



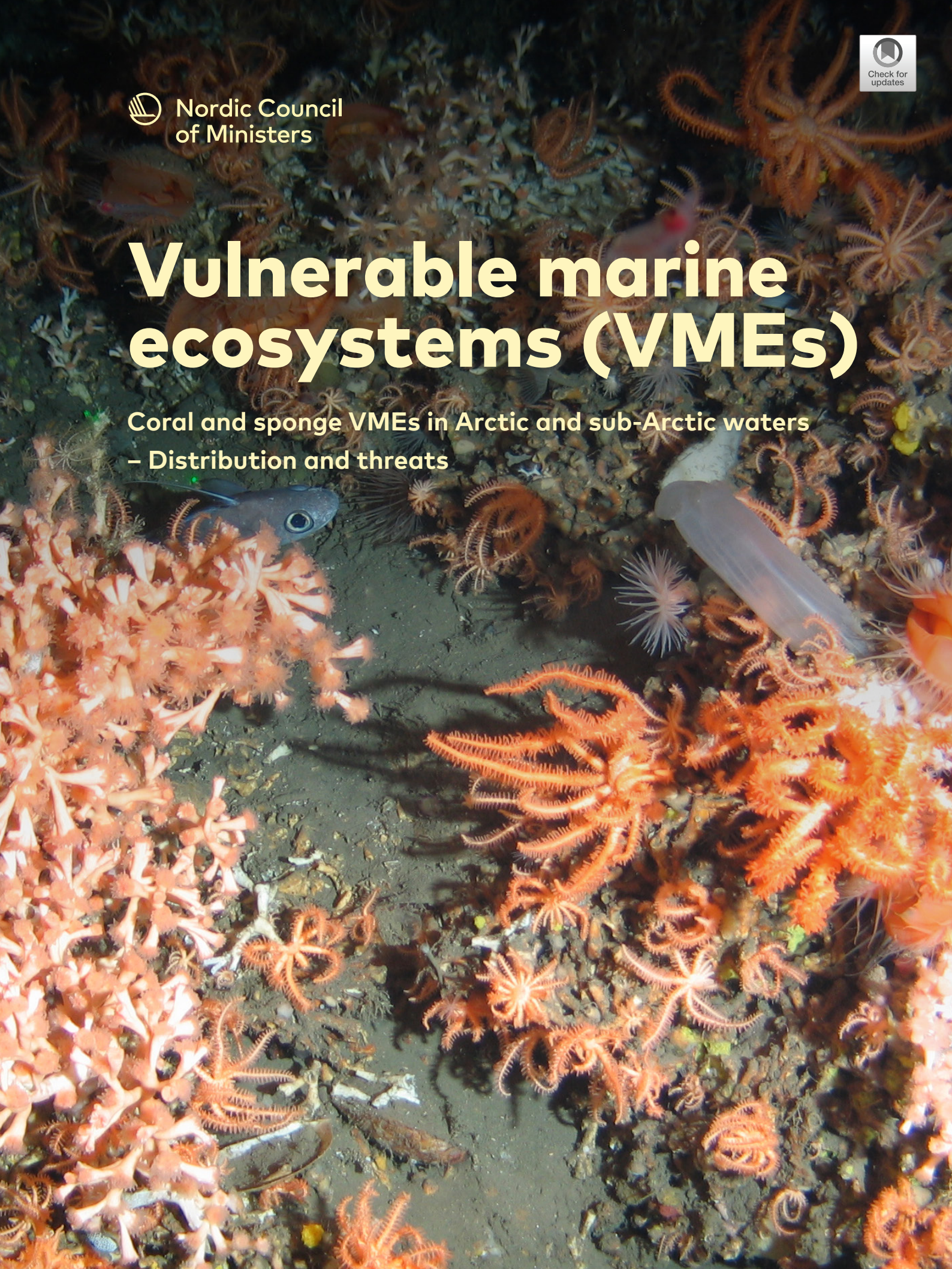
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Vulnerable marine ecosystems (VMEs)

Coral and sponge VMEs in Arctic and sub-Arctic waters
– Distribution and threats



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*Lene Buhl-Mortensen, Julian Mariano Burgos, Petur Steingrund,
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A "cold water coral reef" VME, with common associated species, from video mapping off Iceland.

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Contents

Summary	7
1. Introduction	9
1.1 Background	9
1.2 Predictive mapping for area-based management	10
2. Study area	13
3. Project objectives, structure and activities	15
3.1 The main objectives of NovasArc:	15
3.2 Main tasks.....	15
3.3 Workshops.....	17
3.4 Joint activities.....	17
3.5 Project dissemination	18
4. Data and methods	19
4.1 Data gathering.....	19
5. Definition of VMEs.....	23
5.1 Criteria to identify VMEs	23
5.2 VME types selected for this project	24
6. Distribution of cold-water corals in the Arctic and sub-Arctic – New knowledge from NovasArc.....	33
7. Predictive modelling of suitable habitat for VMEs	35
7.1 Environmental predictors.....	35
7.2 Predictive distribution models of VMEs	38
7.3 Results from model.....	39
8. Threats to VMEs in the N-Atlantic.....	43
8.1 Evaluating human impact on VMEs	43
8.2 Compilation of data on trawling effort.....	44
9. Risk analysis	51
9.1 Method used.....	51
9.2 Results.....	52
9.3 Methodological uncertainties.....	53
10. General conclusions and future work	61
10.1 Future needs.....	62
10.2 Acknowledgement.....	62
11. References	63
12. Summary in Danish	69
List of appendices.....	71
Appendix 1. List of participants.....	73
Appendix 2. Timeline of activities	75
Appendix 3. List of VME species.....	77
Appendix 4. Data sources	79
Appendix 5. Predicted VME distribution.....	83
Appendix 6. Overlap between fishing intensity and predicted VME distributions.....	89
Appendix 7. Identification guides	101
Underwater Identification guide for corals and sponges in the Nordic Seas.....	101
Identification guide for corals and sponges as by-catch from bottom trawling.....	136

Summary

The report presents results from the NovasArc project and based on information that has been collated by the project it provides the distribution of vulnerable marine ecosystems (VMEs) in Arctic and sub-Arctic waters. Eleven VMEs were identified, based on management goals for coral and sponge communities, of these Sponge aggregations and sublittoral sea pens were the widest distributed VMEs. Bottom related fishing was the human activity that was the largest threat to the VMEs, and trawling occurred in 40 – 50% of the study area. In general less than 50% of the predicted VME distribution overlapped with fishing, and 10 – 30% had experienced high fishing intensity. In parts of the study area the information on the seafloor environment is very poor and the prediction of the occurrence of VMEs is not possible with any certainty.

1. Introduction

This report evaluates the risk of vulnerable marine ecosystems (VMEs) in Arctic and sub-Arctic waters to bottom trawling. It is based on an exhaustive compilation of data on the distribution of VME indicator species, including published and unpublished data, and new data gathered during the project from areas where information is sparse. An overview of the approaches and methodologies for mapping of VME distribution is presented. Eleven VMEs are identified based on management goals for coral and sponge communities present in the study area.

Bottom related fisheries were the human activities that were identified as the biggest threat to the VMEs. A risk analysis is conducted based on the modelled distribution of VMEs and its co-occurrence with high fishing intensity. The report discusses the uncertainty associated with modelled distributions and fishing pressure estimates and management implications. Areas where information on VMEs is lacking are identified and the need for more detailed knowledge on the distribution of human activities is discussed.

1.1 Background

The NovasArc project was supported by the Nordic Ministers, with the main goal to evaluate the extent of vulnerable marine ecosystems (VMEs) in the Arctic and sub-Arctic waters, and quantify the risks these areas are facing.

Despite the importance of the biological resources in Arctic and sub-Arctic waters, and the increasing levels of human activities, a coherent and systematic compilation of knowledge of VMEs and vulnerable species within the whole region does not yet exist.

Presently it is known that VMEs in the area include: cold-water coral reefs, coral gardens, sea pens, and deep-sea sponge aggregations. Adverse negative impacts on these vulnerable habitats have been documented as result of bottom fishing (Buhl-Mortensen *et al.* 2016). Increasing pressures from human activities within Arctic and sub-Arctic waters, poses additional risk to VMEs and it is thus urgent to map the seafloor in these areas to facilitate a sustainable management of the VMEs found there.

Potential impacts of climate change, including temperature increase and ocean acidification, may have a dramatic impact on the health status and distribution of VMEs, especially those that are comprised mostly of calcifying organisms (Davies and Guinotte 2011; IPCC 2018).

There is an increased demand for information and understanding of the marine ecosystems, both regarding the scientific understanding of ecological and biological processes, but also as inputs to formulate management decisions to preserve biodiversity and maintain ecosystem functioning.

Several benthic marine ecosystems have been classified as vulnerable to human impacts. Management entities like the Food and Agriculture Organization of the United Nations (FAO), the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) and the North East Atlantic Fisheries Commission (NEAFC) have published lists of vulnerable ecosystems.

In this project, scientists from Norway, Iceland and the Faroe Islands, collaborated with the objective to fill some of this knowledge gap. Prior to NovasArc, scientists from Marine Research Institute of Iceland and the Institute of Marine Research of Norway received three mobility grants from the Science Cooperation Fund (<http://www.arcticstudies.is>) in 2013, 2014 and 2015 to carry out research on vulnerable marine ecosystems. This work resulted in the publication of a peer reviewed article on the distributions of nine cold-water coral species within the North Atlantic (Buhl-Mortensen 2014). In the NovasArc project, this collaboration continued, and the consortium was expanded by including the Faroe Marine Research Institute.

1.2 Predictive mapping for area-based management

The conservation of VMEs is very high on the agenda worldwide. Examples of management actions that have facilitated the conservation of VMEs, mostly in the high seas, include the UN General Assembly resolutions 61/135 and the OSPAR list of threatened species and habitats. Further measures include the establishment of marine protected areas in the N-Atlantic (NEAFC and OSPAR) and encounter thresholds on corals and sponges (NEAFC and NAFO).

The co-occurrence of vulnerable habitats like coral reefs, and intensive fishing pressure can create conflicts between those stakeholder groups (user groups) that want to protect VME areas and those who want to harvest the fishery resources within them. Reconciling such conflicts can be especially difficult as the distribution of VMEs in many areas within the Arctic and the sub-Arctic is poorly known, and any exploration represents numerous logistical and financial challenges. If the industries want to pursue product certification and eco labelling for sustainability there is now increasing demand to provide evidence that shows that fisheries are minimizing their environmental impact on other species and habitats to provide evidence of sustainable use of the resources.

Environmental policies are increasingly emphasizing the need for a holistic approach to marine resource management. Such a management approach needs to address the increasing amount of anthropogenic pressures on marine environments as well as conflicts between multiple users competing for space and resources.

Thus, the need for an “ecosystem-approach” has been advocated widely since its adoption is an integral concept of the Convention on Biological Diversity at the Earth Summit in Rio de Janeiro in 1992 (Arkema *et al.* 2006; Pikitch *et al.* 2004).

Ecosystem-based management has been defined as: The comprehensive integrated management of human activities based upon the best available scientific knowledge about the ecosystem and its dynamics, to identify and take action on influences which are critical to the health of marine ecosystems and thereby achieving sustainable use of goods and services and maintenance of ecosystem integrity (ICES, 2005a).

Consequently, several European legislations have recently been issued with the aim of achieving the maintenance of good environmental status (GES) through the sustainable use and conservation of marine biodiversity, e.g. the Habitats Directive (EC 1992), Integrated Maritime Policy (Borja *et al.* 2008), the Water Framework Directive (Day 2008), and more recently the Marine Strategy Framework Directive (Rogers *et al.* 2007).

A much-advocated tool to progress from the traditional fragmented single sector management approach to an ecosystem-based approach is the concept of place-based management such as Marine Spatial Planning (MSP) (Pomeroy *et al.* 2005; Curtin and Prellezo 2010). One of the main goals of marine spatial management is to promote a sustainable use of marine resources while not putting marine biodiversity and habitats at risk. Objectives for marine biodiversity and habitats are stated in the Biodiversity Convention, the Habitat Directive, and the Marine Strategy Framework Directive (EC, 2008a; EEC, 1992; UN, 1992), which affirm that no species or habitats should be lost, and that the integrity of the sea floor should not be compromised by human activities. To make marine spatial plans (MSP) and decisions that can reach these objectives requires knowledge of the composition and distribution of benthic communities, the characteristics of a natural and healthy state, and the effects of different human activities (e.g. EC, 2008b; epbrs, 2013; Steltzenmüller *et al.*, 2013). It has been estimated that only 5–10% of the seafloor is mapped at a comparable resolution to similar studies on land (Wright and Heyman, 2008). Furthermore, marine ecosystems are poorly described compared to their terrestrial counterparts. On land the proportion of unknown habitats has been estimated as 17% whilst for the marine realm it has been estimated as 40% (EC, 2007). In recommendations from the European Platform for Biodiversity Research Strategy (epbrs, 2013) it was emphasized that “a sound reporting based on scientific methods and knowledge is of major importance” and it was recognized that “research is needed to substantially advance our knowledge of marine habitats and species in support of evidence-based policy and its implementation”. The ability to reach national and international management goals depends, to a large degree, on detailed knowledge of the benthic environment and ecosystem including its state of health and signs of human impact.

Vulnerable Marine Ecosystems (VMEs) are managed according to national legislations by the three different countries represented in this report. Coral reefs are given much attention from a management perspective by all three countries.

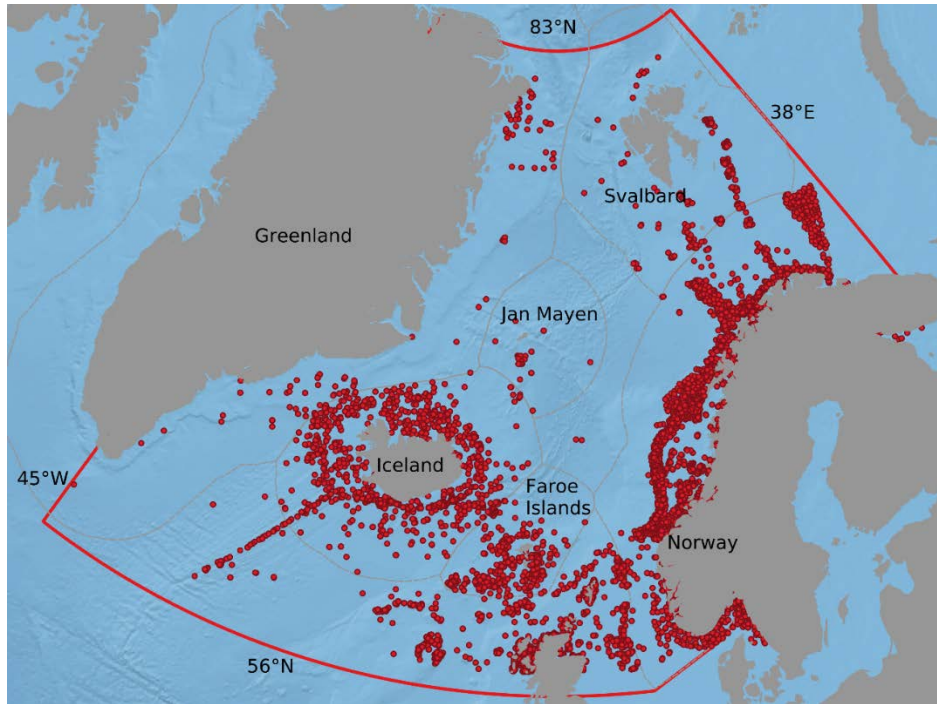
In addition, Denmark as an EU member must adopt further regulations, such as the MSFD. For Norway, this project will provide valuable results that can be taken into consideration during up-coming revision of the management plans that are already implemented for the Norwegian part of the Barents Sea, the Norwegian Sea, and the North Sea.

2. Study area

The study area includes the Exclusive Economic Zone (EEZ) of Norway and Iceland, and the shelf and slope of the Faroe Islands, and the Svalbard archipelago. Areas outside of these countries were also included (i.e. the NEAFC regulatory area), and in total the study area covers the Norwegian Sea, The Iceland Sea, parts of the Barents Sea and the North Atlantic (Figure 1). It can be divided into three main basins separated by the northern extension of the mid Atlantic Ridge and the Greenland-Iceland-Scotland Ridge (the GIS ridge).

The oceanography of the area is characterized by relatively warm surface water supplied from the south by the North Atlantic Drift (NAD – the extension of the Gulf Stream) overlying colder water masses (Norwegian Sea Deep Water, Arctic Intermediate Water) supplied from deep-water formation in Arctic areas. In coastal areas, the water is influenced by run-off from land. The seasonal variation is much less in the deeper waters than in the upper layers. Current velocities are controlled by the flow of the water masses and the tide, modified by the seabed topography. The GIS-ridge has a major impact on the distribution of water masses. The main pathway of water crossing this ridge is through the Wyville-Thomson Ridge between the Faroes and Scotland. Here, the warm NAD passes into the Norwegian Sea above a “sill” of approximately 500 m. South of the Wyville-Thomson Ridge, the NAD water extends deeper and overlies a watermass characterized by water from the Mediterranean Ocean (the Mediterranean Outflow Water). The ridge system from Greenland to Scotland represents a major geographic barrier with great implications for distribution of marine species.

Figure 1: Map of the study area



Note: Red dots indicate the position of the records of VME indicator species compiled in this study.

3. Project objectives, structure and activities

The NovasArc project has been mapping the vulnerable marine ecosystems (VMEs) in the sub-Arctic and Arctic seas between 2016 and 2018, by compiling published and new knowledge for the area relevant VMEs and predicting their distribution using Environmental Niche Models. In addition, an analysis of the distribution and intensity of bottom trawling was conducted to evaluate areas of conflict and VMEs at risk. Detailed overview of the project activities and results are found in the appendices 1-7.

3.1 The main objectives of NovasArc:

- Compile existing information on the distribution of indicator species for the VMEs present in the study area from various sources including national mapping surveys, compiled databases, and published articles and reports.
- Carry out a gap analysis to identify poorly known areas where future survey efforts are needed.
- Examine the spatial distribution patterns of VME indicator species and their relationship with environmental parameters.
- Use Environmental Niche Models to predict the distribution of VMEs in the study area.
- Assess the magnitude of the overlap between fishing activities and the predicted distribution of VMEs and their indicator species.
- Provide relevant input for management authorities to underpin conservation of VMEs.

3.2 Main tasks

The tasks of the project were divided into four work packages. Three work packages provide: the basic empirical information distribution of VME species, human pressures, and geomorphology and oceanographic settings. The risk analysis, describing the overlap between fishing activity and the distribution of VMEs, was conducted in the fourth work package.

The importance of evaluating each VME-type independently was emphasized and discussed, together with the underlying assumptions for the risk assessment approaches, such as the criteria for VME presence.

WP1: Compilation of available information on vulnerable species and habitats and exchange of knowledge and research methods among the participants

All available information on the occurrence of vulnerable species or habitat forming species, using data from: habitat mapping activities conducted by each partner, published papers and reports, and NEAFC, ICES and NAFO bycatch data from commercial fisheries. Knowledge on methods of habitat mapping, analysis, and sampling was exchanged among the participating countries.

WP2: Compilation on human activities with potential impacts on the sea bottom and analysis of data from all participant countries

From the analysis of human activity in the study area i.e. shipping, oil and gas industry, tourism and fishing, it was clear that bottom related fishing was the main threat to VMEs (see also Buhl-Mortensen *et al.* 2013). Fishing intensity (FI) from bottom trawlers was estimated from VMS (Vessel Monitoring System) and AIS (Automatic Identification System) data, using the highest spatial resolution available.

WP3: Identifying the environmental settings that are related to the presence of VMEs e.g. geomorphology and oceanography

Data on the near-bottom physical and oceanographic environment was compiled, with focus on variables known to influence the distribution of VMEs. Environmental Niche Models were used to model the distribution of VMEs in the study area and explore the association between the presence of a specific VME and the environmental settings where they occur.

WP4: Risk analysis, management implications, and dissemination

The spatial overlap between the modeled distribution of VMEs and the human impacts was examined to identify possible conflict areas. Conflict areas were defined as areas with the presence of VMEs that are targeted by trawlers as indicated by VMS and AIS data. Data poor areas where predictive models suggest occurrence of VME species were identified as target areas for future habitat mapping surveys. Results and information were disseminated to the public through a website, and a flyer/brochure focusing on vulnerable marine ecosystems, pressures, and the goal of this project.

Results are in preparation to be published in two peer reviewed papers.

3.3 Workshops

During the project, between 2016-2018, a total of 6 workshops were arranged in Torshavn, Bergen, and Reykjavík (See Appendix 1 and 2 for list over participants and activities in the project).

3.4 Joint activities

Exchange of VME mapping strategy and technology

To exchange knowledge on the technological aspects of marine habitat mapping, scientists and engineers participated in national cruises and in the development of equipment and procedures for underwater video survey.

The mapping of vulnerable habitats was initiated in the Faroe Islands in collaboration with NovasArc. A video camera and cable were contributed by the NovasArc project to the Faroe Marine Research Institute (FMRI).

In June 2017 scientists from Norway (IMR) joined a mapping cruise conducted by the FMRI to share expertise in using video equipment and habitat mapping methods. In February 2017, a technician involved in the habitat mapping project in Iceland was on board the new Norwegian research vessel, R/V Dr. Fridtjof Nansen during an IMR cruise to gain experience and knowledge on the use of video equipment and annotation of video observations in the field.

Training was conducted by IMR in the Faroes on video analysis using the video annotation software (VideoNavigator, IMR).

Exchange of taxonomical experience

As a result of the first workshop in January 2016 in the Faroes, an initiative was taken to register selected vulnerable marine species in bycatches from the Faroese ground fish surveys in February 2016. This registration will be continued in the Faroese ground fish surveys in the years to come.

Developing an identification guide for VME indicator species

In the joint effort of NovasArc to compile knowledge on the vulnerable marine ecosystems, photos of their indicator species were collected from the study area. There is currently no guide available that is especially suitable for the Nordic seas. To fill this gap, NovasArc was to produce on-board identification sheets both for fishermen and scientists to aid in the identification of corals, seapens, and sponges. The project has compiled a first version of an identification guide, using own seabed imagery from

ongoing mapping projects, that will increase the quality and precision of the taxonomic identification of corals and sponges in this area (Appendix 7).

A database of VME indicator species has been developed. The NovasArc joint compilation of available information from literature and new observations of species indicating vulnerable ecosystems, and their recorded positions, has resulted in a database containing > 40 000 records at present. The records from the database were used to produce distribution maps that were ingredients for the predictive distribution modelling describing areas where data was lacking.

3.5 Project dissemination

The project and results have been presented at numerous meetings and conferences (Appendix 2) and a project webpage is available at the site:

<https://novasarc.hafogvatn.is/>

4. Data and methods

4.1 Data gathering

Data was compiled from a vast range of published, historical, and more recent papers that includes studies in the Nordic seas from the late 19th century and up to present time. An overview of sources is provided in appendix 4. The bulk of the data used in this study was obtained from national mapping projects, and from existing databases:

Norway

The MAREANO (Marine AREA database for NORwegian waters) programme conducts seabed mapping, upon request from the Norwegian government, in order to fill knowledge gaps in relation to the implementation of management plans for the different parts of the Norwegian EEZ. The program was launched in 2005 and has so far covered ca 190,000 km² and spans depths ranging from 40 to 2700 m. The area covers a wide variety of topographic features including banks, troughs, ridges, canyons, large sand waves, cold seeps and coral reef areas. MAREANO is jointly financed by the Ministry for the Environment and the Ministry of Trade, Industry and Fisheries. The goal is to obtain information that can be used as a scientific basis to manage human activities such as the oil industry and fisheries. To map bottom topography, seabed substrates, pollutants, biodiversity and vulnerable biota in a varied seascape is challenging and requires a range of mapping methods. Multibeam echosounder data (bathymetry and acoustic backscatter) provide information on terrain and softness of substratum. Sampling of sediment and benthos is performed with a suite of gears (multicorer, grab, boxcorer, beam trawl and epibenthic-sledge) and includes visual inspection with video. The three national institutes, Institute of Marine Research (IMR), Geological Survey of Norway (NGU) and Norwegian Hydrographic Service (NHS) work in cooperation to fulfil the various mapping tasks. Analysis of the biological data provides information about biodiversity, biomass, and distribution and abundance of benthic species. Data from Norwegian waters were also compiled from other short-term projects such as Epigraph and the Sognefjord project (a collaboration between University of Bergen and IMR), and from the “coral database” maintained and updated by IMR.

Iceland

In 2004 an initiative towards mapping and protecting cold-water corals in Icelandic waters was undertaken by the Marine and Freshwater Research Institute, involving for the first time a video documentation of coral-reefs south of Iceland. As a result, the coral-reefs that were mapped and were considered to be at risk of damage by bottom fishing were protected. As a follow up to this initiative, a benthic habitat mapping project was started with the long-term goal of mapping and describing the various benthic habitats around Iceland. The main focus of this project is mapping vulnerable habitats or ecosystems. Among the more recent outputs from this work include records of sponge and sea pen aggregations. In addition, since 2016 the benthic by-catch captured in the annual ground fish survey has been analysed and recorded, including species that are indicators of vulnerable ecosystems.

The Faroe Islands

In relation to this project, the Faroe Marine Research Institute has initiated mapping of corals in Faroese waters. In June 2017 and in June 2018, the Research vessel "Magnus Heinason" performed video transects on the Faroe Plateau as well as on the southwestern banks. The video equipment consisted of a steel-rig to which two cameras, two lights, two weights and a steering fin were attached (Figure 2). In 2017 the rig was held up by a CTD-cable while the video signal was transferred up to monitors on the ship by a video cable allowing the crew to hold the video-rig in a proper position above the seafloor. The second camera (a GoPro), which was not in contact with the ship, recorded high-quality video files that were copied from the camera after each video station. In 2018 the video signal was transferred to the ship through the CTD-cable and no additional video cable was used (but high-quality video files were still recorded by the GoPro camera). This allowed the video-rig to be used down to 800 m in 2018 instead of down to 450 m in 2017. In 2017 a total of 53 video stations of 30 minutes duration were recorded (red dots) and in 2018 the total was 63 video stations (black dots) (Figure 3).

Figure 2: The towed video equipment with two cameras, two lights, two weights and a steering fin attached to a signal and power cable

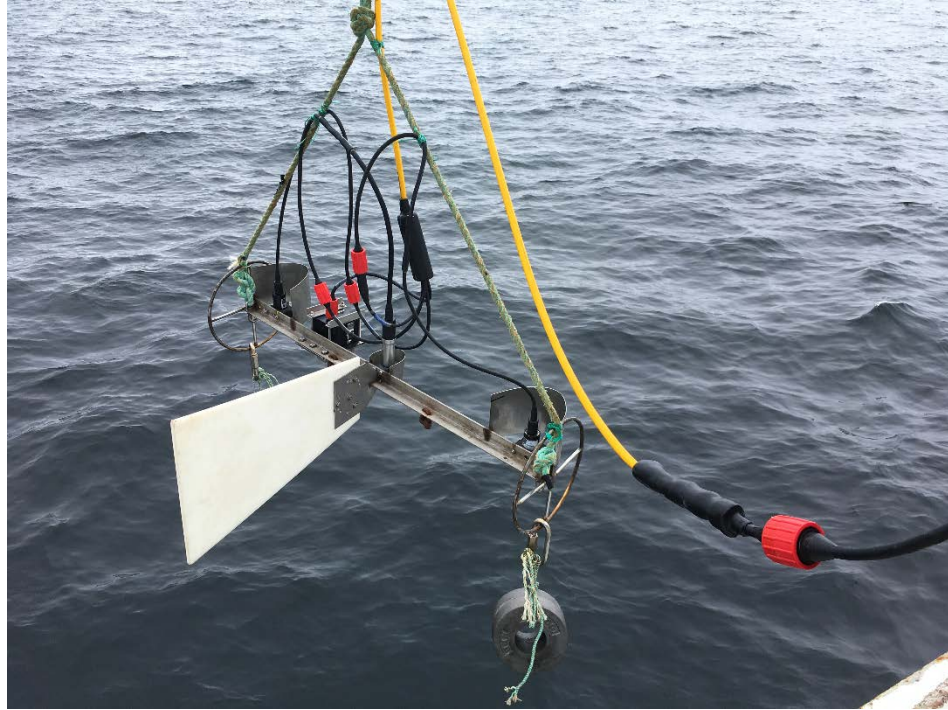
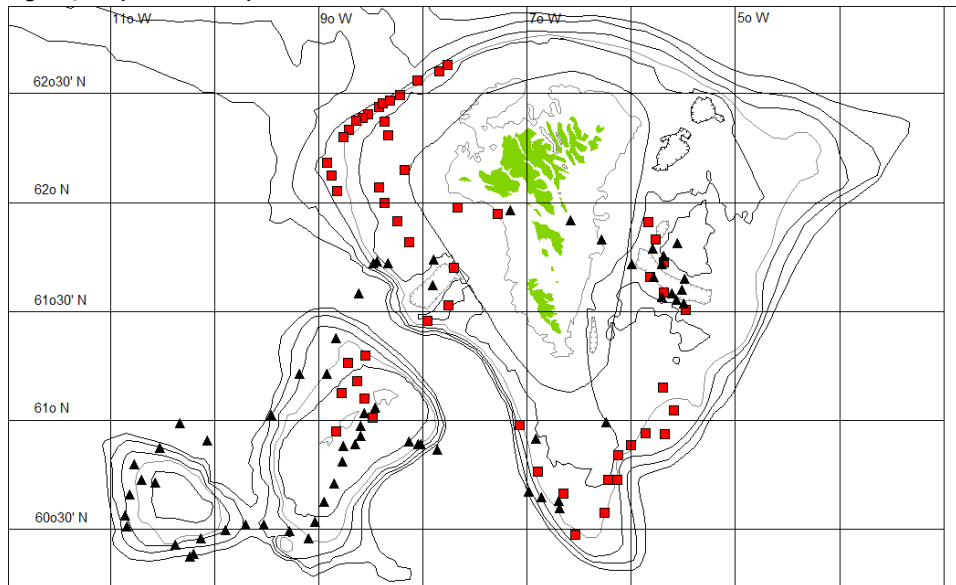


Figure 3: Map of the surveyed areas around the Faroes



Note: Red squares: 2017 survey.
Black triangles: 2018 survey.

5. Definition of VMEs

Vulnerable Marine Ecosystems (VMEs) may be regarded as habitats characterized by habitat forming species sensitive to anthropogenic activities. A habitat is a recognizable space which can be distinguished by its abiotic characteristics and associated biological assemblage, operating on particular spatial and temporal scales (ICES, 2005b).

The NovasArc project uses the FAO definition of VMEs, where “VMEs constitute areas that may be vulnerable to impacts from fishing activities” (www.fao.org).

Description of vulnerability – FAO Guidelines: Vulnerability is related to the likelihood that a population, community, or habitat will experience substantial alteration from short-term or chronic disturbance, and the likelihood that it would recover and in what time frame. These are, in turn, related to the characteristics of the ecosystems themselves, especially biological and structural aspects. VME features may be physically or functionally fragile. The most vulnerable ecosystems are those that are both easily disturbed and very slow to recover or may never recover.

5.1 Criteria to identify VMEs

FAO presented the following criteria which can be used to identify a VME (FAO, 2019):

1. Uniqueness or rarity – an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems. These include habitats that contain endemic species, habitats of rare threatened or endangered species that occur only in discrete areas, or nurseries or discrete feeding, breeding, or spawning areas.
2. Functional significance of the habitat – discrete areas or habitats that are necessary for the survival, for function, spawning/reproduction or recovery of fish stocks, particular life history stages (e.g. nursery grounds or rearing areas), or of rare, threatened or endangered marine species.
3. Fragility – an ecosystem that is highly susceptible to degradation by anthropogenic activities.
4. Life-history traits of component species that make recovery difficult – ecosystems that are characterized by populations or assemblages of species with one or more of the following characteristics: slow growth rates, late age of maturity, low or unpredictable recruitment, or long-lived.
5. Structural complexity – an ecosystem that is characterized by complex physical structures created by significant concentrations of biotic and abiotic features.

In these ecosystems, ecological processes are usually highly dependent on these structured systems. Further, such ecosystems often have high diversity, which is dependent on the structuring organisms.

5.2 VME types selected for this project

For selecting the relevant vulnerable marine ecosystems in the Arctic and sub-Arctic areas for this project, previous VME classifications for the North Atlantic were considered. This included the classifications of the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR 2008), the North East Atlantic Fisheries Commission (NEAFC) VMEs outside EEZs, and the revised list of deep-water VMEs and their characteristic taxa in NEAFC waters from the ICES workshop on vulnerable marine ecosystem database (WKVME, ICES 2016).

As a result, VME classes known to occur within the study area, based on observations from various sources including previous national mapping projects, were selected with modifications benefitting from recent experience and knowledge from the study region. The eleven VMEs that was studied are listed below, and the indicators species that are used in the project are given in Appendix 3.

Sponges

- Soft bottom sponge aggregations
- Hard bottom sponge aggregations
- Deep arctic sponge aggregations

Cold water coral reefs

Sea pen communities

- Sublittoral sea pen communities
- Bathyal sea pen communities

Coral gardens

Soft-bottom coral gardens

- Soft bottom gorgonians
- Cup coral fields

Hard-bottom coral gardens

- Hard bottom gorgonians
- Stylasterid corals
- Cauliflower corals

Soft bottom sponge aggregations

Soft-bottom sponge aggregations are known as “ostur” by Faroese and Icelandic fishers. In Norway fishers call them “sopp” (mushrooms). In the whole study area fishers have experienced high catches of these sponges in certain regions. This VME type is defined by the presence of several large tetractinellid sponges (*Geodia* spp., *Stryphnus ponderosus* and *Steletta* spp.). For shelf areas in the Southwestern part of the Barents Sea (Tromsøflaket and Eggakanten), data from the MAREANO project has demonstrated that these sponges (Figure 4) create a bottom substrate that is a mixture of sandy mud and sponge spicules.

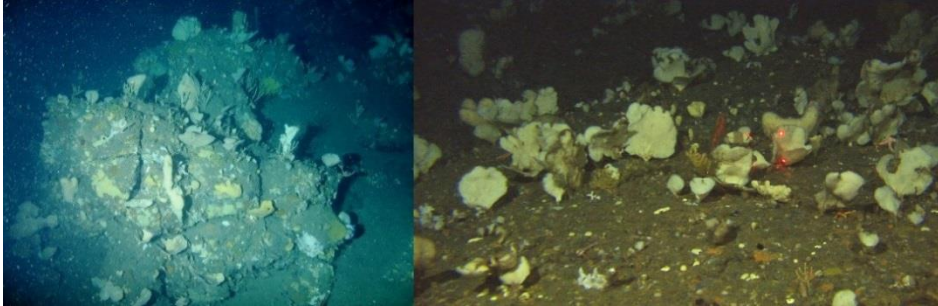
Figure 4: Example of soft bottom sponge aggregation at Tromsøflaket, north of Troms county, Norway



Hard bottom sponge aggregations

A range of medium, to large sized sponge species have been found to occur on hard substrates including bedrock, lithified crust, lava rocks, cobbles and boulders. These habitats comprise in particular various axinellid sponges (e.g: *Phakellia* spp., *Axinella infundibulum*) (Figure 5), *Antho dichotoma* and *Mycale lingua*.

Figure 5: Example of hard bottom sponge aggregation from Iceland (left) and Norway (right)



Deep Arctic sponge aggregations

Several species of glass sponge are found in relatively high colony densities in deep cold (<2 °C) waters. One of the most common species of glass sponge in the Norwegian Sea is *Caulophacus arcticus* (Figure 6), which is generally found on hard bottoms at the lower part of the continental slope. The demospongian species *Chondrocladia gigantea* and *Cladorhiza* sp. are found in cold Arctic waters in the Nordic Seas, normally in low densities. However, north of Iceland, they occur in greater abundances.

Figure 6: Example of deep arctic sponges, *Caulophacus arcticus* at 1950 m depth off Lofoten, Norway



Cold-water coral reefs

There are four species of scleractinian (stony corals) cold-water corals that are known to form reefs in the North Atlantic (*Lophelia pertusa*, *Madrepora oculata*, *Solenosmilia variabilis* and *Oculina varicosa*).

In the Northeast Atlantic, *Lophelia pertusa* is the main reef-building coral (but on rare occasions, *Madrepora oculata* has been known to constitute the major framework of the reef). *L. pertusa* can form isolated colonies, but under the right environmental conditions these can grow and merge with other colonies to form large coral reefs (Figure 7). *L. pertusa* reefs develop slowly.

The Norwegian coral reefs have been dated to be 3000 to 9000 years old. The third reef building species, *Solenosmilia variabilis*, is recorded deeper than the other two species, and has not been confirmed to form reefs in the NovasArc study area. Coral reefs are habitat to a variety of other species, ranging from fish to smaller invertebrates, also including other coral species, and harbouring higher biodiversity and biomass than in surrounding areas.

Sublittoral sea pen communities

Sea pens are found in high densities in some locations with soft sediments. In OSPAR's list of threatened and/or declining habitats, this biotope is termed "sea-pens and burrowing megafauna communities" (Curd 2010). This biotope is found in the relatively warm Atlantic water shallower than 700 m.

Figure 7: *Lophelia* reef (Cold water coral reef) off northern Norway



The most common sea pen species are *Funiculina quadrangularis*, *Virgularia mirabilis*, *Pennatula phosphorea* and *Kophobelemnon stelliferum* (Figure 8).

Figure 8: Sea pen and burrowing megafauna community from the shelf off northern Norway



Bathyal sea pen communities

The deep-sea (below 700m) sea pen species *Umbellula* spp. and *Anthoptilum* spp. occur in an environment that is very different from shallower waters, with colder temperatures and a different species composition. The anthropogenic activities are fewer and different from on the shelf and this sea-pen community should be regarded as a separate VME or at least a distinct sub-type. High densities of *Umbellula encrinus* (Figure 9) are found in deep waters north of Iceland and in Norway, at depths below 800 m. This large sea pen can reach a height of three metres. There are often high densities of tube-building amphipods (*Neohela*) in areas with *Umbellula*. Off southern Iceland, sea pens of the genus *Anthoptilum* are also found in deep, albeit warmer waters.

Figure 9: *Umbellula encrinus* is the most common species constituting bathyal sea pen communities



Soft bottom gorgonians

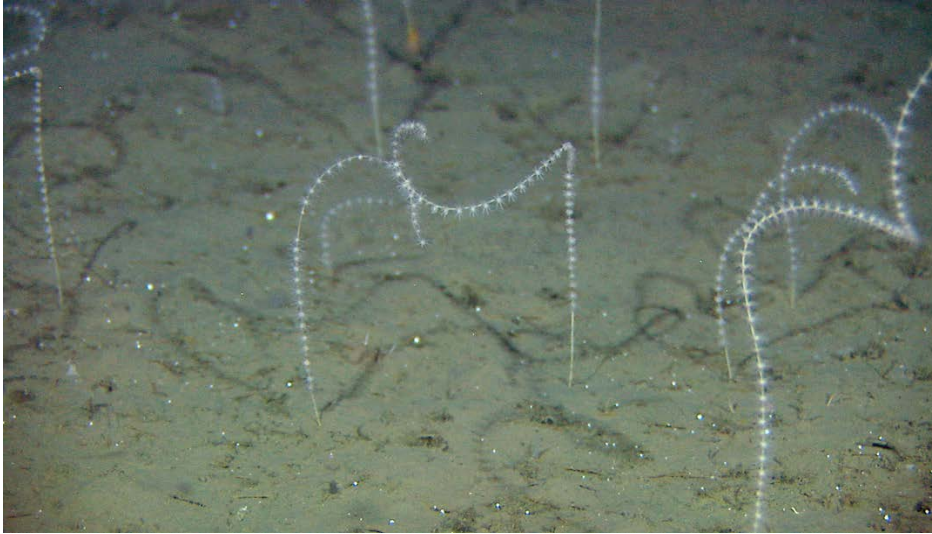
In the Norwegian Sea two species of gorgonian corals (*Radicipes gracilis* and *Isidella lofotensis*) can form dense stands on sandy soft bottoms. In Norwegian waters *R. gracilis* (Figure 10) had not been observed until MAREANO found dense concentrations of this sea whip in the area known as the Bjørnøya slide. In the warmer waters off southern Iceland the bamboo coral *Acanella arbuscula* is relatively common.

As well as several cup corals of the genera *Caryophylla*, *Flabellum* and *Stephanocyathus*.

Cup coral field

Cup corals of the genera *Caryophylla*, *Flabellum* and *Stephanocyathus* are frequent both on the Norwegian and Icelandic shelf.

Figure 10: Dense stands of the chrysogorgiid coral *Radicipes gracilis* in the Bjørnøya slide area at around 700 m depth



Hard bottom gorgonians

In locations where currents are strong, and the sea bed is hard, sea fans and other non-reefal coral species may provide a habitat for fish, brittle stars and small crustaceans. The most common sea fans constituting hard-bottom coral gardens in the North Atlantic are *Paragorgia arborea* (Figure 11), *Primnoa resedaeformis*, *Paramuricea placomus* and *Swiftia* spp. Although the biodiversity in these habitats is lower than in coral reefs, they nevertheless sustain many individuals and a large number of host-specific species that are not found in other habitats (Buhl-Mortensen and Mortensen 2004, 2005).

Stylasterid corals

These hydrozoans, with hard calcified skeletons, have sometimes been recorded in high abundances, but are in general rarely forming dense stands in the study area.

Cauliflower corals

Cauliflower corals are widely distributed in the study area. Gardens of these species have been observed in video surveys, for example at 500–600 m in the shelf area both NW and SE of Iceland. Cauliflower corals (or *nephtheids*) mainly comprise species from three genera (*Gersemia*, *Duva*, *Drifa*), and their species can be difficult to identify from video records.

Figure 11: *Paragorgia arborea* is a common species that may form hard bottom coral gardens in the Nordic seas. This picture is taken from the shelf off northern Norway



6. Distribution of cold-water corals in the Arctic and sub-Arctic – New knowledge from NovasArc

In 2014, researchers (of which almost all are currently in the NovasArc project), published a peer reviewed article on the distribution of the nine most common cold-water corals in the cold temperate North Atlantic (Buhl-Mortensen *et al.* 2015). The paper was based on existing records as described previously. The species studied were *Lophelia pertusa*, *Madrepora oculata*, *Paragorgia arborea*, *Primnoa resedaeformis*, *Paramuricea placomus*, *Acanella arbuscula*, *Isidella lofotensis*, *Radicipes gracilis* and *Acanthogorgia armata*. The compiled number of records were 5,854, of which 4,875 were obtained from own databases and 979 from publications.

Distribution maps were produced, and temperature, broad-scale topography, and current patterns were considered in order to understand the distribution patterns and environmental conditions at which the species thrive. Currents connecting shelves and slopes above 500 m can explain the wide spatial distribution of *L. pertusa*, *P. arborea* and *P. resedaeformis*. However, *L. pertusa* is scarce on the western side of the North Atlantic, *P. arborea* has only few records off Iceland, and *A. arbuscula* and *A. armata* are not found on the Norwegian shelf.

The differences in distribution patterns between species indicate that they are differently affected by the topographic barrier between the North Atlantic and the Nordic Seas. Present knowledge of dispersal ability of cold-water corals does not allow a firm causal explanation to the observed distribution patterns. These, however, are indicative of biogeographic provinces relevant to cold-water corals and their habitat requirements.

7. Predictive modelling of suitable habitat for VMEs

The lack of information on the distribution of VMEs in the deep sea is hampering the development and application of measures to protect these habitats from anthropogenic impacts (Weaver *et al.* 2011). Given the wide distribution of deep-sea habitats, and the expense and complexity of documenting these habitats (e.g. using video or photographs), Environmental Niche Models (ENMs) are increasingly recognised as an effective way to obtain knowledge on the likely distribution of VMEs and other deep-sea ecosystems (Vierod *et al.* 2014). Indeed, several studies have used ENMs to predict the distribution of VME indicator species (e.g. Davies and Guinotte, 2011; Yesson *et al.* 2012; Rengstorf *et al.* 2013; Ross and Howell, 2013), and the use of these models has been recommended as part of the process for designing management plans to protect VMEs from fishing impacts (Ardron *et al.* 2014; Vierod *et al.* 2014). The models developed in this study represent a first attempt to model the distribution of all important VMEs in the Arctic and sub-Arctic region of the Northeast Atlantic.

7.1 Environmental predictors

A series of environmental variables were selected as predictors in the ecological niche models used to map the potential distribution of VMEs.

Bathymetry data for the study area was obtained from the General Bathymetric Chart of the Oceans (GEBCO) 2014 (<http://www.gebco.net/>), a global relief model with a resolution of 30 arc-seconds. The data was projected using a Lamberts Equal Area projection centered at 69°N and 4°W and bilinearly interpolated to obtain a raster with a resolution of 500 m. All other environmental datasets were adjusted to match the same projection and resolution using bilinear interpolation (Figure 12).

The seabed morphology was characterized following Lecours *et al.* (2017), using the following terrain variables derived from the 500 m bathymetry raster: local mean depth, slope, aspect (divided into northness and eastness), bathymetric position index (BPI), and vector ruggedness.

The terrain analysis variables were calculated for two spatial scales (using moving windows of 3 and 21 cells) corresponding to scales of 1500 and 10500 m.

Temperature and *salinity* depth profiles for the study area were obtained from the NISE (Norwegian Iceland Seas Experiment) database (Nilsen 2008). Near-bottom temperature and salinity was estimated following the methodology described by

Jochumsen *et al.* (2016). Measurements from the lower 20% of the water column above the bottom were extracted from the database and gridded in boxes with a longitudinal resolution of 0.2° and a latitudinal resolution of 0.1°. Mean, minimum and maximum temperature and salinity were calculated for each cell, and values for cells with no data were estimated by interpolating along topography following Davis (1998). An additional layer was created showing the difference between the maximum and minimum temperature values in each cell. A map of the minimum bottom temperature is shown in Figure 12.

The aragonite saturation state (omega arag) for the study area was obtained from data provided by Jiang *et al.* (2015) and interpolated into the 500 m grid also following Davis (1998).

Primary productivity (mg C m⁻² day⁻¹, NPP) was included as monthly averages of mean net primary production estimated from MODIS data, using the carbon-based Production Model (CbPM) (Behrenfeld *et al.* 2005; Westberry *et al.* 2008). Data were obtained from the Ocean Productivity site.

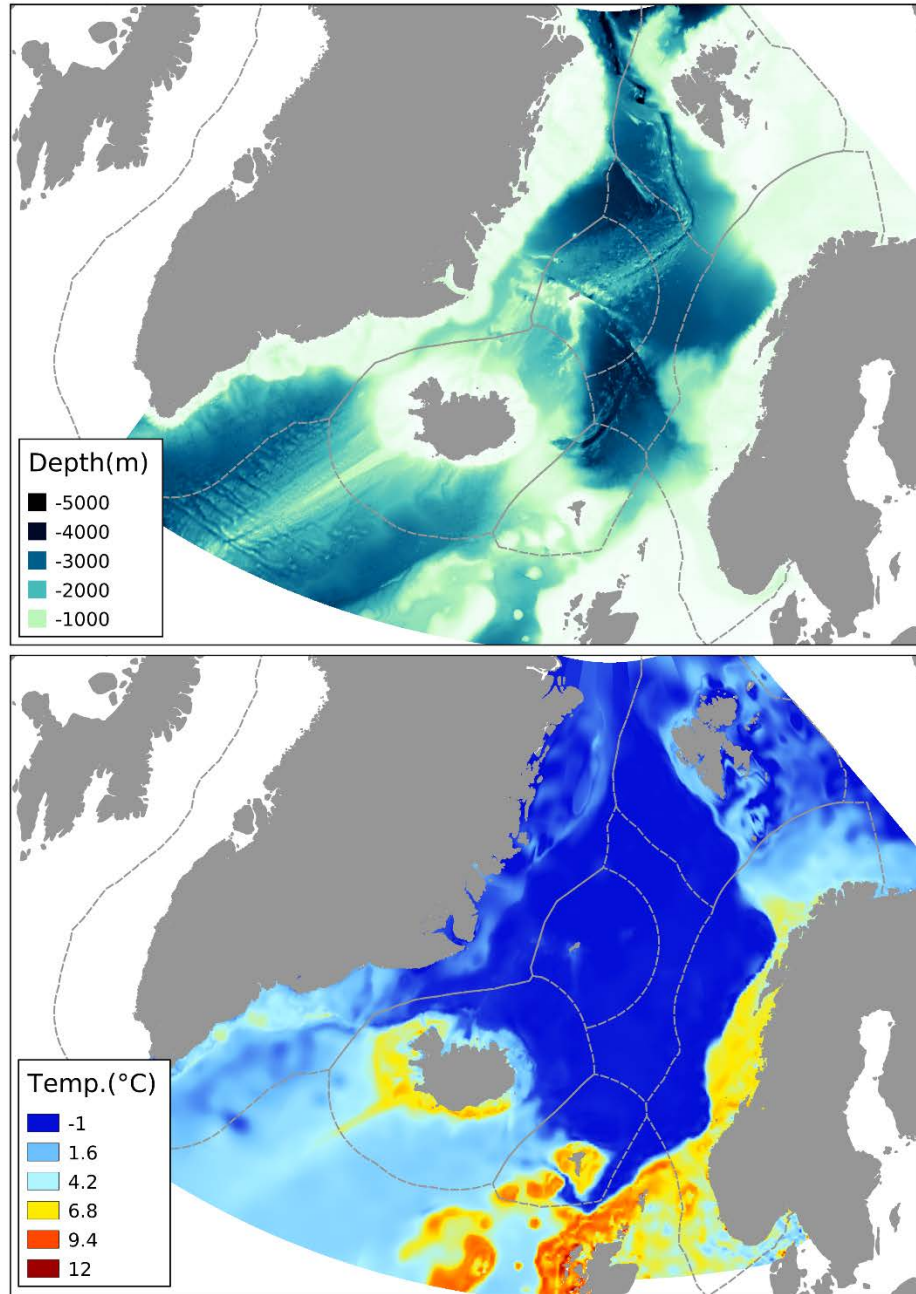
(<http://www.science.oregonstate.edu/ocean.productivity/index.php>), and downloaded for the period 2006-2015 with a resolution of 5 arcmin.

Particulate organic carbon flux to the seafloor (POC flux; g C m⁻² year⁻¹). POC was estimated from the bottom depth and the seasonal variation in NPP which was defined as the ratio between the standard deviation and the mean of monthly NPP values (Lutz *et al.* 2002; Lutz *et al.* 2007).

Current speed and nutrients. Data on near-bottom average current speed and concentrations of *nitrate, phosphate and silicate* were obtained from the Bio-ORACLE v2.0 database using the R package "sdmpredictors" (Assis *et al.* 2017), which provides layers of near-bottom physical and chemical parameters. Current velocity data (m*s⁻¹) was produced by the Global Ocean Physics Reanalysis (ECMWF), and nutrient concentrations (in mmol*m⁻³) by the Global Ocean Biogeochemistry Non-assimilative Hindcast (PISCES). In both cases, data was obtained from the E.U. Copernicus Marine Service Information (<http://marine.copernicus.eu>), and statistically downscaled to a resolution of 5 arcmin using a kriging model (Assis *et al.* 2017).

Collinearity among environmental layers was explored by computing the Variance Inflation Factor (VIF, Dormann *et al.* 2013). Variables with high collinearity were eliminated through a stepwise procedure in which the VIF was calculated for all variables, the variable with highest VIF was removed, and VIFs were recalculated until all variables had a VIF value lower than 10 (Naimi *et al.*, 2014).

Figure 12: Depth and minimum temperature in the study area



Note: Depth data was obtained from the General Bathymetric Chart of the Oceans (GEBCO).
Temperature data was compiled by the NISE (Norwegian Iceland Seas Experiment) project.

7.2 Predictive distribution models of VMEs

The distribution of VMEs was predicted using ecological niche models (ENM), also known as species distribution models or habitat suitability models. ENMs predict the geographic distribution of a species by identifying the combinations of environmental variables where the species is likely to be prevalent and mapping that combination of variables into geographic space.

MaxEnt (version 3.4.1) is an ENM using a presence-only approach to quantify the relationship between environmental variables at locations where a species has been observed versus background locations in the study region (Phillips *et al.*, 2006). These relationships were modelled by applying “feature classes” (FC), that are transformations of the original environmental variables. Different combinations of feature classes allow the construction of very flexible models. By default, MaxEnt selects the number of feature classes based on the number of presence observations. To avoid overfitting, MaxEnt uses regularization, which penalizes the inclusion of parameters that produce little improvement in the model (Merow *et al.*, 2013). Regularisation is controlled by setting a parameter termed the regularisation multiplier (RM, default value = 1). Higher RM values reduce the flexibility of the relationships between species presence and predictor variables.

The performance of ENM models is sensitive to model specifications (Merow *et al.* 2013; Elith *et al.* 2011; Warren *et al.* 2014). Recent studies have shown that the default MaxEnt options can produce models that perform poorly (Radosavljevic and Anderson, 2014). To select model settings approximating optimal levels of model complexity, for each VME, we made models with different combinations of feature classes, using the ENMeval package (Muscarella *et al.* 2014) in the statistical software R (R development core team, 2008). To select the model with the optimal combination of feature classes and regularization parameter we followed a two-step procedure. First, models with low OR₁₀ (10% training omission rate, values lower than 10%), which indicates that the model is not overfitting, were selected. Secondly, from these the model with the highest discrimination power by choosing the model with the highest AUC (Area Under the receiver operating characteristic Curve) value was selected. The model selected was used to predict the suitability of the VME in the study area. Predictions were exported in the cloglog scale, which under specific conditions can be approximated to a probability of presence (Phillips *et al.* 2017).

Predicted suitability values may be unreliable when based on combinations of environmental parameters outside of the observed ranges in the training data (Elith *et al.*, 2011; Radosavljevic and Anderson, 2014), in particular where these variables are indirect drivers of species distributions (Braunisch *et al.* 2013). For each of the selected models we computed the Multivariate Environmental Similarity Surfaces (MESS). MESS quantifies the similarity in the environmental parameters between the occurrence locations and the entire study area (Elith, *et al.* 2010). Locations with negative MESS values, which indicate model extrapolation, were removed from the analysis.

7.3 Results from model

Ecological Niche Models (ENM) were fitted to the presence data for species indicators of the 11 VMEs considered. The AUC is a number used to evaluate a model's performance, and for all models it was relatively high with values ranged from 0.813 to 0.962, indicating that the models had good performance (Table 1). The presence/absence threshold ranged between 0.019 for VME "hard bottom gorgonians" and 0.385 for VME "soft bottom sponge aggregations". The most important explanatory environmental variables differed between the VME models, but in general the most important were: minimum bottom temperature, depth, large-scale and small-scale bottom ruggedness, and particulate organic carbon (indicating food availability) (Table 1).

There was good agreement between the areas of high predicted suitability of each VME and the locations of the records of indicator species. Figure 13 provides the predicted distribution of soft bottom sponge aggregations. Areas of high suitability correspond spatially to the distribution of the available observations of VME key species, including the Norwegian and Icelandic shelf breaks. Maps of the predicted distribution for each of the VMEs are included in Appendix 5.

Predicted distribution area (Table 1): VMEs that covered the largest proportion of the study area were: cup coral fields (24.1%), sublittoral sea pen communities (20.4%), and Deep arctic sponge aggregations (20.2%), and VMEs that covered the least proportion were: cold-water coral reefs covering 10.4%, bathyal sea pen communities (11.0%), and stylasterid corals (11.6%). When only areas with a suitability higher than 0.8 was considered as optimal habitats the predicted distribution was much more limited, and ranged between 0.75% for stylasterid corals to 9.62% to Deep arctic sponge aggregations. The sum of the areas covered by all VMEs is greater than 100% of the study area. This is caused by the predicted co-occurrence of several VMEs as shown in Figure 14.

Areas with predicted high co-occurrence of VMEs are the southern and western Icelandic shelf, the shelf break off southern Greenland, the Faroe Shelf and Faroe Bank, the Norwegian shelf break, and a wide area on the Norwegian shelf.

Models will in general overpredict the occurrence of VMEs and the prediction depends on the available environmental information and knowledge of the ecology of the key VME species. Caution is always needed when interpreting and analysing the outputs of broad scale Environmental Niche Models because they can be subjected to a series of biases and uncertainties (Vierod *et al.* 2014). For example, Anderson *et al.* (2016) validated models for four reef-forming corals in the South Pacific Ocean using data from photographic surveys collected independently from the data used to fit the model. They found that the observed frequency of corals was much lower than predicted and that the correlation between observed and predicted coral distribution was not particularly high. The poor performance of the models was attributed to the low precision of the global bathymetry data, and to the lack of data on geomorphology and substrate data at the scale appropriate to the taxa modelled (Anderson *et al.* 2016). These factors may be also relevant for the models in our study.

An inspection of high-resolution bathymetry derived from multibeam data available for the Norwegian shelf and some regions in the Icelandic shelf indicates that the GEBCO global bathymetry models are much less detailed and do not resolve small geomorphic features that may be important for the distribution of VMEs (Davies *et al.* 2009; Henry *et al.* 2010). Nevertheless, Ross *et al.* (2015) observed that sometimes models with coarse resolution bathymetry performed better than models with fine resolution bathymetry, depending on the spatial scale of the processes regulating the distribution of the target species. The lack of information describing substrates is also likely to affect the results of our models, as sediment composition is highly variable and is known to influence the distribution of epibentic sessile organisms (Davies and Guinotte 2011; Tracey *et al.* 2011). The effect of the lack of substrate data in our models can be illustrated by the fact that the cold-water coral model predicts high suitability in regions of the Skagerrak known to be dominated by soft sediments and where cold-water corals are usually not observed. This effect is accentuated by the low resolution of the bathymetry model, because terrain variables derived from high-resolution bathymetry can play a better role serving as proxy variables for sediment composition (Dunn and Halpin 2009). Given these factors, there is a need to produce ENMs at finer scales, incorporating high resolution bathymetry and sediment distribution data, if available.

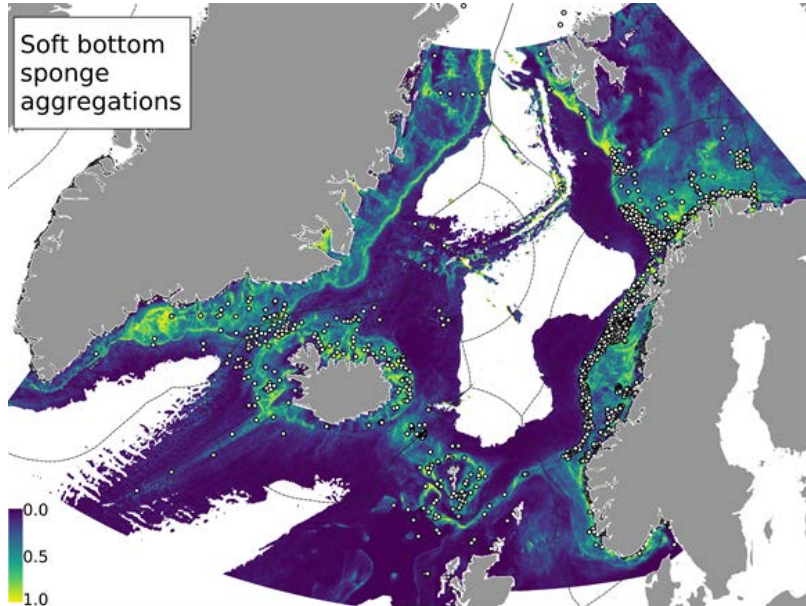
In this study we have not produced uncertainty estimates for the predicted distribution of VMEs. Although the internal uncertainty of MaxEnt models is difficult to quantify, bootstrap methods have been used to quantify the variability of the MaxEnt predictions (Anderson *et al.* 2016a). Before predicted VME distributions can be used for management applications, it is necessary to quantify their uncertainty and to develop methods to incorporate the uncertainty in management decisions. For example, if planning tools like Zonation or Marxan would be used to prioritise areas for protection, it is possible to prioritise locations with high conservation value (i.e. with high VME suitability and low uncertainty) (Anderson *et al.* 2016a).

Table 1: Distribution area for the eleven vulnerable marine ecosystems (VMEs) predicted by the habitat suitability models resulting from the MaxEnt program

VMEs	Presence			Optimal			MaxEnt Model		Environmental predictors % contribution to model											
	km ² x 10 ³	% Total area	% area <1000 m	km ² x 10 ³	% Total area	% area <1000 m	AUC	Thresh- hold	Min Temp	Bathy	LS Rough	SS Rough	POC	Slope	Speed	Si.	Arag.	NPP	Var. Temp	SS BPI
Sublittoral sea pen communities	892.5	20.4	26.6	153.9	3.5	5.6	0.887	0.418	11.7	8.2	17.7	6.1	6.3	14.6	10.1				11.9	
Cauliflower corals	575.3	13.1	21.1	140.7	3.2	5.3	0.899	0.417	9.7	29.9		7.6	6.9	7.9	6.4	14.1	5			
Hard bottom sponge aggregations	590.7	13.5	22.1	107.3	2.5	4.0	0.94	0.196	26.3		6.1	8.3	31.5		5.4	7.1				
Soft bottom sponge aggregations	831.4	19.0	29.5	119.4	2.7	4.0	0.813	0.385	16	17.5	8.7	9.5			30.9					
Bathyal sea pen communities	482.9	11.0	9.5	80.5	1.8	2.7	0.955	0.185	10.7	49.3	5			5.1	12.7					
Deep arctic sponge aggregations	885.7	20.2	6.4	421.6	9.6	2.3	0.896	0.547	48.8	27.3				7.7						
Cold water coral reefs	457.2	10.4	16.1	53.1	1.2	2.0	0.962	0.081	41.7	7.7	12.5		16.2							
Hard bottom gorgonians	721	16.5	25.1	50.8	1.2	1.8	0.948	0.019						72.3						20
Cup coral fields	1056.9	24.1	17.8	113.2	2.6	1.6	0.894	0.181	27.6	21.3	5.7					25.9			6.7	
Soft bottom gorgonians	629.7	14.4	10.9	50	1.1	1.5	0.95	0.092	31.1	20.1				5.2	10.2			12.7		
Stylasterid corals	509.6	11.6	18.8	32.9	0.8	1.2	0.924	0.105	11.7			14.4	20.2	16.3	5.6		9.9			
All VMEs	3234.5	54.6	44.5	1003.4	16.9	14.1														

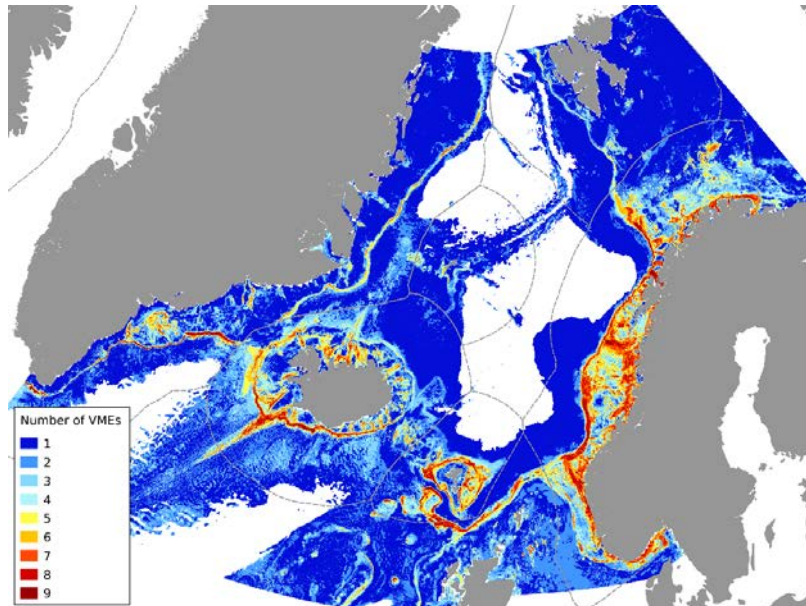
Note: The models are based on observed occurrences of the indicator species for the different VMEs, and the value of environmental parameters at their site of occurrence are used as predictors. The table lists the distribution area for the VME as: km², % of the total study area, and % of the area that is shallower than 1000m. "Presence" values are based on the model estimated threshold and "Optimal" based on a threshold of 0.8 indicating that habitat conditions are optimal. AUC (Area Under the Curve) value: measures the model performance, "Threshold": is the model estimated threshold for presence. The environmental predictors that contributed > 5.0% to the model are listed with percent contribution as follows: minimum seafloor temperature (Min Temp), bottom depth (Bathy), large-scale-vector ruggedness (LS Rough), small-scale vector ruggedness (SS Rough), particulate organic carbon (POC), bottom slope (Slope), current speed (Speed), Silicate concentration (Si), aragonite saturation state (Arag.), primary productivity (NPP), variation in seafloor temperature (Var.Temp), and small-scale Bathymetric Position Index (SS BPI).

Figure 13: Predicted distribution of soft bottom sponge aggregations



Note: The color indicate the predicted suitability by the MaxEnt model, ranging between 0 (low suitability) to 1 (high suitability). The white docs indicate the locations of species indicators of this VME in the complied database.

Figure 14: Co-occurrence of VMEs, defined as the number of VMEs with predicted presence in each cell



Note: Areas with high predicted co-occurrence are indicated with a red colour.

8. Threats to VMEs in the N-Atlantic

Significant adverse impacts, as described in the FAO guidelines, are those that compromise ecosystem integrity (i.e. ecosystem structure or function) in a manner that:

- impairs the ability of affected populations to replace themselves;
- degrades the long-term natural productivity of habitats; or
- causes, on more than a temporary basis, significant loss of species richness, habitat or community types.

An overview of fisheries and other human impacts and how they conflict with the presence of VME species is provided in what follows. The fisheries are considered to represent the largest pressure on VMEs in the Nordic seas at present. Therefore, the focus of the present study was on mapping the bottom touching fishing gear within the study area.

Examination of the overlap between human activities and predicted VME distributions will identify potential hot spot areas where there are conflicts between commercial and nature/conservation values.

8.1 Evaluating human impact on VMEs

The important questions are: how much pressure the different VME types are facing, and is it possible to predict how increased activities in the Nordic sea will impact upon these areas.

The steps involved

- Identifying the relevant VMEs (section 6)
Produce VME distribution maps for the whole study area based on the compiled database.
- Identify relevant anthropogenic stressors (section 8).
Produce a fishing pressure map based on trawling data (VMS records) for the study area.
- Predictive modelling (section 7).
Produce modelled distribution using MaxEnt predicting areas of occurrence for the relevant VMEs

- Risk analysis (section 9).
Develop risk analysis strategy using a cut off level for likely occurrence of VMEs and different levels of fishing pressure
- Produce VME-risk maps

8.2 Compilation of data on trawling effort

Fishing intensity estimates were derived from Vessel Monitoring System (VMS) and Automatic Identification System (AIS) data. VMSs are satellite-based monitoring systems in which vessels are equipped with a transmitter that sends at regular intervals information on the vessel identification, position, and speed. The information is received by a station on land. VMSs were introduced to track the positions of vessels for safety purposes, and in the case of fishing vessels, to monitor compliance with fishing regulations (e.g. fisheries closures). A large number of studies have used VMS data to describe the spatial distribution of fishing effort (Bez *et al.* 2011; Bastardie *et al.* 2010; Gerritsen and Lordan, 2011), examine the behavior of fishing vessels (Bertrand *et al.* 2005; Joo *et al.* 2015), evaluate the level of compliance with spatial closures (Posen *et al.* 2014), and study the impacts of the use of fishing gear on the sea bottom (Gerritsen *et al.* 2013; Buhl-Mortensen *et al.* 2015; Buhl-Mortensen and Buhl-Mortensen 2018). The reliability of the transmissions is high, although the interval between VMS transmissions is relatively large (usually 1–2 hours) due to the cost of satellite communications, limiting the spatial resolution of the resulting data.

Data on vessel positions for the period 2013–2015 was obtained from a variety of sources. AISs are radio-based systems designed to allow vessels to share identification, position, and speed with the other vessels in the area, improving navigation safety (Natale *et al.* 2015; Russo *et al.* 2016). Vessels fitted with AIS transceivers can also be tracked by land-based stations placed along the coastlines, and by low-orbiting satellites. AISs are based on a dedicated VHF transceiver, and therefore have limited range, but can provide information in near real-time. The high frequency of transmission (down to once every few seconds, depending on the vessel activity) allow for a very detailed description of fishing effort (Russo *et al.* 2016; Oberle *et al.* 2016), although there may be gaps in the data due to uneven satellite coverage, absence of vessels in the vicinity, or lack of receiving stations on land.

Norwegian VMS data was provided by the Directorate of Fisheries in Norway and consisted of two datasets. The first one included VMS records of Norwegian vessels operating within and beyond Norway's EEZ and of vessels from the European Union fishing within Norway's EEZ. The data included fishing gear codes. The data was classified as otter trawlers and as small trawlers (which included vessels using Nephrops trawls, shrimp trawls, Danish seines, and Beam seine). We also distinguished between vessels using a single trawl and vessels using double trawls. The second dataset included non-EU vessels operating in Norwegian waters. From this dataset we removed

records from Icelandic and Faroese vessels, to avoid double-counting. Both datasets only included VMS records classified as fishing. This dataset did not distinguish between types of bottom trawls, so we considered that all trawlers were otter trawlers. Neither dataset included timestamps, therefore it was assumed that the interval between VMS records was one hour, and that vessels were fishing at a speed of 4 knots.

Positions of Icelandic vessels operating within and beyond Iceland's EEZ were provided by the Icelandic Directorate of Fisheries. The data consisted of a combination of VMS and AIS data. In most cases the temporal resolution ranged between 10 and 15 minutes. Similar to the Norwegian VMS data, we classified vessels as using otter trawls versus smaller trawls and registered when vessels were using double trawls. VMS records from vessels with otter trawls and small trawls were classified as fishing when vessel speed was between 1.6 and 6.5 Kts, and between 1 and 4 Kts, respectively.

Faroese VMS data were provided by Faroese Coastal Guard and included records from Faroese bottom trawlers, with fishing speeds considered to range between 1 and 4 knots. The temporal resolution of the data ranged between 20 and 120 minutes.

Data from the Global Fisheries Watch (GFW, Kroodsmá *et al.* 2018) was used as a supplement to the compiled VMS data, to obtain fishing effort estimates from east-Greenland and the high seas in the study area for which we were not able to obtain VMS data. GFW compiles AIS data from fishing vessels. The data is analysed by GFW to assess vessel movement and behaviour using neural network algorithms and logistic models to classify vessel types and identify which transmissions originate during fishing operations (Souza *et al.* 2016). Daily fishing effort data was used, gridded at 0.01 degrees, classified by gear type and flag state, for the period 2013–2015. Data from Norwegian, Icelandic, or Faroese vessels, which were already represented in the VMS datasets were removed and all data within the Norwegian EEZ, because the Norwegian VMS dataset included vessels from all nations fishing in Norwegian waters.

In the GFW dataset, vessels classified as “trawlers” included both pelagic and bottom trawlers. As a result, it is possible that the GFW fishing effort data overestimates the effort on the seafloor, in particular in deep areas where bottom trawling is rare or non-existent. In order to estimate the effort due only to bottom trawlers we compiled the starting position of all trawl tows carried out by Icelandic trawlers between 2010 and 2017, including pelagic and all types of bottom trawlers. Using these data, a binomial model to predict the ratio between bottom trawling and all trawling was fitted, as function of mean bottom depth and slope calculated on a 12.5 km grid. The resulting model was used to adjust the GFW effort estimates. In addition, the effort in all cells with bottom depths below 1000m was considered to be only for pelagic trawlers, as Icelandic logbook data indicated that bottom trawling rarely occurs in deeper waters.

To obtain estimates of the swept-area ratio (SAR) the method proposed by Gerritsen *et al.* (2013) was followed. A nested grid was generated from the locations of the VMS records, using an initial cell size of 2.5 Km. Cells that had more than 20 records were divided in half, until no cells remained with a higher number of records. Data on

vessel speed and trawl width was used to estimate the area swept by the trawl associated to the VMS records in each cell. SAR is the proportion of the total area swept and the area of the cell. A SAR value of 1 indicates that on average the entire cell is trawled once per year. The resulting nested grid was converted into a regular grid with extent and resolution matching the grid using for the environmental variables.

Results

Fishing was irregularly distributed in the study areas (Table 2). In Icelandic waters, 54.4% of the areas with depths of 1000m or less experienced some degree of fishing. A total of 14.0% of the area experienced high or very high fishing intensity, including a wide area north of the Westfjords, along the southern shelf break, and in several other areas within the Icelandic shelf (Figure 15). Within the Greenlandic EEZ fishing effort is relatively low (1.7% of the areas at <1000m), and it is high or very high only in very restricted locations along the shelf break. The Faroese had fishing activity across 47.0% of areas at <1000m and 18.7% had high or very high intensity (Table 2). Fishing effort is very high on the Faroe Shelf, particularly east of the Faroe Islands, and to a lesser degree around the Faroe Bank. There is also low to intermediate fishing effort on the Iceland-Faroe ridge (Figure 16). Fishing effort in the Norwegian EEZ was similar in proportion to the Faroese EFZ, with 38.9% of areas at <1000m experiencing some degree of fishing and 18.0% with high or very high effort (Table 2). High or very high fishing pressure was observed widely in the Skagerrak and on the Viking and Bergen Banks (Figure 16). Along the Norwegian coast areas with high or very high fishing effort were located mostly north of 67°N, in the vicinity of the Lofoten Islands, although fishing effort was high also in delimited areas farther south (Figure 17). In the Barents sea, within Norway's EEZ, effort is high along the Norwegian coastline, south of Bear Island along the limit with the Svalbard fishery protection zone (Figure 18).

Figure 15: Fishing effort in Icelandic waters

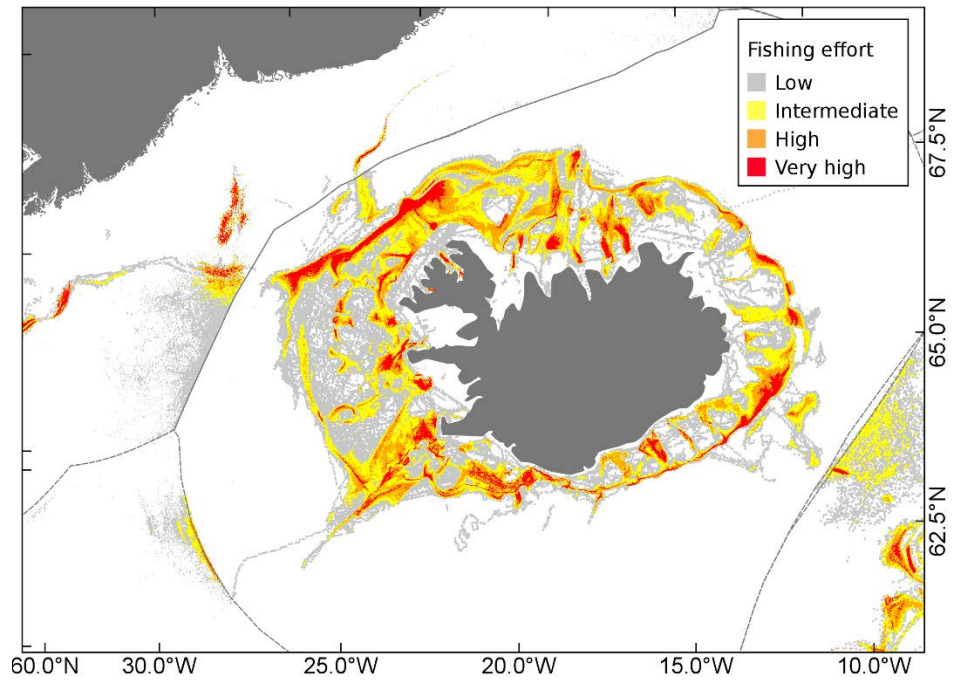


Figure 16: Fishing effort around the Faroes and the North Sea

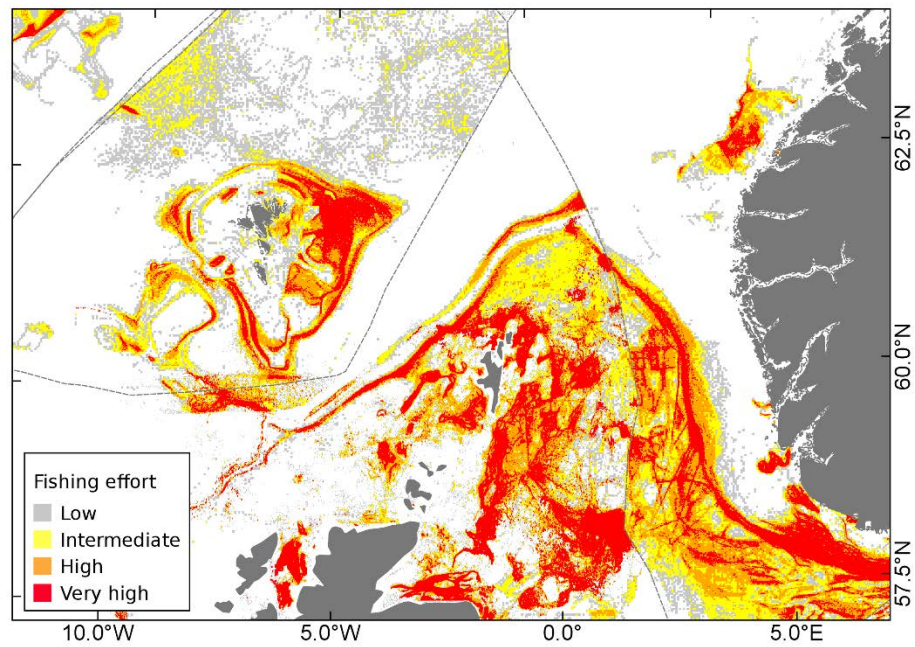
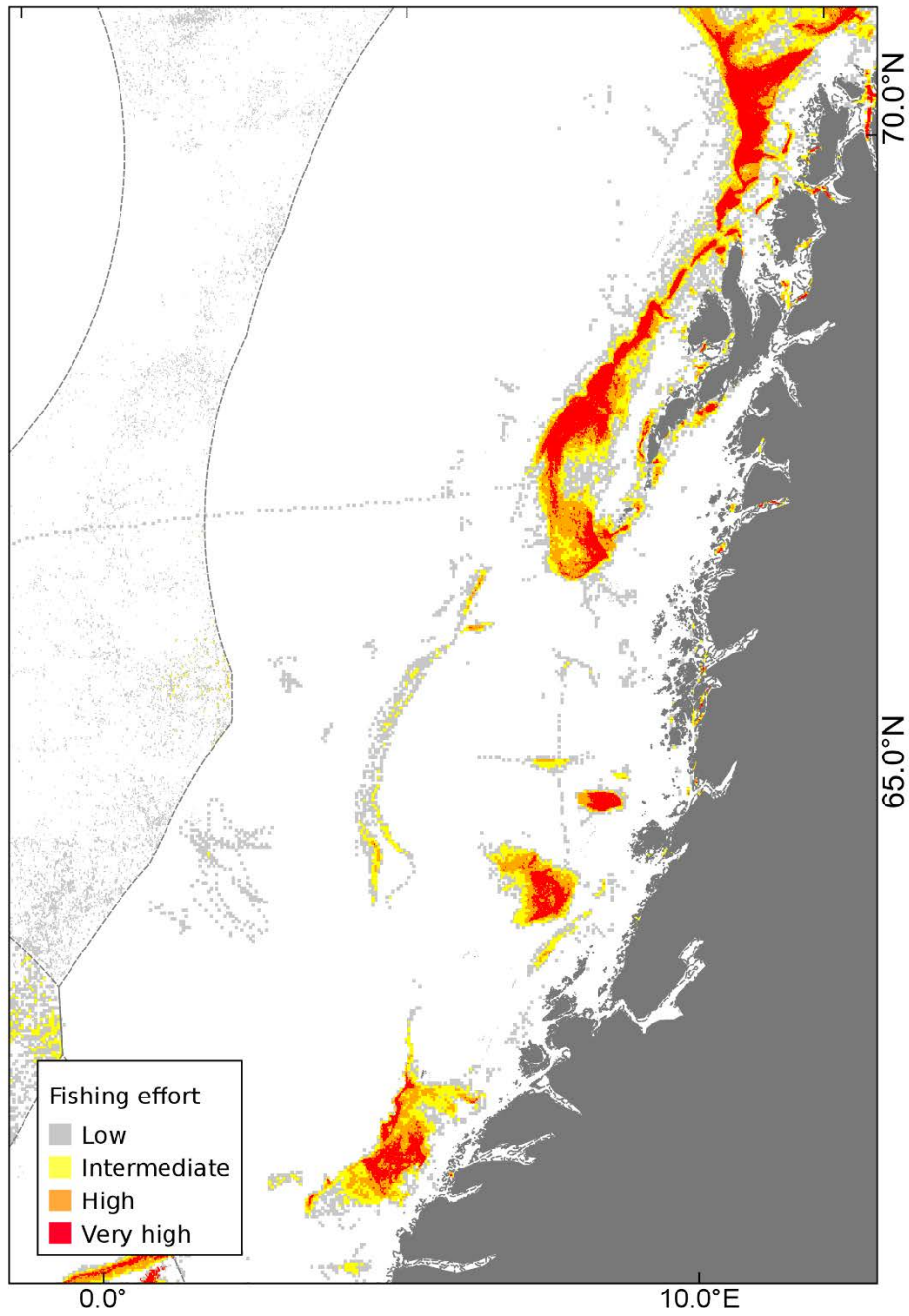
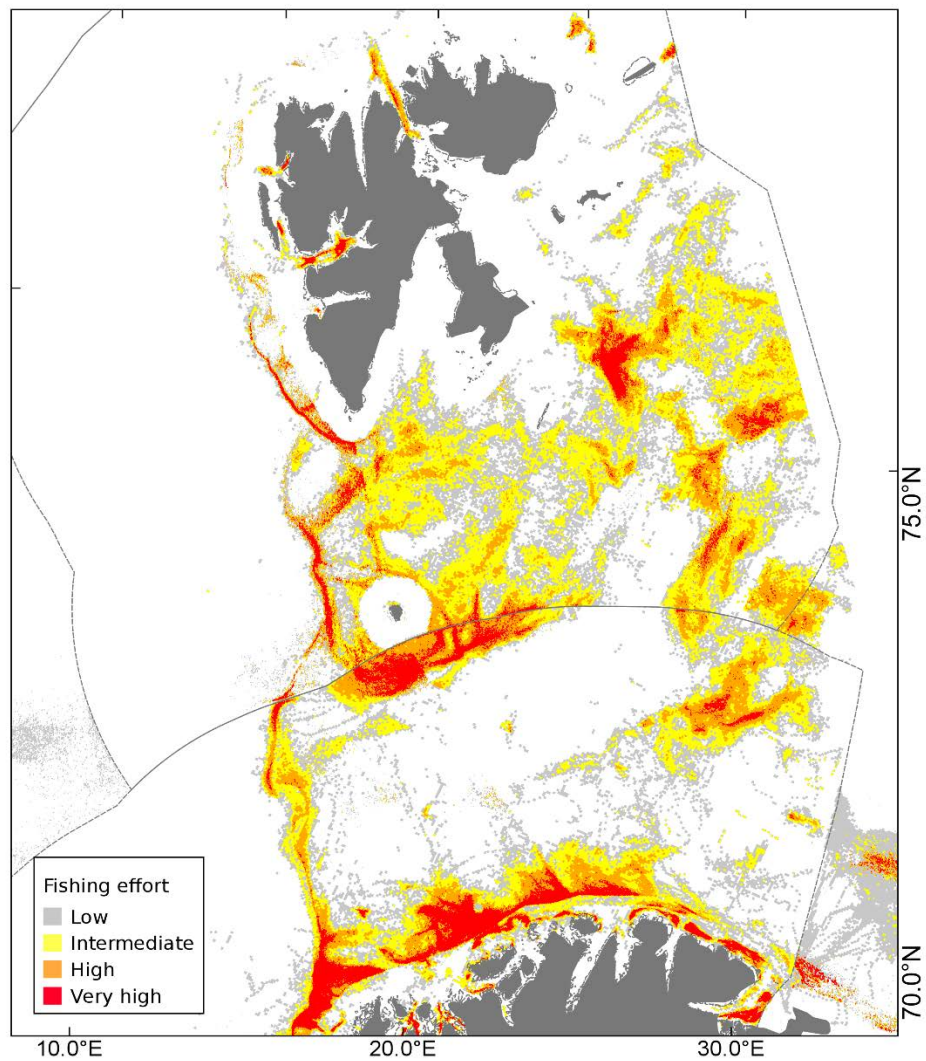


Figure 17: Fishing effort in Norway from Møre og Romsdal to Troms



Effort is more widely spread within the Svalbard fishery protection zone itself, where 37.1% of areas at <1000m experience some degree of fishing effort, but high or very high effort was observed in only 8.5% of that area. Little fishing effort was observed within the Jan Mayen EEZ, or in the adjacent international waters, with only 0.7% of areas at <1000m experiencing any fishing effort.

Figure 18: Fishing effort in the central and southern Barents Sea



9. Risk analysis

In order to quantify the degree of overlap between fishing effort and predicted VME distributions, we carried out a risk analysis based on the Ecological Risk Assessment for Effects of Fishing (ERAEF) developed by Hobday *et al.* (2011). The ERAEF is primarily an exposure-effect analysis suited to assessing ongoing pressures like fishing, as opposed to the likelihood-consequence approach to estimating risk used in many ecological risk assessments (Williams *et al.* 2011). The ERAEF is increasingly being used to quantify the risk of different fishery impacts on the environment, including impacts on the benthos (Clark and Tittensor 2010; Williams *et al.* 2011; Penney and Guinotte 2013).

The ERAEF is a hierarchical framework consisting of three levels, each of increasing complexity. The analysis in each level serves to screen out low-risk impacts, allowing the higher-risk impacts to be evaluated at the next level. The first level is a qualitative assessment of all potential fishery-environment interactions, termed Scale, Intensity and Consequence Analysis (SICA). The second level is a semi-quantitative Productivity/Susceptibility Analysis (PSA). Finally, the third level is a fully quantitative model-based risk assessment (Hobday *et al.* 2011).

9.1 Method used

Our risk analysis methodology follows Penney and Guinotte (2013) and is based on the second level PSA of the ERAEF. It consists of comparing the likelihood of VME occurrence and the likelihood of fishery interaction. As a measurement of the likelihood of VME occurrence we utilised the prediction of the Ecological Niche Models (ENMs) of each of the VMEs. The PSA utilises a number of indicators to generate an integrated measure of productivity (Hobday *et al.* 2011). An ENM is analogous to the PSA because it provides an integrated measurement of the likelihood of favourable habitat (Penney and Guinotte 2013). The PSA also requires a measurement of the likelihood of fisheries interaction. We used the swept area ratio (SAR) estimates, as they are a measure of fishing intensity. The rationale is that for benthic organisms the likelihood of impacts increases with fishing intensity.

Risk evaluation was based on classifying the fishing intensity SAR values into four levels, with values indicating the number of times the grid cell is swept per year: low (>0–0.1), medium (0.1–0.2), high (0.2–2) and very high (>2). We selected these values based on what is known about the life spans of the VME indicator species. For example, the threshold between low and intermediate fishing intensity was based on the

maximum life span of sea pens which is estimated to be 10 years. A cell with an SAR value of 0.1 would be totally covered by trawling within 10 years.

The output of each of the ENM models was classified into three levels: absent, present, and optimal. For computing the absence/presence threshold we selected threshold that maximizes the sum of sensitivity and specificity (maxSSS), minimizing omission and commission errors (Liu *et al.* 2016). This threshold is commonly used to transform the output of ENM models into a binary output (Liu *et al.* 2005; Elith *et al.* 2006). The threshold was computed independently for each ENM model. Cells with predicted suitability below and above this threshold were classified as absent and present, respectively. In addition, any cell with suitability values higher than 0.8 were considered as optimal. Finally, a cross-tabulation of each cell in the study area into the four levels of fishing was performed.

9.2 Results

Entire study area: All of the eleven VMEs has experienced some degree of fishing effort within the area of their predicted distribution, albeit to a varying degree. In general, the VMEs associated with deeper waters had low overlap with fishing activity. For deep arctic sponge aggregations only 16.6% of the predicted distribution had been exposed to fishing effort, and fishing effort was intermediate to high only on 8.5% of their predicted distribution (Table 3). Overlap with soft bottom gorgonians and bathyal sea pen communities was also relatively low, 23.6% and 26.4% respectively. On the other hand, for VMEs associated with shallower depths the degree of interactions with the fisheries is higher. Eight VMEs has experienced some degree of fishing effort in 46% to 68% of their habitat, and sublittoral sea pen communities, stylasterid corals, hard bottom sponge aggregations, and cauliflower corals has experienced intermediate to high fishing effort in more than 30% of their predicted area of presence.

When considering only the areas with optimal suitability for the VMEs (Threshold >0.8) the percentage overlap with fishing increased in general. In a few cases this changed substantially, and for soft bottom gorgonians and bathyal seapen communities the overlap with any degree of fishing changed from 23.6 to 51.8% and from 26 to 43% respectively (Table 3). Maps showing the overlap between the predicted distribution of each of the VMEs and fishing effort are included in Appendix 6.

Regions: The proportion of each VME under fishing pressure varied among the regions in this study. In the Norwegian EEZ, all VMEs experienced some degree of fishing effort in their predicted presence area. In particular cup coral fields, sublittoral sea pen communities, and soft bottom sponge aggregations have experienced intermediate to very high fishing efforts in over 30% of their respective areas of predicted presence. In terms of the predicted optimal habitat, the VMEs with highest overlap with intermediate or higher fishing effort were cup coral fields (65.3%),

sublittoral sea pen communities (50.7%), soft bottom sponge aggregations (43.4%), and soft bottom gorgonians (40.9%) (Table 4).

In the Svalbard fishery area, fewer VMEs were present but the overlap between the predicted VME distribution and fishing effort was higher for several of the VMEs compared to the mainland Norwegian EEZ. The VMEs soft bottom gorgonians, bathyal sea pen communities, cauliflower corals, and soft bottom sponge aggregations, have experienced intermediate to very higher fishing effort in 67.6%, 65.5%, 65.4%, and 52.6% of their respective area of optimal habitat. Within the Jan Mayen EEZ, cauliflower corals are the only VME experiencing some degree of overlap with fisheries, although the predicted area for this VME is small (Table 4).

Within the Icelandic EEZ, overlap between the fishing effort and the optimal predicted habitat was high for several VMEs, including sublittoral sea pen communities (54.8% of their optimal habitat), hard bottom sponge aggregations (51.2%), stylasterid corals (50.5%), cold-water coral reefs (50.4%), soft bottom sponge aggregations (41.6%), and hard bottom gorgonians (42.3%) (Table 4). Similarly, within the Faroese EEZ there was high degree of fishery overlap with several VMEs including stylasterid corals (76.0% of the predicted optimal habitat experiencing intermediate or higher fishing effort), soft bottom sponge aggregations (73.3%), hard bottom sponge aggregations (69.0%), hard bottom gorgonians (62.4%), soft bottom gorgonians (51.8%), and cauliflower corals (50.5%).

In general, in the Greenlandic EEZ the overlap between fishing effort and predicted VME habitat was low, except for cup coral fields (for which 55.8% of the predicted optimal habitat experienced intermediate fishing effort or higher) and stylasterid corals (36.4%).

9.3 Methodological uncertainties

When evaluating the potential for interactions between bottom trawling and VME distributions, it is necessary to incorporate the effect of historical fisheries. Some areas may have high predicted VME suitability, but if these areas are continuously being trawled, they may not have high concentrations of VME indicator species because of the cumulative effect of fishing-induced mortality. Penney and Guinotte (2013) suggested computing a “discounted suitability”, where the suitability of each cell is reduced proportionally to the swept-area ratio. This method assumes that VME indicator species do not survive the impact of a single trawling event, and therefore in cells that are fished more than once per year the suitability is reduced to zero. This assumption can be adjusted to incorporate differences in the vulnerability of each VME to bottom trawling.

Table 2: Fishing effort intensity (% area)

	Area (km ² x 10 ³)	No	Low	Intermediate	High	Very high	Intermediate to V high
Shallower than 1000 meters							
Norway	631.3	61.1	10.4	10.5	9.6	8.4	28.5
Svalvard	431.5	62.9	13.7	14.9	6.3	2.2	23.4
Jan Mayen	17.9	88.0	4.0	4.7	2.9	0.5	8.1
Iceland	323.2	45.6	26.1	14.3	9.7	4.3	28.3
Faroe Islands	132.0	53.0	16.0	12.3	9.7	9.0	31.0
Greenland	561.9	98.1	1.0	0.3	0.3	0.4	1.0
Total area							
Norway	1158.8	98.3	1.1	0.2	0.2	0.2	0.6
Svalvard	747.4	78.6	8.0	8.6	3.6	1.3	13.5
Jan Mayen	292.8	99.3	0.2	0.3	0.2	0.0	0.5
Iceland	759.2	76.2	11.7	6.2	4.2	1.9	12.3
Faroe Islands	263.8	65.0	17.6	8.0	5.0	4.5	17.5
Greenland	1158.8	98.3	1.1	0.2	0.2	0.2	0.6

Note: The intensity of fishing effort within the EEZs (Exclusive Economic Zones) based on vessel positions for the period 2013–2015 (see main text for information of sources). The intensity is expressed as Swept-Area Ratio, i.e. the proportion of a grid cell (500 m x 500 m) that is swept by trawl each year. Low: >0–0.1, Intermediate: 0.1–0.2, high: 0.2–2, and very high: >2.

Table 3: Percentage areas of VMEs overlapping with fishing of different intensity

Fishing intensity	No		Any fishing		Low		Intermediate		High		Very high		Intermediate - Very high	
	Present	Optimal	Present	Optimal	Present	Optimal	Present	Optimal	Present	Optimal	Present	Optimal	Present	Optimal
Sublittoral sea pen communities	53.0	31.4	47.0	68.6	13.0	14.2	11.4	13.8	11.0	14.8	11.7	25.8	34.1	54.4
Stylasterid corals	46.8	42.5	53.2	57.5	15.6	13.4	12.2	13.8	11.7	11.7	13.7	18.6	37.6	44.1
Hard bottom sponge aggregations	43.6	41.5	56.4	58.5	18.7	16.8	13.9	14.4	11.9	11.8	11.9	15.5	37.7	41.7
Cauliflower corals	50.7	44.3	49.3	55.7	15.7	16.5	14.0	15.7	12.2	14.2	7.4	9.3	33.6	39.3
Soft bottom sponge aggregations	55.9	50.4	44.1	49.6	15.0	14.3	11.8	12.4	9.7	11.3	7.7	11.7	29.1	35.3
Soft bottom gorgonians	76.5	48.2	23.6	51.8	9.1	20.9	6.1	14.0	4.5	9.6	3.9	7.3	14.5	30.9
Hard bottom gorgonians	50.3	54.6	49.7	45.4	16.9	14.5	12.0	11.9	10.5	8.8	10.3	10.2	32.8	30.9
Cold-water coral reefs	54.1	58.4	45.9	41.6	13.6	11.9	10.5	10.0	9.9	7.6	11.9	12.2	32.3	29.8
Cup coral fields	68.2	67.9	31.8	32.2	8.7	5.9	7.8	8.9	7.9	9.9	7.4	7.5	23.2	26.3
Bathyal sea pen communities	73.6	56.8	26.4	43.2	11.4	19.0	7.4	12.9	5.0	7.2	2.6	4.1	15.0	24.2
Deep arctic sponge aggregations	83.4	85.2	16.6	14.8	8.1	7.9	4.7	4.1	2.8	2.2	1.1	0.6	8.5	6.9

Note: The VME areas are based on two model thresholds: "present", areas with suitability > presence threshold, and "optimal", areas with suitability > 0.8. The table also lists the proportion of presence and optimal areas with no fishing, any intensity of fishing and four different levels of fishing intensity (low, intermediate, high and very high).

Table 4: Percentage area of VMEs overlapping with fishing of different intensity, by EEZ. The VME areas are based on two model thresholds: "present", areas with suitability > presence threshold, and "optimal", areas with suitability > 0.8.

	Area of VME				Fishing intensity in % of VME area											
	Km ² x 10 ³		% eez		No fishing		Low		Intermediate		High		Very high		Intermediate - Very high	
	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt
Norway																
Cup coral fields	184.8	10.4	19.5	1.1	43.9	20.1	14.2	14.6	14.6	25.5	16.1	28.8	11.2	11.0	41.9	65.3
Sublittoral seapen communities	279.5	70.0	29.5	7.4	45.5	35.8	13.6	13.6	13.8	14.8	14.0	16.3	13.2	19.6	41.0	50.7
Soft bottom sponge aggregations	291.4	44.6	30.8	4.7	51.3	39.0	15.7	17.7	12.6	15.1	9.7	11.4	10.7	16.9	32.9	43.4
Soft bottom gorgonians	168.6	17.2	17.8	1.8	62.6	45.5	12.8	13.6	10.3	18.2	7.3	12.0	7.0	10.7	24.6	40.9
Hard bottom sponge aggregations	318.3	85.6	33.7	9.1	55.2	47.4	14.5	15.3	11.1	12.2	8.9	9.9	10.3	15.2	30.3	37.3
Cauliflower corals	195.8	66.3	20.7	7.0	53.5	48.9	15.0	15.6	12.4	13.3	9.5	11.5	9.5	10.7	31.5	35.5
Stylasterid corals	176.8	12.3	18.7	1.3	57.5	60.5	12.5	10.7	9.4	9.6	8.1	6.2	12.5	13.0	30.0	28.8
Bathyal seapen communities	52.4	22.0	5.5	2.3	69.5	60.9	13.3	16.0	9.7	13.0	4.8	6.0	2.8	4.1	17.3	23.1
Hard bottom gorgonians	299.2	25.6	31.6	2.7	57.6	68.1	14.3	10.8	10.6	7.6	8.3	4.9	9.1	8.7	28.1	21.2
Cold-water coral reefs	198.9	26.7	21.0	2.8	63.2	72.0	11.8	9.4	8.4	6.2	6.7	3.9	9.9	8.5	25.0	18.6
Deep arctic sponge aggregations	81.4	37.8	8.6	4.0	86.4	84.2	9.8	11.7	3.1	3.4	0.7	0.7	0.1	0.1	3.9	4.2
Svalbard																
Soft bottom gorgonians	7.9	0.0	1.0	0.0	93.1	8.1	2.6	24.3	1.9	24.3	1.4	16.2	1.0	27.0	4.3	67.6
Bathyal seapen communities	11.8	1.7	1.4	0.2	44.2	15.9	18.5	18.6	18.2	31.9	15.5	27.1	3.6	6.6	37.3	65.5
Cauliflower corals	92.5	20.9	11.3	2.6	30.6	19.9	13.0	14.7	22.0	26.4	25.9	29.8	8.6	9.2	56.5	65.4
Soft bottom sponge aggregations	64.2	15.8	7.8	1.9	40.4	39.0	11.6	8.4	17.9	14.5	21.2	23.0	8.9	15.1	48.0	52.6
Sublittoral seapen communities	40.0	1.5	4.9	0.2	57.5	38.8	11.4	24.2	12.6	21.9	13.0	13.4	5.6	1.8	31.2	37.1
Deep arctic sponge aggregations	103.3	71.5	12.6	8.7	92.8	97.4	4.1	1.9	2.2	0.7	0.7	0.1	0.1	0.0	3.1	0.7
Jan Mayen																
Cauliflower corals	7.0	1.3	2.4	0.4	83.1	80.0	6.6	7.4	6.5	7.0	3.3	5.1	0.5	0.5	10.3	12.6

	Area of VME				Fishing intensity in % of VME area											
	Km ² x 10 ³		% eez		No fishing		Low		Intermediate		High		Very high		Intermediate - Very high	
	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt
Bathyal sea pen communities	12.3	2.2	4.2	0.8	89.2	86.8	4.6	6.1	4.7	5.7	1.5	1.4	0.0	0.0	6.2	7.1
Deep arctic sponge aggregations	131.2	100.8	44.7	34.4	94.3	94.9	2.3	2.1	2.3	2.1	1.0	0.9	0.1	0.1	3.4	3.1
Soft bottom sponge aggregations	14.6	4.0	5.0	1.4	90.5	96.0	3.6	1.6	3.8	1.8	1.8	0.5	0.3	0.0	5.9	2.4
Sublittoral sea pen communities	9.3	0.0	3.2	0.0	95.0	94.1	2.3	4.0	2.1	1.0	0.6	1.0	0.0	0.0	2.7	2.0
Iceland																
Sublittoral sea pen communities	107.6	14.1	12.4	1.6	44.7	10.9	29.0	34.3	12.1	21.4	8.6	22.0	5.5	11.5	26.2	54.8
Hard bottom sponge aggregations	117.2	9.5	13.5	1.1	21.1	14.5	38.0	34.3	20.7	24.3	13.6	16.6	6.7	10.2	40.9	51.2
Stylasterid corals	102.2	3.7	11.8	0.4	32.7	18.5	30.2	31.0	17.2	15.8	12.2	13.9	7.7	20.8	37.1	50.5
Cold-water coral reefs	67.7	5.6	7.8	0.6	24.7	22.8	31.9	26.8	19.8	19.2	15.0	16.4	8.6	14.9	43.4	50.4
Hard bottom gorgonians	156.7	8.9	18.1	1.0	36.8	25.6	32.4	32.0	14.9	19.1	10.5	13.3	5.4	9.9	30.8	42.3
Soft bottom sponge aggregations	143.7	16.0	16.6	1.9	26.5	23.4	34.1	34.9	20.6	18.5	13.0	12.6	5.7	10.6	39.3	41.7
Cauliflower corals	116.7	21.2	13.5	2.5	44.3	39.8	25.4	26.0	16.2	17.3	10.0	11.0	4.1	5.9	30.3	34.2
Soft bottom gorgonians	192.6	22.8	22.3	2.6	80.2	40.7	12.3	32.4	4.0	13.8	2.4	9.4	1.2	3.7	7.6	26.9
Bathyal sea pen communities	195.7	33.0	22.6	3.8	74.6	54.0	13.3	26.0	6.5	12.5	4.0	4.9	1.5	2.6	12.1	20.0
Deep arctic sponge aggregations	180.7	72.8	20.9	8.4	83.3	82.6	7.8	8.0	4.8	4.8	3.1	3.6	1.0	1.0	8.9	9.4
Cup coral fields	244.8	18.9	28.3	2.2	82.7	94.6	11.1	4.2	3.4	0.7	1.9	0.4	0.9	0.1	6.2	1.2
Faroe Islands																
Stylasterid corals	76.2	6.9	28.9	2.6	39.4	12.5	14.0	11.5	13.5	24.7	16.4	22.6	16.8	28.8	46.7	76.0
Soft bottom sponge aggregations	43.3	5.8	16.4	2.2	25.7	14.8	15.3	11.8	17.4	24.2	20.4	27.5	21.3	21.7	59.1	73.3

	Area of VME				Fishing intensity in % of VME area											
	Km ² x 10 ³		% eez		No fishing		Low		Intermediate		High		Very high		Intermediate - Very high	
	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt
Hard bottom sponge aggregations	47.1	7.5	17.8	2.8	28.1	17.7	13.8	13.3	16.7	28.0	20.0	24.1	21.5	16.9	58.1	69.0
Sublittoral sea pen communities	41.0	3.8	15.5	1.5	32.3	18.2	18.1	16.2	16.5	21.3	17.7	23.8	15.4	20.5	49.6	65.6
Hard bottom gorgonians	68.8	6.6	26.0	2.5	40.9	23.3	14.1	14.3	14.1	25.8	15.8	20.3	15.0	16.2	45.0	62.4
Soft bottom gorgonians	34.5	0.7	13.1	0.3	66.6	39.9	7.3	8.4	10.0	20.2	10.6	19.5	5.6	12.1	26.2	51.8
Cauliflower corals	37.5	9.7	14.2	3.7	32.6	24.9	22.9	24.6	17.2	19.1	14.0	16.5	13.4	14.9	44.6	50.5
Bathyal sea pen communities	46.2	6.2	17.5	2.3	49.8	22.7	21.7	27.4	14.7	23.6	9.0	18.5	4.8	7.7	28.5	49.9
Cold-water coral reefs	53.1	10.9	20.1	4.1	36.3	42.0	13.7	15.8	15.2	18.4	17.4	11.0	17.5	12.8	50.0	42.2
Cup coral fields	29.0	0.7	11.0	0.3	42.5	40.8	16.3	20.2	16.3	26.0	12.4	12.0	12.4	0.9	41.2	39.0
Deep arctic sponge aggregations	58.3	32.2	22.1	12.2	44.3	54.3	31.6	31.0	12.4	8.8	7.0	4.3	4.6	1.7	24.0	14.8
Greenland																
Cup coral fields	60.9	3.9	5.1	0.3	81.0	38.8	7.5	5.5	6.2	21.4	4.4	30.1	0.9	4.3	11.5	55.8
Stylasterid corals	56.5	5.5	4.7	0.5	67.9	47.1	10.8	16.5	9.1	14.2	7.2	12.6	5.1	9.6	21.4	36.4
Cold-water coral reefs	17.1	1.0	1.4	0.1	65.4	57.6	12.8	13.8	7.8	7.5	6.7	7.4	7.4	13.7	21.8	28.5
Hard bottom gorgonians	51.8	2.6	4.3	0.2	74.0	56.5	8.7	18.9	7.7	11.8	5.6	7.0	4.1	5.8	17.3	24.6
Hard bottom sponge aggregations	31.1	0.6	2.6	0.1	74.5	59.1	7.7	18.3	8.1	12.1	6.5	6.5	3.1	4.0	17.8	22.6
Cauliflower corals	83.7	14.0	7.0	1.2	84.5	74.6	5.1	7.5	5.2	9.0	3.5	6.0	1.8	2.9	10.4	17.9
Bathyal sea pen communities	88.9	8.7	7.5	0.7	79.7	76.3	8.1	7.8	6.7	6.6	3.9	5.3	1.6	4.0	12.2	15.9
Sublittoral sea pen communities	170.0	14.7	14.3	1.2	86.4	77.6	4.8	7.7	4.4	5.5	2.9	4.4	1.5	4.8	8.8	14.7
Soft bottom gorgonians	57.6	5.0	4.8	0.4	80.0	80.8	6.0	7.8	7.0	3.9	4.8	3.1	2.3	4.5	14.0	11.4

	Area of VME				Fishing intensity in % of VME area											
	Km ² x 10 ³		% eez		No fishing		Low		Intermediate		High		Very high		Intermediate - Very high	
	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt	Pres	Opt
Soft bottom sponge aggregations	230.0	27.5	19.3	2.3	90.3	89.6	3.5	3.8	2.8	3.0	2.1	1.9	1.4	1.8	6.3	6.6
Deep arctic sponge aggregations	214.3	65.7	18.0	5.5	87.7	91.4	5.8	4.8	3.8	2.8	2.0	1.0	0.7	0.2	6.4	3.9

Note: Percentage areas of VMEs overlapping with fishing of different intensity, by EEZ. The VME areas are based on two model thresholds: "present", areas with suitability > presence threshold, and "optimal", areas with suitability > 0.8. The table also lists the proportion of presence and optimal areas subjected to no fishing, any intensity of fishing and four different levels of intensity (low, intermediate, high and very high). VMEs with predicted distribution lower than 1% of the total area in each region were not included in the table.

10. General conclusions and future work

Many of the vulnerable marine ecosystems (VMEs) in the study area are widely distributed. Soft and hard bottom sponge aggregations, hard bottom gorgonians, sublittoral sea pen communities, and cauliflower corals are predicted to cover > 20% of the study area shallower than 1000 meters.

These VMEs are also among the most frequent at regional scale, but in addition cold-water coral reefs are common in Norway and the Faroe Islands, stylasterid corals in the Faroe Islands, deep arctic sponge aggregations in Iceland, the Faroe Islands and Jan Mayen, and bathyal sea pen communities in Iceland.

Of the anthropogenic activities in the study area bottom trawling represents the main threat to the VMEs. The compilation of trawling activity in the study area shows that fisheries mainly occurs shallower than 1000 meters and that 50 to 60% of the seafloor is not targeted. However, 30% of the seafloor has experienced intermediate to very high fishing effort.

Eight of the VMEs has experienced fishing effort in 46% to 68% of their habitat and intermediate to high fishing effort occur in more than 30% of the Stylasterid corals, hard bottom sponge aggregations, and cauliflower corals predicted area of presence.

Regionally, several VMEs are predicted to have experienced intermediate to high level of fishing effort in > 50% of their optimal habitat, and for some regions these are the same VMEs, and example is sublittoral sea pen communities in Norway, Iceland, Faroe Islands, and Greenland, cup coral fields in Greenland and Norway, hard bottom sponge aggregations in Iceland and Faroe Islands, Stylasterid corals in Iceland and Faroe Islands, Cold-water coral reefs in Iceland, soft bottom sponge aggregates in Iceland, hard bottom and soft bottom gorgonians in Faroe Islands.

The VMEs overlap with fishing increases in general when risk analysis is based on areas with optimal suitability. However, even when a conservative threshold value was used to model the distribution of VMEs the results indicate that most VMEs have experienced an intermediate to high level of fishing in less than 40% of their distribution area in the whole study area.

10.1 Future needs

The data availability on VME indicator species in the study area is very uneven, and density of observations high in areas with active habitat mapping programmes using underwater images, particularly on the Norwegian shelf, in the Barents Sea, and some areas on the Icelandic shelf. Observations are less abundant and more dispersed when they are the result of benthic fauna surveys like the BIOICE and BIOFAR projects in Icelandic and Faorese waters. Undoubtedly the absence of VME records in many areas reflects the absence of the environmental conditions required by the indicator species. However, in some areas the Environmental Niche Models predict high suitability for VMEs where few field records exist mainly due to lack of seafloor mapping. This is in particular the case for some areas on the Greenlandic shelf and shelf break. These areas, where VMEs are likely to occur and knowledge is poor, should be in focus for future habitat mapping surveys. In addition, there are broad areas on the Icelandic, Norwegian and Faroese shelves where visual habitat mapping has not yet been carried out.

It is important to carry out these studies, as they provide information that cannot be obtained by other means. Locations with confirmed VME presence, for example from underwater video surveys, would have no uncertainty and receive the highest priority for conservation. Uncertainty maps would also inform which areas should be targeted by future surveys, by highlighting locations where VMEs are predicted to occur and where the predictions are uncertain because of the lack of samples. An analysis of this type should follow this study.

The vulnerability of the different VMEs to fishing is poorly understood and fishing effort is only a proxy for the physical stress trawling may impose on them. The study has estimated the potential pressure on eleven VMEs in their predicted distribution area, however, and more detailed studies are needed to establish a connection between their environmental status and fishing activity.

Nevertheless, this study has shown that a large-scale estimate of the distribution of eleven VMEs can provide useful information on areas of conflict with human activities and it reveals that in general areas under pressure are less than 50% of the VMEs total distribution.

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12. Summary in Danish

Rapporten præsenterer hovedresultater fra projektet NovasArc, som i perioden 2016–18 fik støtte fra Nordisk Ministerråds arbejdsgrupper HAV og AG-Fisk.

Målsætning for projektet var at:

- Give en sammenstilling af forekomst af følsomme økosystemer (VME's) i Arktiske og sub-Arktiske havområder.
- Identificere områder med datamangel, hvor fremtidige studier er nødvendige.
- Undersøge sammenhæng mellem miljøvariabler og forekomst af VME's.
- Modellere VME's udbredelse i studieområdet med udgangspunkt i deres miljøkrav.
- Undersøge grad af overlap mellem antropogene aktiviteter og de følsomme økosystemers udbredelse.
- Bidrage med den nye information til forvaltningen af VME's.

Udbredelsen af følsomme marine økosystemer, Vulnerable Marine Ecosystems (VME's) i Arktiske og sub-Arktiske havområder bliver præsenteret. Rapporten bygger på information, som er sammenstillet fra publicerede såvel som upublicerede data, og nye data indhentet af projektet fra områder, hvor der tidligere kun fandtes sparsomt med information. Der gives en oversigt over approximationer og metoder, som bruges til kortlægning af udbredelse af forskellige VME's i det nord-østlige Atlanterhav.

I studieområdet kunne elleve VME's identificeres med udgangspunkt i forvaltningsmål for koraller, marine svampe og de samfund, som er tilstede. Disse er: Svampe aggregeringer på blød, og på hård havbund, Koldtvandssvampe, Lopheliarev, Søtræer på blød og på hård bund, Solitære stenkoraler, Hydroide koraller, Blomkålskoraller, Dybhavs-søfjer, og Sublittorale søfjer. Baseret på miljøforhold (dybde, temperatur m.v.) under hvilke de elleve VME forekommer, blev elleve versioner af en statistisk model udviklet, som med udgangspunkt i miljøforholdene i studieområdet, blev brugt til at forudsige deres udbredelse. VME's med størst udbredelse er: Svampe aggregeringer på blød, og på hård havbund, Søtræer på hård bund og Sublittorale søfjer. Der er regionale forskelle og Lopheliarev er relativt mere almindelige ved Færøerne og Norge end ved Island, mens Dybhavs-søfjær og Søtræer på blød bund oftere ses ved Island.

Af de antropogene aktiviteter, som foregår i området (skibsfart, olieboring, turisme) repræsenterer bundrelaterede fiskerier (bundtrawling og line) den største

trussel mod VME's. Udbredelsen af VME's blev sammenholdt med data for fiskeriintensitet i studieområdet. I området fiskes der på 40–50 % af arealet med en havdybde på mindre end 1000 meter, og på 30 % af arealet er der høj trawlaktivitet.

En risikoanalyse i forhold til fiskeriet blev udført ved at estimere, hvor stor del af udbredelsesområdet for de enkelte VME's, som faldt sammen med fiskeriaktivitet af forskellig intensitet. Generelt var mindre end 50 % af VME's områder sammenfaldende med fiskeriaktiviteter. I og med at kundskab om belastningsgrænser for de forskellige VME's i forhold til fiskeri er meget begrænset, kan man med henvisning til forsigtigheds- princippet hævde, at alle steder, hvor der foregår trawling (uanset frekvens), vil VME's være truede. Dette vil føre til, at 40–60 % er under trussel. Omvendt, hvis man mener, at kun høj frekvens af trawling vil have en tydelig negativ effekt, så er 10–30 % under trussel. Regionalt er truslen til dels større for enkelte VME's, dette gælder for eksempel Sublittorale søfjer.

Denne analyse indeholder usikkerhed knyttet til: Den modellerede udbredelse af VME's, kvantificeringen af fiskeriintensitet og effekten af fiskeri på VME's; disse bliver diskuteret i rapporten.

Det blev påvist, at flere havområder har så mangelfuld information om forholdene på havbunden, at det er vanskelig at forudsige forekomsten af VME's med sikkerhed. Endvidere er der også behov for en bedre forståelse af forskellige VME's følsomhed overfor antropogene påvirkninger.

List of appendices

- Appendix 1 – Participants list.
- Appendix 2 – Timeline of workshops, cruise participation and list of outreach effort (presentations, posters, and meetings).
- Appendix 3 – List of VME species used in the suitability modelling.
- Appendix 4 – Data sources.
- Appendix 5 – Predicted VME distribution.
- Appendix 6 – Overlap between fishing intensity and predicted VME distributions.
- Appendix 7 – Identification guides: a) Underwater Identification guide for corals and sponges in the Nordic Seas. b) Identification guide for corals and sponges as by-catch from bottom trawling.

Appendix 1. List of participants

Lene Buhl-Mortensen	Institute of Marine Research Norway
Julian Burgos	Marine and Freshwater Research Institute Iceland
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Hanna Sundahl	Institute of Marine Research Norway
Haraldur Einarsson	Marine and Freshwater Research Institute Iceland
Hjalte Karlsson	Marine and Freshwater Research Institute Iceland
Hjálmar Hátún	Faroe Marine Research Institute
Helga Bára Mohr Vang	Faroe Marine Research Institute
Una Matras	Faroe Marine Research Institute
Ebba Mortensen	Faroe Marine Research Institute
Poul Vestergaard	Faroe Marine Research Institute

Appendix 2. Timeline of activities

Table 5: Timeline of workshops, cruise participation and list of outreach effort (presentations, posters, and meetings)

Presentations and activities	Location	Date
Startup meeting	Tórshavn, Faroes	12–14 January 2016
Presentation of the project given to the staff members of Havstovan.		
Local radio interview.		
Workshop	Bergen, Norway	21–23 November 2016
Workshop	Reykjavík, Iceland	2–4 February 2017
Presentation of the project given in open talk series at the MFRI.		
Cruise participation by an engineer from MFRI on MAREANO cruise–technical collaboration.	R/V Dr. Fridtjof Nansen Norway	21–25 February 2017
Cruise participation by two scientists from IMR on FMRI Habitat Mapping cruise.	R/V Magnus Heinason Faroe Islands	15–21 June 2017
Workshop	Tórshavn, Faroes	20–24 November 2017
Workshop	Bergen, Norway	19–23 February 2018
Presentation of the project and preliminary results at the Directory of fisheries in Bergen.		
Poster presentation: Mapping Vulnerable Marine Ecosystems in Arctic and Sub-Arctic Waters.	GEOHAB conference. Santa Barbara, California	7–11 May 2018
Poster presentation: Vulnerable marine ecosystems in arctic and sub-arctic waters.	Third General Assembly meeting of the Atlas project Mallorca, Spain	9–12 April 2018
Poster presentation: Predictive distribution of vulnerable marine ecosystems in arctic and subarctic waters.	The 15 th Deep Sea Biology Symposium, Monterey, California	9–14 September 2018
Oral presentation: Evaluating the risk of vulnerable marine ecosystems to commercial fisheries in Arctic and subarctic waters.	ICES annual Science Conference, Hamburg, Germany	24–27 September 2018
Workshop Presentation of results given at open talk series at MFRI.	Reykjavík, Iceland	29. October – 2. November 2018
Oral presentation Evaluating the risk of vulnerable marine ecosystems to commercial fisheries in Arctic and subarctic waters.	Meeting of the ICES Working Group on Fisheries Benthic Impact and Trade-offs (WGFBIT). Copenhagen, Denmark	November 12–16, 2018

Appendix 3. List of VME species

Table 6: List of VME species used in the suitability modelling

VME	Taxa	VME	Taxa	VME	Taxa
	Soft bottom sponge aggregations		Hard bottom sponge aggr. (cont.)		Soft bottom gorgonians
	<i>Aplysilla</i> sp.		<i>Phakellia vermiculata</i>		<i>Radicipes challengerii</i>
	<i>Aplysilla arctica</i>		<i>Tethya aurantium</i>		<i>Radicipes gracilis</i>
	<i>Aplysilla rosea</i>		<i>Tethya citrina</i>		<i>Radicipes</i> sp.
	<i>Aplysilla sulfurea</i>		<i>Tethya norvegica</i>		<i>Acanella arbuscula</i>
	<i>Geodia</i> sp.		<i>Tethya</i> sp.		<i>Isidella</i> sp.
	<i>Geodia atlantica</i>		<i>Craniella cranium</i>		<i>Isidella lofotensis</i>
	<i>Geodia barretti</i>		<i>Craniella</i> sp.		Cup coral fields
	<i>Geodia cydonium</i>		<i>Craniella zetlandica</i>		<i>Caryophylla</i> sp.
	<i>Geodia hentscheli</i>		<i>Mycale arctica</i>		<i>Caryophyllia ambrosia</i>
	<i>Geodia macandrewii</i>		<i>Mycale contarenii</i>		<i>Caryophyllia atlantica</i>
	<i>Geodia mesotriaena</i>		<i>Mycale lingua</i>		<i>Caryophyllia crosnieri</i>
	<i>Geodia parva</i>		<i>Mycale macilenta</i>		<i>Caryophyllia sarsiae</i>
	<i>Geodia phlegraei</i>		<i>Mycale marshallhalli</i>		<i>Caryophyllia seguenzae</i>
	<i>Geodia</i> sp.		<i>Mycale</i> sp.		<i>Caryophyllia smithii</i>
	<i>Isops phlegraei pyriformis</i>		<i>Mycale rotalis</i>		<i>Caryophylliidae</i>
	<i>Stelletta normani</i>		<i>Mycale subclavata</i>		<i>Flabellum chunii</i>
	<i>Stelletta raphidiophora</i>		<i>Tetilla</i> sp.		<i>Flabellum alabastrum</i>
	<i>Stelletta</i> sp.		Deep arctic sponge aggregations		<i>Flabellum angulare</i>
	<i>Stryphnus fortis</i>		<i>Asbestopluma</i> sp.		<i>Flabellum macandrewii</i>
	<i>Stryphnus ponderosus</i>		<i>Asconema setubalense</i>		<i>Flabellum</i> sp.
	Hard bottom sponge aggregations		<i>Caulophacus arcticus</i>		<i>Stephanocyathus moseleyanus</i>
	<i>Antho dichotoma</i>		<i>Caulophacus arcticus</i> var. <i>groenlandicus</i>		<i>Stephanocyathus nobilis</i>
	<i>Axinella</i> sp.		cf. <i>Pheronema carpenteri</i>		<i>Stephanocyathus</i> sp.
	<i>Axinella arctica</i>		<i>Cladorhiza abyssicola</i>		Hard bottom gorgonians
	<i>Axinella calyciformis</i>		<i>Cladorhiza corticocancellata</i>		<i>Acanthogorgia armata</i>
	<i>Axinella damicornis</i>		<i>Cladorhiza gelida</i>		<i>Anthothela grandiflora</i>
	<i>Axinella dissimilis</i>		<i>Cladorhiza iniquidentata</i>		<i>Gorgonian</i>
	<i>Axinella infundibuliformis</i>		<i>Cladorhiza oxedata</i>		<i>Paragorgia</i> sp.
	<i>Axinella rugosa</i>		<i>Cladorhiza tenuisigma</i>		<i>Paragorgia arborea</i>
	<i>Axinella setosa</i>		<i>Cladorhizidae</i> sp.		<i>Paramuricea biscaya</i>
	<i>Axinella trichophora</i>		<i>Hexactinellida</i> sp.		<i>Paramuricea frater</i>
	<i>Axinellidae</i>		<i>Schaudinnia rosea</i>		<i>Paramuricea habibi</i>
	<i>Phakellia bowerbanki</i>		Cold-water coral reefs		<i>Paramuricea parentes</i>
	<i>Phakellia lambei</i>		<i>Desmophyllum dianthus</i>		<i>Paramuricea placomus</i>
	<i>Phakellia robusta</i>		<i>Desmophyllum pertusum</i>		<i>Paramuricea</i> sp.
	<i>Phakellia rugosa</i>		<i>Madrepora</i> cf		<i>Primnoa</i> sp.
	<i>Phakellia</i> sp.		<i>Madrepora oculata</i>		<i>Primnoa resedaeformis</i>

VME	Taxa	VME	Taxa	VME	Taxa
	Hard bottom gorgonians (cont.)		Cauliflower corals (cont.)		Sublittoral seapen communities (cont.)
	<i>Primnoidae</i>		<i>Gersemia rubiformis</i>		<i>Halipterus finmarchica</i>
	<i>Swiftia borealis</i>		<i>Gersemia</i> sp.		<i>Halipterus</i> sp.
	<i>Swiftia pallida</i>		<i>Pseudodrifa groenlandica</i>		<i>Kophobelemnon</i> sp.
	<i>Swiftia</i> sp.		<i>Pseudodrifa</i> sp.		<i>Kophobelemnon stelliferum</i>
	Sylasterid corals		Bathyal seapen communities		<i>Pennatula</i> cf. <i>Inflata</i>
	<i>Pliobothrus symmetricus</i>		<i>Anthoptilum</i> cf. sp.		<i>Pennatula</i> cf. <i>Inflata</i>
	<i>Stylaster erubescens britannicus</i>		<i>Anthoptilum grandiflorum</i>		<i>Pennatula grandis</i>
	<i>Stylaster erubescens groenlandicus</i>		<i>Anthoptilum murrayi</i>		<i>Pennatula phosphorea</i>
	<i>Stylaster gemmascens</i>		<i>Umbellula encrinus</i>		<i>Pennatula</i> sp.
	<i>Stylaster norvegicus</i>		<i>Umbellula huxleyi</i>		<i>Pennatulacea</i>
	<i>Stylaster</i> sp.		<i>Umbellula lindahli</i>		<i>Virgularia glacialis</i>
	<i>Stylasteridae</i>		<i>Umbellula</i> sp.		<i>Virgularia mirabilis</i>
	Cauliflower corals		Sublittoral seapen communities		<i>Virgularia</i> sp.
	<i>Drifa glomerata</i>		<i>Funiculina quadrangularis</i>		<i>Virgularia tuberculata</i>
	<i>Duva florida</i>		<i>Funiculina</i> sp.		<i>Virgulariidae</i>
	<i>Gersemia fruticosa</i>		<i>Halipterus christii</i>		

Appendix 4. Data sources

Published papers

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Research and Mapping projects, Data suppliers

Norway

- MAREANO VME data 2006-2017
- Acergy survey, ROV inspeksjoner, 12.-13.02.07
- Cruise_BP_DNV
- IMR Project 13674
- IMR-Shrimp trawl 2017-2018
- Institute of Marine Research (2005-2013)
- Institute of Marine Research – Database on *Lophelia pertusa* records
- Norsk Hydro reports
- Martin Hovland (pers comm)
- Langeled Project report
- Hermesprosjektet
- Tomas Lundalv (pers comm)
- Deep ocean survey, ROV inspectiones
- Statnett
- Statoil

Iceland

- Benthic Invertebrates of Icelandic waters (BIOICE)
- MFRI Video Data 2004-2012
- MFRI trawl bycatch data 2002
- MFRI Bottom Trawl Survey 2015-
- Records from the fisheries observers Fisheries Directorate
- Natural History Museum material
- Iceland fisheries bycatch 2008-2012

Faroe Islands

- Benthic Investigations Of the FARoes (BIOFAR)
- Faroe Marine Research Institute, Magnus Heinason 2017
- Magnus_Heinason_benthos_filtered_per_nov2018.xlsx
- Bottom trawl Faores data
- Faroe Marine Research Institute, Video observations

Open databases

- Seamounts <http://seamounts.sdsc.edu/>
- OBIS (2018) Ocean Biogeographic Information System. Intergovernmental Oceanographic Commission of UNESCO. www.iobis.org.

Appendix 5. Predicted VME distribution

These maps indicate the distribution of the VMEs, as predicted by the MaxEnt models based on presence locations (shown as white dots) of indicator species and using environmental parameters as predictors. Light colors indicate high habitat suitability and can be considered as an indication of high probability of VME presence.

Figure A5.1

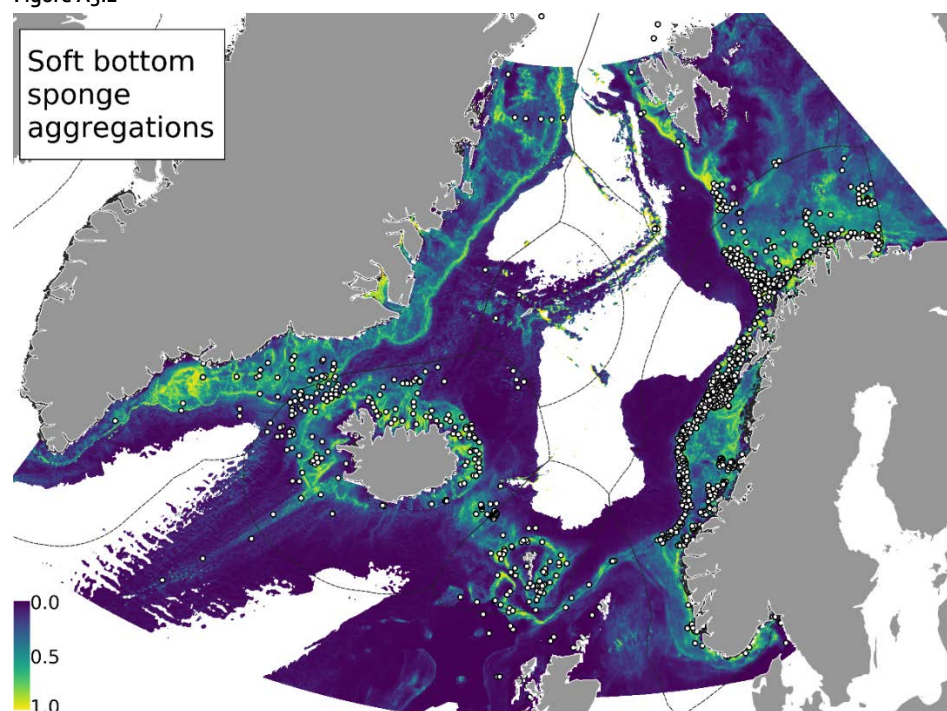


Figure A5.2

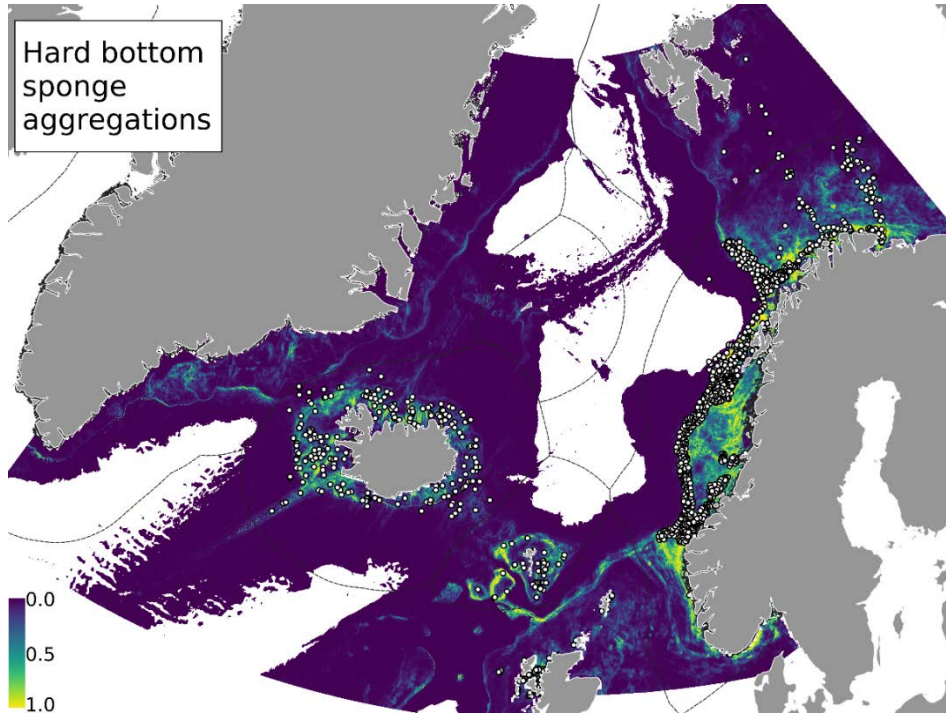


Figure A5.3

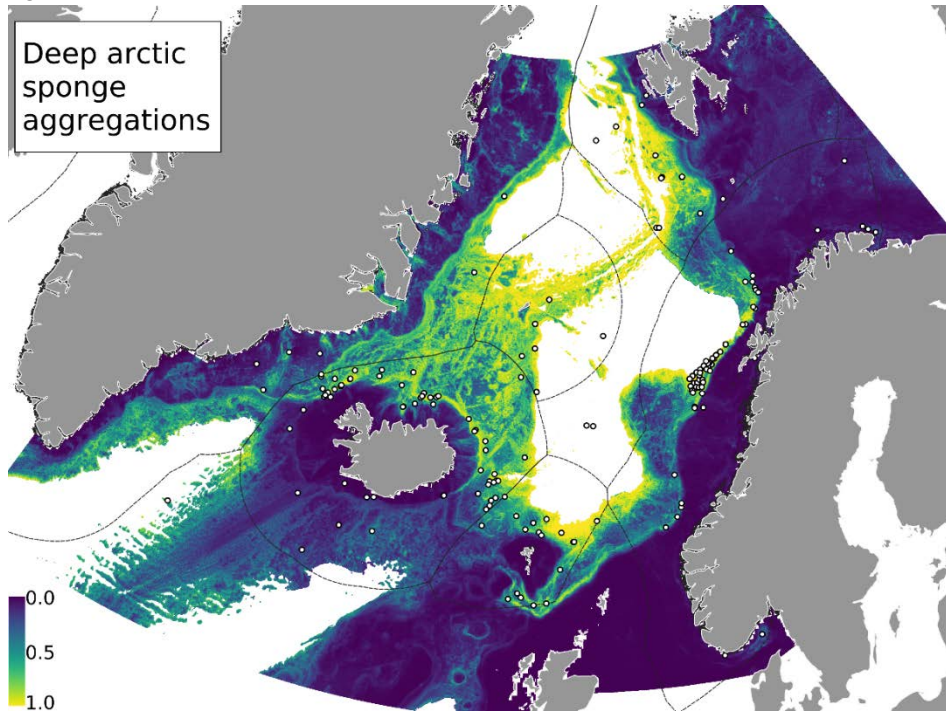


Figure A5.4

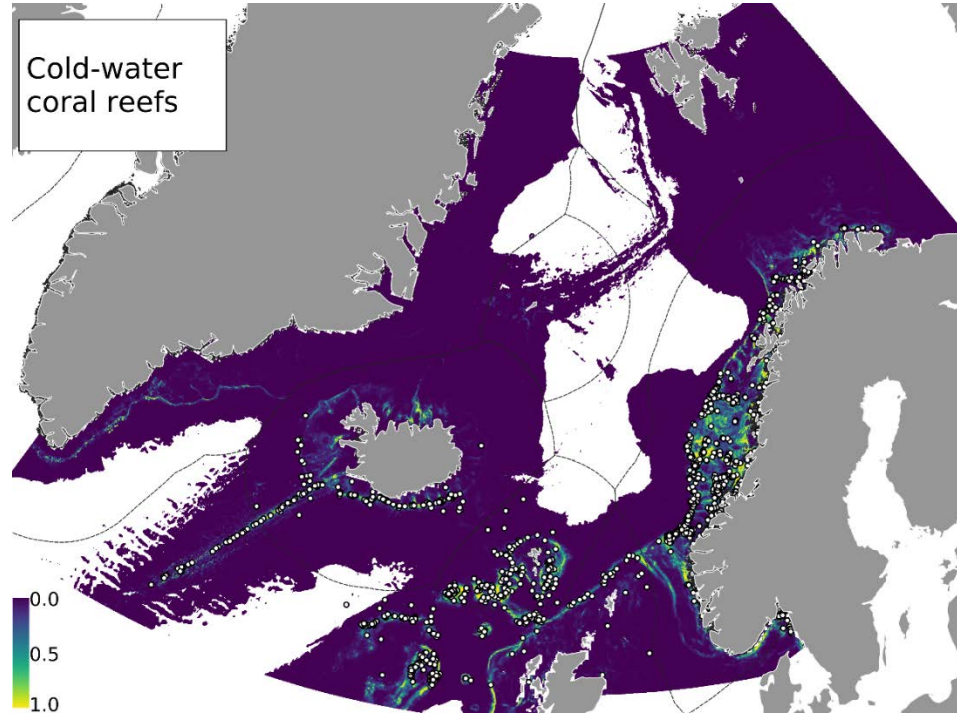


Figure A5.5

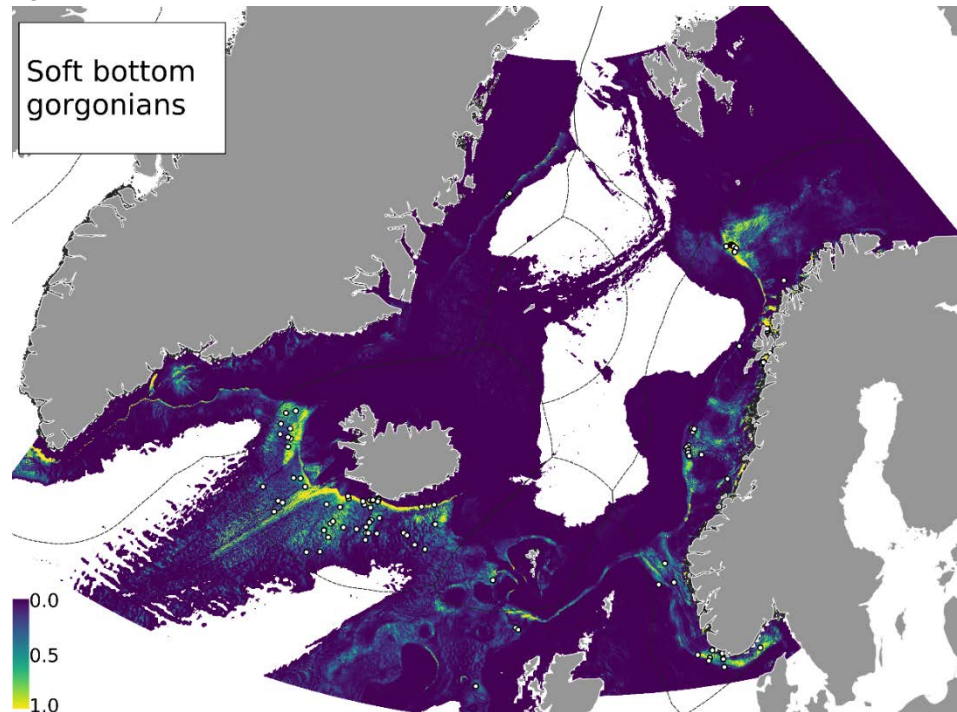


Figure A5.6

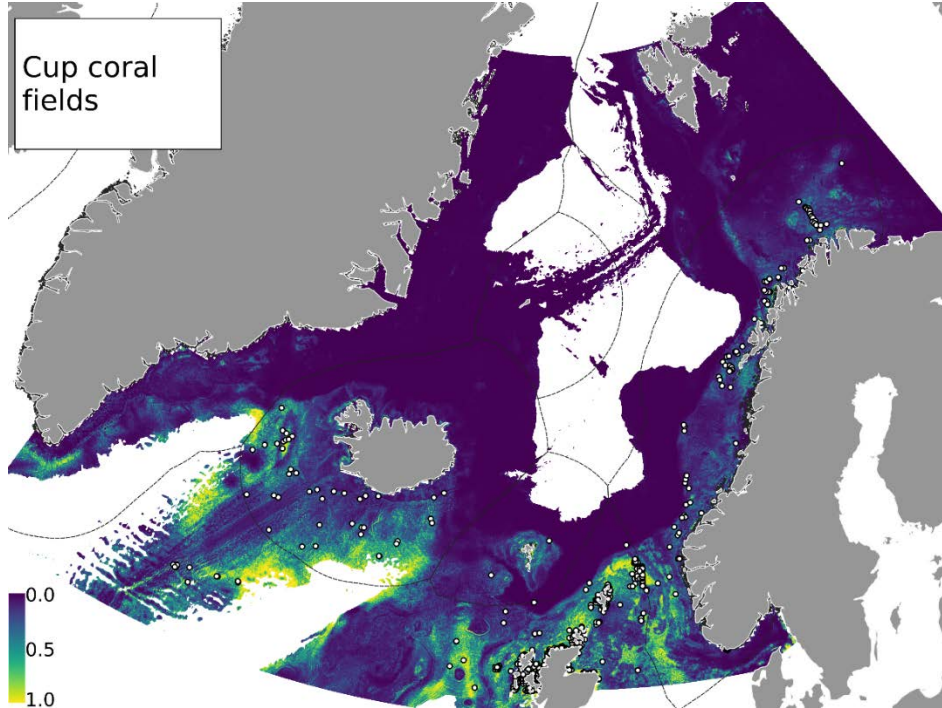


Figure A5.7

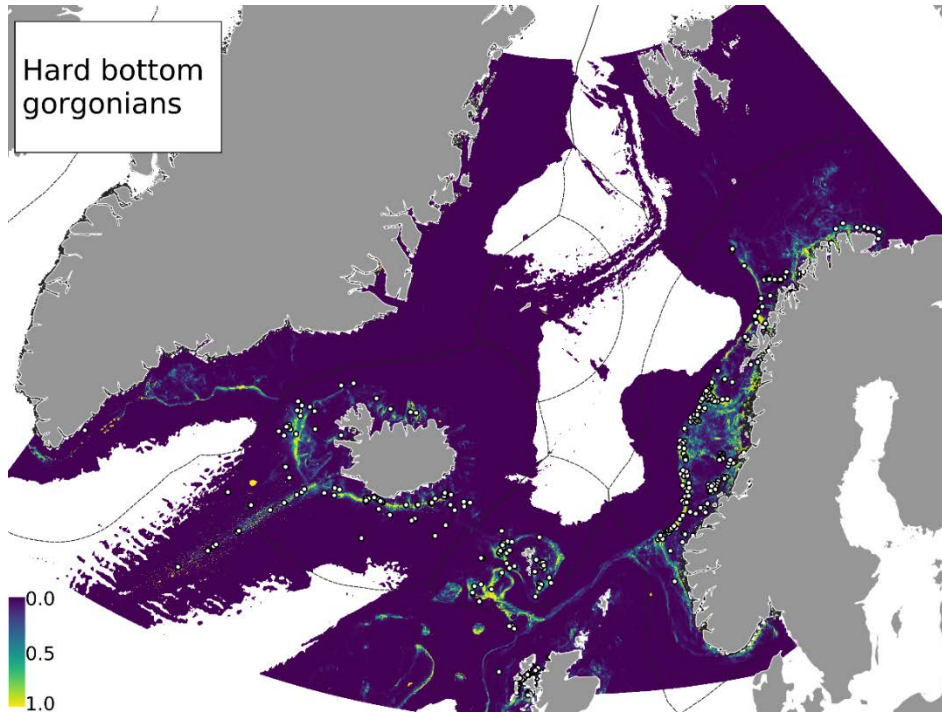


Figure A5.8

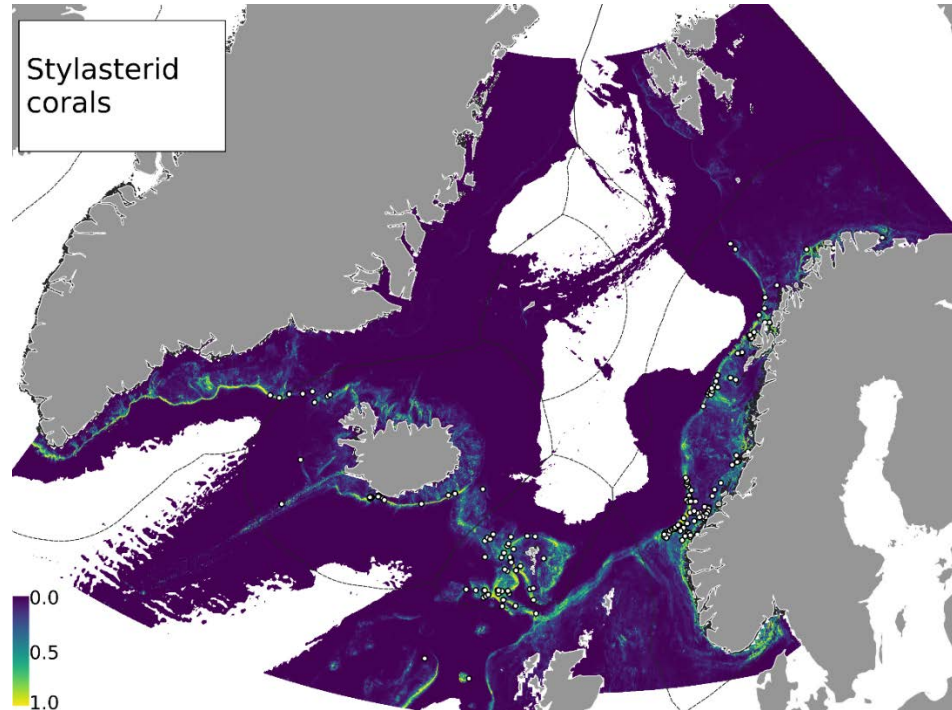


Figure A5.9

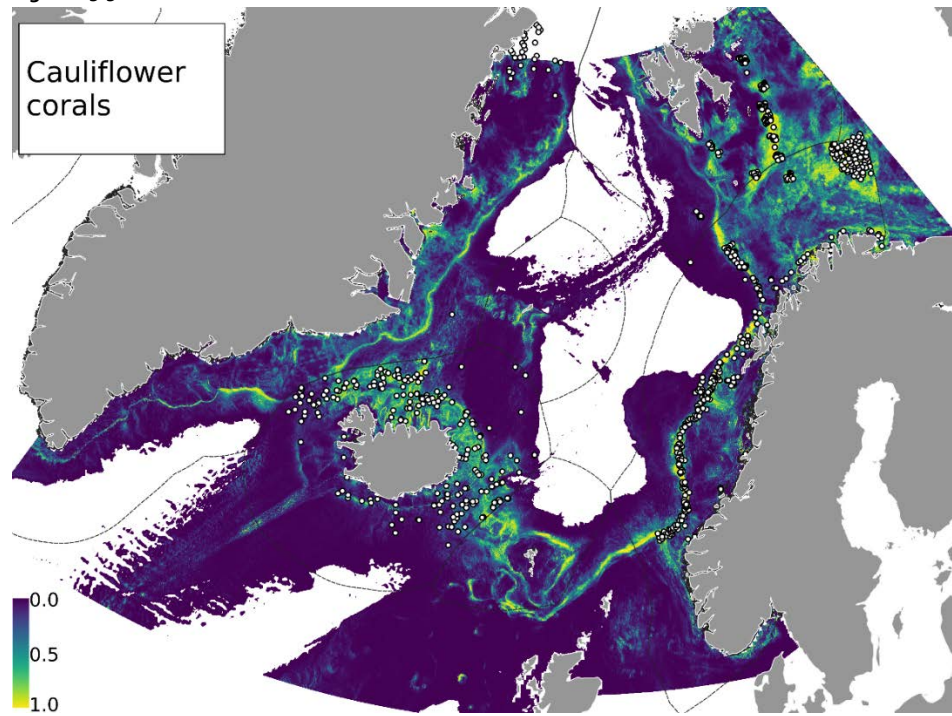


Figure A5.10

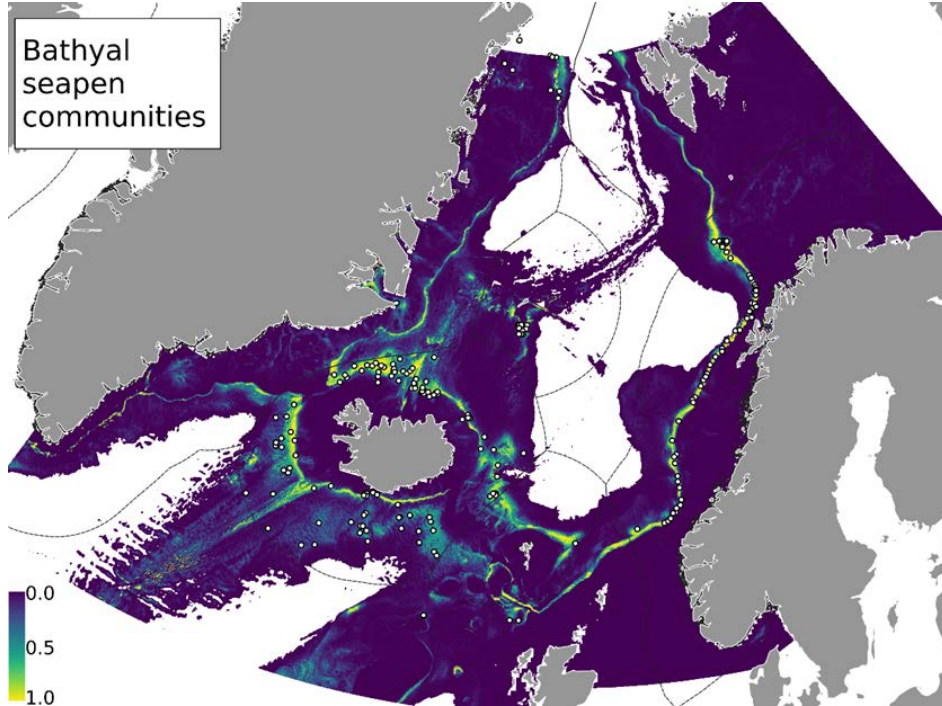
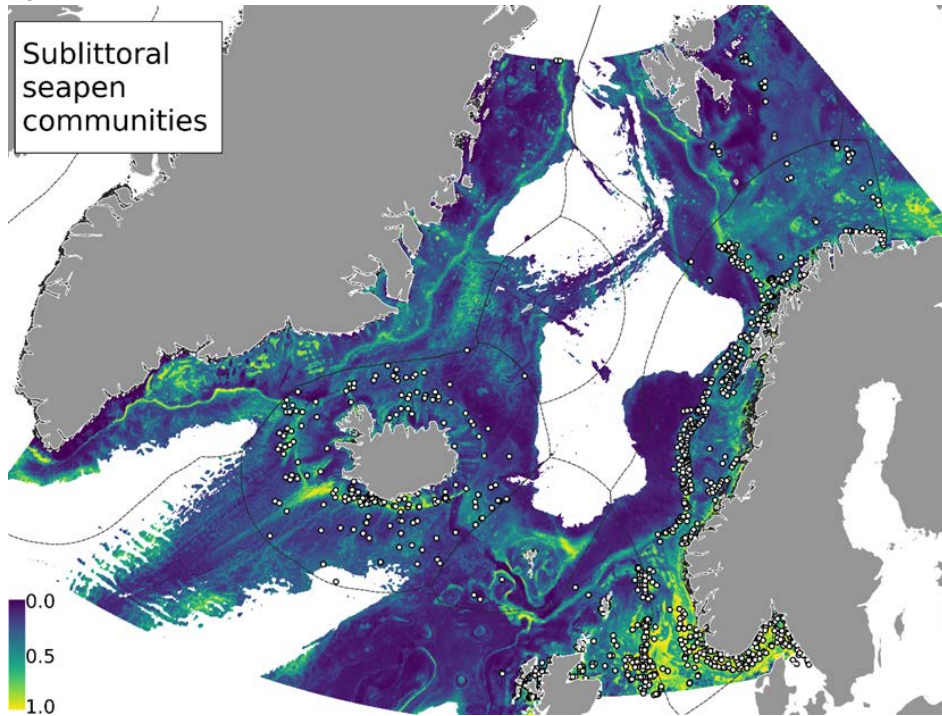


Figure A5.11



Appendix 6. Overlap between fishing intensity and predicted VME distributions

These maps show the overlap between the predicted distribution of VMEs and fishing intensity. The blue scale shows the overlap between areas where the VME is considered to be present and the four levels of fishing intensity (low, intermediate, high and very high). The red scale shows the overlap in areas considered “optimal” (with suitability values above 0.8).

Figure A6.1

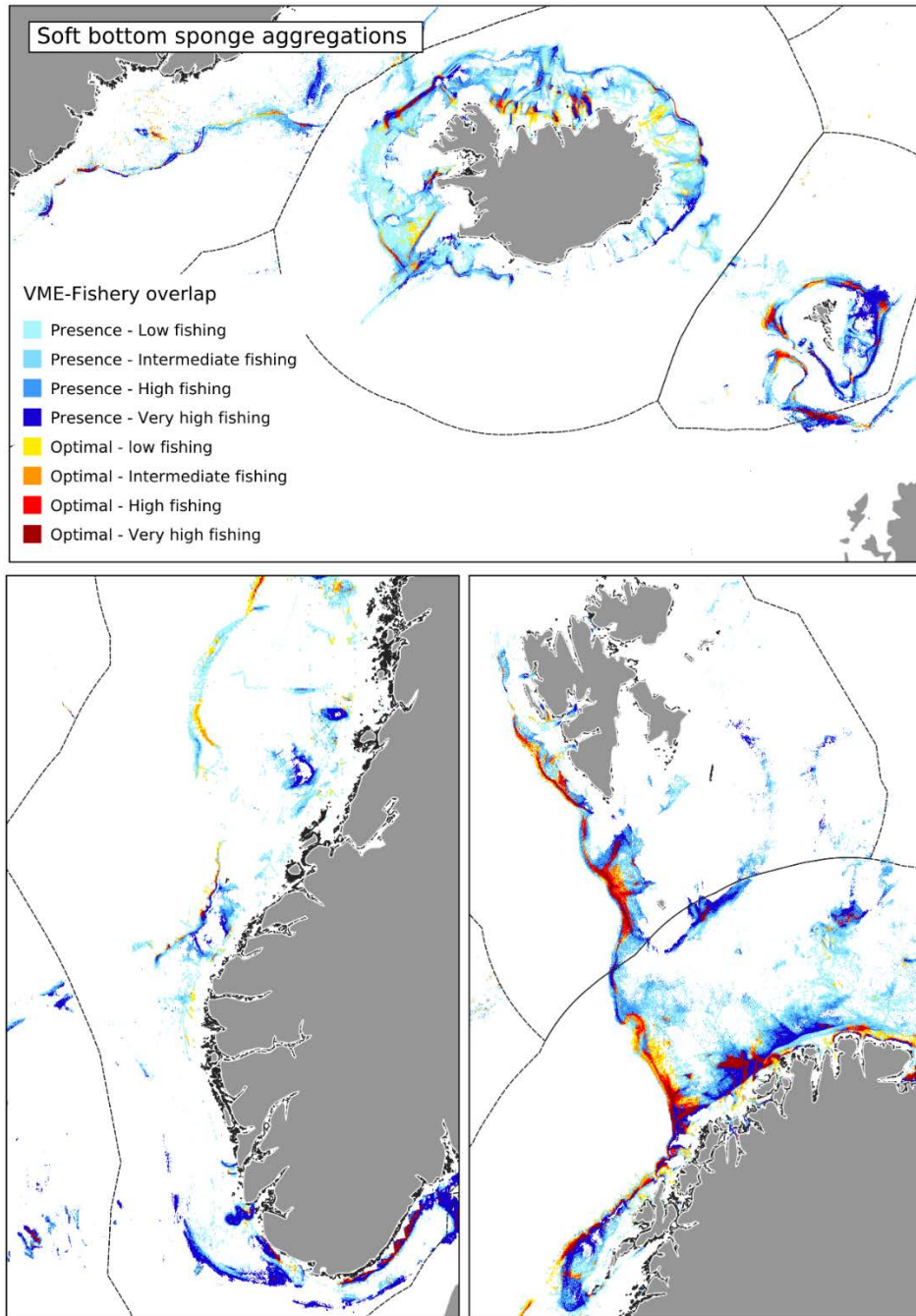


Figure A6.2

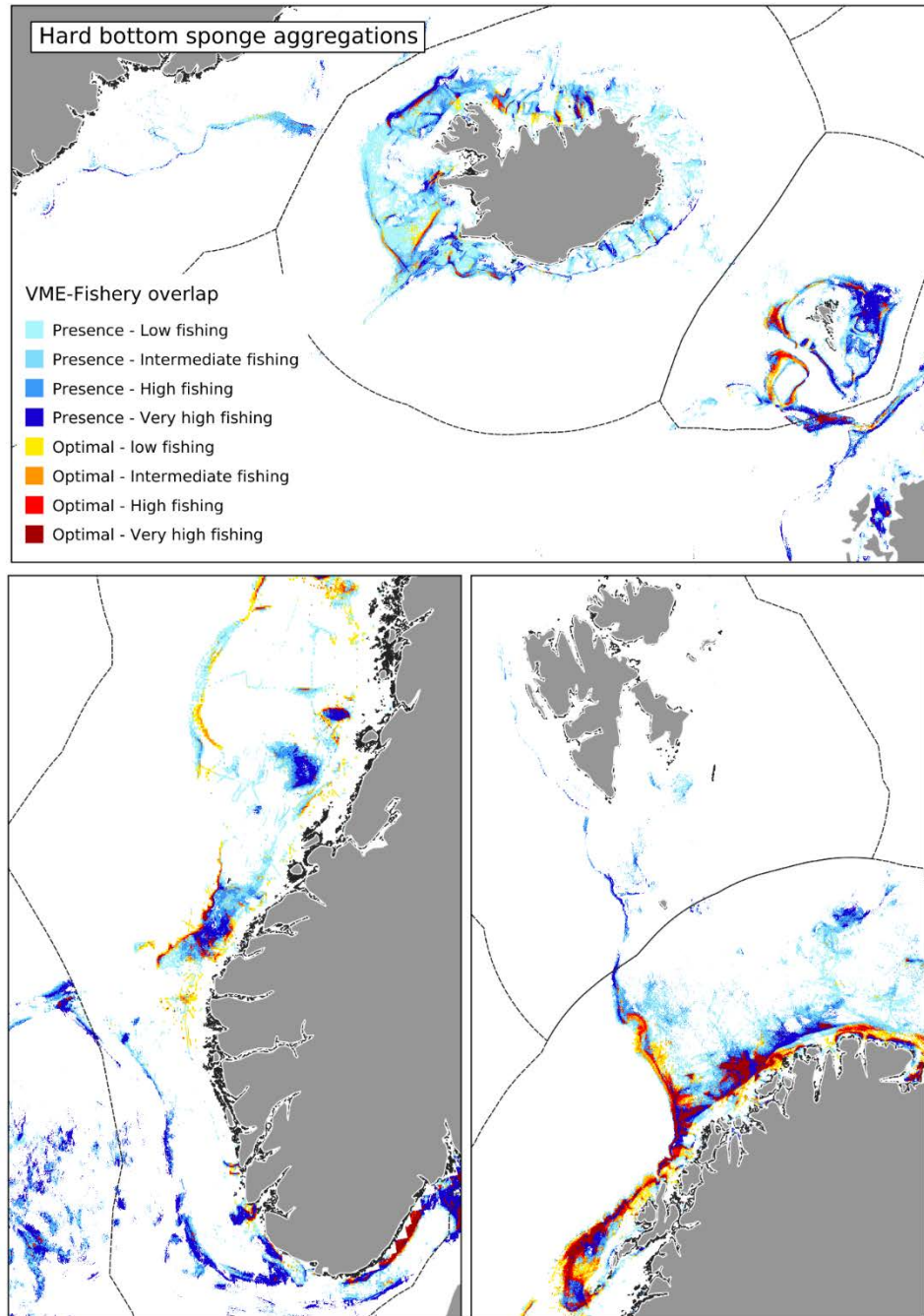


Figure A6.3

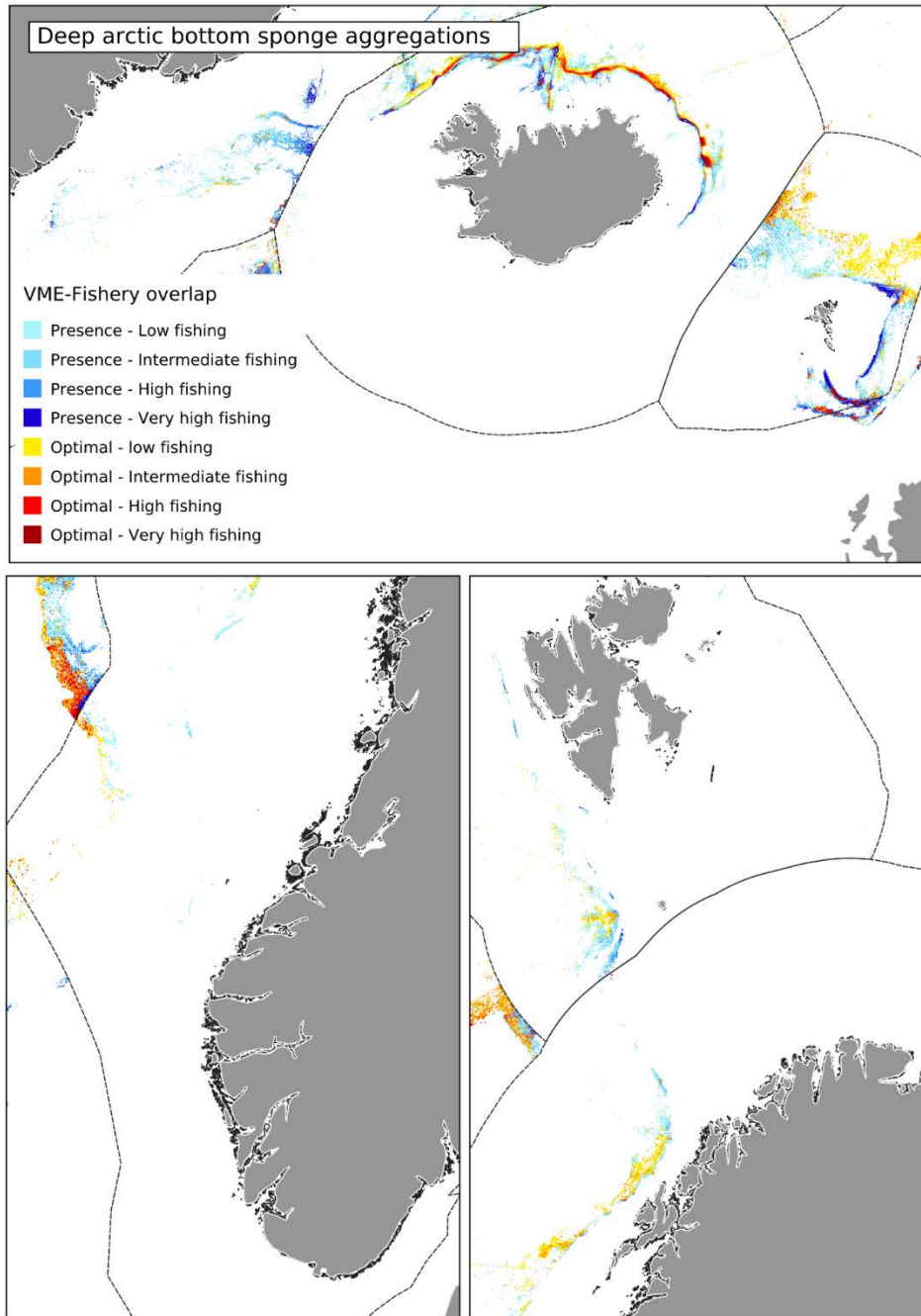


Figure A6.4

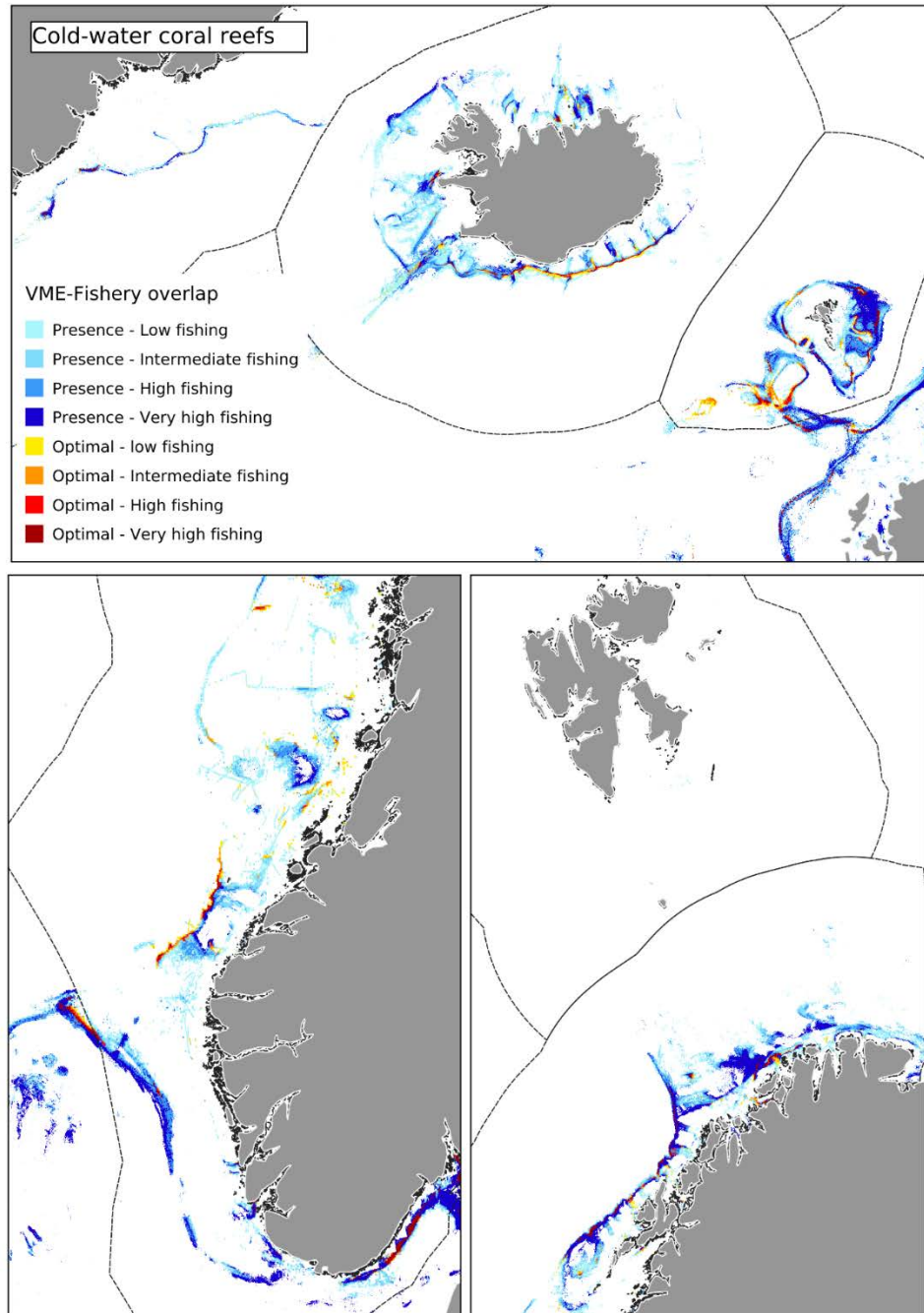


Figure A6.5

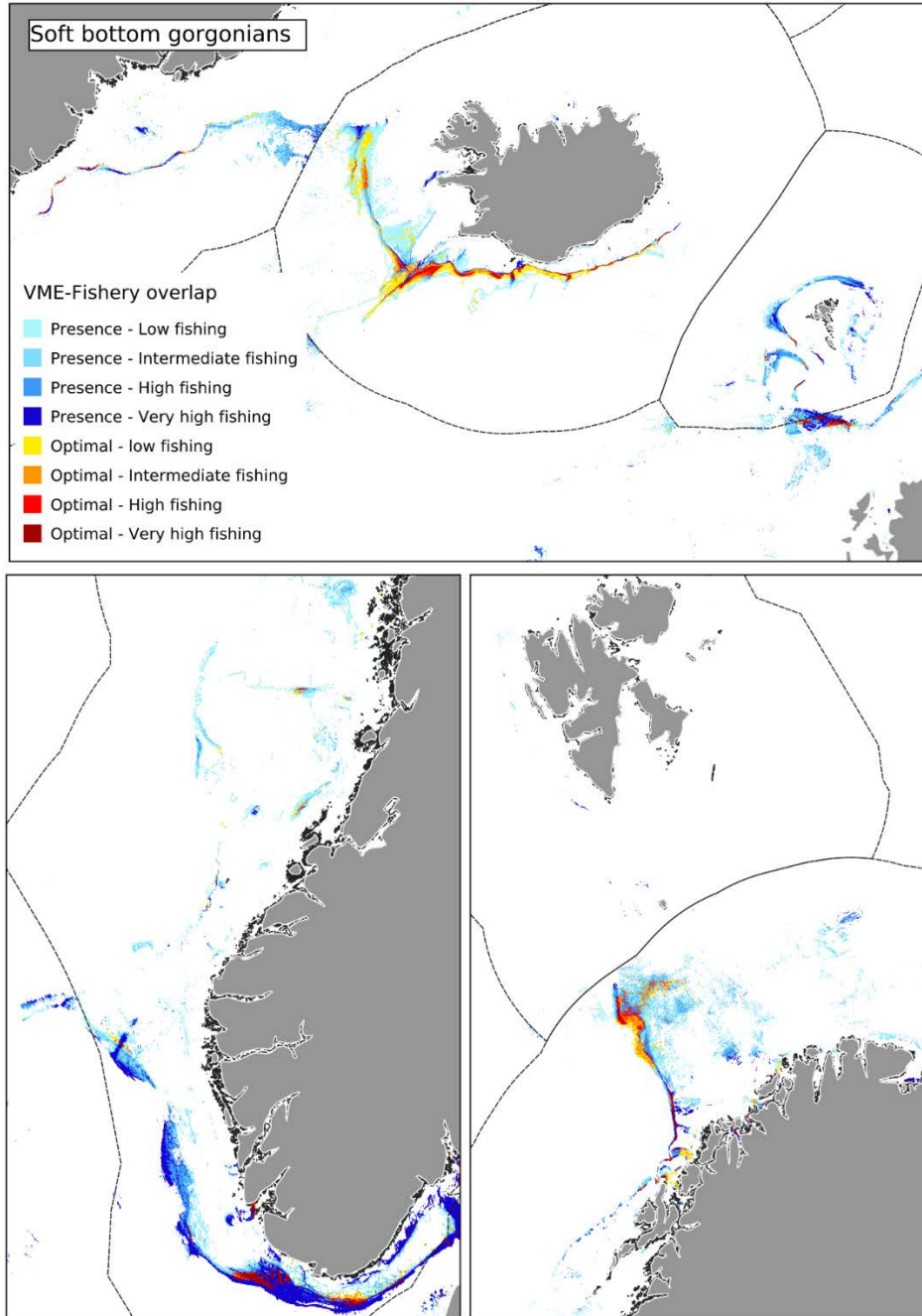


Figure A6.6

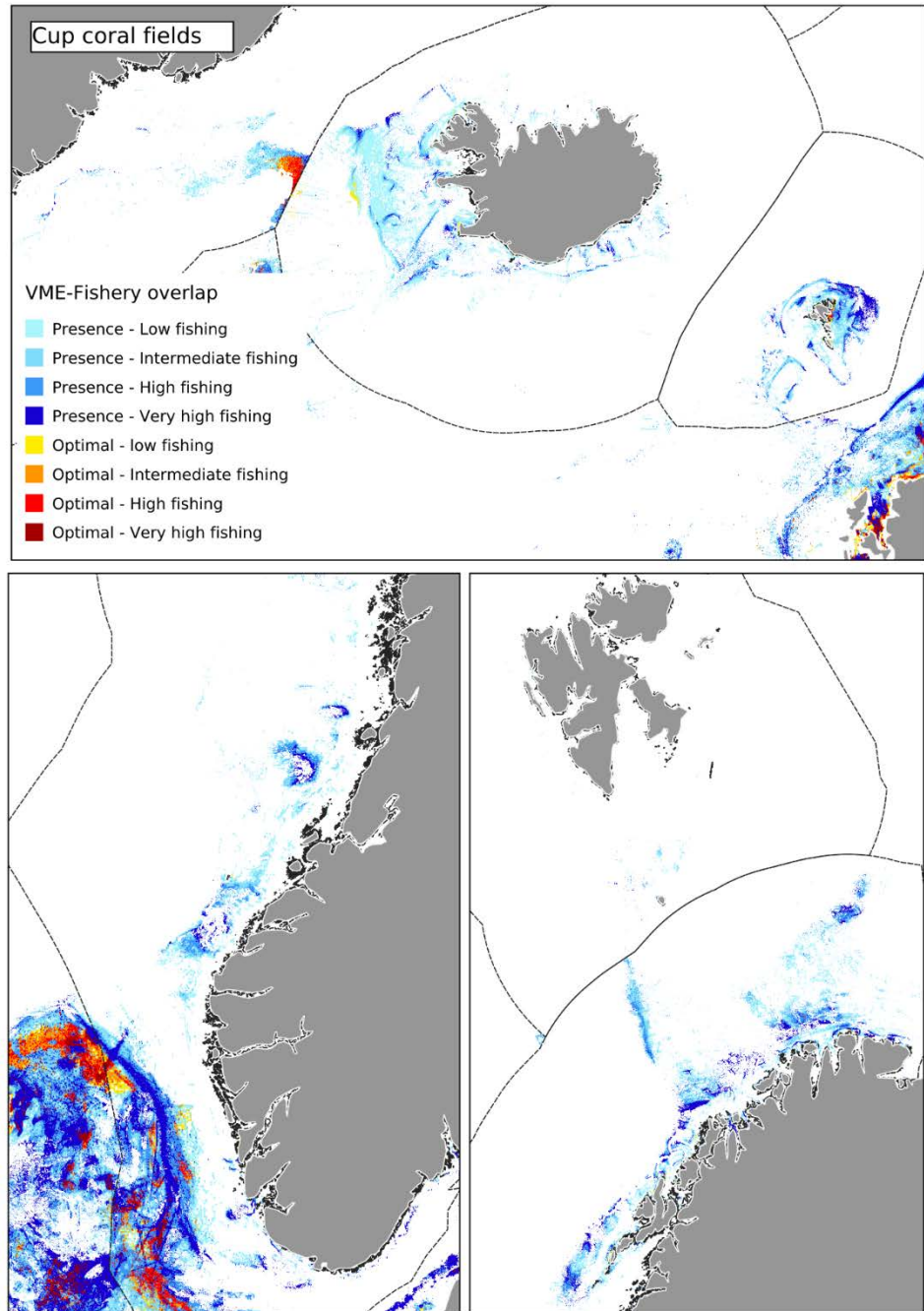


Figure A6.7

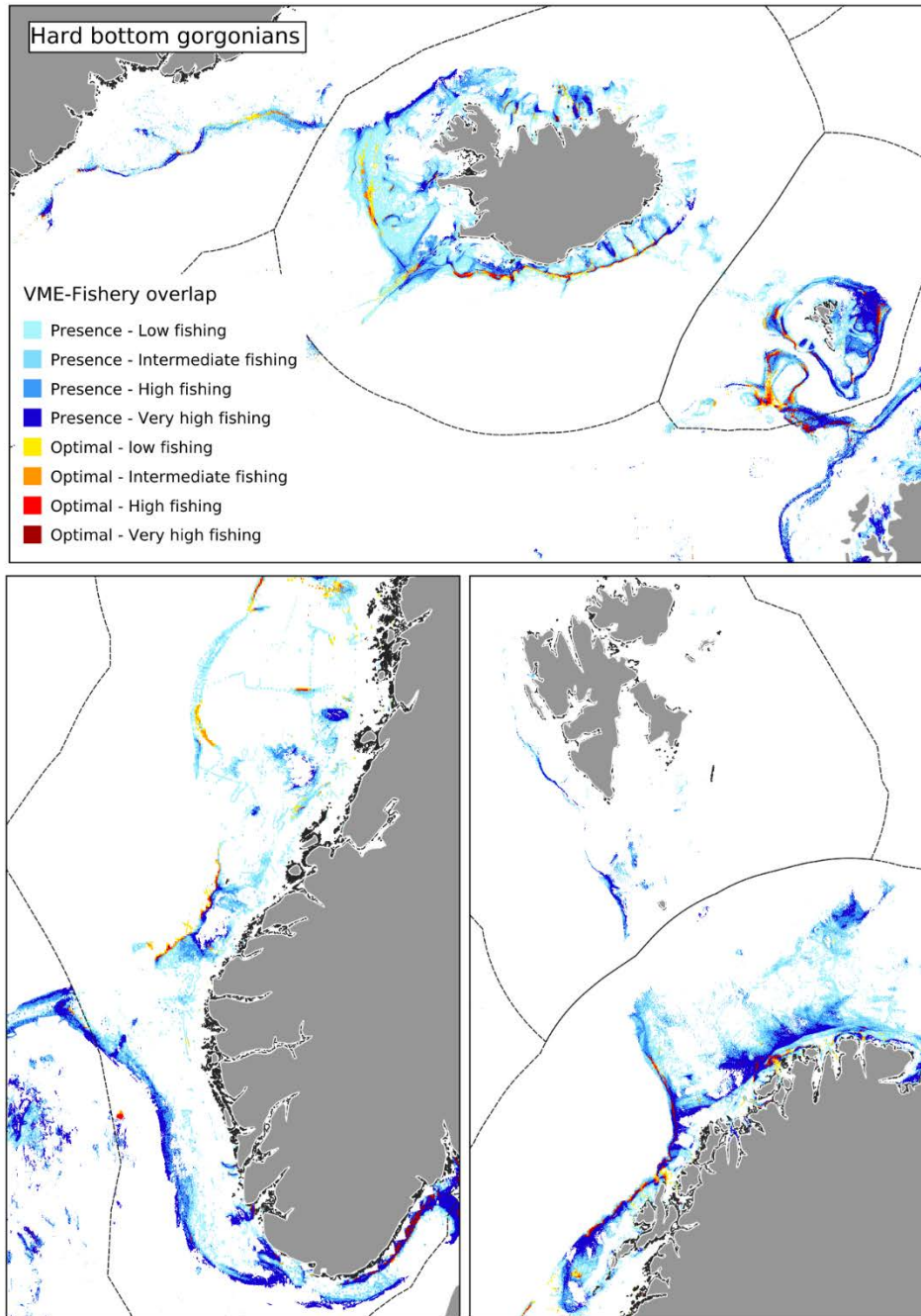


Figure A6.8

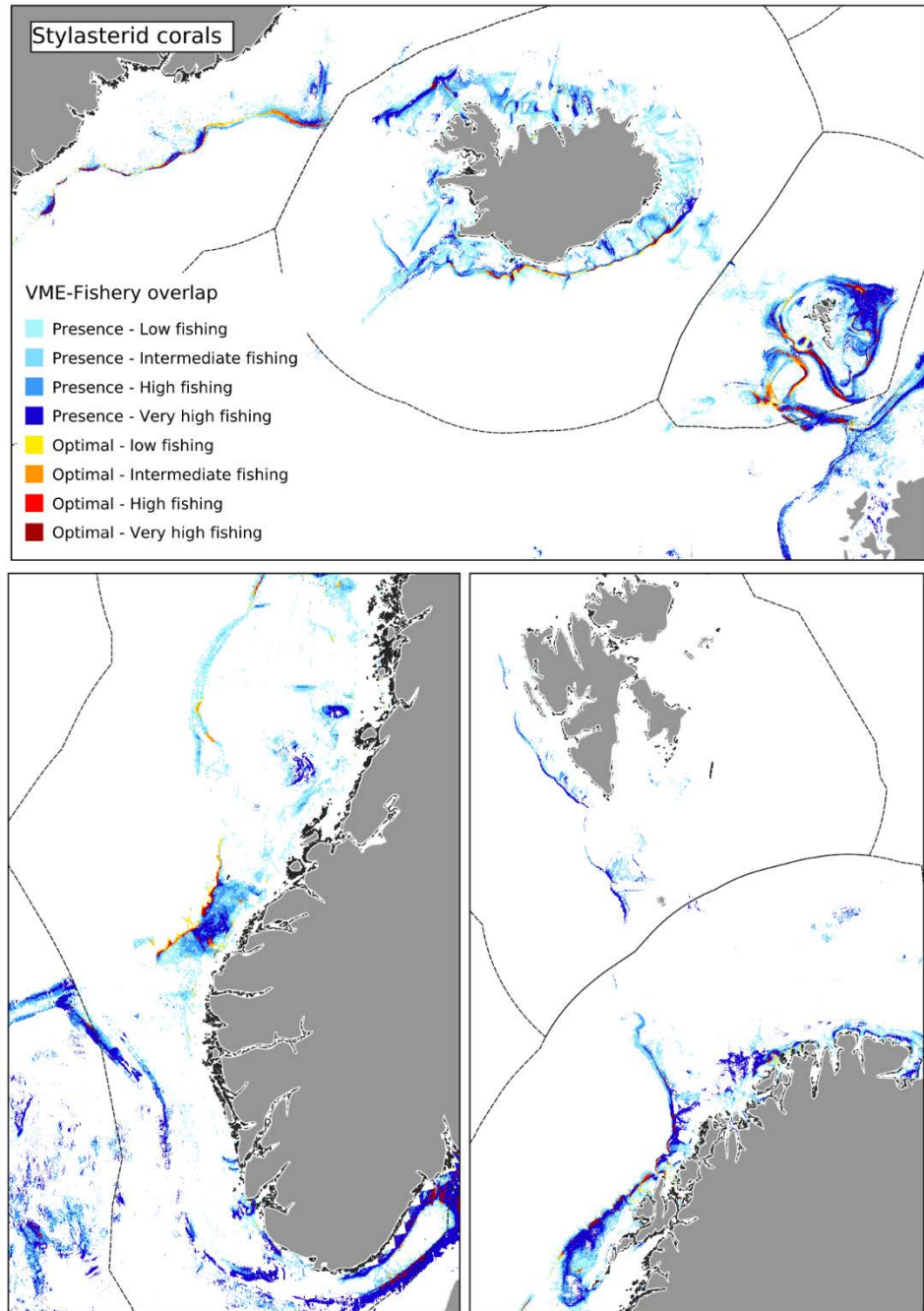


Figure A6.9

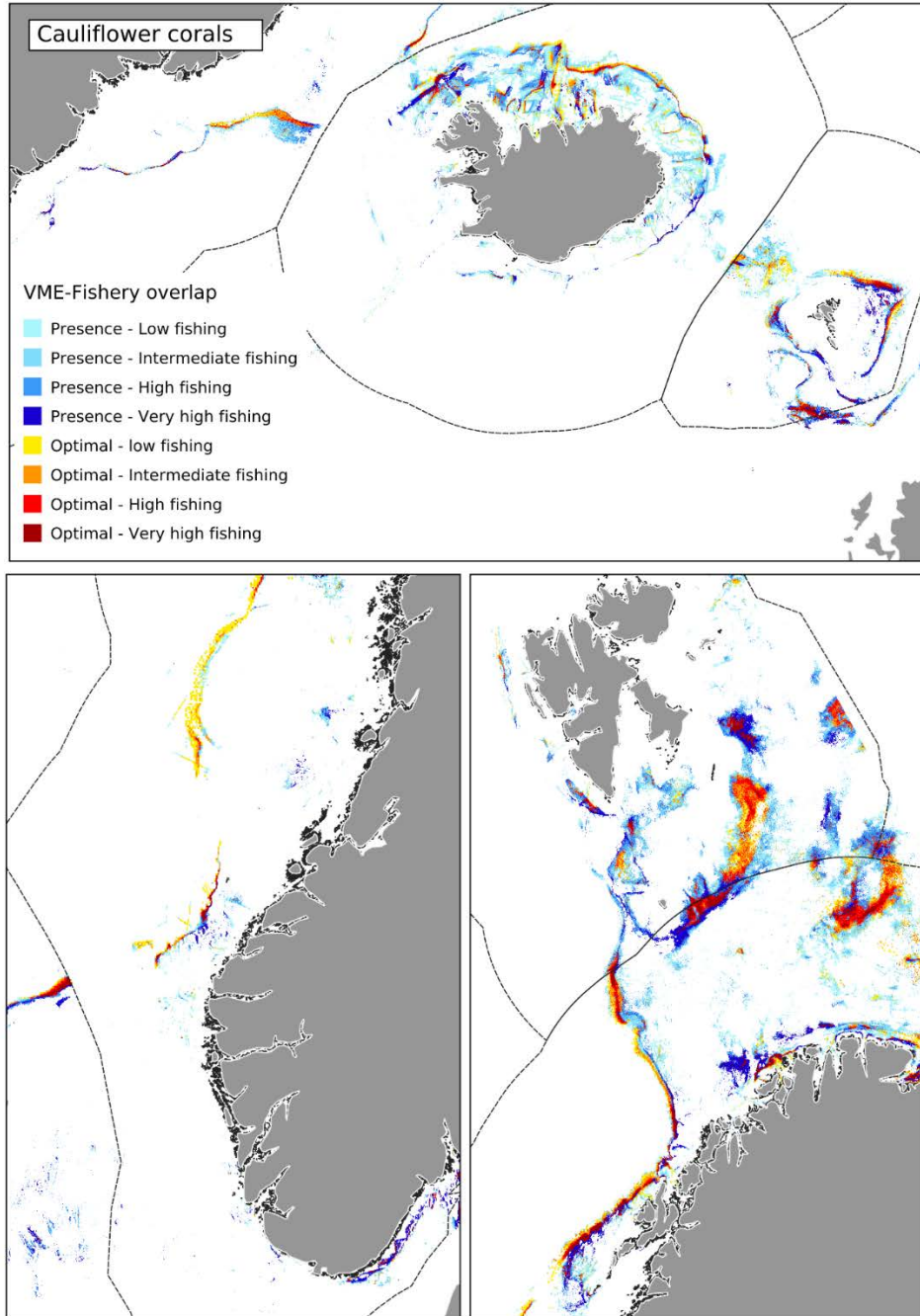


Figure A6.10

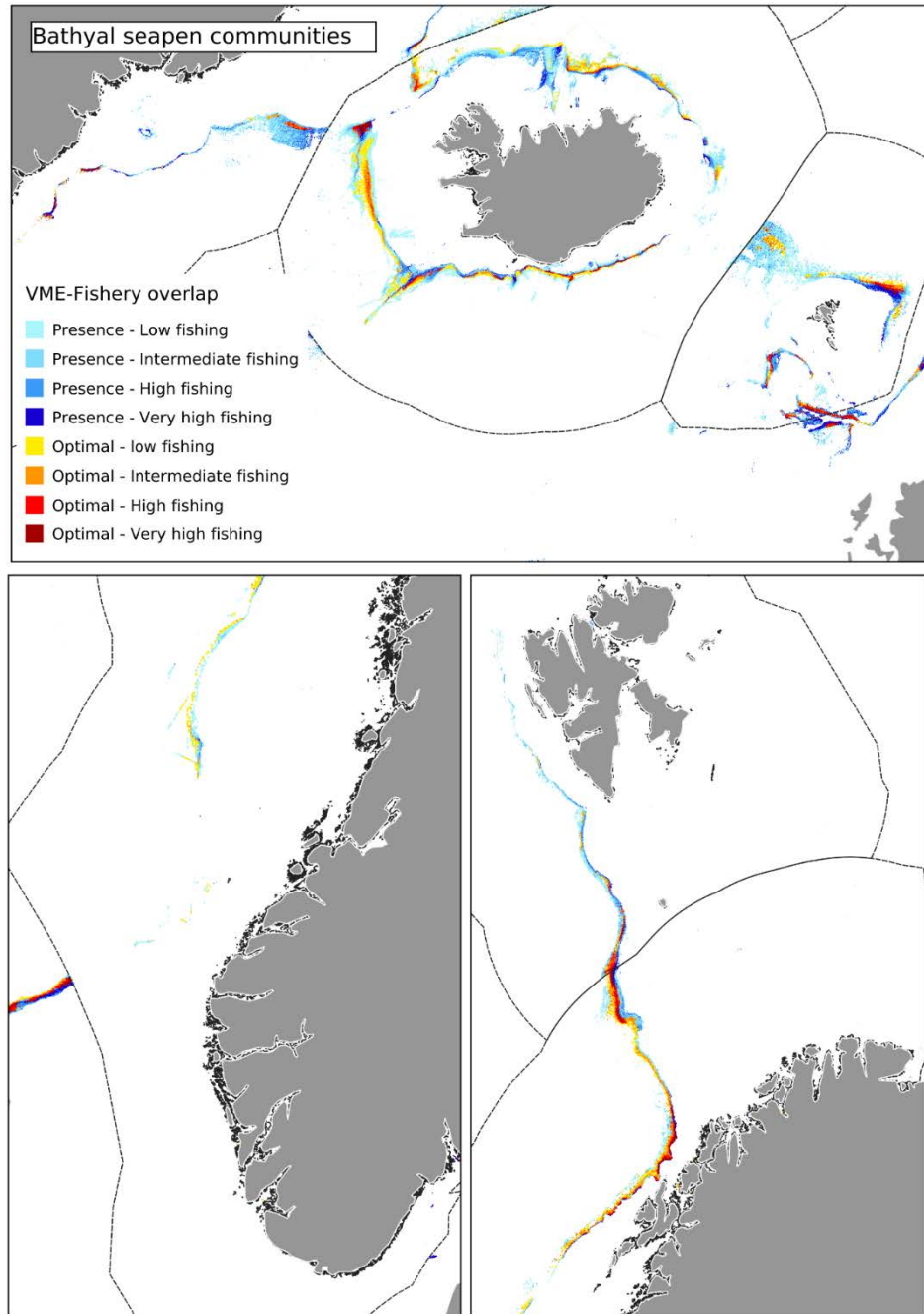
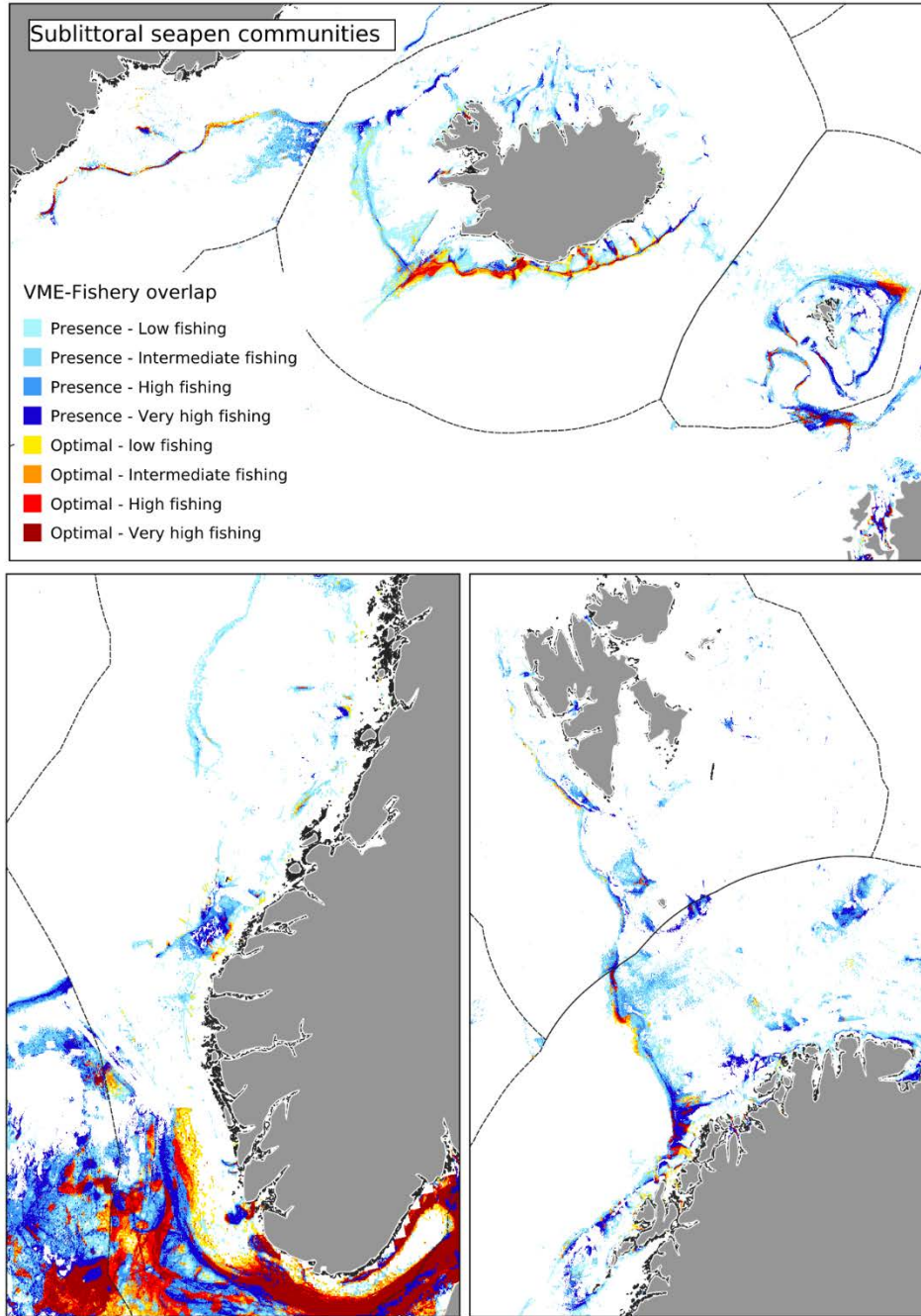


Figure A6.11



Appendix 7. Identification guides

There is currently no identification guide for VME species available that is suitable for the Nordic seas. To fill this gap, NovasArc has produce on-board identification sheets both for fishermen and scientists to aid in the identification of corals, sea pens, and sponges.

This section includes a) Underwater Identification guide for corals and sponges in the Nordic Seas. b) Identification guide for corals and sponges as by-catch from bottom trawling.

Underwater Identification guide for corals and sponges in the Nordic Seas – Steinunn Hilma Olafsdottir, Pål Buhl-Mortensen



Introduction

This identification guide is intended for use by people with experience in identification of marine invertebrates, as well as those with limited background from practical marine taxonomy.

The guide does not provide a complete overview of cold-water corals and sponges from the Nordic Seas, but is meant as a supplement for identification of specimens from field observations, during seabed video observation. Such observation does not allow for classical taxonomic investigations involving examination of microscopic details.

The groups included in this guide are: Stony corals (Scleractinia), black coral (Antipatharia), soft cauliflower and gorgonian corals (Alcyonacea), seapens (Pennatulacea), lace corals (Stylasteridae) and sponges (Porifera). The selected sponges were limited to those with a status as indicators of vulnerable marine ecosystems as well as some commonly encountered species in the Nordic waters.

The images are taken in situ on the seabed during research cruises with Icelandic and Norwegian vessels. Most images provided by the Institute of Marine Research (IMR) were taken during MAREANO seabed mapping surveys. The images provided by the Marine and Freshwater Research Institute (MFRI) were taken during coral mapping surveys.

For each species we have included information about: Latin name, Nordic names, English names, distribution within Iceland, Norway and Faroe Islands, and recorded depth distribution within these regions.

This guide is a working document. The definitions and descriptions were made to the best knowledge of the authors

Taxonomic overview

Cnidaria

Class Anthozoa

Subclass Hexacorallia

Order Scleractinia Stony corals

Family Caryophyllidae

Desmophyllum pertusum (Lophelia pertusa)

Desmophyllum dianthus

Caryophyllida sp.

Family Flabellidae

Flabellum macandrewi

Flabellum sp.

Family Oculinidae

Madrepora oculata

Family Fungiacyathidae

Fungiacyathus fragilis

Order Antipatharia Black corals

Family Schizopathidae

Bathypathes sp.

Stauropantes arctica

Subclass Octocorallia

Order Alcyonacea

Suborder Calcaxonia

Family Chrysogorgiidae

Radicipes gracilis

Family Isididae

Acanella arbuscula

Isidella lofotensis

Family Primnoidae

Primnoa resedaeformis

Callogorgia sp.

Suborder Holaxonia

Family Plexauridae

Swiftia sp.

Paramuricea placomus

Suborder Scleraxonia

Family Acanthogorgiidae

Acanthogorgia armata

Family Anthothelidae

*Anthothela grandiflora/Lateothela
grandiflora*

Family Paragorgiidae

Paragorgia arborea

Suborder Stolonifera

Family Clavariidae

Clavularia arctica

Suborder Alcyoniina cauliflower corals

Family Nephtheidae

Drifa glomerata

Duva florida

Pseudodrifa sp.

Gersemia fruticosa

Family Alcyoniidae

Anthomastus sp.

Family Xenidae

Ceratocaulon wandeli

Order Pennatulacea Sea pens

Family Anthoptilidae

Anthoptilum grandiflorum

Family Funiculinidae

Funiculina quadrangularis

Family Protoptilidae

Unidentified species

Family Halipteridae

Halipteris sp.

Family Umbellulidae

Umbellula encrinus

Family Pennatulacea

Pennatula aculeata

Pennatula phosphorea

Pennatula grandis

Family Virgulariidae

Virgularia sp.

Class Hydrozoa

Family Stylasteridae Lace corals

Stylaster erubescens brittanicus

Stylaster norvegicus

Stylaster gemmascens

Pliobothrus symmetricus

Porifera

Class Demospongiae

Family Mycalidae

Myclae (Myclae) lingua

Family Microcionidae

Antho (Antho) dicathoma

Family Tetillidae

Craniella zetlandica

Family Tethyidae

Tethya citrina

Family Geodiidae

Geodia atlantica

Geodia barretti

Geodia hentscheli

Family Ancorinidae

Stryphnus ponderosus

Family Polymastiidae

Polymastia thielei

Polymastia hemisphaerica

Quasillina brevis

Polymastia mammilaris

Polymastia uberrima

Weberella bursa

Family Axinellidae

Phakellia ventilabrum

Phakellia robusta

Axinella infundibuliformis

Family Cladorhizidae

Asbestopluma pennatula

Asbestopluma furcata

Asbestopluma bihamatifera

Lycopodina sp.

Chondrocladia (Chondrocladia) grandis

Cladorhiza cf. *oxeata*

Class Hexactinellida

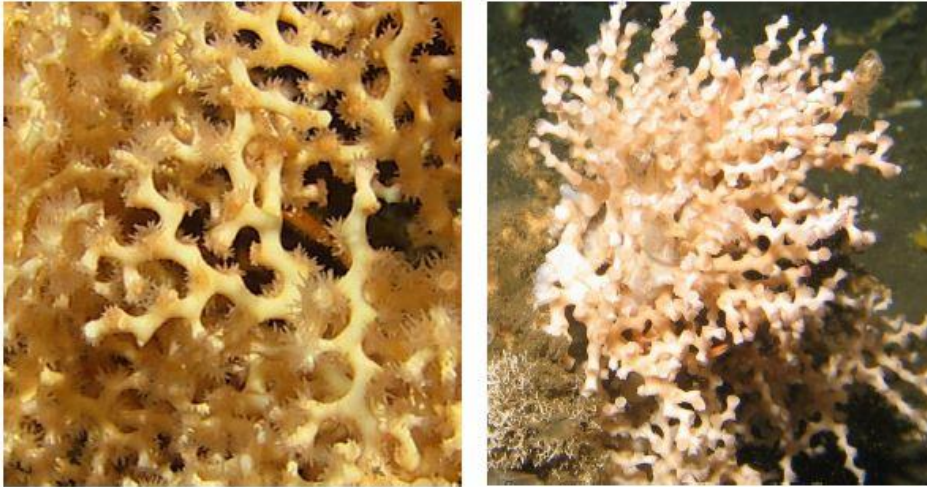
Family Rossellidae

Asconema foliatum

Caulophacus arcticus

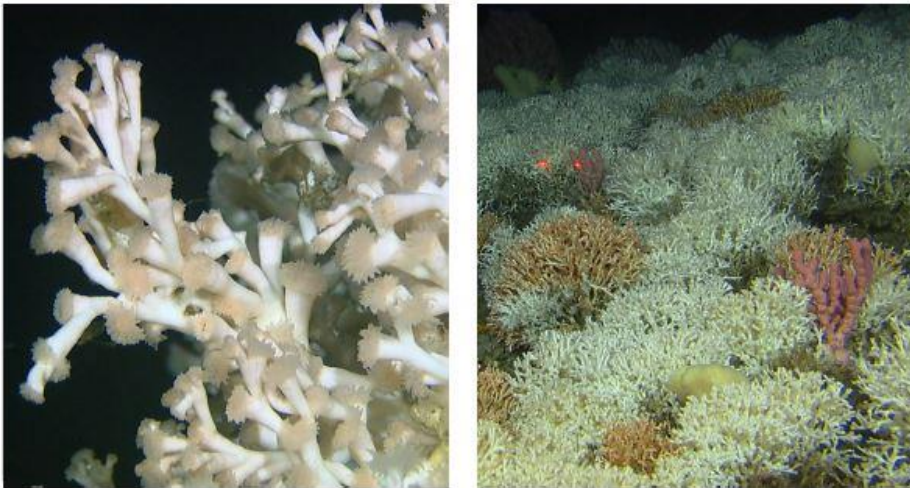
Scleractinia

Figure A7.1: Oculinidae



Note: *Madrepora oculata* – Nor: Sikk-sakkkorall, Isl: Glókkórall, Eng: White coral, ocular coral. Distribution: Iceland, Norway, Faroe Islands. Depth: 100-500m (Nor), 200-1600 m (Isl) 230-1000 m (Far). The colour is white or orange.

Figure A7.2: Caryophylliidae



Note: *Desmophyllum pertusum* (*Lophelia pertusa*) – Nor: Øyekorall, Isl: Postulínskórall, Eng: white stony coral, eye coral, spider hazards. Distribution: Iceland, Norway, Faroe Islands. Depth: 100-1200 m (Isl), 30-500 m (Nor), 210-1000 m (Far). The colour is white or orange.

Close-up, showing partly expanded polyps.

Overview from a reef. Red lazer dots: 10 cm. Both orange and white varieties present. The dark red coral is *Paragorgia*.

Figure A7.3: Caryophylliidae



Note: *Desmophyllum dianthus* (left)

Eng: cockscomb cup coral. Distribution: Norway, Iceland, Faroe Islands. In the Nordic Seas it occurs only as solitary, individual polyps, whereas in other parts of the world it has been reported to form colonies. Depth: 260-2070 m (Isl).

Caryophyllia sp. (right)

Nor: Begerkorall, Eng: cup corals. Distribution: Norway, Iceland, Faroe Islands. This group is difficult to identify to species from underwater images.

Figure A7.4: Flabelliidae



Note: *Flabellum macandrewi* – Distribution: Norway, Iceland, Faroe Islands. Depth: 200-500m (Nor), 250–950 m (Isl).

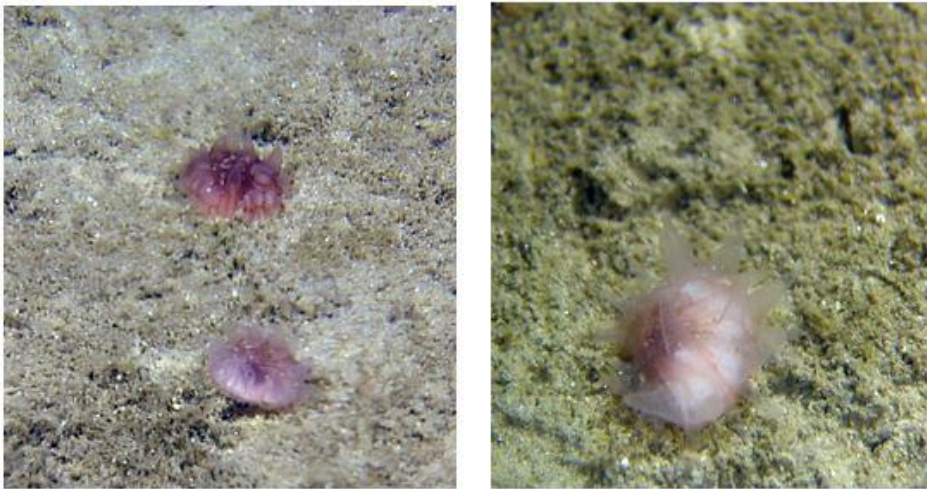
Picture above shows an inflated polyp.

Figure A7.5: Flabelliidae



Note: *Flabellum* sp. – Distribution: Norway, Iceland, Faroe Islands. Depth: 250-2400 m (Isl), 200-500 m (Nor). *Flabellum alabastrum*, *Flabellum angulare* and *Flabellum macandrewi* are found in the Nordic seas.

Figure A7.6: Fungyacyathidae

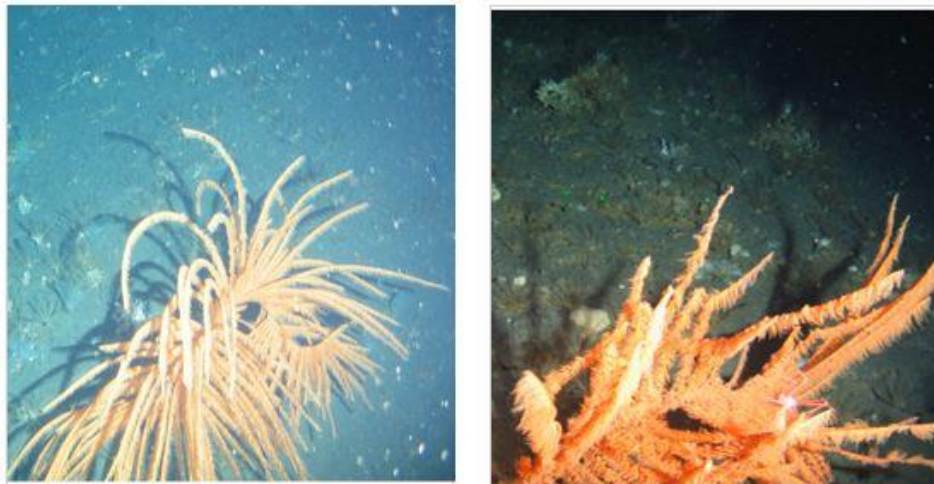


Note: *Fungyacyathus fragilis* – Distribution: Norway, Iceland. Depth: 200-500 m (Nor), 290-1960 m (Isl). Another species, *Fungyacyathus marenzelleri* is also found in the Nordic seas.

Antipatharia

Antipatharia = svartkoraller (Nor), svartkórall (Isl), black coral or thorny coral (Eng).

Figure A7.7: Schizopathidae



Note: *Bathypathes* sp. – Distribution: South and west of Iceland. Depth: 630–1300 m.

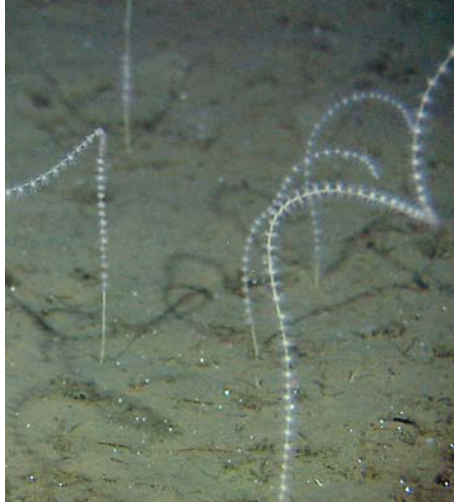
Figure A7.8: Schizopathidae



Note: *Stauropathes arctica* – Þyrnikórali (Isl).
Distribution: South and west of Iceland
Depth 630-1300 m.

Alcyonacea Calcaxonia

Figure A7.9: Chrysogorgiidae



Note: *Radicipes gracilis* – Nor: Grisehalekorall, Eng: Pigtail coral. Distribution: northern slope areas Norway, Iceland. Depth: 700-900 m (Nor), 950-1690 m (Isl).

Figure A7.10: Isididae



Note: *Acanella arbuscula* (left) – Isl: Bambuskóráll, Eng: Bonsai bamboo coral. Distribution: South-west Iceland. Depth: 200-2200 m.

Isidella lofotensis (right) – Nor: Bambusskorall
Distribution: Norway, mainly in deep open fjords. Depth: 200-500 m.

Figure A7.11: Primnoidae



Note: *Primnoa resedaeformis* – Nor: Risengrynkoral, Isl: rískóral, Eng: red trees, mignonette red tree coral. Distribution: Faroe Islands, Norway, Iceland. Depth: 100-600 m (Nor, Isl), 90-1020 m (Far).

Figure A7.12: Primnoidae



Note: *CF. Callogorgia* sp. (left).
Distribution: Iceland. Depth: 345-650 m
Unidentified Primnoidae species (right).
Distribution: Reykjanes ridge, Iceland. Depth: 300 m.

Alcyonacea Holaxonia

Figure A7.13: Plexauridae



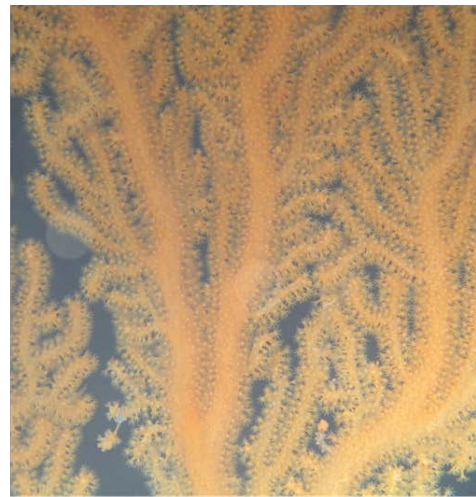
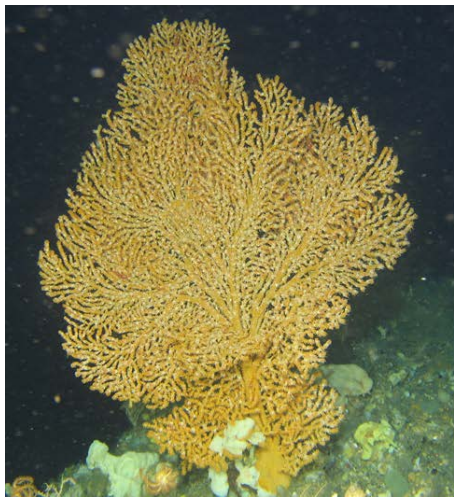
Note: *Swiftia* sp. (left).

Distribution: Norway, Iceland, Faroe Islands. Depth 80-3600 m (Nor), 100-1600 m (Isl).

Paramuricea placomus – Nor: Sjøbusk. (right).

Distribution: Iceland, Norway, Faroe Islands. Depth: 190-1300 m (Isl), 50-600 m (Nor), 205-600 m (Far).

Figure A7.14: Plexauridae



Note: *Plexauridae* is represented by several genera in Icelandic waters - *Muriceides*, *Placogorgia* and *Paramuricea* can be difficult to distinguish as well as identification to species level from underwater images. Depth range of *Plexauridae* 90-1960 m.

Alcyonacea Holaxonia – Scleraxonia

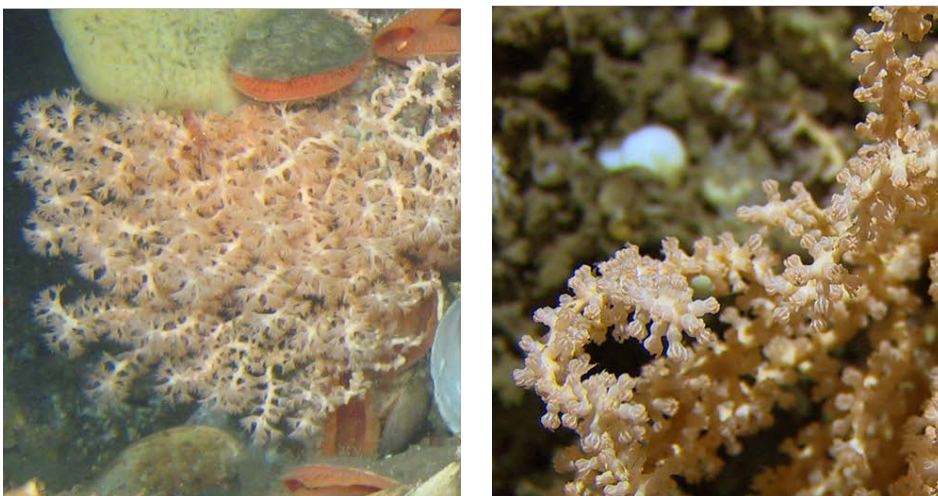
Figure A7.15: Acanthogorgiidae



Note: *Acanthogorgia armata* – Eng: armoured sea fan coral. Distribution: Iceland. Depth 550-1300 m.

Picture above shows close up image of the polyps.

Figure A7.16: Anthothelidae



Note: *Anthothela grandiflora* – Eng: greater flowerbud coral. Distribution: Iceland, Norway, Faroe Islands. Depth: 100-500 m (Nor), 240-2500 m (Isl), 40-990 m (Far).

Lateothela grandiflora is very similar to *A. grandiflora* and is found in same areas. These can not be told apart from underwater images.

Alcyonacea – Scleraxonia - Stolonifera

Figure A7.17: Paragorgiidae



Note: *Paragorgia arborea* – Nor: Sjøtre, Eng: Bubble gum coral. Distribution: Norway, Iceland, Faroe Islands. Depth: 100-600 (Nor), 180-1200 m (Isl), 260-650 m (Far).

Figure A7.18: Clavulariidae



Note: *Clavularia borealis* – Distribution: Norway, Iceland. Common on cold water coral reefs. Depth: 100-500 m (Nor). Three other species of *Clavularia* are found in Icelandic waters. *Clavularia* spp. 90-2050 m (Isl).

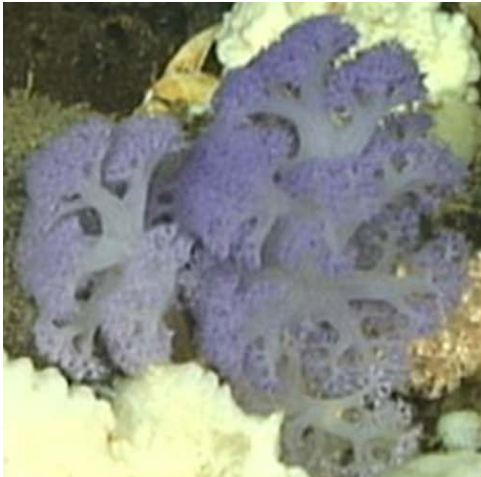
Alcyonacea Alcyoniina

Figure A7.19: Nephtheidae



Note: *Drifa glomerata* – Eng: orb carnation coral. Distribution: Iceland, Faroe Islands, Norway. Depth: 70-1700 m (Isl) 80-1590 m (Nor). Colours may vary.

Figure A7.20: Nephtheidae



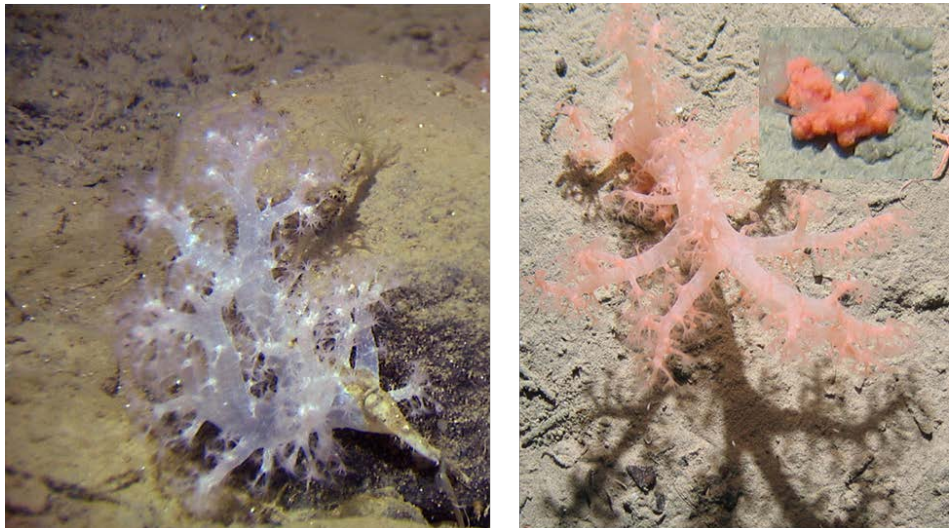
Note: *Duva florida* – Eng: flowery carnation coral. Distribution: Iceland, Faroe Islands, Norway. Depth: 80-1350 m (Isl), 50-1100 m (Nor). Colours may vary.

Figure A7.21: Nephtheidaeidae



Note: *Pseudodrifa* sp. – Distribution: Iceland. Depth 295- 1130 m. Large polyps.

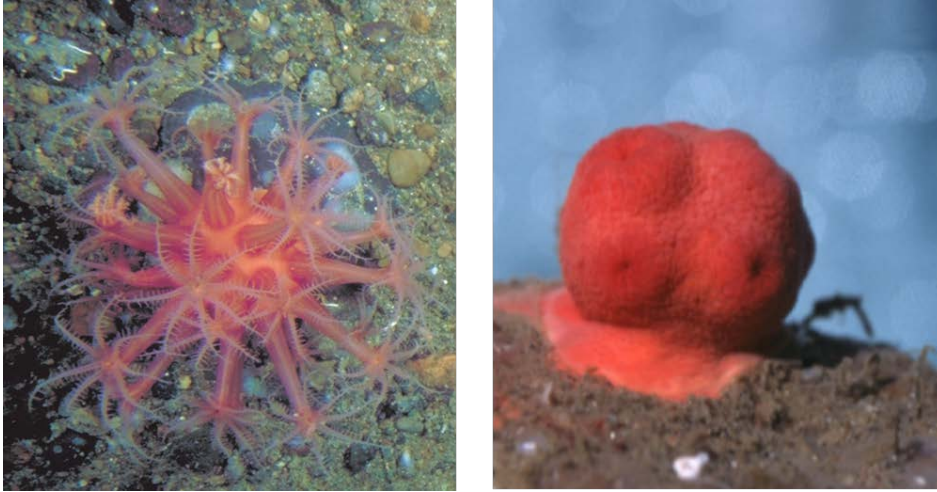
Figure 7.22: Nephtheidaeidae



Note: *Gersemia fruticosa* – Eng: hedge carnation coral. Distribution: Iceland, Faroe Islands, Norway.
Depth: 20-2000 m (Nor) 215-2000 m (Isl).

Other species in Nordic seas: *Gersemia rubiformis* and *Gersemia clavata*.

Figure A7.23: Alcyoniidae



Note: *Anthomastus* sp. – Nor: Kjøttkorall, Eng: large-polyped deep-sea soft coral. Distribution: Norway, Iceland, Depth: 200-700 m (Nor), 570-2400 m (Isl), 500-1112 m (Far). Known species in the Nordic seas: *Anthomastus grandiflorus* and *Anthomastus purpureus*. Similar species that have been confused with *Anthomastus* are: *Pseudoanthomastus* spp. and *Heteropolypus* spp.

Figure A7.24: Xeniidae



Note: *Ceratocaulon wandeli* – Distribution: North of Iceland. Depth: 260-1200 m.

Pennatulacea

Figure A7.25: Anthoptilidae



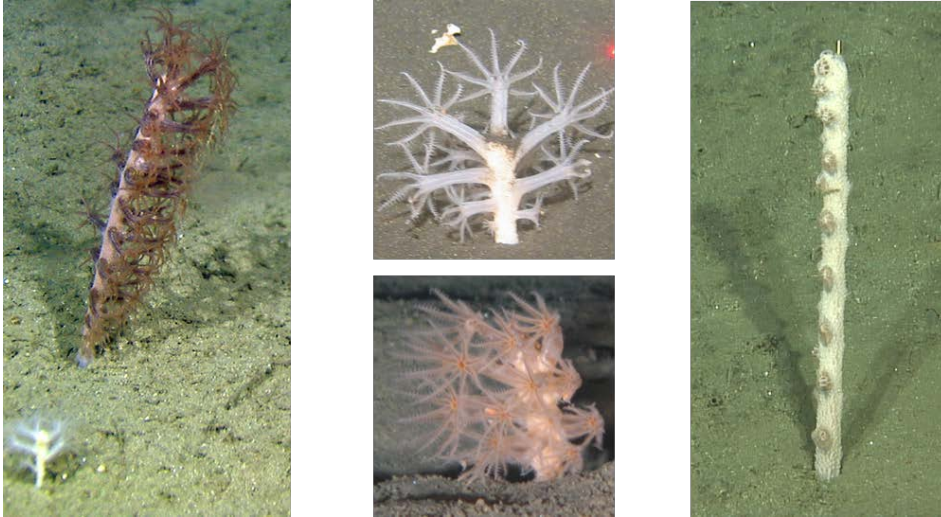
Note: *Anthoptilum grandiflorum* – Eng: full-flowered sea pen. Distribution: Iceland. Depth: 400-1300 m.
Another species: *Anthoptilum murrayi* is in Icelandic waters but is less fleshy.

Figure A7.26: Funiculinidae



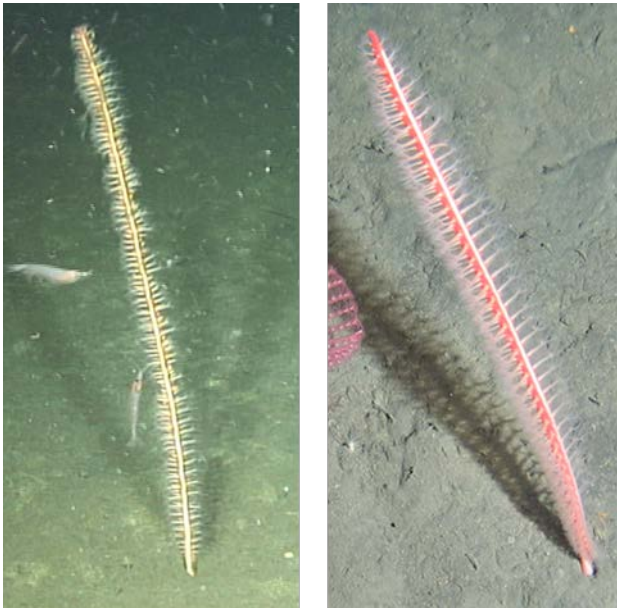
Note: *Funiculina quadrangularis* – Nor: Stor piperenser., Eng: tall sea pen. Distribution: Iceland, Norway, Faroe Islands. Depth: 230-2300 m (Nor), 290-2270 m (Isl).

Figure A7.27: Kophobelemnidae



Note: *Kophobelemnon stelliferum* – Nor: Hanefot, Eng: wilde Star seapen. Distribution: Iceland, Norway, Faroe Islands. Depth: 100-600 m (Nor), 120-2600 m (Isl). Colour: white, pink, brown.

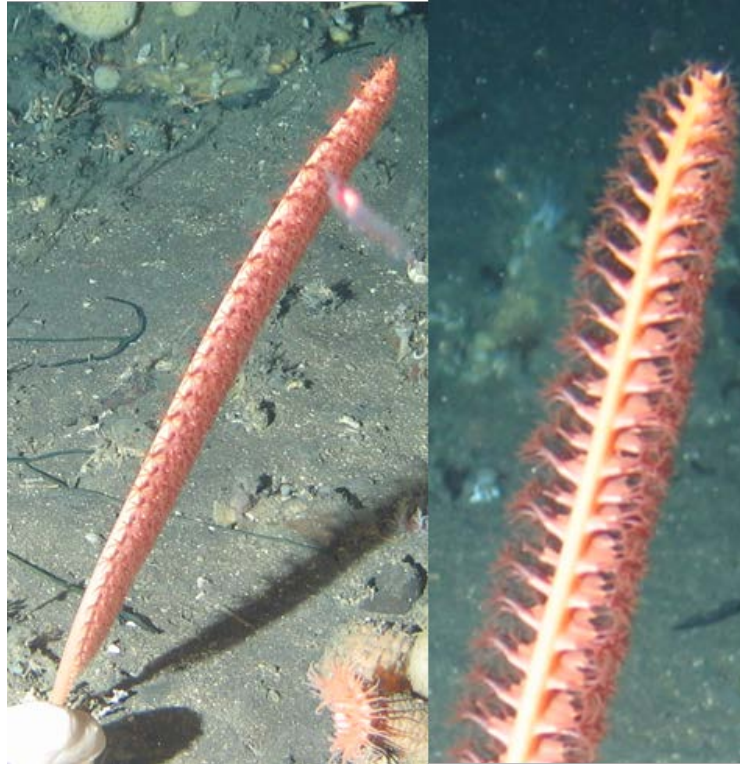
Figure A7.28: Protoptilidae



Note: Unidentified Protoptilidae species – Distribution: Iceland. Depth: 130-3400 m.

Distichoptilum gracile, *Protoptilum carpenteri* and *Protoptilum thomsoni* are found in Icelandic waters.

Figure A7.29: Halipteridae



Note: *Halipteris* sp. – Distribution: Iceland. Depth: 165-2100 m. Blade-shaped polyp stands.

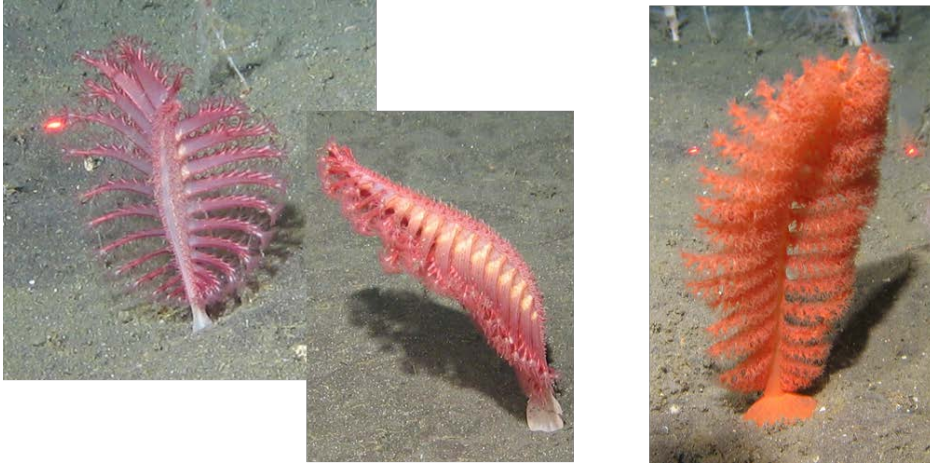
Two species are found in Nordic seas: *Halipteris christii* with 6 polyps on each polyp-leaves and *Halipteris finmarchica* with 15 polyps.

Figure A7.30: Umbellulidae



Note: *Umbellula encrinus* – Eng: lily sea pen. Distribution: Norway, Iceland, Faroe Islands. Depth: 260-2100 m (Isl), 700-2000 m (Nor), 580-1500 m (Far).

Figure A7.31: Pennatulidae



Note: *Pennatula aculeata* and *Pennatula phosphorea* (left) Eng: thorny and luminescent sea pens, are found in Iceland and Norway. These are difficult to identify from underwater photos. Depth: 125-2700 m.

Pennatula grandis (right) - Eng: greater sea pen. Distribution: Norway, Iceland. Depth: 200 -1600 m.

Figure A7.32: Virgulariidae

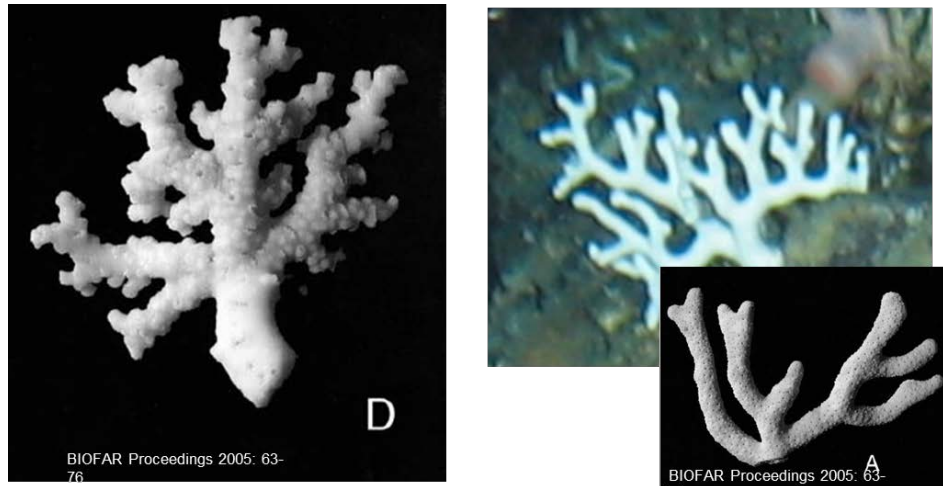


Note: *Virgularia* sp. – Nor. Liten piperenser.

There are four Virgulariidae species in Iceland; *Virgularia glacialis*, *Virgularia mirabilis*, *Virgularia tuberculata* and *Stylatula elegans*. In Norway *V. mirabilis* is the most common. Distribution: Norway, Iceland, Faroe Islands. Depth: 90-1200 m.

Stylasteridae

Figure A7.33: Stylasteridae



Note: *Stylaster erubescens britannicus* (left) – Distribution: Faroe Islands, Iceland. Depth: 191-1006 m (Far), 213-1645 m (Isl).

Pliobothrus symmetricus (right) – Distribution: Faroe Islands, Iceland.

Figure A7.34: Stylasteridae

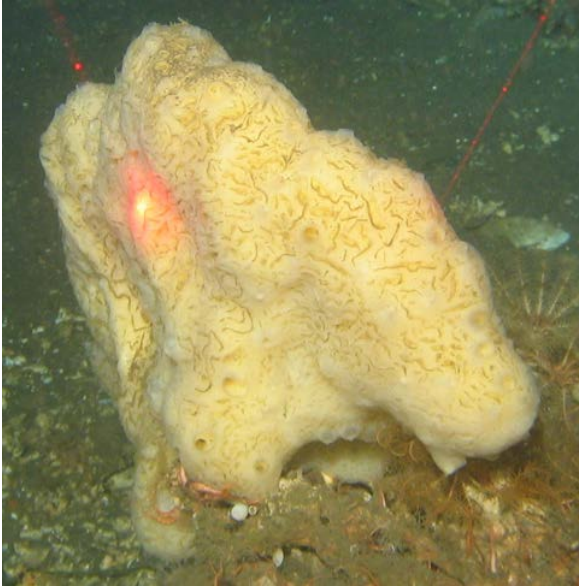


Note: *Stylaster norvegicus* (left) – Distribution: Norway, Faroe Islands, Iceland. Depth: 400-1400 m (Isl), 75-997 m (Far).

Stylaster gemmascens (right) - Distribution: Norway, Faroe Islands, Iceland. Depth: 410-620 m (Isl), 203-700 m (Far).

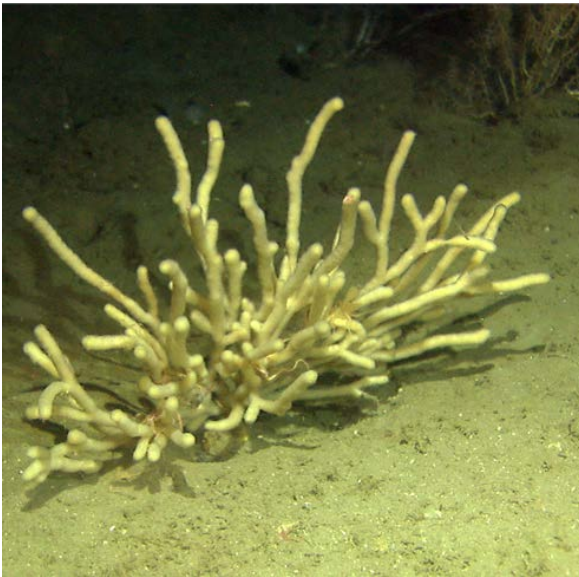
Demospongiae

Figure A7.35: Mycaliidae



Note: *Mycale lingua* – Eng: sheep's tongue sponge, furrowed horny sponge. Distribution: Iceland, Norway, Faroe Islands. Depth: 111. 880 m (Nor), 14-2150 m (Isl), 283-290 m (Far).

Figure A7.36: Microcionidae



Note: *Antho dichotoma* – Nor: Fingersvamp. Distribution: Iceland, Faroe Islands, Norway. Depth: 120-1290 m (Isl), 127-940 m (Nor).

Craniella and *Tethya* species are very similar in appearance and often not possible to distinguish between them from underwater images.

Figure A7.37: Tetillidae



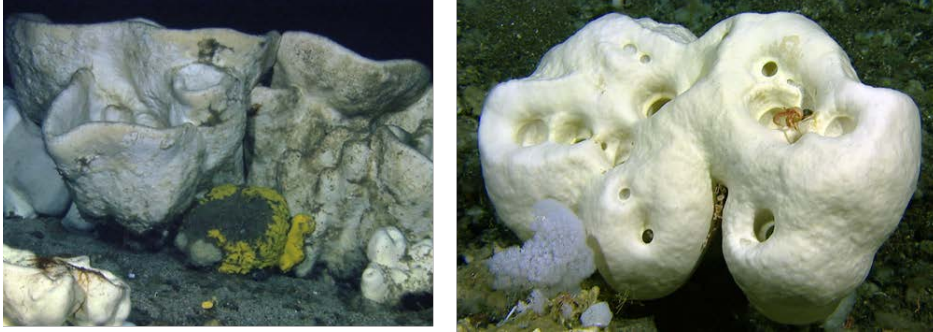
Note: *Craniella zetlandica* – Distribution: Iceland, Norway, Faroe Islands. Depth: 170-1000 m.
Craniella cranium is very similar but is more yellowish.
Both are northern deep water species.

Figure A7.38: Tethyidae



Note: *Tethya citrina* – Nor: Appelsinsvamp Eng: yellow golf ball sponge, sea lemon.
Distribution: Iceland, Norway. Depth: 150-1300 m. Very similar species *T. norvegica* is in north Atlantic but is only 2 cm in diameter.

Figure A7.39: Geodiidae



Note: *Geodia atlantica* (left) – Distribution: Iceland, Faroe Islands, Norway.
Depth: 161-808 m (Nor), 260-650 (Far), 230-1505 m (Isl).

Geodia barretti (right) – Distribution: Iceland, Faroe Islands, Norway.
Depth: 110-1290 m (Isl), 60-808 (Nor), 250-273 (Far).

Geodia macandrewii, *Geodia phlegraei* and *Geodia parva* are also found in Iceland and Faroe Islands but no underwater images have been confirmed of these species yet.

Figure A7.40: Geodiidae



Note: *Geodia hentscheli* – Distribution: Iceland.
Depth: 260-1230 m.

Figure A7.41: Ancorinidae



Note: *Stryphnus ponderosus* with encrusting sponge (*Aplysilla sulfurea*) – Distribution: Iceland, Norway, Faroe Islands. Depth: 145-660 m, 470-1230 m (Isl), 250-282 m (Far).

Figure A7.42: Polymastiidae



Note: *Polymastia thielei* (left) – Distribution: Iceland, Norway, Faroe Islands. Depth: 300-1000 m (Isl).
Polymastia hemisphaerica (right) – Distribution: Iceland.

Figure A7.43: Polymastiidae



Note: *Polymastia uberrima* (left). Distribution: Iceland.

Polymastia mamillaris (right) – Distribution: Iceland, Norway, Faroe Islands.

Figure A7.44: Polymastiidae



Note: *Quasillina brevis* (left) – Distribution: Iceland, Norway.

Weberella bursa (right).

Distribution: Iceland.

Figure A7.45: Polymastiidae



Note: Many Polymastiida species are found in Nordic seas but good reference to underwater images and verified species is lacking. Distribution of this group: Iceland, Norway, Faroe Islands. Depth: 40-1900 m.

Figure A7.46: Axinellidae



Note: *Phakellia ventilabrum* (left) – Nor: Griseøresvamp. Distribution: Iceland, Norway, Faroe Islands. Depth: 50-1300 m. Vase or leaf form, thin walls with visible „veins“.

Phakellia robusta (right) – Distribution: Iceland, Norway, Faroe Islands. Depth: 19-500 m. Irregular growth form, but thin walls. Often found growing on coral reefs

Figure A7.47: Axinellidae



Note: (left) Several Axinellidae species are found in the Nordic seas. *Phakellia bowerbanki*, *Phakellia lambei*, *Axinella arctica*, *Axinella rugosa*.

(Right) *Axinella infundibuliformis* – Nor: Traktsvamp. Distribution: Iceland, Norway, Faroe Islands. Depth: 50-600 m. Funnel shape with thicker walls than *Phakellia*.

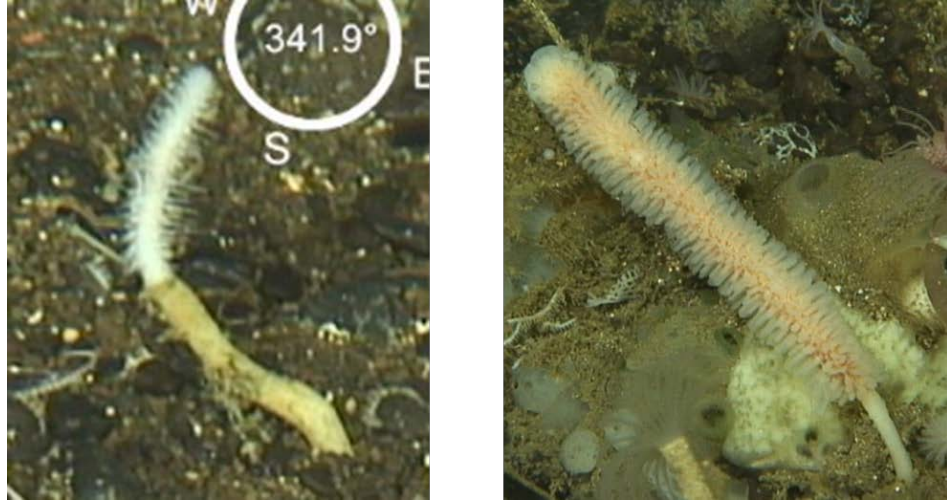
Figure A7.48: Cladorhizidae



Note: *Asbestopluma pennatula* (left) Distribution: Iceland, Norway, Faroe Islands. Depth: 100-1600 m.

Asbestopluma furcata (right) – Distribution: Iceland, Norway. Depth 610-3000 m.

Figure A7.49: Cladorhizidae



Note: *Asbestopluma bihamatifera* (left) – Distribution: Iceland. Depth: 320-921 m.

Lycopodina sp. (right) – Distribution: Iceland. Depth 600 m.

Figure A7.50: Cladorhizidae



Note: *Chondrocladia grandis* – Distribution: Iceland, Norway. Depth: 380-965 m (Isl), 700-2000 m (Nor).

Figure A7.51: Cladorhizidae



Note: *Cladorhiza cf. oxeata* – Distribution: Iceland.
Depth: 400-1000 m.

Hexactinellida

Figure A7.52: Rossellidae



Note: *Asconema foliatum* (left) – Eng. Leafy glass sponge. Distribution: Iceland, Norway, Faroe Islands.
Depth: 170-1240 m (Isl).

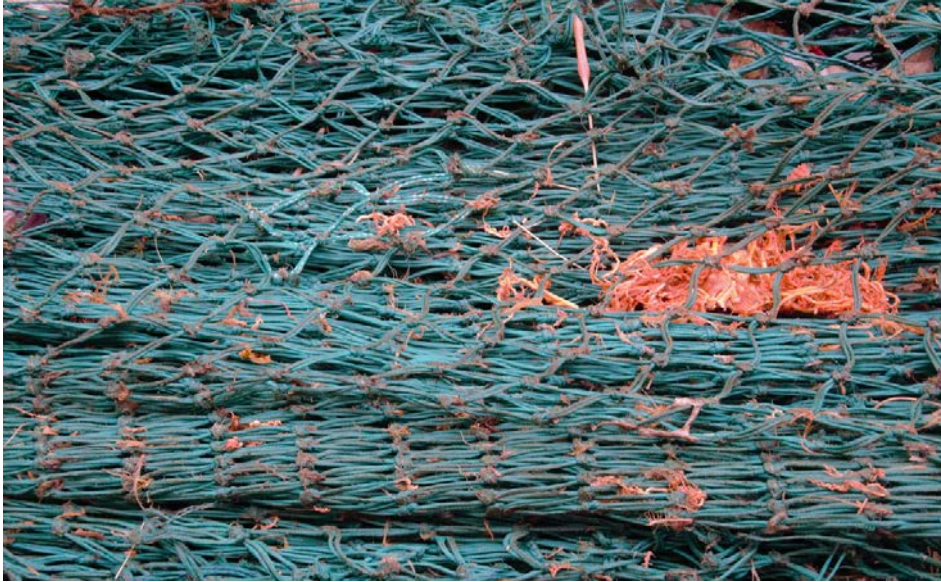
Caulophacus arcticus (right) –
Nor: Kantarellsvamp. Distribution: Norway. Depth: 1500-2000 m.

Figure A7.53: Rossellidae



Note: Rossellidae spp. – Vase shaped sponges. Distribution: Iceland. Depth: 600 m.

Identification guide for corals and sponges as by-catch from bottom trawling - Steinunn Hilma Olafsdottir



Introduction

This identification guide is intended for use by people with experience in identification of marine invertebrates, as well as those with limited background from practical marine taxonomy.

The guide does not provide a complete overview of cold-water corals and sponges from the Nordic Seas, but is meant as a supplement for on-board identification of specimens caught as by-catch during bottom trawling.

The groups included in this guide are: *Scleractinia* Stony corals – both colonial and solitary, *Alcyonacea* – both coral trees (gorgonians) and cauliflower (soft) coral, *Antipatharia* black coral, *Pennatulacea* sea pens and *Porifera* sponges. The selected porifera were limited to those that represent specific “sponge aggregations” like *Ostur aggregation*, *hard bottom sponge* aggregation (mixed sponges) and *deep cold water sponges*.

The images were taken by the Marine and Freshwater Research Institute (MFRI) Iceland, during annual ground fish surveys on RV Árne Friðriksson.

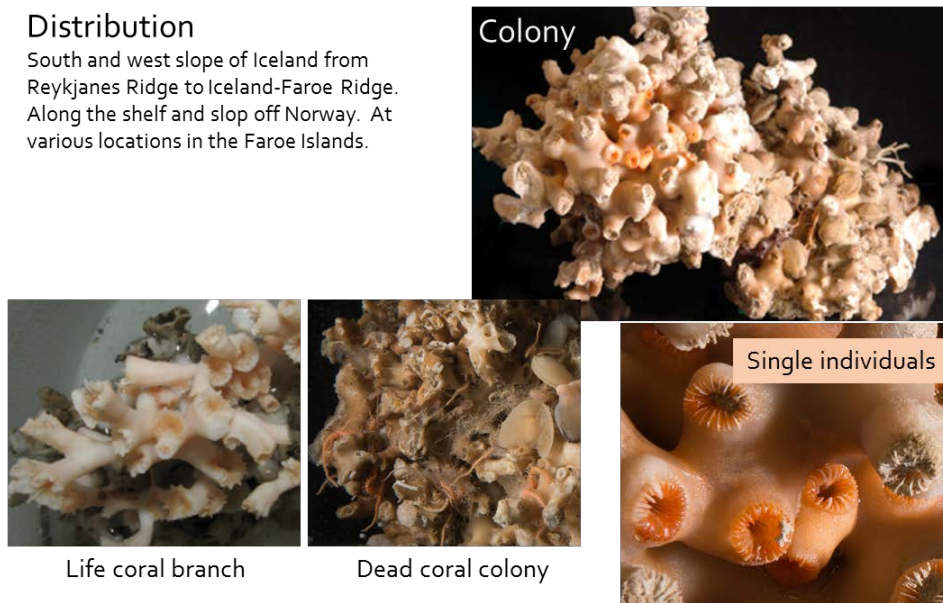
This guide is a working document. It has been tested on board commercial trawlers where the crew was recording different types of corals and sponges.

Scleractinia – Colonial stony corals

Figure A7.54: Scleractinia – Colonial stony corals

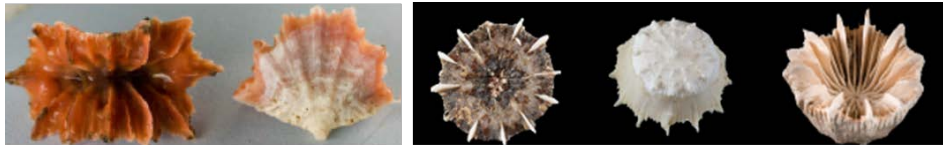
Distribution

South and west slope of Iceland from Reykjanes Ridge to Iceland-Faroe Ridge. Along the shelf and slope off Norway. At various locations in the Faroe Islands.



Scleractinia – Solitary stony corals

Figure A7.55: Scleractinia – Solitary stony corals



Flabelliferae sp.

Stephanocyathus sp.



Desmophylum sp.



Various solitary coral species

Alcyonacea – Coral trees

Figure A7.56: Alcyonacea – Coral trees

Size range from 5 cm to 5 m

Distribution:

South slope of Iceland from Reykjanes Ridge (RR) to Iceland-Faroe Ridge. From RR to Kolbeinsey Ridge. Along the slope and shelf off Norway and around Faroe Islands.



Paramuricea sp.
Up to 1.5 m high



Primnoa resedaeformis
Up to 1 m high



Acanella arbuscula Bamboo coral
Often 10-12 cm.



Anthothelidae



Acanthogoriidae



Paragorgia arborea
Large trees – up to 5 m high



Dead coral branch

Alcyonacea – Alcyoniina Cauliflower coral

Figure A7.57: Alcyonacea – Alcyoniina Cauliflower coral



Distribution:
All around Iceland.

Can be yellowish, grey, pinkish, black or purple. Rarely over 10 cm in height.



Antipatharia – Black coral

Figure A7.58: Antipatharia – Black coral



Distribution:
Rare. Deep water S and W of Iceland.

Black stalk and orange polyps.



Pennatulacea – Sea pens

Figure A7.59: Pennatulacea – Sea pens



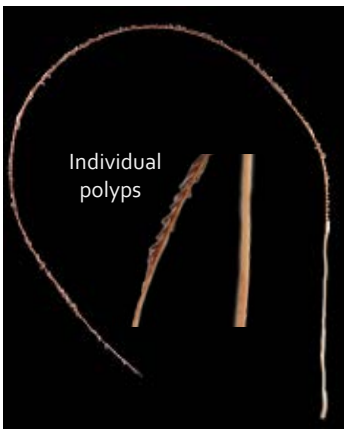
Anthoptilum grandiflorum



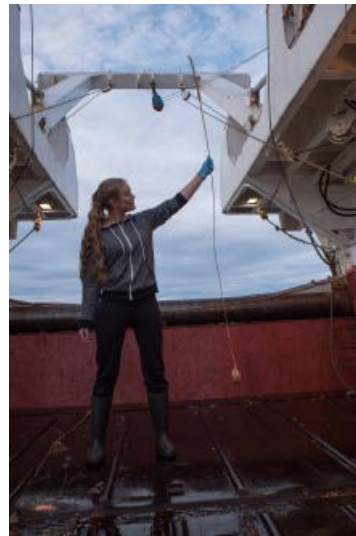
Pennatula sp.

Distribution:

Large specimens are found in deep cold waters north and north east of Iceland and in Norway. Smaller specimens are found south and west of Iceland.



Funiculina quadrangularis



Umbellula encrinus

Umbellula can be up to 3 m high
Gets tangled in the net.

Porifera – Demospongiae

Figure A7.60: Porifera – Demospongiae

„Ostur“ - *Geodia* sponges

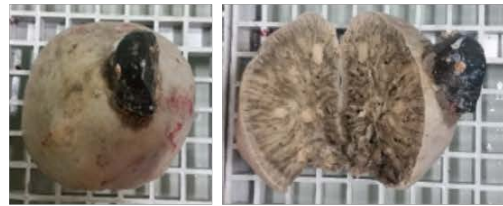


Craniella sp. – like golf ball

Also referred to as “potatoes”. Several species are considered “ostur”. Can be as large as 50 cm in diameter.

Distribution:

Iceland - Norway - Faroe Islands.



Geodia sp. – many species



Stryphnus sp. – has sharp spicules that give a very unpleasant feeling if touched with bare hands.

Porifera – Demospongiae

Figure A7.61: Porifera – Demospongiae

Mixed sponge species

Distribution:

Iceland - Norway - Faroe Islands.



Axinellidae – leaf like species



Mixed catch with round, leaf like and branching species.



Antho dichotoma
Branching sponge

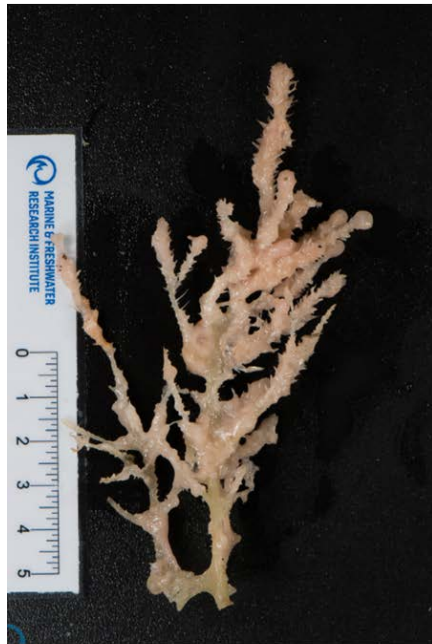


Figure A7.62: Porifera – Demospongiae

Deep coldwater sponges

Distribution

NV and North of Iceland. North Norway.



Cladoriza sp.



Chondrocladia grandis

Porifera

Figure A7.63: Porifera

Various forms of sponges



"Spikule clump"



Mycale lingua



Thenea sp.



Polymastia



"Net like"



"Wool like"



Glass sponge



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Vulnerable marine ecosystems (VMEs)

This report presents results from the NovasArc project that has collated data on the distribution of vulnerable marine ecosystems (VMEs) in Arctic and sub-Arctic waters. Eleven VMEs were identified, based on management goals for coral and sponge communities. Many of the vulnerable marine ecosystems (VMEs) in the study area has a wide distribution. Soft and hard bottom sponge aggregations, hard bottom gorgonians, sublittoral sea pen communities, and cauliflower corals are predicted to cover > 20% of the study area shallower than 1000 meters.

Of the anthropogenic activities in the study area bottom trawling represents the main threat to the VMEs. The compilation of trawling activity in the study area shows that fisheries mainly occurs shallower than 1000 meters and that 50 to 60% of the seafloor is not targeted. However, 30% of the seafloor has experienced intermediate to very high fishing effort.

In general, the VMEs shows a larger overlap with fishing when the risk analysis is based on areas with an optimal habitat suitability. Using this conservative threshold to model the distribution of VMEs the results indicate that most VMEs have experienced an intermediate to high level of fishing in less than 40% of their distribution area in the whole study area.

