Seabed mapping in Norwegian waters: programmes, technologies and future advances

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Abstract: A holistic understanding of the oceans as part of the Earth system is imperative for the future management and sustainable utilization of the ocean’s natural resources. Increasing pressures on global resources have been accompanied by important advances in acoustic remote sensing technologies, allowing us to map the seabed in unprecedented detail. The MAREANO (Marine areal database for Norwegian waters) programme in Norway, one of the world’s largest seabed mapping programmes, is designed to close the knowledge gaps with the use of the new technologies.

To date, since the start in 2005, c. 1170 million NOK (Norwegian kroner), equivalent to c. US$115m have been allocated to this programme (2005–20). This paper outlines the development of MAREANO and other large marine mapping and science programme proposals in Norway, and considers which factors influenced whether they were realized or not. In conclusion, funding of MAREANO came as a result of the convergence of political needs, technical capacity and multi-institutional co-operation.

We further give an overview of the new and improved seabed mapping technologies, and finally we discuss the Norwegian programmes in connection with similar major international ongoing programmes and new initiatives and take a look at possible advances in future seabed mapping.

Norwegian seas are the main areas for value creation in the country. The oil and gas industry, developed exclusively in marine areas, is the country’s largest industry and amounts to 14% of the gross domestic product (GDP) and 39% of total export incomes (Anon 2018). The seafood sector, including fisheries, aquaculture and fish processing, is another important marine sector contributing to 1.6% of GDP and 11% of total export incomes (Anon 2018). The area of Norwegian continental shelf (Fig. 1), including the Norwegian Exclusive Economic Zone (EEZ) and international waters (High Seas), encompassed in the ocean management plans is 2 356 977 km2. This is about seven times the size of the Norwegian land area (323 000 km2). The coastline is 100 915 km in length, the second longest for a single country in the world, fragmented by fjords and thousands of islands, islets and skerries. The waters are biologically rich and some of the most productive in the world. The environmental status of Norway’s marine areas is generally good, but there is a growing need for more ocean space for aquaculture, extensive fishing, oil and gas production, marine mining, shipping, infrastructure, tourism and recreation (Olsen et al. 2007; Anon 2011).

Over the years, knowledge-based management has become central to the regulation of human activities in Norwegian waters and, in the 1990s, there was a growing recognition that science must play an important role in sustainable ocean management (Boesch 1999). The development of the Norwegian ocean management plan for the Barents Sea and the sea areas off the Lofoten Islands was viewed in this context (Douvere 2008; Cochrane et al. 2014). At that time, there was an emerging understanding that it is important to know the totality of any human impact on the ecosystems, rather than just maximizing fishing catch from fish stocks (Knol 2010). Risk assessments with worst-case scenarios are important parts of the management process. The levels of uncertainty and need for alternative approaches have been discussed by Hauge et al. (2014).

The white paper ‘Protecting the riches of the sea’, published in 2002 (Anon 2002), marked the official start of the development of ocean management plans in Norway. The government declared that it intended to establish an integrated management plan for the Barents Sea; to develop integrated management plans for coastal waters including fjords; and to introduce a long-term policy focused on...
ecosystem-based management. The government established a strong political steering group with members from all the relevant sector-ministries, showing that this was a politically driven top-down approach (Olsen et al. 2014, 2016). The plan for the Barents Sea was succeeded by similar plans for the Norwegian Sea (Anon 2009) and the North Sea, including the Skagerrak (Anon 2013). The process for the Norwegian Sea plan has been described and discussed by Ottersen et al. (2011). Several science-driven proposals for marine programmes have been developed over the last decades, including the ‘Marine areal database for Norwegian waters’ (MAREANO). Here, scientific and applied needs have been identified by groups of scientists. The rate of success of these proposals in terms of funding seems to be related to the number of institutions and ministries involved, and the stakeholder support.

Fig. 1. Overview map of the Norwegian continental shelves and management areas (inset map). AN, Aktivneset; BS, Barents Sea ocean management plan (OMP) area; F, Finland; N, Norway; NS, North Sea OMP area; N VII, Nordland VII; NWS, Norwegian Sea OMP area; R, Russia; S, Sweden; T II, Troms II.
The first attempt in Norway to establish a scientifically integrated and cross-sectoral seabed mapping programme involving several ministries with dedicated funding from the government came in 1990, when a plan for marine geological mapping of the Norwegian sea territories was launched (Anon 1990). The scope of the plan was broadened, and a new concept – the MAREANO programme – was developed towards 2000. Special focus was given to the potential for mapping the distribution of cold-water coral reefs, because extensive (30–50%) destruction of coral reefs had been indicated (Fosså et al. 2002), making this a timely topic. The MAREANO programme was developed to meet the applied science needs for the management of benthic ecosystems in the particularly valuable areas identified in the preparatory phase of the management plan (Olsen & von Quillfeldt 2003). A report from an expert group (Anon 2005a) identified knowledge needs for the Barents Sea, and provided further guidance on the methods and products for the programme. The management plan for the Barents Sea and the sea areas off the Lofoten Islands (Anon 2006) provided detailed directions for which areas should be covered in the first years of the programme. The MAREANO programme received start-up funding in 2005. An overview of the key ministries, agencies, universities, organizations and companies involved in the development of MAREANO and its predecessors is given in Table 1. Note that the ministries of Trade and Industry, and Fisheries/Fisheries and Coastal Affairs merged in

| Table 1. Ministries, agencies, universities, organizations and companies involved in MAREANO, and their roles |
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| **Ministries** |
| Trade, Industry and Fisheries | NFD | Financing: NFD 2005–present, KLM 2005–13, KMD 2014–present |
| Climate and Environment | KLM | KLM 2005–13, KMD 2014–present |
| Petroleum and Energy | OED | KMD 2014–present |
| Local Government and Modernisation | KMD |
| Transport and Communications | TR | Steering Board |
| **Agencies** |
| Geological Survey of Norway | NGU | Executive group, and Programme group |
| Institute of Marine Research | IMR |
| Norwegian Mapping Authority | NMA |
| Directorate of Fisheries | DF | Programme group |
| Norwegian Environment Agency | NEA |
| Norwegian Petroleum Directorate | NPD |
| Norwegian Coastal Administration | NCA |
| Norwegian Polar Institute | NP |
| Norwegian Defence Research Establishment | FFI | Executive group 2006–09 |
| Norwegian Military Geographic Service | FMGT | Reference group 2006–09 |
| Biobank of Arctic Marine Organisms | MB |
| Norwegian Biodiversity Information Centre | NBIC |
| Norwegian Institute for Water Research | NIVA |
| World Wildlife Fund | WWF |
| Norwegian Oil and Gas Association | NOROG |
| Norwegian Fishermen’s Association | NFA |
| Directorate for Cultural Heritage | DCH |
| University of Tromsø | UiT | Reference group 2006–09, Scientific co-operation |
| Directorate for Nature Management | DN | Programme group. Merged into NEA in 2013 |
| Norwegian Pollution Control Authority | SFT | Programme group. Merged into NEA in 2013 |
| Norwegian University of Science and Technology | NTNU | Scientific co-operation |
| University of Oslo | UiO | Scientific co-operation |
| University of Bergen | UiB | Scientific co-operation |
| Continental Shelf Institute | IKU | Scientific co-operation |
| Norwegian Technical Nature Science Research Council | NTNF | Funded pre-MAREANO seabed mapping |
| Norwegian Research Council | NRC | Funded preparatory method development |
| Kongsberg Maritime (formerly K. Simrad) | KM | Private industry co-operation |
2014, and for simplicity they are referred to as one entity (the Ministry of Trade, Industries and Fisheries (NFD)). An overview of the current organization structure for MAREANO is given in Table 2.

The MAREANO concept, providing knowledge for ecosystem-based management of the oceans grounded in a holistic understanding of the benthic ecosystems, was breaking new ground at this time. A dedicated research project – SUSHIMAP (Survey strategy and methodology for marine habitat mapping) – was therefore funded by the Norwegian Research Council (NRC), investigating how habitat mapping of large areas in Norwegian waters could be best performed economically as well as scientifically (Christensen 2006). This research project provided important input to the survey methodology applied by MAREANO. The scientific methods in MAREANO were also inspired by innovative work in Canada, where benthic mapping based on multibeam bathymetry, surficial geology and seafloor photographs was developed (Kostylev et al. 2001; Pickrill et al. 2014).

The present paper outlines the development of MAREANO (Thorsnes et al. 2008) and previous large marine mapping programme proposals in Norway, and considers which factors influenced whether or not they were realized.

These include:

- the political context for the development of the MAREANO programme;
- the role of developing technology, and how that influenced the ability to design a programme which could cover political needs;
- how co-operation with academia works, and supported the work for establishing the programme;
- lessons learnt.

We base our study on published documents developed for the proposals, including official Norwegian documents, such as white papers to the Norwegian Parliament (Storting). Note that our review includes only marine programme proposals developed from the scientist level, bottom up, and only proposals intended to receive dedicated funding allocated from the government. We further survey the new and improved seabed mapping technologies which today allow us to illuminate the ocean floors and verify our measurements on seabed topography and marine landscapes, sediment composition, biodiversity, habitats and biotopes, and pollution on the seabed. Finally, we discuss the Norwegian programmes in connection with similar major international ongoing programmes and new initiatives.

The development of seabed mapping programmes from the 1970s to the present

Role of the Geological Survey of Norway

Most countries in the world have a geological survey with a mission to carry out services for the benefit of society, and the Geological Survey of Norway (NGU) has long traditions of providing, and applying, geological knowledge and data for multiple purposes and needs. It is an agency under the Ministry of Trade, Industries and Fisheries (NFD) (Table 2). NGU was established in 1858 and the history of the survey reflects the political and social situation of Norway over the past 160 years. The late nineteenth century was characterized by notable industrialization, urbanization and the development of efficient and modern farming. The surveys were established to meet the rapidly developing needs for greater knowledge about national mineral resources, materials for construction and land areas for agriculture.

In 1959, the Groningen gas discovery in the Dutch sector of the North Sea initiated search for petroleum also on the Norwegian shelf. The first licencing round was launched in April 1965, and the first discovery, the Ekofisk Field, was made in
1969. Exploration activities in the 1970s were first confined to the area south of the 62nd parallel, but activities moved northwards and, in 1980, the southern Barents Sea was opened for commercial exploration. In 1962, the NGU merged with two other institutions, Geofysisk malmleting (Geophysical ore prospecting) and Statens råstofflaboratorium (National laboratory for raw resources) and moved from Oslo to Trondheim. The same year, the new NGU started aeromagnetic mapping on the shelf, a task which has continued until today and is ongoing. In 1972 the Norwegian Petroleum Directorate (NPD) was established as a governmental specialist directorate and administrative body under the Ministry of Petroleum and Energy (OED), with a national responsibility for the data from the Norwegian continental shelf. NGU’s geophysical surveys on the Norwegian shelf are carried out in close co-operation with NPD, and regional datasets are included in the national databases.

For 100 years the geological mapping by NGU was concentrated to the mainland. In the early 1970s, mapping for sand and gravel along the coast was initiated, first in co-operation with the Continental Shelf Institute (IKU). Regional marine mapping was expanded and also came to include site surveys for marine infrastructure, such as harbours, submarine tunnels and fjord-crossing bridges. In 1985 NGU received its own marine research vessel and, in 1988, the ministries NFD, OED and Environment (later Climate and Environment – KLM) agreed to give NGU the national responsibility for co-ordinating mapping of the seabed and surficial-deposits (Quaternary deposits) along the Norwegian coast and on the continental shelf. The growing concern in society for the marine environment during the 1990s meant that multidisciplinary programmes addressing the entire marine ecosystem were necessary, replacing the traditional strict geological approach to marine mapping with an integrated approach combining multibeam bathymetry, geology, biology and chemistry.

The MGK plan and the Skagerrak project

The first proposal for an integrated national seabed mapping programme was the ‘Plan for marinegeologisk kartlegging av norske havbunnsområder (MGK)’ ([Plan for marine geological mapping of the seabed in Norwegian territorial waters (MGK)], Anon 1990). It can be viewed as a predecessor to MAREANO, even though the scope was more limited. The MGK plan was a co-operation between NPD, NGU, the Norwegian Mapping Authority (NMA) and the Norwegian Polar Institute (NP).

These institutions formed a formal MGK steering committee, chaired by NPD, and with NGU as secretary. The purpose of the programme was to:

- collect and make available marine geological information from the upper part of the seabed in Norwegian territorial waters for use in public management, industrial activities, planning and research;
- give grounds for national involvement in international co-operation, with regards to environment and resources.

This plan was the result of a long process, starting in 1974 (Table 3), involving the Norwegian Technical Nature Science Research Council (NTNF), government institutions such as NP, NGU, NPD, the research institute IKU, the University of Bergen (UiB) and the ministries OED, NFD and KLM.

The plan proposed to focus on three areas (Fig. 1): (1) Skagerrak (the deepest part of the North Sea, with borders to Sweden and Denmark); (2) an area in the North Sea; (3) the coastal areas along the southwestern part of Norway. The first project period was set to 1991–95, with a total budget of 20 million NOK for NGU granted from NFD as the most ambitious alternative. This included 13.2 million NOK in extra funding for the programme. The strategy for the plan was to conduct time-limited, cross-disciplinary projects with defined user values within prioritized areas, in co-operation with national government institutions, research institutes and private companies. Priority was given to themes considered to be particularly important for the needs of the Norwegian management institutions regarding the environment and resources. These themes were:

- pollution studies;
- resource assessments (surficial deposits);
- studies relevant for petroleum activities;
- climate-related studies;
- regional geological compilations.

The Norwegian Parliament did not grant dedicated funds through NFD for the plan. Instead, co-funding for the Skagerrak project was granted by the Norwegian Pollution Control Authority (SFT, later part of the Norwegian Environment Agency – NEA) and by the regional and local authorities in the coastal areas. The studies in Skagerrak were carried out in co-operation with NMA, UiB, University of Oslo (UiO) and the Institute of Marine Research (IMR), who contributed significant funding for their own activities.

The results from the Skagerrak project were published in a popular scientific publication (Longva & Thorsnes 1997) and in several papers in peer-reviewed journals. The coastal studies were published in NGU reports, as were the underlying data from the Skagerrak project. Further, the results from the Skagerrak project were presented to the Parliamentary Committee for Energy and Environment in 1996, and the committee recommended that the Skagerrak project should be expanded to cover the
entire North Sea. A stakeholder workshop held at NGU in January 1995, with representatives from the petroleum industry, research institutes and management, concluded that the North Sea was a good alternative for future investigation, but also pointed towards the mid-Norwegian shelf and the Barents Sea as potential sites. A proposal for marine geological mapping of the North Sea was submitted from NGU to NFD in January 1997 (cost of 84.7 million NOK), but did not receive any dedicated funding.

First phase of MAREANO proposals: the Norwegian Sea

The negative response from NFD on the proposal for the North Sea prompted a strategic discussion in late 1997 on how to proceed, including choice of ocean areas. By this time, IMR and SFT had become members of the MGK steering committee. The mid-Norwegian shelf and continental slope between Søre Sunnmøre and Lofoten (Fig. 1) were at that time becoming important areas for the petroleum industry, and the destruction of cold-water coral reefs (Paulsen 1997) on the shelf was a subject of major concern. It was therefore decided, in 1998, to shift the focus from the North Sea to the mid-Norwegian continental shelf and slope. The focus on cold-water coral reefs and the inclusion of IMR in the MGK steering committee led to a stronger emphasis on biological aspects of the mapping programme. A strategy for mapping of habitats and coral reefs using a combination of multibeam bathymetry, geological mapping and biological studies was developed.

The first proposal was submitted to the relevant ministries in January 2000 as a three-year programme with a total budget of 57.9 million NOK (Table 3). It was included in the Strategic plan for NGU for 2001–05 as a priority commitment. The proposal consisted of five work packages:

1. areal database for the Norwegian Sea;
2. basic mapping of bathymetry;

Table 3. Selected major events in Norway and globally relevant for marine mapping and research

| Year | Events |
|------|--------|
| 2020 | Marine basemaps programme funded for 2020–22. Budget 85 million NOK. MAREANO budget 2005–20 1170 million NOK. |
| 2019 | MAREANO start-up deep-sea mapping. |
| 2018 | Nansen Legacy programme proposal funded for 2018–23. Budget 740 million NOK. |
| 2017 | Marine basemaps programme proposal submitted. Budget 85 million NOK. GWP: Updated Norwegian Sea management plan. |
| 2016 | Seabed 2030 initiative launched. |
| 2015 | UN 2030 Agenda for sustainable development adopted by all UN member states. |
| 2014 | Nansen Legacy programme proposal submitted. Budget 740 million NOK. |
| 2013 | GWP: North Sea ocean management plan |
| 2011 | GWP: Updated Barents Sea management plan. Ratification of Barents Sea boundary agreement. Increase in MAREANO programme funding. |
| 2009 | GWP: Norwegian Sea ocean management plan. UN adopted Norwegian recommendations regarding the continental shelf limits. MAREANO organization restructured. Reference group abandoned. |
| 2006 | GWP: Barents Sea ocean management plan. SUSHMAP project completed. Norway submitted continental shelf limit recommendations to UN. Reference group established. |
| 2005 | GWP: (1) Fields of blue; (2) Environmental policy. Change of government from conservative–liberal to red–green. Sixth MAREANO proposal submitted. Budget 235 million NOK. First MAREANO programme grants. |
| 2004 | Fifth MAREANO programme proposal. Budget 233.5 million NOK. |
| 2003 | Fourth MAREANO programme proposal. Budget 233.5 million NOK. Switch from mid-Norwegian shelf to Barents Sea. |
| 2002 | GWP: Protecting the riches of the sea. Third MAREANO proposal. Budget 217.4 million NOK. |
| 2001 | Second MAREANO programme proposal submitted. Budget 191.2 million NOK. Start-up Barents Sea management plan process. AMOEBE programme proposal submitted. |
| 2000 | First MAREANO programme proposal submitted, mid-Norwegian shelf. Budget 57.9 million NOK. |
| 1997 | North Sea programme proposal submitted. Budget 84.7 million NOK. Mid-Norway shelf coral reef destruction documented. |
| 1996 | Skagerrak project completed. |
| 1991 | Start-up Skagerrak project. |
| 1990 | MGK plan submitted. Budget 20 million NOK. |
| 1984–89 | Pro Mare programme. |
| 1974–90 | MGK plan preparations. |
(3) mapping of seabed types, mineral resources and geotechnical conditions;
(4) basic studies of pollution;
(5) mapping of nature types, biological diversity and marine resources.

The primary executive partners were IMR, NGU, NMA, with SFT and NPD participating in database work package (1). The strategy of the proposal was to establish new knowledge and compile existing knowledge in a marine areal database for users within public management, industry (fishery, petroleum), research and the public, including environmental NGOs such as the World Wildlife Fund (WWF) and Bellona.

The database was to be publicly available, free of charge, through a web-based interface with geographic information system (GIS) functionality, allowing the users to browse and produce their own maps online. The concept was based on a network of distributed databases, with the original data kept at the institution with data management responsibility, to ensure that data were continuously updated. This was in contrast with many other database projects at that time, which were based on sending all data to a centralized database forming the core of the web system, creating challenges for data updating.

The participating institutions (NGU, NPD, SFT, NMA, IMR) were intended to form the steering committee for the programme, with a reference group consisting of representatives from public management, industry and organizations. No ministries were intended to be directly involved in the management of the programme. The proposal for 2001–03 was not funded.

The participating institutions decided to re-submit the proposal, and strong emphasis was given to providing information about the proposal to a broader group of stakeholders. As early as 1999, an article in Aftenposten, Norway’s largest national newspaper, stated that ‘The seabed shall be mapped’ and described the MAREANO initiative. In 2000, the proposal was portrayed in a popular scientific programme on NRK, the largest television channel in Norway. During the following years, several short television programmes addressing MAREANO and/or the scientific objectives of MAREANO were broadcast. Presentations about the content of the proposal were given at science conferences, including the ICES Annual Science Conference (Noji et al. 2000). Communication with stakeholders was given high priority. The proposal was presented to, and gained support from, a wide range of stakeholder groups. Industry organizations, such as the Norwegian Fishermen’s Association (NFA) and the Norwegian Oil and Gas Association (NOROG), were informed and consulted about the programme. NGOs, such as WWF and Bellona, were also involved in the process and gave oral and written support through different channels.

A new application was submitted to NFD in January 2001. The new proposal was expanded to five years (2002–06), with a total budget of 191.2 million NOK. The budget was allocated for three executive partners – IMR, NGU and NMA. The steering group now included the Directorate for Nature Management (DN, later part of the Norwegian Environment Agency – NEA) and NP, and it changed its name from the MGK to MAREANO steering committee. However, again no funding was allocated for the programme.

An application for 2003–07 was submitted in January 2002 to the Office of the Prime Minister (SMK). The total budget had now increased to 217.4 million NOK. The reason for submitting the proposal to SMK was the experience that none of the ministries wanted to take the main responsibility for advocating the programme in the government budget negotiations. The SMK forwarded the proposal to NFD, which was given primary responsibility for further handling of the proposal. The first mention of the MAREANO programme by the government came in March 2002, in the white paper ‘Protecting the riches of the sea’ (Anon 2002), saying: ‘The government will consider to carry out the project ‘Marine mapping and development of an areal database for Norwegian coast areas and oceans (MAREANO)”. The purpose for this was to improve knowledge about the structure and functioning of the marine ecosystem. In the same white paper, the Norwegian government recognized the need for integrated and ecosystem-based management of the Norwegian marine regions (Barents Sea, Norwegian Sea and North Sea–Skagerrak) and it was decided that such plans should be developed for these regions. NGOs such as WWF responded to the white paper, and they demanded that the Norwegian seabed should be properly mapped, using the MAREANO slogan ‘We know far more about the surface of the planet Mars than about the seabed right outside our coastline’.

Second phase of MAREANO proposals – aligning the proposal with the Barents Sea management plan process

The development of ocean management plans following the white paper (Anon 2002) began for the Barents Sea and the sea areas off the Lofoten Islands in 2002. This meant that the focus of public management was directed to these areas. As a consequence, the MAREANO proposal was changed according to the new requirements, and new applications were
sent to the NFD in January 2003 and 2004 concentrating on the Barents Sea and the sea areas off the Lofoten Islands. The total budget for these proposals was 233.5 million NOK, with 199.3 million NOK as extra funding, and the rest from the existing budgets of IMR and NGU. No major changes were made to the proposal, except for the proposed target area. In parallel with this, the management plan for the Barents Sea and the sea areas off the Lofoten Islands evolved, and it was documented that the benthic ecosystems were poorly known.

A new application was submitted in January 2005. In March 2005, two white papers were presented to the Norwegian Parliament. One of them (Anon 2005b) focused on the value creation from fisheries and aquaculture. It was titled ‘Fields of blue. Industrial and commercial development of marine resources’. Here, the MAREANO programme was given significant attention, and the government stated that it would consider whether MAREANO should be implemented in co-operation between several ministries. This was presented to the Norwegian Parliament from NFD. The other white paper was titled ‘The Government’s environmental policy and the state of the environment in Norway’, from KLM (Anon 2005c). In this white paper, the government stated that it would implement MAREANO mapping in marine areas no later than 2010, in order to stop the loss of biological diversity. The government stated that mapping and monitoring of the sea areas shall be strengthened as basis for a future ecosystem-based and integrated management of the sea areas as the Management plan for the Barents Sea is an example of. The mapping shall be done through the cross-sectoral mapping and knowledge programme MAREANO in the period 2006–10.

The discrepancy in wording between the white papers from the NFD and the KLM indicates that the question of funding MAREANO was still under debate in the first half of 2005 within the Conservative–Liberal coalition government, consisting of Høyre (the Conservatives), Kristelig Folkeparti (the Christian Democratic Party) and Venstre (the Liberal Party). The government gave a small grant in the revised state budget presented in June, but apparently there was no broad consensus regarding full-scale funding of MAREANO. This seems to have changed with the Red–Green coalition coming to power through the election for the Norwegian Parliament autumn 2005. The Red–Green coalition was formed by Arbeiderpartiet (the Labour party), Senterpartiet (the Centre party) and Sosialistisk Venstreparti (the Socialist Left party). The Labour party was in favour of opening the environmentally sensitive Lofoten–Vesterålen areas for offshore oil and gas exploration, the Centre party was more pragmatic about the issue, but the Socialist Left party, with a pronounced environmental protection focus, was in favour of protecting the areas. In the governing document for the coalition (‘The Soria Moria’ declaration), it was agreed to postpone a decision on opening the Lofoten–Vesterålen areas until improved knowledge on the status of these vulnerable areas was provided. The MAREANO programme proposal was by then a well-prepared programme of work, ‘ready to go’, to achieve one of the controversial goals of the Red–Green coalition government for the next four years. From 2006 and onwards, the MAREANO programme was properly funded. It appears that the shift of government provided the last push in the process of funding MAREANO.

The management plan for the Barents Sea (Anon 2006) – integrated management of the marine environment of the Barents Sea and the sea areas off the Lofoten Islands – was approved by the Council of State on 31 March 2006. The plan was developed to consider the expansion of oil and gas activities in the Barents Sea–Lofoten areas in a knowledge-based manner (Winsnes & Skjoldal 2008). The plan only covered the Norwegian part of the Barents Sea ecosystem, as the remaining area is within the Russian EEZ and jurisdiction. Area-based management/spatial planning approaches were considered key tools for the implementation of the plan. The plan stated that MAREANO was established in 2005, and was to focus mainly on the High North, i.e. the southern part of the Barents Sea from Lofoten northwards to the Russian border (Fig. 1). The plan gave specific instructions on which areas MAREANO should concentrate on – the sea from the Lofoten Islands to the border towards Russia. The petroleum provinces Nordland VII and Troms II, together with the shelf edge west of Tromsøfjellet (the Eggakanten area), were given highest priority (Fig. 1). The Barents Sea management plan was updated in 2011, with considerable input from MAREANO on the benthic ecosystems (Anon 2011). Since then, MAREANO has continued mapping in the Barents Sea and also provided vast amounts of data from the Norwegian Sea (Buhl-Mortensen et al. 2015). Following the degree of interest in the high Arctic regions, MAREANO has initiated a mapping programme in two of the fjords in Svalbard and on the continental slope west and north of Svalbard. From 2019 mapping the deep of parts of the Norwegian Sea, including the Mid-Atlantic Ridge with potential mineral resources, has commenced (Fig. 1).

**Organization of the MAREANO programme: need for adjustment**

The MAREANO proposals involved several institutions with different competences and roles. In 2006,
the programme was organized with an inter-ministerial steering group, a programme group and an operational project group. The inter-ministerial steering group consisted of the NFD, KLM and OED. The programme group had members from IMR (leader), NGU, NMA, DN and the Directorate of Fisheries (DF). Other institutions, including NPD, the Norwegian Defence Research Establishment (FFI), SFT and NP were consulted when necessary. In April 2006, a reference group was started (Table 1). This group had members from the Norwegian Institute for Water Research (NIVA), NP, the Norwegian Biodiversity Information Centre (Artsdatabanken, MB), the Biobank of Arctic Marine Organisms (Marbank, MB), the Norwegian Military Geographic Service (FMGT), the University of Tromsø (UiT), the Directorate for Cultural Heritage, NFA, NOROG and WWF. The executive group running the programme had members from six institutions – IMR, NGU, NMA (the executive institutions) and DN, DF and FFI.

The initial organization turned out to be sub-optimal. There were disputes among the executive institutes in priorities and allocation of resources, and lack of influence by the directorates from public management. A reorganization was necessary. In 2009, the funding ministries took a more pronounced governing role by forming a formal steering group, while the directorates and executing institutions formed a programme group led by DF (NEA since 2016). The operational side of the programme was taken care of by a project group from the three executing institutes. This organization has been the basis of the programme since 2009 (Table 2). The system with a reference group providing stakeholder input was abandoned. Since 2009, communication with stakeholders has been carried out by direct contact when necessary, and through biannual user conferences.

### Funding of MAREANO

Since the start in 2005, around one billion NOK (c. US$115m) have been allocated to the programme from the government. The funding has been provided through the National budget, as part of the priorities of NFD, KLM until 2013, and KMD from 2014 (Table 1). The funding of MAREANO has continued uninterrupted through periods with reorganization of the funding ministries.

The possibility of obtaining financial support from the industry sector was discussed between MAREANO management and the petroleum industry in 2007 and 2008. Support for multibeam bathymetry and current modelling were the two main subjects for discussion. The importance that financial support should not be tied to prioritization of areas to be mapped was stressed by the MAREANO management. In 2008, it was concluded by both parties that industry financing of MAREANO was not an option.

Annual funding increased moderately from 2005 to 2010 (Fig. 2) and received a sudden increase in 2011. In the revised state budget, the MAREANO allocation was raised with 44 million NOK from 52.4 to 96.4 million NOK. This increase was caused mainly by the ratification of the agreement between Russia and Norway on the boundary in the Barents Sea between the two states. The territory of the

![Fig. 2. Annual funding allocation in million NOK to the MAREANO programme from 2005 to 2020. Note the jump from 2010 to 2011 – this is related to the agreement with Russia regarding the border in the Barents Sea.](image-url)
Norwegian sea increased by 80,000 km². Since 2011, MAREANO funding has been in the order of 90 to 110 million NOK per year, with approximately 30% of the allocated funds spent on mapping in the new territories in the eastern part of the Norwegian Barents Sea.

**Technology development – a facilitating factor**

Seabed mapping of bathymetry, geology, biology and chemistry relies upon several acoustic and visual instruments, and physical sampling tools. In MAREANO, the use of statistical tools for planning and performing seabed mapping has been recognized as an important component (Thorsnes et al. 2015). Studies in the marine environment are fundamentally different from studies in the terrestrial environment, where the scientist or surveyor can observe the landscape and the physical environment of the objects of interest. In order to observe the underwater landscape and thus provide the physical framework for marine studies, scientists and surveyors rely upon different methods of remote sensing. Mapping of the ocean depths – bathymetry – started using long lines with a lead weight on the end, or long poles centuries or even millennia ago. In the 1930s, the single-beam echosounder was developed, using sound to calculate the depth beneath a vessel. In the 1970s, multibeam echosounders were developed, allowing detailed 3D models of the topography of the seabed to be constructed. The first commercial system was launched by Seabeam in 1977.

In Norway, the first multibeam echosounder was developed by Kongsberg Simrad (later Kongsberg Maritime) in 1986 – the EM100. This echosounder was used by the NMA in the Skagerrak project and provided full-coverage depth measurements for the entire basin. The development of multibeam echosounders was paralleled by development of more powerful computers and advanced software for processing and visualization, allowing scientists outside the hydrographic domain to utilize this new data source (Pickrill & Todd 2003; Brown et al. 2011; Pickrill et al. 2014). It was also realized that backscatter (the return signal strength from multibeam echosounders) provided information regarding the nature of the seabed, which could be used for surficial geology and habitat mapping (Brown & Blondel 2009). For the major parts of the Norwegian oceans, the hydrographic databases of NMA in the 1990s had enough depth soundings recorded to provide a bathymetry grid with 500 m cell size (Fig. 3) for water depths of a few hundred metres. The early generations of multibeam echosounders, such as Kongsberg Simrad EM100, in combination with computers with limited processing capacity compared to present-day computers, allowed bathymetry grids with 50 m cell size to be produced (Fig. 3). Modern multibeam echosounders gives at least 10 times more soundings than the early multibeam echosounders. Combined with modern software and computers, this allows grids with grid size of 5 m or less to be produced for similar

**Fig. 3.** Shaded relief images produced from bathymetric data, with grid sizes of 500, 50 and 5 m, respectively. This reflects broadly the capability of imaging the seabed before 1990, in the mid-1990s and at present day. Source bathymetry data: FFI. Illustration: MAREANO/NGU.
ocean depths, where, for example, coral reefs and sand waves can be recognized (Fig. 3).

The development of software allowing very large bathymetry datasets (several gigabytes in the last few years) to be processed, analysed and visualized has been very important for MAREANO. Geological features ranging in size from a few metres to tens of kilometres can be recognized and described. Many of these features have a distinct role in the benthic ecosystems. On the Sula Reef on the mid-Norwegian shelf, glacial landforms, such as iceberg ploughmarks and mega-scale glacial lineations can be seen to form a hard bottom substrate for settlement and growth of cold-water stone corals (Thorsnes et al. 2016). A similar feature can be observed in the Aktivneset region (Fig. 1), where several hundred coral reefs are found, mainly located on the berms of iceberg ploughmarks (Fig. 4).

Ship-based multibeam echosounders providing detailed bathymetry and backscatter data have been the backbone for the production of a variety of seabed map products in the MAREANO programme. Multibeam water column data describing objects like gas bubbles, fish or plankton have been recorded and utilized since 2010 and, to date, nearly 1000 natural gas flares have been found. Ship-based multibeam echosounder bathymetry and backscatter data provide very useful data for regional seabed maps, but there is a need for more detailed observations in special areas. Autonomous underwater vehicles (AUVs) or remotely operated vehicles (ROVs) equipped with special sensors, such as synthetic aperture sonars, provide an extremely detailed image of the seabed. They provide imagery with a backscatter pixel resolution in the order of a few centimetres, over a swath width of in excess of 300 m. Such tools were tested by MAREANO in 2015 (Thorsnes et al. 2018) and proved to give very detailed imaging of coral reefs (composed of dominantly coral rubble and sand with coral

![Fig. 4. 3D terrain model showing coral reefs located on the berms of iceberg ploughmarks in the Aktivneset area. Source bathymetry data: MAREANO/NMA. Illustration: MAREANO/NGU.](image-url)
blocks – likely *Lophelia pertusa*) and trawl marks produced by fishing vessels (Fig. 5).

During the last decade, a dramatic increase in the availability of digital bathymetric data and tools capable of analysing geomorphological structures (geomorphometry) using GIS has resulted in a large effort using geomorphometry to characterize the marine environment (Lecours et al. 2016). MAREANO scientists have co-operated with the Irish seabed mapping programme INFOMAR (http://www.INFOMAR.ie) and a number of institutions in the MAREMAP consortium (http://www.MAREMAP.ac.uk) in the UK to establish common procedures and classification schemes (e.g. Thorsnes et al. 2017). Increased use of geomorphometry and object-based image analysis (OBIA) classification has resulted in new procedures for using multibeam bathymetry for mapping likely occurrences of coral reefs in Norwegian waters (Diesing & Thorsnes 2018). More than 200 000 likely occurrences of cold-water coral reefs have been recognized using this methodology on the mid-Norwegian shelf. In contrast, around 600 coral reefs are documented and positioned using video and other tools, but it should be noted that some of these are composite reefs consisting of several individual coral mounds. An example of documented coral reefs v. likely occurrences based on OBIA classification is shown in Figure 6.

Other major marine science and mapping programmes in Norway

**Pro Mare programme**

The Pro Mare programme (‘Norwegian research programme for marine Arctic research’) carried out in the Barents Sea in 1984–89 was, for its time, among the most comprehensive research programmes in Arctic marine ecology (Sakshaug et al. 1994, 2009). The goals of the programme were to

1. increase the understanding of the functioning of Arctic marine ecosystems;
2. carry out long-term ecological research to improve the knowledge base for management.

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**Fig. 5.** Synthetic aperture sonar imagery acquired with an AUV, showing coral reefs (pale yellow outlines) surrounded and partly crossed by trawl marks. Individual coral blocks (likely *Lophelia pertusa*) are present, but coral rubble and other bioclastic material constitute the main part of the reef. Modified from Thorsnes et al. (2018).
of important commercial fish stocks while ensuring the survival of sea bird and marine mammal populations and their sustainable exploitation; and
(3) educate the next generation of marine polar scientists.

The Norwegian Fisheries Research Council, the NRC and KLM funded the programme, and Norwegian universities (Oslo, Bergen, Trondheim and Tromsø) participated together with IMR and NP, which both provided additional support. IMR and the Norwegian Coast Guard contributed ship time. The findings and main achievements of the Pro Mare programme were compiled by Sakshaug et al. (2009). It is regarded as a breakthrough for marine research in Norway through establishment of large, co-ordinated programmes that create research possibilities beyond the capability of single institutions and separate projects.

Norwegian Sea programme

In the early 1990s, leading scientists at IMR and UiB took an initiative to develop a research programme on the ecology of the Norwegian Sea (Skjoldal et al. 1993). The programme proposal followed along the lines of the Pro Mare programme, being restricted to a national geographical area and focusing on issues important for managing living resources and the marine environment. A clear motivation was to provide knowledge on ecological issues in order to support fisheries management for an area that was little known (a mare incognitum as stated by Helland Hansen & Nansen 1909). The programme was initiated at the start of a new herring period as the Norwegian Spring Spawning Herring was about to return to the Norwegian Sea in the early 1990s. Knowledge provided through the Norwegian Sea programme was compiled in the book The Norwegian Sea Ecosystem (Skjoldal 2004).

The AMOEBE programme

In 2001, a substantial multidisciplinary programme proposal on marine ecological studies and modelling was developed by scientists at IMR, NTNU, UiB and other institutions (Svendsen et al. 2002) The proposal was evaluated through NRC, with varying
critiques. The KLM did not show much interest in the programme proposal, and therefore it became difficult to argue for the proposal from a management level of the institutions involved. Nevertheless, the impact of the proposal was quite substantial. Some of the basic ideas were used in the scientific argumentation for a major reorganization of IMR 2002–04, and some of the organizational ideas of the programme proposal were implemented in the new IMR organization that was operational from 2004 (Misund et al. 2008). In addition, many of the scientific issues addressed in the AMOEBE proposal were used when developing the Sea and coast programme under the NRC in 2004.

**Nansen Legacy programme**

Starting in 2011, a new large bottom-up marine programme proposal was developed by 10 Norwegian universities and research institutions. The proposal was initiated after a seminar in the Norwegian Academy of Science and Letters in September 2011, pointing out the lack of knowledge about the environment in the northeastern Barents Sea. The gap in knowledge would hamper the possibility for industrial development in the area in relation to potential oil and gas resources. A programme steering committee led from UiT and a programme drafting group were set up to outline the programme. The programme planning was supported as a SAK (Cooperation, Aggregation and Concentration) project financed by the Ministry of Education and Research. A programme proposal was delivered to the Ministry in 2014 (Eldevik et al. 2014) and a full programme plan was completed the year after (Anon 2015). The Nansen Legacy plan was reviewed by the National Academy of Sciences in 2015, with a very positive result. The programme received funding for start-up in 2018 and is planned for 6 years (2018–23).

The Nansen Legacy programme has four main research foci: physical drivers; human impacts; the living Barents Sea; and the future Barents Sea. The present budget is 740 million NOK, including in-kind contributions from involved institutions, 25% from NRC and 25% from the Norwegian Ministry of Education and Research. The research group includes more than 130 scientists from the involved institutions, about 50 recruitment positions (PhD and post-docs), associated members and international collaborators (http://www.NansenLegacy.org).

**Marine Basemaps in Norway**

The experience and positive results from the Skagerrak project and later offshore pilot projects paved the ground for similar, but geographically more restricted, seabed mapping in the Norwegian nearshore and coastal areas. First steps were taken in north Trøndelag (Sandberg et al. 2005), in the Astafjordene region in north Norway (Longva et al. 2008; Thorsnes et al. 2013) and in Søre Sunnmøre in western Norway (Elvenes et al. 2019), where separate seabed mapping projects were financed by municipalities and the counties. The Søre Sunnmøre project was further extended to include testing of new methods with airborne bathymetric LiDAR (Light Detection and Radar; a laser scanning system), providing high-precision measurements of water depth and benthic environments based on extracts of statistical parameters derived from the bottom backscatter.

In 2017, NMA, NGU, IMR and NIVA developed a proposal for a pilot project on application of methods and testing of instruments for production of marine basemaps in Norwegian waters. Three different test areas were proposed: Stavanger and Nordre Sunnmøre on the western coast and Skjervøy/Kvennangen in north Norway. The project was commissioned by KMD. In addition to the outline of goals and methods, the report to the ministry also included a feasibility report and a report on socio-economic analysis by the private consultant company Metier. The main conclusion was in line with previous assessments (i.e. the Astafjordene project), stating the seabed mapping projects and programmes serve several groups of end-users and have positive socio-economic effects.

In 2018 and 2019, proposals for a Marine Base-maps programme were presented to KMD and NFD, with the intention to start in 2020. In the government’s proposal for the National Budget 2020, a sum of 13.8 million NOK is allocated as a start-up for this programme.

**The future of large seabed mapping programmes**

In 2015, the 2030 Agenda for Sustainable Development was adopted by all United Nations’ Member states (United Nations 2015). Goal no. 14 addresses life below water and reads: ‘Conserve and sustainably use the oceans, seas and marine resources for sustainable development’. This has been followed by the Seabed 2030 initiative launched in 2016 by the Nippon Foundation in co-operation with the General Bathymetric Chart of the Oceans (GEBCO). The goal of Seabed 2030 is to provide a high-resolution bathymetry map of the entire World Ocean by 2030. Large national seabed mapping programmes, such as MAREANO and INFORMAR, form a necessary basis for fulfilment of the UN Sustainable development goals, and for the completion of the Seabed 2030 map. An example of this is that MAREANO in 2019 collected bathymetry,
backscatter and water column data from c. 60 000 km² of the deep parts of the Norwegian Sea (northern Atlantic Ocean).

Future mapping of the oceans can be expected to be severely affected by two megatrends – machine learning and autonomy. Machine learning and advanced algorithms for data analysis are already being employed to cope with the ever-increasing amounts of high-resolution data coming from an increasing number of sensors. The level of autonomy, i.e. the capability of platforms and sensors to operate without human interference, is also being rapidly developed (Ludvigsen & Sørensen 2016). While many standard AUVs today require substantial human interaction for survey planning and continuous supervision during the survey, we can expect this to decrease to a minimum level. We can expect that the level of autonomy will allow a fleet of AUVs to be launched to survey a specific area, that the AUVs will communicate and co-operate to survey the area in an efficient and safe manner, and use machine learning algorithms to come up with a complete and integrated model in terms of bathymetry, geology and habitats. This will include the ability of the AUV to compute and analyse high-resolution acoustic data on-the-fly, and to perform a close-to-bottom photographic survey after identifying key targets for in-depth study (Sture et al. 2018).

In Norway, the government launched an Ocean strategy in 2017, with an update in 2019 (‘New growth, proud history’, Anon 2019). The update was presented as a response to the rapid development of ocean industries, both technologically and economically. The start-up of the national coastal seabed mapping programme in 2020, and financing of 55 million NOK for planning of a new Ocean Space Center at NTNU in Trondheim are important means for delivering the strategy. The strategy states that knowledge of depths and seabed conditions is important for planning and for facilitating activity in the Norwegian ocean industries. It is further stated that the MAREANO programme provides such vital knowledge.

Discussion

Since the 1970s, several large marine programmes with budgets exceeding 100 million NOK have been proposed by scientists in universities and government institutions in Norway. A common factor for these programme proposals is that they have used a bottom-up approach – scientific and applied needs have been identified by groups of scientists, and the programmes have been planned accordingly. Another common factor is that these programmes aim to provide knowledge which is important for ecosystem-based management of Norwegian waters. The programmes differ on the ratio of science v. basic mapping – with the AMOEBE, the Norwegian Sea programme, the Pro Mare and Nansen’s Legacy programme dominated by basic science, while MGK, MAREANO and Marine Basemaps are aimed at seabed mapping and follow-up marine science (Fig. 7).

Different strategies have been chosen for the organization of the programmes, in terms of number of institutions and ministries involved, and to what extent stakeholders in the society have been engaged. For MAREANO, alliance building with stakeholders within government institutions with an ocean governance mandate, industry organizations and NGOs was prioritized. An important part of strategy was to emphasize that MAREANO represented a neutral, common ground of knowledge that could create a better basis for dialogue, giving the foundation for decisions which all parties could accept.

Some of the programmes were basically single institution–single ministry programmes, while other programmes involved several partners and/or ministries, and the MAREANO programme also included stakeholders from industry and NGOs in their programme preparations. The Pro Mare programme with a multitude of scientific partners attracted substantial funding through the research councils and the KLM, while the follow-up programme – the Norwegian Sea programme – which was basically a single institution–single ministry proposal did not attract any dedicated funding. Instead, it was funded mainly by IMR, which gave the programme a high priority. The AMOEBE never received external funding, but the proposal
played a major role in the rejuvenation of the structure and scientific goals taking place at IMR a few years into the new millennium. The MGK programme never received any dedicated funding, but produced good results based on co-financing with other institutions and internal funding. The Nansen Legacy programme, involving many scientific partners, has received funding for a six-year period (2018–23). The MAREANO programme has been funded since 2005 by several ministries, without involvement of the NRC. Broadly speaking, there seems to be a positive correlation between the number of institutions and ministries, the degree of stakeholder involvement and the degree of funding. The value of a multitude of institutions, broad stakeholder involvement and a multi-disciplinary approach is one of the important lessons learnt from the process.

Co-operation with the academic institutions has been important for MAREANO. In the initial years, research projects and transfer of experience were necessary in order to develop the methodology. It was also important to clarify the different roles, with the universities responsible for basic science and education, and MAREANO responsible for small-scale mapping covering large areas. MAREANO has held a number of workshops with participants from universities and institutes in order to benefit from the scientific knowledge of academia in planning and execution of the mapping. This has been very important for the survey design of the mapping around Svalbard and the Mid-Atlantic Ridge, for example. The academic institutions have free access to the results from MAREANO and use them in their research. A number of MSc projects have been carried out in co-operation between MAREANO institutions and the universities. MAREANO scientists regularly meet the leading scientists from the Nansen Legacy programme to discuss scientific co-operation, data exchange and logistical practicalities.

Political processes have been very important. After five years of programme proposal development, submission and re-submission to ministries, redrafting, lobbying and outreach, the fate of the MAREANO programme proposal was rather uncertain even as late as 2005. The shift of government in the autumn of 2005 from a Conservative–Liberal coalition to a Red–Green coalition seems to have pushed the question of funding over a tipping point. There were strongly differing views regarding the opening of the environmentally sensitive Lofoten–Vesterålen areas for petroleum exploration, and this was a potentially serious conflict for the coalition government. Funding MAREANO to acquire new knowledge on the marine environment meant that the decision on opening could be postponed for four years. In addition, MAREANO was a well-known concept for the ministries and other stakeholders, with broad support from NGOs, academia and agencies. This meant that MAREANO was ‘ready-to-go’ and could be implemented immediately. An important lesson is therefore that timing and readiness to respond to political needs may be very important.

For MAREANO, the development of facilitating technologies seems to have played an important role for the approval of the programme by the funding authorities. The development of multibeam echosounder technology in parallel with computers capable of handling large datasets, and software transferring numerical data to 3D seabed models was important. Using this technology, complex seabed features, including the newly discovered coral reefs on the shelf off mid-Norway, could be visualized (Fig. 4) and provided an entirely new platform for communication between scientists on one side and politicians and managers on the other side. This represented a tipping point where new technology opened up new possibilities and was fundamental for demonstrating that a large programme could be done in an efficient way. Similar experiences were noted by Konisrunkul & Tuaycharoen (2013) in the planning process for the Koh Mudsum island in Thailand, noting that 3D visualization is deemed appropriate as a communicative tool to facilitate public engagement. A good example demonstrating how advanced 2D and 3D visualization of the seabed has been utilized to communicate with ocean management authorities is found in Pickrill & Todd (2003), addressing the multiple roles of acoustic mapping in integrated ocean management off the coast of Canada.

The 3D seabed models combined with high-resolution video imagery depicting living corals and other organisms on the coral reefs gave substance to the MAREANO slogan ‘Turning on the light in the ocean space’. This provided an excellent position for outreach and lobbying.

Co-operation with private industry, such as Kongsberg Maritime (KM) in Norway – an important producer of multibeam echosounders globally, proved beneficial for all parties. KM supported the programme publicly and in their contact with the potential funding ministries. The MAREANO pilot projects provided excellent examples of how multibeam data could be used, and KM took advantage of these in their marketing.

Future funding of MAREANO is subject to annual allocations from the Norwegian Parliament. Even with a projected total spending exceeding 1 billion NOK by 2020, there are large areas which are still to be surveyed. The area of the Norwegian EEZ is 2 034 271 km², of which 555 698 km² (27.3%) has been mapped by multibeam echosounder. There are also large areas of
international waters (high seas), partly forming part of the continental shelf for Norway. These areas are also mapped by Norwegian authorities and are included in the management plans. This area is 319,706 km², of which 159,510 km² (47.5%) has been mapped with multibeam echosounders. The total area of the EEZ and the international waters is 2,356,977 km². Given an average areal coverage of 20,000 km² by the MAREANO programme, it will take c. 80 years to complete mapping of the entire Norwegian EEZ and international waters. New technological concepts and developments within autonomous platforms for data acquisition (underwater vehicles, unmanned surface vehicles) and for data analysis and interpretation may reduce this time considerably.

Whilst substantial parts of the continental shelf have been covered, there are still important knowledge gaps to be filled. Climate change is reducing the ice cover of the Barents Sea and it is predicted that large parts of the polar regions will be ice free within a few decades. This will create newly accessible areas where knowledge of the seabed and benthic ecosystems will be needed. In the deep sea, along the Mid-Atlantic Ridge, there are large potential geological and biological resources.

In 2006, Norway submitted recommendations for the outer limits of the continental shelf beyond 200 nautical miles from the baselines in the Arctic Ocean (United Nations 2006). This recommendation was adopted in 2009 by the UN Commission on the limits of the continental shelf (United Nations 2009). Today, the Norwegian continental shelf extends north of Svalbard and the northwestern Barents Shelf and includes a large part of the Western Nansen Basin (Fig. 1). The potential for natural resources combined with vulnerable ecosystems in these regions calls for a substantial effort to acquire knowledge on the resources and ecosystems in order to secure sustainability.

Conclusions

Several large marine programmes have been proposed in Norway over the course of the last few decades, with varying degrees of ambition, goals and funding. Factors such as the number of institutions and ministries involved, as well as stakeholder involvement, seem to influence the degree of funding, with single institution–single ministry initiatives having the lowest probability for attracting significant funding. MAREANO serves as a good global example of a programme with multiple institutions involved, with support from multiple ministries, industry organizations and NGOs which has received substantial financial support from the government.

The MAREANO programme has benefited from a tight and constructive co-operation with academia. After an early clarification of complementary roles, MAREANO has received support and competence, and is now returning large datasets and know-how to academia.

The technology tipping point around 2000 with regards to efficiency in multibeam data acquisition, and capabilities to process, analyse and visualize large datasets was of fundamental importance for the programme. It became possible to communicate the complexity of the seabed ecosystems, and to convince the stakeholders that such a large programme could be successfully executed.

The International Council for the Exploration of the Sea, ICES, points out that MAREANO is probably the largest and most extensive seabed mapping programme of its kind in the world. The programme provides knowledge for ecosystem-based management, within the framework of the Norwegian ocean management plans. MAREANO has been funded since 2005, with a total project budget in excess of 1 billion NOK at the end of 2020. The programme was first proposed in 2000, by a consortium of research institutions, agencies and directorates, in a scientifically driven, bottom-up approach. The original proposal focused on the Norwegian Sea, but it was changed in 2003 in order to align with the development of the management plan for the Barents Sea and the sea areas off the Lofoten Islands which commenced in 2006. The management plan had a politically driven, top-down approach and important knowledge gaps were identified in the broad process leading to the plan. The management plan was implemented in 2006, by which time the MAREANO programme was a well-developed programme proposal ready to be approved and started by the government. This marked the end of a more than five-year-long process of proposal submission, re-drafting, lobbying and re-submission.

The convergence of these scientifically driven, bottom-up and politically steered, top-down processes was the most important factor securing funding for the MAREANO programme, but political considerations and tactics also played a significant role. An information delivery strategy encompassing the public, the scientific community and government institutions, together with alliance building with government institutions with an ocean governance mandate, industry organizations and NGOs is also considered to have contributed.

The UN Sustainable Development Goals from 2015 underline the importance of long-term national seafed mapping programmes which can provide the necessary knowledge for the sustainable use of the world’s oceans. The need for increased food supply from the marine environment makes it inevitable that we learn more and understand the processes and
relationships between the different parts of the ecosystems. Rapid technological developments within machine learning and autonomy of data acquisition platforms augur well for future marine management and harvesting.

Important lessons learnt are the necessity of having a multi-disciplinary approach that addresses the needs of a broad stakeholder community and ensures convergence between scientifically driven and politically steered processes, to be able to respond to political needs rapidly, to have a constructive co-operation with academia, and to benefit from technological advances. And, finally, perhaps the most important lesson learnt is that establishing large programmes may take a long time and it is crucial to have stamina.

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