

Ellen Øseth, Lis L. Jørgensen,
Paul E. Renaud and Hector Andrade

Benthos vulnerability to bottom trawling





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Addresses:

Ellen Øseth,
Norwegian Polar Institute, FRAM Centre, PO box 6606 Langnes, NO-9296 Tromsø, Norway

Lis L. Jørgensen,
Institute of Marine Research, Sykehusveien 23 PO box 6404, NO-9294 Tromsø, Norway

Paul E. Renaud,
Akvaplan niva, FRAM Centre, PO box 6606 Langnes, NO-9296 Tromsø, Norway

Hector Andrade,
Akvaplan niva, FRAM Centre, PO box 6606 Langnes, NO-9296 Tromsø, Norway

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Norwegian Polar Institute, Fram Centre, NO-9296 Tromsø,
www.npolar.no, post@npolar.no

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Project report from MOSJ (Environmental monitoring of Svalbard and Jan Mayen), funded 2014 by Fram Centre flagship MIKON (Environmental impacts of industrial activity in the north).

Summary

Bottom trawling has been shown to have significant impacts on seafloor communities, but these effects vary with intensity of trawling, type of trawl, depth, and bottom type. The Svalbard area has experienced varying trawling intensities over the past several decades, but the expansion of the range of Atlantic cod around Svalbard and the maintenance of high shrimp densities in some areas suggest that trawling may increase in the coming years in this area. We know little about the historical impacts of trawling in this region, despite recent evidence that some benthic communities may be at particular risk to intense trawling. Here we investigate epibenthic communities in several areas around the island of Spitsbergen in an effort to document whether there is evidence for trawling effects, in order to make suggestions for monitoring indicators.

The largest mean megabenthic biomass (>25 kg per 15 min trawling) was recorded at deep stations (>335 m), where the highest fishing intensity occurred; i.e. Hinlopenstretet and Kongsfjord. Shallow stations from all fjords (except Kongsfjord) were untrawled.

In areas of high fishing intensity, the biomass was mainly dominated by the deep-sea shrimp *Pandalus borealis*. Low trawling-intensity areas included Hinlopenstretet (HL) and areas inside Wijdefjorden (WHL), which were dominated by the sea star *Ctenodiscus crispatus*. The domination of the sea star *Ctenodiscus crispatus* is most likely the reason for low trawling intensity in that area. Stations in Kongsfjorden (KF) were dominated by Porifera (sponges), in spite of greater trawling intensity, which might result in the removal of sponges and *Bathypolypus arcticus* (an octopus) together with the deep sea shrimps in commercial trawl catches.

Contrary to the expected, areas experiencing high trawling intensity also presented rather high biomass of megafauna (besides the deep sea shrimp). Some of this biomass consisted of species having a rather large body size which consequently are more vulnerable to trawling. These species might function as indicators, meaning that a stable population of these species means low degradation of these areas.

Vulnerable species, such as the sea pen *Umbellula encrinus*, were present among the top 10 species in some areas with intermediate and high trawling intensity. This shows that even reported (OSPAR) vulnerable animal groups such as sea pens must be used with caution as indicators in the Svalbard fjords.

Areas with low trawling intensity showed a “high mean biomass” of many top dominant species with large bodies, including *Gorgonocephalus arcticus*, *Geodia macandrewii*, *Icasterias panopla*, and *Solaster endeca*. Large-bodied sea stars, basket stars and sponge

biomass can be used with caution, together with the vulnerable sea pen *Umbellula encrinus*, as indicators of trawling impact.

Introduction

Bottom trawling, suggested to be the equivalent of forest clearcutting on land (Watling and Norse 1998), has significant and potentially long-lasting impacts on seafloor communities. These include removal of habitat-forming organisms, homogenization of seafloor habitats, altered sediment structure, and reduced oxygen penetration into the sediments (e.g. Collie et al. 2000, Thrush and Dayton 2002, Widdicombe et al. 2004, Kaiser et al. 2006, Olsgard et al. 2008). These changes not only reduce the local and regional biodiversity, but also alter the ecosystem services provided by benthic communities, including nutrient cycling at the sea floor, and the food-web interactions support commercial fish and shellfish stocks. A short review of the literature indicates there is reasonable agreement on the traits of species that would be most sensitive to trawling activities. These include slow moving, large-biomass species (corals, sponges), filter feeders, grazers, bioturbating decapods, large molluscs, echinoderms, and cnidarians (Tillin et al. 2006, Callaway et al. 2007, Olsgard et al. 2008, Strain et al. 2012, Mangano et al. 2013, 2014, Jørgensen et al 2015b). Since many ecologically (habitat-formers, biodiversity promoters) or commercially important (shrimp, scallops) species are included in this list of traits, there is a need to identify indicators of trawling impacts on benthic ecosystems for management purposes. This would provide managers with necessary information to implement or modify fisheries management policies.

Shrimp trawling in the Barents Sea in general, and around Svalbard in particular, has varied considerably since the 1990s, and in recent years there has been a move toward larger vessels entering the fishery (Hvingel and Thangstad 2012). This, combined with the requests for increasing bottom fishing within the 12 nm limit, offers the potential for both expanded and more significant impacts of trawling in the future. Thus, the aim of this pilot project is to develop a conceptual framework for identification of indicators of trawling impact to improve the ability of Norway's monitoring system MOSJ (Environmental monitoring of Svalbard and Jan Mayen) to document environmental effects from fisheries and other human drivers of the system. We do this through regional case studies around Svalbard where we compile relevant trawling, environmental and biological data, and conduct preliminary analyses.

Study area

The west coast of Svalbard is characterised by a generally narrow continental shelf intersected by trenches associated with many of the large fjords. Some fjords, such as Isfjorden and Kongsfjorden, have direct connections to the shelf and deeper waters whereas others (e.g. van Mijenfjorden) have shallow sills that reduce their mixing with shelf waters. Environmental conditions are highly dynamic. According to Nilsen et al. (2008) and references therein, Atlantic, Arctic and glacial waters converge, mix and are exchanged across The West Spitsbergen shelf. The waters on the shelf and in the adjacent fjords alternate from a state of Arctic dominance (cold and fresh in winter) to one of Atlantic dominance (warm and saline in summer) within an annual cycle. There is also continuous modification of the water masses through heat and mass exchanges with the atmosphere resulting in ice formation brought about by the prevailing wind direction. These conditions modify the composition of benthic diversity. The coastal and fjord epibenthic assemblages off the north-west of Svalbard have been classified in two Barents Sea megafaunal sub-groups. The first sub-group, dominated by sponges (Porifera), pertains to the Southeast, banks and Svalbard coast assemblage. The second sub-group located relatively closer to land is dominated by echinoderms and belongs to the Svalbard north coast, fjords and sounds, banks of Nordaustlandet group (Jørgensen et al. 2015a).

Rich benthic production supports commercial shrimp fisheries. Trawling occurs mostly within Isfjorden, a small area of Kongsfjorden/Krossfjorden, and along the shelf north of Kongsfjorden. Relatively intense shrimp trawling is observed in the northern part of Hinlopen and in the Hinlopenstretet trench extending north from Svalbard (Pers. comm, Per Finne, Directorate of Fisheries).



Figure 1: Map of Svalbard with Kongsfjorden, Isfjorden, Hinlopenstretet and Wijdefjorden

Trawling around Svalbard

The Fisheries Protection Zone is a 200 nautical mile zone of fisheries jurisdiction around the Svalbard archipelago. It was established on 3 June 1977 pursuant to the Act of 17 December 1976 relating to the Economic Zone of Norway. Norway regulate the fishery for shrimps in the Fisheries Protection Zone by stating that only countries with traditions for shrimp fisheries (Canada, Faroe Islands, Greenland, Iceland, EU, Russia and Norway) are allowed to fish (latest regulated in revision of the regulations in 2005).

In the Svalbard area the shrimp fisheries are regulated by number of effective fishing days and number of vessels by country. In the Barents Sea and Svalbard area, Norwegian rules regulate that the fisheries are to be regulated by smallest allowable shrimp size (a maximum 10% of the catch weight may consist of shrimp less than 15 mm carapace length, CL) and by provisions of the fishing licenses (ICES 2004).

Within the 12 nautical mile zone, in the large nature protected areas, a certain number of licenses are given to a certain number of fishing vessels, both Norwegian and other. Trawling is only allowed at depths deeper than 100 meters. The only trawling allowed within the 12 nautical mile zone is the shrimp fishery, as this fishery is regulated as an exception from the general trawling ban in the protected areas.

Data

Fishing intensity data in this report are delivered by the Directorate of Fisheries, and are based on the automatic identification system (AIS), electronic logbooks reported to the Fisheries Directorate, and vessel monitoring system (VMS) position reports. Tracking lines from continuous low speed (1 – 5 knots) as indicated from the AIS are defined as trawling activity, and lines are constructed as linear interpolation between the points registered in the automatic tracking system, given certain conditions regarding speed and distance from the last point. This information is modified based on the other two methods to remove other low-speed activities. Presumed trawl tracks are then located and areal statistics are calculated. The calculation is done as a density plot, based on Line Density plot. A Line Density Plot calculates the density of linear features in the neighborhood of each output raster cell. Density is calculated in units of length per unit of area. Conceptually, a circle is drawn around each raster cell center using a defined search radius. The length of the portion of each line that falls within the circle is multiplied by its population field value. These figures are summed and the total is divided by the circle's area. See <http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?topicname=how%20line%20density%20works&> for more details on the method. The sum of the lines in the defined cells (500m x 500m), given a search radius of 1500m, are divided by the cell area, (500m x 500m = 250 000 m² or 0.25 km²), providing pixel value of m/m². The reason for choosing a density plot is its ability to distinguish between the different variations of intensity.

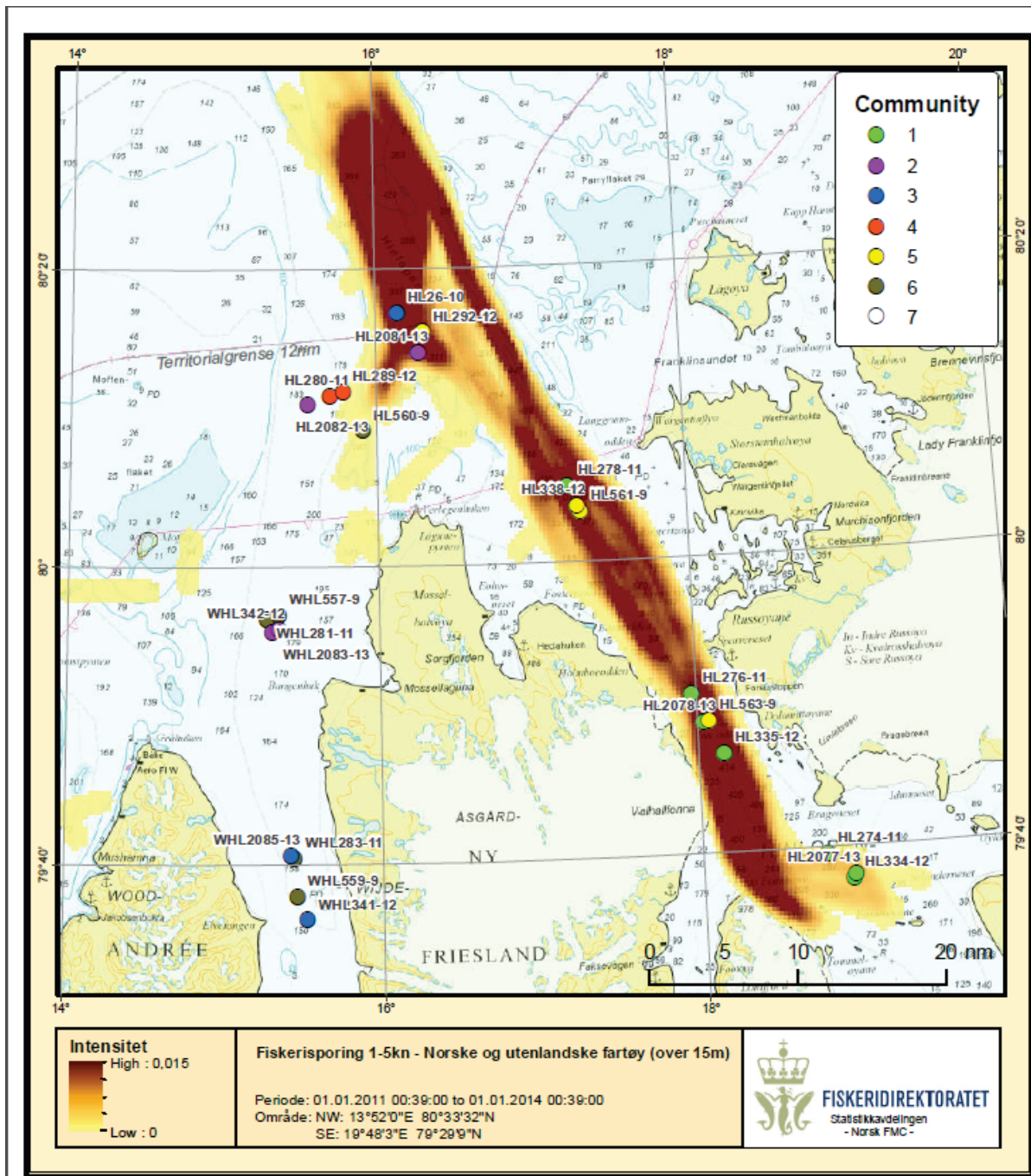


Figure 2: Hinlopenstretet and Wijdefjorden case study area with trawling intensity (brown-yellow background colour) and stations belonging to one of the communities 1-7 (illustrated as coloured dots).

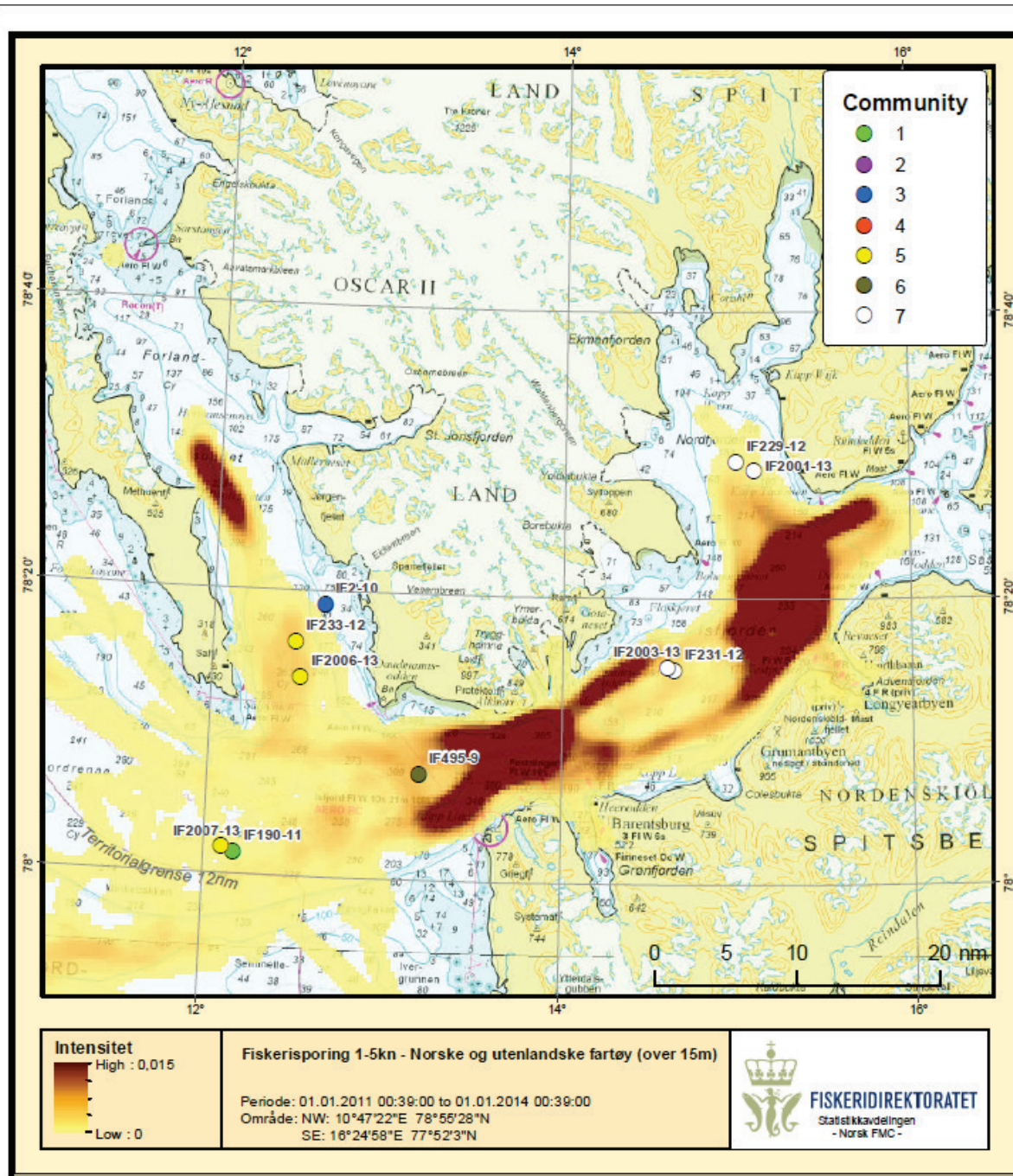


Figure 3: Isfjorden case study area with trawling intensity (brown-yellow background colour) and stations belonging to one of the communities 1-7.

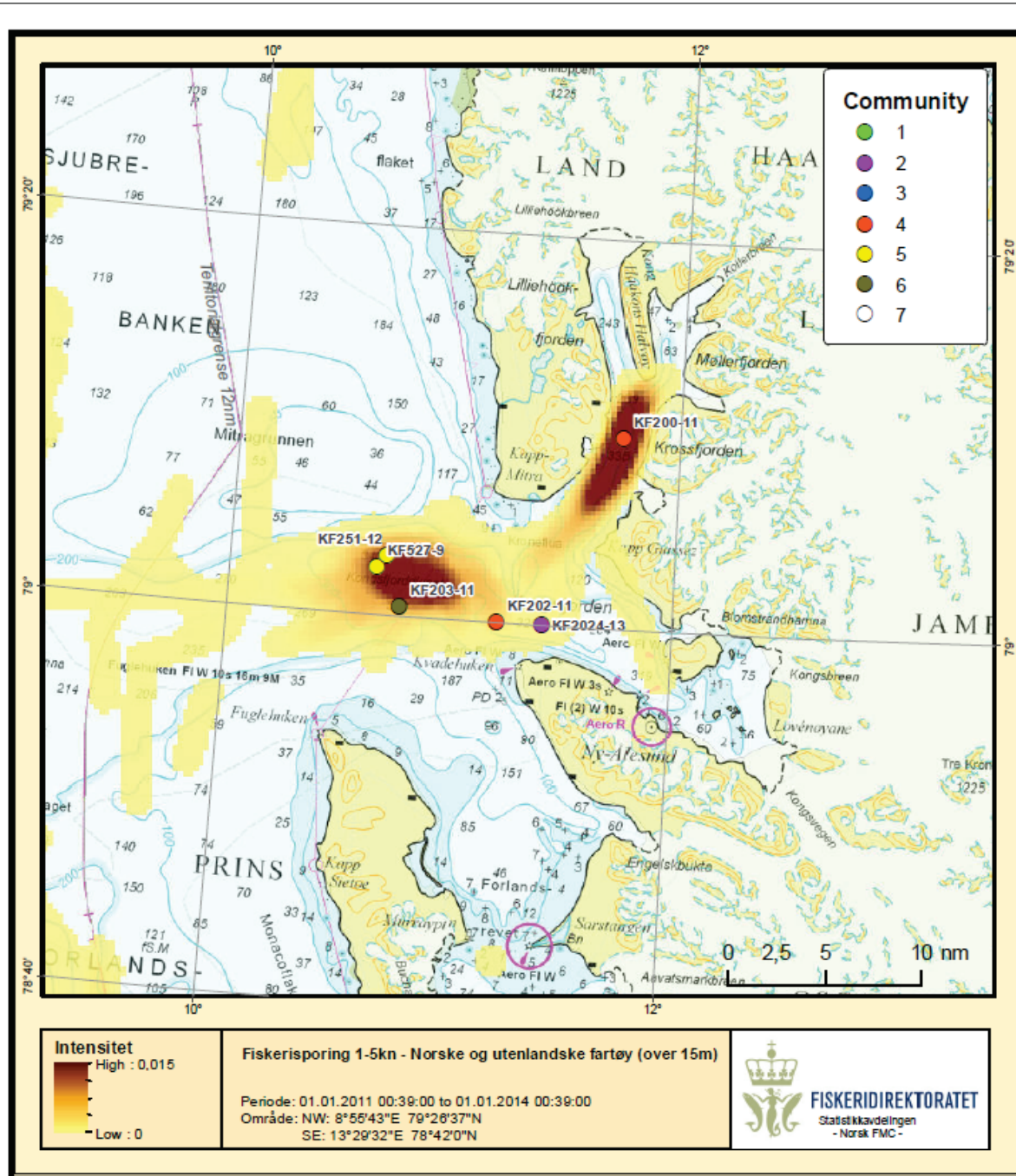


Figure 4: Kongsfjorden case study area with trawling intensity (brown-yellow background colour) and stations belonging to one of the communities 1-7.

Data to assess possible trawling impact on benthos were obtained from the annual joint IMR-PINRO Ecosystem survey (see also Jørgensen et al 2015a, 2015b). Each station (n=42) that included benthos investigations was assigned a total trawling intensity for the period 2011-2013 by reading the value of the trawling “intensity” from Figures 2-4. Bottom-water temperatures and salinities were taken from the lowermost sample (5 m above the seabed) from vertical casts made with a Seabird CTD at the same locations as the bottom trawling. Monthly averaged sea-ice concentration data were taken from the National Snow and Ice Data Centre in the USA (SMMR and SSM/I passive microwave data). The number of days with ice

absent/present in each grid cell was calculated based on average ice concentration data for the period 2007–2011.

Biomass (after 15 minutes trawling) data were used for the analyses of spatial patterns of species distributions because specimen counts are inapplicable for colonial taxa. The benthic-biomass data were fourth-root transformed and sample stations were clustered into groups by the Sorensen (= Bray and Curtis) similarity index performed in PC-ORD version 6.08 (McCune and Mefford, 2011). Ward’s method was used as the group-linkage method.

Three “case studies” were investigated:

Hinlopenstretet, HL (17 stations) –Wijdefjorden, WHL (8 stations) (2009-2013)

Kongsfjorden, KF (7 stations) (2009-2013)

Isfjorden, IF (10 stations) (2009-2013)

Data were analysed both with and without shrimp included. When shrimp were included in the analyses, they dominated the biomass at nearly all stations, regardless of region and trawling intensity. As such, they overwhelmed the importance of other taxa, including those that may be useful indicators. Thus, we proceed here with analyses excluding shrimp.

Community analyses without the deep sea shrimp *Pandalus borealis*

Cluster analyses of benthic communities indicate seven main clusters, each with approximately 50% similarity (Figure 5). Communities 1, 4 and 5 (Figures 2-6) had the deepest mean depth and highest trawl intensity (Table 1), indicating that the trawling for *Pandalus borealis* occurs primarily deeper than 300 m. The lowest mean temperature (1.2° C) was recorded at the deep community 5, while the deep communities 1 and 4 were approximately 1 and 2 degrees warmer, respectively. The shallowest communities 2, 3 and 6 had the lowest trawling intensity and were relatively warm (Table 1).

Table 1. Mean values of environmental and biological factors per community cluster. Colour = colours associated with these community clusters in Figures 2-4 and 6, Species = average number of species present in trawl, Biomass = average biomass per 15 min trawling, Temp = average bottom temperature at trawl site, Salt = average salinity at trawl site.

| Community | Colors in fig 3-5 | Depth | Temp | Salt | Trawl Intensity | Species | Biomass |
|-----------|-------------------|-------|------|------|-----------------|---------|---------|
| 1 | Green | 357 | 2.6 | 34.9 | 28 | 28 | 8696.3 |
| 2 | Purple | 226 | 2.8 | 34.8 | 7.4 | 33 | 433.7 |
| 3 | Blue | 204 | 3.0 | 34.9 | 13 | 13 | 1294.4 |
| 4 | Red | 306 | 3.4 | 34.9 | 14 | 22 | 13739.8 |
| 5 | Yellow | 331 | 1.2 | 34.9 | 25 | 19 | 1837.2 |
| 6 | Grey/brown | 192 | 2.2 | 34.7 | 7 | 21 | 8054.3 |
| 7 | White | 229 | 2.8 | 34.8 | 17 | 17 | 1141.2 |

Communities 1 (in green in Figures 2-4) and 5 (shown in yellow) are deeper than 300 m and dominated by the mud star *Ctenodiscus crispatus* (> 50% biomass). A total of eight stations are included in Community 1 (mean depth 357 m) and nine stations are in Community 5

(mean depth 331 m). Both are also heavily trawled, although abundance and biomass are much higher at Community 1 stations (Table 2). Community 5 has more infaunal taxa (*Spiochaetopterus*, Ampharetidae, *Clinocardium*, *Maldane*) than Community 1, and neither has a high biomass of presumed sensitive taxa. Community 2 (shown in purple) is the only station cluster where 50% of the biomass is not accounted for by 1 or 2 taxa (Table 1). These five stations at an average depth of 226 m have the highest average species richness, the lowest biomass, and low trawling intensity. Two cephalopods, potentially trawling-sensitive taxa, are among the top 10 biomass dominants. The Natantia (decapod) *Sabinea septemcarinata* is the biomass dominant in both this cluster and in Community 7 (shown as white), although in the latter grouping of 7 stations (average depth 192 m) it comprises 68% of the total biomass. Community 7 stations are characterized by moderate trawling intensity, relatively low species richness, and low biomass, and shows only 10% similarity to any other station grouping. One presumed sensitive soft-coral taxon (Nephthyidea) is in the top 10 biomass contributors.

Community 3 (shown in blue) includes four stations at an average depth of 204 m, and is characterised by low biomass, abundance, and species richness, and moderate trawling levels (Table 1). The shrimp group Natantia comprise over 60% of the biomass, and one sensitive taxon, the basket star *Gorgonocephalus eucnemis*, is a top 10 biomass contributor. The “trawling-sensitive” sponges (Porifera) comprised 85% of the biomass in Community cluster 4 (shown in red). These five stations (average depth 306 m) experience moderate trawling and have by far the highest biomass, along with moderate species richness. Finally, community 6 has the lowest trawling intensity along with relatively high biomass and include two sensitive taxa (*Gorgonocephalus arcticus*, *Geodia macandrewii*) among the 10 biomass dominants. This station cluster may also have heterogeneous sediment since the top two biomass dominants are soft- and hard- substrate associated, respectively.

Stations from each of the geographical areas are well distributed among the community clusters, suggesting that local processes are more important than water mass characteristics at the scale that was evaluated. Furthermore, there did not appear to be any characteristic communities associated with position within a fjord (Figures 2-4). Bottom salinity was virtually invariant across the region during the time of sampling (Table 1).

Table 2. The top 10 biomass-dominant taxa per community with presumed trawling-sensitive taxa written in bold text. See also Figures 2-4 for the specific locations of each community, and the cluster diagram defining these community similarities (Figure 5). Cephalopods, due to their large size and high potential for being caught in trawls are written in bold face as they are potential trawling-sensitive taxa (Jørgensen et al. 2015b).

| Community 1 | | | Community 2 | | |
|---------------------|--|------|--------------------|--|------|
| Taxon | Species | % | Taxon | Species | % |
| Asteroidea | <i>Ctenodiscus crispatus</i> | 56 % | Natantia | <i>Sabinea septemcarinata</i> | 31 % |
| Bivalvia | <i>Batharca glacialis</i> | 8 % | Bivalvia | <i>Chlamys islandica</i> | 17 % |
| Ophiuroidea | <i>Ophiura sarsi</i> | 8 % | Ophiuroidea | <i>Ophiura sarsi</i> | 8 % |
| Natantia | <i>Sclerocrangon ferox</i> | 3 % | Echinoidea | <i>Strongylocentrotus</i> sp. | 6 % |
| Actiniaria | <i>Hormathia digitata</i> | 3 % | Polychaeta | <i>Spiochaetopterus</i> sp. | 6 % |
| Ophiuroidea | <i>Ophiacantha bidentata</i> | 3 % | Cephalopoda | <i>Gonatus fabricii</i> | 4 % |
| Asteroidea | <i>Icasterias panopla</i> | 3 % | Asteroidea | <i>Ctenodiscus crispatus</i> | 3 % |
| Gastropoda | <i>Neptunea despecta</i> | 3 % | Cephalopoda | <i>Rossia</i> sp. | 3 % |
| Gastropoda | <i>Buccinum hydrophanum</i> | 2 % | Gastropoda | <i>Colus islandicus</i> | 2 % |
| Natantia | <i>Sabinea septemcarinata</i> | 2 % | Actiniaria | <i>Hormathia digitata</i> | 2 % |
| Community 3 | | | Community 4 | | |
| Taxon | Species | % | Taxon | Species | % |
| Natantia | <i>Sclerocrangon boreas</i> | 54 % | Porifera | Porifera | 85 % |
| Natantia | <i>Sabinea septemcarinata</i> | 16 % | Cephalopoda | <i>Bathypolypus arcticus</i> | 4 % |
| Echinoidea | <i>Strongylocentrotus</i> sp. | 8 % | Brachyura | <i>Hyas araneus</i> | 4 % |
| Asteroidea | <i>Urasterias linckii</i> | 7 % | Natantia | <i>Sclerocrangon boreas</i> | 1 % |
| Ophiuroidea | <i>Gorgonocephalus eucnemis</i> | 7 % | Natantia | <i>Sclerocrangon ferox</i> | 1 % |
| Asteroidea | <i>Ctenodiscus crispatus</i> | 4 % | Asteroidea | <i>Ctenodiscus crispatus</i> | 1 % |
| Ophiuroidea | <i>Ophiura sarsi</i> | 1 % | Asteroidea | <i>Poraniomorpha hispida</i> | 0 % |
| Natantia | <i>Spirontocaris</i> sp. | 1 % | Ophiuroidea | <i>Ophiura sarsi</i> | 0 % |
| Polychaeta | <i>Spiochaetopterus</i> sp. | 0 % | Natantia | <i>Sabinea septemcarinata</i> | 0 % |
| Asteroidea | <i>Crossaster papposus</i> | 0 % | Ophiuroidea | <i>Ophiopholis aculeata</i> | 0 % |
| Community 5 | | | Community 6 | | |
| Taxon | Species | % | Taxon | Species | % |
| Asteroidea | <i>Ctenodiscus crispatus</i> | 58 % | Asteroidea | <i>Ctenodiscus crispatus</i> | 37 % |
| Polychaeta | <i>Spiochaetopterus</i> sp. | 10 % | Echinoidea | <i>Strongylocentrotus</i> sp. | 20 % |
| Polychaeta | <i>Ampharetidae</i> g. sp. | 6 % | Ophiuroidea | <i>Ophiura sarsi</i> | 9 % |
| Ophiuroidea | <i>Ophiura sarsi</i> | 6 % | Ophiuroidea | <i>Gorgonocephalus arcticus</i> | 9 % |
| Asteroidea | <i>Icasterias panopla</i> | 4 % | Natantia | <i>Sabinea septemcarinata</i> | 8 % |
| Natantia | <i>Sabinea septemcarinata</i> | 3 % | Brachyura | <i>Hyas araneus</i> | 4 % |
| Bivalvia | <i>Hiatella arctica</i> | 2 % | Porifera | <i>Geodia macandrewii</i> | 2 % |
| Actiniaria | <i>Urticina felina</i> | 1 % | Natantia | <i>Spirontocaris</i> sp. | 1 % |
| Bivalvia | <i>Clinocardium ciliatum</i> | 1 % | Bivalvia | <i>Hiatella arctica</i> | 1 % |
| Octocorallia | <i>Umbellula encrinus</i> | 1 % | Asteroidea | <i>Icasterias panopla</i> | 1 % |
| | | | | | |

| Community 7 | | |
|--------------|-------------------------------|------|
| Taxon | Species | % |
| Natantia | <i>Sabinea septemcarinata</i> | 68 % |
| Brachyura | <i>Hyas araneus</i> | 12 % |
| Bivalvia | <i>Clinocardium ciliatum</i> | 9 % |
| Octocorallia | Nephtheidae | 5 % |
| Ophiuroidea | <i>Ophiacantha bidentata</i> | 2 % |
| Asteroidea | <i>Poraniomorpha hispida</i> | 2 % |
| Bivalvia | <i>Astarte</i> sp. | 1 % |
| Asteroidea | <i>Ctenodiscus crispatus</i> | 1 % |
| Ophiuroidea | <i>Ophiura sarsi</i> | 0 % |
| Natantia | <i>Spirontocaris</i> sp. | 0 % |

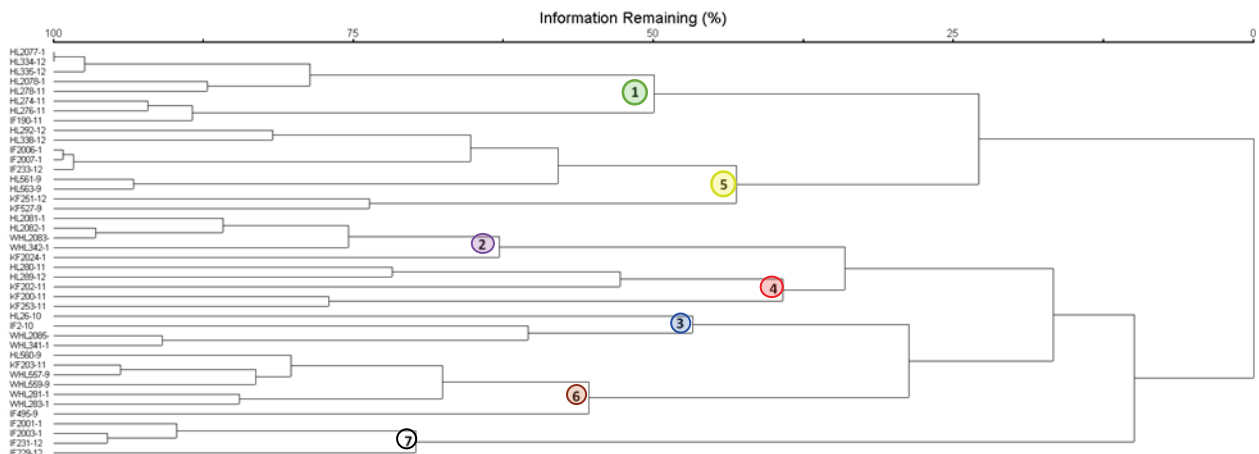


Figure 5: Community-similarity dendrogram (excluding *Pandalus borealis*) for all stations (year 2009-2012) from Hinlopenstretet (HL), Wijdefjorden (WHL), Isfjorden (IF) and Kongsfjorden (KF). Clusters of stations have numbers as given in the trawling-intensity maps in Figures 2-4. Bray-Curtis similarity (%) of square-root transformed biomass is indicated on the horizontal axis.

Canonical correspondence analyses (CCA) indicated that the environmental variables collected with the survey trawls (depth, temperature, salinity), ice cover and trawling intensity explained little of the among-station variability in communities. The first three canonical axes explained only 12% of the total variance. Figure 5 shows the plot of the two first axes, explaining a total of 8.8% of the variance. Trawling intensity does not enter the ordination as a significant variable here, but depth, ice days, and temperature were significant. As noted above (Table 1), temperature varied by only 2 degrees C (1.2 – 3.5°C), which might have had little biological meaning. Based on the results of the CCA, it is clear that other variables have had stronger influence over community structure than those we measured, and bottom heterogeneity might be one of these influences.

There may be a relationship between trawling intensity and the occurrence of presumed vulnerable taxa. Under the heaviest trawling intensity (clusters 1 and 5), only 1 taxon (the sea pen, *Umbellula encrinus*) appeared as a top-10 biomass contributor. Under moderate and light trawling intensity, however, several other taxa were observed in the top-10 list, including sponges, basket stars, soft corals, scallops and sea pens (Table 2). These results must, however, be viewed with caution as sample size is too low to address this statistically.

Table 3: Correlation matrix on station level indicating the CCA correlation coefficient between each pair of variables. Coefficients highlighted in yellow indicate statistical significance at $\alpha=0.05$. Trawl = trawling intensity (see text), sppsta = species per station, sqrtbiom = square-root transformed biomass values per station.

| | Depth | Trawl | sqrtbiom | sppsta |
|----------|--------|--------|----------|--------|
| Depth | 1 | 0.768 | 0.203 | -0.059 |
| Trawling | 0.768 | 1 | 0.005 | -0.168 |
| Biom15 m | 0.203 | 0.005 | 1 | -0.021 |
| Species | -0.059 | -0.168 | -0.021 | 1 |

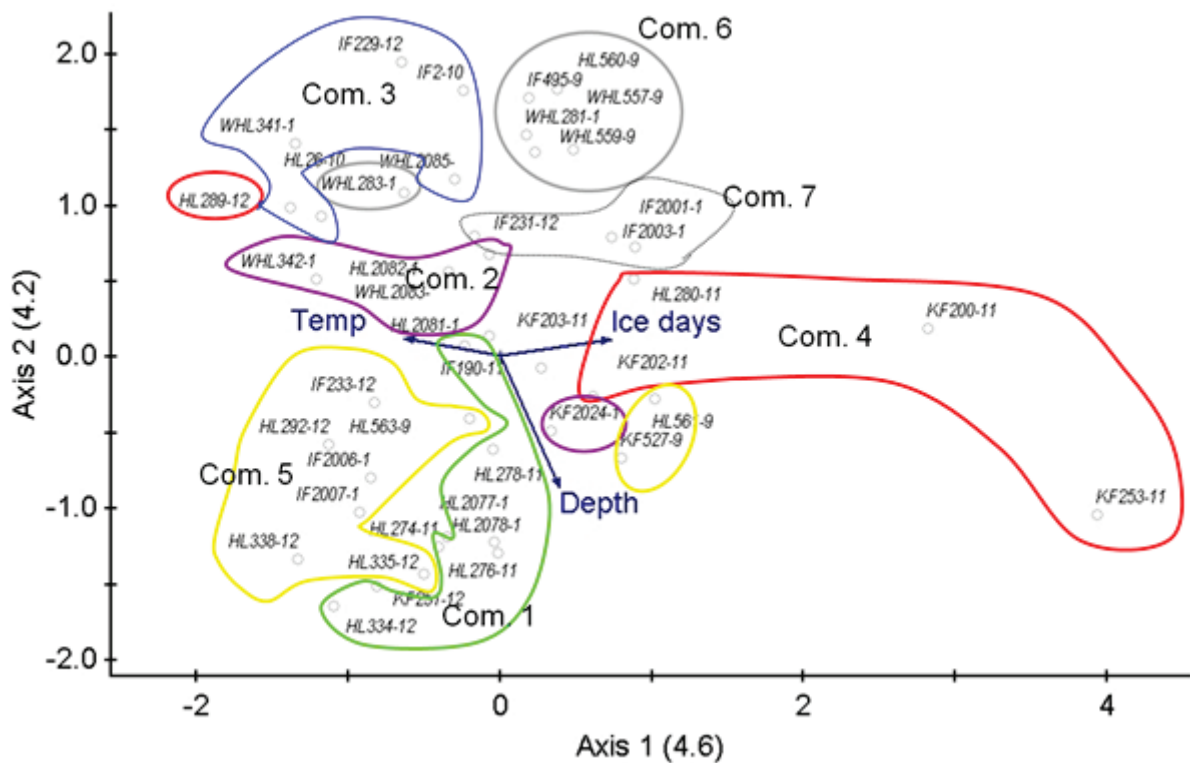


Figure 6: Canonical correspondence analyses (CCA) showing the species ordination and significant environmental drivers. Axes 1 and 2 explain 8.8% of the total variance in the data. Faunal groupings indicated by shapes drawn around stations. Communities 2, 4, 5 and 6 are discontinuous.

Discussion

Megafaunal community structure in the regions we studied shows no clear relationship with geographic location or position within the fjord/open shelf continuum. This may indicate a high variability in bottom topography/sediment characteristics leading to a mosaic of different communities. It is well known that sediment parameters have a strong influence on benthic community structure, so in this way, the results are not surprising. It could be expected, however, that benthic communities would have varied more consistently along down-fjord gradients, or between western and northern coasts of the island of Spitsbergen (Kędra et al. 2010). This was not observed, suggesting an overwhelming influence of Atlantic water in all areas, leading to small scale differences in sediment characteristics as the main driver of the communities.

We did observe that community composition was roughly related to depth, a finding echoed by Sswat et al. (2015) using bottom photographs in some of the same regions north of Svalbard. They also found indications of trawling at all locations deeper than 300 m, a pattern we also see in the trawling intensity data, as these depths correspond to shrimp grounds in the area. Of course, depth itself is not driving these communities, but instead it is a series of depth-covariates such as current speed, sedimentary organic matter, sediment stability, and grain size.

Several studies have documented the severe impacts that bottom trawling can have on the marine environments. These include habitat alteration, incidental mortality of non-target species, evolutionary shifts in population demographics and changes in the function and structure of ecosystems (Mangano et al. 2013 and references therein). Specific functional groups of benthic organisms have been shown to be particularly sensitive to trawling. These include emergent epifauna, some bioturbating decapods, suspension feeders, and long-lived and high-biomass organisms (including sponges and corals) (Guijarro-Garcia 2007, Olsgard et al. 2008, Hinz et al. 2009, Mangano et al. 2014). Large biota i.e. corals and sponges, are more expected to be particularly vulnerable to trawling gear and have lower intrinsic rates of increase, and hence a lower capacity to sustain or recover from elevated mortality (Kaiser et al. 2006). Another taxonomic group identified as “high risk of being caught by a trawl” is the Cephalopods. Little is known about the vulnerability of these species, but Cephalopoda are widely distributed, and with their highest biomass occurring in the untrawled northeastern areas of the Barents Sea (Jørgensen et al 2015b). The cephalopods might rise above the seabed in response to sensing the bottom trawl, a behaviour which might make them more vulnerable to capture. In this regard, bottom trawling can drive benthic assemblages towards smaller, short-lived and fast growing species causing system shifts from high to low diversity, and from a high biomass–low turnover to a low biomass–high turnover system (Dannheim et al 2014).

Our pilot study revealed contrasting results. The effect of trawling on community parameters, including community structure, distribution of functional groups, total biomass, and presence of “trawling sensitive” taxa, was not consistent. There is considerable evidence that the impacts of trawling can depend on natural disturbance regimes already present in the system. For example, areas of Georges Bank, western Atlantic, with high bottom currents and coarser

sediments exhibited less obvious impact of trawling than deeper, more quiescent areas with fine sediments (Link et al. 2005). We have limited information on sediment grain size in our study areas, but many of the fauna collected with trawls are indicative of hard substrate or mixed bottoms. In addition, communities in our case-study areas have been described to be at low, and in some cases low-moderate, risk of trawling impact (Jørgensen et al. 2015b). We do not, however, have adequate data to conclude about natural disturbance or inherent vulnerability in these regions with any confidence. Finally, it is difficult to know whether the trawling intensities estimated in these regions are high enough to expect impacts. We only have relative values in different areas of an, admittedly, lightly modified shelf. Higher trawling intensities can be expected in the future, however, as ice-cover declines (increasing accessibility) and southern fisheries target species (cod, haddock) spread northward. These results, at a minimum, can serve as a baseline for lightly trawled areas for future reference.

A second factor that may be important in interpretation of our results are the different spatial scales whereby trawling intensity is estimated versus how communities are sampled. Firstly, there is a methodological issue. Interpolated VMS data used in part to calculate trawling intensity by the Fisheries Directorate are appropriate for mapping the large-scale distribution of fishing effort and the area impacted; but VMS is suggested to be insufficient for linking fishing activities with small-scale mapping of benthos (Skaar et al. 2011). The second factor is statistical, in that sample density is not high enough in these areas to have adequate replication for many more appropriate statistical methods. In addition, there is only one 15 minute trawl per station, and is likely not sufficient to adequately sample even local heterogeneity in habitat characteristics. Thus, the results presented here must be considered preliminary, but the presence of presumed vulnerable taxa, even in the most trawled areas, suggests that impact thus far is minimal. We do not believe that this invalidates the use of the taxa and functional groups as indicators of trawling impact. Far too many studies have consistently identified these organisms as vulnerable to conclude that this understanding does not apply here. One could discuss whether sponges as a group (opposed to particular species) should be considered vulnerable however, as it is not uncommon to find a high sponge biomass where trawling is moderate, or even heavy (Jørgensen et al. 2015b).

Finally, trawling occurs in these areas due to the presence of (for the most part) shrimp. These locations have environmental characteristics that cover only a small range of that observed on the Svalbard shelf and coastal waters. The relatively clear water-mass-biotic relationships in determining community structure in the region (Jørgensen et al. 2015a) are not possible to investigate further (alone or in relation to trawling) due to the limited availability of data in this study. Conditions promoting good shrimp grounds (soft sediment, relatively deep water, etc.) may also result in fewer trawling-sensitive taxa. Thus, our data set would have an inherent bias against finding effects of trawling.

Conclusions and recommendations for further work

The Svalbard area has experienced varying trawling intensities over the past several decades, but the expansion of Atlantic cod around Svalbard and the maintenance of high shrimp

densities in some areas suggest that trawling may increase in the coming years, given a change in fishing regulations in the area.

We investigated epibenthic communities in several areas around the island of Spitsbergen and found largest mean megabenthic biomass (>25 kg per 15 min trawling) at deep stations (>335 m), where the highest fishing intensity occurred; i.e. Hinlopenstretet and Kongsfjord.

Shallow stations from all fjords (except Kongsfjord) were untrawled.

In areas of high fishing intensity, the benthos biomass was mainly dominated by the deep-sea shrimp *Pandalus borealis*, while low trawling intensity areas were dominated by the sea star *Ctenodiscus crispatus* (Hinlopenstretet, Wijdefjorden).

Stations in Kongsfjorden were dominated by Porifera (sponges), despite elevated trawling intensity which might result in the removal of these organisms along with the deep sea shrimps in commercial trawl catches.

Even though the unexpected result with areas experiencing high trawling intensity also presented rather high biomass of megafauna other than the deep sea shrimp, we recommend large bodied and exposed species to function as indicators. Examples are the sea pen *Umbellula encrinus*, the basket stars *Gorgonocephalus* spp., and the sponges, including *Geodia macandrewii*. This means that a stable population of these species means no further degradation of these areas. The concrete definition of possible indicator designs needs further attention, also compared to what is practical and economical feasible.

In order to understand the effect of trawling on fjord-communities, a detailed understanding of the varied bottom-topography and consequently the varied species compositions must be known together with the precise position of the trawling impact. This will allow a precise location for collecting trawl impacted seabed. Furthermore, species reaction (survival, reestablishment and regeneration) toward being caught by a trawl and reentered into the water must be known. This will include controlled studies of trawl-injured individuals of several expected sensitive species.

Appendix 1: - List of species found at the stations

| Species |
|----------------------------------|
| <i>Abietinaria abietina</i> |
| <i>Acanthostepheia malmgreni</i> |
| <i>Actinaria</i> g. sp. |
| <i>Actinostola</i> sp. |
| <i>Admete</i> sp. |
| <i>Alcyonidium</i> sp. |
| <i>Amathillopsis</i> sp. |
| <i>Ampharetidae</i> g. sp. |
| <i>Amphipoda</i> g.sp. |
| <i>Anonyx</i> sp. |
| <i>Arctinula greenlandica</i> |
| <i>Arrhis phyllonyx</i> |
| <i>Asbestopuma pennatula</i> |
| <i>Ascidia prunum</i> |
| <i>Ascidacea</i> g. sp. |
| <i>Astarte</i> sp. |
| <i>Balanus</i> sp. |
| <i>Bathyarca glacialis</i> |
| <i>Bathypolypus arcticus</i> |
| <i>Bivalvia</i> g. sp. |
| <i>Boreonymphon abyssorum</i> |
| <i>Boreonymphon</i> sp. |
| <i>Brada</i> spp |
| <i>Bryozoa</i> g. sp. |
| <i>Buccinidae</i> g. sp. |
| <i>Buccinum ciliatum</i> |
| <i>Buccinum elatior</i> |
| <i>Buccinum finmarchianum</i> |
| <i>Buccinum fragile</i> |
| <i>Buccinum hydrophanum</i> |
| <i>Buccinum undatum</i> |
| <i>Cellepora</i> sp. |
| <i>Chlamys islandica</i> |
| <i>Clinocardium ciliatum</i> |
| <i>Colus islandicus</i> |
| <i>Colus sabini</i> |
| <i>Colus</i> sp. |
| <i>Cribrinopsis similis</i> |
| <i>Crossaster papposus</i> |
| <i>Cryptonatica affinis</i> |
| <i>Cryptonatica clausa</i> |
| <i>Ctenodiscus crispatus</i> |

| Species |
|--------------------------------|
| <i>Musculus</i> sp. |
| <i>Myriapora</i> sp. |
| <i>Myriozoella</i> sp. |
| <i>Myxilla</i> sp. |
| <i>Naticidae</i> g. sp. |
| <i>Nemertini</i> g. sp. |
| <i>Nephasoma</i> sp. |
| <i>Nephtheidae</i> |
| <i>Nephtyidae</i> g. sp. |
| <i>Neptunea despecta</i> |
| <i>Nereididae</i> g. sp. |
| <i>Nymphon brevirostre</i> |
| <i>Nymphon elegans</i> |
| <i>Nymphon grossipes</i> |
| <i>Nymphon hirtipes</i> |
| <i>Nymphon hirtum</i> |
| <i>Nymphon</i> sp. |
| <i>Nymphon spinosum</i> |
| <i>Nymphon stroemi</i> |
| <i>Onchidoridae</i> g. sp. |
| <i>Ophiacantha bidentata</i> |
| <i>Ophiocten sericeum</i> |
| <i>Ophiopholis aculeata</i> |
| <i>Ophioscolex glacialis</i> |
| <i>Ophiura sarsi</i> |
| <i>Ophiuroidea</i> g. sp. |
| <i>Pagurus</i> sp. |
| <i>Pandalus borealis</i> |
| <i>Paramphithoe hystrix</i> |
| <i>Parasmittina jeffreysii</i> |
| <i>Pectinaria</i> sp. |
| <i>Phakellia</i> sp. |
| <i>Phascolion</i> sp. |
| <i>Philine</i> sp. |
| <i>Phyllodocidae</i> g. sp. |
| <i>Poliometra prolixa</i> |
| <i>Polychaeta</i> g. sp. |
| <i>Polycitor vitreus</i> |
| <i>Polymastia</i> sp. |
| <i>Polynoidae</i> g. sp. |
| <i>Pontaster tenuispinus</i> |
| <i>Pontophilus norvegicus</i> |

| |
|---------------------------------|
| <i>Cumacea</i> g. sp. |
| <i>Cuspidaria arctica</i> |
| <i>Dendronotus</i> sp. |
| <i>Didemnidae</i> g. sp. |
| <i>Epimeria loricata</i> |
| <i>Eualus</i> sp. |
| <i>Eucratea loricata</i> |
| <i>Eunicida</i> sp. |
| <i>Euphosine</i> sp. |
| <i>Geodia macandrewii</i> |
| <i>Geodia</i> sp. |
| <i>Golfingia</i> sp. |
| <i>Gonatus fabricii</i> |
| <i>Gorgonocephalus arcticus</i> |
| <i>Gorgonocephalus eucnemis</i> |
| <i>Gorgonocephalus</i> sp. |
| <i>Grammaria</i> sp. |
| <i>Haleciidae</i> sp. |
| <i>Halichondria</i> sp. |
| <i>Haliclona</i> sp. |
| <i>Halocynthia pyriformis</i> |
| <i>Heliometra glacialis</i> |
| <i>Hemithyris psittacea</i> |
| <i>Henricia</i> sp. |
| <i>Hiatella arctica</i> |
| <i>Holothuroidea</i> g. sp. |
| <i>Hormathia digitata</i> |
| <i>Hyas araneus</i> |
| <i>Hydroidea</i> g. sp. |
| <i>Hymedesmia</i> sp. |
| <i>Hymenaster pellucidus</i> |
| <i>Icasterias panopla</i> |
| <i>Lafoea</i> sp. |
| <i>Lebbeus polaris</i> |
| <i>Lepeta caeca</i> |
| <i>Liljeborgia fissicornis</i> |
| <i>Lophaster furcifer</i> |
| <i>Lumbrineris</i> sp. |
| <i>Lunatia</i> sp. |
| <i>Maldane</i> sp. |
| <i>Margarita</i> sp. |
| <i>Molgula</i> sp. |

| |
|-------------------------------------|
| <i>Poraniomorpha hispida</i> |
| <i>Porella</i> sp. |
| <i>Porifera</i> |
| <i>Priapulul caudatus</i> |
| <i>Propebela</i> sp. |
| <i>Pseudamussium septemradiatum</i> |
| <i>Psolus</i> sp. |
| <i>Pteraster militaris</i> |
| <i>Pteraster obscurus</i> |
| <i>Pteraster pulvillus</i> |
| <i>Rachotropis</i> sp. |
| <i>Radiella grimaldi</i> |
| <i>Retepora</i> sp. |
| <i>Rhizocaulus verticillatus</i> |
| <i>Rossia</i> sp. |
| <i>Sabellidae</i> g. sp. |
| <i>Sabinea septemcarinata</i> |
| <i>Sabinea</i> sp. |
| <i>Sclerocrangon boreas</i> |
| <i>Sclerocrangon ferox</i> |
| <i>Serripes groenlandicus</i> |
| <i>Sertella septentrionalis</i> |
| <i>Sipunculidea</i> g. sp. |
| <i>Solaster endeca</i> |
| <i>Solaster</i> sp. |
| <i>Spiochaetopterus</i> sp. |
| <i>Spirontocaris</i> sp. |
| <i>Stegocephalus</i> sp. |
| <i>Stegohornera lichenoides</i> |
| <i>Strongylocentrotus</i> sp. |
| <i>Stylocordyla borealis</i> |
| <i>Suberites</i> sp. |
| <i>Taxodont</i> |
| <i>Terebellidae</i> g. sp. |
| <i>Terebratulina</i> sp. |
| <i>Tethya</i> sp. |
| <i>Thenia muricata</i> |
| <i>Umbellula encrinus</i> |
| <i>Urasterias linckii</i> |
| <i>Urticina felina</i> |
| <i>Velutina</i> sp. |
| <i>Yoldia hyperborea</i> |
| <i>Yoldiella</i> sp. |

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