# Deep-water communities in the West-Nordic area

*Eric dos Santos, Ámundur Nolsø, Christoffer Schander,*
*Ole S. Tendal, Stefán Á. Ragnarsson, Jörundur Svavarsson*

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**Nordic Council of Ministers**
Store Strandstræde 18
DK-1255 Copenhagen K
Phone (+45) 3396 0200
Fax (+45) 3396 0202

**Nordic Council**
Store Strandstræde 18
DK-1255 Copenhagen K
Phone (+45) 3396 0400
Fax (+45) 3311 1870

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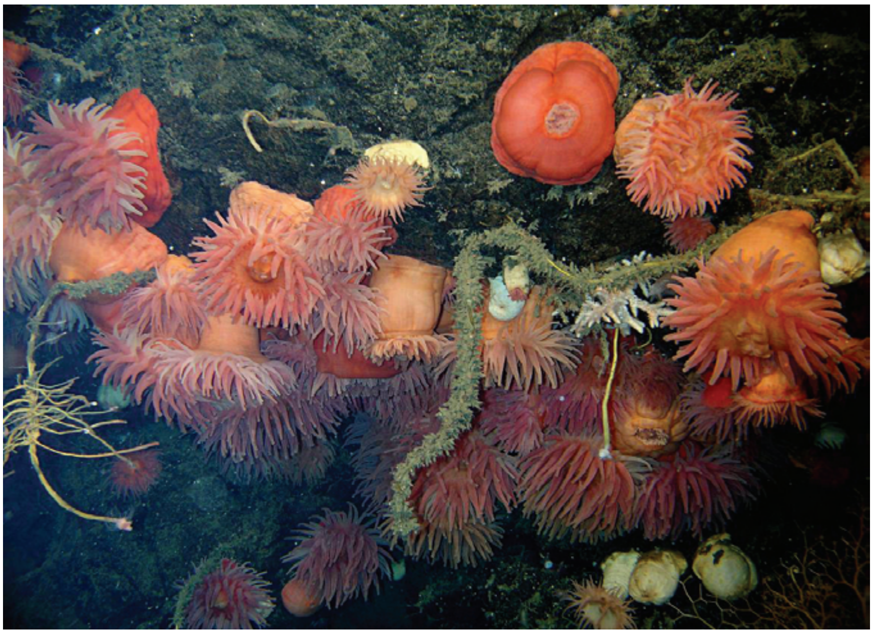
# Content

# Preface

The Nordic Council of Ministers funded this project from 2006–2008 with the focus of examining the benthic fauna of the west Nordic Seas. The aims of the study were to describe the structure of epibenthic animal communities at different depths and on different bottom types and to examine the importance of hard bottoms. The purpose for this research was to add to the basis of knowledge used in making policy decisions about the delineation of marine protected areas and fishing practices as well as to augment ecological understanding of deep-water communities in the region.

This project involved collaboration of specialists from Iceland, Denmark, Norway and the Faeroe Islands. Through this collaboration, two articles are in preparation for publication in peer-reviewed journals. Posters based on these articles have been presented at two conferences: Science Conference of the University of Iceland (Raunvísindaþing) in Reykjavík, Iceland (2008) and the World Conference on Marine Biodiversity in Valencia, Spain (2008).

**Figure 1. Community dominated by the cnidarian Hormathia cf. digitata but containing other species such as Cladorhiza *sp.* (Porifera), Gorgonocephalus *sp.* (Ophiuroidea) and Tubularia *sp.* (Cnidaria).**



This community was photographed at about 680 m depth. Photo: Centre for GeoBiology, Bergen.

# Summary

The aim of the presented project was to provide information about the community structure and diversity of epibenthic megafauna in the western region of the Nordic Seas. The focus was on the importance of hard substrate in the formation and definition of animal communities.

The study was based on review of the literature and unpublished data as well as photographs from Iceland and both photographs and video collected from the vicinity of Jan Mayen. In addition, video footage from an expedition of R/S Árni Friðriksson to the Reykjanes Ridge southwest of Iceland was used for visual comparison of animal communities in an area that had suffered recent disturbance. The photographs from Iceland were taken at eight sites to the northwest and north of the country ranging in depth from 240 – 374 m. Videos and stills collected during expeditions by the research vessel G.O. Sars along an undersea trench that lies from Jan Mayen northeast toward Spitzbergen were used to describe the animal communities in the Nordic Seas. All animals large enough (>1 cm diameter for photographs, > 5 cm diameter for videos) were identified to lowest possible taxonomic level.

In the photographs analyzed, community structure was found to vary strongly between sites in Icelandic waters but not much within sites. Furthermore, community structure seemed to be strongly effected by the presence of any hard surfaces rather than just the clear difference between soft and hard bottoms which has often been reported as being the important ecological distinction. That is, the presence of hard surfaces in soft sediment effect the community structure in the same way that solid hard substrate does. The wider scope provided by video data from the Jan Mayen region showed a highly patchy distribution of epifauna and that patches are often dominated by a single macrofaunal species or a few species of a single genus. This patchiness seems to be the result of presence or absence of hard surfaces to act as anchor sites for sessile and semi-sessile species.

This study leads to questions about why distribution of much of the megafauna in the study area is organized in such species-specific patches and whether such patchiness and observed diversity patterns are typical for the region. Also, it suggests that in order to protect the true diversity of the region marine protected areas will have to be large and not limited to small areas of a specific bottom type. Furthermore, our analysis indicates that three specific areas should be the focus of immediate consideration for protection. First, the analysis of photographs from Kolbeinsey Ridge indicated that species diversity of macrobenthic species was high in relation to that found in photographs of other regions in Icelandic wa-

ters. Second, the GIF Ridge, especially its southern face, is an important habitat for deep-water corals in the North Atlantic. Third, the hydrothermal and cold seep areas investigated between Jan Mayen and Spitzbergen are populated by patchy but diverse fauna. This last area is potentially at risk because there are commercially valuable fish species there and because the geological characteristics of the area suggest that exploration for fossil fuels and metal salts may be imminent.

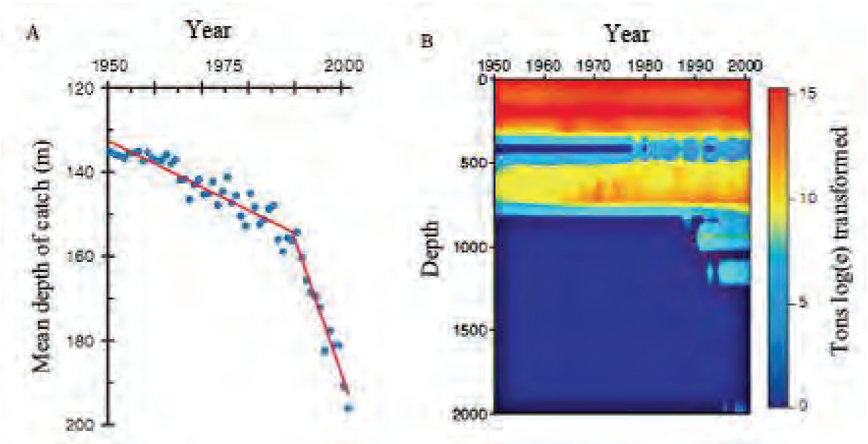
# 1. Introduction

## 1.1 Background

Exploitation of coastal waters has a long history that has led to drastic declines in many fish stocks over the continental shelves. There are two alarming trends that have emerged from the declines of these fish populations. One trend is that populations of traditional target species are fished for at depths that have hitherto functioned as refuges. The other trend is that fishers are forced to aim their effort at poorly understood species not traditionally exploited because of the depths which they inhabit. Many of these are demersal fish that live just above the seabed for the major part of their lives. Recent research shows that there is a global trend of increased fishing pressure on bottom fishes in greater depths (Fig. 2, Kaiser, *et al.*, 2001; Morato *et al.* 2006; Sigurðsson, *et al.*, 2006).

Fishing equipment can have negative effects on the invertebrate fauna of the sea floor as well as the fish populations (Turner *et al.* 1999). This includes infaunal organisms which are responsible for the recycling of organic and inorganic compounds that have settled to the seafloor out of the water column. Furthermore and perhaps of more direct importance to fisheries, is the destruction of habitat and habitat-forming species that may support the fish stocks. Studies have demonstrated (e.g. Jensen and Frederiksen, 1992; Klitgaard, 1995; Lindholm et al., 2001; Ross and Quattrini, 2009) that some commercial fish species use the larger megafaunal animals such as sponges (Porifera), soft corals (Cnidaria) and to lesser extent colonial polychaetes (Annelida) as spawning grounds and nurseries for their young. The destruction of habitat caused by some types of fishing gears contributes to declines in fish stocks by reducing the area of bottom useable to demersal fish populations.

**Figure 2. Increase of fishing pressure on the deep-water ecosystems of the North Atlantic. A) Average depth of catch in meters, B) Total catch by depth and year in tons loge transformed.**




Figures from Morato et al., 2006.

Human destruction of fragile deep-sea ecosystems is avoidable following proper management based on sound science. It is important that damage to slow-growing habitat-forming invertebrates such as hard coral reefs and mass occurrences of large-sized sponges be kept to a minimum. When German fishermen began fishing the waters southeast of Iceland before World War II, they referred to the region as Rosengarten probably because of the amount of reddish deep-water coral that came as bycatch in net hauls. However, as early as 1924 the Icelandic researcher Bjarni Sæmundsson reported noticeable declines in the abundance of large scleractinian coral communities in the undersea canyon outside of Berufjörður (Sæmundsson, 1942). More recently, far less coral has been reported and in some instances areas where fishermen have reported high amounts of coral by-catch in the past are now bare of the important reef-building species. One species of deep-water coral in the genus *Paragorgia* was reported to be present, though in modest abundance, to the south of Iceland on the southern face of the Greenland – Iceland – Faeroes Ridge (GIF Ridge) (Tendal, 1992). Most of the observed corals in that study were small colonies. The observed declines have a history of close to 100 years in many areas. The decline in coral abundance is also detrimental to the diversity of the marine fauna. Corals have been shown to support unique and diverse communities of fishes (Ross and Quattrini, 2009).

**Figure 3. In among the large poriferans found during investigation of the phenomenon called ostur by researchers and fisherman are some specimens of commercial fish.**

Photograph: A.B. Klitgaard.

Other benthic species susceptible to damage from fishing gears are the sponges (Porifera). In some areas the sponge communities form three dimensional structures that are large enough for other animals to utilize as nurseries for young as well as habitat for adults. These mass occurrences of large poriferans have been called ostur (which means cheese) by researchers and fishermen from Scandinavia and such phenomena have been observed as far afield as the seas to the north of Spitzbergen (Klitgaard *et al.*, 2004) (Fig. 3). Most of the sponge species grow mainly on hard bottoms but on soft bottoms with many dropstones large colonies can form by smaller colonies that have settled on separate rocks joining together as they grow. Such habitats may take hundreds of years to recover following destruction by trawled fishing gear, if indeed recovery is possible. Often the abiotic environment (sediment and stones of the region) is altered by fishing gears as they re-suspend sediment which then settles to cover the bottom in such a way that hard-bottom species cannot re-establish colonies (Turner *et al.*, 1999). Change to the abiotic deep-sea environment leads to changes in the structure and distribution of emergent epifauna communities (Kaiser *et al.*, 2000) and this, in turn, can have drastic effects on the survivorship of young fish (Lindholm *et al.*, 2001).

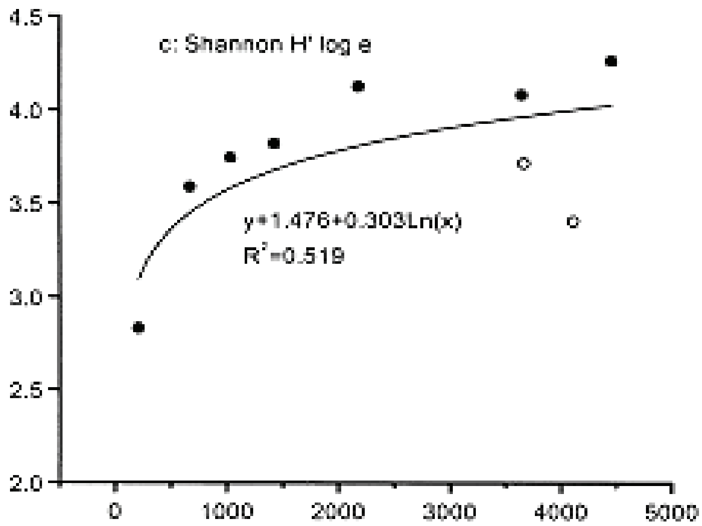
The majority of fishing activity in the study area (Fig. 6) is conducted by four of the Nordic countries (Norway, Iceland, the Faeroe Islands and Greenland), several EU countries and Russia. In addition, some vessels flying convenience flags are participating in the harvesting of fish from these same stocks. In this region the natural status of animal communities on the sea floor in deep waters is poorly understood. Proper management of exploitative activities in the deep-sea should be based on a better understanding of the functioning of benthic ecosystems because without this understanding the effects of disturbance will be unpredictable.

Of particular interest to this study are the GIF Ridge and the trenches and seamounts in the Nordic Seas, specifically those near to Jan Mayen. These areas are taken under consideration because of their similarity in species composition and the variation in the amount of fishing activity present. The Jan Mayen sites are not yet areas of significant human disturbance and as such they represent a more natural condition of a cold water habitat in the deep ocean. However, the presence of hydrothermal vents and cold seeps make this area a likely site for future disturbance due to the search for useable resources like fossil fuels and metal salts. The forms of disturbance that are the result of such mineral exploitation depend on the type of resource that is harvested. Some forms of disturbance, such as drilling, have highly localized impact while dredging for metal salts has an effect on a much larger area (Jones, *et al.* 2007c). The sites from the west and north of Iceland represent habitats in cold water that have been recently disturbed to some degree by human activity. The likely importance of these areas as fishing grounds in the near future makes them good regions to study now before exploitation is begun in full.

Despite lacking comprehensive understanding of the ecosystem dynamics in question and their resilience to disturbance, governing bodies have designated only a small fraction of the Nordic Seas as permanent marine protected areas (MPA's). Two main areas where permanent MPA's exist are offshore from the western Norwegian coast and close to the Faeroe Islands. In Icelandic waters several areas of closure to bottom-trawl fishing have been established. The closed areas are mainly centered on the continental slope. Only three MPAs have been established in Icelandic waters on the GIF Ridge east of Iceland and none in the vicinity of Kolbeinsey Ridge (Report of the committee appointed by the Ministry of Fisheries, 2004).

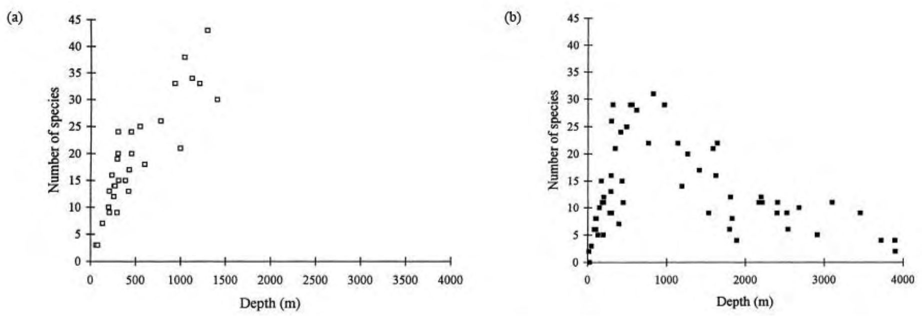
Fishing in the studied area is controlled mainly by a system of quotas and temporary closures except in the Faeroes where the main control is a so-called day-system whereby fishermen are allocated a certain number of days per year that they can fish. They are free to choose which days they go out but there are regulations about what fish can be harvested from specific areas in a given season as well as restrictions on the types of gear used in those areas. There has been a tendency in management of fish populations to concentrate on present and historical numbers of fish and the fecundity of the species without factoring in the environmental factors that support those populations. Admittedly, measuring the importance of a healthy ecosystem is problematic at best and difficult to include in a statistical analysis of the population ecology upon which policy decisions are made. During the last decade, a shift to an approach that is more based on ecosystem objectives rather than single species management was set in motion by international agreements of sustainable exploitation objectives (e.g. Rio Convention on Biological Diversity, Anon., 1992; and the World Summit on Sustainable Development, Anon., 2002). This shift is bringing about positive change in the quality of our knowledge base in the form of increases in the support given to research into marine ecology. These changes in policy are pressuring fishers and gear producers to create efficient equipments that are less damaging to the benthic ecosystems.

**Figure 4. The pattern of total macrobenthos diversity (Shannon H' log e) increase in relation to depth from samples across the continental shelf in the Northeast Atlantic found by Flach and de Bruin (1999).**




In studies of benthic biodiversity in the North Atlantic and Nordic Seas, a trend of increase in macrobenthic diversity to a depth of about 1000 m is well documented (Fig. 4 and 5) (e.g. Svavarsson, 1997; Flach and de Bruin, 1999; Gage *et al.*, 2000, Gage, 2004). This general trend has been reported as the result of biodiversity analyses on single groups such as families and genera as well as those focusing on total benthic diversity. Below 1000 m depth, a different pattern emerges in fauna to the north and south of the ridge (Fig. 5).There is a lower regional diversity of macrobenthic fauna in the Nordic Seas than there is in the North Atlantic. This is thought to be a result of the ridge itself acting as a barrier limiting the distribution of benthic organisms (Svavarsson, *et al.*, 1993). In addition, research has shown that for many groups there is a decline in macrofauna below a depth of 1100 m in the western part of the Nordic Seas whilst this decline does not hold true for many taxa in the North Atlantic (e.g. Svavarsson, 1997; Flach and de Bruin, 1999). These studies focus on soft-bottom sites. Areas where the bottom is hard substrate of some sort may show a very different biodiversity pattern in the Nordic Seas.

**Figure 5. A very steep linear increase of the number of species of isopods (Crustacea) in single samples was found in the North Atlantic (a) and a peak of diversity was found around 900 m in the Nordic Seas (b) by Svavarsson (1997).**




## 1.2 Aims and approach

The main objective of the project is to gather information on deep-water communities with large epifauna in the West-Nordic area. Both research in the literature and use of state of the art technology (ROVs, AUVs, photographs and video) are employed in order to gain a better understanding and a new insight into the following:

- biodiversity and community characteristics of deep water benthic communities
- status of these communities in connection with human disturbance
- necessity of establishing MPA's in these waters
- to augment the knowledge in the field of marine biodiversity and habitat mapping
- gather information which is requested by international agreements, signed by the Nordic countries

# 2. Study area

The total study area is the western Nordic Seas and includes part of the Norwegian Sea, the Exclusive Economic Zone (EEZ) of the Faeroe Islands and the waters of the Icelandic EEZ. Review of literature and unpublished data expand the field of reference to a large area beyond the scope of photographic data analyzed specifically for this project. Parts of this region have been studied intensively during the long history of marine biological research in the North Atlantic. Most recently, two major projects have been conducted to further develop the understanding of the large-scale distribution of important invertebrate species. BIOFAR (1987–1990) was a research program aimed at investigating the benthic invertebrate fauna of the Faeroe Islands and BIOICE (1992–2004) did the same in the waters surrounding Iceland. Both of these involved collection of samples, mostly in offshore areas. Data from these programs have been reviewed here in order to expound upon the accuracy and relevance of the data accumulated from the images analyzed in the current project. In addition, video footage from the Reykjanes Ridge was surveyed as an example of an ecosystem that has been severely damaged. Historically, the Reykjanes Ridge was an area of high abundance of scleractinian corals (especially *Lophelia pertusa*) (Cairns and Chapman, 2001; Keller and Pasternak, 2001; Moldostova, 2006) and when videos recorded to search for the associated mollusk *Acesta excavata* it became clear that large specimens of the slow-growing corals were absent and the bottom was littered with broken bits of coral and small living colonies. Following reasoning presented by Mortensen et al. (2008), the degree to which fishing gears have contributed to the destruction of this once rich habitat is unclear. On one hand, such small living colonies as those witnessed in the video could represent a few decades of recovery after a major disturbance. On the other hand, no clear marks of fishing gears were visible neither in our video nor in the analysis of Mortensen et al. (2008). However, no major natural event is known that could account for the decimation that is evident in the area.

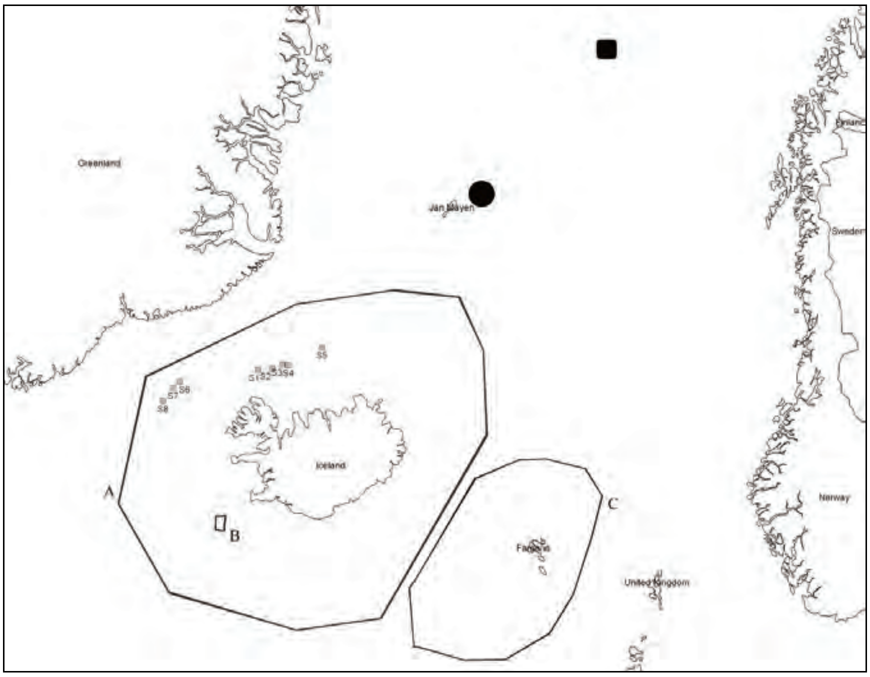
The image samples used for the current study are all from the seas north of Iceland and the GIF Ridge. Photographs were taken at eight sites in Icelandic waters and videos and digital photographs were collected during 19 ROV dives in the northern Norwegian Sea to the northeast of Jan Mayen, but the primary data from the latter was in video form (Fig. 6, Tables 1 and 2). These waters are not likely to be heavily exploited at present but accurate data of fishing activity from the region is difficult to find. However, an increase in the amount of human disturbance on the benthic animal communities is likely in the near future due to the presence of natural resources in the region. Demersal fish and deep-sea shrimp are potential attractions for the fishing industry and both groups were observed in this study. Furthermore, recent discussion of the possible presence of oil reserves under the sea floor along the coast of Greenland and in the northeastern corner of the Icelandic EEZ increases the likelihood of human disturbance of the area's environment at least at the level of exploration. The areas to the east of Jan Mayen are likely locations for the expansion of fishing pressure from northern Europe considering that declines in near-shore fish populations and contamination of the marine environment near to shore have already caused fishing effort to move farther off-shore. In addition to the aforementioned natural resources, parts of this region also have geological value as sites of deep sea thermal vents and cold seeps, such as those observed in the video data in the current. Such areas are not thought to be common in this region and they are scientifically interesting enough that protecting them is worth considering. Furthermore, cold seeps and deep-sea thermal vents have been indicators of hidden mineral resources such as oil, methane and useable metals (e.g. manganese) in other regions. For this reason, the Jan Mayen region may be expected to undergo disturbance if exploration for such resources becomes likely.

The Icelandic sites are located on the continental shelf and on the top of the western GIF as well as one site (S5) to the north of Iceland which is located on Kolbeinsey Ridge. These sites all feature mostly relatively warm Atlantic water brought there by the Irminger Current. The total variation in bottom temperature at the time of sampling was 1.51° C and water temperatures ranged from -0.21° C to a maximum of 1.3° C. Salinity at the bottom did not vary significantly between sites (34.78–34.88 ppm). Depth ranged from 240 – 374 m. Bottom types ranged from fine mud to rocky with very little sediment. The small size of the photographs (actual area of bottom in each photograph: 0.83 $m^2$) did not allow any estimation of bottom topography.

**Table 1. Sampling sites from Icelandic waters including the factors depth and bottom type.**

| Site | Latitude | Longitude | Depth (m) | Bottom type |
|---|---|---|---|---|
| S1 | 67°08'82" N | 22°44'76" W | 292 | Mud & stones |
| S2 | 67°12'10" N | 21°47'46" W | 240 | Sand & pebbles |
| S3 | 67°18'71" N | 21°08'90" W | 304 | Mud |
| S4 | 67°18'06" N | 20°45'96" W | 316 | Mud |
| S5 | 67°45'42" N | 18°32'40" W | 342 | Rocky |
| S6 | 66°39'11" N | 27°41'50" W | 250 | Mud & stones |
| S7 | 66°28'62" N | 28°03'93" W | 337 | Sand & pebbles |
| S8 | 66°06'21" N | 28°35'19" W | 374 | Pebbles |

**Figure 6. Map of the study area. Icelandic sample sites marked with squares, Jan Mayen dives marked with solid circle (dives 1–12) and solid square (dives 13–19). Three literature samples: A) BIOICE, B) Reykjanes Ridge videos and C) BIOFAR.**




The videos from the deep-sea Jan Mayen region provided a somewhat different kind of information than did the photographs from Iceland. First, there was a far greater range of depths sampled during ROV dives east of Jan Mayen (530 – 2900 m) than was sampled off Iceland because the camera equipment used in Iceland was not designed for greater depth than 600 m (Table 2). Second, though a similar range of bottom types was observed in the two data sets (Table 2) streaming video footage shows transitions between areas of soft bottom type and solid rock that are not often visible in small-area photographs. Third, the amount of suspended particles in the water column varied between dives as well. Some dives showed no suspended particles of any kind while others showed enough suspended particles to make the water cloudy. Bottom topography is extremely hard to measure from an ROV video because there is no point of reference in the video as to the orientation of the craft in relation to the seabed; but changes in topography were obvious and sometimes dramatic. For example, rock walls rose out of smooth soft sediment as did smaller rocky outcroppings.

**Table 2. Sampling dives in the vicinity of Jan Mayen in the northern Nordic Seas.**

| Year | Dive | Lat | Lon | Depth (m) | Bottom Type |
|---|---|---|---|---|---|
| 2005 | D1 | 71°17.608' N | 5°47.771' W | 680 | Rocky |
| | D2 | 71°17.835' N | 5°47.057' W | 645 | Rocky |
| | D3 | 71°17.980' N | 5°46.881' W | 600 | Rocky |
| | D4 | 71°15.727' N | 5°50.503' W | 750 | Rocky |
| | D5 | 71°16.063' N | 5°50.779' W | 795 | Variable |
| | D6 | 71°16.880' N | 5°49.570' W | 800 | Rocky |
| | D7 | 71°18.010' N | 5°46.750' W | 600 | Variable |
| | D8 | 71°17.880' N | 5°47.100' W | 645 | Mud |
| | D9 | 71°17.710' N | 5°47.025' W | 620 | Variable |
| | D10 | 71°17.870' N | 5°46.370' W | 530 | Rocky |
| 2006 | D11 | 71°15.559' N | 5°48.888' W | 735 | Rocky |
| | D12 | 71°17.988' N | 5°46.839' W | 612 | Sand & stones |
| 2007 | D13 | 73°33.217' N | 8°17.112' E | 2900 | Rocky |
| | D14 | 73°33.632' N | 8°15.528' E | 2950 | Mud |
| | D15 | 73°33.405' N | 8°14.113' E | 2700 | Mud & stones |
| | D16 | 73°50.276' N | 7°36.575' E | 895 | Rocky |
| | D17 | 73°50.299' N | 7°37.228' E | 1129 | Mud & stones |
| | D18 | 73°33.475' N | 8°16.162' E | 2927 | Mud |
| | D19 | 73°52.643' N | 7°33.302' E | 1305 | Sand & pebbles |

# 3. Methods

Photographs and video were analyzed to gather information about the structure and distribution of communities in the study area. Photographs taken as part of the BIOICE research program were used. The eight sites photographed extend from west of northern Iceland clockwise to directly north of the country (Fig. 6). All eight sampling sites had similar salinity (34.78 – 34.88 ppm) and similar temperature (-0.21 – 1.3° C) but the depth ranged from 240 – 374 m. Photographs were taken using a weight-triggered camera mounted on a metal frame. About 400 photographs were collected in total. The first ten photographs from each site that were of excellent quality (in focus, well lit and free of suspended sediment clouding the image) were chosen for analysis. This number of photographs was sufficient for the aims of investigating broad scale patterns of epibenthic community structures. Adding further images introduced nothing but occasional specimens of locally rare species.

Videos collected by remotely operated vehicle (ROV) in the deep ocean to the northeast of Jan Mayen were analyzed. The original purpose of the G.O. Sars voyages was the exploration of previously discovered geothermal vents and cold seeps as well as a search for new locations of such activity. The crew used the ROV Bathysaurus XL50, which is equipped with two digital video cameras and a digital still camera, to record 49 dives. Of these, 19 were approved for the purposes of this project while 30 were rejected because they featured hydrothermal areas that do not exhibit the natural conditions of most of the region due to the oddity of heated water and chemical nutrients resulting from subterranean geological processes. The approved 19 dives ranged in depth from 530 – 2950 m and bottom type varied from soft sand to solid rock (Table 2). The videos were analyzed by stopping every 30 seconds to assess the quality of the frozen image based on the following characteristics:

- The ROV must be facing the bottom at an acceptable
- angle and distance or identification to be possible
- The frame must not be blocked in part or in full by sampling equipment or suspended sediment
- The frame must not include vents or seeps

Along with identification, specimens were counted in order to describe community structure and the importance of each species in the system as a whole. High quality digital stills taken during the dives were used as a second reference for quality control of identifications (Fig. 7–9).

**Figure 7. The most common sea basket in this study, Gorgonocephalus cf. eucnemis (Echinodermata: Ophiuroidea). It was observed individually, as in the photograph or in large colonies. The arms of this specimen are contracted.**

Photo: Centre for GeoBiology, Bergen.

The software packages Biodiversity Pro v. 2.00 (Natural History Museum, London and Scottish Association for Marine Science, Oban) and Primer 5 Windows v.5.2 (Primer-E, Ltd.) were used to analyze diversity and community composition. Species diversity is presented here in the form of several calculated indices and is illustrated as the rarefaction index (Hurlbert, 1971). The rarefaction index has often been used on deep water samples (e.g. Gage, *et al.*, 2000; Flach and de Bruin, 1999; Jones *et al.*, 2007a & b). Also, a Bray Curtis similarity index was calculated in order to develop dendrograms of the sites for the photographs and the videos based on the similarities from one site to another.

# 4. Results and discussion

## 4.1 Macrofaunal species

The compiled list of species observed at the sites from Icelandic waters contains 118 species from 10 phyla. It was possible to identify most of these well enough to assign a *conformis* (cf.) species name to the specimens because recently the benthic fauna of much of this area has been sampled and catalogued during the BIOFAR and BIOICE programs. Identifications were based on external characteristics, consequently, animals smaller than one centimeter in diameter had to be omitted as they were too small for reliable identification.

At rocky sites, diversity of species was not dominated by a single group. Rather, these communities were a fairly even assemblage of sponge species (Porifera), sea lilies and brittle stars (Echinodermata), sea anemones (Hexacorallia), soft corals (Octocorallia) and hydroids (Hydrozoa). Softer bottom areas were inhabited by a less diverse fauna dominated by brittle stars (Ophiuroidea). This difference has been well documented (e.g. Gage, 2004; Jones et al., 2007b; Jones et al., 2007c). Moreover, at some sites of soft bottom where small hard surfaces were present, the diversity and community structure were more similar to those of hard bottom areas than those of soft bottoms. That is, in assemblages where small stones were abundant, the community structure was more like that of the hard bottom sites in that they featured a higher number of sessile and semi-sessile species than did the soft sediment sites. This was manifested primarily by an increase in the number and diversity of tunicates and poriferans in soft bottom sites where small stones were present.

Four species were observed at all eight of the sampling sites. Three of them were brittle stars (Ophiuroidea): *Ophiura* cf. *ophiura, Ophiura* cf. *albida and Ophiothrix* cf. *fragilis*. The fourth species found at all sites was *Corymorpha* cf. *nutans* (Cnidaria). There were also 32 rare species that were observed at only a single site and 22 of those were observed on a single photograph. While most 30 of these 32 site-specific species were present in extremely low abundance, 29 specimens of the sponge *Mycale* Sp 2 were present at one site and at a different site 18 specimens of the crinoid *Antedon* cf. *bifida* were observed. These two species were therefore somewhat common in small areas although they were rare over the study as a whole. This illustrates a difficulty commonly encountered by deep-sea researchers in community analysis. Specifically, rarity is poorly understood in the deep ocean due to the scarcity of data in relation to the vast expanse of the habitat in question.

**Figure 8. Close-up of a crinoid echinoderm. The net of feathery arms above the body are used by the creature to gather nutrient particles from the current just above the bottom. They are capable of swimming, though normally are stationary.**

Photo: Centre for GeoBiology, Bergen.

Many of the species found in Icelandic waters were also present at the deep-water sites northeast of Jan Mayen. On the videos from the 19 dives that were analyzed a total of 67 species were observed. These were then compared to a list of taxa derived from specimen samples taken from the region during 2005 (Schander pers. Comm.) and 24 identifications were achieved. Following research in the literature an additional 12 species from the videos were identified to at least genus level. This means that over half of the species observed on the videos were successfully identified to at least genus level.

The three dominant taxa in areas of hard substrate were *Gorgonocephalus* spp. (Fig. 7), the crinoid *Heliometra* cf. *glacialis* (Fig. 8) and the anemone *Hormathia* cf. *digitata*. In between communities, especially on soft sediment areas, a few species were commonly observed. Two of these were the sponges *Tethya* cf. *aurantum* and *Stylocordyla borealis*. The cnidarian *Umbellula* cf. *encrinus* (Fig. 9) was also observed standing in recesses in the sea floor where bottom topography changed significantly. Possible reasons for this are unknown and trying to test the significance of the relationship between presence of *U. encrinus* and recesses in the seafloor was outside the scope of this study.

**Figure 9. Umbellula cf. encrinus is a cnidarian that reaches a length of greater than two meters. It is common in soft sediments in subarctic deep water.**

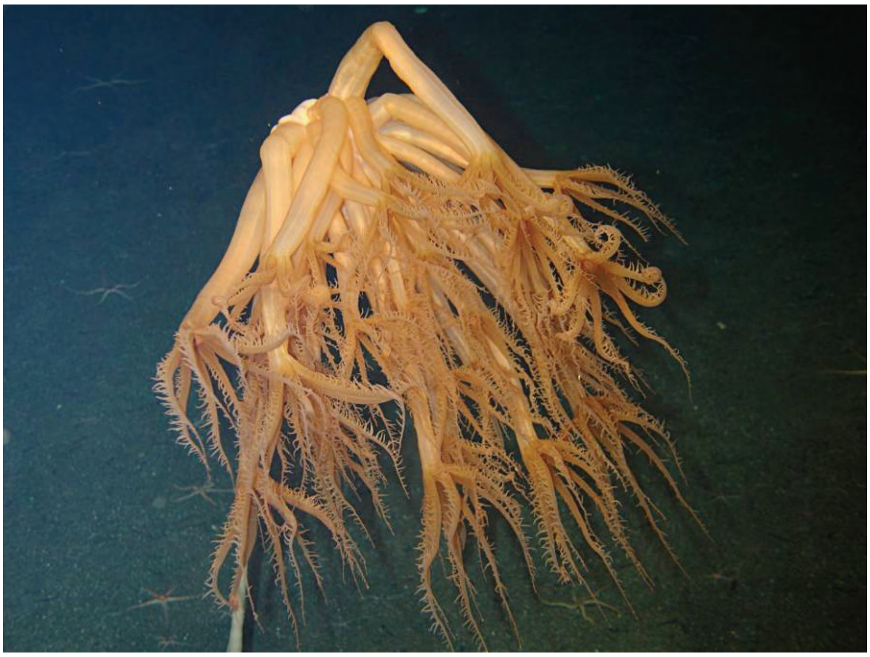


Photo: Centre for GeoBiology, Bergen.

In addition to the sessile and semi-sessile species already mentioned, at least three species of fish were observed that are considered of potential commercial value; the onion-eye grenadier (*Macrourus berglax*; nordlig skolæst, isgalt), the Arctic rockling (*Gaidropsarus argentatus*) and the Greenland halibut (*Reinhardtius hippoglossoides*; svartkveite, hellefisk). Given the small scope of video footage in relation to the expansive environment of the deep-sea, the presence of these three species and the likelihood of other commercial fish species suggest the potential importance of the region for future exploitation. The onion-eye grenadier is fished with trawl nets. The Greenland halibut is fished by both trawl and net. The rock-hopping trawl nets are known to destroy the communities described herein. The Arctic rockling is fished by the long line. This method of fishing has far less of an effect on the environment than towed nets because of the smaller size of the equipment and a lower degree of sediment re-suspension. But it has been shown to harm soft corals such as the families Gorgonacea and Alcyonacea (Witherell and Coon, 2000; Bavestrello et al., 1997). Some of the large species observed in this study might be vulnerable to similar negative effects as those inflicted upon the Gorgonacea as reported by Witherell and Coon (2000) and Bavestrello et al. (1997) because of their similar arboreal shape and the structural fragility of their colonies. But this has not been researched as of yet.

## 4.2 Community structure

Communities of benthic fauna in Icelandic waters varied in terms of species richness and specimen abundance from one sampling site to another. As expected, areas of bottom featuring hard substrata were covered by a more diverse and usually more abundant fauna than areas of soft bottom (Table 3 & 4). Through analysis of the community, it became apparent that even the presence of individual stones had the effect of raising the diversity and abundance of a site beyond that found to be typical at other soft muddy bottoms in the current study that lacked substratum such as rocks or pebbles (Figs. 10 & 11). This is an important finding because most studies of the distribution of benthic fauna have focused separately on either a soft sediment bottom or a rocky bottom and the differences between the two, without considering the importance of the mixed sediment zone. One reason for this distinction in previous studies is that different gears are needed to sample the two types of bottom. Furthermore, sampling very coarse bottoms from great depth is extremely difficult because of loss of specimens as a result of movement of stones in the sampling gear Gage (2001). Areas of soft sediment where stones are present may well serve as a means of range expansion for sessile and semi-sessile species. This expansion could likewise provide for a larger range for the fish and other species often found associated with species such as soft corals and sponges. Distribution of rocks and pebbles is likely to be much wider than that of exposed bedrock in the deep-sea where expanses of soft sediment bottom are the norm. For this reason, the importance of these small hard surfaces should be investigated further.

**Figure 10. Rarefaction of frequency data from Icelandic sites. Sites s3 and s4 are soft sediment sites others contain some hard surfaces. A steeper beginning to the curve shows higher diversity.**

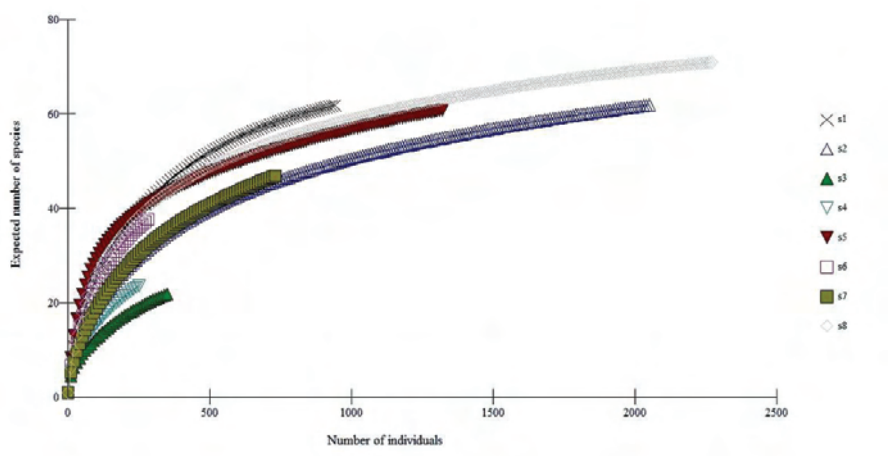


**Table 3. Frequency and diversity calculations for Icelandic stations. S: number of species. N: number of individuals. d: species richness [(S-1)/Log(N)]. J': Pielou's evenness. Fisher: Fisher's α. Shannon: H'($Log_{10}$). Simpson: 1-λ'.**

| Station | S | N | d | J' | Fisher | Shannon | Simpson |
|---|---|---|---|---|---|---|---|
| s1 | 14.9 | 90.3 | 3.082 | 0.697 | 5.563 | 0.779 | 0.712 |
| s2 | 19.7 | 187.6 | 3.600 | 0.701 | 5.748 | 0.899 | 0.799 |
| s3 | 5.4 | 29.4 | 1.357 | 0.749 | 2.784 | 0.494 | 0.626 |
| s4 | 5.7 | 25.1 | 1.504 | 0.733 | 2.658 | 0.544 | 0.642 |
| s5 | 24.1 | 127.6 | 4.796 | 0.861 | 9.219 | 1.181 | 0.916 |
| s6 | 7.6 | 25 | 2.142 | 0.831 | 5.678 | 0.712 | 0.787 |
| s7 | 12.4 | 68.1 | 2.714 | 0.667 | 4.631 | 0.724 | 0.698 |
| s8 | 24.6 | 155.2 | 4.686 | 0.771 | 8.364 | 1.072 | 0.843 |

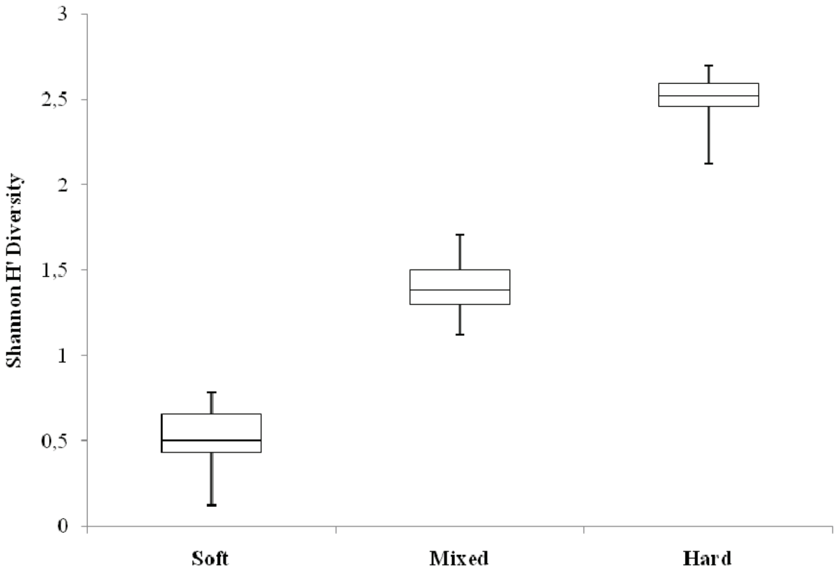
Icelandic communities of megabenthos on hard bottoms were not dominated by single species as were those found at Jan Mayen, but showed a fairly even diversity of species from several phyla. The most important hard bottom phyla were Porifera, Cnidaria, Bryozoa, Echinodermata and Tunicata. The largest percentage of the community (39% - averaged across dives) was represented by Echinodermata. On average about 45% of all species belonged to Porifera, Bryozoa and Tunicata. The proportion of these three taxonomic groups varied considerably. At sites where the only hard surfaces were small pebbles tunicates were more prevalent than sponges. But the numbers of individuals and species of Cnidaria and Echinodermata did not vary much in areas with some hard substrate. However, the two sites with primarily soft sediments were dominated by the echinoderms – especially brittle stars (Ophiuroidea). Ophiuroids and polychaete worms were the only common species observed during dives over expanses of soft sediment and any other species observed were very rare. These sites featured very little megafauna and were almost devoid of the large habitat-forming species observed at other sites.

**Table 4. Expected number of species in two samples of differing size calculated with rarefaction.**

| Site | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 |
|---|---|---|---|---|---|---|---|---|
| $Es_{(250)}$ | 40.5 | 30.8 | 20.7 | 24 | 40.1 | - | 31.5 | 44.2 |
| $Es_{(100)}$ | 26.2 | 19.6 | 13.7 | 15.8 | 29.9 | 25.4 | 19.8 | 30.8 |

Often, when speaking of diversity a discussion focuses only on the number of species in an area. This point of view assigns great importance to rare species while decreasing the importance of common species. Evenness is a method of taking into account the abundance of each species in determining biodiversity of an area in order to understand its heterogeneity. We include the measurement of evenness in the exploration of macrobenthic diversity. In the Icelandic sample, species diversity ranged from high in hard bottom sites to low at soft bottom sites (Fig. 11). Calculation of evenness of the sample showed that higher diversity sites were not dominated by few taxa – where there were many species there were many specimens of each - whereas where few species were found a higher number of rare species were observed. This means that it was not merely the introduction of rare species into the communities that increased the diversity calculations, rather that with an increasing number of species, abundance of each species increased. The dominance of a single group, Ophiuroidea, at soft sediment sites skewed the evenness of calculated diversity at those sites while the mixed sediment sites were dominated by a tunicate (Eudistoma vitreum)

**Figure 11. The average diversity of macrofauna shown as a box-plot with samples grouped by bottom type. Diversity varied least on sites with hard bottoms. Error bars show distance to farthest outliers.**



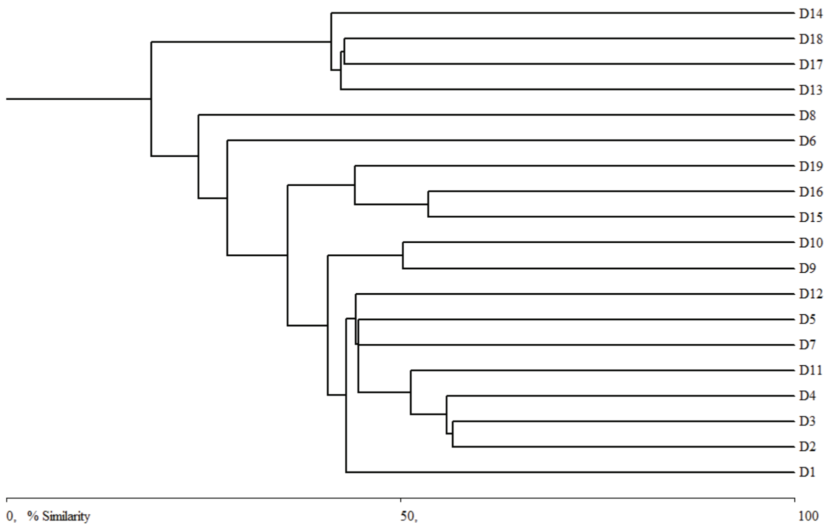

The 80 photographs from Iceland revealed that the proportion of the seabed covered with animals was highly variable and was highly dependant upon bottom type. The overall result of this analysis was that in areas of hard substrate the bottom was completely covered by animals from many families. This total cover was composed of both large and small species. Several observations were made of small species which were growing on a large species and this led to multilayered cover of the bottom. In the soft bottom sites the majority of cover was due to the mobile species of Ophiuroidea and cannot therefore be considered a true measure of cover *per se*. There were, however, some specimens of sessile or semi-sessile nature, especially cnidarians, inhabiting muddy or sandy bottoms. None of the sites from Iceland were bare of epifauna.

Analysis of the data from the ROV dives northeast of Jan Mayen included the calculation of a Bray-Curtis Similarity index which formed the basis for a cluster analysis which examined similarity in community structure among dives (Fig. 13). The four deepest dives (13, 14, 17 and 18) were shown to be dissimilar to the shallower sites. The extreme depths and the prevalence of soft bottom of these dives led to the not unexpected result that these are more similar to each other than to the sites of less depth. Although the dendrogram shows a general trend of increasing similarity with decreased depth, that variable does not seem to be the defining character in community structure.

**Figure 12. The edge of a community of Gorgonocephalus sp. where a hard bottom changes to soft bottom. Also in the image is a specimen of Gaidropsarus argentatus.**


During most dives animals were distributed in patches separated by areas of little or no megafauna (Fig. 12). Fauna of these spaces of soft sediment was generally dominated by ophiurids, although species of other taxa were occasionally observed. While some patches had diverse taxa, in other patches a single taxon dominated local abundance. This dominance of single species has been observed at similar depths in the Nordic Seas (Mayer and Piepenburg, 1996). Sea baskets (Echinodermata: *Gorgonocephalus* spp.) are a conspicuous example of a single taxon showing localized dominance because of their size when their arms are spread for feeding (Fig. 12). These are large animals that can reach more than a meter across with their arms spread. Dense colonies of the species resemble thick hedge rows and appear mostly on rocky outcroppings and steep rock faces. They sit on these hard surfaces and spread their heavily branched arms up into the water column to capture edible particles and small creatures out of the water column (Fig. 7 and 12). Sea lilies (Echinodermata: Crinoidea) formed the most extensive colonies composed of three species, of which the most common was *Heliometra* cf. *glacialis* (Fig. 8 and 15). The third distinct colony type was composed almost entirely of the anemone species *Hormathia* cf. *digitata* (Cnidaria: Hexacorallia) (Fig. 1). This organism is known to reproduce asexually by producing buds which results in small incredibly dense colonies of individuals because they do not disperse from the original parent. Cloning does not occur in *Gorgonocephalus* spp. or crinoid animals, however, so it cannot be the reason for the density of those species within animal assemblages. One possible explanation is that the density of the present colony might preclude settlement of larvae of other species later.

**Figure 13. A dendrogram of overall community structure shows the similarity of communities observed during different dives. Shorter branches mean more similarity.**

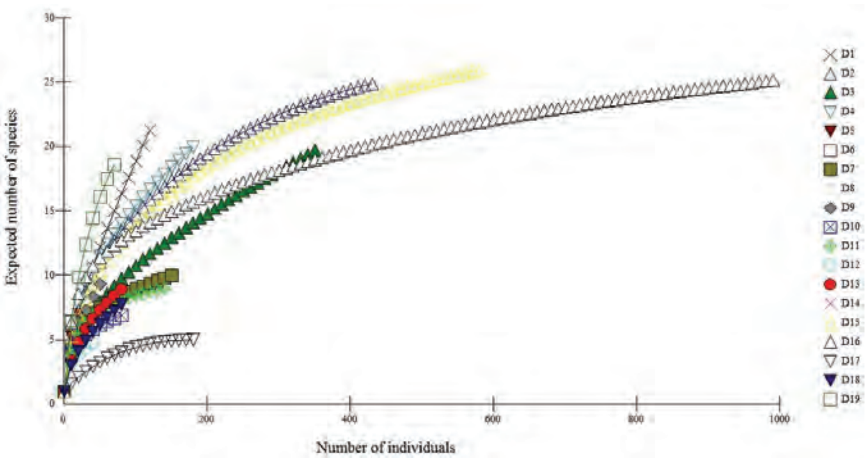



However, during two of the dives a highly diverse megafaunal assemblage was witnessed that was not dominated by a small number of species. At these two dive sites, the bottom appeared to be primarily sandy but with many rocks and pebbles of varying size for most of the length of the video, though at times expanses of solid rock were exposed. Sponges, tunicates, octocorals and anemones clung to all visible hard surfaces. There were a great many other animal colonies – probably bryozoans, tunicates, or sponges – that were too small or cryptic to be identified due to the resolution of the video image. More fish were observed during these two dives than during all other dives in the study. A combination of adult and juveniles of the fish species *Macrourus berglax* (nordlig skolæst, isgalt) represented the largest proportion of observed fish but Greenland halibut and *Gaidropsarus argentatus* were also observed.

**Table 5. Expected number of species in two sample sizes calculated by rarefaction of Jan Mayen data.**

| Dive | D1 | D2 | D3 | D4 | D5 | D6 | D7 | D8 | D9 | D10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $Es_{(125)}$ | 21.3 | 15.0 | 11.7 | 16.7 | - | - | 9.4 | 14.6 | - | - |
| $Es_{(50)}$ | 12.2 | 11.0 | 8.0 | 11.5 | - | - | 7.5 | 10.2 | 9.3 | 6.2 |
| Dive | D11 | D12 | D13 | D14 | D15 | D16 | D17 | D18 | D19 | |
| $Es_{(125)}$ | 8.7 | - | - | - | 15.0 | 14.0 | 4.7 | - | - | |
| $Es_{(50)}$ | 7.3 | - | 7.3 | - | 10.2 | 11.2 | 3.3 | 6.2 | 16.1 | |

**Figure 14. Rarefaction of pooled specimen counts from dives in the Jan Mayen region.**



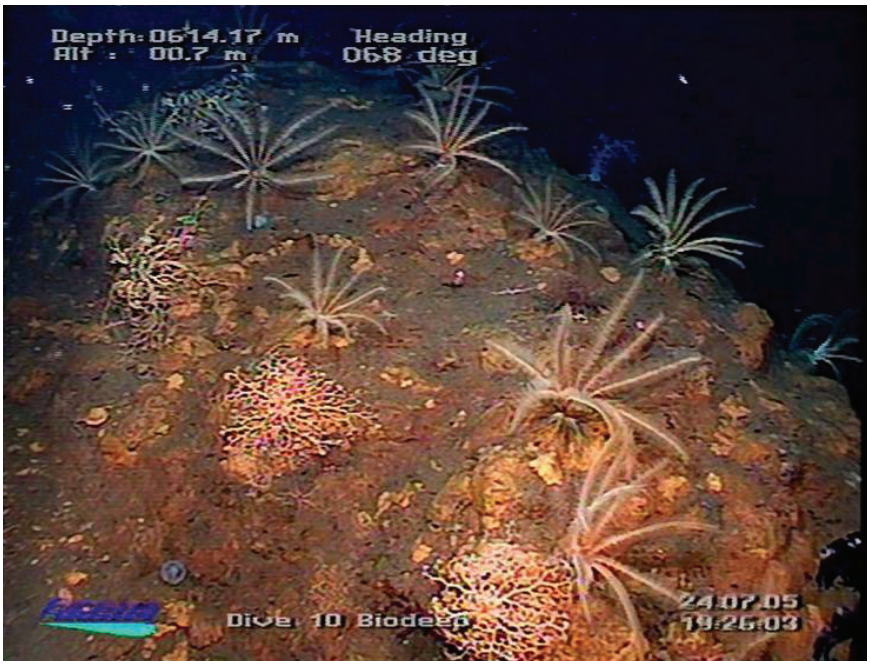

Diversity of the dives from the Jan Mayen area was illustrated using the Hurlbert rarefaction method (Table 5, Fig. 14) and the same series of diversity indices as the was used for the Icelandic data (Table 6). A wide range of diversity indices was found for the 19 dives when all 30 second stops of the videos were pooled together. This was done because the dives were of variable length and portions of each video could not be used. The rarefaction method allows one way of standardizing samples of differing size. Highest diversity was observed during dives 2, 15 and 16. These three dives cover the entire depth range of the total sample and feature examples of all bottom types observed. As was mentioned before, communities were often dominated by single species in these samples so evenness did not show the same pattern as in the samples from Icelandic waters. On the other hand, evenness remained skewed in the communities observed in the Jan Mayen area videos. Furthermore, it appears from this analysis that depth does not play a significant role in determining diversity of animal communities. Specifically, four of the dives (7, 10, 11 and 12) with the lowest diversity are among the shallowest sites of the sample sites with depths of 600, 530, 735 and 612 meters respectively. Some of these dives exhibit even lower diversity than some of the deepest sites, namely dives 13, 15, 16, 18 and 19.

The crinoids were not only observed within colonies but also as individuals or in small groups where rocks or small ridges of bedrock appeared in the soft sediment. When the ROV approached close enough to clearly see these specimens it was often clear that other species might be associated with the tall-standing crinoids. This is something that would be worth studying. Any structure, living or otherwise, standing above the sea floor changes water flow regimes in its immediate vicinity. Among the species observed apparently associated with these pioneer crinoids were occasionally other potentially habitat-forming specimens of the Porifera, Tunicata, and Cnidaria.

**Table 6. Averages of community measurements for video data from Jan Mayen region dives. See Table 3 for definition of column headings.**

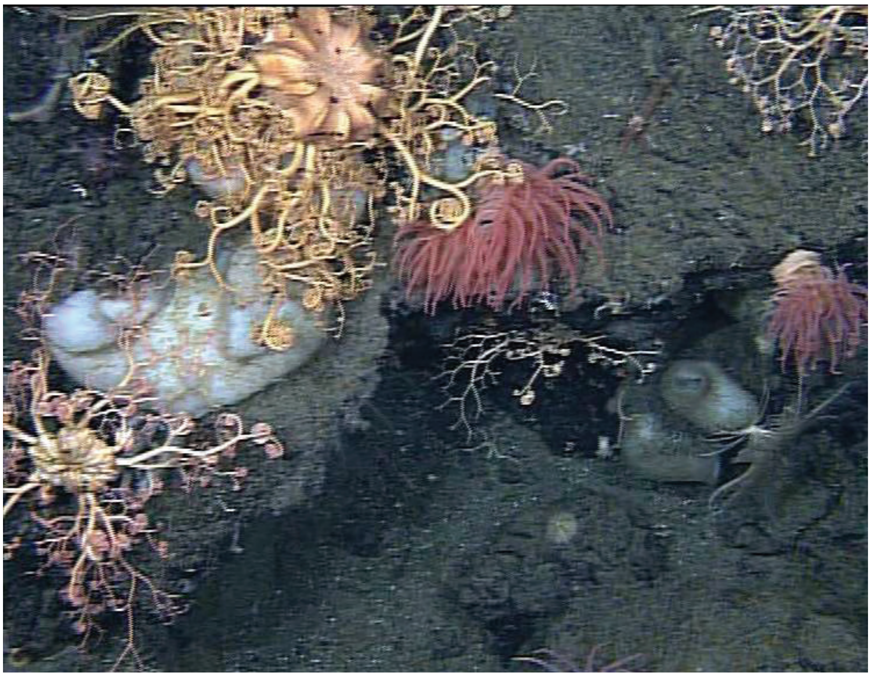
| Dive | S | N | d | J' | Fisher | H'(Log10) | 1-Lmabda' |
|---|---|---|---|---|---|---|---|
| d1 | 3,3 | 8,5 | 1,246 | 0,863 | 2,837 | 0,402 | 0,702 |
| d2 | 3,3 | 15,1 | 0,953 | 0,806 | 1,690 | 0,381 | 0,561 |
| d3 | 2,2 | 15,7 | 0,664 | 0,619 | 2,005 | 0,188 | 0,334 |
| d4 | 2,8 | 10,1 | 0,946 | 0,739 | 2,089 | 0,265 | 0,431 |
| d5 | 1,7 | 4,7 | 0,613 | 0,654 | 1,258 | 0,135 | 0,310 |
| d6 | 1,2 | 2,2 | 1,329 | 0,855 | 3,133 | 0,155 | 0,705 |
| d7 | 3,4 | 12,7 | 1,049 | 0,711 | 2,061 | 0,366 | 0,530 |
| d8 | 2,3 | 8,9 | 1,262 | 0,787 | 3,280 | 0,260 | 0,670 |
| d9 | 1,9 | 7,4 | 0,552 | 0,765 | 1,053 | 0,180 | 0,401 |
| d10 | 2,8 | 21,3 | 0,596 | 0,717 | 0,925 | 0,297 | 0,434 |
| d11 | 4,3 | 35,5 | 1,191 | 0,618 | 1,686 | 0,338 | 0,501 |
| d12 | 2,0 | 6,0 | 0,808 | 0,715 | 1,414 | 0,191 | 0,461 |
| d13 | 0,7 | 1,6 | 0,419 | 0,847 | 0,828 | 0,038 | 0,256 |
| d14 | 1,3 | 2,5 | 0,180 | 0,811 | 0,995 | 0,061 | 0,125 |
| d15 | 5,0 | 23,4 | 1,353 | 0,792 | 2,265 | 0,506 | 0,670 |
| d16 | 10,3 | 70,1 | 2,224 | 0,834 | 3,531 | 0,840 | 0,822 |
| d17 | 1,3 | 6,3 | 0,177 | 0,709 | 0,541 | 0,057 | 0,120 |
| d18 | 0,9 | 2,4 | 0,417 | 0,778 | 1,144 | 0,054 | 0,262 |
| d19 | 3,2 | 6,3 | 1,508 | 0,858 | 4,070 | 0,375 | 0,736 |

**Figure 15. Edge of a crinoid patch where hard bottom gives way to soft bottom. Also photographed are three specimens of Gorgonocephalus sp.**




The overall conclusion from the analysis of photographic samples is that the community structure of the macrobenthic epifauna varies between locations and that it is complex and often fragile. Further investigation is desirable before it is disturbed by human action. From the videos we come to the conclusion that while macrobenthic diversity may be high in the deep sea, its distribution is patchy. Also, we determine that because of the variations in dominance of single taxa within patches of abundance on hard substrata a description of bottom type does not suffice to accurately predict the local diversity of the epibenthic megafauna in the deep ocean. This information combined with the literature we have reviewed indicates that in-depth analysis of megabenthic communities and their relationship with demersal fish populations is still required in order for us to be able to understand the importance of the animal communities on the floor of the deep ocean.

**Figure 16. Clouse-up of a diverse community from a depth of about 650 m. Here species from a few groups coexist on a rocky bottom.**



# 5. Recommendations

- Consideration of future MPA's should include Kolbeinsey Ridge off the north coast of Iceland for its diversity and the studied region northeast of Jan Mayen.
- More research needs to be invested in understanding the patchiness that apparently dominates the area northeast of Jan Mayen examined in this study.
- Further research into developing a satisfactory guide to identify sponges (Porifera) and tunicates (Tunicata) from photographic and video images is required.

The structure of the deep-water communities of the West-Nordic region is still poorly known but all recent research shows that species diversity (e.g. Piepenburg and von Juterzenka, 1994; Klitgaard and Tendal, 2004), in particular diversity in the sponge communities (e.g. Klitgaard, 1995; Flach and de Bruin, 1999; Jones et al., 2007a), is fairly high and that both science and fisheries management have much to gain from further research before the region is despoiled. Also, the deep-water fauna shows very strong patchiness, indicating that care should be taken when interpreting data from deep water sites so as to avoid loss of biologically important ecosystems. This project shows that the patchiness of the distribution of species and the structure of megafaunal communities are impossible to predict solely from the composition of the bottom. The reasons for the observed patchiness and the ecological importance of that patchiness are both needed for a fuller understanding of the ecological processes that influence the fisheries that we would like to expand.

In order for proper conservation of the largest diversity of both the physical and the biological aspects of the deep-water sea floor MPA's of large area should be established following further research into the biological and geological value of the region. There should be a great effort applied to the discovery of the unknown biological and geological richness of the region before it is disturbed further by human activity.

One area of knowledge that we feel must be augmented is the inclusion of better identification of sponges (Porifera) and tunicates (Tunicata) in studies heavily relying on photographic and/or video data. In most studies, reference is made to species of these extremely important groups as unidentified species with assigned numbers (i.e. unidentified sponge sp 1, sp 2, etc.). Many of the sponge and tunicate genera can be classified with some veracity through analysis of external characteristics (shape, size, apparent texture and color) and comparison with previous samples from the region as well as consultation of the literature. Physical samples taken at the locations of photographic sampling would also greatly aid in this goal. Although no physical samples were taken in the current study, comparison of identified species from nearby locations aided in the identification of many of the observed sponges to genus and even species level. Porifera is a diverse and often dominating group in sea floor communities and to identify them carefully would give a more realistic picture of the overall diversity of a region. This holds true for Tunicata as well. The need for this type of expertise in identification extends to others of the most common groups such as cnidarians.

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# Optional summaries

Målet med studien var att skaffa information om samhällsstruktur och diversitet hos bottenlevande megafauna i den västra delen av de nordiska haven. Huvudfokus ligger på betydelsen av hårdbotten för uppkomst och strukturering av djursamhällen.

Studen baserar sig på en genomgång av litteratur och opublicerade data, fotografier från Island samt video och stillbilder från området runt Jan Mayen. I tillägg till detta användes video från en expedition med forskningsfartyget Árni Friðriksson till Reykjanesryggen som jämförelse med djursamhällen i ett område som är kraftigt påverkat av fiske. De isländska fotografierna var tagna på åtta lokaliteter nordväst och nord om Island djupare än 200 meter. Video och stillbilder tagna med forskningsfartyget G.O. Sars utefter en djupvattenränna belägen i ett område nordöst om Jan Mayen mot Svalbard. Dessa användes till att beskriva djursamhällen i de boreala delarna av de nordiska haven. Alla djur av tillräcklig storlek (> 1 cm i diemeter för fotografier, > 5 cm för video) identifierades till lägsta möjliga taxonomiska nivå.

Samhällsstrukturerna varierade mycket mellan lokalerna, men var tämligen konstanta inom dessa. Vidare var samhällsstrukturerna starkt påverkade av förekomsten av hårda ytor, och inte bara i en klar skillnad mellan huvudsakligen hårda respektive mjuka bottnar, vilket tidigare har rapporterats som den viktigaste ekologiska skillnaden. Jan Mayen-området uppvisade en tydligt fläckvis förekomst av makrofauna och samhällena var ofta dominerade av en enstaka art. Denna fläckvisa förekomst verkar vara resultatet av förekomst eller avsaknad av hårda ytor som kan fungera som förankringspunkter får fastsittande och semi-fastsittande arter. Den fläckvisa förekomsten har tidigare observerats i videoanalyser, men orsakerna är fortfarande inte helt uredda.

Den här föreliggande studien ger upphov till frågeställningar om varför distributionen av en stor del av megafaunan i det studerade området är fördelad i artspecifika fläckar, och huruvida detta är en generell trend i området. Resultaten indikerar också att om man skall skydda den verkliga diversitetet i området, måste marina skyddsområden vara stora, och inte begränsade till små områden med en specifik bottentyp. Vår studie visar också att det är tre områden som man bör fokusera på i skyddssammanhang. Området runt Kolbeinsey Ryggen visade på en mycket hög biodiversitet. GIF ryggen, särskilt sydsidan, är ett viktigt område för djupvattenskoraller i nordatlanten. De hydrotermala områdena mellan Jan Mayen och Svalbard håller en fläckvis men divers fauna. Det sistnämnda området är särskilt känslig på grund av förekomsten av komersiellt viktig fisk

och på grund av att områdets geologi indikerar möjligheter till utvinning av fossila bränslen och malm.

The study was based on review of the literature and unpublished data as well as photographs from Iceland and both stills and video collected from the vicinity of Jan Mayen. In addition, video footage from an expedition of R/S Árni Friðriksson to the Reykjanes Ridge was used for visual comparison of animal communities in an area greatly impacted by fishing gears. The photographs from Iceland were taken at eight sites to the northwest and north of the country in waters deeper than 200 meters. Videos and stills collected during expeditions by the research vessel G.O. Sars along an undersea trench that lies from Jan Mayen northeast toward Spitzbergen were used to describe the animal communities in the boreal Nordic Seas. All animals large enough (>1 cm diameter for photographs, > 5 cm diameter for videos) were identified to lowest possible taxonomic level.