned the code 1. Anomalies interpreted to be flares are given the codes: 2 - weak, 3 - medium strong; 4 - strong; 5 - very strong. Interesting water column anomalies which are not related to gas leakage are given the code 9. These may represent large fish schools, large plankton schools, or mammals. Lines without any identified flares or interesting non-gas features are given the code 0. The coordinates and attributes of the gas flares are displayed in ArcMap shape files for visualisation and quality control. NGU is will establish a web service to display locations of gas flares with associated attributes in 2016. As part of this process, a scientific publication describing methods and preliminary findings is in preparation (Thorsnes et al., in prep.).

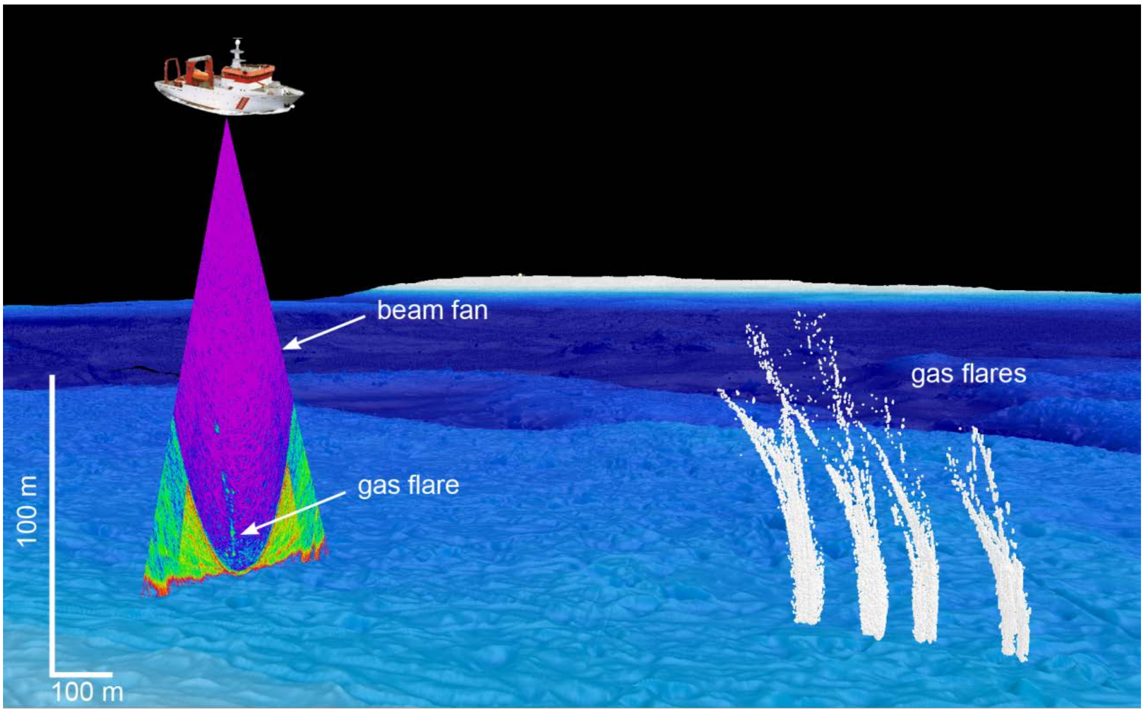

Figure 5. Visualisation of gas flares in the multibeam echosounder beam fan, showing records from the vessel H.U.Sverdrup (Norwegian Defense Research Establishment) using an Kongsberg EM710 system in the Harstad Basin off Northern Norway. 5x vertical exaggeration.

References

Chand, S., Thorsnes, T., Rise, L., Brunstad, H., Stoddart, D., Bøe, R., Lågstad, P., Svolsbru, T., 2012. Multiple episodes of fluid flow in the SW Barents Sea (Loppa High) evidenced by gas flares, pockmarks and gas hydrate. Earth and Planetary Science Letters 331-333, 305-314.

Thorsnes, T., Chand, S., Lepland, A., Aarrestad, S., Brunstad, H. & Hodnesdal, H. in prep. Gas Flares and Fluid Flow Seabed Features in Norwegian waters - the MAREANO database.

2.2 High resolution seismic data

High resolution seismic data are collected to complement multibeam data, permit characterization of sediment stratigraphy and sediment types, and for studies of geological processes on the seabed and in the upper sediment column. Lines with high resolution seismic data should ideally cover a wide range of geological settings, in order to provide information on the geological processes which have formed the seabed. This would give additional information for optimal location of visual and physical sampling. In practice, the majority of high resolution seismic lines acquired by MAREANO are collected on the sampling cruises, in transit between sampling stations, or on transits to and from ports. This still gives valuable information, but is not ideal.

G.O. Sars, which is the main vessel used by MAREANO, is equipped with a hull mounted TOPAS PS 18 (TOpographic PArametric Sonar). The TOPAS data are used, in combination with other seabed data, for mapping seabed sediment distribution and linking biological and geological processes. TOPAS PS 18 is designed for sub-bottom profiling with very high spatial resolution in water depths from less than 20 metres to full ocean depth. The low frequency signal is generated in the water column by non-linear interaction between two high frequency signals (centered symmetrically around 18 kHz). Similarly, a sum frequency signal is also generated. However, only the low frequency signal (0.5-6 kHz) is used for sub-bottom profiling. The parametric sources have the advantage of generating a low frequency, narrow (4.5 degrees for TOPAS PS 18) signal beam with no distinct side lobe structure.

The system can operate with various signal waveforms for optimal performance: Typically, Ricker pulses are used for very high resolution work, Chirp pulses are used for deep water, high penetration work and CW pulses are used for narrow band, frequency sensitive work. Penetration performance depends on sediment characteristics, water depth, transmitted signature, noise level etc. According to Kongsberg Defence Systems, penetration of 200 metres has been achieved in water depths of more than 3000 metres with a sediment layer resolution of typically 20 cm or better.

MAREANO has experienced that TOPAS PS 18 can penetrate 100-150 metres into soft, fine-grained sediments and that the resolution is better than 0.5 metre in Chirp-mode. The penetration is less in sand, in coarse-grained sediments, or where the bottom is hard (i.e. till). The resolution increases towards shallower water due to the decreasing area of the signal footprint. In areas with irregular seafloor topography or steep slopes the resolution decreases because of larger footprint. Where the seabed slopes more than 4-5 degrees, the data cannot be used. Reasonably good data are obtained with up to 4-5 metres wave height when the survey vessel runs in the direction of the weather.

The primary frequency pulses around 20 kHz or its harmonics can interfere with other acoustic systems onboard, and the systems should be synchronized so that high quality data can be acquired both during transit and planned surveys. Raw data from the TOPAS are stored as TOPAS-files and later processed and converted to segy-files for seismic interpretation utilizing commercial software.

High resolution seismic data are crucial for reliable mapping of seabed sediments and bottom types. TOPAS PS 18 is installed also onboard H.U. Sverdrup (FFI). Other bottom penetrating sonar/pinger systems onboard of other ships can be used for collection of high resolution seismic data. Data quality may vary depending on weather condition, type of system, processing etc. It is also possible to collect very high resolution bottom penetrating sonar data utilizing autonomous underwater vehicle (AUV). For further details on high resolution seismic data, see Bøe et al. (2010).

It is possible to use high resolution seismic systems together with multibeam echosounders, but they must be carefully synchronized with the echosounder, so that they do not disturb each other. This will reduce the ping rate of the echosounder (i.e. how often it can measure), but high resolution does not need to be measured on every line. Every fourth line should be adequate in order to meet the objectives of providing relevant information to support the interpretation of seabed substrates.

TOPAS data collected by MAREANO onboard G.O. Sars are brought back to NGU for processing and storage. The following steps are followed:

1. Processing of raw-files to SEGY-files using TOPAS software from Kongsberg.
2. Navigation correction and import into NGU database
   - Calculation of correct CMP-positions based on antenna/TOPAS separation, and removal of GPS-introduced inaccuracies using FME-software (www.safe.com)
   - Creation of corrected SEGY-files.
3. Print-delay correction of SEGY-files.
4. Production of JPEG2000-versions of SEGY-files for interpretation, visualization and web-thumbnails.

References

Thorsnes, T., van Son, T.C., Dolan, M.F.J., Gonzalez-Mirelis, G., Baeten, N., Buhl-Mortensen, P., Bjarnadóttir, L.R., Hodnesdal, H., Bellec, V. 2015: An assessment of scale, sampling effort and confidence for maps based on visual and acoustic data in MAREANO. NGU Report 2015.043, 97 p.
http://www.ngu.no/upload/Publikasjoner/Rapporter/2015/2015_043.pdf

Sediment echosounder (TOPAS) http://mareano.no/om_mareano/arbeidsmater

TOPAS lines and mini pictures
http://geo.ngu.no/kart/marin/MARINEKART.html?kart=4&latlon=74.55,29.6&zoom=5#

3. VISUAL DATA AND PHYSICAL SAMPLES FOR GEOLOGY (AND BIOLOGY)

3.1 Cruise planning and sampling strategy

The current main survey strategy for MAREANO is full area-coverage bathymetry/ backscatter/water column data, with visual and physical sampling at a pre-defined density (10 and 2 stations per 1000 square kilometers), respectively. However, specific data needs and other circumstances have led to different survey strategies being employed in certain areas (Thorsnes et al. 2015, section 4.1).

Sampling stations for geological and biological sampling are selected primarily on the basis of multibeam data. Since 2015, oceanographic data have also been taken into account. Stations are placed to ensure representative sampling across the survey area, based on the allotted number of samples per square kilometres set in the annual budget. This standard sampling effort of 10 video stations, including 2 physical stations per 1000 square kilometres has been a general guideline, not a rigid standard over the years and there are several areas where sampling effort has varied from this standard (Thorsnes et al. 2015, section 3, figure 10). In some cases this has been a result of adapting the strategy to accommodate the use of existing data (e.g. Olex at Mørebankene), or in other cases to provide an increased level of documentation in places of special interest (e.g Hola/Bleiksdjupet) (Thorsnes et al. 2015, section 4.1). Since 2012 the standard has been more closely followed, however in recognition of the fact that the environmental variability across the Norwegian seabed is not constant, development of a standard for sampling effort which is guided by the degree of variability –

the Environmental Variability Index (EVI) was developed by MAREANO (van Son et al. 2015).

The sampling stations acquire data for multiple objectives:

- Ground truthing of multibeam backscatter data for sediment interpretation
- Visual documentation of biotopes (expected to vary with physical environment)
- Visual documentation of vulnerable habitats (Norwegian Environment Agency and OSPAR - Convention for the Protection of the Marine Environment of the North-East Atlantic)
- Video and sample material for assessment of biodiversity and production
- Sample material for geological and geochemical analysis
- Verification of morphological features identified by multibeam bathymetry data, particularly those with ecological relevance, e.g. coral reefs

An order of priority for positioning sampling stations with respect to each of these objectives has not yet been set by MAREANO (see also section 2.2). Selection of sampling stations in MAREANO has largely been guided by expert judgement in an attempt to obtain representative samples of all major habitats in the study area and a good geographic spread spanning depth intervals of known biological relevance (e.g. water mass boundaries). The station planning process is typically as follows: A preliminary assessment of the geology and geomorphology of an area is conducted by NGU scientists based on multibeam bathymetry data from NHS. Multibeam backscatter data are processed by NGU and assessed as a first pass indication of surficial sediment type. After combining bathymetry and backscatter data, sampling stations are planned to obtain representative sampling of the major geomorphic features and to ground-truth the different acoustic signatures in the multibeam backscatter. Multibeam data for a bio-geo survey area typically come from several mapping surveys that have used different survey vessels/contractors/multibeam systems (figure 6). Sampling must ensure, as far as possible, that backscatter levels from each of the individual surveys are ground truthed so that the data can be used to interpret sediment distribution across the entire area.

In addition to a visual assessment, these multibeam data are also subjected to a coarse unsupervised classification which splits the survey area into areas with similar physical characteristics based on bathymetry, backscatter, and terrain attributes (e.g. slope, curvature etc.) at both local (100s metres) and broader scales (kilometres). To date the ISOCLUSTER algorithm with maximum likelihood classification in ArcGIS has been used to provide this initial, broad-scale assessment of physically distinct areas, which are likely to reflect different seabed habitats in terms of the bottom type and structure, and the biological communities living there.

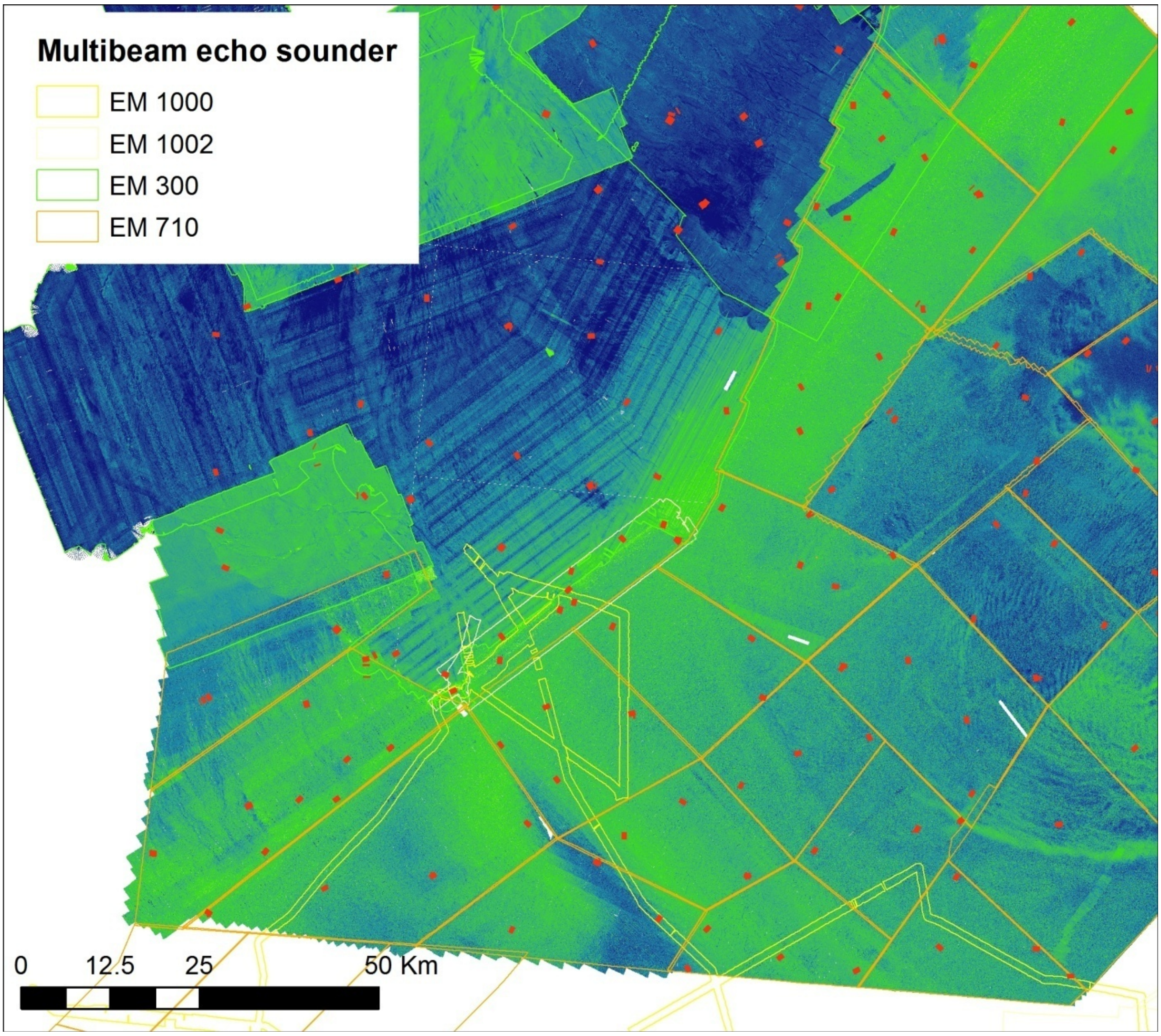

Figure 6. Example of backscatter data from Nordland VI. Data are from 4 different echosounders - EM1000, EM1002 (95kHz), EM710 (70-100), EM300, (30kHz), which have different penetration depths. Backscatter dB from each survey are shown on the same colour ramp highlighting differences in the values from low (blue) to high (green). MAREANO video stations are shown in red.

This ISOCLUSTER layer (figure 7) is used to provide a more objective overview of the study area and sufficient number of samples from each major class is ensured by expert judgements. Other data/knowledge from the study area is also considered at the cruise planning stage e.g. available records of coral occurrences. Oceanographic data has been taken into account since 2015.

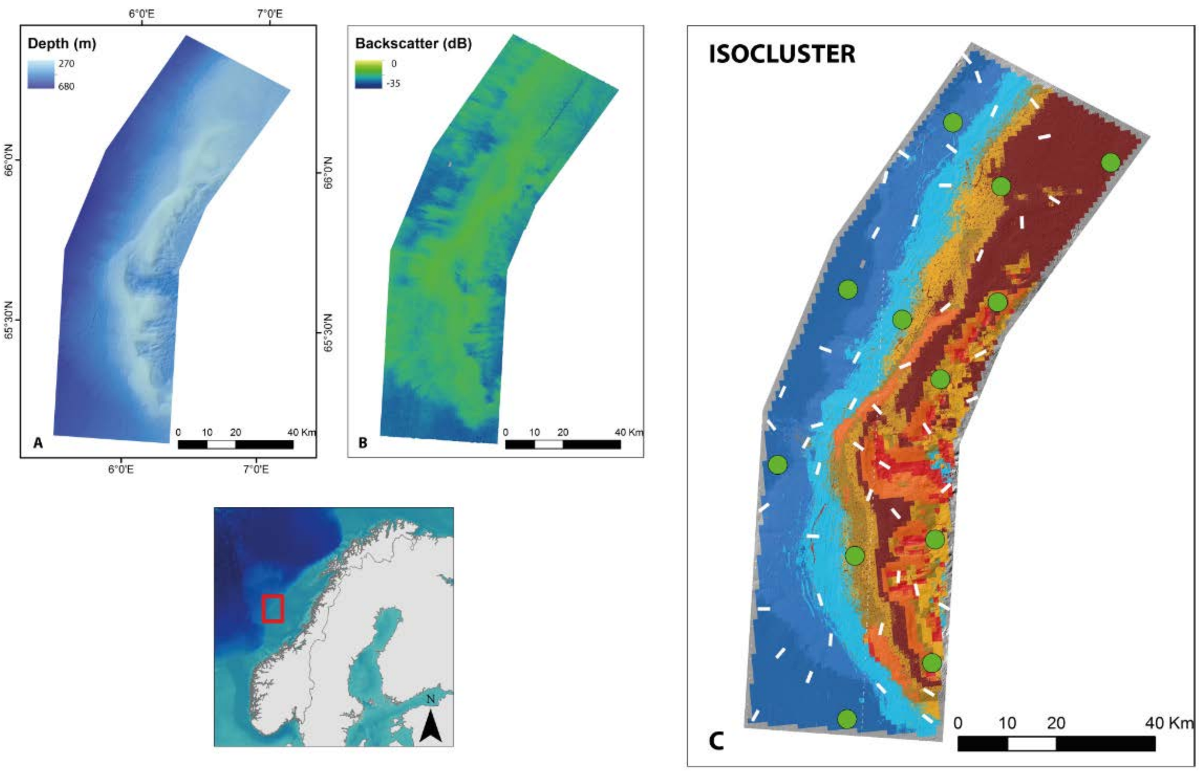

Figure 7. Example data used for planning MAREANO survey stations with location map at Skjoldryggen in the Norwegian Sea, surveyed by MAREANO in 2013. (A) Multibeam bathymetry shown as colour shaded relief. (B) Multibeam backscatter map indicating variation in sediment properties. (C) ISOCLUSTER map based on unsupervised classification of bathymetry, backscatter and derived quantitative terrain variables. The colours indicate physically different areas based on these variables — similar colours indicate areas with similar physical characteristics while contrasting colours indicate physically different areas. Planned video lines indicated with white lines, green circles indicate full sampling stations.

In due time before each cruise, a more formal cruise planning meeting is held to review suggested survey plans and harmonise biological, geological and chemical sampling objectives. This meeting is also open to members of the MAREANO programme group, representing different stakeholder interests. The survey area is discussed using a live GIS presentation of all available data, and any suggested sampling stations from NGU and IMR are discussed and optimized. In addition to planning visual stations, a selection of the video stations are chosen as stations where also physical sampling is conducted. These stations are considered to be representative of the study area, and also suitable for the sampling gear, to minimize damage to the seabed/sampling gear. For example, preliminary assessment of the suitability of each physical station for multicore sampling is made on the basis of backscatter data which give a good guide to areas with fine (soft) sediments.

The cruise planning meeting marks a formal acceptance of the sampling design for a forthcoming cruise. Any onboard revisions of this plan (e.g. due to bad weather, equipment problems, fishing gear in sampling area) are made by the cruise leader (IMR) in consultation with NGU scientists on board, involving MAREANO project management onshore as necessary.

During some cruises, MAREANO has been able to acquire additional samples due to particularly favourable weather/sea conditions, other cruises have not managed to acquire all the planned samples. Whether or not these missed samples are acquired by later cruises has been assessed by the MAREANO project managers etc. in planning the next MAREANO activities.

References

Thorsnes, T., van Son, T.C., Dolan, M.F.J., Gonzales-Mirelis, G., Baeten, N., Buhl-Mortensen, P., Bjarnadóttir, L.R., Hodnesdal, H & Bellec, V. 2015: An assessment of scale, sampling effort and confidence for maps based on visual and acoustic data in MAREANO. NGU Report 2015.043, 97 p.
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http://www.ngu.no/upload/Publikasjoner/Rapporter/2015/2015_027.pdf

3.2 Recent developments in MAREANO cruise planning

In addition to developing a method for determining sampling effort based on environmental variability (see section 2.1 & Van Son et al. 2015), MAREANO has been investigating more optimal methods for planning the locations of video/physical sampling stations. A review of the options was undertaken in the report *An assessment of scale, sampling effort and confidence for maps based on visual and acoustic data* (Thorsnes et al. 2015) concluding that the need for statistical independence among sampling stations, together with objective survey planning are key drivers for future improvements.

The multiple objectives of MAREANO sampling make this particularly challenging and as a result there is no best practice template available among the scientific community for this type of sampling programme. Further development within MAREANO is required to achieve an optimal station planning methodology that is suitable for the programme. The most promising approach identified to date is Generalised Random-Tesselation Stratified sampling (GRTS). When coupled with a method for stratifying the survey area (e.g. ISOCLUSTER/k-means) GRTS provides a method for placing sample stations which are spatially balanced (independent). Details on the technical background and initial testing of GRTS for survey planning are given in section 4.3 of Thorsnes et al. 2015. Incorporating feedback from this initial survey planning further development of the implementation approach is underway and a modified GRTS-based approach is currently being used for survey planning of the 2016 cruise in the Eastern Barents Sea (based on reduced resolution multibeam data, and best available oceanographic data – 4km grid). Subject to successful results of this automated planning at the present time it is intended that a GRTS-based design will account for 75% of sampling stations, while 25% will be added by expert judgement (based on full resolution multibeam data), facilitating the inclusion of areas or features of biological/geological/ management importance, which may not be captured by the automated approach (e.g. due to data resolution). The final planning of the sample stations will be discussed and agreed at survey planning meetings in May 2016.

Refinement of the automated sampling design approach is an ongoing process that will continue under MAREANO and will likely need to adapt to the data available for, and the nature of the survey area in question for any particular sampling cruise. A flexible yet objective method for providing independent samples is the overarching goal.

A potential reduction in the length of video lines has also been discussed among MAREANO partners but as yet no decision has been reached as to whether this change should be implemented. Reducing the length from the current standard of 700 m to a shorter length e.g. 200 m would allow more samples to be taken. This approach could potentially provide better opportunities to ground-truth backscatter data, and to more fully sample the total seabed physical environment. A greater number of truly independent samples would be beneficial for biotope classification and modelling, and will become more and more important for geological mapping as semi-automated methods for sediment classification are adopted. This issue and the related ship-time use is discussed further in sections 4.3.3 and 4.4.4 of Thorsnes et al. 2015. A simulation study planned to start later in 2016 may be a convenient platform to investigate this issue further and reach a decision without involving tests using real (costly) shiptime.

References

Thorsnes, T., van Son, T.C., Dolan, M.F.J., Gonzales-Mirelis, G., Baeten, N., Buhl-Mortensen, P., Bjarnadóttir, L.R., Hodnesdal, H & Bellec, V. 2015: An assessment of scale, sampling effort and confidence for maps based on visual and acoustic data in MAREANO. NGU Report 2015.043, 97 p. http://www.ngu.no/upload/Publikasjoner/Rapporter/2015/2015_043.pdf

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3.3 Methods for collection of visual data

Individual video survey lines were first selected to be 1000 metres long, but after the initial MAREANO sampling cruise in 2006, results were assessed and the distance was reduced to 700 m, based on cumulative curves for the number of observed taxa along individual transects (Buhl-Mortensen et al. 2015). Each transect starts and ends with the video platform standing on the seabed, enabling close-ups and visual scanning within an area of approximately 6 m^2. Between start and end-points, the video platform is towed behind the survey vessel at a speed of approximately 0.7 knots and controlled with the winch to provide a distance of around 1.5 metres above the seabed.

References

Lene Buhl-Mortensen, Pål Buhl-Mortensen, Margaret F. J. Dolan & Børge Holte (2015) The MAREANO programme – A full coverage mapping of the Norwegian off-shore benthic environment and fauna, Marine Biology Research, 11:1, 4-17, DOI: 10.1080/17451000.2014.952312

Thorsnes, T., van Son, T.C., Dolan, M.F.J., Gonzales-Mirelis, G., Baeten, N., Buhl-Mortensen, P., Bjarnadóttir, L.R., Hodnesdal, H & Bellec, V. 2015: An assessment of scale, sampling effort and confidence for maps based on visual and acoustic data in MAREANO. NGU Report 2015.043, 97 p.
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3.4 Technical description of visual platforms

The survey performance and the technical specifications used for visual inspection cover all requirements described by the European standard for "Visual seabed surveys using remotely operated and/or towed observation gear for collection of environmental data" (CEN 2012).

The seabed and its epifauna are documented by means of underwater video using the video platforms Campod and Chimaera (since 2014). Campod is a tripod equipped with a high definition colour video camera (Sony HDC-3200) for inspection purposes, and an analog CCD video camera for navigation. It also has four parallel laser pointers (10 cm apart arranged in a square), for scaling of the imagery, and an altimeter to measure the height above the seabed. This video platform was built in 2005 based on the Canadian Campod (Gordon et al. 2000). With the high survey activity of MAREANO, the pressure on the equipment is also high, and production of a new platform was needed after seven years. During planning for a new video platform, experience with Campod was used to make modifications (see Fig. 8).

The new platform, Chimaera (named after the Latin name of the rat tail fish) has two wide runners instead of three legs like Campod and is also equipped with additional cameras for safety and navigation purposes, directed backwards and upwards, monitoring the cable. The main camera on Chimaera is a Sony HDC-P1camera equipped with a Canon HJ17 EX7.6B IASE lens. The rest of the instrumentation is similar to Campod. Chimaera also has two rudders to prevent side-way drifting. Geo-positioning of observations and of the track of the video platforms is provided by a hydroacoustic positioning system (Simrad HIPAP and Eiva Navipac software) with a transponder mounted on the platform. This system provides positions accurate to about 2% of the water depth.

References

Lene Buhl-Mortensen, Pål Buhl-Mortensen, Margaret F. J. Dolan & Børge Holte (2015) The MAREANO programme – A full coverage mapping of the Norwegian off-shore benthic environment and fauna, Marine Biology Research, 11:1, 4-17, DOI: 10.1080/17451000.2014.952312

Thorsnes, T., van Son, T.C., Dolan, M.F.J., Gonzales-Mirelis, G., Baeten, N., Buhl-Mortensen, P., Bjarnadóttir, L.R., Hodnesdal, H & Bellec, V. 2015: An assessment of scale, sampling effort and confidence for maps based on visual and acoustic data in MAREANO. NGU Report 2015.043, 97 p.
http://www.ngu.no/upload/Publikasjoner/Rapporter/2015/2015_043.pdf

3.5 Video resolution and formats, data storage volumes

The image resolution of the video images is 192030080 pixels, and images are sampled at a rate of 25 images per second. Video is recorded in a slightly compressed High-definition format (HD-DVCpro), and stored in Quick time format. The video files are written to file in real time during the survey. For this purpose a 3TB raid is used. The files on the raid are later transferred to external hard discs. One hour of video recording occupies about 60 GB of disk space, and one video transect results in approximately 45 minutes of video footage

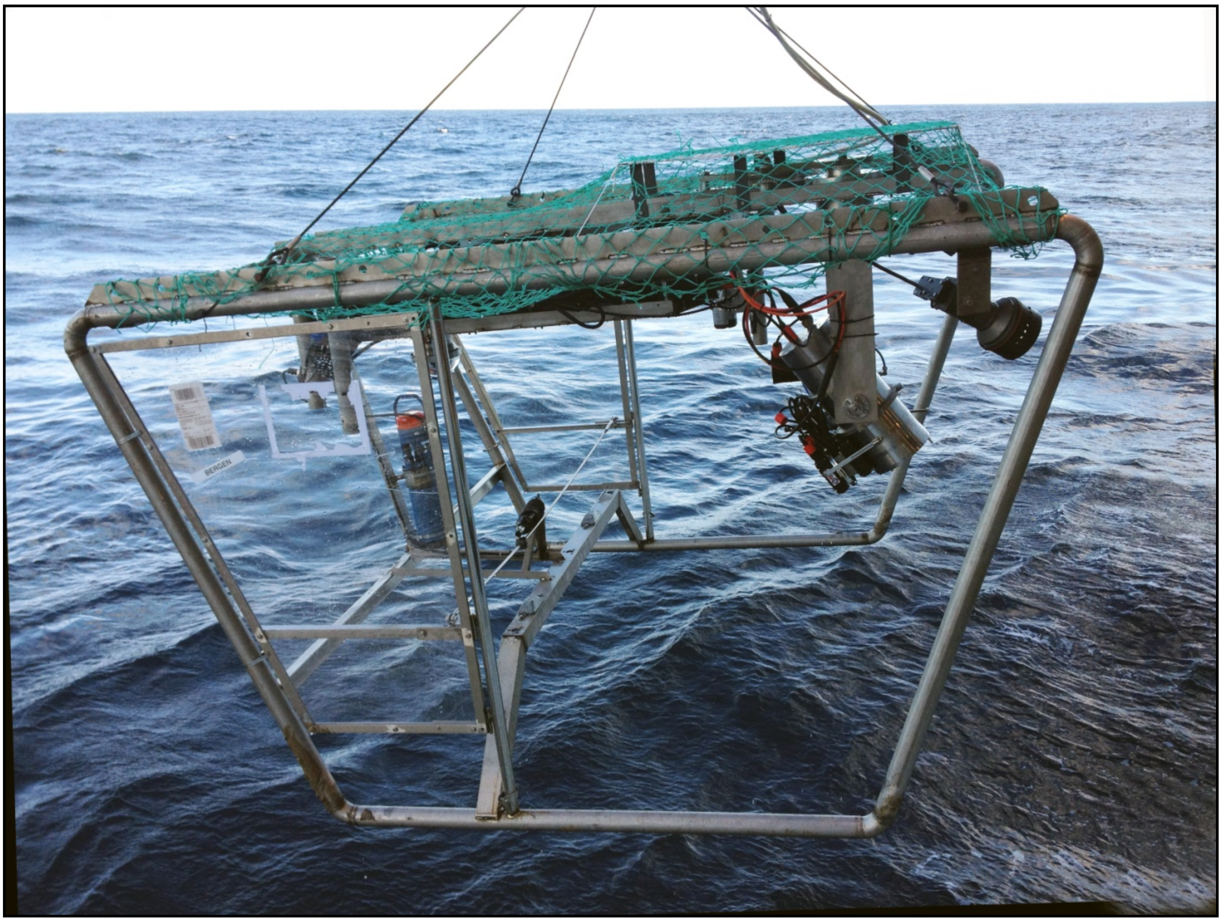

Figure 8. The video platform Chimaera has four video cameras. The main camera has High-Definition standard whereas the three additional cameras have Standard Definition. In addition, the video platform has current meters (short range ADCP) and sensors for temperature, salinity, and optical backscatter.

References

Lene Buhl-Mortensen, Pål Buhl-Mortensen, Margaret F. J. Dolan & Børge Holte (2015) The MAREANO programme – A full coverage mapping of the Norwegian off-shore benthic environment and fauna, Marine Biology Research, 11:1, 4-17, DOI: 10.1080/17451000.2014.952312

Thorsnes, T., van Son, T.C., Dolan, M.F.J., Gonzales-Mirelis, G., Baeten, N., Buhl-Mortensen, P., Bjarnadóttir, L.R., Hodnesdal, H & Bellec, V. 2015: An assessment of scale, sampling effort and confidence for maps based on visual and acoustic data in MAREANO.

NGU Report 2015.043, 97 p.
http://www.ngu.no/upload/Publikasjoner/Rapporter/2015/2015_043.pdf

3.6 Field recording and sub-sampling

Real-time registration of observations of the seabed substrates and fauna are made along video lines. Bottom types and organisms are identified and recorded in the field using the event-logging software 'Campod Logger' developed at the Institute of Marine Research. The bottom types are classified into one of the following classes: mud, sandy mud, sand, gravelly mud, gravelly sand, sandy gravel, gravel, boulders, bedrock, and coral reef, modified from the Folk grain size scale (Folk, 1954), provided in a list appearing in a drop-down menu in the logging program. More substrate classes have been added to the list of standard bottom types as MAREANO has gained more experience from field observation.

Since registration of all occurrences of organisms is not feasible in the field, the registration is carried out as described below. Navigational data from transponder and HIPAP (Date, UTC time, and positions) and depth are recorded automatically at ten seconds intervals. Each transect is divided into five sequences: two locations (start and end of transect) with detailed inspection while the video platform was parked on the seabed, and three consecutive sequences between 150 and 250 metres long when the video platform is towed between the start and end location. Each observed taxon is recorded only the first time that it occurs within each of the five sequences. The identified bottom type is recorded automatically at the same intervals until a change is observed. Then, the bottom type is manually changed to the new bottom type. Separate logs are recorded for biological and geological observations.

References

Lene Buhl-Mortensen, Pål Buhl-Mortensen, Margaret F. J. Dolan & Børge Holte (2015) The MAREANO programme – A full coverage mapping of the Norwegian off-shore benthic environment and fauna, Marine Biology Research, 11:1, 4-17, DOI: 10.1080/17451000.2014.952312

Thorsnes, T., van Son, T.C., Dolan, M.F.J., Gonzales-Mirelis, G., Baeten, N., Buhl-Mortensen, P., Bjarnadóttir, L.R., Hodnesdal, H & Bellec, V. 2015: An assessment of scale, sampling effort and confidence for maps based on visual and acoustic data in MAREANO. NGU Report 2015.043, 97 p.
http://www.ngu.no/upload/Publikasjoner/Rapporter/2015/2015_043.pdf

3.7 Post-cruise handling and analysis of video data

The following text is from section 2.2.6 of Thorsnes et al. 2015, describing post-cruise handling and analysis of video data, both with respect to biology and geology:

Video records are analyzed in detail with respect to biology after the cruises using the software VideoNavigator (developed at the Institute of Marine Research). The analysis provides quantitative species data for samples consisting of video sequences of desired length. After initial analyses (ordination of biological and environmental video-data) of video sequences of different lengths (50, 200, and 1000 m), it was concluded that 200 metres was the best compromise between needed spatial detail and time consumption and computing capacity. This conclusion was based on comparisons of similarities between the different ordination plots. The adequacy of this size has been recently confirmed through additional statistical analyses of spatial patterns of megafauna. The size of the areas for the sequences is calculated based on distance travelled (from navigation data) and average field width. The field width is estimated from the ratio between measurements of the distance between two laser points on the video screen, and the width of the screen.

All organisms are identified to the lowest possible taxon and counted, or quantified as a percentage of seabed coverage following the method described by Mortensen and Buhl-Mortensen (2005). Lebensspuren, burrows, and encounters with lost fishing gear and litter are also counted. Abundance data for solitary organisms is standardized to number of individuals observed per 100 m^2.

The relative composition of bottom substrate classes (mud, sandy mud, sand, pebble, cobble, boulder, bedrock, consolidated mud, coral rubble, dead *Lophelia*, and live *Lophelia*) is estimated based on the average of estimates of at least three still images within the video sequence. The percentage cover of these classes is estimated subjectively at a scale of 5% intervals.

Analysis of video data for the purposes of geological mapping is mainly limited to quality control of the field logs and examination of features of special scientific interest. Video data and extracted still images are analysed by the geologist as required along each video line and the logged bottom type checked and aligned with the SOSI sediment grain size classes used in mapping (Bøe et al. 2010) in a GIS environment. Video observations are related to the multibeam backscatter data, bedforms and geological setting as well as physical samples, where available, in order to make the best possible interpretation of seabed sediment type at the relevant map scale for the area in question.

References

Thorsnes, T., van Son, T.C., Dolan, M.F.J., Gonzales-Mirelis, G., Baeten, N., Buhl-Mortensen, P., Bjarnadóttir, L.R., Hodnesdal, H & Bellec, V. 2015: An assessment of scale, sampling effort and confidence for maps based on visual and acoustic data in MAREANO. NGU Report 2015.043, 97 p.
http://www.ngu.no/upload/Publikasjoner/Rapporter/2015/2015_043.pdf

3.8 Methods for collection of physical samples

Methods for collection of physical samples are described at www.mareano.no. See:
http://www.mareano.no/resources/Oversikt_over_datainnsamling_i_MAREANO_navnsetting_pa_stasjoner.pdf

and

http://www.mareano.no/om_mareano/arbeidsmater

See chapter 5 - *Environmental status and pollution* for further information on sample preparation and analytical methods.

4. GEOLOGICAL MAPS

This section outlines methods for the use of MAREANO data for the production of geological maps. With the exception of landscape maps, which are based on bathymetry data along, the other products all use multibeam data and video data as their primary source of input data.

4.1 Landscapes

MAREANO maps the broad scale marine landscapes of the seabed. In our mapping, landscape is defined as "large geographical areas with a visually homogeneous character". The landscape classification in the sea areas that have been mapped must be full-coverage and non-overlapping. That means that every point must be classified as belonging to a single landscape. Bathymetric data enable us to determine which areas should be classified as plains, continental slopes, valleys and strandflats. We use an automated GIS classification following the definitions of Naturtyper i Norge (NiN, Nature types in Norway) that employs low-resolution depth data and parameters that can be extracted directly from these to enable us to define the boundaries of these features in a manner that is reproducible and as far as possible does not involve interpretation. Mapping is performed according to the Classification of landscapes list.

References

Elvenes, S. 2013: Landscape mapping in MAREANO. NGU Report 2013.035, 39 p. http://www.ngu.no/upload/Publikasjoner/Rapporter/2013/2013_035.pdf

Thematic text on Marine landscapes http://www.ngu.no/Mareano/Landskap.html
http://www.mareano.no/tema/marine_landskap

Classification of Landscapes http://www.ngu.no/Mareano/Landscape.html

4.2 Sediments (grain size)

The Sediments (grain size) map reflects the grain size in the uppermost 0-15 cm of the seabed. When mapping Sediments (grain size) we choose amongst more than thirty classes of grain compositions. Mapping is performed in line with MAREANOs Standard for geological seabed mapping offshore and in accordance with standard procedures for map production and quality control. Sediments usually consist of mixtures of several different grain sizes, with each combination constituting its own class. Grain size is interpreted based on landforms (from multibeam bathymetry), backscatter (from multibeam bathymetry), photographs and video films of the seabed, bottom samples taken with grabs, box corers, sledges and multicorer, and shallow seismic data. The classification of sediment type is determined by the scale of the map produced and the degree of detail in the data used during the interpretation and the map compilation.

References

Bellec, V.K., Dolan, M.F.J, Bøe, R., Thorsnes, T., Rise, L., Buhl-Mortensen, L. & Buhl-Mortensen, P. 2009: Sediment distribution and seabed processes in the Troms II area - offshore North Norway. Norwegian Journal of Geology 89, 29-40.

Bellec, V.K., Bøe, R., Rise, L., Slagstad, D., Longva, O., Dolan, M.F.J. 2010: Rippled scour depressions on continental shelf bank slopes off Nordland and Troms, North Norway. Continental Shelf Research 30, 1056-1069.

Bøe, R., Bellec, V.K., Dolan, M.F.J., Buhl-Mortensen, P.B., Buhl-Mortensen, L. & Rise, L. 2009: Giant sand waves in the Hola glacial trough off Vesterålen, North Norway. Marine Geology 267, 36-54.

Elvenes, S., Dolan, M. F. J., Buhl-Mortensen, P. & Bellec, V. K. 2014: An evaluation of compiled single-beam bathymetry data as a basis for regional sediment and biotope mapping. ICES Journal of Marine Science 71, 4, 867–881.

Classification of sediments based on grain size (Folk 1954, modified). Updated 2016. http://www.ngu.no/Mareano/Kornstorrelse.html

Thematic text on Sediments (grain size) http://www.mareano.no/tema/bunnsedimenter

Standard for geological mapping offshore http://mareano.no/__data/page/9267/2010_033.pdf

Standard procedures for map production http://www.mareano.no/resources/Digitazing-in-MGDB-Scale-and-size_v-4.pdf

Quality control of seabed maps in Marine Geology (NGU) http://www.mareano.no/resources/Quality-control-procedures-seabed-maps.pdf

4.3 Sediments (genesis)

The Sediments (genesis) map represents a compilation of the Quaternary geology in the uppermost 1-2 m of the seabed in the mapping area. Several data sets are used for compilation, including landforms, landscapes and sediment grain size, photographs and video footage, samples from grab, box corer, sledge and multicorer, and shallow seismic data. The map represents an interpretation of the sediments in the uppermost few meters of the seabed. Mapping is performed in line with MAREANOs Standard for geological seabed mapping offshore, Classification of sediments based on genesis, and in accordance with standard procedures for map production and quality control.

References

Bellec, V.K., Dolan, M.F.J, Bøe, R., Thorsnes, T., Rise, L., Buhl-Mortensen, L. & Buhl-Mortensen, P. 2009: Sediment distribution and seabed processes in the Troms II area - offshore North Norway. Norwegian Journal of Geology 89, 29-40.

King, E.L., Bøe, R, Bellec, V.K., Rise, L., Skarðhamar, J., Ferré, B. & Dolan, M. 2014: Contour current driven continental slope-situated sandwaves with effects from secondary current processes on the Barents Sea margin offshore Norway. Marine Geology 353, 108-127.

Classification of Sediments (genesis) http://www.ngu.no/Mareano/SedGenesis.html

Thematic text on Sediments (genesis) http://www.ngu.no/Mareano/SedGenesis.html
http://www.mareano.no/tema/dannelse_av_bunnesedimenter

Standard procedures for map production http://www.mareano.no/resources/Digitazing-in-MGDB-Scale-and-size_v-4.pdf

Quality control of seabed maps in Marine Geology (NGU)
http://www.mareano.no/resources/Quality-control-procedures-seabed-maps.pdf

4.4 Bioclastic sediments

Bioclastic sediments is a term used to describe carbonate rich sediments consisting of fragments/shells of dead organisms. On the continental shelf, we find bioclastic sediments with a high content of the remains of stony corals. These sediments form mounds and ridges in many places, which may be associated with live corals. Information on the methods used for mapping bioclastic sediments can be found at www.mareano.no.

References

Bellec, V., Thorsnes, T. & Bøe, R. 2014: Mapping of bioclastic sediments - data, methods and confidence. NGU Report 2014.006, 23 pp.
http://www.ngu.no/upload/Publikasjoner/Rapporter/2014/2014_006.pdf

Thematic text on Bioclastic sediments http://www.mareano.no/en/topics/bioclastic_sediments

4.5 Sedimentary environment

The Sedimentary environment map is based on the maps for Seabed sediments (grain size) and Seabed sediments (genesis). The main purpose of the map is to show areas of present erosion and deposition of sediments, and how bottom currents influence the seabed. Areas of deposition of fine-grained sediments (mud and sandy mud) are primarily found in deep areas. In shallower areas, fine-grained sediments may erode locally on topographic highs, while sand is deposited on the lee side of such highs, where the bottom currents may be weaker. The shallowest areas are dominated by current erosion; however, fine-grained sediments may accumulate in local depressions found in the shallow areas. A lag deposit comprised of sandy gravel, cobbles and boulders is often formed where bottom currents are strong. Grain size indicates the strength of the bottom currents; mud suggests the presence weak bottom currents, while coarser sediments or erosion suggest stronger currents. Bottom current directions can be determined by studying the areas where eroded sediments are deposited. If transported sediments are deposited along only one side of an iceberg plough mark, the sediments are coming from that side to be deposited in lee. Modelling of bottom currents shows large variations in current direction and current strength depending on time of the year and tidal cycles. Mapping is performed in line with MAREANOs Standard for geological seabed mapping offshore, Classification of sediments based on sedimentary environment, and in accordance with standard procedures for map production and quality control.

References

Bellec, V.K., Dolan, M.F.J, Bøe, R., Thorsnes, T., Rise, L., Buhl-Mortensen, L. & Buhl-Mortensen, P. 2009: Sediment distribution and seabed processes in the Troms II area - offshore North Norway. Norwegian Journal of Geology 89, 29-40.

King, E.L., Bøe, R, Bellec, V.K., Rise, L., Skarðhamar, J., Ferré, B. & Dolan, M. 2014: Contour current driven continental slope-situated sandwaves with effects from secondary current processes on the Barents Sea margin offshore Norway. Marine Geology 353, 108-127.

Classification of sediments based on Sedimentary environment
http://www.ngu.no/Mareano/Sedimentasjonsmiljo.html

Thematic text on Sedimentary environment
http://www.mareano.no/tema/sedimentasjonsmiljo

Standard procedures for map production http://www.mareano.no/resources/Digitazing-in-MGDB-Scale-and-size_v-4.pdf

Quality control of seabed maps in Marine Geology (NGU)
http://www.mareano.no/resources/Quality-control-procedures-seabed-maps.pdf

4.6 Landforms

The Landforms tell us how the seabed is formed, and what sedimentation processes are active today. The age of the marine landforms can vary, from just a few years, to several million years. Similarly, the size of the land forms can vary immensely. On the continental slope, we find the giant submarine landslides that date anywhere between a few thousand years to several hundred thousand years old. Examples of seabed landforms mapped by MAREANO are channels, canyons, sediment waves, areas with sediment waves, glacial lineations, iceberg plough marks, moraines, slide escarpments, slide scars, slide areas, areas with slide deposits, submarine fans and areas with pockmarks. Mapping is performed according to NGUs SOSI standard for Quaternary geology (Løsmassegeologi) and Classification of landforms.

References

Rise, L., Bøe, R., Riis, F., Bellec, V., Laberg, J.S., Eidvin, T., Elvenes, S., Thorsnes, T. 2013: The Lofoten-Vesterålen continental margin, North Norway: Canyons and mass-movement activity. Marine and Petroleum Geology 45, 134-149.

King, E.L., Bøe, R, Bellec, V.K., Rise, L., Skarðhamar, J., Ferré, B. & Dolan, M. 2014: Contour current driven continental slope-situated sandwaves with effects from secondary current processes on the Barents Sea margin offshore Norway. Marine Geology 353, 108-127.

Rise, L., Bellec, V.K., Chand, S. & Bøe, R. 2015: Pockmarks in the southwestern Barents Sea and Finnmark fjords. Norwegian Journal of Geology 94, 263-282.

Bøe, R., Skarðhamar, J., Rise, L., Dolan, M.F.J., Bellec, V.K., Winsborrow, M., Skagseth, Ø., Knies, J., King, E.L., Walderhaug, O., Chand, S., Buenz, S. & Mienert, J. 2015: Sandwaves and sand transport on the Barents Sea continental slope offshore northern Norway. Marine and Petroleum Geology 60, 34-53.

Løsmassegeologi – oversikt over oppdaterte kodelister for revisjon av SOSI 4.0 (januar 2016).

Classification of landforms http://www.ngu.no/Mareano/Terrengformer.html

4.7 Quality control of geological mapping

Geological maps by MAREANO are made according to a standard set of rules and quality controlled prior to publication.

Bøe, R., Dolan, M., Thorsnes, T., Lepland, A., Olsen, H., Totland, O. & Elvenes, S. 2010: Standard for geological seabed mapping offshore. NGU Report 2010.033, 15 pp. http://mareano.no/__data/page/9267/2010_033.pdf

Marine Geological Interpretations – Digitizing scale, details and methods. http://www.mareano.no/resources/Digitazing-in-MGDB-Scale-and-size_v-4.pdf

Quality control of seabed maps in Marine Geology (NGU). http://www.mareano.no/resources/Quality-control-procedures-seabed-maps.pdf

4.8 Development of semi-automated sediment map classification

NGU has recognised the need for developing more automated methods for sediment grain size classification in order to overcome the challenges associated with expert-based interpretation. It is considered that software assisted sediment grain size classification may yield a more objective, reproducible and efficient way of classification. NGU has previously considered software tools such as QTC multiview, or more recently the Angular Range Analysis (ARA) in QPS-Fledermaus FMGT module (see document Multibeam backscatter procedures for the MAREANO programme, Geological Survey of Norway (NGU)), without concluding to incorporate it into the standard workflow for geological map production. ARA outputs are currently being assessed by NGU in relation to development of semi-automated methods for sediment interpretation.

In December 2015, in parallel with the methods study conducted in cooperation with the Institute of Marine Research and the Norwegian Hydrographic Service (NGU report 2015.043), NGU organised a " MAREANO-MAREMAP-INFOMAR workshop on methods for marine geological map production". Leading scientists from the Geological Survey of Ireland (GSI) responsible for the geological part of the Irish Infomar programme (http://www.infomar.ie) and the British MAREMAP programme (http://www.maremap.ac.uk) were invited and gave presentations and participated in discussions during a two-day workshop held at the premises of NGU 8-9th December 2015.

Key issues for the workshop were data quality problems related to backscatter, and various software applications for software assisted classification. This included scripts for ArcMap developed by Dr. Rhys Cooper from the British Geological Survey in UK, the software RSOBIA developed by Dr. Tim Le Bas at National Oceanography Centre (NOC) in UK, and the application of the software eCognition by Dr. Markus Diesing, Centre for Environment, Fisheries and Aquaculture Science (CEFAS) in UK. One of the outcomes from the workshop was to initiate a more formal cooperation between NGU, the GSI and the partners in the MAREMAP programme (BGS, CEFAS and NOC). Three task forces were formed:

- Analysis and Interpretation, coordinated by Dr. Diesing, CEFAS
- Geomorphology, coordinated by Dr. Scott, GSI
- Sampling strategy, coordinated by Dr. van Son, NGU

In early 2016, NGU started testing the methods presented at the workshop, with two data sets from earlier MAREANO mapping. The purpose of this has been to evaluate the different methods for software assisted classification, and decide whether NGU shall implement such tools in the sediment grain size clasification. This was followed up by a workshop held at NGU 15-18th March 2016 dedicated at testing and evaluating the eCognition software. The workshop was led by Dr. Diesing from CEFAS, with support from the Norwegian eCognition expert Dr. Jørgensen from Terranor (http://www.terranor.no/) which is a company providing systems for imagery, GIS and digital map analysis. The majority of participants were from NGU, but also included participants from BGS and GSI.

Preliminary results from the evaluation will be presented as an oral presentation at the GeoHab meeting (http://geohab2016.org/) in Winchester, UK, in May 2016, and the test data sets will be used as examples in the Geohab workshop held at the first day. The results of the evaluation will be reported as an NGU report in the fall 2016, and a scientific paper is planned for 2017.

References

Diesing, M., and Stephens, D., 2015, A multi-model ensemble approach to seabed mapping: Journal of Sea Research, v. 100, p. 62-69.

Diesing, M., Green, S. L., Stephens, D., Lark, R. M., Stewart, H. A., and Dove, D., 2014, Mapping seabed sediments: Comparison of manual, geostatistical, object-based image analysis and machine learning approaches: Continental Shelf Research, v. 84, p. 107-119.

Lamarche, G., Lurton, X., Verdier, A.-L., and Augustin, J.-M., 2011, Quantitative characterisation of seafloor substrate and bedforms using advanced processing of multibeam backscatter—Application to Cook Strait, New Zealand: Continental Shelf Research, v. 31, no. 2, Supplement, p. S93-S109.

Lucieer, V., and Lamarche, G., 2011, Unsupervised fuzzy classification and object-based image analysis of multibeam data to map deep water substrates, Cook Strait, New Zealand: Continental Shelf Research, v. 31, no. 11, p. 1236-1247.

5. BIOTOPE MAPS

This section refers to the production of general biotope maps (i.e. Regions with similar communities of animals living on the seabed, in a similar physical environment). This map is produced by NGU in collaboration with IMR and is distinct from the Vulnerable Biotope map produced by IMR.

To produce full coverage maps of the distribution of biotopes, as required by management, predictive modelling techniques are used. These models use information on the characteristics and distribution of biological communities (based on visual documentation at MAREANO stations) and combine it with physical characteristics of the seabed identified by terrain analysis and geological interpretation. Since 2014, when oceanographic data first became available to MAREANO, these data have also been incorporated in biotope modelling.

MAREANO has refined the methods used for spatial prediction of biotopes over the years since the first map for Tromsøflaket was produced in 2008, testing various methods for classification and modelling as well as improving methods for map validation. Currently prediction of biotope distribution is performed using maximum entropy distribution modelling (Maxent: Phillips et al. 2004). The workflow for biotope modelling is summarized in figure 9 (see also Mortensen et al. 2009, Dolan et al. 2009, Elvenes et al. 2014)

5.1 Biotope mapping - data and workflow

MAREANO biotope mapping utilizes all video data acquired by MAREANO with station density as shown in figure 10, as the basis for identification of faunal groups indicating biotope classes. The taxonomic nomenclature is revised on a regular basis in order to provide comparable data sets from different cruises. Results from video lines with unreliable navigational data are not included in analyses of the relationship between faunal composition and spatially explicit predictors. Data from physical sampling are not directly used in the production of biotope mapping.

Following detailed video analysis and documentation of fauna the first step in biotope mapping is the identification of biotope classes. Detrended correspondence analysis (DCA) (Hill, 1973) using the software PC-Ord (McCune and Mefford, 2006) is the ordination method currently used to identify groups of samples (video sequences of 100-200 metres length) with high similarity of fauna composition. DCA is an unconstrained ordination that is suitable for conducting indirect gradient analysis. DCA resultsfacilitate the identification of groups of samples with similar species composition. The correlation of the environmental variables in relation to the various axes ordination result can also be analysed for identification of complex gradients. By plotting samples on the first 2 (or 3) DCA axes and then clustering of these points through expert judgement (2008-2012) or statistical algorithms (k-means since 2012) the samples are split into biotope classes with similar faunal composition (figure 10).

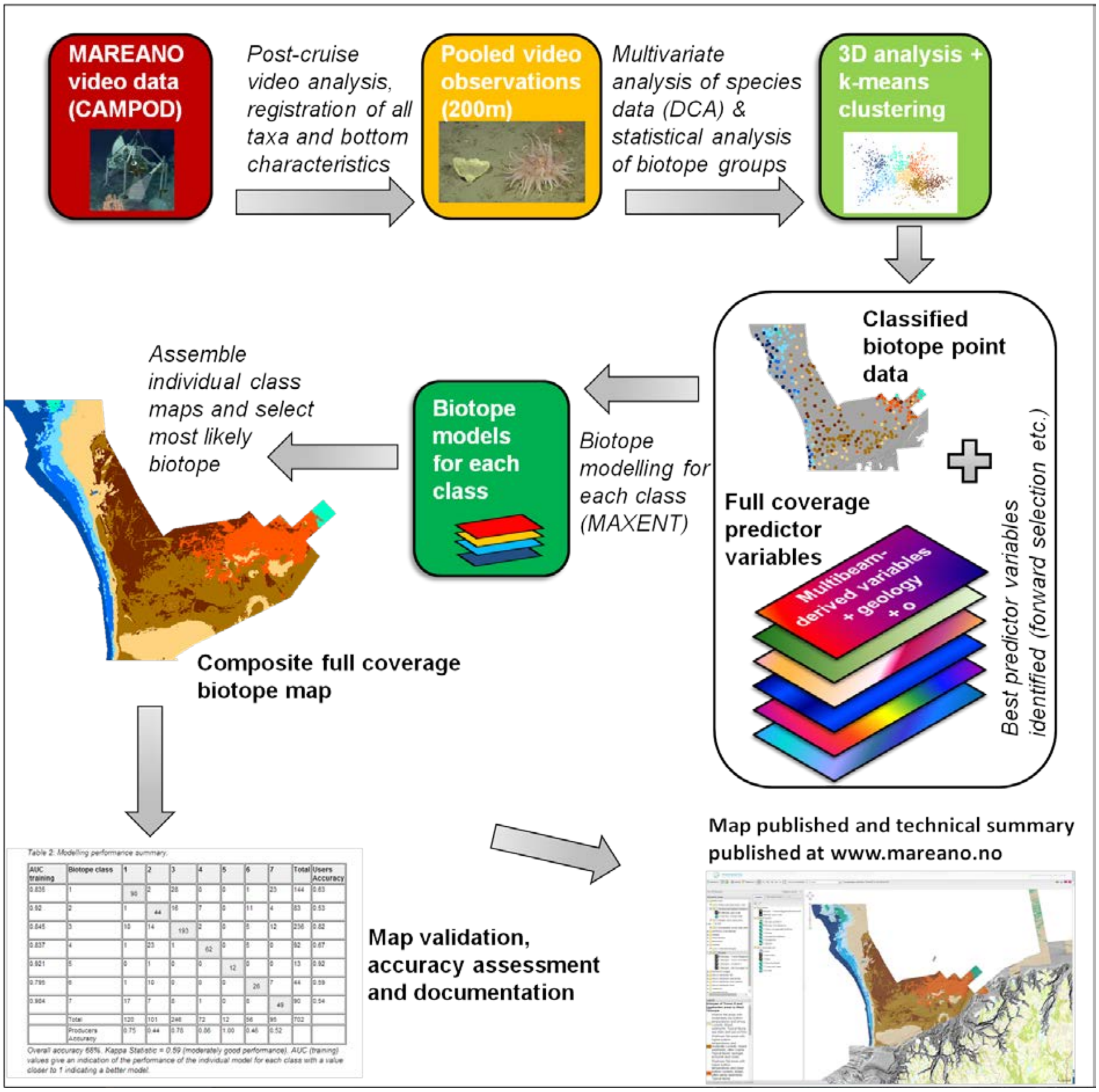

Figure 9. Summary of MAREANO biotope mapping workflow.

By re-plotting these samples in geographic space using GIS we are able to see the geographic distribution of the samples now classified by biotope, and examine how the spatial distribution of biotopes varies in relation to environmental variables (figure 1). Moreover, this step allows extraction of physical characteristics for each sample (biotope) point from the full coverage quantitative terrain variables (e.g. slope, curvature etc.), as well as sediment grain-size class, landscape type and oceanographic variables (temperature, salinity, bottom currents). Together these provide a large number of physical seabed

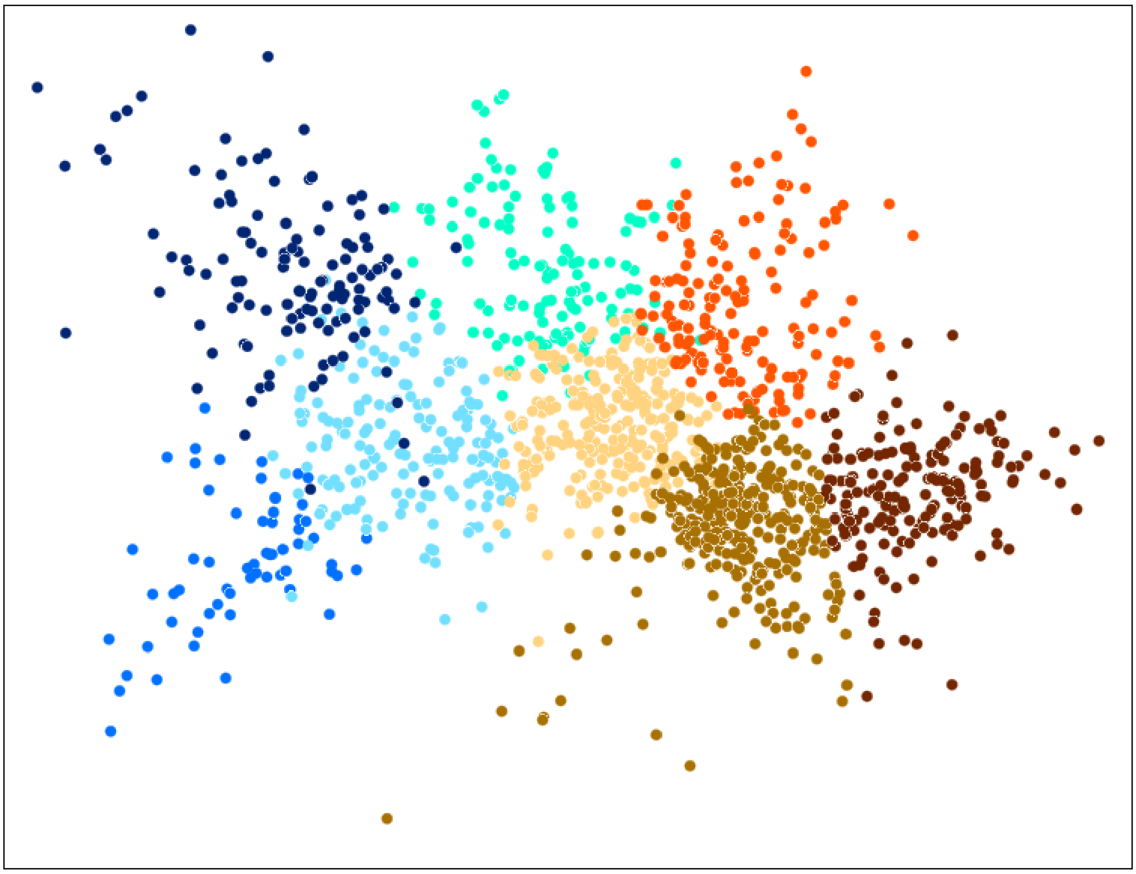

Figure 10. Example of samples plotted in multivariate space on DCA axes 1, 2 and 3. 3D visualization from ArcScene - points are rotated to show best separation of the 8 biotope classes determined by k-means classification, each of which is shown with a unique colour (see also figures 19 and 22).

descriptors which can potentially serve as predictor variables which allow the model to predict from point observations to a full coverage map.

To avoid using predictors that are strongly collinear, or that are proxies for the same structuring processes, and to avoid overfitting of the models, we use forward selection with Monte Carlo permutation using CANOCO for Windows 4.52 (ter Braak and Smilauer, 2002). This is done to select the most suitable (continuous) predictor variables from all those available, as well as examining correlations graphically. Internal routines in Maxent are used to assess the importance of categorical variables (sediment, landscape) and Maxent and Random Forest Models (Breiman, 2001) are also used as a check on the ranking of variable importance suggested by forward selection.

Although biotopes are defined first on the basis of their faunal composition, each biotope is characterized by different substrate, depths, terrain characteristics and oceanographic

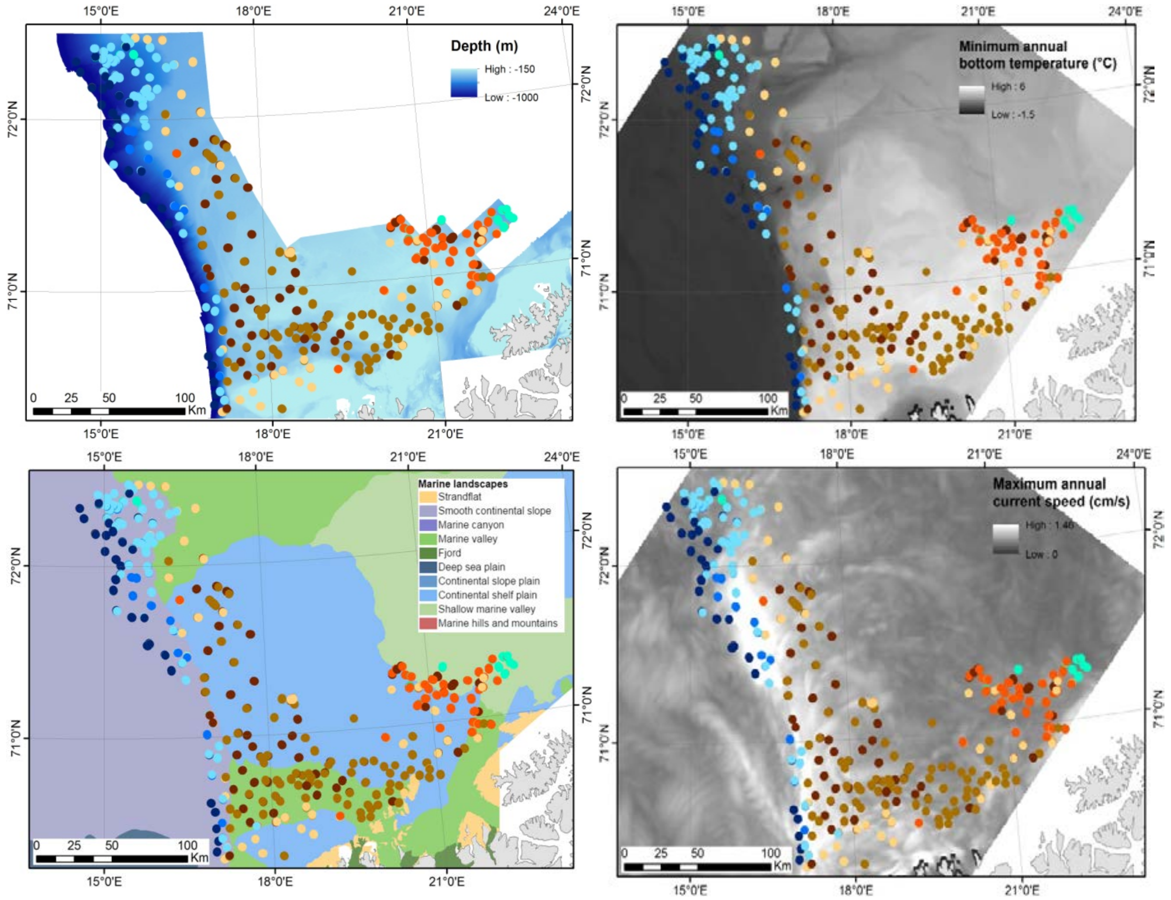

Figure 11. Examples of how the distribution of biotope classified samples (model response variable) varies across the Troms III-Eggakanten-Tromsøflaket mapping area in relation to potential model predictor variables reflecting different properties of the physical environment (a - upper left) bathymetry, (b - upper right) minimum annual bottom temperature, (c - lower left) marine landscape, (d - lower right) Maximum annual current speed. Sample points are coloured by biotope class (see figure 22) – note not all points are visible at this map scale.

conditions. These characteristics, based on the most important predictor variables and typical taxa, are summarised in the map legend and a more detailed description given in the technical summary document that is published on www.mareano.no as supporting information to each biotope map.

Modelling and prediction is conducted using the software program Maxent (Phillips et al., 2004), which implements the maximum entropy principle to predict biotope distribution based on presence-only point data and full-coverage environmental predictor variables. The Maxent method is one that performs well in comparison with other modelling approaches and which has gained widespread use in terrestrial and increasingly in marine habitat modelling applications (see Elvenes et al. 2014 for further background and examples).
Modelling and prediction typically involves production of several alternative models and selecting the best based on model performance and expert validation. Although Maxent remains the primary modelling tool at the time of writing since 2013 parallel modelling using Random Forests has been conducted as a cross check on the Maxent-based map result (and as part of an evalution and development of alternative methods). Maxent modelling requires that one model and prediction is generated for each biotope class (figure 12). Each map is a probability distribution map (0 to 1) indicating the likelihood of finding that class at any location across the study area. All models are produced at a resolution of 50 m pixel size

which provides an adequate level of detail for regional mapping while allowing reasonably large areas to be modelled at once. Therefore, all predictor variables are resampled to 50 m for use in modelling including those originating from finer scale data (e.g. 5 metres bathymetry), coarser data (e.g. 800 metres oceanography), and categorical data (e.g. sediment grain size).

Validation statistics are generated for each map in the form of a Receiver Operator Characteristics (ROC) curve (figure 13), indicating how well the models based on training and test data (typically 25%) compare with random prediction (AUC = 0.5). These AUC statistics are included in the MAREANO technical summary for each area in tables similar to Table 1 where values close to 1 indicate good performance. Typical AUC values for MAREANO models to date are 0.75 – 0.95 although this value varies between classes and mapping areas. Whilst the AUC value gives an indication of model performance its importance should not be overplayed as it has a number of shortcomings (Lobo et al. 2008).

Since the required map product for MAREANO is a single biotope map showing the overall distribution of all biotopes, not one map for each biotope, a composite map which combines the results of all the individual models also needs to be produced. This step is performed in ArcGIS Spatial Analyst using the probability scores from each individual map to determine the most likely biotope occurring at any given location (figure 14).

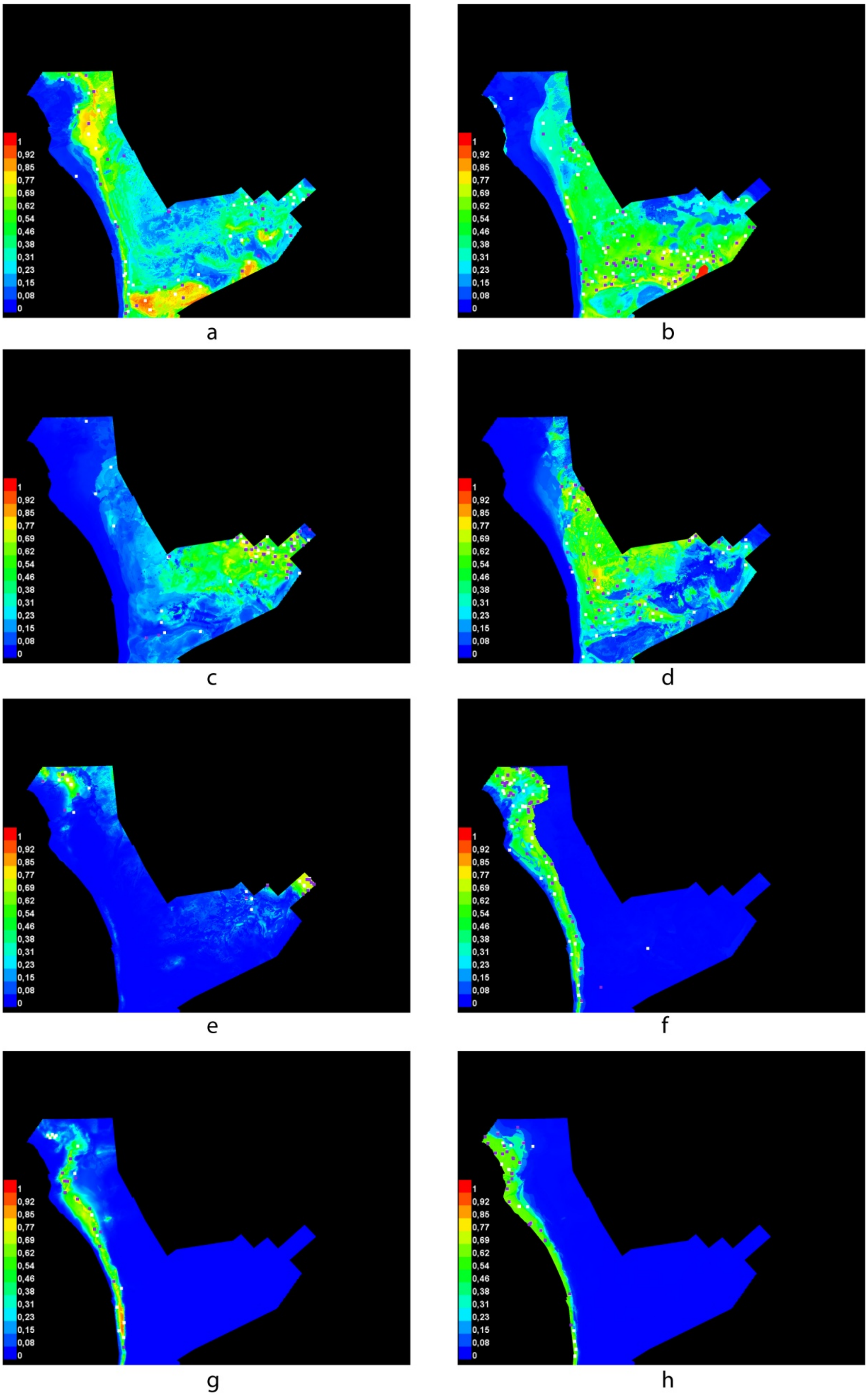

Figure 12. Individual biotope maps for the 8 biotope classes in the Troms III – Eggakanten – Tromsøflaket mapping area (see figure 22). Maps are shown on a rainbow colour scale with values 0 to 1 where blue indicates low probability and red indicates the highest probability.

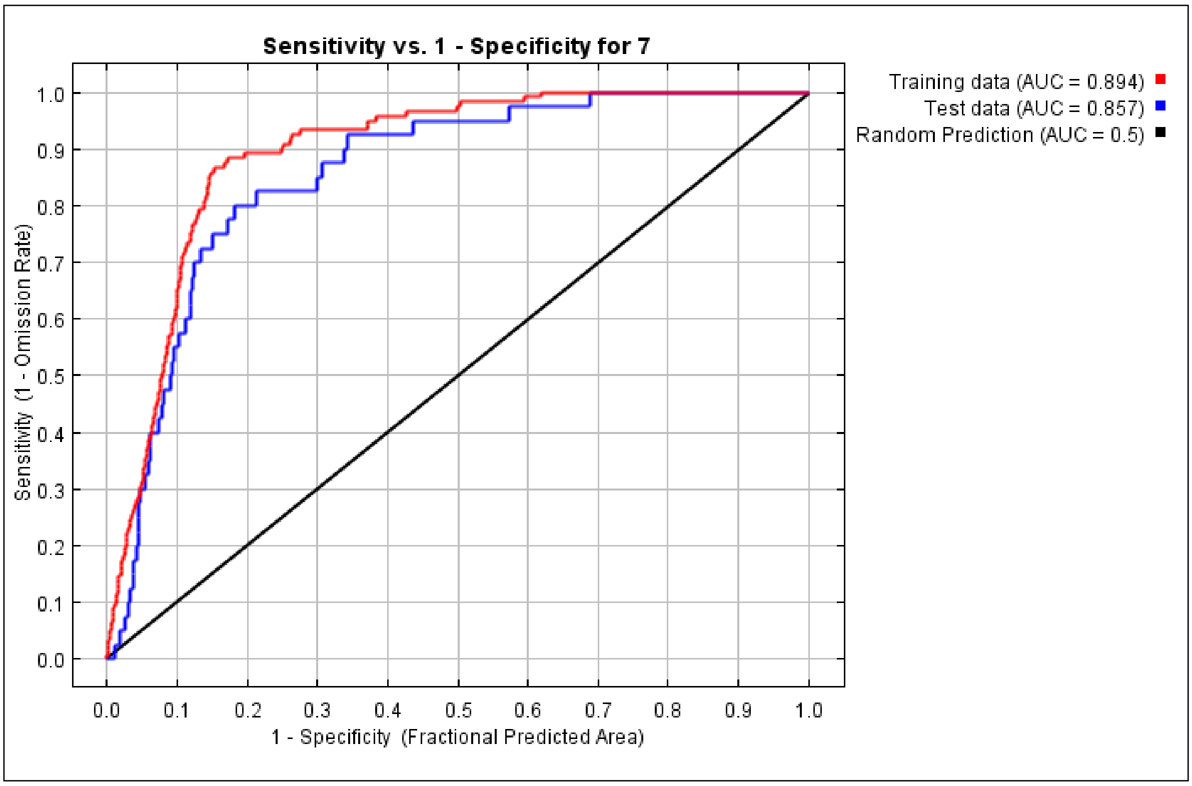

Figure 13. Example ROC curve generated by Maxent for Class 1 of the Troms III – Eggakanten-Tromsøflaket biotope map.

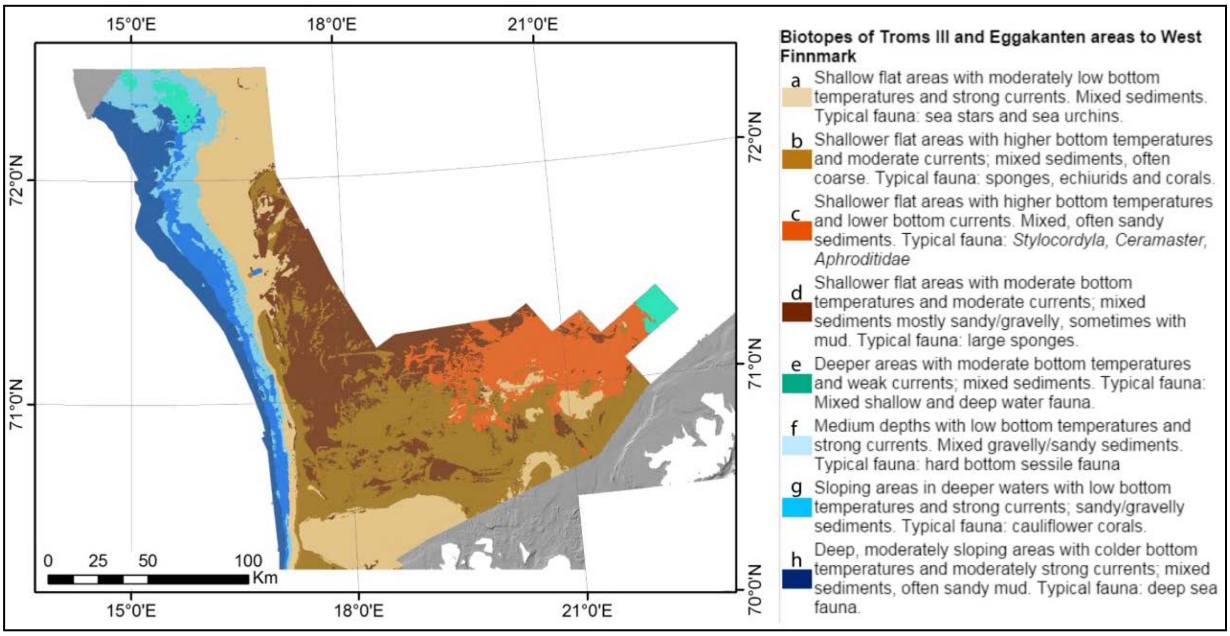

Figure 14. Example Biotope map for Troms III – Eggakanten - Tromsøflaket. See figure 20 for individual biotope maps with probabilities.

Until 2012, this map was tested using only an overall accuracy figure indicating the percentage of input points that are predicted correctly with respect to all available classified biotope points by the final composite map. Since 2013, an additional check on model performance has been introduced where the user's and the producer's accuracy provide a summary of performance across biotope classes and summarised in the Kappa Statistic (Table

3). This additional test on map performance was first reported by MAREANO in Elvenes et al. (2014). Since MAREANO biotope maps for all areas have either been published for the first time or updated since that time, confusion matrices and Kappa Statistics are available for all areas (except west Finnmark, where only low resolution oceanography data were available).

The producer's accuracy refers to the probability that a certain biotope observed on the seabed is classified as such by the model, while the user's accuracy refers to the probability that a pixel with a certain biotope class value in the modelled biotope map really is this class. The Kappa statistic (K), calculated using these accuracy values, provides a measure of overall performance assessing the degree to which the biotope map and point data agree over and above that which could be expected by chance alone. According to the interpretation scale of Altman (1991), which was adopted by Lucieer et al. (2013) for benthic habitat mapping, the values of the Kappa statistic can be interpreted as: $K < 0.2$ poor, $0.2 < K \leq 0.4$ fair, $0.4 < K \leq 0.6$ moderate, $0.6 < K \leq 0.8$ good, $0.8 < K \leq 1.0$ very good.

Although the confusion matrices and Kappa Statistic give a good level of information on map accuracy they do not fully address the more challenging issue of assigning a map confidence rating. As we see from figure 20, many of the biotope classes typically have very different distributions, however there are typically a few classes where the probability of more than one biotope occurring at a given location is more similar. It is in these areas that our confidence in the most likely biotope is less, even if accuracy assessments indicate that the map performs well. This issue is highlighted by the current biotope modelling approach combing results from single models for each species, but it is an underlying issue even if other modelling and prediction methods are used which take a more direct route from input data to a composite map.

Table 3: Confusion matrix table and AUC summaries for 8 biotope classes (Troms III-Eggakanten-Tromsøflaket).

AUC training	*0.909*	*0.833*	*0.951*	*0.953*	*0.848*	*0.883*	*0.894*	*0.95*		
AUC test	*0.869*	*0.803*	*0.936*	*0.956*	*0.763*	*0.82*	*0.857*	*0.93*		
BIOTOPE CLASS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**	**User's accuracy**
1	*127*	1	3	18	9	1	0	7	166	0.7651
2	2	*234*	0	0	24	32	4	1	594	0.8939
3	5	0	*59*	1	0	0	8	1	74	0.7973
4	14	0	0	*46*	2	0	0	0	62	0.7419
5	8	21	7	1	*74*	3	20	1	135	0.5481
6	1	45	0	1	5	*126*	9	0	187	0.6738
7	0	12	7	0	8	12	*122*	0	161	0.7578
8	6	0	5	2	0	0	0	*102*	115	0.8869
TOTAL	163	610	81	69	122	174	163	112	**1197**	
Producer's accuracy	0.779	0.8705	0.7284	0.6667	0.6065	0.7241	0.7485	0.9107		
Kappa statistic	***0.737043***									
Overall accuracy	***74.35%***									

It is important to note that the performance of all these model assessment statistics will depend on the number of biotope classes. Models with fewer classes will generally give better statistics as there are more training (and test) points per class. However, fewer classes means a lower level of information content in the resulting map. The pragmatic solution is therefore to find a reasonable trade-off between level of detail and an acceptable accuracy measure.

A related issue currently under investigation as part of the MAREANO biotope methods development study is the sample length extracted from video lines. To date a sample length of 200 metres has been standard for biotope mapping since an initial test on cumulative species richness at Tromsøflaket (figure 15). This choice of length is currently being evaluated across several representative mapping areas in order to test if this length remains the most suitable choice for future biotope modelling. Rank correlograms of the data from Nordland VI have provided further evidence in favour of this length (see below).

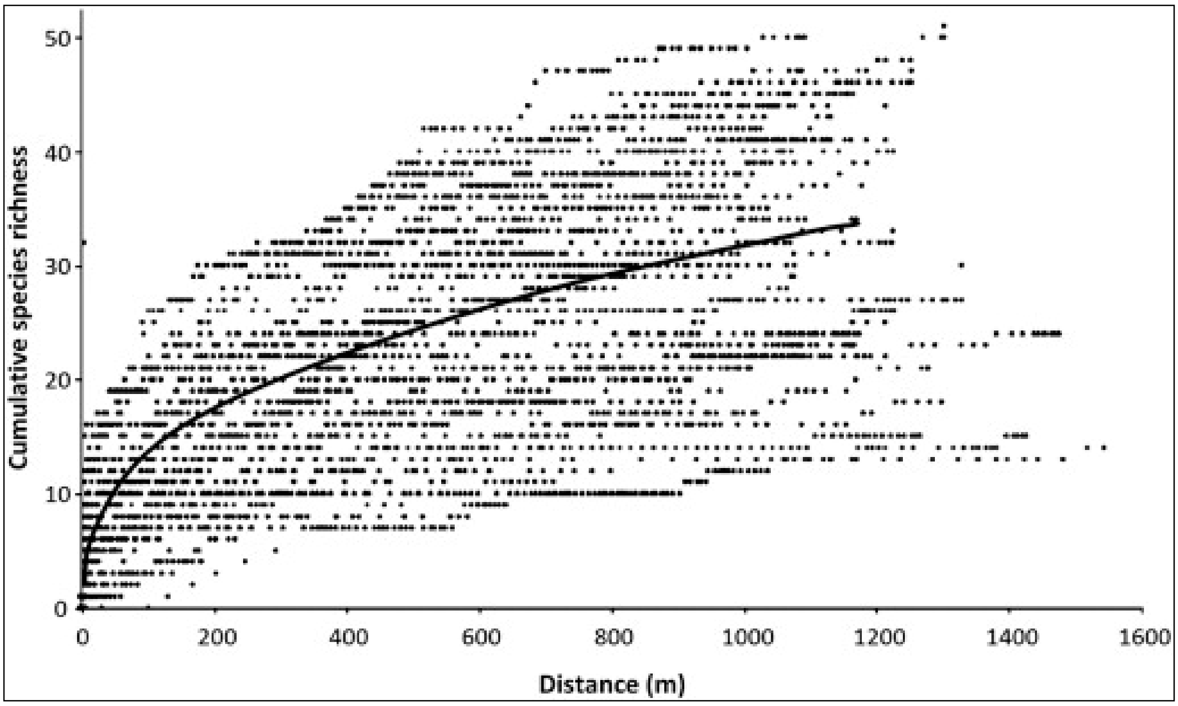

Figure 15. Cumulative number of taxa versus distance along 48 video lines recorded at Tromsøflaket. The solid line indicates the mean cumulative number of taxa for the same distances for all 48 video lines. From Buhl-Mortensen et al. (2015).

The method for definition of biotope classes has been changed in recent years from expert-based to automated (k-means) providing greater transparency and repeatability to the classification, however, the current approach still requires that biotope classes are determined from ordination (DCA) results specific to each mapping area. This means that maps for different MAREANO mapping areas are not harmonised (figure 16) and leads to changes in class definitions over time as mapping area boundaries extend and some areas e.g. Tromsøflaket are remodelled. With no pre-defined biotope (habitat) classification to work according to and an initial lack of knowledge about Norwegian offshore fauna MAREANO's first ten years have been largely a discovery phase for biotope mapping. Within this framework evolving biotope maps have generally proved acceptable and useful for management and other users. However, now that MAREANO mapping is well established and knowledge of the benthic fauna of this area much advanced thanks to MAREANO the demand for harmonised and stable biotope maps is growing.

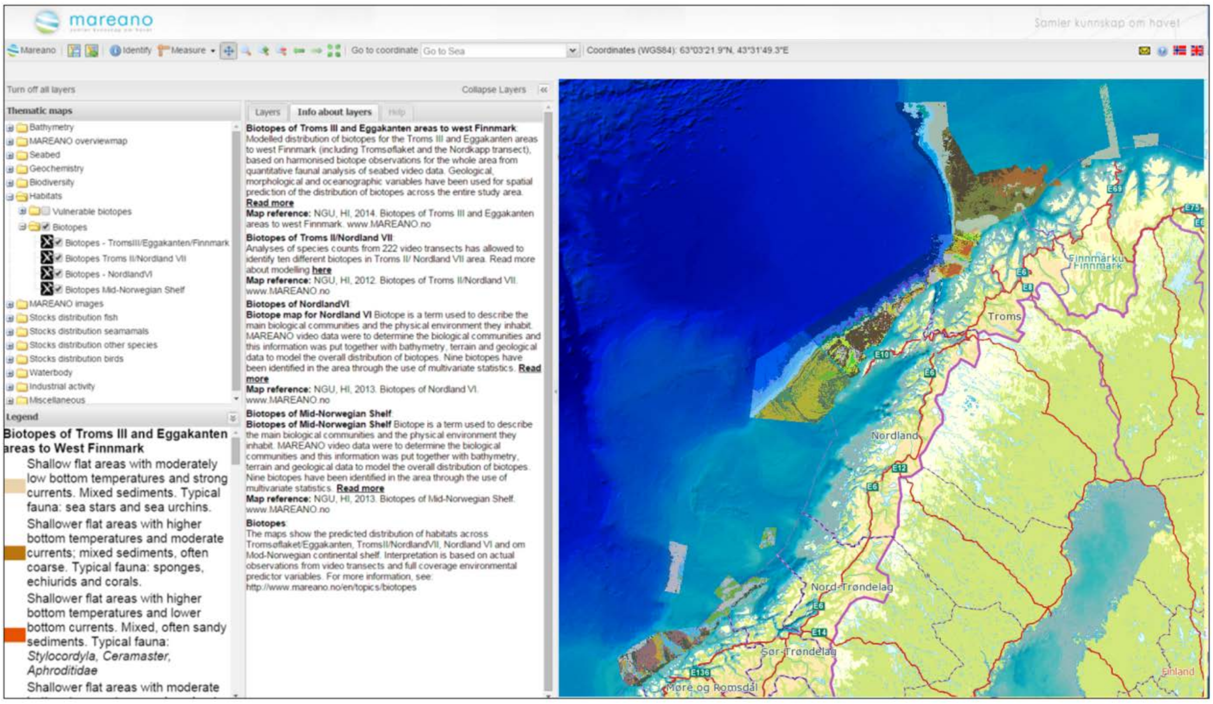

Figure 16. All MAREANO biotope maps currently published on www.mareano.no. Biotope maps have been separately produced for 4 areas: Troms III and Eggakanten to west Finnmark, Troms II and Nordland VII, Nordland VI, Mid-Norwegian Shelf. Some of these maps are already updated from previous versions.

The classes of video samples based on similarities in species composition are challenging to compare between areas modelled separately. As new areas are surveyed and new video samples are added to the database, biotope classes need to be revised. Although tests of this between MAREANO survey areas have proved useful with only small changes of clear classes identified by the prior separate ordinations this area-by-area based analysis strategy does not seem sustainable especially in light of the growing demand for a harmonised map. Tests to date indicate, however, that the solution to harmonisation is not simply a matter of working with an ordination that pools all available biological data to date. Important faunal groups can be obscured by such methods, and the species turnover may be too great for the ordination methods to handle when operating across several biogeographic regions. Alternatives to DCA such as Non-metric multidimensional scaling (NMDS) (Kruskal 1964 a, b) are also under investigation, either as ways to obtain more relevant information for identification of biotope classes and/or as parallel ordination (van Son and Halvorsen 2014) to validate the DCA results, increasing the overall confidence.

MAREANO biotope mapping has now been conducted across several biogeographic regions from the mid-Norwegian shelf to the Barents Sea. It is important to remember that when the geographic area increases, the “biological signals” resulting from regional “climatic” gradients become increasingly important. Across larger biogeographic regions oceanographic gradients become less or varyingly correlated with predictor variables derived from the terrain, that may have served as an adequate proxy within a certain ‘climatic setting’. Across areas spanning thousands of square kilometres spatial prediction based on depth, terrain and sediment classes will have less explanatory ability and the model will be poor. To address this problem, the best solution is to include full-coverage information about the seabed “climate” as predictor variables (e.g. temperature, salinity and currents, including estimates for their variability, maximum and minimum values). The first biotope maps incorporating oceanographic data were published in 2014 (Troms III, Eggakanten and west Finnmark) incorporating data from related projects and IMRs database. These data have demonstrated that oceanographic data will be an important input to future MAREANO biotope modelling as well as prerequisite for the production of "harmonised" biotope maps across larger areas of the MAREANO mapping area. Oceanographic data from the NorKyst 800 model (Albretsen et al. 2011) have been provided to MAREANO in 2015 and will be used in future biotope modelling within the area covered by these data (figure 17).

Another practical consideration that will need to be addressed when modelling over large areas is that of model resolution. A raster size of 50 metres offers a good compromise between detail and processing capability for limited mapping areas however in predicting across wider areas this may need to be revised to a coarser resolution, or the mapping area subdivided into areas of a size suitable for predictions to be run at 50 m.

Biotope maps are just one component of the overarching theme of habitat mapping. Another potential, and possibly parallel, route towards harmonised habitat maps for MAREANO mapping areas is through use of the newly updated Norwegian Nature Types classification descriptive system (Halvorsen et al. 2015).

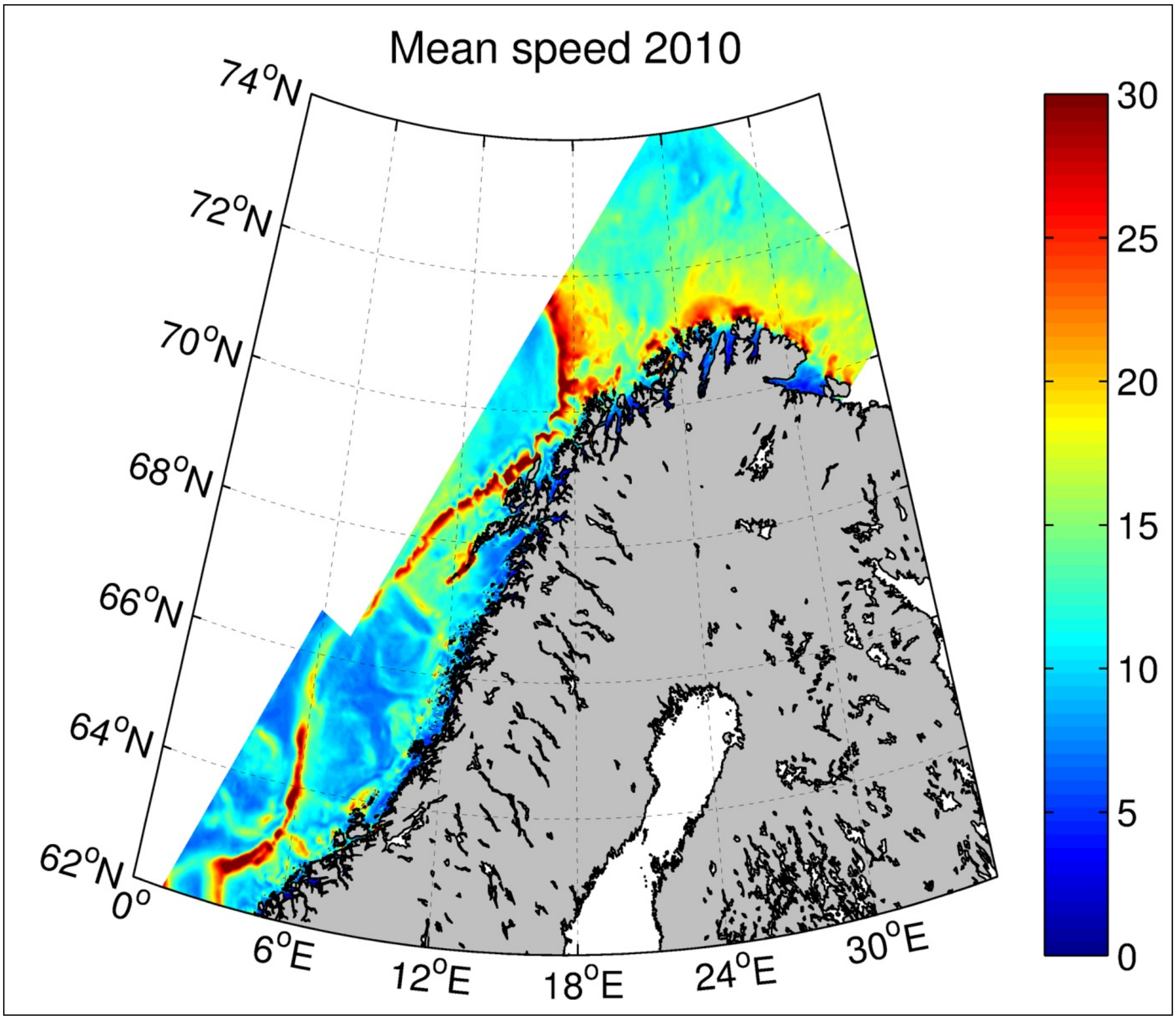

Figure 17. Example of oceanographic data from the NorKyst 800 model. Bottom current speed calculated from the lowest layer in the model given in cm/s.

5.2 Biotope maps - technical summaries

Since 2013 MAREANO has produced a technical summary document to support each biotope map published. This provides an overview of the input data, modelling methods and statistical validation of the final map product. Technical summaries are available for the following areas:

- Nordland VI http://mareano.no/en/topics/biotopes/biotope_modelling_technical_summary_nordland_vi
- Mid-Norway http://mareano.no/en/topics/biotopes/biotope_map_for_the_mid_norwegian_continental_shelf
- Troms III, Eggakanten to west Finnmark http://mareano.no/en/topics/biotopes/biotope_map_for_the_mid_norwegian_continental_shelf

The biotope map for Troms II, Nordland VII was published before technical summaries were introduced as standard practice, but is reported in a report and scientific paper as part of the investigation into the use of Olex data for MAREANO.

5.3 Ongoing method development for biotope mapping

Method development has been ongoing since the first MAREANO biotope map was produced in 2008 and has to date involved testing of several approaches to modelling and the incorporation of oceanographic data. Although Maxent modelling is the current standard we have introduced parallel modelling using Random Forests as a reference to the Maxent results. We remain open to the adoption of improved modelling methods which are constantly being developed in the wider scientific community. Alternative methods may improve the workflow and results, and/or provide greater insight into the environmental gradients driving biotope distribution.

A more pressing issue related to biotope modelling is the handling the large volume of biotope sample data (from video), and the classification and harmonization process of data across several mapping areas. A workshop addressing potential methods for streamlining the workflow is planned for June 2016 at HI with participants from NGU. The relevance of these and other methods will be discussed by all MAREANO scientists involved in biotope mapping with a view to streamlining the workflow across the 2 institutions and working together towards more spatially and harmonized biotope and related nature-type products.

5.4 NiN 2.0 - towards nature type mapping

'Natur i Norge' (NiN) – Nature Types in Norway version 2.0 (Halvorsen et al. 2015) was released April 15, 2015 following a project managed by Artsdatabanken and led by Professor Rune Halvorsen of the Natural History Museum/University of Oslo. Further details available here (in Norwegian) http://www.artsdatabanken.no/NaturiNorge. NiN is due to be phased in as the standard way of classifying and describing all nature in Norway (terrestrial, marine, freshwater) and from 2018 government signals indicate that NiN should be used in all publicly funded nature-type mapping. This has potentially wide-reaching implications for

MAREANO. The foundation for progress towards NiN mapping is already in place since MAREANO has had a close working relationship with other institutes leading to the development of NiN v.2.0.The natural progression of this collaboration is to work, in collaboration with Artsdatabanken/NiN towards production of NiN-based nature type maps that make full use of MAREANO data, especially since MAREANO is financed directly through the national budget and produces map-related information that is used in marine management. However, no funding is currently in place to address this additional effort, or develop guidelines for marine mapping (equivalent to those already developed for terrestrial mapping).

A move towards NiN-based mapping potentially removes the need to classify biotopes from scratch each time a new area is being mapped. In contrast to the methods currently used by MAREANO for biotope classification, NiN operates on non-metric multidimensional scaling (NMDS) ordinations on theoretical and generalised lists of species and how they respond to and are structured by environmental complex-gradients. This way, NiN is a fixed, although adjustable, system that will classify species-compositions into known nature types. The delineation of these types is based on so-called ecological distance units. A nature type (grunntype) is bounded by one ecological distance unit along both axes (represented by a box in Table 4). These units correspond to a certain range along major complex-gradients (represented by NMDS axes) scaled in half-change units, which again correspond to a certain amount of change in species composition.

Thus, a NiN-classification will be based on a combination of (a) looking at where observations fall into the combination of major complex-gradients (which defines the nature type, 'grunntype') and (b) the position in ordination space. The advantage of this is that classifications based on NiN should always be the same, irrespective of the amount of biological data and the extent of the study area that are used for the classification. Furthermore, while biotope maps have faced problems with regard to naming conventions, NiN will always yield the same and recognizable name for areas of similar environmental conditions giving information with greater stability for management and other users.

In addition to providing a basis for a more stable system of nature type classification the NiN approach, using generalised species lists, overcomes another problem. There will always be quite a bit of noise in species data collected in the field that will tend to distort the ordination result. Such distortions will propagate into biotope modelling and introduce errors. Further, by basing the class boundaries on half-change units directly related to species turnover we remove the need to use a non-deterministic method such as k-means to split the biotope classes into a more arbitrary number of classes not directly linked to the species turnover.

Table 4: Example of NiN classification for M4 Eufotisk marin sedimentbunn (translated from and modified after Halvorsen et al. 2015) showing the concept of types (so-called 'grunntyper') varying along two major complex gradients. Each box represents a 'grunntype', and each box represents a standardised change in species composition along both axes. For example, it is expected that grunntype S1-g corresponds to a certain species composition that is characterised by little resistance to erosion and contain little fine-grained sediment particles.

S3–F– Mud content									
	¤ High mud content	unconsolid. mud with high water content	unconsolid. mud	S1·h coarse silt	S1·h fine and intermediate silt	S1·i clay	consolidated clay		
	bc Intermediate mud content			coarse sand with intermediate mud content	fine sand with intermediate mud content S3–S·c	gravel and rocks with intermediate mud content S3–S·d			
	0a Low mud content		S1·g fine and intermediate sand	S1·f coarse sand (and very fine gravel)	S1·e fine and intermediate gravel	S1·d coarse gravel S3–S·a S3–S·b	S1·c rocks	S1·b boulders	S1·a bedrock
M4 Explanation To S3-Diagram		0 very low	a low	b quite low	c intermediate	d quite high	e high	f very high	¤ bedrock
		S3–E – Resistance to erosion							

At the time of writing we see that the NiN system is promising, however we note that the publication of NiN 2.0 only presents the theory behind NiN. There is considerable work to be done in taking this theory into practical use in classification of nature and mapping, especially in the marine realm. MAREANO has gathered a wealth of biological and environmental information over the past decade but a dedicated effort will be required in collaboration with NiN to make full use of these data to produce generalised species list for marine nature types. This work should be prioritised as soon as possible. Until this is done any NiN-based mapping will rely on theory alone and therefore be based largely on physical environmental data while underusing MAREANO's rich biological data resource. As long as this is the case a separate biotope map is likely to be required in order to present biological results from MAREANO. In preparation for the phasing in of NiN from 2018, MAREANO is starting to investigate the necessary actions and preparation, in collaboration with NiN.

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6. ENVIRONMENTAL STATUS AND POLLUTION

The MAREANO programme collects sediment samples from the seabed. Sediment analyses provide information about both current levels of pollution and changes over time, particularly during the past 100–150 years since industrialisation began. The sediment samples (cores) are brought up in tubes and are then cut into 1 cm slices to determine the age of the sediments. This is done using the lead- 210 isotope (210Pb), which has a half life of 22.3 years, and the carbon-14 isotope (14C). The analysis of more than 40 of these core samples has revealed that each centimetre can be equivalent to at least 5–20 years of sedimentation. This means that the top 20 centimetres may represent the sedimentation from the past 100–200 years. The deepest layers of sediment in a 50 cm core sample may be several hundred, or even several thousand, years old. Core samples are analysed for a number of environmental pollutants, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs) and other organic pollutants. This chemical analysis provides us with important information on background levels.

In MAREANO, NGU is responsible for inorganic geochemical analyses to study pollution and environmental status. NGU analyses heavy metals, As and Ba, and is also responsible for dating of sediment cores to study changes in environmental status in the past tens to hundreds of years.

References

http://www.mareano.no/tema/forurenset_havbunn

6.1 Primary sampling & sample preparation

A multicorer is used for the sediment sampling. Sampling methods and methods for sample preparation onboard are described in the references given below.

References

Jensen, H. et al. 2015: Miljøkjemiske data og dateringsresultater fra Norskehavet, Finnmark og Barentshavet Øst - MAREANO. NGU Rapport 2015.038, 65 s.
http://www.ngu.no/upload/Publikasjoner/Rapporter/2015/2015_038.pdf

Sedimentprøvetaking på MAREANO-tokt (document describing procedures).
http://www.mareano.no/resources/Oversikt_over_datainnsamling_i_MAREANO_navnsetting_pa_stasjoner.pdf

News article describing sampling and sub sampling during cruises
http://www.mareano.no/nyheter/nyheter_2015/pa-jakt-etter-forurensning-i-norskehavet
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6.2 Analytical methods

Analytical procedures and compounds analysed are described in detail in the references provided below.

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MAREANO Activity plan 2016 http://www.mareano.no/resources/images/2016/MAREANO-aktivitetsplan-2016.pdf (Appendix 8, 48-53)

MAREANO Summary report 2014 http://www.mareano.no/resources/files/MAREANO-aarsrapport-2014.pdf (47-49 and Appendix 3, 64-66)

7. DATA MANAGEMENT

Management of geodata and geological knowledge is one of NGU's core tasks. Data are made available via various map applications, downloadable data sets and map services (WMS). The services use several national databases with information about bedrock, sediments, mineral resources, ground water, geohazards, pollution, marine data etc. All NGU's maps and databases are available at www.ngu.no. MAREANO (www.mareano.no) publishes maps directly from NGU's databases.

References

Link to information about marine data sets http://www.ngu.no/emne/datasett-og-nedlasting?field_temagruppe_tid=2362&visning=liste

Link to information about marine map services http://www.ngu.no/emne/karttjenester?field_temagruppe_tid=2362&visning=liste

Data download http://download.ngu.no/download/

NGU data policy http://intra/Documents/Kart_databaser/NorgeDigitalt_InternasjonalePortaler/NGU_Bilag_3_2014.pdf

7.1 Map interpretations

Interpretation of the maps Sediments (grain size), Sediments (genesis) and Sedimentary environment, Landscapes (based on modelling) and Landforms is done directly in NGUs database (see procedures above). Biotope maps are based on modelling (see above) and the results are stored on server in a file based management system. The system ensures safe storage and backup of all interpretations, modelling results and final maps. Details can be obtained on request.

7.2 Multibeam data

Raw multibeam data (seabed and water column) and bathymetry data are managed and disseminated by the Norwegian Hydrographic Service (NHS). NGU maintains a copy of processed bathymetry data received from NHS for internal use. This is currently a file-based management system, however, a GIS based system using ESRI Mosaic Dataset (see Multibeam backscatter procedures for the MAREANO programme, Geological Survey of Norway (NGU)) is under development for internal NGU use. This will provide a more convenient user-interface to the growing data volume that is suitable for multiple users, and data storage has recently been re-organised to support this development. Confidential data are kept under confidential storage conditions and can only be accessed by security approved persons.

7.3 Backscatter data

NGU requires access to raw seabed multibeam data for backscatter data processing and maintains a local copy of these data in a file based system organised by survey year. Confidential data are kept under confidential storage conditions and can only be accessed by security approved persons. Processed backscatter data are currently available for internal use via a file-based system, but NGU is developing a GIS-based management solution for these data, supported by reorganization of the backscatter data which will provide a long-term solution. For further details see the document mentioned below.

Reference

Multibeam backscatter procedures for the MAREANO programme, Geological Survey of Norway (NGU).

7.4 Water column data

NGU requires access to both raw seabed multibeam data (RAW) and water column data (WCD) in order to analyse WCD. NGU maintains a local copy of RAW and WCD data based on a hard disk system, while the original data are managed by the Norwegian Hydrographic Service. The processed data (Fledermaus format) are stored in a local hard disk system. The interpretations are stored on the NGU internal data network.

7.5 TOPAS data

All TOPAS data (raw TOPAS data and SEGY data) are stored on a server in a file based management system. Data can be obtained from NGU on request. An overview of all collected TOPAS data with mini picture views can be found at http://geo.ngu.no/kart/marin/MARINEKART.html?kart=4&latlon=74.55,29.6&zoom=5

7.6 Video observations

IMR are responsible for the management of MAREANO video data. NGU has copies of selected videos as well as representative images from the video data for internal use.

7.7 Environmental data

Results of the environmental studies are published in reports and as maps on www.mareano.no on a yearly basis. Analytical results are stored on a server in a file based system and can be obtained on request. Analytical results are also delivered to a national database on water quality (see references).

References

Vannmiljø: http://www.miljodirektoratet.no/no/Tjenester-og-verktoy/Database/Vannmiljo/

Vannmiljø: http://vannmiljo.miljodirektoratet.no/