Towards improved management of deep-sea sponge grounds in Norwegian waters

Thesis for the degree of Master of Science

Marine Biology

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Summary

Sponge grounds have been increasingly recognized as ecologically and biologically important and vulnerable marine ecosystems of the deep-sea. But despite their inclusion in a number of international agreements (e.g. OSPAR list, FAO International Guidelines for the Management of Deep-sea Fisheries) few directed actions have been made to protect sponge grounds from anthropogenic impacts (e.g. fishing, oil and gas exploration). In this thesis I provide an overview of our current knowledge of sponge grounds in the North Atlantic and Norwegian waters. In collaboration with the Institute of Marine Research, I used data collected in the course of the BEES surveys in the western Barents Sea to make a spatial and temporal characterization of the sponge communities in this area. Further, with the international and national implementation of an ecosystem approach (EA) to management, I participated in the AORA-CSA workshop: "Making the ecosystem approach operational" (Copenhagen, Denmark) during which several discussions were held to identify the challenges to a successful implementation of EA to management. In Norway, three marine integrated management plans have been developed, encompassing the North Sea, the Norwegian Sea and the Barents Sea and Lofoten areas. Actions towards management and conservation of sponge grounds in the plans as well as in national laws and regulations have been identified, and so have several shortcomings. Finally, recommendations towards an improved integration of sponge grounds in management and conservation policies in Norway are put forward and discussed.

List of abbreviations

AORAC-SA	Atlantic Ocean Research Alliance Coordination and Support Action
AUV	Autonomous Underwater vehicle
BSMP	Barents Sea Management Plan
BEES	Barents Sea Ecosystem Survey
CBD	Convention on Biological Diversity
DFO	Department of Fisheries and Oceans Canada
EA	Ecosystem Approach
EBM	Ecosystem-Based Management
EEZ	Exclusive Economic Zone
EIA	Environment Impact Assessments
EU	European Union
EEA	European Environment Agency
FAO	Food and Agriculture Organization of the United Nations
ICES	International Council for the Exploration of the Sea
IMR	Institute of Marine Research
JFC	Joint Norwegian-Russian Fisheries Commission
UNCLOS	United Nations Convention on the Law of the Sea
MAREANO	Marine Areal Database for Norwegian Coasts and Sea Areas
MSFD	Marine Strategy Framework Directive
NAFO	Northwest Atlantic Fisheries Organization
NEAFC	North East Atlantic Fisheries Commission
NEA	North East Atlantic
NA	North Atlantic
NWA	North West Atlantic
NOAA	National Oceanic and Atmospheric Administration
OSPAR	North East Atlantic Environment Strategy
RAs	Regulatory Areas
RFMO	Regional Fisheries Management Organization
ROV	Remotely operated vehicle
SEAPOP	Seabird Populations
UN	United Nations
UNEP	United Nations Environment Programme
VME	Vulnerable Marine Ecosystem
WBS	Western Barents Sea
PINOR	Knipovich Polar Institute of Marine Fisheries and Oceanography, Russia

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Rationale

For centuries, the contribution of the deep-sea to global marine biodiversity was largely overlooked which has made it receive fairly little scientific or conservation attention, when compared to shallower coastal areas. With the development of increasingly sophisticated remote sensing and survey technologies (e.g. multibeam echosounders ROV's, AUV's), we have been able to explore deeper areas, and discover unique biodiversity hotspots such as cold-water reefs, sponge grounds, and hydrothermal vents, all of which are now acknowledged to provide a number of goods and services for the functioning of the Oceans. However, the same technological advance has also made it possible to expand, intensify, and even diversify our extractive activities towards the same depths. The conservation and sustainable use of these vulnerable ecosystems in deep-sea and open ocean areas are among the most critical challenges today (Hogg et al., 2010). An integrated, long-term and knowledge-based action that considers the environmental, social and economic dimension is required if we are to halt the expanding human footprint over these ecosystems. Deep-sea sponge grounds have been identified as complex, highly diverse and fragile habitats that encompass ecologically and biologically important functions, and with a huge biotechnological potential that can benefit society. Yet, they currently face major threats from human activities, where bottom trawling is the highest threat, and are listed as threatened and/or declining species and habitats under the OSPAR Convention. Several sponge grounds with variable species composition and density, are widely distributed in Norwegian waters. However, to date, there have been there have been few directed actions to manage and protect these ecosystems from various anthropogenic stressors, which contrast, for instance with the considerable efforts directed towards cold-water reefs. This thesis aims at providing a step towards improved management of deep-sea sponge grounds in Norway by: 1) reviewing the state of the knowledge on deep-sea sponge grounds of the North Atlantic and in Norwegian waters; 2) providing an overview of the current marine management framework associated with management of sponge grounds in Norway; 3) discussing current management status of sponge grounds in Norway further identifying flaws; and 4) proposing practical steps to incorporate sponge grounds into Norwegian marine management plans and conservation policies at the national level.

1 Deep-sea sponge grounds of the North Atlantic

1.1 Diversity and distribution

Sponges (Phylum Porifera) are true living fossils existing for over 600 millions of years and are the oldest living animal group on Earth (Hogg et al., 2010). Almost 9,000 species have already been formally described where the majority belongs to the class Demospongiae (Van Soest et al., 2012; Van Soest et al., 2016), and more than another 7,000 species are estimated to exist (Hogg et al., 2010). In many deep-sea areas, sponges dominate the benthic communities with densities attaining up to 25 individuals/m2, and representing up to 99% of total invertebrate biomass, forming structurally complex ecosystems known as sponge grounds, gardens, aggregations and reefs (Beazley et al., 2015; Kutti et al., 2013). Deep-sea sponge aggregations are found globally settled in deep fjords, continental shelves and slopes, seamounts, mid-ocean ridges and deep ocean basins ranging in depth from 30m to approximately 3000m (Hogg et al., 2010; Maldonado et al., 2016).

North Atlantic sponge grounds vary greatly in terms of structural species richness, community composition, and in bathymetric and geographic distribution. In the northernmost areas and in the Nordic Seas Boreo-Arctic Tetractinellid grounds, usually referred to by fishermen as "Ostur = cheese bottoms" in the NEA or "Patatada = potato mix" in the NWA are found. These communities are composed of large Tetractinellids of the genera *Geodia, Stelletta, Stryphnus* often mixed with glass sponges (Class Hexactinellida), typically occurring on gravel and coarse-sand bottom at depths from 150-1700m (Klitgaard and Tendal, 2004; Murillo et al., 2012). These grounds are divided into two sub-communities: 1) boreal grounds at the flow path of warmer waters of the North Atlantic Current, found in the Faeroe Islands, Norway, Sweden, parts of the western Barents Sea and south of Iceland extending over the northwest Atlantic along Labrador and Newfoundland shelves. These are dominated by the species *Geodia barretti, G. macandrewi, G. atlantica, G. phlegraei, Stryphnus ponderosus* and *Stelletta normani*; and 2) cold-water grounds at the polar waters and outflow of the Arctic Basin and the Davis Strait, found in north of Iceland, most of Denmark Strait, off East Greenland and north of Spitzbergen. These are instead dominated by *Geodia hentschelli*, *G. parva* and *Stelletta raphidiophora* often mixed with the glass sponges *Schaudinnia rosea*, *Scyphidium septentrionale* and *Asconema foliata* (Klitgaard and Tendal, 2004; Murillo et al., 2012).

In southern temperate waters, monospecific aggregations of glass sponges seem to be more prevalent. Examples are dense aggregations of the birds' nest sponge *Pheronema carpenteri*, found on the Porcupine Seabight and on the continental slope off Morrocco (Rice et al., 1990; Barthel et al., 1996); *Nodastrella asconemaoida* occurring on the bathyal coral reefs of Rockall Bank (W of Ireland) between 524-857 m depth (van Soest et al., 2007); *Asconema setubalense*, on the summit of Le Danois Bank (Cantabrian Sea), between 400-600 m depth (Sánchez et al., 2008); *Poliopogon amadou* found at 2700 m depth on the Great Meteor seamount (Xavier et al., 2015); and the Russian Hat sponge, *Vazella pourtalesi* found on the Scotian shelf in Canada (Fuller, 2011) (Fig. 1.1).

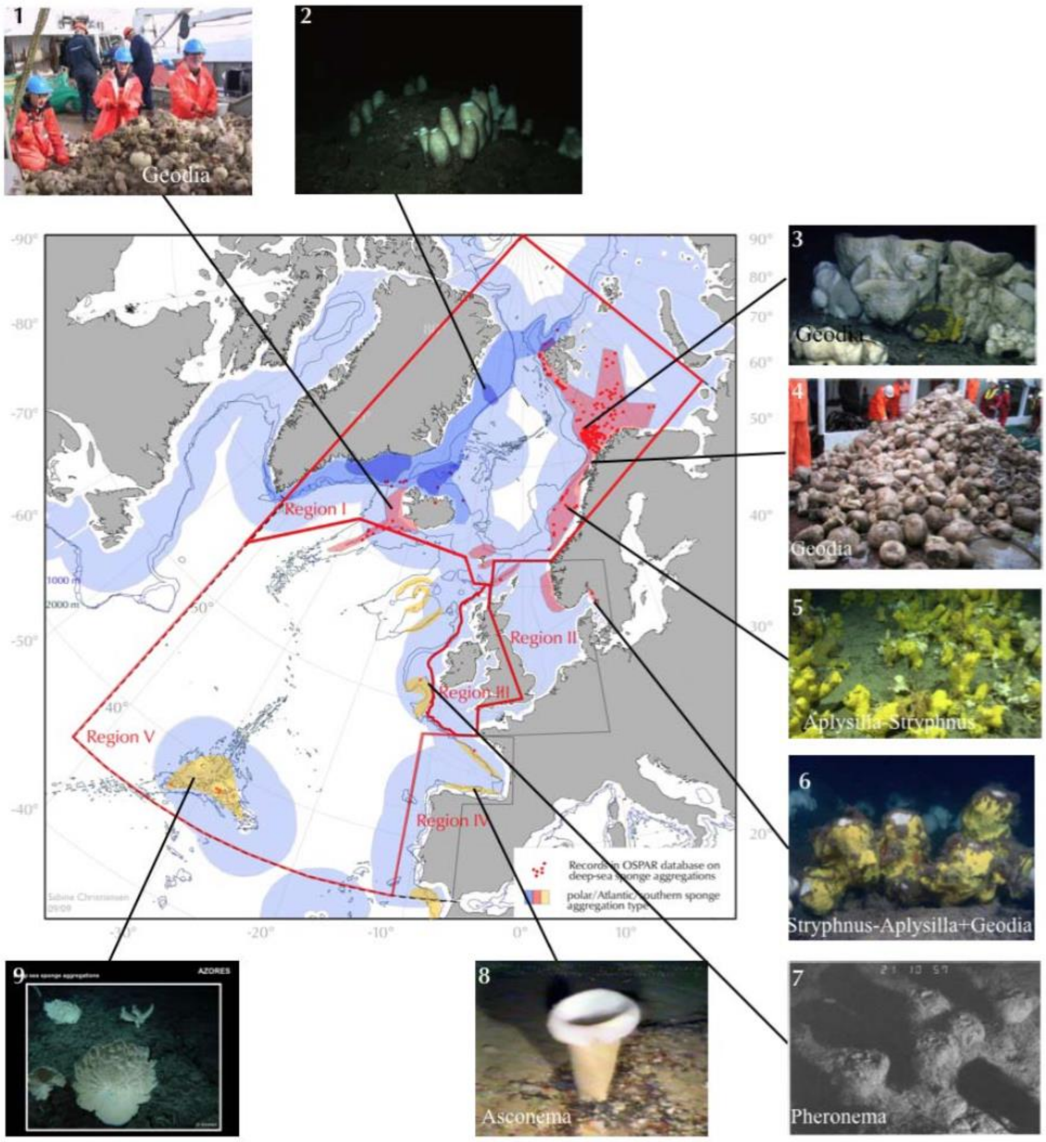

Fig. 1.1: General distribution of different types of sponge-dominated communities in the OSPAR area (Northeast Atlantic and Nordic Seas). Three biogeographic bands of deep-sea sponge aggregations are shown in colours: blue (polar), red (Cooperation), and yellow (Iberian) shading (OSPAR, 2010).

The abundance and species composition of the sponge grounds located in the Northern Atlantic varies between different localities. *Geodia barretti, G. macandrewii* and *G. phlegraei* are the most dominant species of the sponge grounds of Newfoundland with a 90% of bulk biomass and considered biodiversity hotspots (compared to non-sponge habitats) (Kutti et al., 2013; Murillo et al., 2012). Whereas on the shelf of the Faroe Island sponge communities are dominated by *Stryphnus ponderosus* with large abundance of *G. barretti, G. macandrewii* and *G. phlegraei* (Kutti et al., 2013; Klitgaard and Tendal, 2004). Overall, *Geodia barretti* is clearly the most widespread and most abundant species distributed in the northern Atlantic sponge grounds (Kutti et al., 2013). Further, Beazley et al., (2015) observed megafaunal communities dominated by sponges in the Northwest Atlantic, similar to the distribution of "ostur" in the Northeast Atlantic (Klitgaard and Tendal, 2004). On the slope of the Flemish pass, in the Northwest Atlantic, axinellid and polymastiid sponges were dominating, whereas in the deeper grounds, *Geodia* spp. and *Asconema* sp. dominate (Beazley et al., 2013). A complete community composition and structure of deep-sea sponge grounds in the Northern Atlantic remain largely understudied and their fully geographically distribution are still fairly unmapped. A recent study has also shown that sponge grounds can be rather ancient, persisting through major climatological events. From the analysis of spicules in sediment cores, Murillo and co-workers have shown that the boreal Tetractinellid grounds currently found in the Flemish Cap and Grand Bank have been continuously present in this area from 17 ka through to our days, i.e. they pre-date the Last Glacial Maximum (Murillo et al., 2016)

1.2. Environmental drivers

As sponges are sessile and filter feeders they rely on currents for food, and studies suggests that sponge distribution highly depends on specific oceanographic conditions e.g. salinity, current sped, temperature, location and depth for functioning (Beazley et al., 2015; Johannesen et al., 2016; Jørgensen et al., 2015). However, very little is still known about factors driving the formation of sponge grounds (ICES, 2009; Beazley et al., 2015). In the northeast Atlantic observations suggest that sponge grounds occur where the seabed interacts with the tides to create internal waves and to boost local currents for enhancement of food supply, which creates a favourable habitat for suspension feeding communities (Klitgaard and Tendal, 2004; Beazley et al., 2015). Knuby and co-workers pointed out the importance of hydrology where current speed, water depth and bottom salinity were found to constitute the most important factors determining the presence and distribution of sponge grounds in the northwest Atlantic (Knudby et al., 2013). Beazley and co-workers concluded that sponge grounds on the Sackville Spur, northwest Atlantic are associated with the warm and salty local current dwelling over the slope in the area, and urges further research at fine scale mapping of water masses to further investigate the environmental conditions driving such sponge grounds (Beazley et al., 2015).

In the western Barents Sea, Johanessen and co-workers identified that communities of the large-bodied *Geodia barretti* and *G. macandrewii* are forming dense sponge aggregations in the warm and saline deeper waters. The southwest of the Barents Sea is characterised by inflow of warm Atlantic water transporting food material and linked to the high primary production (Johannesen et al., 2016). And as suggested by Jørgensen and co-workers, the inflow of productive Atlantic and Coastal waters explains the dominant occurrence and high biomass of *Geodia* spp. that are covering almost 90% of the Tromsøflaket area (Jørgensen et al., 2015). Total annual primary production for the Barents Sea is estimated to range from 20 to 200 g C m $^{-2}$ with an average of 90 g C $^{-2}$ where high rates are found in the Atlantic and Coastal waters of the south western entrance area (Wassmann et al., 2006). Together with the hard bottom making it the ideal place for sessile feeders where bottom fauna is estimated to be at least twice as rich as the surrounded gravel or soft bottoms (Jørgensen et al., 2014; Kutti et al., 2013; Murillo et al., 2012; Klitgaard and Tendal, 2004).

1.3 Ecosystem goods and services

It is increasingly recognized that the deep-sea (and its ecosystems) provides the planet, and us mankind, a wealth of supporting, regulating, provisioning and cultural goods and services (EA, 2005; Armstrong et al., 2012; Thurber et al.). At present, sponge grounds are regarded as ecologically important benthic ecosystems that play a variety of operational roles in the marine environment, influence the structure of benthic communities and dominate large areas (Table 1.1) (Kutti et al., 2015; Murillo et al., 2012). They provide spawning and nursery grounds, feeding areas and refugee from predators for a number of fish and invertebrates species (Kenchington et al., 2013; Kutti et al., 2015; Beazley et al., 2015). With their unique morphology and high diversity, sponge grounds influence the occurrence and composition of the local fauna. Sponge grounds are believed to enhance biodiversity and abundance of local epibenthic fauna compared to non-sponge grounds. Early research has shown over 240 epifauna and infauna species associated to the main grounds-forming sponges species of the North Atlantic (Klitgaard and Tendal, 2004). Sponge grounds are habitat builders that add complexity to the benthic community by supporting spatial interactions and favouring increased abundance and diversity of other marine organisms (Kutti et al., 2013; Beazley et al., 2015). However, at what degree deep-sea sponge grounds alter the composition of associated megafaunal community remains unknown (Beazley et al., 2015).

Being suspensions feeders their feeding activity has been suggested to play a significant role in the trophic link between the benthos and the water column by influencing the deep microbial loop, impacting the benthic pelagic coupling of carbon fluxes and influencing the availability of nutrients (Maldonado et al., 2016; Beazley et al., 2015; Kutti et al., 2013). With the high abundance of sponge grounds in the benthic communities they impact the availability of compounds they take up and release, altering water properties and affecting the benthic coupling and cycling rates of chemical elements. As sponge grounds operate in high-density numbers they present high volumetric flow rates and high grazing rate. Benthic grazing rates are used to understand the effect of suspension feeders on the surrounding water as grazing rates quantify the mass being transferred from the water column to the benthos (Kahn et al., 2015). Sponges capability of pumping water through numerous small pores (ostia) transfers energy from the pelagic waters to benthic ecosystems and capable of efficiently consume both carbon and nitrogen (Kutti et al., 2013). Dissolved nutrients play a significant role on primary production and their use of phytoplankton are creating interconnections of ecological, environmental and biogeochemical relevance between C, N, P and Si cycles (Maldonado et al., 2012). Along the Norwegian continental shelf high biomass of sponges are distributed and suggested to play an important ecological role as links between the pelagic and benthic food webs (Kutti et al., 2013). Sponges capacity to exploit carbon from different sources has been suggested to explain their capacity of forming high biomass communities in the marine environment (Kutti et al., 2013). Kahn et al., (2015) a study carried out in the Strait of Georgia, British Colombia, identified sponge reefs as the highest benthic-grazing rate of any suspension feeding community ever measured. Here, sponge reefs extracted seven times more carbon than vertical flux of total carbon alone and to obtain such high grazing rate, productive waters and steady currents were needed, supporting the assumption that sponge ground distribution depends on specific oceanographic conditions (Klitgaard and Tendal, 2004; Beazley et al., 2015; Knudby et al., 2013; Degen et al., 2016). At what level sponge grounds affect the availability and cycling of chemical elements remains unknown and it is urgent to provide further understanding of sponges as a source, sink and cycler of nutrients.

Sponges also represent a remarkable potential for blue biotechnological innovations, namely in the fields of drug discovery and, more recently, in areas such as tissue engineering. As sessile organisms, and with a long evolutionary history, sponges developed range of chemical defence strategies against predators, spatial competitors, or as antifouling. These often imply the production of secondary metabolites that varies both temporally and spatially (Thoms and Schupp, 2008). These secondary metabolites with antimicrobial, analgesic, antiviral, and anticancer activities have placed sponges among the most prolific producers of pharmaceutically-interesting compounds (Munro et al., 1994). In fact, approximately 50% of all new marine natural products discovered between 1990-2009 in invertebrates had sponges as source organism. An average of 250 new sponge-derived natural products per year, totalling 4700+, were discovered in this period (Leal et al., 2012).

Table 1.1: Synthetic table of the ecosystems goods and services provided by sponge grounds, according to the classification set out by the Millenium Ecosystem Assessement.

Service	**Example and/or evidence**	**Reference**
Supporting		
Habitat and refugia	Association of several demersal fish taxa with sponge grounds in the Flemish Cap and Grand Banks (NWA) or on the Norwegian continental shelf and the Tromsøflaket area	Kenchington et al. 2013, Kutti et al., 2015, Jørgensen et al., 2015
Nursery function	Association of red rockfish (Sebastes spp.) juveniles with sponge grounds in the Gulf of Alaska and British Columbia	Freese & Wing 2003, Marliave et al., 2009
Nutrient cycling	Conversion of DOM into POC making energy available to higher trophic levels	De Goeij et al., 2013
Regulating		
Carbon sequestration	200 mg C m-2 day -1 of carbon consumed by *Geodia barretti* in the Traenadypet MPA in Norway Sponge reefs extracted seven times more carbon than vertical flux of total carbon in British Colombia	Kutti et al., 2013 Kahn et al., 2015
Water filtration	2000 l m-2 day-1 of water filtered by *Geodia barretti* in the Traenadypet MPA in Norway	Kutti et al., 2013
Provisioning		
Pharmaceuticals	Nearly 5.000 new marine natural products isolated from sponges since 1990	Leal et al., 2012

1.4 Vulnerability and threats

Sponges are sessile and long lived in their adult life and short lived in their larval stage and therefore assumed to exhibit low dispersal capabilities that limit their distribution range and connectivity levels (Klitgaard, 1995; Klitgaard and Tendal, 2004). In addition, on account of their expected slow growth and long recovery time deep-sea sponge aggregations are considered very sensitive to human impacts (Table 1.2). For these reasons they are classified as vulnerable marine ecosystems (VMEs) of utmost conservation priority and have been listed under the OSPAR convention list of threatened and/ or declining species and habitats (OSPAR, 2008).

At present, fishing is ranked as the highest threat towards sponge grounds as it occurs over a wide spatial scale and at an increasing intensity. High level of sponge by-catch has been reported for many deep-sea trawling fisheries. In fact, the effects of trawling on complex and large habitats and associated fauna have been compared with the effects of forest clear-cutting and significant negative correlation of bottom biomass with trawling activity has been documented in the Barents sea (Jørgensen et al., 2015). In addition, continuous events of trawling and dredging do not favour reproduction between the trawling events. Combined effect of climate variability, trawling and dredging are believed to be the main factors reducing benthic biomass up to 70 % in some areas in the Barents Sea (Stiansen et al., 2009). Direct impacts of fishing include physical removal, mortality and damage that leads to the destruction and fragmentation of the habitat; whereas indirect impacts arising from increased sedimentation (trawl plumes) may encompass physiological shut down such as pumping arrest and decreased respiration rate (Tjensvoll et al., 2013). Other bottom tending gears such as gillnets or longlines have shown to also exert some pressure but to a considerably lower extent than trawling (Pham et al., 2014; Muñoz et al., 2011).

Climate change effects on marine life are usually associated with the increase in temperature and carbon dioxide concentration (i.e. ocean acidification) projected for the atmosphere and the oceans. The variable effects of these two potential stressors on other deep-sea organisms such as cold water corals have been frequently assessed in the past decade and show that individual species exhibit different responses to such stressors (Maier et al., 2009; Hennige et al., 2014). In contrast, very few studies have been performed to date on sponges, and none on grounds-forming species. However, studies performed in shallow tropical reefs suggest that today's coral-dominated communities may become future sponge-dominated communities, as growth and distribution seems to be stimulated by these two hypothesized stressors (Bell et al., 2013; Fang et al., 2013). Until further studies are performed it is unclear whether climate change will exert a detrimental or beneficial impact over deep-sea sponge grounds.

The oil and gas industry have a direct impact over deep-sea benthic communities, during infrastructure installation (deployment of anchors and pipelines) or routine activities (discharge of drilling muds) but these are typically restricted to a radius of some 100 meters and could lead to "smothering" effects on a local scale (Stiansen et al., 2009). However, accidental impacts as those resulting from an oil spill will have consequences not only in a much larger spatial but also temporal scale (Cordes et al., 2016). Other more emerging activities such as deep-sea mining will probably have similar effects as bottom trawling, i.e. direct removal/destruction and physiological stress, only thought to likely occur at smaller spatial scales. Lastly, bioprospecting for biotech enterprises (e.g. drug discovery) and/or research (e.g. fishing surveys) may too have an impact especially if the sampling methods are in direct contact with the seafloor such as trawling.

Table 1.2: Overview of the main threats and impacts to deep-sea sponge grounds (Commission, 2010b)

Threats	**Extent and degree of threat**	**Impacts or effects**
Fishing (trawling, longline)	Large scale, high to very high	Physical damage, direct removal by gear, e.g. 'smoothering' effects from disturbance (clogging of pores)
Climate change	Large scale, unknown	Unknown for demosponges; probably detrimental for calcareous sponges
Oil and gas exploitation	Local, variable	Physical damage, direct removal during installation. 'Smothering' during activity. In the event of an oil spill significant impacts can be expected
Deep-sea mining	Local, very high	Physical damage by direct removal
Bioprospection/research	Local, variable	Minimal impact if collection is made with selective gear (e.g. ROV). In fishing surveys with trawl impact is similar to that of fishing only less extensive.

1.5. Conservation status and international action

Adopted in December 2006, the United Nations General Assembly (UNGA) resolution 61/105 called upon states and regional fisheries management organizations (RFMOs) to adopt and implement measures, in accordance with the precautionary and ecosystem approach to prevent significant adverse impacts on vulnerable marine ecosystems (VMEs). Through the publication of the International Guidelines for the Management of Deep-sea Fisheries in the High Seas, FAO provided practical guidance for the implementation of the provisions contained in that resolution, listing *"some types of sponge dominated* *communities"* as examples of vulnerable marine ecosystems sensitive to deep-sea fishing activities (Eayrs et al., 2009). To date such implementation has been made via encounter protocols designed to trigger a "move-on" rule. At present, the encounter thresholds for sponge by-catch adopted in the North Atlantic are 400 kg/tow and 300 kg/tow for NEAFC and NAFO regulatory areas, respectively. Upon encounter with such thresholds the vessel is required to stop its fishing operations and move >2 nautical miles from the encounter area. However, to date there haven't been any reports of VME encounter by fishing vessels in neither the NEAFC or NAFO RAs which raises serious concerns as to the efficacy of this approach (Gianni M, 2016).

In August 2016, the Deep-Sea Conservation Coalition provided a ten-year review of the implementation of UNGA 61/105 on the management of bottom fisheries in areas beyond national jurisdiction. In this document they report the considerable progress and important achievements made by some RFMOs (e.g. the closure to bottom fishing of substantial areas of the high seas, including a number of areas where VMEs are known to occur), but also highlight persistent gaps in the implementation of key provisions contained in this resolution (e.g. lack of adequate impact assessments, insufficient move-on rules, unregulated catches, etc). In this document they further provide a number of recommendations to ensure effective management of deep-sea fisheries in the context of the ecosystem and precautionary approach (Gianni M, 2016)..

Furthermore, the EU Integrated Maritime Policy and the Marine Strategy Framework Directive (MSFD) aim to achieve Good Environmental Status by 2020. And the EU 'Maritime Strategy for the Atlantic Ocean Area' aims to sustainable exploit the Atlantic seafloor natural resources, where sponge grounds are the best source of marine natural products in the marine ecosystem. Deep-sea sponge aggregations are listed under the OSPAR List of threatened and/or declining species and habitats (OSPAR agreement 2008-6). OSPAR Recommendation 2010/10 on the protection and restoration of deep-sea sponge aggregation in the OSPAR Maritime Area noted that "*deep-sea sponge aggregations are very sensitive to human impacts on account of their longevity,* *unknown reproduction patterns and expected long recovery times"* and that *"deep-sea sponge aggregation are very sensitive to physical damages as a result of commercial bottom trawling and suffer significant declines as a result"* (OSPAR, 2010). On May 2013 high-level representatives from the European Union, the United States of America and Canada signed the Galway Statement on Atlantic Ocean Cooperation to launch a Transatlantic Ocean Research Alliance. This cooperation aims for mutual benefits resulting in better ecosystems assessments and a better understanding of vulnerabilities and risks. Furthermore, it can help to generate new and better management tools to conserve the biodiversity, manage risks and determine social, environmental and economic priorities (Galway Statement, 2013).

1.6 Status of knowledge of sponge grounds in Norwegian waters

Boreal sponge grounds along the Norwegian coast and in the cold-temperate north Atlantic have been named as "ostur or cheese bottom" by local fishermen and are composed of multispecific assemblages of large sized and very abundant tetractinellid sponges of the genera *Geodia*, *Stryphnus, Stelletta and Thenea*, often mixed with a number of other groups, e.g. *axinellids* (Klitgaard and Tendal, 2004; Hogg et al., 2010). In colder (Arctic) waters or at larger depths the sponge grounds become more dominated by hexactinellids (glass sponges). These tetractinellid sponge grounds are found scattered along the entire Norwegian coast from the Swedish border to the Barents Sea and Svalbard whereas grounds of glass sponges have so far been found only along the Arctic Mid-Ocean Ridge (Fig.1.2) (HT Rapp pers. comm.). However, less prominent aggregations of glass sponges have been found along the continental slope off Lofoten (Buhl-Mortensen et al., 2012b; Buhl-Mortensen et al., 2015). The boreal sponge grounds have their main distribution from off Hordaland and further north along the coast, with a very clear peak off Vesterålen and at Tromsøflaket where *Geodia* species can reach up to 80 cm in size and weigh more than 38 kg (Klitgaard and Tendal, 2004; Kutti et al., 2013; Cardenas et al., 2013).

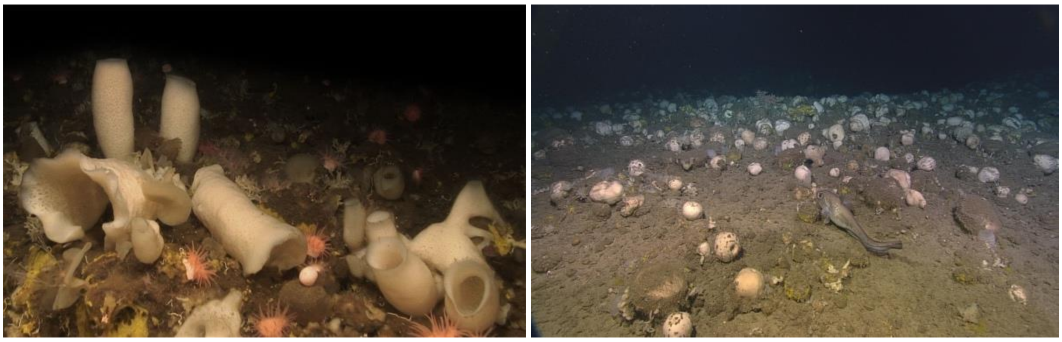

Fig. 1.2: Left photo: Coldwater sponge grounds at the Schultz massif on the Arctic Mid-Ocean Ridge (AMOR) dominated by the glass sponge *Schaudinnia rosea*. Right photo: Boreal tetractinellid sponge grounds dominated by *Geodia spp.* (source: University of Bergen and Fisheries and Oceans Canada).

Although it is known that sponge-dominated ecosystems are widespread benthic communities in Norwegian waters, their full geographical extent and composition remain largely understudied. However, the MAREANO mapping program has been developed to further map benthic communities and identify impacts from human activities (Fig. 1.3 and 1.4) from mid-Norway and northwards (Buhl-Mortensen et al., 2012a; Buhl-Mortensen et al., 2015), and more recently the establishment of the SponGES project will contribute substantially to the knowledge about the distribution of sponge-dominated communities in the North Atlantic, including Norway.

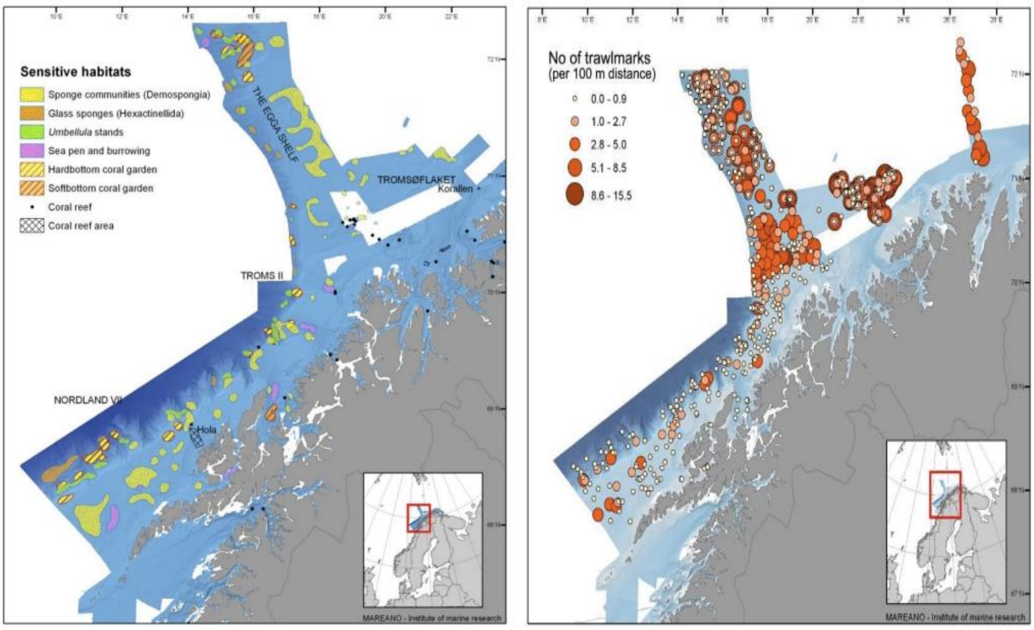

Fig. 1.3: Maps of: identified sensitive habitats (left); and fishing (trawl) footprint (right) in the Lofoten – Vesterålen area as a result of MAREANO's mapping program(Buhl-Mortensen et al., 2013).

Further, the dense communities of sponges are identified as a "problem" for the fishing industry as a single trawl is capable of being completely filled up with sponges (Føyn et al., 2002). Consequently, the fisheries acknowledge that they preferred already "cleaned up areas", free of sponges so they can enhance their trawling activity, thus fishing fleets are avoiding known sponge communities, or using already trawled areas (Føyn et al., 2002; von Quillfeldt, 2010; Jørgensen et al., 2015). Lack of knowledge makes it difficult to evaluate the total impact from the fishing activity in valuable and vulnerable areas, such as Tromsøflaket and Eggakanten (Gullstad, 2004; von Quillfeldt, 2010).

Fig. 1.4: Video analyses from the MAREANO program identifying trawling marks in the dense communities of *Geodia* spp in Tromsøflaket. *Geodia* sp. and *Steletta* sp. that are often concentrated in trawl paths in either long rows or in masses (Buhl-Mortensen et al., 2013).

Notably, none of the grounds-forming sponge species is included in the 2015 Norwegian Red List, which at present includes 29 other sponges classified under the "Data Deficient" category.

1.7 Sponge grounds in the Western Barents Sea – a case study

The Barents Sea is a continental shelf area located north of Norway, covering roughly 1.6 million km^2 of seafloor with an average depth of 230m (Jørgensen et al., 2014). Boreal "ostur" in the western Barents Sea are located on the slope of the Tromsøflaket bank and dominated by tetractinellid sponges such as *Geodia barretti* and *G. macandrewii* growing on sandy-silty bottom covered by sponge spicules (spicule mats) at depths between 150 and 350m (Klitgaard and Tendal, 2004; Knudby et al., 2013; Maldonado et al., 2016). The studies of sponge by-catch made by Jørgensen et al. (2014 and 2015) form a good basis for further studies on sponge ground distribution and diversity in the Barents Sea.

Fig. 1.5: Sponge by-catch from the Barents Sea Ecosystem Survey trawl in the Barents Sea at the Tromsøflaket bank with dominated *Geodia* species (Source: University of Bergen).

In collaboration with the Institute of Marine Research (IMR)[1] I have received by-catch data of sponges (Fig. 1.5) from the Barents Sea Ecosystem Survey (BESS), collected in August – September in the years 2010, 2011, 2012, 2013 and 2015, and enabled me to look closer into sponge abundance and biomass, as well as species composition on a spatial scale. Sponge material from the surveys was retrieved from demersal bottom trawl hauls in the Barents Sea (including Tromsøflaket) (Michalsen et al., 2013) (Fig. 1.6).

[1] The aim of IMR research and management advice is to ensure that Norway's marine resources (e.g. fish stocks) are harvested in a sustainable matter, and have in the later years analysed benthic fauna and sponges from the Barents Sea ecosystem survey (Jørgensen et al., 2015).

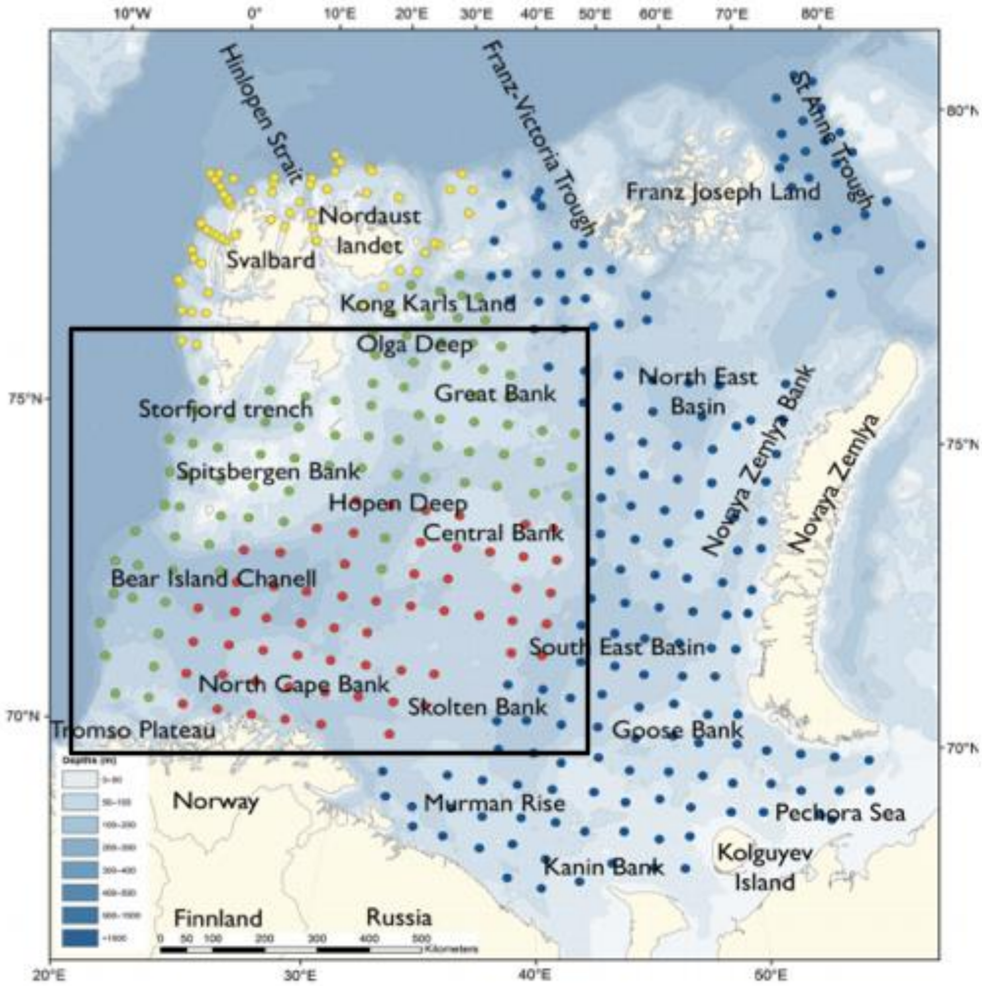

Fig. 1.6*:* Stations sampled during the BEES survey completed each year in August –September in the Barents Sea. In total, 4 vessels are used to cover the entire area with more than 400 stations located in the area. The square illustrates the area covered in this case study (Modified from Jørgensen et al., 2014).

1.7.1 Sponge distribution in the Western Barents Sea, Tromsøflaket

Based on analyses of the by-catch data it is clear that the catch and biomass vary from year to year, where 2012, 2013 and 2014 show highest catch of sponges (Fig. 1.7). The high catch rates of sponges from the 2012 survey was further analysed in detail to look at species distribution and total biomass of dominating species (Table 1.4). The total catch from 2012 was 10928 kg from a total of 340 conducted trawls. In comparison, in 2011 less than half of the trawls (141) were completed and only a total of 512 kg sponges were collected (Fig. 1.7 and Table 1.3). Species identification differed amongst the years and a percentage of specimens that have not been identified down to species level are shown. With a low catch rate, higher percentages of species are identified. However, in year

2015 with a total of 1462 specimens, roughly three times higher than year 2010 and about 500 specimens less than year 2013, only 3% were not identified down to species level. Whereas in year 2010 and 2013 a much higher percentage were not identified, 18 and 20 percent, respectively. Both 2011 and 2012 stands out with 80 and 70% of total catch not identified down to species level (Table 1.3).

Table 1. 3: Sponges identified during the BEES surveys where each station was trawled between 1 – 16 times. The 2012 survey, which has been analysed in greater detail, is shown in blue.

Year	Number of sponge species identified	Specimens not identified down to species level (%)	Total number of specimens/catch weight (kg)	Number of trawls	Number of stations
2010	17	18	451/21	117	40
2011	12	80	4653/512	141	50
2012	22	70	42569/10928	340	70
2013	21	20	2131/2951	217	59
2015	14	3	146/1381	135	34

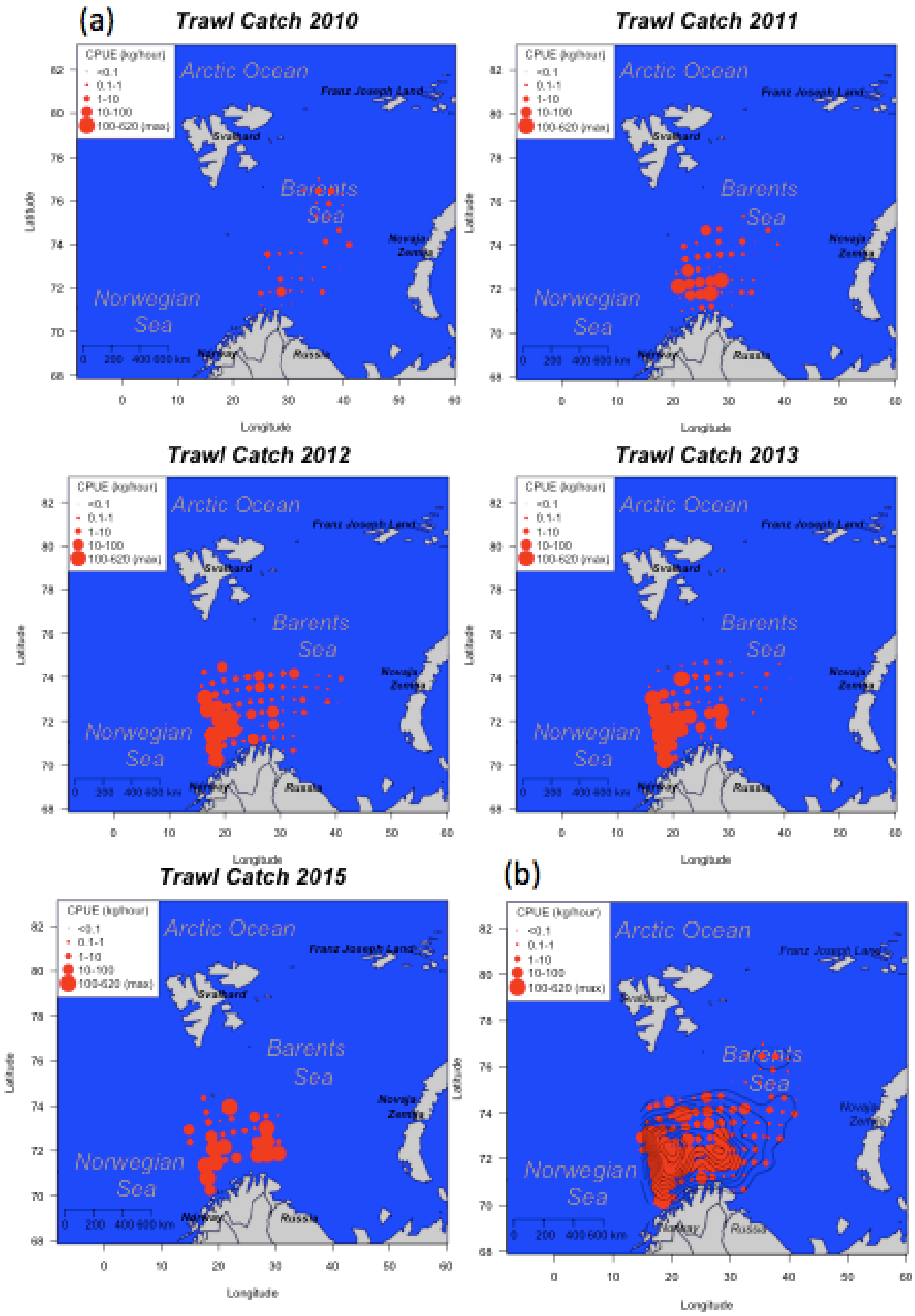

Fig. 1.7: Total sponge by-catch from BEES research trawls: (a) in 2010, 2011, 2012, 2013 and 2015; and (b) across all years. Catch per unit effort (CPUE) indicates total wet weight biomass, converted into kg/hour.

Table 1.4: Taxonomic composition of the sponge by-catch from the 2012 BEES survey. Total catch of species (biomass) are given in percentage. Depths are presented for each species, and when large variation occurs the average depth is shown in brackets. Numbers in bold highlight the most abundant species in biomass and/or number of specimens. In addition, the Tetractinellida are the most dominant group and also highlighted in bold.

Class	**Order**	**Species**	**Depth (m)**	**Wet biomass (% of total catch)**	**Number of specimens**	**Total number of trawls (15 min/trawl)**
Demospongiae	Poecilosclerida	*Antho dichotoma*	216	<0,01	4	1
Demospongiae	Dictyoceratida	*Aplysilla* sp	206 - 385	<0,01	13	5
Demospongiae	Halichondrida	*Axinella* sp	236 - 490	<0,01	31	2
Demospongiae	**Tetractinellida**	***Geodia barretti***	159 - 471	**22**	**395**	15
Demospongiae	**Tetractinellida**	***G. macandrewii***	206 - 471	**64**	**231**	14
Demospongiae	**Tetractinellida**	***Geodia* sp**	236 - 472	0,3	**271**	3
Demospongiae	Halichondrida	*Halichondria* sp	446	<0,01	52	1
Demospongiae	Haplosclerida	*Haliclona* sp	447	<0,01	1	1
Demospongiae	Poecilosclerida	*Hymedesmia* sp	236	<0,01	NA	1
Demospongiae	Poecilosclerida	*Mycale* sp	216 - 422	0,01	49	8
Demospongiae	Poecilosclerida	*Myxilla* sp	264 - 558	0,02	**398**	11
Demospongiae	Halichondrida	*Phakellia* sp	162 - 454	0,03	133	18
Demospongiae	Hadromerida	*Polymastia* sp	162 - 558	0,01	28	13
NA	NA	Porifera	58 - 558 (321)	**2,4**	**29752**	66
Demospongiae	Hadromerida	*Radiella grimaldi*	242 - 472	0,07	**362**	28
Demospongiae	Hadromerida	*R. hemisphaericum*	61 - 471 (334)	0,03	**766**	18
Demospongiae	**Tetractinellida**	***Stelletta* sp**	206 - 490	**9,6**	**884**	8
Demospongiae	Suberitida	*Stylocordyla borealis*	257 - 325	<0,01	26	4
Demospongiae	Hadromerida	*Suberites* sp	216 - 473	<0,01	37	8
Calcaera	Leucosolenida	*Sycon* sp	257	<0,01	19	1
Demospongiae	Poecilosclerida	*Tedania suctoria*	216 - 446	<0,01	71	10
Demospongiae	Hadromerida	*Tentorium semisuberites*	216 - 473	<0,01	42	6
Demospongiae	Hadromerida	*Tethya* sp	61 - 524 (338)	0,03	**684**	25
Demospongiae	**Tetractinellida**	***Tetilla* sp**	162 - 472	0,09	**1249**	35
Demospongiae	**Tetractinellida**	***Thenea muricata***	61 - 473 (329)	1,1	**7073**	38

Table 1.5: Additional sponge species identified in 2010/11/13/15 that were not identified in the 2012 survey. Total catch of individual species is given in percentages with given depths. Numbers in bold are highlighted to illustrate the most abundant species in both biomass and numbers.

Taxonomic group	Species	Depths (m)	Percentage of species catch	Total number of specimens per year	Total number of trawls (15 min/trawl)	Year(s)
Demospongiae - Poecilosclerida	*Asbestopluma pennatula*	331 - 660	<0,01	11/NA	4/3	2013/15
Demospongiae - Poecilosclerida	*Chondrocladia gigantea*	334 - 342	<0,01	4	2	2013
Demospongiae - Poecilosclerida	*Histodermella* sp.	212 - 463	<0,01	85	12	2013
Demospongiae - Tetractinellida	*Stryphnus ponderosus*	176 - 437	**21,6**/0,1	**316**/16	10/5	2013/15
Demospongiae - Hadromerida	*Sphaerotylus* sp.	254 - 275	0,01	1/4	1/2	2010/11

In addition to large wet weight biomass of *Geodia* species, high numbers of other dominating species, mostly from the Tetractinellida group, were collected in lower biomass weight (Tables 1.4 and 1.5). In wet biomass, the Tetractinellida group dominates (depths of 159 - 490m), but Hadromerida (depths of 216 - 558m) are also documented in high numbers. The three species, *Tethya* sp. (684 specimens), *Radiella grimaldi* (362 specimens) and *Radiella hemisphaericum* (766 specimens), all Hadromerida, are low in total wet biomass but high in numbers of specimens found, even higher than the dominant *Geodia* species (Table 1.4). *Tetilla* sp. is documented with 1249 specimens and is the highest abundance identified in the 2012 survey. Most species are found between 150 - 680 m depth, whereas *Thenea muricata*, *Tethya* sp., and *Radiella grimaldi* are also found at shallower depths (down to 61 m). The vast majority of the specimens collected in 2012 (29752 specimens) was not identified down to species and only identified as Porifera, accounting for 2,4 % of total wet biomass.

1.7.2 Dominant species

Geodia barretti and *G. macandrewii* are clearly the most dominant species in Tromsøflaket, e.g. in the 2012 survey a total of 86 % coverage of *Geodia* species were documented. Overall, *Geodia macandrewii* are distributed in highest biomass as every year, except 2010, shows a much higher percentage cover than *Geodia barretti* (Fig. 1.8).

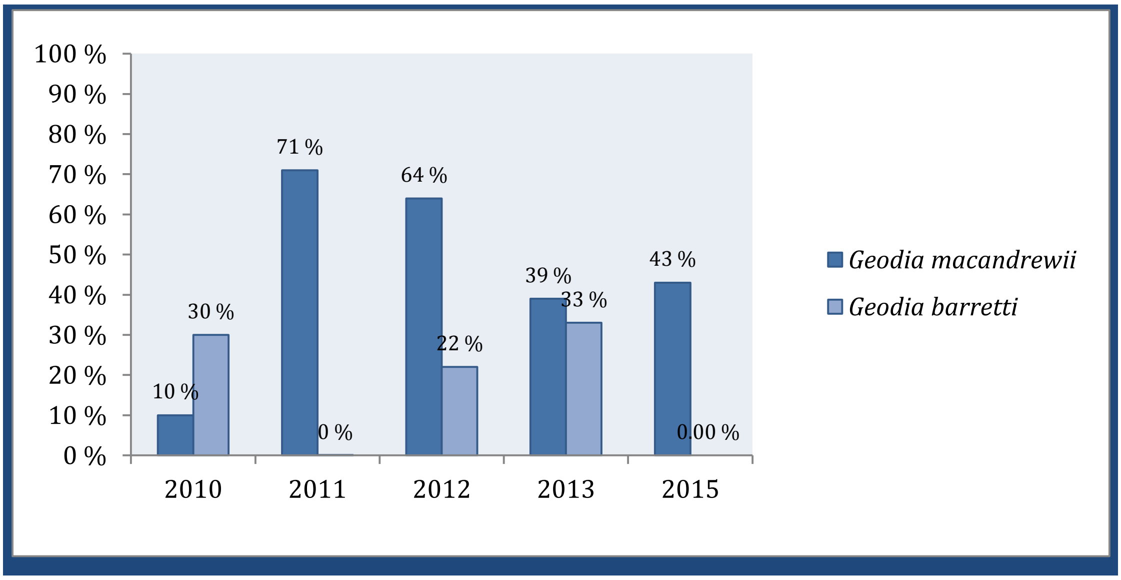

Fig. 1.8: Total wet biomass of total CPUE per year of dominant *Geodia* spp., *Geodia macandrewii* and *Geodia barretti*. *Geodia* species only identified as genus are not included as they occurred in very low numbers.

The large-bodied *Geodia barretti* and *G. macandrewii* are distributed in the same area as *Stelletta sp.*, *Thenea muricata* and *Stryphnus ponderosus.* Slightly towards the east we see a more mixed distribution of species (*Radiella sp., Tethya sp., Stelletta sp., Thenea muricata* and the *Geodia spp.*). Further east a more dominating area of *Tetilla sp., Myxilla sp., Thenea muricata* and *Radiella grimaldi* are shown. *Stryphnus ponderosus* are shown in dense communities near the continental shelf and *Radiella grimaldi* and *Radiella hemisphaericum* are more scattered throughout the Tromsøflaket area (Fig. 1.9). In the *Geodia*-dominated communities we also see a high biomass of *Stelletta* sp., 9,6 % of the 2012 total catch, *Thenea muricata* and an even higher biomass of *Stryphnus ponderosus,* 21,6 % of the 2013 total catch (Tables 1.4 and 1.5).

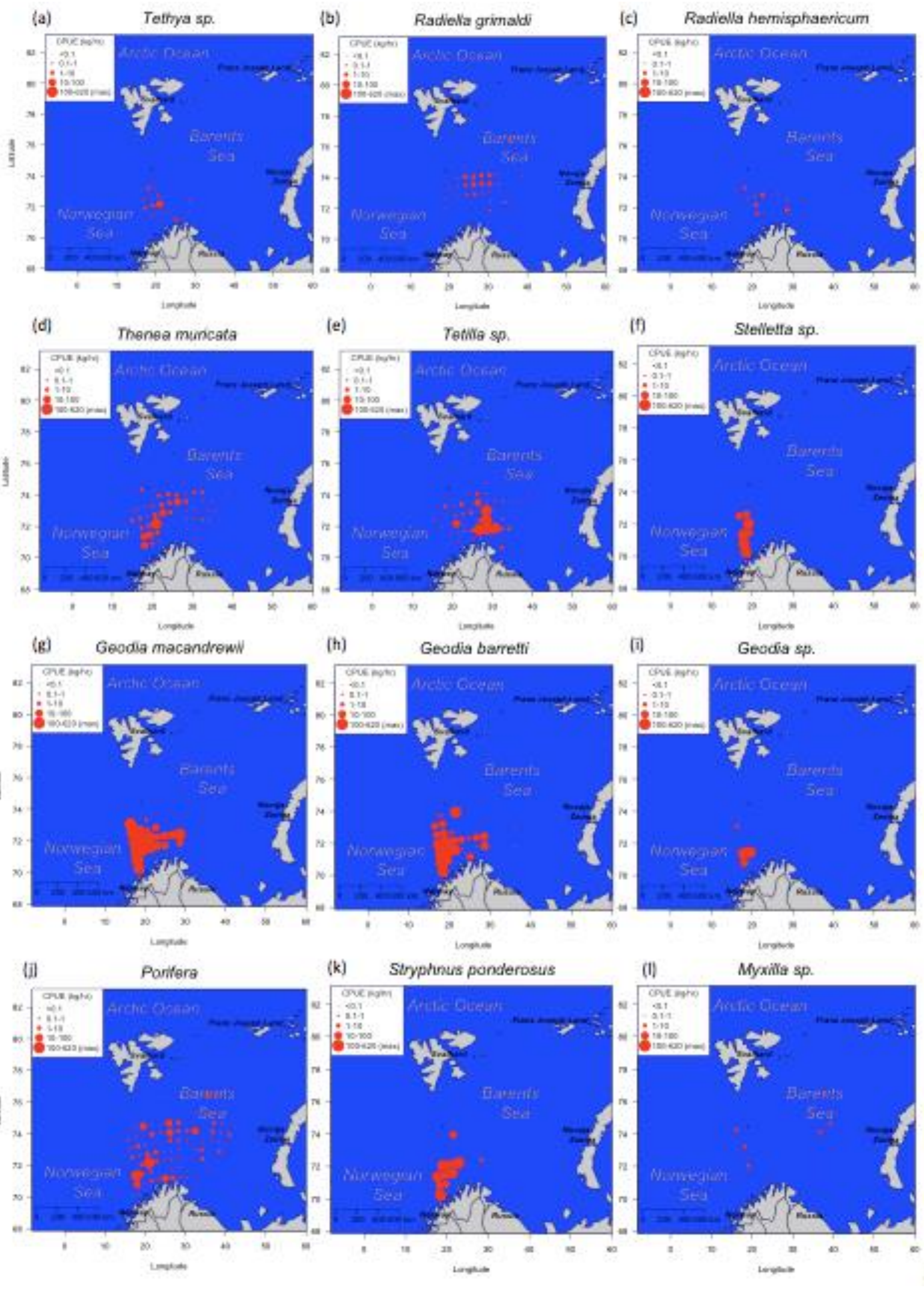

Fig. 1.9: Distribution and biomass (wet weight kg/hour) of the most dominant identified sponge species collected as by-catch in the Barents Sea during the BEES surveys in the period 2010-2013, 2015: (a) *Tethya sp*., (b) *Radiella grimaldi*, (c) *Radiella hemisphaericum,* (d) *Thenea muricata*, (e) *Tetilla sp.,* (f) *Stelletta sp.,* (g) *G. macandrewii, (h) Geodia barretti,* (i) *Geodia sp*., (j) Porifera, (k) *Stryphnus ponderosus and* (l) *Myxilla sp.*

1.7.3 Concluding remarks

As identified through this work and in correlation with already existing studies in the Barents Sea, large and dense communities of large-bodied tetractinellid sponges are dominating the Tromsøflaket area (Klitgaard and Tendal, 2004; Kutti et al., 2013; Cardenas et al., 2013; Jørgensen et al., 2014; Jørgensen et al., 2015; Johannesen et al., 2016). The most abundant species found in the 2012 trawl survey were *Geodia barretti* representing 22 % and *G. macandrewii* representing 64 % of total wet biomass, mostly located at the Tromsøflaket bank and clearly dominating the area. Jørgensen et al (2015) identified specimens of *Geodia barretti* and *G. macandrewii* that were accounting total trawl haul of 4 tonnes, up to 15 kg per individual, and with a diameter of 40 cm. Through large-scale studies, temperature and depth were found to be the most significant factor structuring benthic communities (Jørgensen et al., 2014 and 2015; Johannesen et al., 2016) and as suggested from Jørgensen et al. (2014), the inflow of productive Atlantic and Coastal waters explains the dominant occurrence and high biomass of *Geodia* spp. that contributed almost 90 % of total faunal biomass in the Tromsøflaket area. Further south, in the Traenadypet coral MPA (Marine Protected Area), Kutti et al. (2013) documented dominated communities of *Geodia* species, forming an almost continuous belt. Here, *G. barretti* compose 40% of total sponge biomass, and suggested to be capable of filtering approximately 250 million^3 of water and consume 60t of carbon daily, and clearly influencing the carbon and nutrient cycling in the benthic boundary layer. *G. barretti* were seen in diameter of 6 and 106cm, with an average diameter of 35 cm and *G. macandrewii* average diameter was estimated to 35 cm with a range of sizes between 12 and 99 cm. *G. atlantica* was also identified in the dominating area and ranged in diameter between 12 and 128 cm, with an average width of 51 cm (Kutti et al., 2013).

Further, and as already identified in previous literature (Maldonado et al., 2016) *Thenea* grounds occurs along the Norwegian continental shelf as well as on seamounts in the northeast Atlantic and in the deeper Arctic at depths of 100-900m, forming spicules mat-like structures on muddy bottom. *Thenea muricata* is the most common species, also the only *Thenea* species identified in the BEES surveys, and documented in body size of 50 cm in diameter (Maldonado et al., 2016). Most commonly found at depths below 200m and as documented from the BEES survey registered at depths down to 473m. Further, fauna of the western and northern coast of Svalbard are dominated by *Geodia* sp*., Phakellia* sp*., and Haliclona* sp*.,* that are covering more than 60 % of total biomass in the area (Jørgensen et al., 2014; Klitgaard and Tendal, 2004). *Phakellia* sp. and *Haliclona* sp. are shown in high density numbers in the Barents Sea, however, due to fragmentation and difficult species identification, mostly identified as Porifera in the BEES (Jørgensen et al., 2015). *Geodia* species have also been documented as occurring in high biomass eastward to the northern Kara Sea, and along the shelf facing the Arctic Ocean (Jørgensen et al., 2015).

In conclusion, Tetractinellida species dominate the Tromsøflaket area and the westernmost Barents Sea, with *Geodia barretti, G. macandrewii, Stelletta* sp*.,* and *Stryphnus ponderosus,* while species more adapted to soft sediments, such as *Radiella grimaldi, Thenea muricata* and *Myxilla* sp., are more dominant in the eastern Barents Sea.

2 Ecosystem-based management

"Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history. This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth".

Millennium Ecosystem Assessment Report (2005)

2.1 History and concept

Multiple pressures and impacts are threatening the marine environment, by driving entire ecosystems to altered states. Yet, there is still poor knowledge on the cumulative effects that human activities have on such ecosystems (EEA, 2015; Knol, 2013). In the past, policies have targeted single endangered or vulnerable species and habitats often in relation to one or few stressors. However, such approaches have proven to be largely inefficient and unable to reverse negative impacts affecting such species or habitats. The goal of an ecosystem approach (EA) is intended to provide a holistic approach to management, also called ecosystem-based management (EBM), by monitoring the state of ecosystems precautionary and manage them as a whole, including human activities (EEA, 2015; Knol, 2010). EBM seeks to depart from the traditional management approaches for a full understanding of the ecosystem and the complex relationships within (ICES, 2016; McBride et al., 2016; Ottersen et al., 2011; OSPAR, 2010; EA, 2005) (Table 2.1). Scientist and managers have recognised the need for an ecosystem approach for a long time but the fully awareness of the approach has only been developed into international agreements during the past 10-15 years (Misund and Skjoldal, 2005), where the "Malawi principles"[2] (Table 2.4) has served has a framework for the approach (Ottersen et al., 2011)

[2] Malawi principles are an international formalised description of the ecosystem approach to management.

Table 2.1: Illustrating a paradigm shift in marine management (modified from Lubchenco, 1994)

FROM	TO
Individual species Small spatial scale Short-term perspective Humans: independent of ecosystems Management divorced from research Managing commodities	Ecosystems Multiple scales Long-term perspective Humans: integral part of ecosystems Adaptive management Sustaining production potential for goods and services

The present ecosystem approach has emerged from international environmental agreements within the frame of the United Nations (UN) and the first description of the EA was already illustrated in the Stockholm Declaration in 1972 (Misund and Skjoldal, 2005). In 1992 the Convention on Biological Diversity (CBD) calls for an ecosystem approach in marine management and was later followed by several associations such as the Conference on Sustainable Fisheries in the Marine Ecosystems (Reykjavik, 2001), the Johannesburg Declaration of the World Summit on Sustainable Development (UN, 2002) and Code of Conduct for Responsible Fisheries with an ecosystem approach to fisheries (FAO, 2003). Further, the EA was central for the development of the strategic plan of the International Council for the Exploration of the Sea (ICES, 2002). In addition, the Large Marine Ecosystem (LME)[3] concept has been the basis for practical development of ecosystem approach to the management of marine resources and environment (Misund, 2006).

Over the years several definitions of EA and EBM have been put forward. However, they share several common principles. EA/EBM are an adaptive and long-term approach, aimed at preserving the potential and capacity of ecosystems to continue to deliver the services and goods of which human societies depend, and created to maximize benefits for human's well-being with a sustainable and ecological approach (ICES, 2016; OSPAR, 2010; FAO, 2005) (Table 2.2).

[3] Large Marine Ecosystems (LMEs) are relatively large geographical areas and defined on the basis of ecological criteria where most LMEs are located on the continental shelves, such as the Barents Sea, the Norwegian Sea and the North Sea (Sherman and Hempel, 2008)

Table 2.2. Definitions of EA and EBM in several international agreements. Highlighted in bold are common (or related) terms used in the definition.

The Convention on Biological Diversity (CBD) defines (EA) as *"...a **strategy** for the **integrated management** of land, water and living resources that promotes conservation and **sustainable** use in an equitable way. Application of the ecosystem approach will help to reach a **balance** of the three objectives of the Convention. It is based on the application of appropriate scientific methodologies focused on levels of biological organization which encompass the essential **processes, functions and interactions** among organisms and their environment. It recognizes that **humans**, with their cultural diversity, are an integral component of ecosystems."* (see: www.cbd/int/ecosystem)
The Marine Strategy Framework Directive clearly states that *"Marine **strategies** shall apply an ecosystem-based approach to the **management** of **human activities**, ensuring that the collective pressure of such activities is kept within levels compatible with the achievement of **good environmental status** and that the capacity of marine ecosystems to respond to human-induced changes is not compromised, while enabling the **sustainable use** of marine **goods and services** by present and future generations."*
The OSPAR Convention defines EA as *"the comprehensive **integrated management** of **human activities** based on the best available scientific knowledge about the ecosystem and its **dynamics**, in order to identify and take action on influences which are critical to the **health** of marine ecosystems, thereby achieving **sustainable** use of ecosystem **goods and services** and maintenance of ecosystem **integrity**"*
The Food and Agriculture Organization (FAO) of the United Nations mostly applies it to the fisheries sector as an approach that *"strives to **balance** diverse societal objectives, by taking into account the knowledge and uncertainties about biotic, abiotic and **human** components of ecosystems and their **interactions** and applying an **integrated** approach to fisheries within ecologically meaningful boundaries".*

2.2 Making the EBM approach operational

The ecosystem approach (EA) or ecosystem-based management (EBM) is not a new concept, however, it is the implementation that seems to be of continuous struggle. We are not only moving from a single species approach but also from a sector-by-sector approach and towards an integrated and cross-sectoral management governance (Olsen et al., 2007; Ottersen et al., 2011). The cooperation between regions and the different industries are highly important and finding a sustainable balance between exploitation and protection are of major challenge (Ottersen et al., 2011). A multi-sectoral approach is needed and the integrated approach is bringing science, politics and nature together in a context of marine governance (Knol, 2013). The interaction between human activities and ecosystems are complex with uncertainties and risks, however, adaptive management with a long-term perspective engaging stakeholders at all levels makes it possible to overcome the challenge (Ehler and Douvere, 2010 2010). Managers must understand the science, and the knowledge must come across and be translated into high-level international goals.

Further, EU believe that through long-term and integrated management regime, marine ecosystems can be economical, social and ecological beneficial for human well-being (Fig. 2.1). EU integrated maritime policy will strengthen ecosystem-based management of our seas, and corporations across nations will strengthen our understanding of complex ecosystem relationships. Potential of adaptive management open for adjustments according to needs of the respective ecosystem, and improved understanding of human and external impacts (e.g. pollution, physical and biological disturbance, energy and climate change) affecting the marine ecosystem, together with increased knowledge base of ecosystem goods and services, sustainable exploiting of marine ecosystems is highly possible (EEA, 2015).

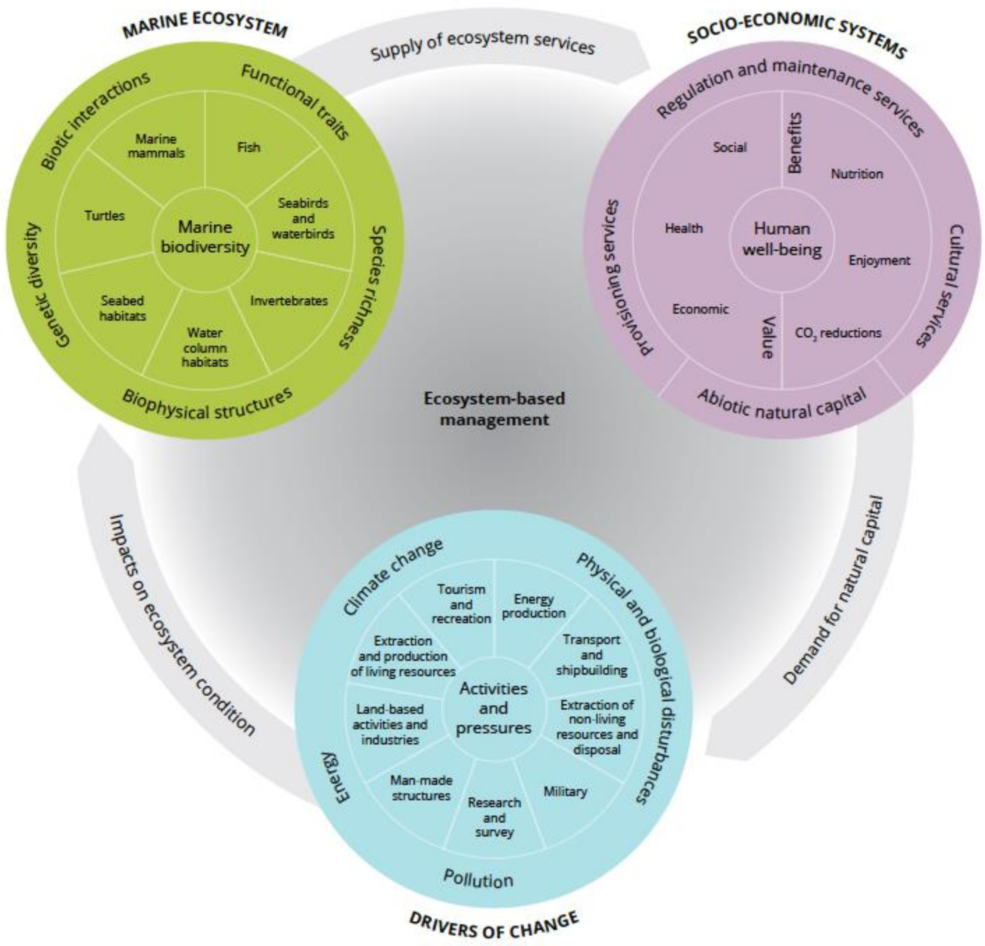

Fig. 2.1: Displaying EU's marine environment in a EU policy context – towards ecosystem-based management (EEA, 2015).

To further discuss the implementation of EBM successfully in Europe the workshop "Making the ecosystem approach operational"[4] was created and took place in Copenhagen, 20-22 January 2016. All presentations can be found at: http://www.ices.dk/explore-us/pro-jects/Pages/Making-the-ecosystem approach-operational.aspx ICES (2016). As already mentioned, ecosystem-based management is not unknown but rather difficult to implement into practice and management. This workshop was held to scope priorities and strategies of policy developers and stakeholders with the ecosystem approach. Overall, there is a

[4] The international workshop was held by the Atlantic Ocean Research Alliance Coordination and Support Action (AORAC-SA), which are designed to support the Galway statement implementation process and science for blue growth, and the Food and Agriculture Organization of the United Nations (FAO). Held at the Headquarters at the European Environment Agency, Copenhagen, Denmark. Additional supportive partners: Fisheries and Ocean Canada (DFO) European Union (EU), International Council for the Exploration of the Sea, European Environment Agency and National Oceanic and Atmospheric Administration (NOAA).

broad agreement of the concepts of EBM and best practices for making it operational (ICES, 2016). Ecosystem-based management is about balancing available marine resources and cooperation between sectors by looking at the ecosystem as a whole. It is not a "we" against "them" process and only through cooperation and including humans as part of the ecosystem we can achieve successful implementation of EBM (Fig. 2.2). However, many challenges were identified with regards to its full operationalization and implementation (Table 2.3). What seem to be the greatest weaknesses of the approach is the lack of participation from stakeholders and the synthesising of knowledge that is directly useful when evaluating trade-offs or spatial management (ICES, 2016). And as discussed during the workshop, the communication of science to policymakers is a key factor, and if not improved, important ecosystem will be lost for future generation (ICES, 2016).

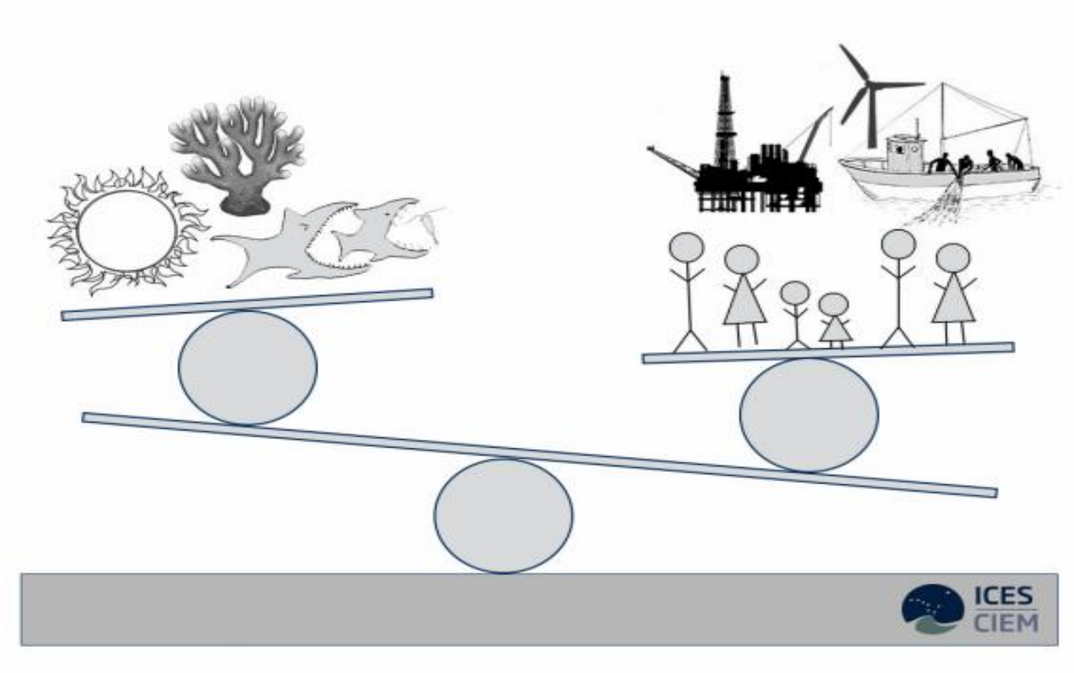

Fig. 2.2: Illustration of EBM in a balanced multiple use context, created during the workshop: "Making the ecosystem approach operational" (ICES, 2016)

Table 2.3: Challenges identified as hampering the implementation of the EBM

Gap between science and government
Science must be translated into policy and then to management plans across stakeholders, policy advisors and managers resulting into actions addressing the respective issue and ecosystem
Cumulative impacts
Measuring of cumulative impacts have been proven to be challenging (assessing of external and internal factors)
Agreement on trade-offs
Economic, ecological and social well-being but also agreeing on the different objectives and priorities
Scientific knowledge and transparency
A strong weakness of the EA is the lack of participation from stakeholders and synthesising of knowledge that is directly useful when evaluating trade-offs or spatial management. Open access of science to create a connection to media and the public - believed to increase engagement of the public and stakeholders. The ecological, economic and social values that could be beneficial from the system must be addressed, identified and made obvious.
Communication
Need to speak the same language and policymakers need clear goals written in a short and clear context making it understandable for all, regardless of your field of expertise. Focus on evaluating and clearly communicating the ecological, societal and economical trade-offs of possible future outcomes.
Guidelines
Lack of stepwise framework to guide such a public examination and decision-making is a proven challenge. The definitions of EBM goals are unclear and an open cross-sectoral discussion to develop transparent action plan agreed upon by the different sectors are necessary. EBM is a costly and long-term process and even when simplified for public and policies it can be seen as a too complex process that lacks clarity and ambition
Performance
The knowledge base of EBM seems to be satisfying but the social science knowledge is lacking and we are clearly failing when it comes to performing upon our knowledge base and in risk of creating dominance of only natural sciences, and failing in cooperation across the different sectors.

At a more national level, the Fifth International Conference on the Protection of the North Sea in Bergen towards an ecosystem approach (NSC, 2002) strongly influenced the first report on marine policy in Norway aiming for an EA to marine management (Riches of the Seas, 2001-2002)[5]. The report emphasised the integration of already existing legislations with the aim of achieving improved overview and monitoring of the ecosystem and was described as "*integrated management of human activities based on ecosystem dynamics. The goal is to achieve sustainable use of resources and goods derived from ecosystems and to maintain their structure, functioning and productivity*" (Ministry of the Environment, 2002). Consequently, the ecosystem approach was integrated in Norwegian management plans and already in 2006 ecosystem-based management was implemented in the first management plan, covering the Barents Sea and Lofoten areas (Ministry of the Environment, 2006).

In Norway, the Ministry of Climate and Environment has made the Norwegian Environment Agency responsible for putting EA into practice and further developing an integrated ecosystem-based management regime. The different sectors such as fisheries, maritime transport, oil and gas are still responsible for ecosystem-based management within their own field of responsibility and activities, while the environmental authorities have the overall responsibility for coordination so that the cumulative environmental effects from all sectors are taken into account with an ecosystem approach (Monitoring Group, 2014).

[5] The white paper "Riches of the Seas, 2001-2002" was the first report that emphasised the need of EA to marine management in Norway. Subsequently, three independent Norwegian integrated management plans with an EA was developed, covering the Barents Sea and Lofoten area (2006), the Norwegian Sea (2009) and the North Sea (2013).

Table 2.4: The Norwegian Environment Agency framework for putting EBM into practice where the below 8 points are developed from the Malawi principles (12 principles in total) for the ecosystem approach in Norway (Source: Norwegian Environment Agency)

Ecosystem-based management framework in Norway based on the Malawi principles
1. Management must be based on a shared vision, and must involve all relevant stakeholders. 2. Planning and management must be based on an integrated approach with clear goals, but must also be flexible enough to allow changes to be made in the light of new knowledge. 3. The management regime for an area or ecosystem must take into consideration any impacts it might have on neighbouring areas or ecosystems. 4. One of the main goals of management is to conserve ecosystem structure and functioning. The management of different species and habitats must therefore be coordinated. 5. Management goals must ensure sustainable use and development and must reflect societal choices. 6. Decisions must be made about society's aims for ecological status expressed in terms of ecosystem structure and functioning. 7. Management must be based on the precautionary principle, the user-pays principle and the principle of preventive action. The best available techniques (Munro et al.) and best environmental practices (BEP) should also be applied. 8. Coordinated monitoring and assessment programmes and implementation and control and enforcement systems must be developed.

The framework for an ecosystem approach to marine management, as derived from the Bergen Declaration, consists of 5 major elements (Fig. 2.3) or modules in a management cycle: 1) Objectives should relate to the state of the ecosystem; 2) monitoring and research should be performed to updated information about status and trends and insight into mechanisms and relationships; 3) assessments should use the information gained from monitoring and research to evaluate whether the objectives are being met and/or progress is being made towards meeting them; 4) scientific advice should be clearly translated and communicated for decisions-makers; and 5) management should respond to the advice given to meet the agreed objectives (Misund and Skjoldal, 2005).

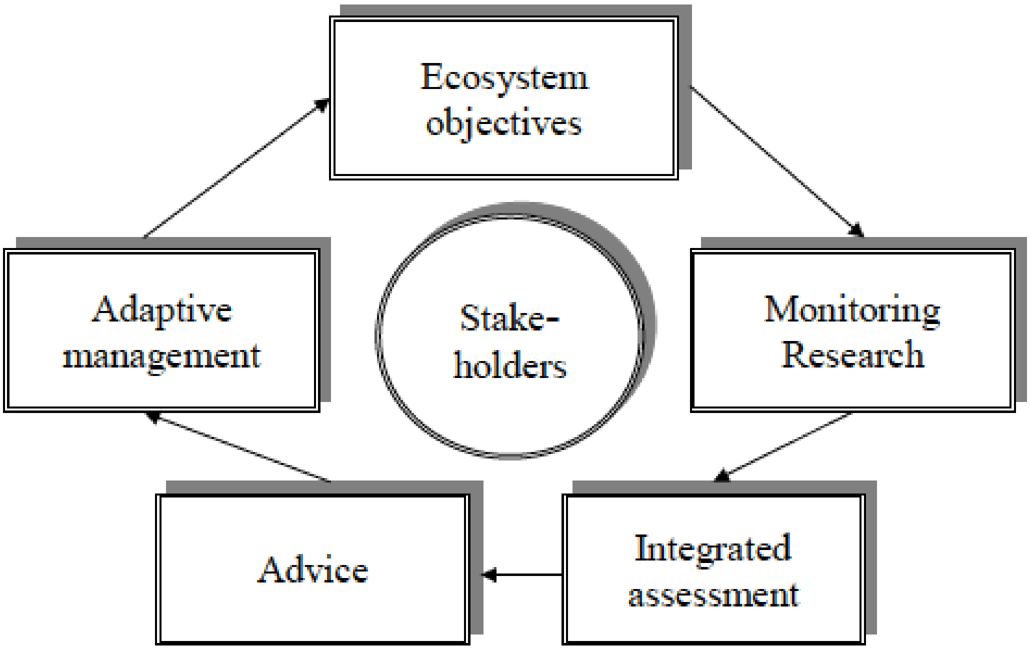

Fig. 2.3: Framework for ecosystem approach to ocean management with 5 main components or modules shown in an iterative management decision cycle, where stakeholders should be included in the process to promote openness and transparency (Misund and Skjoldal, 2005).

The approach of marine spatial planning (MSP)[6] in Norway is considered as a practical approach when implementing ecosystem-based management in order to sustainable manage the marine environment. Such approach requires the involvement of various actors and stakeholders at different governmental and societal levels and it is a complex process between science, management and policies. Ecosystem-based management and marine spatial planning are both versatile management approaches by merging the management of multiple sectors and goals under the same umbrella (Olsen et al., 2011b). Placed-based management increases in complexity along with a larger spatial scale. Thus, increase of uncertainties follows and decisions are made upon limited knowledge and the precautionary approach is normally taken into consideration. Additionally, agreeing on what is precautionary and what is sufficient knowledge

[6] "*Ecosystems are places and maritime spatial planning (MSP) is the process by which ecosystem-based management is organized to produce desired outcomes in marine environments*". Further, *"ecosystem-based management, in turn, is an approach to analysis, planning and decision making that considers entire ecosystems, including humans, and evaluates the cumulative impacts in human activities* (Olsen et al., 2011b).

in a multi-sectoral setting is difficult when integrating ecosystem approach to management (Olsen et al., 2011a). The integrated management plans emphasises that special precautions are needed to protect areas where marine resources are considered to be particularly valuable and vulnerable based on scientific assessments and acknowledged for their significance for the biodiversity and biological production (McBride et al., 2016).

3 Marine management in Norway

3.1 Overview

Norway is rich in natural resources, fish, oil and gas, and the exploitation of these has been instrumental for economic growth and welfare in Norway (Ministry of the Environment, 2006; Olsen et al., 2015). Continuous economic growth has led to continuous and increased pressure on the marine environment and for the last 50 years, technological development e.g. within the fisheries, made it possible to over harvest (Gullestad et al., 2014). The technological development played a major role and is believed to be one important factor for the herring stock collapse in the 1960s (Lorentzen and Hannesson, 2004; Gullestad et al., 2014). Moreover, parallel to the challenges caused by increased fishing effort and over harvest, problems connected to physical damage caused by bottom trawling became apparent, and hence became the most significant impact and threat to sponge grounds and the deep-sea (OSPAR, 2010; Buhl-Mortensen et al., 2016; Jørgensen et al., 2015; Clark et al., 2016). Reduced fish stocks led to socioeconomic challenges and were an important drive for the gradual development of marine policies to prevent overfishing, and by the late 1980s Norwegian fisheries were regulated to develop towards long-term sustainability of fish stocks (Gullestad et al., 2014; Johnsen and Eliasen, 2011; Michalsen et al., 2013). However, the management was very focused on stock and species control and bottom trawling continued as before, with protection of bottom communities being included in the fishery management as late as 1999 (Rice et al., 2012), i.e. a century after the establishment of the Fishery Directorate and the Institute of Marine Research in Norway (Table 3.1).

Fisheries was the main threat to the marine environment for decades but, from the 1970s the petroleum industry (Knol, 2010) added to the already existing environmental pressure. New areas for oil exploitation were continuously opened and expanded first northwards to the Norwegian Sea and later to the Barents Sea and have, interestingly, been a major drive for the development of current management plans (Olsen et al., 2015; Knol, 2010). Thus, combined with more knowledge, a growing awareness that management must be holistic and a still increasing pressure on the marine environment (shipping, petroleum, coastal construction, fishing, aquaculture etc.) a new era of marine management emerged. For Norway it began with Norway's ocean policy, report No. 12 (2001 – 2002) *Protecting the Riches of the Seas* aimed at establishing a framework capable of balancing commercial interests while sustaining the marine environment (Environment, 2002). Some years later the management plans for the Barents Sea (2006), the Norwegian Sea (2009) and the North Sea and Skagerrak (2013) developed.

Table 3.1: Timeline of major events and management actions in Norway. Highlighted in bold are events more relevant for the management of sponge grounds. Years shown in red are management plans/policy report established.

1900	**Directorate of fisheries and Institute of Marine Research established**
1946	Ministry of fisheries (first in the world)
1960s	North Sea herring stock depleted
1970s	Oil and gas industry and aquaculture expansion
1972	Fishing Act 1972
1976	Zone act – 200 nm EEZ
1977	**Fishery protection zone around Svalbard**
1978	The Grey zone agreement between Norway and Russia
1980	Fishery zone around Jan Mayen
1996	Petroleum Act 1996
1999	**First MPA of cold water coral reefs**
2002	Riches of the seas (first national marine policy report)
2006	Barents Sea and the Lofoten areas management plan
2005	Aquaculture Act 2005
2007	Ship Safety and Security Act 2007
2009	**Marine Resources Act**
2009	Norwegian Sea management plan
2009	**Nature Diversity Act – serve as guideline for the authority**
2010	Offshore Energy Act 2010
2010	New border with Russia in the Barents Sea
2011	**Regulation protecting VMEs**
2013	North Sea management plan
2016	**Adjusted regulation protecting VMEs**

3.2 Management structure

Human activities are managed in relation to national political, economic and environmental priorities under a governmental structure, and are implemented through specific legislations (Buhl-Mortensen et al., 2012). Directorates and departments within the ministries are responsible for ensuring that respective industries are in harmony with the *Nature Diversity Act* (Fig. 3.1) and each integrated management plan, a "Report to the Parliament" (white paper), provides guidance on how the existing legislations and management structure are to be achieved (Buhl-Mortensen et al., 2012). Consequently, ministries (government) and the parliament cannot ideally make decisions against recommendations provided in the integrated management plans. Moreover, the different sectors operate according to sector legislations, e.g. the Directorate of Fisheries manages the fisheries based on fishing legislations on day-to-day basis, whereas the integrated management plans are important governing documents necessary for policy makers.

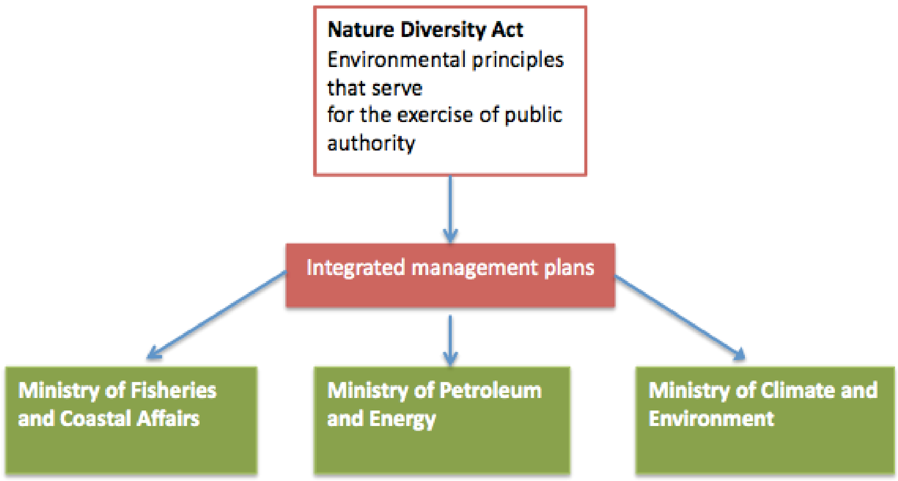

Fig. 3.1: Simplified illustration of management structure relating to marine resources. In green, the three ministries that manage human activities at sea, including department/institutions that also monitor the marine environment under each respective ministry. In red, the three integrated management plans that each ministry and sector must follow, including own sector laws, where the Nature Diversity act serve as a guideline for the public authorities.

3.3 Norwegian integrated management plans

The first integrated management plan with an ecosystem approach – the Barents Sea and Lofoten - was initiated in 2002 and implemented in 2006 and later updated in 2011 and 2015 (Ministry of the Environment, 2011 and 2015) (Fig. 3.2). Next step covered the Norwegian Sea (implemented in 2009 and update planned for 2017), and finally the North Sea and Skagerrak that was implemented in 2013 (Olsen et al., 2016; Ministry of the Environment, 2013) (Fig. 3.3). Naturally the updates (every fourth year) will follow the original order of the plans, aiming for adaptive updates according to specific needs and knowledge, whereas the revisions are more comprehensive, accounting for a longer period where all objectives are revised.

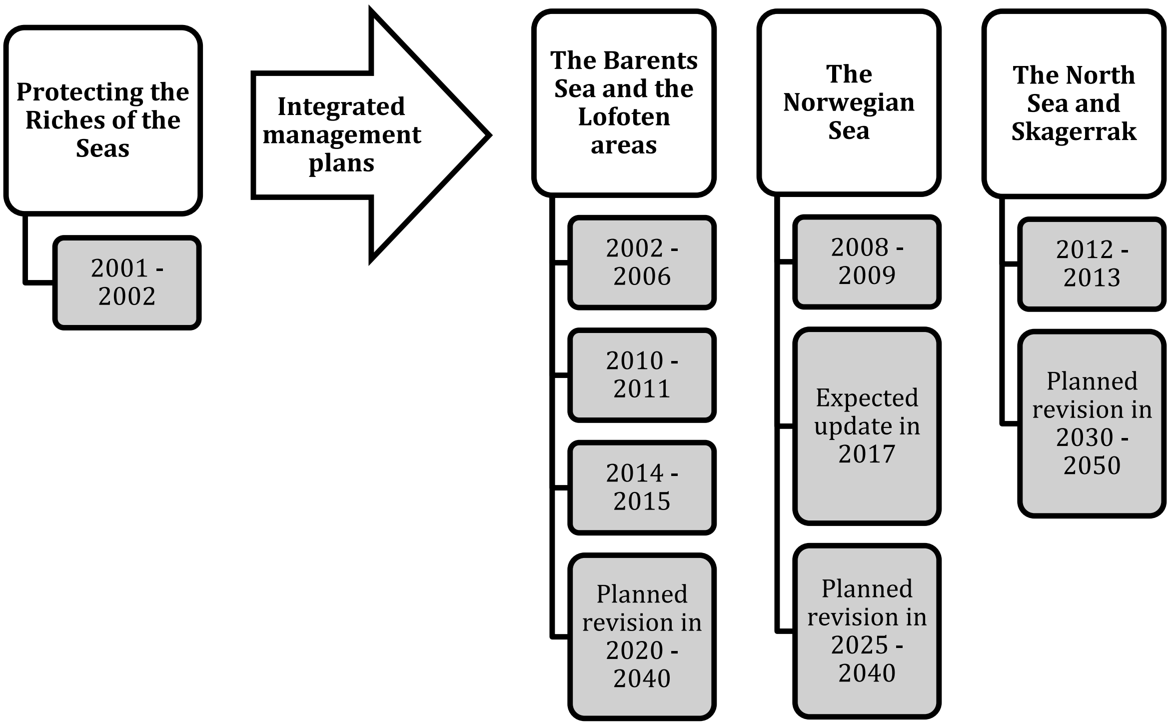

Fig. 3.2: Illustrating the development of the integrated management plans initiated from the *Protecting the Riches of the Seas* in 2002. Updates and planned revision are shown for each individual plan.

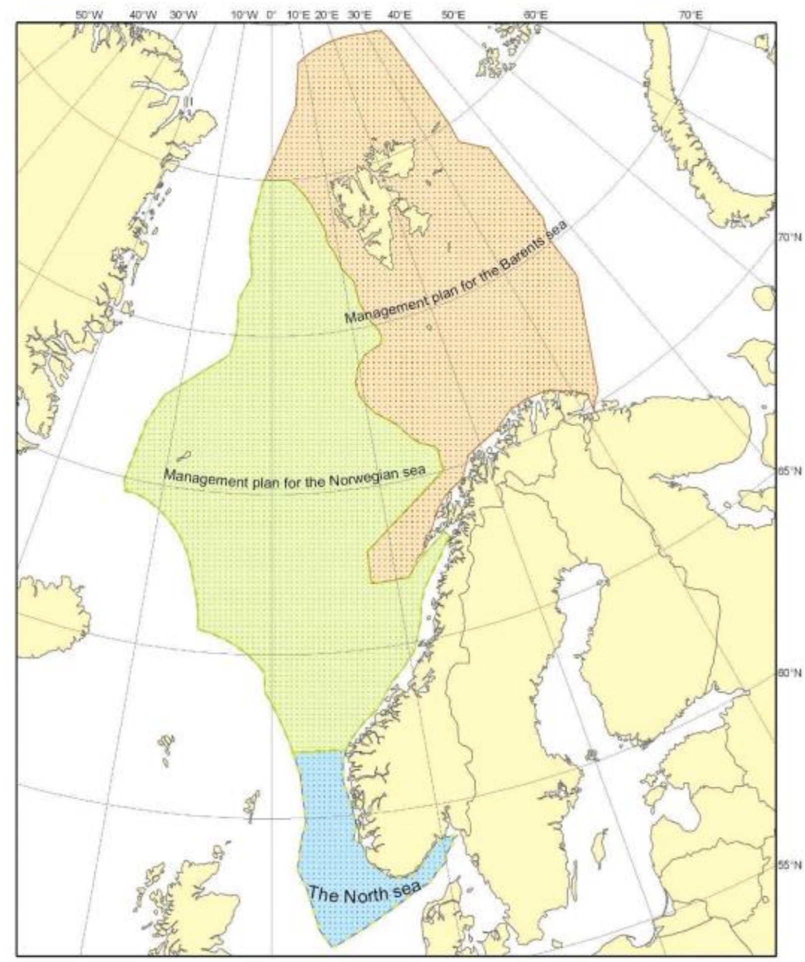

Fig. 3.3: Illustrating the three integrated management plans: the North Sea - Skagerrak; the Norwegian Sea and the Barents Sea. Each plan covers the sea areas from 1 nautical mile beyond the coastal baselines to the limit 200 nautical mile limit of national jurisdiction (Buhl-Mortensen et al., 2012).

The integrated management plans share strategic objectives:

i. Promote economic development by allowing sustainable use, and at the same time ensure healthy ecosystems

ii. Clarify overall framework and encourage closer coordination and priorities

iii. Provide direct regulations to industries utilizing area of interest

iv. Increase predictability and facilitate coexistence between sectors and natural resources

v. Simplify and improve the system for involving parties to ensure engagement from stakeholders

(Ministry of the Environment, 2006, 2009, 2013)

3.3.1 Implementation steps

Through this process integrated management went beyond the traditional sectoral environmental and resource management, which allow cooperation across sectors and government institutes, thus focus on the cumulative impact (Olsen et al., 2007; Buhl-Mortensen et al., 2012). Each plan has been adapted for the ecosystem in question and the planning process is centralized with low local involvement where decisions are made by the government and approved by the parliament (Olsen et al., 2014). Still, implementation of cross-sectoral management plans requires supervision and control in order for all sections to comply. Ministry of Environment was set to coordinate the implementation (and development) of the integrated management plans and an inter-ministerial steering group was formed (Olsen et al., 2014) (Fig. 3.4). The steering group tasked each institutions and directorates under each ministry to contribute to implementation (and development) (Olsen et al., 2015). Three advisory groups; 1) *Management Forum* 2) *Risk Forum* and 3) *Monitoring Group* where created to report back to the inter-ministerial steering group. Government directorates and research institutes constitute the *Management Forum* that is chaired by the Norwegian Environment Agency, and they are responsible of background reports for the integrated management plans. The *Risk Forum* is headed by the Coastal administration and constitutes the Norwegian Petroleum Directorate. The *Risk forum* is responsible for monitoring potential risks to the ecosystem and ensure dissemination of information. The *Monitoring Group* is led by the Institute of Marine research (IMR), and coordinates the monitoring and mapping programs SEAPOP (Seabird Populations Monitoring and Mapping) and MAREANO (Marine Areal Database for Norwegian Coasts and Sea Areas) that was developed to increase the knowledge base in the Barents Sea (Buhl-Mortensen et al., 2012).

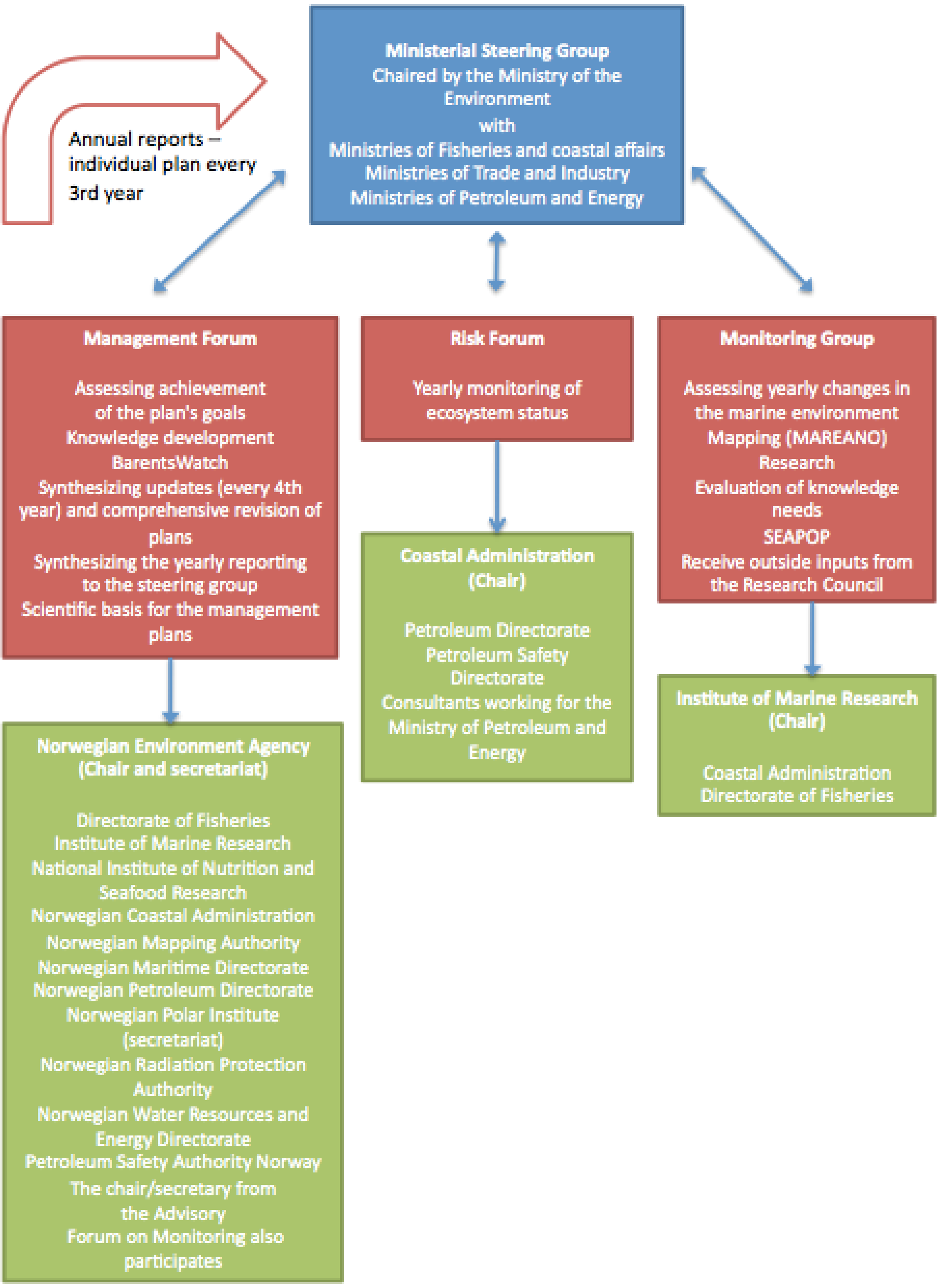

Fig. 3.4: Illustrating the organisational and governance structure of the integrated management plans. The Ministries leading the process (in blue) and the government forums/group following up the process and developed programs are shown in the middle (in red), plus stakeholder reference group (in dark green). Institute and directorates that participate in each group/forum are shown last (in green). In addition, a stakeholder reference group where created, including the fisheries, petroleum industries, shipping and recreational users. Supporting ministries also contributes to the implementation: Finance, Justice, Local and regional Government, Labor and inclusion, Foreign affairs and Defence (Modified from Olsen et al., 2015).

Further, in the development process, both local and regional authorities have had important roles, in addition to the petroleum industry, fishing sector and environmental NGOs that have impacted the process both directly and indirectly through research, mapping, inputs and lobbying (Olsen et al., 2016) (Fig. 3.5).

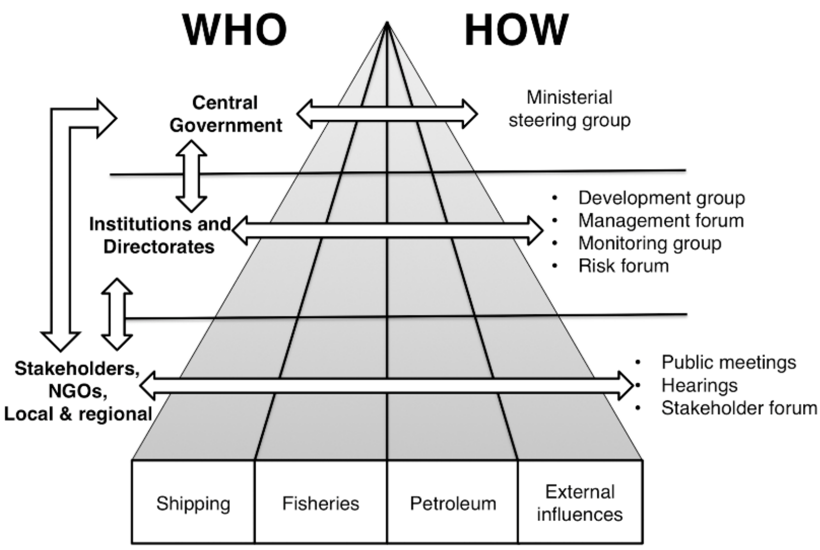

Fig. 3.5: The institutional, government and stakeholder integration in Norway. All respected participants related to the development and implementation of the integrated management plans are shown (Olsen et al., 2014).

All three management plans were developed in a stepwise process starting with a scoping phase to assess the state of the ecosystem and the different activities affecting the ecosystem (Table 3.2). In the next phase, the ecological impacts from human activities were assessed with sectoral Environmental Impact Assessments (EIAs), (fisheries, petroleum, maritime transport and external pressures) (Ottersen et al., 2011). In the final phase EIA results were brought together and cumulative impacts on the ecosystem were assessed and analysed in detail. In particular the valuable and biological vulnerable areas were assessed and gaps in knowledge and management objectives were stated (Olsen, 2008; Von Quillfeldt et al., 2009).

Table 3.2: Illustrating the development steps of the management plans and different phases (Von Quillfeldt et al., 2009)

Phase 1	**Phase 2**	**Phase 3**	
Scoping – status reports	Environmental Impact Assessments (EIAs)	Assessing the EIAs and accounting the cumulative impacts	**Management plans**
Environment and resources Valuable areas Socioeconomic aspects Economic activities	Fishing Oil and gas Shipping External influences	Total impact Management goals Gaps in knowledge Vulnerable areas and conflict of interest	
	Development of Ecological Quality Objectives		

3.3.2 The Barents Sea and the Lofoten areas management plan (BSMP)

The Barents Sea and Lofoten integrated management plan was adopted by the parliament in 2006 and an update was published in 2015 (Fig. 3.2). A comprehensive revision is in progress and will be completed in 2020, and stay effective until 2040. The area of the management plan covers the Barents Sea, until the Russian border and the Lofoten areas. Cumulative impacts (Fig. 3.7) affecting the marine environment in the Barents Sea are evident and expected to increase in the future (shipping, oil and gas, fisheries) and in particular, the expected climate change that will most likely pressure ecosystems further (Ministry of the Environment, 2006). Internationally, the Barents Sea has been identified as a Large Marine Ecosystem (LME) and the plan encourages close cooperation with Russia to ensure an integrated management regime for the entire Barents Sea (Ministry of the Environment, 2006).

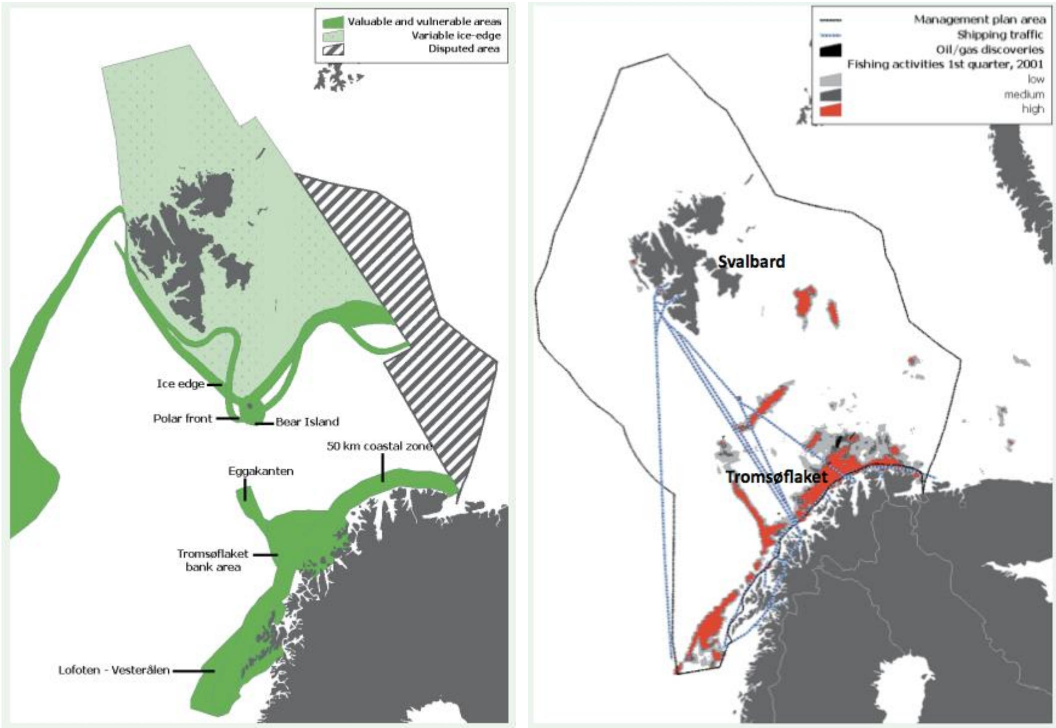

Fig. 3.6: Identified vulnerable and valuable habitats in the Lofoten – Barents Sea areas (left photo). Illustration of human activities in the Lofoten - Barents Sea areas where fishing activities are high (in red) in the dominating sponge communities at Tromsøflaket (right photo). Modified from Von Quellfeldt et al., (2009).

Seven particularly valuable and vulnerable areas (Fig. 3.6) were identified, in the Lofoten – Vesterålen coastal area, Tromsøflaket area, Eggakanten edge of the continental shelf, (all three areas with dense sponge communities) a 50 km coastal zone from Troms to the border with Russia, a 50 km zone around Bear Island, the polar front and the iced edge (Ministry of the Environment, 2006). In the most vulnerable parts, in Lofoten – Vesterålen and along the coast, new petroleum activities have been banned, shipping traffic has moved offshore using mandatory routing, and a series of MPAs along the coast were planned to protect cold-water reefs (Ministry of the Environment, 2006; Von Quillfeldt et al., 2009).

3.3.3 The Norwegian Sea management plan

The Norwegian Sea integrated management plan was adopted by the parliament in 2009 and an update will be ready in 2017. A comprehensive revision of the Norwegian Sea plan is planned to be ready in 2025 and account for a 15-year timeframe (Fig. 3.2). The area includes waters west of Spitsbergen in the north, Jan Mayen and the 62°N latitude towards south. The jurisdiction area share border with Greenland, Iceland, Denmark (Faroese Islands) and Great Britain (Ministry of the Environment, 2009). Ten ecologically valuable and vulnerable areas were identified in the Norwegian Sea, in the Møre bank area, Remman kelp forest, Froan and Sula archipelago and coral reef, Halten bank, Sklinna bank, Iverryggen coral reef, coastal zone, Eggakanten edge of the continental shelf (sponge grounds), the Arctic front and the area around Jan Mayen (Ministry of the Environment, 2009; Ottersen and Auran 2007) (Fig. 3.7).

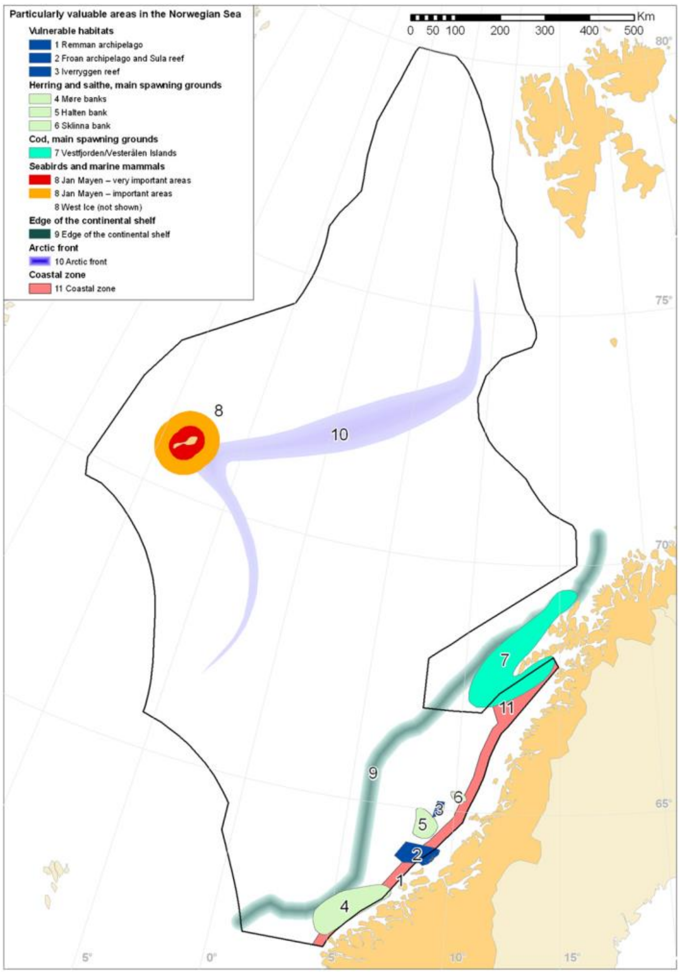

Fig. 3.7: Particular valuable and vulnerable areas identified in the Norwegian management plan (Ottersen et al., 2011).

3.3.4 The North Sea and Skagerrak management plan

The North Sea and Skagerrak integrated management plan was adopted by the parliament in 2013 (Table 3.8). A new version is planned to be ready in 2030 (Fig. 3.2). The area covers both the North Sea and the Skagerrak Sea bordering Sweden, Denmark and Great Britain (Minsitry of the Environment, 2013). In comparison to the Norwegian Sea and the Barents Sea, the North Sea has been heavily exploited and experienced major human impacts for several decades (EEA, 2015). As a result of intense fishing effort, especially bottom trawling, the benthic community has suffered a reduction in diversity (EEA, 2015). The North Sea has experienced cumulative pressures longer, compared to the Barents Sea and the Norwegian Sea and the North Sea and Skagerrak, hence requires a different management approach in close collaboration with the EU (EEA, 2015; Ministry of the Environment, 2013; Knol, 2013). Due to more severe impacts from human activities the management approach must focus on mitigation, recovery and sustainable exploitation (EEA, 2015). There have been no records of sponge communities in the open waters of the North Sea, only located in the coastal waters, and this plan will therefore not be further discussed in this thesis.

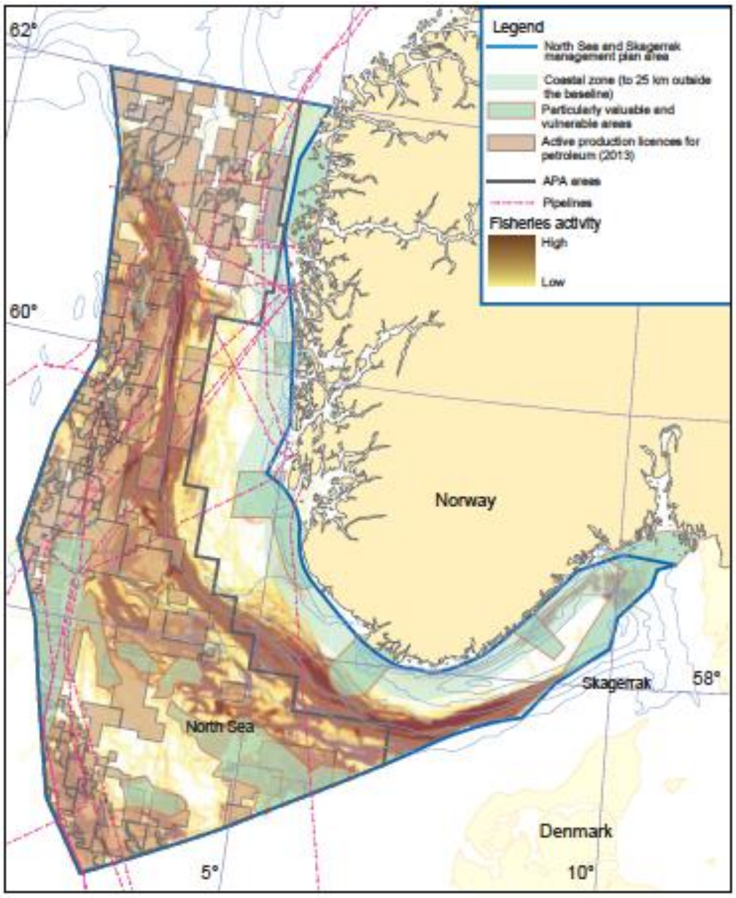

Fig. 3.8: Vulnerable and valuable areas in the North Sea and Skagerrak management plan, including human activities (Minsitry of the Environment, 2013).

3.3.5 Stakeholder conflicts

Beside cumulative impacts on the environment, conflicting interests between stakeholders has been an important driver for the first integrated management plan in the Barents Sea and Lofoten areas (Olsen et al., 2015) (Fig. 3.9).

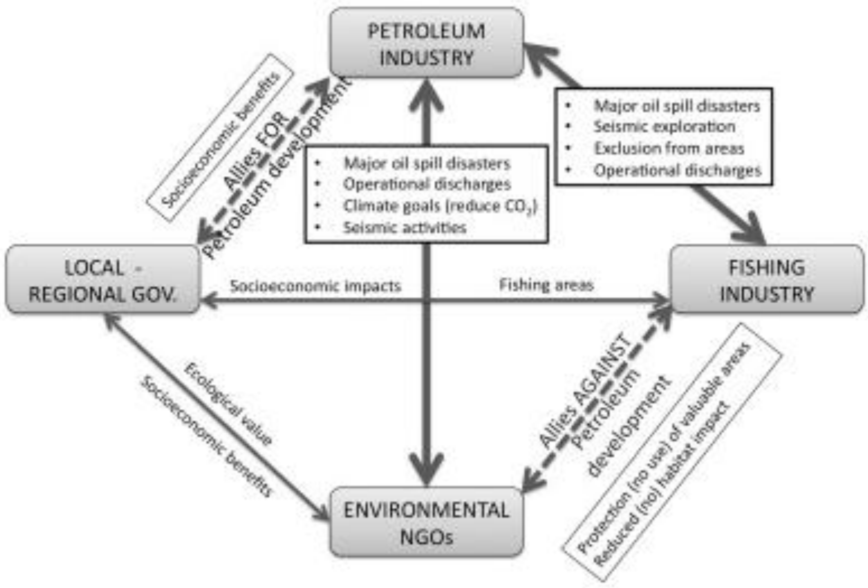

Fig. 3.9: Illustrating conflict at regional/industry/sector level in Norway (Olsen et al., 2016).

Conflicts of interest can be between 1) industries, 2) between industry and conservation, 3) between conservation and local communities (including local governments), 4) between industry and local communities, 5) between NGOs and industries and even 6) between NGOs and local communities. In some controversial cases like e.g. oil exploration in the Lofoten area there will be overlapping conflicts of interests where several stakeholders are involved (Olsen et al., 2015). One example of cross sectoral conflict, is the conflict between petroleum and fisheries because of seismic exploration (noise and space) and establishing of new production sites for oil and gas in the Barents Sea (space) (Olsen et al., 2015). Additionally, conservation may be in conflict with both industries since the consequences of conservation may affect several natural recourses. Regardless of several potential conflicts of interests, Norway has been successful in improving cross-sectoral collaboration. Still, the bottom line is that the industries will always want to increase and maximize their profit and disagreement on acceptable risk and definition of sustainability will also be a source of conflicts in the future.

3.4 National steps towards increased benthic knowledge base

3.4.1 MAREANO – Norwegian database of the seabed

Due to limited benthic knowledge the MAREANO program (Marine Areal Database for Norwegian Coasts and Sea Areas) was initiated as a part of the implementation of the BSMP and developed in 2005 (Buhl-Mortensen et al., 2012). The aim and mandate of the MAREANO program is to map and investigate the seabed and increase the knowledge base of ecosystems, impacts, habitats and biodiversity on the seafloor (Fig. 3.10). MAREANO publishes images, videos, reports and news regularly on their website (www.mareano.no) and provides decision makers with knowledge that can be used in the implementation of the management plans (Buhl-Mortensen et al., 2012). The MAREANO program has mapped the impact from trawling in the vulnerable and valuable areas in Lofoten and Tromsøflaket, same area where dense communities of sponge grounds are located (Jørgensen et al., 2014). Damage to vulnerable sponge grounds has been documented and the limitation of further impacts will be linked to the strengthening of mapping and dissemination of knowledge (Buhl-Mortensen et al., 2012a).

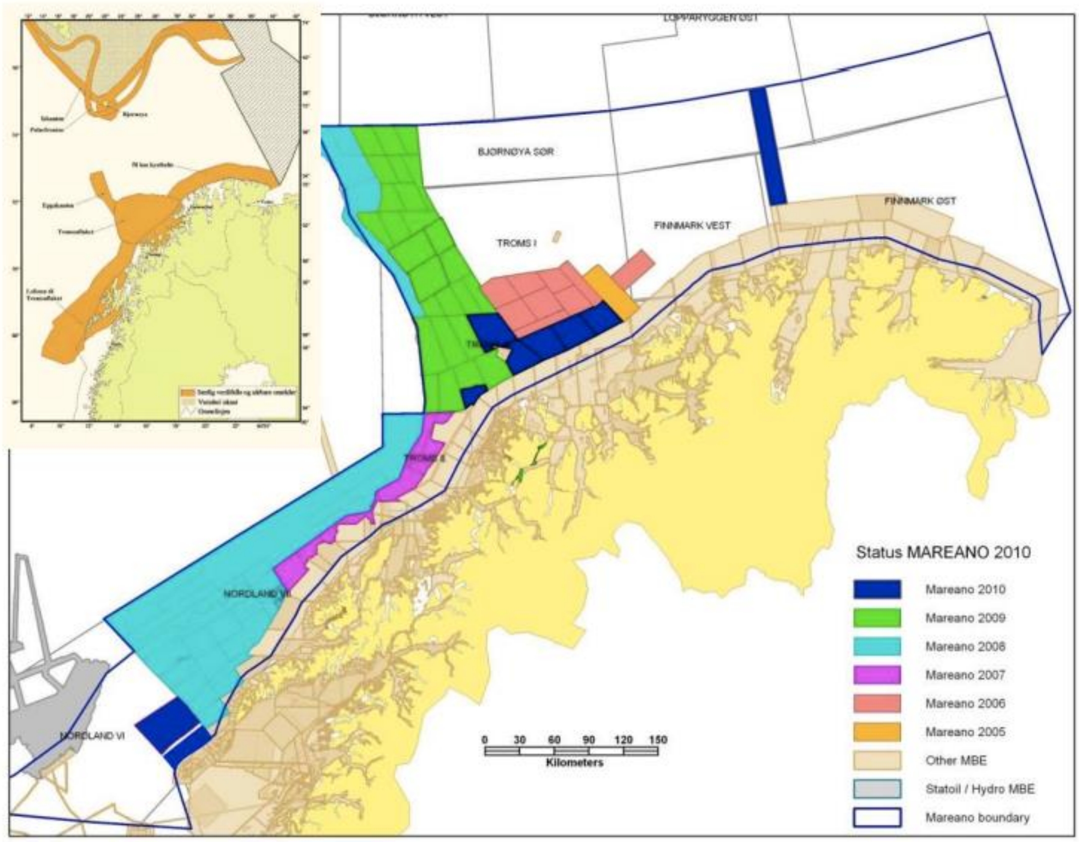

Fig. 3.10: MAREANO mapping areas between 2005-2010. BSMP valuable and vulnerable areas are shown in upper left corner (Buhl-Mortensen et al., 2012).

3.4.2 Joint Norwegian – Russian Barents Sea Ecosystem Survey (BEES)

The joint Norwegian – Russian Barents Sea Ecosystem Survey has been conducted annually since 1954 and is a collaboration between PINRO (Knipovich Polar Institute of Marine Fisheries and Oceanography, Russia) and IMR (Institute of Marine Research, Norway). The ecosystem survey was developed to provide data for annual fish stock assessments and provides long time series of status and changes in the marine environment (Anisimova et al., 2010). In 2003 the first attempts were made to investigate the entire demersal catch and a wide range of megabenthic fauna was analysed, and in 2006 the institutes presented the first overview of benthic fauna caught with scientific survey trawl covering the entire Barents Sea (Rice et al., 2012).

3.4.3 Other research projects

In addition to MAREANO and BEES that address benthic communities as a whole, a number of projects addressing the distribution, biology and ecology of sponges have been developed in recent years in Norway. Two projects on "Taxonomy and distribution of sponges in Norwegian waters (I and II)", coordinated by the University of Bergen (Hans Tore Rapp) were funded by the Norwegian Biodiversity Information Centre (Artsdatabanken). Through these, a thorough taxonomic inventory was conducted and species descriptions and lists with accompanying data on distributions and identification keys, were produced. It further contributed to the development of a high standard sponge collection in Bergen Museum with reference material of all species encountered in the project, and training of a new generation of sponge taxonomists.

The SedExSponge on "Vulnerable habitats and species in petroleum resource management: impact of sediment exposure on sponge grounds" funded by Norwegian Research Council ran between 2013 and 2015. It was coordinated by the Institute of Marine Research (Raymond Bannister) with the collaboration of partners from other Norwegian (UiB) and international universities/institutes. The main goal of this project was to elucidate the effects of increased sediment exposure (due to oil drilling activities) on sponge grounds in Arctic regions.

More recently, a large international project entitled "SponGES - Deep-sea Sponge Grounds Ecosystems of the North Atlantic: an integrated approach towards their preservation and sustainable exploitation" was funded by the European Commission through their Horizon 2020 Blue Growth programme (www.deepseasponges.org). This project that is led by Norway (Hans Tore Rapp, University of Bergen) in collaboration with Canada (Fisheries and Oceans Canada) and USA (Florida Atlantic University), will run from March 2016 until February 2020, and its activities will be performed by a consortium of 19 European, Canadian and American partner institutions. The overarching goals of the project is to fill-in an enormous knowledge gap regarding the diversity, distribution, connectivity, functioning, and biotechnological potential of these ecosystems; and to develop tools for their improved management from regional to international levels across the North Atlantic. Of the seven case study areas to be investigated in the course of the project, two (Schultz massif and Western Barent Sea) are located in Norwegian waters.

3.5 Integration of sponge grounds in Norwegian marine management

Sponge grounds are identified as an system most likely functioning as a key ecosystem and vulnerable to bottom trawling, but due to lack of knowledge not monitored on a yearly basis, however, the advisory groups are suggesting operative monitoring program to monitor effects from bottom trawling (Ministry of the Environment, 2006; 2009; Buhl-Mortensen et al., 2012; von H. Quilfeldt, 2010; Risk Forum, 2009; Management Forum, 2005; Gullestad, 2004; Føyn et al., 2002). Based on knowledge from mapping of the seafloor and reports conducted prior to the plans vulnerable areas with dense communities of sponge grounds have been identified in the northern integrated management plans, covering the Tromsøflaket area, the Norwegian continental shelf and the Lofoten area (Ministry of the Environment, 2006, and 2009).

In addition, Environmental Impact Assessments (EIAs) from the fisheries and the petroleum industry has identified sponge grounds significance for the local fauna, however, in need of increased knowledge base of species distribution, biomass, functioning and categorized as extremely valuable and vulnerable to bottom trawling (Olsen, 2003). Damages to sponge grounds caused by bottom trawling are confirmed from mapping of the ocean floor, e.g. at the Tromsøflaket bank, and sponges are often found in trawling paths, covered in sediments (Buhl-Mortensen et al., 2013) (Chapter 1, Fig. 1.5). Further, impacts scenarios from oil spill scenarios towards sponges were identified as vulnerable, but to a much lower extent (Oil and Energy, 2003). More data of damage to sponge grounds, from e.g. MAREANO, suggests that the impact from trawling may be higher than first suggested in 2005 (von Quillfeldt, 2010). Therefore, limitation of further impacts will be of importance and linked to continuous mapping effort and dissemination of acquired knowledge (Buhl-Mortensen et al., 2012a).

BSMP (2002-2006) emphasised that within 2010:

"*negative impacts on such species as a result of activities in the Barents Sea-Lofoten area are to be reduced as much as possible*".

"*populations of endangered and vulnerable species and species for which Norway has a special responsibility are to be maintained or restored to viable levels as soon as possible*".

And more specific towards identified sponge grounds in the Barents Sea:

1. *Survey the Tromsøflaket bank area in order to identify sponge communities*

2. *Compare the sponge communities on Tromsøflaket with similar communities elsewhere with a view to possible protection*

3. *Further develop gear that is towed along the seabed in order to reduce bycatches and destruction of the benthic fauna*

Two main objectives were then established, however, with large uncertainties if the objectives were met in the Tromsøflaket area (Table 3.4). Mainly due to limited knowledge of impacts from bottom trawling activity and direct effects on the biodiversity. The monitoring group therefore suggested increased knowledge base of ecological functions and evaluation of consequences from trawling. The second objective was not achieved and the large sponge communities have suffered significant damage and it was therefore suggested monitoring in the objective area with precautionary actions (von H. Quilfeldt, 2010).

Table 3.4: The BSMP evaluated objectives towards management of sponge grounds in the valuable and vulnerable areas after the first update. Sponges are included in correlation with OSPAR threatened species list (modified from von H. Quilfeldt, 2010).

Objectives evaluated	Where	Achieved objectives	Evaluation	Management Forum evaluation
"Activities in particularly valuable and vulnerable areas will be conducted in such a way that the ecological functioning and biodiversity of such areas are not threatened".	Tromsøflaket	Uncertain (high)	Significant damage to sponge grounds. Sponge grounds are damaged as a consequence from trawling, but its impacts on local fauna and/or biodiversity is unknown.	Increased knowledge base of damage towards sponge communities is needed. Necessary to evaluate the consequences of damage of sponges, but also ecological functions and biodiversity.
"Damage to marine habitats that are considered to be threatened or vulnerable will be avoided".	Larger communities of sponges in deep water	No	Significant damage to sponge grounds due to bottom trawling. No action directly towards their preservation for limitation of impacts from bottom trawling.	Precautionary actions. Evaluate trawling activity where dense communities of sponges occur. Develop new fishing gear/methods. Suggest monitoring of biomass loss from human activities (e.g. fishing).

Also in the valuable and vulnerable areas identified in the management plan for the Norwegian Sea the government stated that: *"Damage to marine habitats that are considered to be threatened or vulnerable will be avoided".* However, the management forum is uncertain if that has been achieved due to limited monitoring of sponge grounds in the Norwegian Sea. Nonetheless, some systematic monitoring of benthic fauna exists (Video/ROV) from the petroleum industry, but only within a local scale near the platforms (Forum, 2005). Increased knowledge of distribution of sponges has been established through MAREANO mapping also in the Norwegian Sea, however, not covering the entire region and large areas remains unmapped.

The management plans have set ambitious goals and calls for precaution, sustainability and monitoring of the marine environment. Few actions have been made besides mapping. Among those few are *Nature Index* developed by the Norwegian Environment Agency and a developed *monitoring system* functioning in all three management plans. Additionally, several coral reefs MPAs have been established, and indirectly protecting sponge grounds as they are located in the same area such as Traenadjupet (Kutti et al., 2013).

The Nature Index was developed to document trends of major ecosystems and the species they support and additionally provide an idea of where action is needed to halt loss of biodiversity and expected values for indicators by 2010, later adjusted to 2020 as goals were not met (Ministry of the Environment, 2015). A number of indicators were chosen to represent the state of biodiversity where a reference value has been estimated for each indicator (e.g. *Geodia spp*., only sponge species within the Nature Index list) and reflects the ecological sustainable value (Fossheim, 2010).

Applying the principles of an EA requires operational tools and in 1992 OSPAR developed an ecological quality (EcoQ) framework together with input from ICES (Misund and Skjoldal, 2005). Ecological Quality Objectives (EcoQOs) have been developed to link a policy for taking action to indicators that are obtained from monitoring and can provide whether an objective has been met or progress is being made according to objectives (Heslenfeld and Enserink, 2008). Norway has adopted to the exercise of indicators, proposed by the Norwegian Polar Institute (NPI) and Norwegian Marine Research (IMR). It is an adaptive monitoring framework that adapts and evolves in response to new information, research and management questions (Knol, 2013) and has been applied to all management plans (Table 3.5) (Ministry of the Environment, 2006; Heslenfeld and Enserink, 2008; Knol, 2013). The monitoring system works as a tool for managing activity in the area and as described in the BSMP: "*as well as maintaining long time series, the monitoring system for marine ecosystems must* *also be dynamic and flexible enough to be changed and updated in the light of new knowledge".*

Table 3.5: Elements of the monitoring system of the marine environment. Modified from (Environment, 2006).

Ecological quality The ecological quality of an ecosystem is an expression of the state of the state of the system, taking into account the physical, biological and chemical conditions, including the effects of anthropogenic pressures.
Indicators An indicator is a variable that in the present context provides specific information about a particular part of the ecosystem. Indicators will be used to assess how far the management goals have been reached and whether trends in the ecosystem are favourable.
Reference values Reference values correspond to the ecological quality expected in a similar but more or less undisturbed ecosystem, adjusted for natural variation and development trends. Precautionary reference values are used for harvestable stocks.
Action threshold The action threshold is the point at which a change in an indicator in relation to the reference value is so great that new measures must be considered.

Sponges were suggested as an indicator in the development process by the monitoring group in 2005, but not included in the first BSMP, however, later included after the first update in 2011 (Ministry of the Environment, 2011; Quillfeldt and Dommasnes, 2009). In total there are 28 indicators created, however, 9 are under development, including sponges, and hence no direct monitoring of sponge grounds has been taking place (Quillfeldt and Dommasnes, 2009; Ministry of the Environment, 2006; Sunnanå, 2009; Fossheim 2010). Additionally, indicators monitoring human activities are lacking (e.g. direct impacts from bottom trawling) and the monitoring group is engaging such development, especially in the valuable and vulnerable areas (Fossheim, 2010).

The Convention on Biological Diversity inspired the development of the Norwegian *Nature Diversity Act* (Appendix 1, Table 1) that entered into force in 2009 and provides guidelines for management of the marine environment together with individual sector legislation to determine framework for activities and protection of the marine environment (Ministry of the Environment, 2006). However, it is the *Marine Resource Act* (Appendix 1, Table 2) that is the most important environmental law when making guidelines for management of marine resources as the implementation of both integrated management governance and sustainable use of marine ecosystems are relevant (Ministry of the Environment, 2011) According to the *Marine Resource Act*, the Norwegian fisheries authorities have adapted regulations for protection of cold-water corals from commercial fisheries and it is prohibited to damage known coral reefs and precaution is required when fishing in areas where reefs are present (von H. Quilfeldt, 2010). However, no sponge grounds have been banned from bottom trawling in Norway (Rice et al., 2012). However, according to the *Marine Resource Act* adopted the “move on rule” and a new regulation entered into force in September 2011 covering the Norwegian economic zone, fishery zone around Jan Mayen and the protected area around Svalbard. The regulation was later updated in 2016 where a new catch threshold limited was applied (Table 3.6). In addition, the regulation applied banning of new fishing grounds to areas deeper than 1000m, where only vessels with special permission is allowed, and protected deep ocean closed for regular bottom trawling in Norway covers approximately 1 118 000 km2 and 800 000km2 of deep ocean (Rice et al., 2012).

Table 3.6: Encounter protocols that apply to deep-sea sponge grounds and corals in Norway according to the *Marine Resource Act*.

Norwegian Fishing Act on the protection of vulnerable benthic habitats from commercial bottom fisheries operating in areas lower than 1000m.
Same act in 2011, section 2 part d) *When encountering with vulnerable benthic fauna, the allowed catches of corals and sponges are limited to 60kg of corals and/or* ***800kg*** *of sponges per catch (trawl, line - or yarn setting) before a vessel must move to a new area at least 2 nautical miles away.* As of 9 March 2016, when encountering with vulnerable benthic fauna in section 2 part d) *30kg of corals and/or* ***400kg*** *of sponges per catch before requested to move 2 nautical miles away and report back to the authorities.*

As a result from the act a significant decrease of bottom trawls and hours of trawling conducted has been observed (Table 3.7). The Barents Sea is a shallow water basin and the act is not directly affective towards vulnerable sponge grounds in the area (e.g. Tromsøflakte, Eggakanten and the Norwegian continental shelf). However, the water basin of the Norwegian Sea contains areas of deep waters and with the expected move of fishing fleets towards the arctic and deeper areas the act will apply to the protection of deep-sea sponge grounds. Nevertheless, the fleets are not banned from the area but required to move to a new area, potentially harming several untouched areas when permitted to expand their fishing grounds.

Table 3.7: Reduction of Fishing fleets and conducted trawls in 2006, 2009 and 2012 in the Norwegian Sea as a result from the Fishing Act, protecting vulnerable benthic habitats (Agency, 2014).

Norwegian fishing fleets	**2006**	**2009**	**2012**
Number of bottom trawls > 24 m	93	60	57
Hours of trawling conducted	44041	42720	24914

4 Discussion

Through international and national research, sponge grounds have been identified as deep-sea vulnerable marine ecosystems that serve as habitat for numerous species, and play major roles in the nutrient cycling and benthic-pelagic coupling, therefore enhancing biodiversity (e.g. Kutti et al., 2013; Beazley et al., 2015; Jørgensen et al., 2013; Klitgaard and Tendal, 2004; Wassmann et al., 2006; Murillo et al., 2012; Kenchington et a., 2013; Maldonado et al., 2016).

Improved management action requires scientific knowledge of the respective ecosystem and as stated under the *Nature Diversity Act* (section 8) that official decision affecting the biological diversity shall be based on scientific knowledge. However, limited knowledge of sponge grounds functioning for the marine biodiversity and effects from the fisheries makes promoting the conservation rather difficult to implement. Thus, under section 9, the precautionary principle should be applied when lacking appropriate knowledge of an ecosystem. Limited knowledge shall not be used as a reason for postponing or not introducing management measures for deep-sea sponge grounds.

The Norwegian marine management plans have set ambitious goals and call for precaution, sustainability and monitoring of the marine environment. When managing marine resources, Norway has adopted an ecosystem approach. However, the limited knowledge of the distribution, function and dynamics of deep-sea ecosystems as well as the impacts from human activities over such ecosystems, has been hampering full implementation of such approach. Some recommendations are given below as to how current shortcomings could be surpassed to better integrate deep-sea sponge grounds into management and conservation policies at the national level.

1. **Strengthen the knowledge base on sponge grounds**

In recent years considerable advances have been made in terms of mapping the distributions of sponge species and habitats in Norwegian waters (e.g.

MAREANO, Artsdatabanken projects). However, this still only account for a rather small portion of the more coastal and vulnerable shelf areas (e.g. the Tromsøflaket and the Lofoten Area). A lot still needs to be done in terms of the deeper areas and in the Arctic grounds where different activities play a role. However, a closer collaboration between sectors and initiatives, promoting the sharing and integration of currently available data could potentially advance this mapping process and serve as a baseline for future monitoring efforts. For instance, the IMR-PINOR joint surveys have data dating back to 2003 on distribution of benthic taxa in the Western Barents Sea. Furthermore, species distribution data produced in the course of Artsdatabanken projects and mapping made by MAREANO could be integrated, alongside with data on diversity and abundance of sponges produced in the course of EIAs conducted by the petroleum industry.

But the largest gap in our current understanding of sponge grounds is how such ecosystems function and which goods and services are they providing to national waters and us society? Also, how are they impacted by the various human activities and what is their dynamics through time and space? In addition, important knowledge regarding the genetic diversity, structure and connectivity at various spatial scales, is still lacking. An integrated cross disciplinary study addressing such issues is clearly needed to assess the relevance, vulnerability and potential of these ecosystems.

1. **Develop monitoring and identification tools**

Long-term monitoring provides ecological information that is needed to gain insight into changes of ecosystem structure, ecological processes and services (Thrush et al., 2015). No direct long-term monitoring of deep-sea sponge grounds in Norway exists at present and this would be crucial to identify shifts and to predict and avoid significant adverse impacts in these benthic communities (Jørgensen et al., 2015).

And as identified by Knol (2013) "*EBM can only be made operational through a monitoring system if changes in indicators results lead to response at the level of governance".*

Further, sponges described on the Nature Index list for long-term monitoring are in many case based on inadequate data and do not provide an accurate picture of species trends (Fossheim, 2010). New and improved monitoring programs have been suggested to provide better data for the Nature Index and suggested to be further integrated in the management plans (van der Meeren et al., 2010).

The joint effort between Norway and Russia are at present the only research effort currently surveying, through time, sponge grounds in the Barents Sea (Jørgensen et al., 2014). And as identified through the western Barents Sea case study, large amounts of total catch is not identified down to species level which hampers the identification of trends in species composition and abundance (Chapter 1, Table 1.3). A species compendium has been developed for the BEES but it could be further modified and improved to assist the identification and to get more accurate analyses of the benthic catch. Through discussions with Lis Lindal Jørgensen, it seems that the identification skills have improved over time and have been beneficial for BEES efforts towards an integrated ecosystem approach and potential long-term monitoring of sponge grounds (Jørgensen et al., 2015). However, supporting such approach economically has been a challenge as the survey design is a compromise between available economic resources and sufficient data quality required for assessments, while maintaining a long-term monitoring (Michalsen et al., 2013).

2. **Minimize trawling impacts**

In Norway, when fishing fleets are given the permission to trawl in new areas they must provide a detailed protocol including for collection of by-catch data, plan for avoiding vulnerable marine ecosystems and a plan for logging data of vulnerable benthic ecosystems. Here, species and habitats distribution models and suitability maps could greatly assist in avoiding areas where sponge grounds are likely to occur. These models and maps would be iterative and dynamic as new data is produced and reported. Further, the logging of sponges as by-catch could be better implemented and used as a tool for mapping of sponge grounds and quantifying fishing pressure in Norwegian waters. Induced to both new and existing fishing grounds as fishing fleets are required to report back to the authorities (Fisheries Directorates) when encountering vulnerable benthic communities. It would be important to evaluate whether VME encounters are being reported to the competent authorities. This doesn't seem to be the case in NEAFC and NAFO RAs.

Recent research on the reduction of impacts from bottom trawling has been exploring the possibility of using pelagic trawls when targeting demersal fish to reduce impact on the seabed (von H. Quilfeldt, 2010; Stiansen et al., 2009). Additionally, non-destructive data collection techniques such as remotely operated and autonomous underwater vehicles (ROVs and AUVs) could be used for monitoring purposes to reduce further impact on the benthic fauna.

Evaluate new areas for establishment of sponge MPAs

For the last 10-15 years the damage towards corals have been acknowledged with improved governance and conservation actions (Rice et al., 2012). Meanwhile, sponge systems have been damaged during the same time period, and not until recently has there been direct action towards their preservation in the deep sea, such as the fishing regulation act. As already identified by Jørgensen et al., (2015), sponge community degradation from trawling provides significant reason for conservation in accordance with the Biodiversity Convention. Additionally, understating the trades-offs associated with spatial closures can help the cooperation between the fisheries and conservation objectives. This may lead to conservation outcomes preserving the benthic communities, and potentially provide spillover effects to the fisheries (Rice et al., 2012). With the expected move of fisheries further north, the evaluation of MPAs would be highly beneficial towards their preservation.

3. Raise awareness and engage stakeholders

Through dialogues and analysis with explicit trade-offs, across stakeholders, policy advisers and managers, an EA can indicate new possibilities in marine ecosystems and improve the understanding of ecosystem potentials (e.g. support blue growth, identify key ecosystems, environmental drivers) (ICES, 2016).

Potential scenarios – visualizing sponges importance

One possibility is cascade scenarios through the ecosystem and in combination with the complexity of impacts, potentially generates further changes that may exceed sponge grounds carrying capacity. Imagine a scenario where additional 30 percentages of the sponge grounds in the Barents Sea were removed:

1. What impacts will that have on the sponge systems and what cascade effects will that lead into?
2. Will it affect the nutrient cycle and primary production?
3. If a potential sink of carbon, do the opposite and release carbon?
4. Make the ocean even more acid and alter water properties?
5. And if so, at what scale and grade will it affect the marine biodiversity and marine recourses?
6. Will healthy commercial fish stocks be affected?
7. Lead to significant loss in the fisheries?
8. Economically and ecologically consequences?

4. Advance the science-management-policy interface

The Norwegian Government has limited the three advisory groups to report back to the steering group without giving advice on management actions. Buhl-Mortensen and co-workers (2012.), suggest a clearer mandate from the government, providing the advisory groups to identify relevant management actions towards sustainability of ecosystems. When identified, made a priority issues in the relevant departments to develop accurate action plans. Science should assist in the development of monitoring and management actions by addressing issues and providing management actions, regardless of the political orientation of the plan (Buhl-Mortensen et al., 2012).

5. Communication and dissemination

Lack of scientific knowledge and transparency are challenging and suggestion of open access of science to create a direct connection to media and the public are believed to increase engagement of the public and stakeholders (ICES, 2016). As a suggestion to the solution: ecological, economic and social values that could be beneficial from the system must be addressed, identified and made obvious. Further, the use of common language and communication are challenging and policymakers need clear goals written in a short and clear context making it understandable for all, regardless of the field of expertise (ICES, 2016). Brochures, videos and infographics can be created to spread the message. The government acts upon laws, regulations and policies and have the power to impose their actions and decision making. Whereas, the civil society through other acts have the power to influence and shape governmental decisions through a participatory process voicing ideas and values they find of greatest priority.

Conclusion

To conclude, by improving ecosystem assessments, creating relationships cross-sectors and obtaining a deeper understanding of deep-sea ecosystems, including level of impacts from human activities, sustainability of sponge grounds in Norwegian waters are achievable. Further, EBM evaluates state and trends of an ecosystem (long-term perspective) and/or ecological quality that can be measured and managed sustainably with an adaptive approach that is based on increased knowledge. The main focus should be developing a shared vision between different partners, sectors and institutions. EBM strengthens with successful participations of stakeholders along with an open and transparent process and improved by creating methods for integrated trade-off analyses of management options across sectors. Ecological and environmental knowledge is always in flux and with the already increased knowledge base, sponges ecological value and existing monitoring programs, only a question of acting upon the evidence. It is clear that scientific knowledge must be further developed, communicated and translated into policies so that the deep-sea sponge grounds would be fully integrated into management actions and protected in national waters.

References

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ANISIMOVA, N. A., JØRGENSEN, L. L., LYUBIN, P. A. & MANUSHIN, I. E. 2010. Mapping and monitoring of benthos in the Barents Sea and Svalbard waters: results from the joint Russian-Norwegian benthic programme 2006–2008. *IMR-PINRO Joint Report Series*, 1-2010.

ARMSTRONG, C. W., FOLEY, N. S., TINCH, R. & VAN DEN HOVE, S. 2012. Services from the deep: Steps towards valuation of deep sea goods and services. *Ecosystem Services,* 2**,** 2-13.

ASSESSMENT, M. E. 2005. *Ecosystems and human well-being: Biodiversity Synthesis; a report of the Millennium Ecosystem Assessment*, World Resources Institute.

BARTHEL, D., TENDAL, O. S. & THIEL, H. 1996. A Wandering Population of the HexactinelIid Sponge Pheronema carpenteri on the Continental Slope off Morocco, Northwest Africa. *Marine Ecology,* 17**,** 603-616.

BEAZLEY, L., KENCHINGTON, E., YASHAYAEV, I. & MURILLO, F. J. 2015. Drivers of epibenthic megafaunal composition in the sponge grounds of the Sackville Spur, northwest Atlantic. *Deep Sea Research Part I: Oceanographic Research Papers,* 98**,** 102-114.

BEAZLEY, L. I., KENCHINGTON, E. L., MURILLO, F. J. & DEL MAR SACAU, M. 2013. Deep-sea sponge grounds enhance diversity and abundance of epibenthic megafauna in the Northwest Atlantic. *ICES Journal of Marine Science: Journal du Conseil,* 70**,** 1471-1490.

BELL, J. J., DAVY, S. K., JONES, T., TAYLOR, M. W. & WEBSTER, N. S. 2013. Could some coral reefs become sponge reefs as our climate changes? *Global change biology,* 19**,** 2613-2624.

BUHL-MORTENSEN, L., AGLEN, A., BREEN, M., BUHL-MORTENSEN, P., ERVIK, A., HUSA, V., LØKKEBORG, S., RØTTINGEN, I. & STOCKHAUSEN, H. H. 2013. Impacts of fisheries and aquaculture on sediments and benthic fauna: suggestions for new management approaches. *Fisken og Havet,* 3**,** 69.

BUHL-MORTENSEN, L., BUHL-MORTENSEN, P., DOLAN, M. F. J., DANNHEIM, J., BELLEC, V. & HOLTE, B. 2012a. Habitat complexity and bottom fauna composition at different scales on the continental shelf and slope of northern Norway. *Hydrobiologia,* 685**,** 191-219.

BUHL-MORTENSEN, L., BUHL-MORTENSEN, P., DOLAN, M. F. J. & HOLTE, B. 2015. The MAREANO programme–a full coverage mapping of the Norwegian off-shore benthic environment and fauna. *Marine Biology Research,* 11**,** 4-17.

BUHL-MORTENSEN, L., BØE, R., DOLAN, M. F. J., BUHL-MORTENSEN, P., THORSNES, T., ELVENES, S. & HODNESDAL, H. 2012b. Banks, troughs and canyons on the continental margin off Lofoten, Vesterålen, and Troms, Norway. *Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of Seafloor Geomorphic Features and Benthic Habitats. Elsevier Insights, London. http://dx. doi. org/10.1016/B978-0-12-385140-6.00051-7*.

BUHL-MORTENSEN, L., ELLINGSEN, K. E., BUHL-MORTENSEN, P., SKAAR, K. L. & GONZALEZ-MIRELIS, G. 2016. Trawling disturbance on megabenthos and sediment in the Barents Sea: chronic effects on density, diversity, and composition. *ICES Journal of Marine Science: Journal du Conseil,* 73, i98-i114.

BUHL-MORTENSEN, L., OLSEN, E., RØTTINGEN, I., BUHL-MORTENSEN, P., HOEL, A. H., LID RINGHEIM, S., GRØSVIK, B. E., NYGAARD HOLEN, S., GONZALEZ-MIRELIS, G. & SKULSTAD, E. M. 2012c. Application of the MESMA Framework. *Case Study: The Barents Sea. MESMA report*.

CARDENAS, P., RAPP, H. T., KLITGAARD, A. B., BEST, M., THOLLESSON, M. & TENDAL, O. S. 2013. Taxonomy, biogeography and DNA barcodes of Geodia species (Porifera, Demospongiae, Tetractinellida) in the Atlantic boreo-arctic region. *Zoological Journal of the Linnean Society,* 169, 251-311.

CLARK, M. R., ALTHAUS, F., SCHLACHER, T. A., WILLIAMS, A., BOWDEN, D. A. & ROWDEN, A. A. 2016. The impacts of deep-sea fisheries on benthic communities: a review. *ICES Journal of Marine Science: Journal du Conseil,* 73, i51-i69.

COMMISSION, O. 2008. Case Reports for the OSPAR LIst of threatened and/or declining species and habiats. .

COMMISSION, O. 2010a. Background document for deep-sea sponge aggregations. *OSPAR Biodiversity and Ecosystems Series*, 47.

COMMISSION, O. 2010b. OSPAR Recommendation 2010/10 on furthering the protection and restoration of deep-sea sponge aggregations in the OSPAR Maritime Area. . *OSPAR 10/23/1-E, Annex 32.*

COOPERATION, G. S. O. A. O. 2013. Launcing a European Union – Canada – United States of America Research Alliance. *Marine Institute, Galway, Ireland.* .

CORDES, E. E., JONES, D. O., SCHLACHER, T. A., AMON, D. J., BERNARDINO, A. F., BROOKE, S., CARNEY, R., DELEO, D. M., DUNLOP, K. M. & ESCOBAR-BRIONES, E. G. 2016. Environmental impacts of the deep-water oil and gas industry: a review to guide management strategies. *Frontiers in Environmental Science*.

DEGEN, R., JØRGENSEN, L. L., LJUBIN, P., ELLINGSEN, I. H., PEHLKE, H. & BREY, T. 2016. Patterns and drivers of megabenthic secondary production on the Barents Sea shelf. *Marine Ecology Progress Series,* 546, 1-16.

EAYRS, S., SNEDAKER, S. C. & GETTER, C. D. 2009. International guidelines for the management of deep-sea fisheries in the high seas. Directives internationales sur la gestion de la peche profonde en haute mer. Directrices internacionales para la ordenación de las pesquerías de aguas profundas en alta mar. FAO, Roma (Italia).

EEA 2015. State of Europe's seas *EEA Report No 2/2015.*

European Environment Agency, Copenhagen, Denmark.

EHLER, C. N. & DOUVERE, F. 2010. An international perspective on marine spatial planning initiatives. *Environments,* 37, 9.

ENERGY, M. O. O. A. 2003. Utredning av konsekvenser av helårig petroleumsvorksomhet I området Lofoten – Barentshavet Sammendragsrapport.

ENVIRONMENT, M. O. T. 2002. St. meld. nr. 12 (2001-2002) Rent og Rikt Hav, Ministry of Environment, Oslo. .

ENVIRONMENT, M. O. T. 2006. St.meld.nr. 8 (2005-2006) Helhetlig forvaltning av det marine miljø i Barentshavet og havområdene utenfor Lofoten (Barents Sea management plan), Minstry of environment, Oslo. .

ENVIRONMENT, M. O. T. 2009. Report No. 37 to the Storting (2008–2009). Helhetlig forvaltning av det marine miljø i Norskehavet (forvaltningsplan)

ENVIRONMENT, M. O. T. 2011. Meld. St.10 Oppdatering av forvaltningsplanen for det marine miljø i Barentshavet og havområdene utenfor Lofoten (Revised Barents Sea management plan). Ministry of envirionment, Oslo.

ENVIRONMENT, M. O. T. 2013. Report No. 37 (2012-2013) Integrated Management of the Marine Environment of the North Sea and Skagerrak (Management Plan) Report to the Storting (white paper), Ministry of the Environment.

ENVIRONMENT, M. O. T. 2015. Report No. 20 to the Storting (2014–2015). Oppdatering av forvaltningsplanen for Barentshavet og havområdene utenfor Lofoten med oppdatert beregning av iskanten.

FANG, J. K. H., MELLO-ATHAYDE, M. A., SCHÖNBERG, C. H. L., KLINE, D. I., HOEGH-GULDBERG, O. & DOVE, S. 2013. Sponge biomass and bioerosion rates increase under ocean warming and acidification. *Global change biology,* 19**,** 3581-3591.

FORUM, MANAGEMENT. 2005 (Faggruppen) Kunnskapsbehov I Barentshavet, En sammenstilling og prioritering av identifiserte overvåkings-, forsknings og kartleggingsbehov I frbindelse med utarbeidelsen av forvaltningsplanen for Barentshavet

FOSSHEIM (Red). 2010. Forvaltningsplan Barentshavet - Indikatorrapport fra Overvåkingsgruppen 2010.

FULLER, S. D. 2011. Diversity of marine sponges in the Northwest Atlantic.

FØYN, L., QUILLFELDT, C. H. V. & OLSEN, E. 2002. Miljø-og ressursbeskrivelse av området Lofoten-Barentshavet.

GIANNI M, F. S., CURRIE DEJ, SCHLEIT K, GOLDSWORTHY L, PIKE B, WEEBER B, OWEN S, FRIEDMAN A 2016. How much longer will it take? A ten-year review of the implementation of United Nations General Assembly resolutions 61/105, 64/72 and 66/68 on the management of bottom fisheries in areas beyond national jurisdiction. . *Deep Sea Conservation Coalition, August 2016.*

GULLESTAD, P., AGLEN, A., BJORDAL, Å., BLOM, G., JOHANSEN, S., KROG, J., MISUND, O. A. & RØTTINGEN, I. 2014. Changing attitudes 1970–2012: evolution of the Norwegian management framework to prevent overfishing and to secure long-term sustainability. *ICES Journal of Marine Science: Journal du Conseil,* 71**,** 173-182.

GULLSTAD, P. 2004. Utredning av konsekvenser av fiskeri i området Lofoten – Barentshavet. *Høringsutkast, Fiskeridirektoratet, Bergen*

HENNIGE, S. J., WICKS, L. C., KAMENOS, N. A., BAKKER, D. C. E., FINDLAY, H. S., DUMOUSSEAUD, C. & ROBERTS, J. M. 2014. Short-term metabolic and growth responses of the cold-water coral Lophelia pertusa to ocean acidification. *Deep Sea Research Part II: Topical Studies in Oceanography,* 99**,** 27-35.

HESLENFELD, P. & ENSERINK, E. L. 2008. OSPAR Ecological Quality Objectives: the utility of health indicators for the North Sea. *ICES Journal of Marine Science: Journal du Conseil,* 65**,** 1392-1397.

HOGG, M. M., TENDAL, O. S., CONWAY, K. W., POMPONI, S. A., SOEST, R. W. M., GUTT, J., KRAUTTER, M. & ROBERTS, J. M. 2010. Deep-sea sponge grounds: Reservoirs of biodiversity.

ICES 2002. Report of the Working Group on Ecosystem Effects of Fisheries. Advisory Committee on Ecosystems. . *ICES CM 2002/ACE:03.*
ICES 2009. Report of the ICES-NAFO Working Group on Deep-Water Ecology(WGDEC), . *ICES CM 2009/ACOM:23 94 pp*.
ICES 2016. AORAC-SA FAO workshop: Making the ecosystem approach operational, 21-22 January. Copenhagen, Denmark
IMR, L. L. J. & ANISIMOVA, N. Biological–Geological Seabed Mapping and Monitoring in the Barents Sea.
JOHANNESEN, E., JØRGENSEN, L. L., FOSSHEIM, M., PRIMICERIO, R., GREENACRE, M., LJUBIN, P. A., DOLGOV, A. V., INGVALDSEN, R. B., ANISIMOVA, N. A. & MANUSHIN, I. E. 2016. Large-scale patterns in community structure of benthos and fish in the Barents Sea. *Polar Biology*, 1-10.
JOHNSEN, J. P. & ELIASEN, S. 2011. Solving complex fisheries management problems: what the EU can learn from the Nordic experiences of reduction of discards. *Marine Policy,* 35**,** 130-139.
JØRGENSEN, L. L., LJUBIN, P., SKJOLDAL, H. R., INGVALDSEN, R. B., ANISIMOVA, N. & MANUSHIN, I. 2014. Distribution of benthic megafauna in the Barents Sea: baseline for an ecosystem approach to management. *ICES Journal of Marine Science: Journal du Conseil***,** fsu106.
JØRGENSEN, L. L., PLANQUE, B., THANGSTAD, T. H. & CERTAIN, G. 2015. Vulnerability of megabenthic species to trawling in the Barents Sea. *ICES Journal of Marine Science: Journal du Conseil***,** fsv107.
KENCHINGTON, E., POWER, D. & KOEN-ALONSO, M. 2013. Associations of demersal fish with sponge grounds on the continental slopes of the northwest Atlantic. *Marine Ecology Progress Series,* 477**,** 217-230.
KLITGAARD, A. B. 1995. The fauna associated with outer shelf and upper slope sponges (Porifera, Demospongiae) at the Faroe Islands, northeastern Atlantic. *Sarsia,* 80**,** 1-22.
KLITGAARD, A. B. & TENDAL, O. S. 2004. Distribution and species composition of mass occurrences of large-sized sponges in the northeast Atlantic. *Progress in Oceanography,* 61**,** 57-98.
Klitgaard, A.B., 1995. The fauna associated with outer shelf and upper slope sponges (Porifera, Demospongiae) at the Faroe Islands, norhteastern Atlantic. Sarsia 80, 1-22.
KNOL, M. 2010. Scientific advice in integrated ocean management: the process towards the Barents Sea plan. *Marine Policy,* 34**,** 252-260.
KNOL, M. 2013. Making ecosystem-based management operational: integrated monitoring in Norway. *Maritime Studies,* 12**,** 1.
KNUDBY, A., KENCHINGTON, E. & MURILLO, F. J. 2013. Modeling the distribution of Geodia sponges and sponge grounds in the Northwest Atlantic. *PloS one,* 8**,** e82306.
KUTTI, T., BANNISTER, R. J. & FOSSÅ, J. H. 2013. Community structure and ecological function of deep-water sponge grounds in the Traenadypet MPA—Northern Norwegian continental shelf. *Continental Shelf Research,* 69**,** 21-30.
KUTTI, T., FOSSÅ, J. H. & BERGSTAD, O. A. 2015. Influence of structurally complex benthic habitats on fish distribution. *Marine Ecology Progress Series,* 520**,** 175-190.

LEAL, M. C., PUGA, J., SERÔDIO, J., GOMES, N. C. M. & CALADO, R. 2012. Trends in the discovery of new marine natural products from invertebrates over the last two decades–where and what are we bioprospecting? *PLoS One,* 7, e30580.
LORENTZEN, T. & HANNESSON, R. 2004. The collapse of the Norwegian herring fisheries in the late 1950s and 60s: crisis, adaptation, and recovery.
MAIER, C., HEGEMAN, J., WEINBAUER, M. G. & GATTUSO, J. P. 2009. Calcification of the cold-water coral Lophelia pertusa, under ambient and reduced pH. *Biogeosciences,* 6, 1671-1680.
MALDONADO, M., AGUILAR, R., BANNISTER, R. J., BELL, D., CONWAY, K. W., DAYTON, P. K., DÍAZ, C., GUTT, J., KENCHINGTON, E. L. R. & LEYS, D. 2016. Sponge grounds as key marine habitats: a synthetic review of types, structure, functional roles, and conservation concerns. *Marine Animal Forests. Springer, Berlin http://dx. doi. org/10.1007/978-3-319-17001-5_24-1 (in press, Major Reference Works Series)*.
MCBRIDE, M. M., HANSEN, J. R., KORNEEV, O., TITOV, O., STIANSEN, J. E., TCHERNOVA, J., FILIN, A. & OVSYANNIKOV, A. 2016. Joint Norwegian-Russian environmental status 2013.
MICHALSEN, K., DALPADADO, P., ERIKSEN, E., GJØSÆTER, H., INGVALDSEN, R. B., JOHANNESEN, E., JØRGENSEN, L. L., KNUTSEN, T., PROZORKEVICH, D. & SKERN-MAURITZEN, M. 2013. Marine living resources of the Barents Sea–Ecosystem understanding and monitoring in a climate change perspective. *Marine Biology Research,* 9, 932-947.
MISUND, O. 2006. Ecosystem-based management: Definition and international principles. *Bergen, Norway: Institute of Marine Research*.
MISUND, O. A. & SKJOLDAL, H. R. 2005. Implementing the ecosystem approach: experiences from the North Sea, ICES, and the Institute of Marine Research, Norway. *Marine ecology-progress series-,* 300, 260.
MONITORING GROUP 2014. Faglig grunnlag for oppdateringen av forvaltningsplanen for Norskehavet. Rapport fra Faglig forum, Overvåkingsgruppen og Risikogruppen til den interdepartementale styringsgruppen for forvaltningsplanene. . *Rapport, M140-2014*
MUÑOZ, P. D., MURILLO, F. J., SAYAGO-GIL, M., SERRANO, A., LAPORTA, M., OTERO, I. & GÓMEZ, C. 2011. Effects of deep-sea bottom longlining on the Hatton Bank fish communities and benthic ecosystem, north-east Atlantic. *Journal of the Marine Biological Association of the United Kingdom,* 91, 939-952.
MUNRO, M. H. G., BLUNT, J. W., LAKE, R. J., LITAUDON, M., BATTERSHILL, C. N. & PAGE, M. J. 1994. From seabed to sickbed: what are the prospects. *Sponges in time and space*, 473-484.
MURILLO, F. J., KENCHINGTON, E., LAWSON, J. M., LI, G. & PIPER, D. J. W. 2016. Ancient deep-sea sponge grounds on the Flemish Cap and Grand Bank, northwest Atlantic. *Marine biology,* 163, 1-11.
MURILLO, F. J., MUÑOZ, P. D., CRISTOBO, J., RÍOS, P., GONZÁLEZ, C., KENCHINGTON, E. & SERRANO, A. 2012. Deep-sea sponge grounds of the Flemish Cap, Flemish Pass and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): distribution and species composition. *Marine Biology Research,* 8, 842-854.

OLSEN, C. H. V. Q. A. E. 2003. Kunnskapsbehov for området Lofoten – Barentshavet, Supplement til miljø- og ressursbeskrivelsen for Lofoten – Barentshavet. .

OLSEN, E. Identifying particularly valuable and vulnerable areas: a key tool for the integrated management plans for the Barents Sea and Norwegian Sea. 2008. ICES.

OLSEN, E., FAY, G., GAICHAS, S., GAMBLE, R., LUCEY, S. & LINK, J. S. 2016. Ecosystem Model Skill Assessment. Yes We Can! *PloS one,* 11**,** e0146467.

OLSEN, E., FLUHARTY, D., HOEL, A. H., HOSTENS, K., MAES, F. & PECCEU, E. 2014. Integration at the round table: marine spatial planning in multi-stakeholder settings. *PloS one,* 9**,** e109964.

OLSEN, E., GJØSÆTER, H., RØTTINGEN, I., DOMMASNES, A., FOSSUM, P. & SANDBERG, P. 2007. The Norwegian ecosystem-based management plan for the Barents Sea. *ICES Journal of Marine Science: Journal du Conseil,* 64**,** 599-602.

OLSEN, E., HOLEN, S., HOEL, A. H., BUHL-MORTENSEN, L. & RØTTINGEN, I. 2015. How Integrated Ocean governance in the Barents Sea was created by a drive for increased oil production. *Marine Policy*.

OLSEN, E., KLEIVEN, A. R., SKJOLDAL, H. R. & VON QUILLFELDT, C. H. 2011a. Place-based management at different spatial scales. *Journal of coastal conservation,* 15**,** 257-269.

OLSEN, S. B., OLSEN, E. & SCHAEFER, N. 2011b. Governance baselines as a basis for adaptive marine spatial planning. *Journal of Coastal Conservation,* 15**,** 313-322.

OTTERSEN, G., OLSEN, E., VAN DER MEEREN, G. I., DOMMASNES, A. & LOENG, H. 2011. The Norwegian plan for integrated ecosystem-based management of the marine environment in the Norwegian Sea. *Marine Policy,* 35**,** 389-398.

PHAM, C. K., DIOGO, H., MENEZES, G., PORTEIRO, F., BRAGA-HENRIQUES, A., VANDEPERRE, F. & MORATO, T. 2014. Deep-water longline fishing has reduced impact on Vulnerable Marine Ecosystems. *Scientific reports,* 4.

QUILLFELDT, C. H. & DOMMASNES, A. 2005. Forslag til indikatorer og miljøkvalitetsmål for Barentshavet. *Rapport fra et delprosjekt under forvaltningsplanen for Barentshavet.(Proposals for indicators and environmental quality objectives for the Barents Sea. Report from a sub-project under the management plan for the Barents Sea.)*.

RICE, A. L., THURSTON, M. H. & NEW, A. L. 1990. Dense aggregations of a hexactinellid sponge, Pheronema carpenteri, in the Porcupine Seabight (northeast Atlantic Ocean), and possible causes. *Progress in Oceanography,* 24**,** 179-196.

RICE, J., MOKSNESS, E., ATTWOOD, C., BROWN, S. K., DAHLE, G., GJERDE, K. M., GREFSRUD, E. S., KENCHINGTON, R., KLEIVEN, A. R. & MCCONNEY, P. 2012. The role of MPAs in reconciling fisheries management with conservation of biological diversity. *Ocean & coastal management,* 69**,** 217-230.

SÁNCHEZ, F., SERRANO, A., PARRA, S., BALLESTEROS, M. & CARTES, J. E. 2008. Habitat characteristics as determinant of the structure and spatial distribution of epibenthic and demersal communities of Le Danois Bank (Cantabrian Sea, N. Spain). *Journal of Marine Systems,* 72**,** 64-86.

STIANSEN, J. E., KORNEEV, O., TITOV, O. V., ARNEBERG, P., FILIN, A., HANSEN, J. R., HØINES, Å. S. & MARASAEV, S. 2009. Joint Norwegian-Russian environmental status 2008: report on the Barents Sea Ecosystem, part II-complete report.
SUNNANÅ, K., FOSSHEIM MARIA AND VAN DER MEEREN I. GRO 2009. Forvaltningsplan Barentshavet - rapport fra overvåkingsgruppen. *Fisken og Havet*.
THOMS, C. & SCHUPP, P. J. 2008. Activated chemical defense in marine sponges—a case study on Aplysinella rhax. *Journal of chemical ecology,* 34**,** 1242-1252.
THRUSH, S. F., ELLINGSEN, K. E. & DAVIS, K. 2015. Implications of fisheries impacts to seabed biodiversity and ecosystem-based management. *ICES Journal of Marine Science: Journal du Conseil***,** fsv114.
THURBER, A. R., SWEETMAN, A. K., NARAYANASWAMY, B. E., JONES, D. O. B., INGELS, J. & HANSMAN, R. L. 2014. Ecosystem function and services provided by the deep sea. *Biogeosciences,* 11**,** 3941-3963.
TJENSVOLL, I., KUTTI, T., FOSSÅ, J. H. & BANNISTER, R. 2013. Rapid respiratory responses of the deep-water sponge Geodia barretti exposed to suspended sediments.
VAN DER MEEREN, G., ØIGÅRD, T. A., ØIEN, N., NILSSEN, K. T., OUG, E., SUNNANÅ, K., JAKOBSEN, T., MEHL, S., KVAMME, C. & TORSTENSEN, E. 2010. Marine indikatorer.
VAN SOEST, R. W. M., BOURY-ESNAULT, N., HOOPER, J. N. A., RÜTZLER, K., DE VOOGD, N. J., ALVAREZ DE GLASBY, B., HAJDU, E., PISERA, A. B., MANCONI, R. & SCHOENBERG, C. 2016. World Porifera Database, 2015.
VAN SOEST, R. W. M., BOURY-ESNAULT, N., VACELET, J., DOHRMANN, M., ERPENBECK, D., DE VOOGD, N. J., SANTODOMINGO, N., VANHOORNE, B., KELLY, M. & HOOPER, J. N. A. 2012. Global diversity of sponges (Porifera). *PLoS one,* 7**,** e35105.
VAN SOEST, R. W. M., VAN DUYL, F. C., MAIER, C., LAVALEYE, M., BEGLINGER, E. J. & TABACHNICK, K. R. 2007. Mass occurrence of Rossella nodastrella Topsent on bathyal coral reefs of Rockall Bank, W of Ireland (Lyssacinosida, Hexactinellida). *Porifera Research: Biodiversity, Innovation and Sustainability. Museu Nacional, Rio de Janeiro***,** 645-652.
VON QUILLFELDT, C., OLSEN, E., DOMMASNES, A. & VONGRAVEN, D. 2009. 20. Integrated ecosystem-based management of the Barents Sea–Lofoten area.
VON QUILLFELDT, C. H. 2010. Det faglige grunnlaget for oppdateringen av forvaltningsplanen for Barentshavet og havområdene utenfor Lofoten: Rapport fra Faglig forum, Overvåkingsgruppen og Risikogruppen til den interdepartementale styringsgruppen for forvaltningsplanen.
WASSMANN, P., REIGSTAD, M., HAUG, T., RUDELS, B., CARROLL, M. L., HOP, H., GABRIELSEN, G. W., FALK-PETERSEN, S., DENISENKO, S. G. & ARASHKEVICH, E. 2006. Food webs and carbon flux in the Barents Sea. *Progress in Oceanography,* 71**,** 232-287.
XAVIER, J. R., TOJEIRA, I. & VAN SOEST, R. W. M. 2015. On a hexactinellid sponge aggregation at the Great Meteor seamount (North-east Atlantic). *Journal of the Marine Biological Association of the United Kingdom,* 95**,** 1389-1394.

Appendix 1

Table 1: The *Nature Diversity Act*

Act of 19 June 2009 No. 100 Relating to the Management of Biological, Geological and Landscape Diversity (*Nature Diversity Act*)
The purpose of the Act is to protect biological, geological and landscape diversity and ecological processes through conservation and sustainable use, and in such a way that the environment provides a basis for human activity, culture, health and well-being, now and in the future, including a basis for Sami culture.
Section 5 Management objectives for species
The objective is to maintain species and their genetic diversity for the long term and to ensure that species occur in viable populations in their natural ranges. To the extent necessary to achieve this objective, areas with specific ecological functions for different species and other ecological conditions on which they are dependent are also to be maintained. The genetic diversity of domesticated species shall be managed in such a way that it helps to secure the future resource base.
Section 8 Knowledge based
Official decisions that affect biological, geological and landscape diversity shall, as far as is reasonable, be based on scientific knowledge of the population status of species, the range and ecological status of habitat types, and the impacts of environmental pressures. The knowledge required shall be in reasonable proportion to the nature of the case and the risk of damage to biological, geological and landscape diversity. Furthermore, the authorities shall attach importance to knowledge that is based on many generations of experience acquired through the use of and interaction with the natural environment, including traditional Sami use, and that can promote the conservation and sustainable use of biological, geological and landscape diversity.

Section 9 The precautionary principle
When a decision is made in the absence of adequate information on the impacts it may have on the natural environment, the aim shall be to avoid possible significant damage to biological, geological or landscape diversity. If there is a risk of serious or irreversible damage to biological, geological or landscape diversity, lack of knowledge shall not be used as a reason for postponing or not introducing management measures.
Section 10 Ecosystem approach and cumulative environmental effects
Any pressure on an ecosystem shall be assessed on the basis of the cumulative environmental effects on the ecosystem now or in the future.

Table 2: The *Marine Resources Act*

Act of 6 June 2008 no. 37 relating to the management of wild living marine resources (*Marine Resources Act*)
The purpose of this Act is to ensure sustainable and economically profitable management of wild living marine resources and genetic material derived from them, and to promote employment and settlement in Norway's coastal communities. The wild living marine resources belong to the Norwegian society as a whole.

Appendix 2

R studio scripts

SPECIES MAP

```
sponges.df <- read.table ('/Users/idavee/Desktop/Skole/master_oppgave
 /case_study/sponges.csv', header=T, sep=',')

sponges.df$BiomassHour <- sponges.df$Biomass*4/1000
attach(sponges.df)

levels(Species)

#Subdatasett for Porifera:
#porifera.df <- subset(sponges.df, Species=='Porifera')
#attach(porifera.df)
#porifera.df <- subset(sponges.df, Species=='Stryphnus Ponderosus')
#attach(porifera.df)
#porifera.df <- subset(sponges.df, Species=='Stylocordyla borealis')
#attach(porifera.df)
#porifera.df <- subset(sponges.df, Species=='Thenea muricata'
#attach(porifera.df)
#porifera.df <- subset(sponges.df, Species=='Tetilla sp')
#attach(porifera.df)
#porifera.df <- subset(sponges.df, Species=='Axinella sp'
#attach(porifera.df)
#porifera.df <- subset(sponges.df, Species=='Geodia macandrewii')
#attach(porifera.df)
#porifera.df <- subset(sponges.df, Species=='Geodia barretti')
#attach(porifera.df)
#porifera.df <- subset(sponges.df, Species=='Stelletta sp’)
#attach(porifera.df)

porifera.df <- subset(sponges.df, Species=='Geodia sp')
attach(porifera.df)

library(maps)

units='in', width=7, height=7, res=300)

par(oma=c(2,2,0,0), cex.lab=1,5, cex.axis=1,5, las=1)

map('world',ylim=c(68,83),xlim=c(-8,60), resolution=0, type='n')
u <- par('usr')
rect(u[1], u[3], u[2], u[4], col='blue')

map('world',ylim=c(68,83),xlim=c(-8,60),fill=T, col='gray80', resolution=0, add=T,
 xlab='', ylab='')
map.axes()

map.scale(x=-7,metric=T, ratio=F, relwidth=0.20, cex=1)

mtext('Longitude', side=1, line=3, oma=T, cex=1)
mtext('Latitude', side=2, line=3, oma=T, cex=1, las=0)
mtext('Geodia sp.', side=3, line=1, oma=T, cex=2, font=3)
#mtext('Porifera', side=3, line=2, oma=T, cex=2, font=3)
#mtext('Stryphnus Ponderosus', side=3, line=1, oma=T, cex=2, font=3)
#mtext('Stylocordyla borealis', side=3, line=1, oma=T, cex=2, font=3)
#mtext('Thenea muricata', side=3, line=1, oma=T, cex=2, font=3)
#mtext('Tetilla sp', side=3, line=1, oma=T, cex=2, font=3)
#mtext('Axinella sp', side=3, line=1, oma=T, cex=2, font=3)
#mtext('Geodia macandrewii', side=3, line=1, oma=T, cex=2, font=3)

text(59,79, 'Svalbard', cex=1,5, font=4)
text(36,76, 'Barents \n Sea', col='gray60', cex=2, font=3)
text(5,71, 'Norwegian \n Sea', col='gray60', cex=2, font=3)
text(22,82, 'Arctic Ocean', col='gray60', cex=2, font=3)
text(50,69, 'Norway', cex=1,5, font=4)
text(64,69, 'Russia', cex=1,5, font=4)
text(84,74, 'Novaja \n Zemlja', cex=1,5, font=4)
```

```
text(128,81, 'Franz Joseph Land', cex=1,5, font=4)

sirkelstr <- ifelse(BiomassHour < 0.1, 0.1, ifelse(BiomassHour < 1, 0.3,
 ifelse(BiomassHour <10, 1, ifelse(BiomassHour <100,2,3))))

 (kg/hour)
points(EE, NN, cex=sirkelstr, pch=19, col='red')

legend('topleft', title='CPUE (kg/hr)', bg='white', pch=19, col='red',
 pt.cex=c(0.1,0.3,1,2,3), c('<0.1','0.1-1', '1-10', '10-100', '100-620 (max)'))

#Density estimation
#library(MASS)
#k <- kde2d(EE, NN)
#contour(k, add=T)

#dev.off()
```

MAPS PER YEAR

```
sponges.df <- read.table ('/Users/idavee/Desktop/Skole/master_oppgave
 /case_study/sponges.csv', header=T, sep=',')

sponges.df$BiomassHour <- sponges.df$Biomass*4/1000
attach(sponges.df)

levels(Year)

years.df <- subset(sponges.df, Year=='2010')
attach(years.df)
#years.df <- subset(sponges.df, Year=='2011')
#attach(years.df)
#years.df <- subset(sponges.df, Year=='2012')
#attach(years.df)
#years.df <- subset(sponges.df, Year=='2013')
#attach(years.df)
#years.df <- subset(sponges.df, Year=='2015')
#attach(years.df)

library(maps)

#jpeg
units='in', width=7, height=7, res=300)


par(oma=c(2,2,0,0), cex.lab=1,5, cex.axis=1,5, las=1)

map('world',ylim=c(68,83),xlim=c(-8,60), resolution=0, type='n')

u <- par('usr')
rect(u[1], u[3], u[2], u[4], col='blue')

map('world',ylim=c(68,83),xlim=c(-8,60),fill=T, col='gray80', resolution=0, add=T,
 xlab='', ylab='')
map.axes()

map.scale(x=-7,metric=T, ratio=F, relwidth=0.20, cex=1)

mtext('Longitude', side=1, line=3, oma=T, cex=1)
mtext('Latitude', side=2, line=3, oma=T, cex=1, las=0)
mtext('Trawl Catch 2010', side=3, line=1, oma=T, cex=2, font=4)
#mtext('Trawl Catch 2011', side=3, line=1, oma=T, cex=2, font=4)
#mtext('Trawl Catch 2012', side=3, line=1, oma=T, cex=2, font=4)
#mtext('Trawl Catch 2013', side=3, line=1, oma=T, cex=2, font=4)
#mtext('Trawl Catch 2015', side=3, line=1, oma=T, cex=2, font=4)

#mtext('Porifera sp', side=3, line=2, oma=T, cex=2, font=3)
#mtext('Stryphnus Ponderosus', side=3, line=2, oma=T, cex=2, font=3)
#mtext('Stylocordyla borealis', side=3, line=2, oma=T, cex=2, font=3)
#mtext('Thenea muricata', side=3, line=2, oma=T, cex=2, font=3)
#mtext('Tetilla sp', side=3, line=2, oma=T, cex=2, font=3)
#mtext('Axinella sp', side=3, line=2, oma=T, cex=2, font=3)
#mtext('Geodia macandrewii', side=3, line=2, oma=T, cex=2, font=3)

text(59,79, 'Svalbard', cex=1,5, font=4)
text(36,76, 'Barents \n Sea', col='gray60', cex=2, font=3)
```

```
text(5,71, 'Norwegian \n Sea', col='gray60', cex=2, font=3)
text(22,82, 'Arctic Ocean', col='gray60', cex=2, font=3)
text(50,69, 'Norway', cex=1,5, font=4)
text(64,69, 'Russia', cex=1,5, font=4)
text(84,74, 'Novaja \n Zemlja', cex=1,5, font=4)
text(128,81, 'Franz Joseph Land', cex=1,5, font=4)

sirkelstr <- ifelse(BiomassHour < 0.1, 0.1, ifelse(BiomassHour < 1, 0.3,
ifelse(BiomassHour <10, 1, ifelse(BiomassHour <100,2,3))))

points(EE, NN, cex=sirkelstr, pch=19, col='red')

legend('topleft', title='CPUE (kg/hour)', bg='white', pch=19, col='red',
 pt.cex=c(0.1,0.3,1,2,3), c('<0.1','0.1-1', '1-10', '10-100', '100-620 (max)'))

#Total CPUE for all
#legend('topleft', title='Total CPUE (kg/hr)', bg='white', pch=19, col='red',
 pt.cex=c(0.1,0.3,1,2,3), c('<0.1','0.1-1', '1-10', '10-100', '100-620 (max)'))
#Density estimation
#library(MASS)
#k <- kde2d(EE, NN)
#contour(k, add=T)

#dev.off()
```