Comprehensive Databases for Seabed Environment

Kari STRANDE, Norway

Key words: Seabed mapping, Seabed Environment, Coastal Zone Management, Hydrography, Sea Floor,

SUMMARY

Sustainable management of the ocean and value creation linked to the sea will play a vital role for the world's ability to realize the totality of the Sustainable Development Goals (SDGs) by 2030. The SDG specifically addressing the ocean, SDG 14, stresses the urgent need to "conserve and sustainably use the ocean, seas and marine resources for sustainable development".

Norway has a vast marine territory and harvests great wealth from the sea. The fishing industry has been the heart of the Norwegian economy for centuries, and revenue from the oil and gas industry now contributes immensely. Despite this dependency on the sea, our knowledge of the seabed environment has remained poor. Discoveries over the last decade, such as the presence of numerous large coral reefs on the continental shelf off central Norway, highlight how much remain unknown. The Government has set out to fill the gaps in our knowledge through the seabed-mapping programme MAREANO. (Marine areal database for Norwegian Sea areas)

In this presentation, I will share the experiences from a unique collaboration programme in Norway called MAREANO. The programme contribute to a knowledge based conservation and use of the resources at sea. The programme has also been presented for the World Bank, FAO and the UN.

1. MAREANO – NEW KNOWLEDGE ON NORWAY'S MARINE AREAS

The MAREANO program developed through a collaboration between the Institute of Marine Research (IMS), the Geological Survey of Norway (NGU) and the Norwegian Mapping Authority Hydrographic Service (NHS). In June 2005, five million kroner were granted for the start-up phase. At last, after a seven-year-long effort, scientists and engineers could finally start the mapping of bathymetry, geology and biology of the seabed in the areas off Lofoten and in the southern Barents Sea.

There are many arguments for this large-scale mapping of the marine environment and marine resources. This is stated in Report No 12 to the Norwegian Parliament (2001 – 2002) "Protecting the Riches of the Seas" as well as in international conventions signed by Norway. The ecosystem approach is incorporated in both the Marine Resources Act (2008) and the Nature Diversity Act (2009). The Management Plans for the Barents Sea and the Sea Areas off the Lofoten Islands follow up these principles, as well as in the Management Plans for the

Norwegian Sea and for the North Sea and Skagerrak. All the management plans identify particularly valuable and vulnerable area. Figure shows map of the Management Plans area.
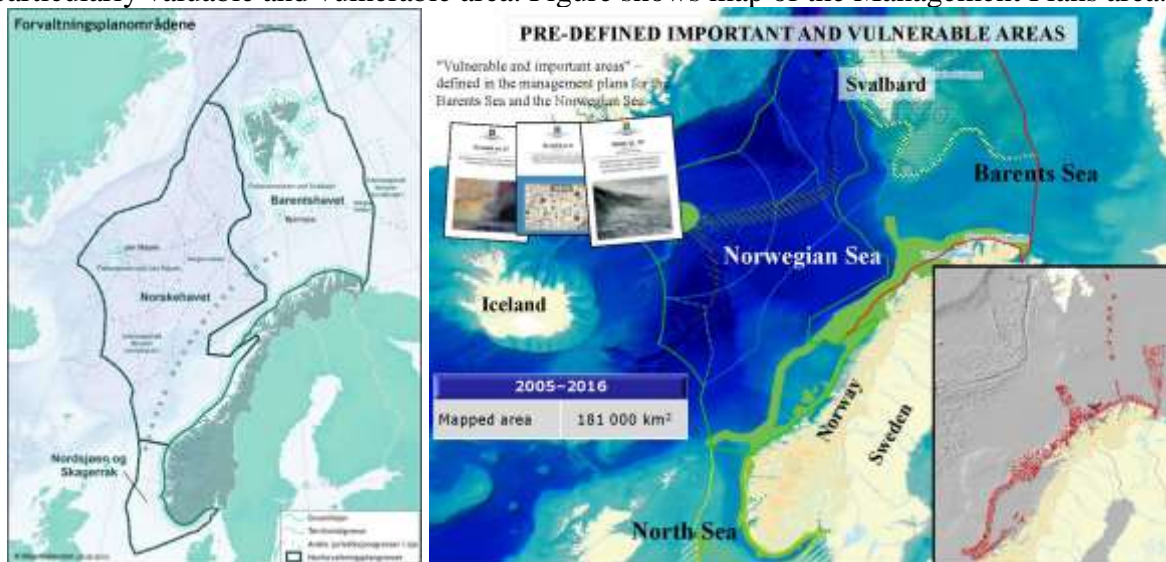

Sustainable use of coastal and marine resources must be based on knowledge. However, this knowledge is difficult to obtain for the various stakeholders within the public administration of aquaculture, fisheries, oil and energy industry etc. Without substantial effort to address this lack of knowledge, future decisions may be based upon deficient foundations – hence the need for a large-scale national initiative to map our sea areas.

Incomplete or missing knowledge of the physical environment undermines the prospect of an integrated management of resources and the environment. Historically, Norway has made little effort to obtain basic knowledge of our seascape, a knowledge that we take for granted on land; what does it look like? What does the seabed consist of? Where are the coral reefs? What do we know about natural diversity and about the interaction between seabed geology, seascape, biodiversity and biological resources? Where do the pollutants end up? We had only vague answers to these questions because Norwegian coastal and sea areas were among the most poorly mapped in Europe.

During the period 2006 -2018, the funding of the MAREANO has increased from NOK 23,6 million to over NOK 100 million per year, the focus still being to improve the knowledge as for future updates of our respective Management Plans. Today Norway has Management Plans for all its sea areas.

The Mareano programme has a Steering Group that comprises representatives from five ministries. A program group, responsible for the progress of the project, consists of government representatives with management responsibilities for the sea areas as well as management representative from the partner agencies. The executive group consisting of The Norwegian Mapping Authority Hydrographic Service (NHS), The Geological Survey of Norway (NGU) and the Institute of Marine research (IMR) carries out the map production.

There is a long-term plan for the programme now updated on to 2023. The left map below shows the planned area to be mapped and the area already mapped. The annual plans are based on the long-term plan. However, there can be some changes due to weather conditions, surveying capacity and changed political priorities. The right map shops sampling areas for Geo/Bio/Chemical samples.
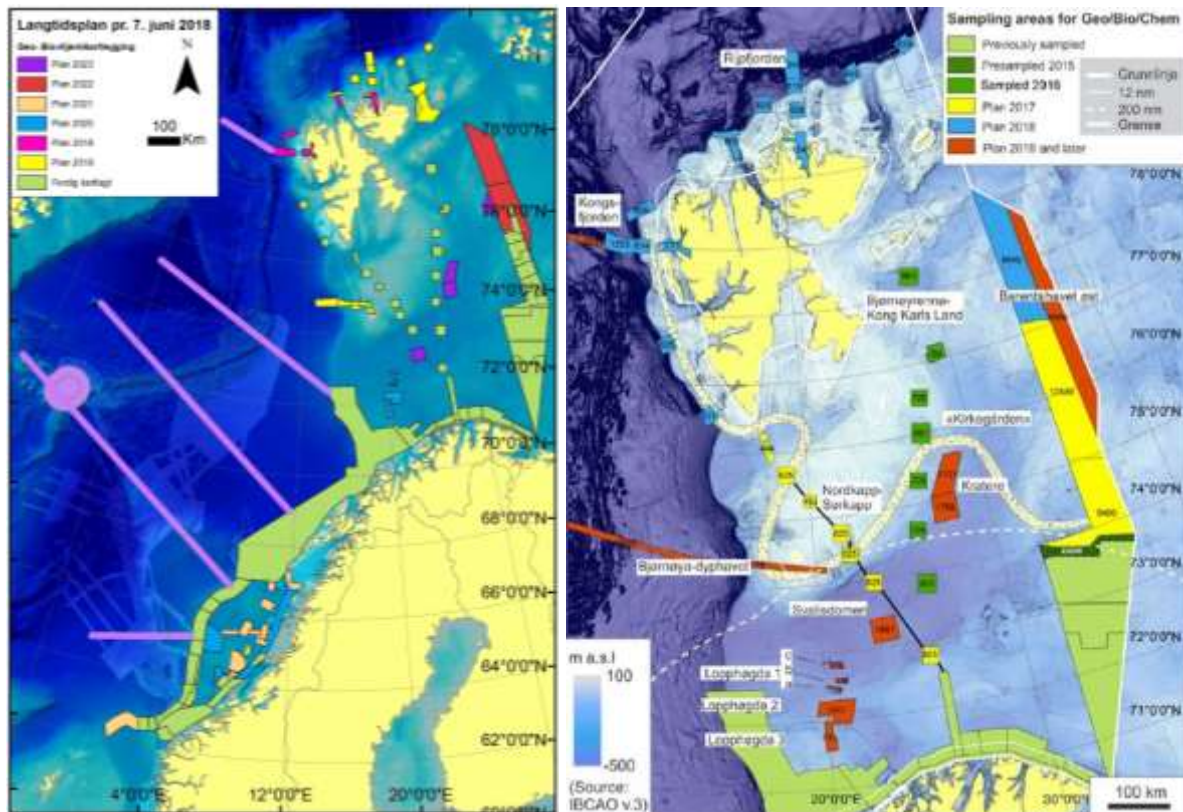

2. SURVEYING THE OCEAN – HOW WE STUDY THE SEABED

The MAREANO program gives information on bottom types, nature types, biotopes and geological conditions. There are many deliverables from the programme that can be examined at the MAREANO website http://www.mareano.no/en. Most information is in Norwegian; however, some information is also presented in English

Norway's sea area is as large as seven times the land area. The sea floor is large and relatively unexplored. What is the most efficient way of studying it? Although the sea floor in Norwegian waters has been the subject of a number of geological and biological surveys, they are not directly applicable to MAREANO. The most useful source of information for the MAREANO project is the new full-coverage bathymetric maps being produced in the first phase of the project. These maps, which have a resolution of 5x5 metres, will play a key role in helping us to carry out future research as efficiently as possible. They allow us to recognise small structures on the sea floor such as coral reefs, pockmarks and iceberg plough marks (which were produced when the ice cap retreated around 10,000 years ago). However, it is hard to spot wrecks and other objects or structures that are shorter than 20 metres long.

2.1 Basic bathymetric mapping
The National Mapping Authority Hydrographic Service (NHS) delivers detailed bathymetric maps based on measurements with multi-beam echo sounders. If bathymetric data of adequate quality and resolution already exist, these will be used in the MAREANO programme. Sources of existing data are NHS, the Norwegian Defence Research Establishment (FFI), the Norwegian Petroleum Directorate, the petroleum industry, universities, research institutes and other bodies. New bathymetric mapping under the auspices of MAREANO has mainly taken place in the Barents Sea and marine areas off the coast off Lofoten (see the summary map below). The last year's bathymetric mapping is carried out also at some part of the cost off Spitsbergen. The seabed surveying is conducted using multi-beam echo sounders aboard surface vessels, as shown in the illustration below.
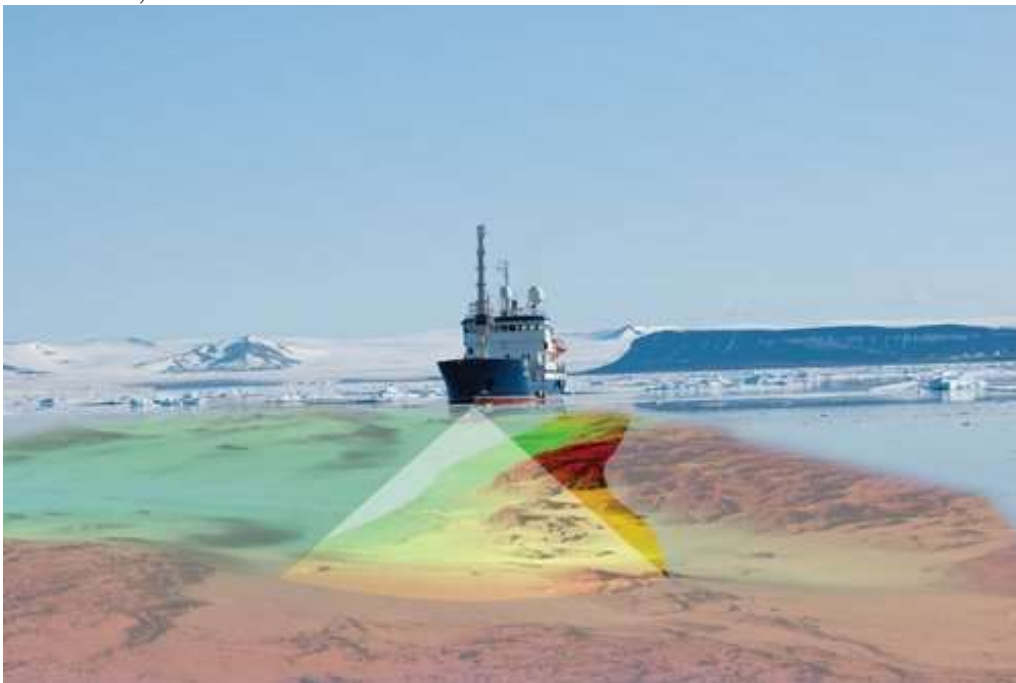
Bathymetric surveying using multibeam echosounder. The width of the surveyed belt is approximately 3.5 times the sea depth. Illustration: Norwegian Mapping Authority Hydrographic Service

2.1.1 Echo sounder
Since 2006, all bathymetric surveys at water depths of less than 1200 metres are carried out using the EM710 echo sounder manufactured by Kongsberg Maritime. This provides a dot spacing of approximately 0.9 metres at a water depth of 100 metres, 1.8 metres at 200 metres depth, and so on. This makes it possible to create high resolution (5 metre grid) terrain models which can be used to interpret highly detailed seabed features (coral reefs, ripple marks, etc.). In areas with more than 1000 metres water depth, the EM300 echo sounder is mainly used, and provides coarser resolution. Echo sounders are normally set up to measure 60 degrees on either side of the vertical, so that a boat line covers a belt on the seabed that is 3.5 times as wide as the water depth. In other words, if the water depth is 100 metres, a 350-metre wide belt is covered, in 200 metres of water the belt is 700 metres wide, and so on.

2.1.2 Additional measurements.

Measurements from the echo sounders also provide reflectivity (backscatter) data that contribute information about the nature of the seabed (hard or soft). This provides a basis for interpretations of, among other things, sediment distribution and habitat type. Since 2010, water column data have also been acquired using echo sounders. 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 gas bubbles in the water column, for example.

In addition to echo sounders, instruments are needed to measure the vessel's position, motion (course, speed, heave, roll and pitch) and the velocity of sound in the water, both close to the sonar transducer and thorough the water column. The interaction between the various sensors is important, and the installation of the equipment must be accurately calibrated with reference to the vessel's coordinate system.

To obtain the best possible geographical positioning, correction data are downloaded from GPS satellites following the actual fieldwork, and these are used to refine the positioning data. The recorded bathymetric data shall be filtered to remove noise and checked for gaps. This involves a certain amount of manual work and is therefore a time-consuming process.

2.1.3 Administrative and distribution responsibility

The role of the Norwegian Mapping Authority Hydrographic Service as a national administrator of bathymetric data places considerable demands on quality assurance and the establishment of bathymetric data in practical, modern administration and distribution systems.

The completed data sets are used to produce data grids of 5, 25, and 50-metre resolution. Inside the territorial boundary, the resolution is limited to 50 m in compliance with Norwegian military classification regulations. The terrain models are available and can be ordered for a charge by contacting the Norwegian Mapping Authority's distribution service by e-mail.

A WMS map service with shadow relief images has been created to visualise detailed bathymetric conditions of seabed features (see the illustration below). Map services have also been created which include a summary of general bathymetric conditions in Norwegian waters, as well as access to available bathymetric data administered by the Norwegian Mapping Authority Hydrographic Service. Most WMS services are open and can therefore be freely used in other applications and GIS tools. See the overview of the Norwegian Mapping Authority's open display services at geonorge.no.

All products and services are available for download and use through the "Norway Digital" initiative, in accordance with MAREANO's data policy. Access to the map services is also available by way of mareano.no and geonorge.no.

2.2 Landscape, bottom types, sediments and geomorphology
The Geological Survey of Norway delivers maps describing the bottom type, sediments and geomorphology of the seabed based on terrain analyses of multi-beam echo sounder, bathymetric data, video footage and sediment samples from the seabed

2.2.1 Hard and soft bottoms
Just like the land surface, the seabed varies in character, and ranges from bare rock and boulders to soft clay.
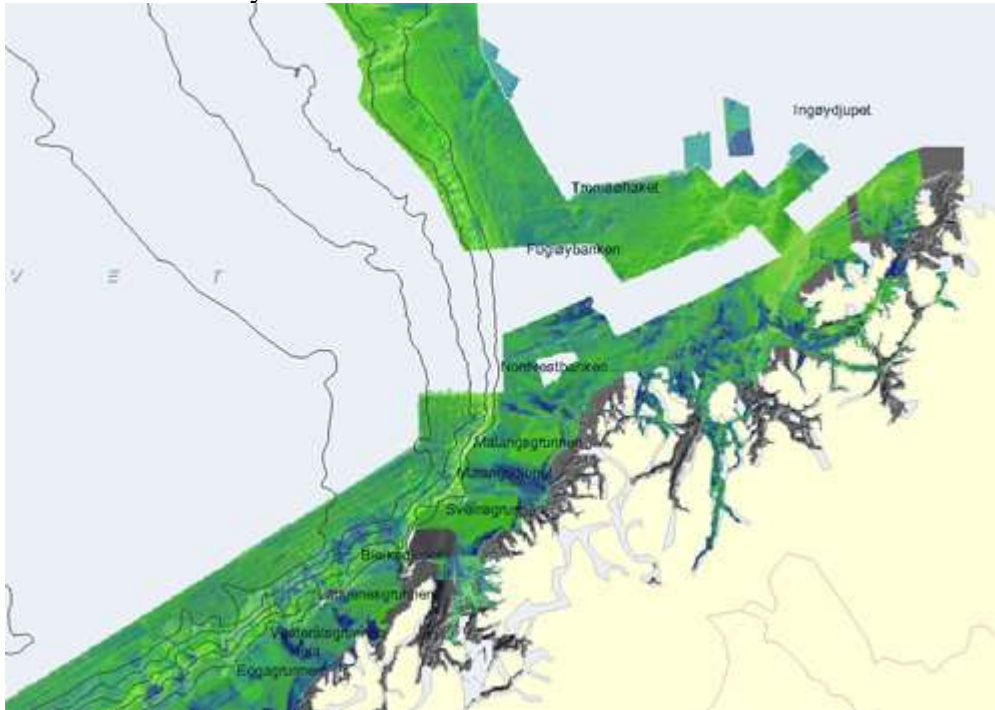
Bottom reflectivity varies from low (blue, relatively soft, fine-grained sediments) to high (green, relatively coarse and/or hard sediments), and are depicted as a semi-transparent layer above a shaded relief map.

The map of hard and soft bottoms is based on data acquired using a multi-beam echo sounder. This instrument is used for detailed mapping of water depths (bathymetry), but also supplies information on the composition of the seabed through the strength of the audio signals reflected back from the seabed. When the bottom reflectivity data are processed, it is possible to acquire detailed information on variations in the types of seabed.

The bottom reflectivity depends upon several factors. A hard or coarse grained, stony type of seabed usually gives a strong signal whereas fine-grained sediments on the bed give weaker signals because the audio signals are absorbed. Other factors influencing the bottom reflectivity are how well the sediments are sorted and how even the seabed is.

2.2.2 Marine landforms
The age of the marine landforms can vary from just a few years to several million years. Similarly, the size of the landforms 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 lineation, iceberg plough marks, moraines, slide escarpments, slide scars, slide areas, areas with slide deposits, submarine fans and areas with pockmarks.

Ploughmarks from drifting icebergs that scraped along the bottom in the Barents Sea. The "9" is about 1000 m long and 5-6 m deep that was formed at the end of the last ice age 10000 – 15000 yeras ago.

Locating these landforms is important for activities related to construction on the sea bottom, fisheries, aquaculture, oil and gas exploration, and environmental monitoring. Detailed mapping of marine landforms is an important task for MAREANO.

2.2.3 Marine landscape
MAREANO maps the large-scale marine landscapes of the seabed. Landscape is here 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. MAREANOs mapping has so far covered 10 types of landscapes.
Bathymetric data enable to determine which areas should be classified as plains, continental slopes, valleys and strand flats. The programme use a GIS-based method that employs low-resolution depth data and parameters that can be extracted directly from these to define the boundaries of these features in a manner that is reproducible and as far as possible does not involve interpretation.
Examples of mapped landscapes:
> **Strandflat.** The crystalline platform that characterises large parts of the Norwegian coast and contrasts sharply with the sedimentary continental shelf in the way it is built up and its topography.
> **Continental slope.** The transition zone between the continental shelf and the deep ocean. Large and small submarine canyons in several places transect it.
> **Marine valleys.** Eroded into the continental shelf and the strandflat, and a result of concentrated glacial erosion during the ice ages.
> **Fjords.** Over-deepened erosion forms which cut into the land and terminate at a threshold.

Abyssal plain. Starts at the foot of the continental slope and embraces all deep-sea areas with low relief, including the continental rise.

Continental shelf plain. The residual landscape on the continental shelf, where the relief is predominantly low, but there are nevertheless areas that are morphologically similar to other types of landscape (particularly shallow marine valleys).

Marine mountain landscape. Seabed area with high relief but without clear valley shape. In Norwegian areas, this landscape type is mainly found along the mid ocean ridges.

2.4 Mapping biotopes

"Biotopes" are a key concept in the MAREANO project. A biotope is a combination of species and the physical environment in which they live – a recognisable combination. This definition is close to the definition of the term "nature type", which is used by The Norwegian Biodiversity Information Centre when defining biotopes in Norway. For consistency, in Norwegian we refer to these biotopes as "nature types".

Bythocaris leucopis shrimp is common down to depths of 2700 metres.

The species on the sea floor are not evenly distributed: they appear in clusters associated with various environments and sea floor types. Each combination of certain species with a particular environment is known as a biotope, or "nature type". It is important to know how species are distributed if you want to manage the sea floor as sustainably as possible.

However, as our waters cover a vast area the process of mapping them is time-consuming and expensive. So what is the best way of collecting information about the biodiversity and biotopes in the large areas that need to be mapped? Currently, the only available detailed information about the compositions of sediments and benthic communities covers small areas dotted around the map. The question is therefore: how do we go from this situation to producing information covering the whole area? There are two main options for this:
- Establish map points ("stations") that are close enough together to provide virtually continuous information about the areas being mapped, or
- Leave larger distances between the stations and then use detailed information about the environment to predict – or to computer model – what biotopes you would expect to find between the stations.

The disadvantage with the first option is that it is expensive to map so many points close together. It is also very time-consuming to analyse either sediment samples taken from the sea floor using a grab, benthic sled or trawl, or videos of the sea floor. The objection to the second option is that we know too little about the relationship between the species and their habitats to allow us to make reliable predictions about the areas between stations. It has proved difficult to predict the distribution of species solely based on information about the surrounding environment.

In general, a variety of environmental factors combines in unknown ways, while biological conditions simultaneously "disturb" the known factors. One of key theories of the MAREANO project is that biological communities, which consist of numerous species, are more stable in relation to environmental variation than individual species. Whole communities can therefore be predicted more reliably than any individual species.

When describing biotopes, it makes sense to start by looking at the environmental conditions, and that is exactly what the bathymetric maps allow us to do. Those conditions are what determine which species can live in an area, and thus what the biotope is. The climatic, hydrological, topographic and geological conditions are the key parameters here. Next, in order to classify a biotope, you need to take into account the species living in the area, which together constitute the benthic community.

Videos of the sea floor are analysed in order to compare and classify different areas, based on the composition of benthic fauna observed. It turns out that these categories also share many characteristics in terms of water depth, acoustic reflection properties, topography and other indicators obtained from multi-beam echo sounding. In MAREANO they have used the correlation between these data sets to predict what biotopes you are likely to find in other similar areas, including places for which we do not have video recordings (i.e. between stations).
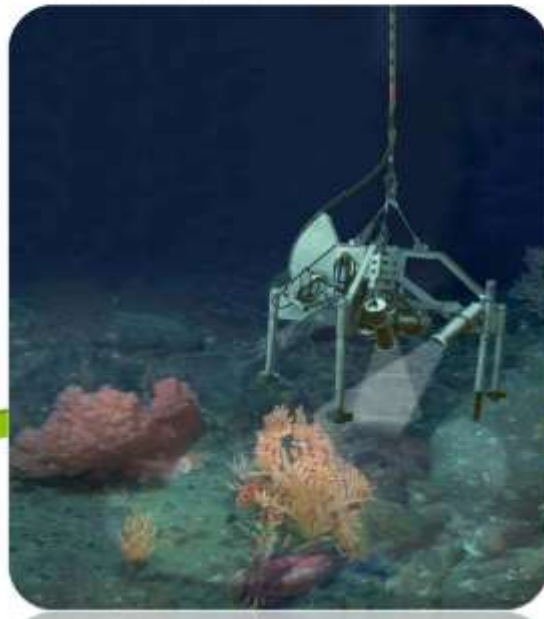
Example: Mapping coral reefs with bathymetry and HD video

3D model from multibeam bathymetry
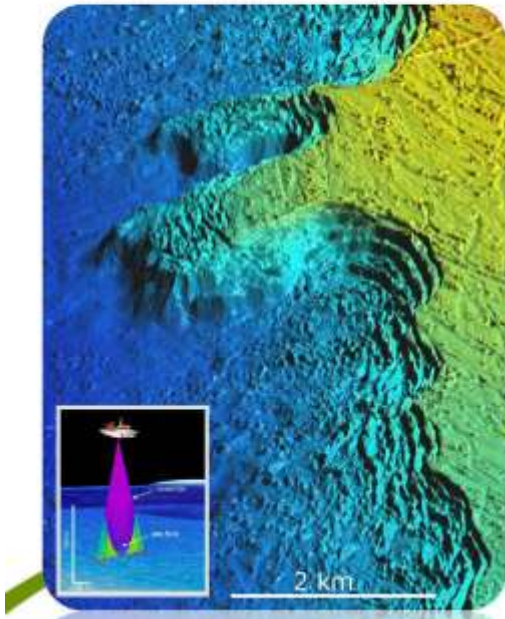
Towed platform with HD video

2 km

2.4. Environmental chemistry and pollution

The seabed receives contaminants from the environment, and sediments become a significant storage place for pollutants. Sediments can therefore be a source of pollution in the fjords and of the uptake of contaminants by biota.

Such contaminants may be heavy metals, organic compounds such as PAH or PCB, or radioactive compounds. Many of these compounds, however, are also found naturally in the ocean, sometimes in relatively high concentrations. For this reason, one has to know the background levels for the region before one may expose a contamination, and an important part of the environmental chemical studies is surveying the natural levels of contaminants in areas that are not polluted.

2.5 Testing Autonomous Mapping

New sensor platforms, such as autonomous vehicles and drones, open up new possibilities for mapping the terrain, sediments and habitats in shallow waters and the foreshore. MAREANO has teamed up with Norwegian University of Science and Technology to test out unmanned and autonomous platforms for interdisciplinary mapping.

AUTONOMOUS UNDERWATER VEHICLE: The AUV "Harald" is prepared for the expedition of the day and taken on board the boat "Lophelia". Photo: Sten-Richard Birkely

During the mapping expedition a variety of platforms both on, under and over the water, were tested, as well as a range of different scientific equipment and sensors. The MAREANO programme is particularly interested in the testing of video systems and multibeam echo sounder on various platforms.

3. KNOWLEDGE FOR THE BLUE ECONOMY

The Norwegian seabed-mapping program is a provider of knowledge for blue growth. MAREANO, provide scientific information on what the Norwegian seabed looks like, its geology, chemistry, and the biological communities that inhabit it. This information, including how anthropogenic processes affect the seabed environment, is needed for the sustainable management of Norway's large marine territory.

Turning aspiration into opportunity as dependence on the oceans increases, to provide food, energy and ecosystem services for a growing population. The Blue Growth faces unprecedented increase, and should at the same time secure sustainable ecosystems and biodiversity

Commercial interest in ocean resources is rapidly expanding, including oil and gas production, fisheries, blue biotechnology and mining.
Development of a blue growth should be based on the best knowledge of pelagic and demersal habitats and ecosystems for sustainable commercial activities in the ocean

MAREANO maps the seabed, presenting knowledge on
  – Habitats –geological and biological composition
  – Nature types –terrain variability and seascape
  – Environmental status in bottom sediments
  – Detailed bathymetry
  – Database-and map services presenting systematic information about the seas
These data and products are important knowledge for fishery, navigation, energy, oil and industry, mining, aquaculture, tourism and recreation, transport, constructions and infrastructure.

One example of value is from the fisheries that have tested active use of new seabed maps from Mareano and depth data.The experiences so far is very good. The maps can contribute to more precise, environment friendly and efficient fishery. The capture has increased, the use of fuel is decreased and the damage on equipment is reduced. Experiences from Canada also shows great economic and environmental benefits by use of detailed depth data and bottom type maps during fisheries. Now we have the same experience in Norway.

The MAREANO programme can contribute to;
 "Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries." Sustainable Development Goals, 14.a

There are still major deficiencies in the basic knowledge of ocean biodiversity, ecosystem functioning, resilience and connectivity. Increasing our fundamental knowledge of the ocean systems is essential to underpin all societal, environmental and economic activities in the ocean.

International cooperation gives better maps and more value for money.
Recently there was a meeting in Norway in a network (MIM) of the three largest marine mapping programmes in Europe; MAREANO (Norway), INFOMAR (Ireland) og MAREMAP (Great Britain), (MIM) will work for more standardised marine mapping across country borders. There are many of the same challenges and problems in all marine countries. In the network, they discuss methods, masterplans for surveying, equipment for samples from the sea floor and mapping of landforms.

To survey the seafloor has a cost of over 100 million NOK every year. The knowledge are valuable and necessary to a good management of the marine areas. In Norway, only 10% of the seafloor on the continental shelf is surveyed so far. In these areas, we know a lot about

terrain, sediments, bottom types, fauna, biotopes and pollution. This knowledge contributes to good management decisions. The nature does not consider the country borders so that is why a core approach to methods, classification and terminology will increase the value of the surveying and the maps. It will simplify seamless maps and reuse of knowledge to make other types of maps.

Other countries show interest for the MIN cooperation and a handful of researcher from other countries participates in some working groups. Researchers from Geoscience Australia participate in the work of harmonising classification of landscape and landforms. Other countries also participate in the work on automation of map production.
In the future, we hope that more countries can make use of the same methods and terminology as- this will contribute to a more objective and reusable surveying and mapping.

The Mareano program is one part in Norway's efforts to get more knowledge about the resources in the Ocean and the programme been presented both to the World Bank, FAO and United Nation. We see the programme of importance also as a contribution to the Ocean Economy. Last year our Prime Minister Erna Solberg launched the Major intergovernmental Panel on the New Ocean Economy. http://www.oceanpanel.org/

Reference:
The Norwegian Sea Floor, New Knowledge from MAREANO for Ecosystem-Based Management. ISBN 978-82-690163-0-7 Editors: Lene Buhl-Mortensen, Hanne Hodnesdal and Terje Thorsnes
The Mareano website: http://www.mareano.no/en

Biographical notes:
Educated surveyor with additional education in architecture and law studies.
Delegate to commission 3 since 2001 with several papers at congresses and WW
Editor of several publications about Map and use of Maps
Leading positions from municipalities, regional planning, Norwegian Mapping Authority and now deputy director general at Ministry of Local Government and Modernisation.
Chaired exchange programme for young surveyors between Vietnam, Laos and Norway 2001-2009 and worked with Norwegian Agency for Development Cooperation.

Contacts:
Deputy Director General Kari Strande
Institution: Norwegian Ministry of Local Government and Modernisation
Address: Akersgt. 59
City: Oslo
COUNTRY: Norway
Tel. + 47 90996515
Email: kari.strande@kmd.dep.no
Web site: https://www.regjeringen.no/KMD