Environmental changes in the Barents Sea

- *Does the invasive snow crab disturb the sediment and geochemical composition in the Barents Sea?*

Marie A. N Sjøblom

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Faculty of Mathematics and Natural Sciences
Department of Geoscience

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Picture: Christian Skauge

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Marie Sjøblom

http://www.duo.uio.no/

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Abstract

The snow crab, *Chionoecete opilio*, is an invasive species in the Barents Sea. The spread of the species has know environmental impacts on the benthic community, removing species important for biominxing. By analyzing short sediment cores (10 cm) from locations with high density of snow crabs and low densities of snow crabs it is clear that the snow crab effects the benthic community. Both macrofauna and benthic foraminifera indicates sediment mixing in the areas with high crab densities. Foraminifera are single celled organisms found in all marine environments, and the main difference in microhabitat characteristic is between the epifaunal and infaunal benthic organisms. The main factors determining the vertical distribution of foraminifera are oxygen concentration and food availability.
Sediment analysis of total organic carbon, water content and sediment size support the evidence of sediment mixing and livable conditions downcore, as the different parameters can be correlated.

Preface

This thesis marks the final part of the master's program in environmental geoscience at the University of Oslo summer 2021.

I would like to send a huge thank you to my three supervisors; Elisabeth Alve, Silvia Hess, and Eivind Oug. You have shown a great interest in my thesis, motivated me and been beyond patient. I am grateful for all your wise inputs, good conversation and high spirits!

This has been and odd year, with covid-19 having a great impact on the process of this thesis. But as my dad says; everything works out in the end.

Oslo, 8. August 2021

Marie Sjøblom

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1 Introduction

1.1 Foraminifera

Foraminifera, single-celled organisms, are found in all marine environments. They are characterized by a protective shell, which can be membranous (organic walled), of clay, silt and sand size sediments cemented together (agglutinated) or calcium carbonate (calcareous). The microhabitats of living benthic foraminifera are explained as the area in the sediment-water interface where we can detect the different species. The foraminifera can be planktic (living in the water column) or benthic (Hallock, 2011; Saraswat & Nigam, 2013). The main difference in microhabitat characteristic is between the epifaunal and infaunal benthic organisms. The epifaunal organisms live on top of the sediment, or are characterized with an "elevated microhabitat", whereas infaunal is used for all taxa which do not show a clear life preference close to the sediment surface (Frans J. Jorissen, de Stigter, & Widmark, 1995). Nearshore, coastal waters are where the benthic foraminifera are most abundant, and the abundance decreases with increasing water depth. The benthic foraminifera are very diverse, with more than 10 000 species described from all over the world's oceans, including fossil species (Saraswat & Nigam, 2013).

Benthic foraminifera are mostly studied in surface sediments, but they may be found at depths 60 cm below the surface. The main factors determining the vertical distribution of foraminifera are temperature, oxygen concentration, and food availability (Bouchet et al., 2009). Food supply is the primary determinant of population abundances of benthic foraminifera, it also influences chemical parameters such as dissolved oxygen concentration, pH, alkalinity and sulfide content in the sediment (Hallock, 2011). In an oligotrophic setting, the foraminiferal sediment depth distribution is controlled by the food availability, while the oxygen level in the sediment column is the controlling factor in eutrophic waters (Saraswat & Nigam, 2013).

The possible presence of oxygen and organic matter, as well as passive transport by macrofaunal bioturbation activities, are speculated to be the reasons for the occurrence of benthic foraminifera deeper in the sediments. Active dispersion through self-locomotion within the sediments is another possibility (Bouchet et al., 2009). High infaunal abundance is also associated with low bottom current rates allowing accumulation of food (F. J. Jorissen, Barmawidjaja, Puskaric, & van der Zwaan, 1992).

Calcareous foraminifera can be found in all types of marine environments above the carbonate compensation depth (CCD). The calcareous diversity is reduced to one or two tolerant species in low salinity and brackish environments, mainly because of low pH. Agglutinated benthic foraminifera occur beneath the CCD and are more abundant in brackish waters. They become dominant in restricted or biologically challenged environments (Hallock, 1999).

1.2 Former studies of foraminifera in the Barents Sea

Østby and Nagy (1982)

The paper is based on shallow sampling of bottom sediments in the western parts of the Barents Sea, carried out during the summer of 1971. Sediment samples from Spitsbergenbanken and the trenches in Stordfjordrenna and Bjørnøyrenna were analyzed. The samples were obtained from locations with water depths from 34 m to 332 m. Foraminiferal faunas were analyzed and the distribution pattern were discussed in relation to water depth, currents and sedimentation. The twelve most common species compose approximately 87% of the total benthic fauna, listed in decreasing abundance; *Cassidulina crassa, Cibides lobatulus, Elphidium excavatum, Cassidulina laevingata, Islandiella norcrossi, Nonion labradoricum, Adercotryma glomeratum, Astrononion gallowayi, Buccella frigida, Elphidium frigidum, Nonion Barleeanum, Trifarina fluens.* The three most common species occur in nearly all samples.

The currents are particularly active on the Spitsbergenbanken, characterized by high energy and current velocities. The shallowest areas (30-80m) of the Spitsbergenbanken consist of gravel and sand, while from 70-100 m there is sandy mud. The foraminifera assemblages found in the Spistsbergenbanken are clearly different compared to the quieter environment in the trenches, consisting of fine-grained mud and clay. The foraminiferal assemblage in the high energy environment of Spitsbergenbanken is dominated by species that are attached to the sediments, while the smaller species are transported form the high energy areas of the bank and redeposited in the trenches with lower energy.

Saher, Kristensen, Hald, Korsun, and Jørgensen (2009)
The paper present living (stained) benthic foraminifera assemblage data from surface sediments sampled in the central Barents Sea in 2005 and 2006. The data show that foraminiferal assemblage changes vary strongly throughout the basin, with maximum change in the extreme north and south of the study area. Division of the species into three major faunal groups related to specific environmental conditions ("warm water species", "cold water species" and "tolerant species") shows that the abundance of cold water species decreases in the eastern part of the study area, while the abundance of warm water species increases in most of the western area. A reverse trend is seen in the most central locality.

1.3 The Barents Sea

The Artic region is warming faster than rest of the globe, leading to significant climate changes. Temperatures in the Barents area has increased with an average up to 2°C since 1954, with the strongest warming in the winter. The Barents Sea is expected to become the first Arctic region free of sea ice, and the declining ice-cover will influence the ocean temperature, salinity and density. This will affect the deep-water convection, global ocean circulation, weather and marine life (AMAP, 2017).

The climate changes will effect marine mammals, especially those adapted to a life on the ice edge. Some species have difficult adapting to scenarios with less ice and the population will decline, other species will relocate as the ice retreats (Øseth, 2011).
Climate effects in the ocean depends on the extent of warmings, but also human impacts. Warmer water can help new species adapt to the environment, and changes in species composition can occur; foreign species have been introduced by humas, while other species have relocated to the area because of the environmental conditions have changed and established new opportunities (Øseth, 2011).

How the individual parts of the ecosystem in the Barents Sea will be affected is not clear, but the climate change will change the species balance. The eco system also has to cope with the changes in composition and distribution of species. Human impact on the ecosystem, in addition to climate change, increases the negative consequences (Øseth, 2011).

The snow crab is listed in the highest impact category on the Norwegian blacklist of alien species; a species with "severe ecological risk" (SE) (Sundet, Gulliksen, Jelmert, Oug, &

Falkenhaug, 2018). The species has an exploitable potential, the expansion has important ecological, economic and political implications (Kaiser, Kourantidou, & Fernandez, 2018).

A general ban on fishing for snow crabs has been introduced on the Norwegian Continental Shelf, but vessels that meet certain requirements can apply for a dispensation. The snow crab is a sedentary species and is managed on the basis of shelf rights, rather than fishing zones. Thus, the continental shelf states that Norway and Russia alone manage the snow crab stock in the Barents Sea. This decision meant that EU-countries that had fished snow crab in previous years were banned form fishing from 2017 onwards. As of June 2017, a snow crab quota was introduced for the Norwegian zone in the Barents Sea set by the Ministry of Trade and Industry. The quota is set again every year, and the quota for 2021 should not exceed 6,500 ton (Havforskningsinstituttet, 2019; Hjelset, Hvingel, Danielsen, & Sundet, 2020).

1.4 The snow crab

The snow crab *(Chionoecetes opilio)* is naturally distributed in the northwestern side of the Atlantic; eastern Canada and west Greenland, the North Pacific and the Sea of Japan (Alvsvåg, Agnalt, & Jørstad, 2008). Since the first recordings in the eastern Barents Sea in 1996 (Kuzmin, Akhtarin, & Manis, 1998), the snow crab has been reported by the bottom trawl fisheries, mainly as bycatch.

Alvsvåg et. al (2008) have provided evidence for a self-reproducing population in the Barents Sea. Annual surveys started in 2004, and the recordings show that the invasive species has spread rapidly north-westerly (Agnalt, Jørstad, Pavlov, & Olsen, 2011). The initial theory of how the snow crab was introduced in the Barents Sea was via ballast water from where the species is naturally distributed (Kuzmin et al., 1998). Genetic analyses of individuals from Canada, the Bering Sea, the west coast of Greenland and the Barents Sea indicates that the crabs have different genetics in the different areas. This implies that the ballast theory might not be correct, but indicates that the snow crab has wandered, probably from the Bering Sea, to the Barents Sea (Nagelsen, 2020).

According to Ribchaud et al. (1989; in Comeau et al., 1998) the snow crab distribution is more related to the sea bottom substrate than water depth, snow crabs are most common on muddy bottoms (Comeau et al., 1998). Snow crabs may partially bury in bottom sediments, only eyes emerging, to hide from predators. At early stages of life the snow crab settles anywhere they may survive and where the location provides the best protection. The snow crab seems more opportunistic than actively directed to the type of sediment where they settle, as the high density patches of early benthic stages are not necessarily found in the same location from year to year (Conan et al., 1996).

Most snow crabs in the Barents Sea are found in waters below 2°C, but are widely distributed in areas with temperatures ranging from 0.7°C to 3.4°C. In the Barents Sea, the snow crabs are for the most part found in areas with 180 m to 350 m water depth (Kaiser et al., 2018).

The snow crab tends to feed on a broad type of preys, and the most frequently types are polychaetas, crustaceans, mollusks, echinoderms and fish (Squires & Dawe, 2003). As the snow crab feeds on the benthic fauna, this may lead to environmental disturbance by removing organisms important for sediment biomixing and bioirrigation, thus the benthic community will be affected. Areas with a high density of snow crabs shows changes in species composition and function in benthic animals (Kling Michelsen et al., 2020).

A comparable species, the invasive red king crab, have caused changes in both total biomass and species composition where adult individuals feed, both the species richness and the biomass of the prey community have been reduced (Eivind Oug, Cochrane, Sundet, Norling, & Nilsson, 2010; Eivind Oug, Sundet, & Cochrane, 2018).

Pots are used for snow crab fishing, and the pot fishing itself has little impact on the ecosystem beyond the problems associated with lost use and ghost fishing. There appears to be little or no bycatch of other species when using pots, beyond the problems associated with lost use and ghost fishing (Hjelset et al., 2020).

1.5 EISA project

Ecology and management of the invasive snow crab: Predicting expansion, impacts and sustainability in the Arctic under climate change (EISA) primary object is to evaluate and predict change in ecosystem structure and function in Arctic marine systems caused by the invasive snow crab in current and future scenarios of global change, for the sustainable, ecosystem-based management of a new biological resource in the complex bio-economic and legal context of the Barents Sea. This thesis will focus on the current impact of the snow crab on structure and function of benthic ecosystem.

Partners in the project are NIVA (Norwegian Institute for Water Research), Akvaplan-niva, University of Oslo, UiT - Norwegian Arctic University, University of Agder, Institute of Marine Research, CSIC Spain and the University of British Columbia, Canada. The project is owned by NIVA, but is led by Akvaplan-niva by Paul Renaud. Akvaplan-niva also contributes expertise in benthic communities, food network interactions and food patterns for the snow crab.

1.6 Research subject

Since the first recordings of the alien species *Chionoecetes opilio* in the Barents Sea in the mid 1990s, it has been blacklisted as a "severe ecological risk" as well been labeled as a potential economic resource. As the species now has a self-reproducing population in the Barents Sea, similar physical habitats are at risk of colonization.

What remains to be determined is the ecological impact the species has on the benthic ecosystem. Changes in community structure can affect the functioning of the benthic ecosystem by altering biogeochemical process through reduction in bioturbating infauna and changing the dominant life-history strategy in the community. The subject of this thesis is therefore: *Does the snow crab impact benthic foraminifera and to what extent does it impact the ecological quality?*

- Does the snow crab disturb the sediments and impact the geochemical composition?
- If so, will this be reflected by changes in benthic foraminiferal microhabitat preferences and their assemblage composition?

By using short sediment cores from locations with high (Loc A) and low density (Loc B) of snow crabs, in the Barents Sea, different analyses will be performed to answer the above mentioned research questions.

2 Background

2.1 Ocean currents

2.1.1 Bathymetry and current direction

Located north of the coast of Norway, the Barents Sea is limited by Franz Josef Land and the deep Arctic Ocean in the north, by Novaja Zemlja in the east, Svalbard and the Norwegian Sea in the west. The Barents Sea, together with the Norwegian Sea, is a transitioning zone for warm, saline water from the Atlantic Ocean to the Arctic Ocean, and colder, less saline water from the Arctic Ocean to the Atlantic Ocean (Loeng & Drinkwater, 2007).

The Barents Sea is a shallow continental shelf area with an average depth around 230 m. The maximum depth of 500 m is found in the Bjørnøyrenna in the western parts of the sea, and Spitsbergbanken in the southeastern part is the shallowest with less than 50 m water depth. The currents are directed towards the east in the southern part of the Barnts Sea, while in the North, the currents move in a westward or southwestward direction (Figure 1). The currents are strongly influenced by the bottom topography, and in most of the Barents Sea the current direction are valid for the whole water column. The areas west and south of Storbanken is an exception, here the Atlantic Water meets the lighter Arctic Water and sinks because of density differences. In this area the deeper layer opposes the surface direction (Loeng, 1991; Loeng & Drinkwater, 2007).

The Nordkapp Current derives from the Norwegian Coastal Current that flows into the Barents Sea along Bjørnøyrenna. The Nordkapp Current divides into two main branches; one that continues eastwards along the Coastal Current system, the other moving along the Hopen trench and divide into smaller brances (Figure 1). Two of these branches continue between Hopen and Storbanken before they submerge below the Arctic Water (Loeng, 1991).
The inflow of Artic Water has two routes into the Barents Sea, between Spitsbergen and Frans Josef Land, and the opening between Frans Josef Land and Novaja Zemlja (Loeng, 1991).

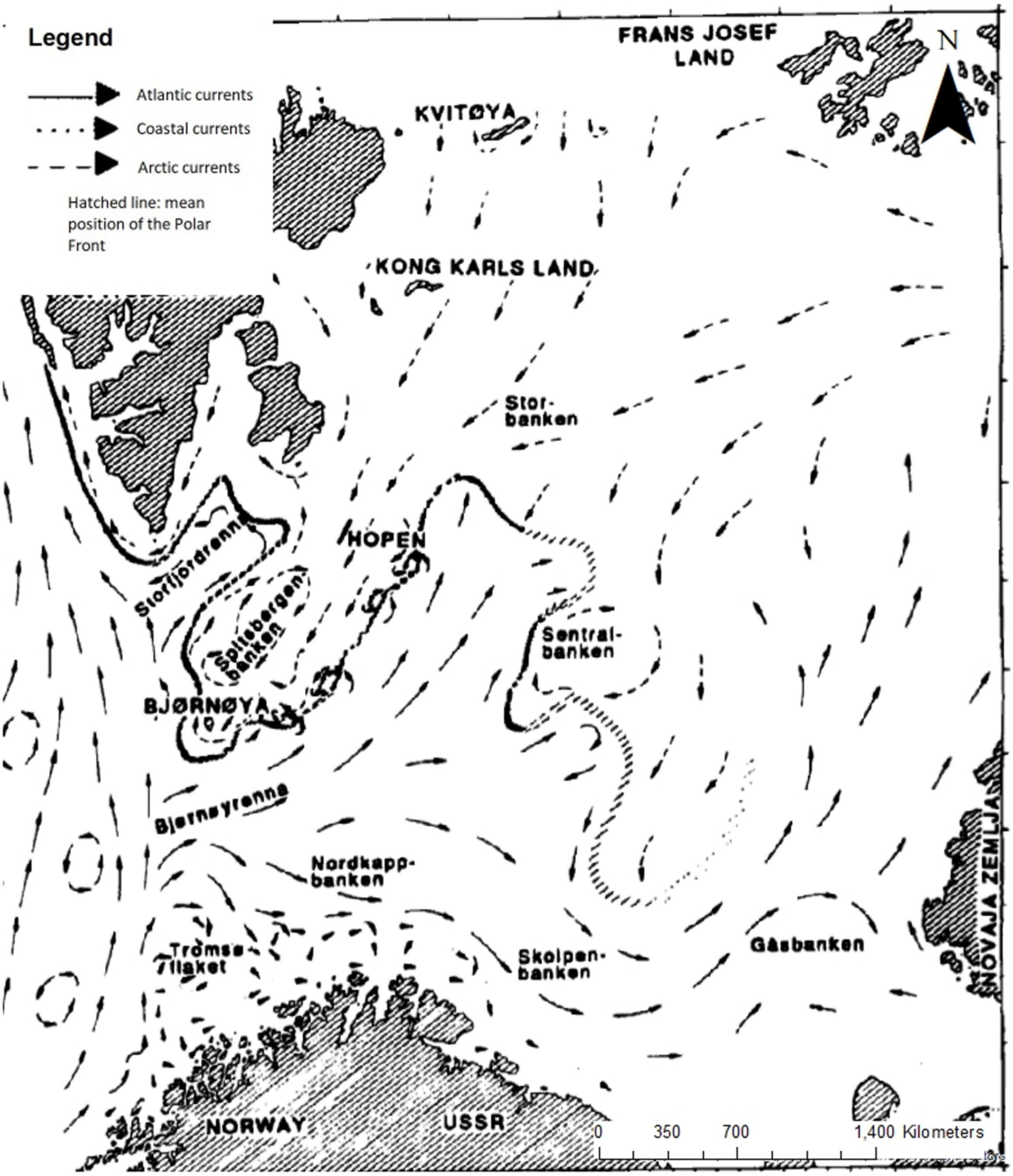

Figure 1: Surface currents in the Barents Sea, from Loeng (1991)

2.1.2 The Polar Front

The Atlantic Water and the Arctic Water are separated by a sharp transition zone called the Polar Front (Figure 1).The Polar Front is a boundary zone in polar oceans between cold, low-salinity waters and warmer, saltier waters (Ruddiman, 2014). The Polar Front follows the topography in the western part of the Barents Sea and remains stable from one year to the next, in the eastern part its position is less stable (Oziel, Sirven, & Gascard, 2016). Between the Bear Island and Hopen Trench, the polar front is fixed at 250 m water depth by the barotropic circulation of Atlantic Water (Harris, Plueddemann, & Gawarkiewicz, 1998). Atlantic Water has a temperature >3.0°C and salinity higher than 35.0, Arctic Water is characterized by temperature <0°C and low salinity (34.3-34.8). The temperature along the Polar Front ranges from -5°C to 2°C, and a salinity between 34.8 and 35.0 (Loeng, 1991; Loeng & Drinkwater, 2007).

The warm and saline Atlantic Water and the cold, lower-saline Arctic Water mix and generate dense water in the winter. This is a result of cooling by the atmosphere and reinforcing by brine rejections due to ice formation. The vertical gradients of temperature and salinity is weak through the frontal region in the winter, indicating the topographic and barotropic controlled front (Harris et al., 1998; Oziel et al., 2016). The dense water flows into the Arctic Ocean along the bottom between Novaya Zemlya and Franz Josef Land to form the Arctic Intermediate Water (Oziel et al., 2016).

During the summer the vertical gradients in the upper level of the water column increase as a result of the fresh, warm surface water produced by melting ice, the meltwater pool contributes to modification of the water masses in the frontal region, and the topographic control of the thermohaline properties is disrupted (Harris et al., 1998). Below 100 m, the gradients remaines weak and tidal flow generates vertical mixing due to the turbulence. The effects of the salinity compensate for the temperature and the fronts becomes more elusive because the density gradients vanish. (Oziel et al., 2016).

2.2 Bottom conditions

2.2.1 Bottom water

In the Barents Sea formation of dense bottom water is a regular occurrence. The formation can be viewed as a two-step process, the first is increased density due to the cooling of the water. The second step is a result of ice formation and increased density because the brine rejection to the water increases the salinity. The dense water formation is faster in shallow areas were the vertical convection reaches the bottom (Midttun, 1985).

2.2.2 Sediments

The epicontinental Barents Sea is one of the largest continental shelves in the world. The bathymetry is characterized by banks and channels opening to the Arctic Ocean in the north and the Norwegian Sea to the west (Vorren, Landvik, Andreassen, & Laberg, 2011).

The surface sediment (upper 50 cm) of the seabed in the Barents Sea form the uppermost part of a sediment sequence covering rocks on the sea floor (Figure 2). The thickness of the sediment sequence is varying from a few to several hundred meters. The sediment layer in the northern and central Barents Sea has a depth around 10 – 15 m, and the thickness increases towards west, at the outer parts the sediment layer may be up to 600m thick. The sediment sequence was mainly deposited the last 2.6 million years, during a period where glaciations took place repeatedly (Hansen, 2017; Landvik et al., 1998).

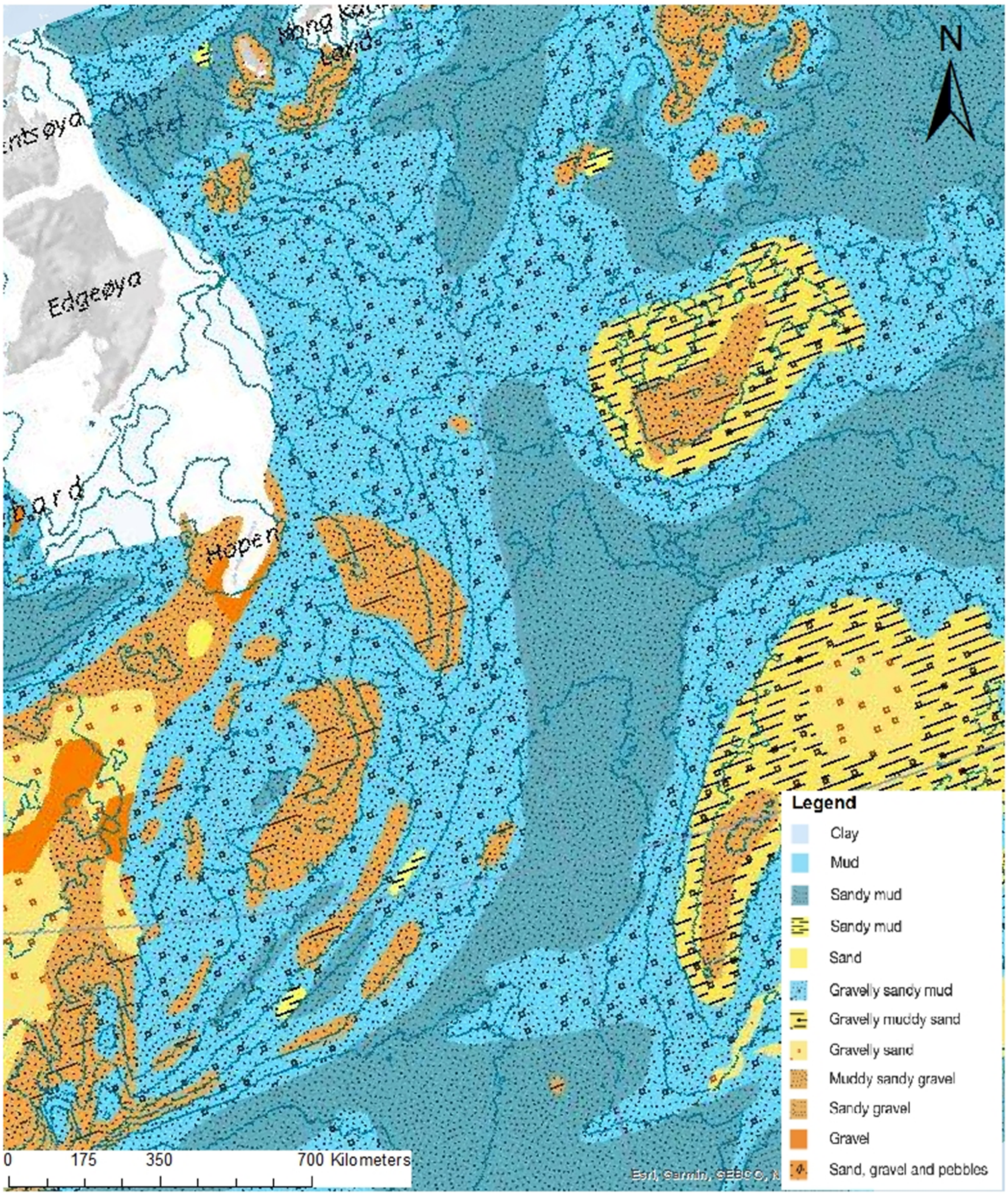

Figure 2: Bottom sediments in the Barents Sea (From NGU database)

During the last deglaciation (15 000-10 000 years ago), clay and silt were transported by the meltwater rivers to the ocean. Strong bottom currents together with the lowering of the sea level, deposited the finer materials in the deeper parts of the ocean, like the Bjørnøyrenna and Storfjordrenna (Figure 1). The coarser particles that resisted the transportation formed sand deposits. In areas where the surface sediments consist of cobbles and boulder, the materials originate from till and iceberg-dropped sediments. Therefore, the coarser sediments are found on the shallow banks (Hansen, 2017; Landvik et al., 1998). The sedimentation patterns in present time on the shallow bank areas in Barents Sea shows low or no sedimentation due to the bottom currents. In the deeper areas where the bottom currents are weaker, fine sediments; clay and silt, are deposited continuously (Hansen, 2017).

2.2.3 Fauna

Epibenthos play a significant role for energy flow and trophodynamics on the Arctic continental shelves. Parts of the primary production oases through the epibenthos, which is an ecologically important group to the benthic habitat. They redistribute and remineralize the organic carbon on the seabed, shelter from predation, and food for a wide variety of fish and invertebrates (Jørgensen et al., 2015). Between 48 and 96% of the primary production in the Barents Sea reaches the sea floor depending on the water mass characteristics. Together with the physical habitat properties, this support rich and varied benthic communities (Carmack & Wassman, 2006).

2.2.4 Carbonate dissolution

The distribution of foraminifera in the sediment is related to the saturation of $CaCO_3$ in the seawater. The occurrence of calcareous foraminifera depends on the carbonate compensation depth (CCD); where the rate of supply of calcium carbonate is equal to the rate of dissolution. Calcium carbonate dissolution is usually found in the deep sea, below 3000 m depth (Binczewska, Polovodova Asteman, & Farmer, 2015; Boltovskoy & Wright, 1976; Burton, 1998). Surface waters are generally saturated with $CaCO_3$, but in shallow areas at high latitudes lower temperatures and higher atmospheric CO_2 may cause dissolution. This results in rich assemblages of agglutinated and organic-walled foraminifera (Murray, 2006).

Sediment cores from Antarctica show reduction of atmospheric CO_2 during the last deglaciation, with CO_2 concentration in sea water an important factor controlling calcium carbonate dissolution (Delmas, Ascencio, & Legrand, 1980; Hald, Danielsen, & Lorentzen, 1989). When sea-ice is formed by freezing surface water, salt is rejected during the growth of ice crystals. The salt increases the density if the residual seawater, and in some situations, it sinks to the deep of the sea. Increasing amount of sea ice and the denser deep water leads to a reduction in atmospheric CO_2 content (Broecker & Peng, 1987).

There is evidence from the Barents Sea that indicates calcium carbonate dissolution during the last deglaciation. Suggesting high biogenic production, reduced ventilation of the water and the formation of corrosive dense bottom water as possible factors (Hald et al., 1989). More recent $CaCO_3$ dissolution is explained by dense, cold, saline and CO_2 rich bottom water and the sea ice production with the position of the polar front as factors, as well as sinking atmospheric CO_2 (Steinsund & Hald, 1994).

2.2.5 Total Organic Carbon

The distribution of Total Organic Carbon (TOC) is dependent on the sediment grain size and bottom topography. Organic material is mainly sorbed on clay minerals and oxide surfaces, and sorted during particle transport. The organic materials originates mostly (70%) from marine sources (Vetrov & Romankevich, 2004). The TOC values are in general higher in the deep-sea basins than on the ridges, however there is, no simple linear correlation between TOC content and water depth (Stein, Grobe, & Wahsner, 1994). For marine sediments, the average TOC values are 0,5% and 2% along the eastern margin of the Barents Sea. In the Barents Sea the average of TOC is 1,1% (Seiter, Hensen, Schröter, & Zabel, 2004).

3 Methods

3.1 Fieldwork and field methods

3.1.1 Fieldwork

The fieldwork was conducted by Akvaplan-Niva and NIVA in cooperation, and the field methods are taken from the cruise report: Ecology and management of the invasive snow crab (Cochrane, 2019).

Fieldwork for the Ecology and management of the invasive snow crab: Predicting expansion, impacts and sustainability in the Arctic under climate change (EISA) project was carried out onboard the MS Lance, between 29th July and 8th August 2019. Three main areas were visited (Location A, Location B and Location C), in the general area of the former disputed zone in the Barents Sea. The areas were selected according to densities of snow crab populations at the time of sampling – low (Location B), medium (Location C) and high (Location A).

At each location the sampling consisted of the following elements:

- Deployment of 70 crab pots and retrieval after 24 hours
- Eight (8) grab samples (0.1m^2) processed for benthic macrofauna
- Four (4) sediment samples for geochemical analyses
- Sediment descriptions (colour, sediment layering/visible bioturbation etc.)

At location A and B (the high- and low crab density areas), the following samples were taken:

- Three (3) sea-floor photo transect using a yo-yo camera (series of about 40 images per transect)
- Four (4) sediment cores, approximately 40 m long, for both sediment descriptions and benthic foraminifera analyses (as indicators of grazed/non-grazed areas).

Grab and core samples were taken among ten randomly placed sampling stations within each location.

3.1.2 Collecting of sediment samples

Sediment samples for benthic fauna and geochemistry were taken using a handcorer from a "combi-grab", which has a bite area of 0.2m^2 and can be divided into two halves after retrieval. Only grab-samples with an undisturbed sediment surface and surfacewater were accepted (Figure 3). The sediment samples for geo-chemistry were sectioned in sediment depths 0-1, 1-2, 2-4, 4-6, 6-8 and 8-10 cm, or as deep it was possible to sample. The samples were frozen until they were analyzed (Oug, pers com.)

The samples collected with Gemini-corer used for foraminifera analyses were sectioned in sediment depths 0-1, 1-2, 2-3, 3-4, 4-6, 6-8 and 8-10 cm using the sectioning tool belonging to the Gemini-corer (Table 1, Figure 4). The samples were kept in a solution of 70% ethanol with rose Bengal to stain all living foraminifera (Oug, pers com.).

Table 1: General information on the core locations.

	Location A		Location B					
	Station 9 (Repl. 1&2)		*Station 5 (Repl. 1&2)*		*Station 9 (Repl. 1&2)*		*Station 2 (Repl. 1&2)*	
Date	02.08.2019		02.08.2019		03.08.2019		03.08.2019	
Latitude, N	76°20,748		76°21,216		76°44,374		76°45,355	
Longitude, E	37°14,557		37°16,033		32°17,633		32°19,452	
Water depth (m)	250		251		241		233	
	Repl. 1	*Repl. 2*	*Repl. 1*	*Repl. 2*	*Repl. 1*	*Repl. 2*	*Repl. 1*	*Repl. 2*
Time	16.20	16.40	18.25	18.47	12.05	12.25	13.00	13.30

Figure 3: Short core with an undisturbed surface and clear surface water (top left), core from Loc A; visible macrofauna and bioturbation in the top sediments (top right), core from Loc B; less visible bioturbation (bottom left & bottom right) Pictures: Christian Skauge.

Two deployments were done at both Location A station 9 (Loc A-9) and station 5 (Loc A-5) and Location B station 9 (Loc B-9) and station 2 (Loc B-2). One core from each deployment were used for sectioning. In most of the cases from Loc A, there was a water leakage from one of the cores, this core was discarded. During the sectioning of the cores from Loc A, the section guide went to the 'bottom' with the result that sections below 4 cm were taken freehand. The sediment at this depth, however, was firm and easy to cut (Oug, pers com.).

The cores from station 9 were shorter and the section guide went to the "bottom" resulting in everything below 2 cm were taken by freehand. The sediment downcore were sticky and stuck to the slicer, but the sectioning was performed without significant problems. Sediment stuck underneath the slicer were washed of and discarded. At station 2, collected last, a temporary extension was inserted in the cutting equipment which proved to work well. The whole core was thereby cut as normal (Oug, pers com.).

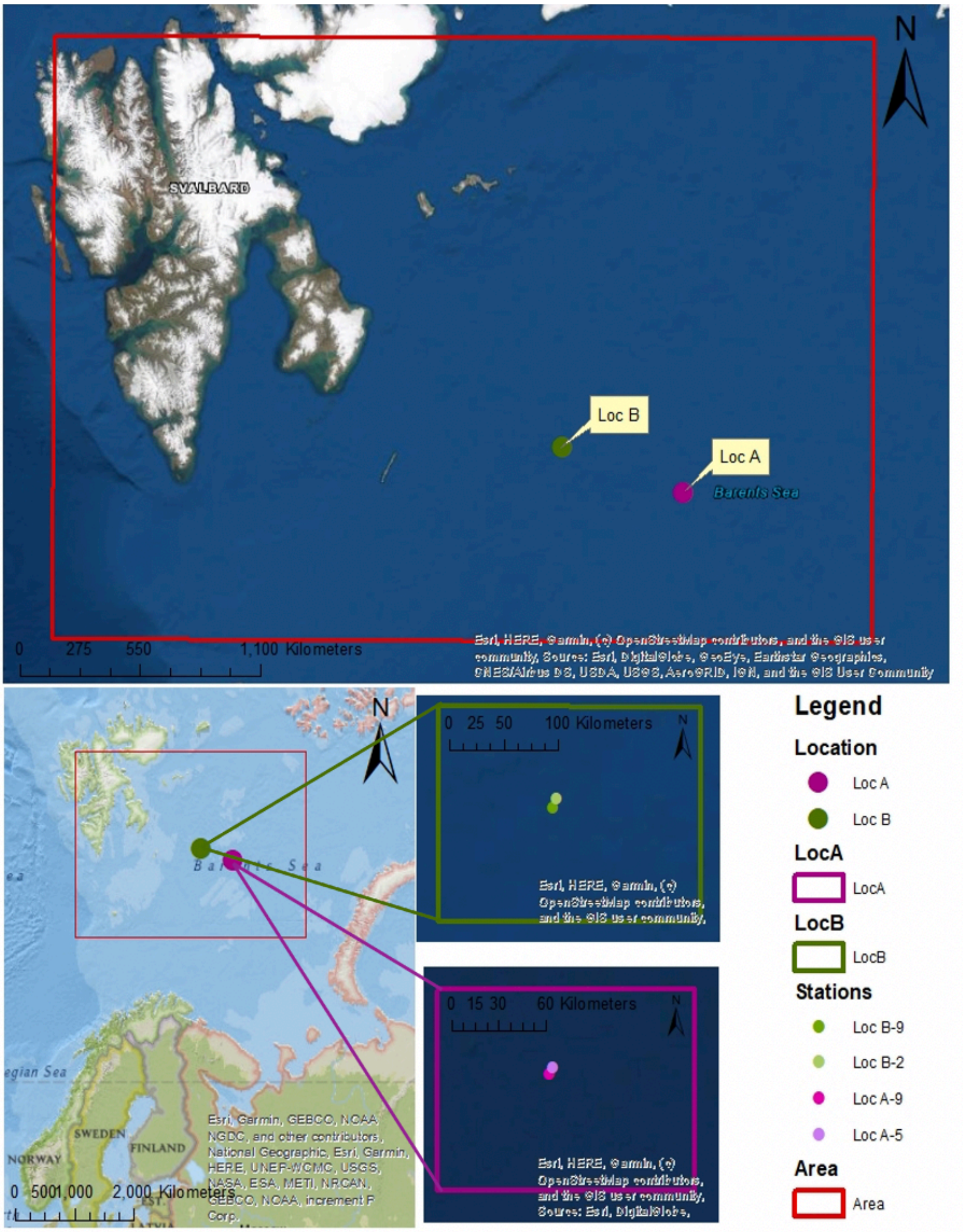

Figure 4: Overviewmap of sample locations

3.2 Samples for sediment and foraminifera analyses

3.2.1 Analysis

Total organic carbon (TOC) and grain-size analysis are performed on samples from Location A station 9 (Loc A-9) and Location B station 9 (Loc B-9), water content is also measured on Loc A-9 and Loc B-9. Foraminifera analysis has been performed on Location A station 5 (Loc

A-5) and station 9 (Loc A-9), Location B station 2 (Loc B-2) and station 9 (Loc B-9). Replicate 1 for all stations and replicate 2 on Loc A-5 and Loc A-9 (Table 2). Data is processed and produced with graphs in Microsoft Excel.

Table 2: overview of tests preformed on cores form the different locations

Method/Core	Loc A-5	Loc A-9	Loc B-2	Loc B-9
Foraminifera	X	X	X	X
Total organic carbon (TOC)		X		X
Grain size analysis		X		X
Water Content		X		X

3.3 Sediment analysis

3.3.1 Freeze drying

The sediments used for total carbon and grain-size analyze were freeze dried to extract water from the already frozen material to avoid the liquid phase by sublimation. The freeze drier creates a vacuum inside the cylinder surrounding the sample-boxes, the lids have holes so the water can evaporate. The pressure is lowered under atmospheric pressure and the temperature is below 0°C. The freeze drier was running for approximately 3 days to make sure all the water had sublimated.

The dried material has the same characteristics as the original material, the process is gentle for the material. Bacterial- and chemical changes are largely avoided, and the dried material is an easily water-soluble product, which make freeze drying an advantage.

3.3.2 TOC analysis

For TOC analyses, cores from Loc A-9 and Loc B-9 were used. The core from Loc A-9 was 10 cm long, and Loc B-9 4 cm long. Approximately 1 g freeze-dried sediments (Table 3) from each sample interval (Loc A-9 and Loc B-9) were pulverized in an agate mortar. The crushed sediments were placed in labeled glass vials. Between each sample the equipment was cleaned with ethanol.

Table 3: Sample weight on Loc A-9 and Loc B-9 for carbon analyses

	Loc A-9	**Loc B-9**
Core depth (cm)	Sample weight (g)	Sample weight (g)
0-1	1,169	1,062
1-2	1,094	1,134
2-4	1,082	1,190
4-6	1,003	-
6-8	1,116	-
8-10	1,033	-

The samples for carbon analysis were sent to ISO Analytical.

Carbon analysis was undertaken by Elemental Analyser – Isotope Ratio Mass Spectrometry (EA-IRMS) by ISO Analytical in the United Kingdom. 30 mg aliquots of sediment were weighted into tin capsules and sealed. The tin capsules were loaded into an auto sampler on a Europa Scientific elemental analyzer. The samples were dropped in sequence into a furnace held at 1000*C and combusted in the presence of oxygen. The tin capsules flash combust, rising the temperature in the region of the sample to app. 1700ºC. (Begley, 2021)

The TOC has been corrected with the amount of finer sediments (<63 um), the TOC is used as a supplement to the faunal data to detect organic load (vanndirektivet, 2018):

$$TOC_{63} = TOC_{mg/g} + 18 \times (1 - p < 63\mu m)$$

3.3.3 Grain-size

Grain-size analysis were done on core Loc A-9 and Loc B-9, the analysis were done using a Beckman Coulter LS13 320 at the University of Oslo. The method is based on laser diffraction, and used to determine grain distribution in sediments in the area 0,4 µm to 2000 µm. The basis for the analysis is that light from a laser is broken on the surface of a particle at a certain angle depending on the size of the particle. The analysis assume that the samples don't have a high content of salt and organic materials, at the same time the samples need to be disintegrated so all grains are free during the analysis (ISO, 2009)

The freeze-dried materials were homogenized to extract a representative amount of sediment to analyze. The extracted amount was sieved through a 2 mm sieve to remove lager particles. Visible organic materials were picked out from the sample to avoid being analyzed as grains.

From the extracted sample approximately 0,2 g were weighted out to a 50 mL beaker with 5-10 mL of 5% Calgon (natriumpyrophosphate). The beaker was placed in a ultrasonic bath for about 3 min to disperse the sample before pouring the solution into the sample vessel in the machine. The beaker was rinsed with water so make sure the entire sample was transferred to the vessel.

The preliminary determination to get the weight which is suitable for preforming the analysis is done by weighting out a representative amount of sample and transfer it to the vessel in the instrument until the concentration shows 8-12% obscuration. The minimum sample quantity is dependent on grain size (Table 4):

Table 4: Sample quantity (g) for the different grain size for analyses, from (ISO, 2009).

Median diameter	Weight (g)
10	0,2
50	0,4
70	0,6
100	0,8
300-400	1,0
600	1,5-2,0

These values (Table 4) are only indicative, the software of the instrument gives a message when sufficient amount of sample is loaded. No methodological calibration of the instrument is required. Autoalignment and background measurement is an integral feature of the analysis and performed at each run.

Each sample were run 2 times, if the gap between the two parallels was greater than 5% a third test was run. Results from analyzing several parallels are given by averaged curve and results.

3.4 Macrofauna

The macrofauna was analysed by NIVA. In the field, all macrofauna samples were sieved on 1 mm screens and fixed in 4% formaldehyde-seawater solution. In the lab, all collected specimen were identified to the lowest possible taxonomic unit, generally to species. The data will be used for describing the structure of the macrofaunal species communities at the three investigated locations (Loc A, Loc B and Loc C) in the EISA project. Preliminary data has been presented by Kling Michelsen et al. (2020).

The macrofauna data will also be subjected to traits analyses in the EISA-project which is a theoretical approach to description of functioning in species communities (Oug, pers com). NIVA operates a database of species traits for soft-bottom macrofauna with traits representing the species' main activities and feeding, size, life history and reproduction (E Oug, Fleddum, Rygg, & Olsgard, 2012). Here two traits describing activity in the sediments have been selected and calculated, *viz.* 'sediment dwelling depth' and 'sediment reworking'. The trait 'sediment dwelling depth' is divided into five categories (modalities) (surface, 0-1, 1-5, 5-15, >15 cm) that represent the level in the sediment where the macrofaunal species are found, i.e. where head or most of the body is located most of the time. Each species is scored on the best fitting categories, in most cases multiple categories, using so-called fuzzy coding. The trait 'sediment reworking' is based on a general categorization of bioturbation with classification of species developed by Queirós et al. (2013)

1) Epifauna: species that occur predominantly above the sediment-water interface and with activity limited to near-surface sediments.

2) Surficial modifier: epi/infauna with activity restricted to uppermost few (1-2 cm) of the sediment column.

3) Upward conveyors: vertically oriented organisms that feed head-down at depth in the sediment and transport particles to the sediment surface (non-local transport).

4) Downward conveyors: vertically oriented organisms that feed on the sediment surface and egest particles in deeper sediment strata (non-local transport).

5) Biodiffusors: species that causes random and local sediment mixing over short distances.

3.5 Foraminifera

The top 10 cm of the cores from Location A and Location B were contained in plastic-boxes with rose bengal/ethanol solution to stain the living foraminifera used analyzing. The amount of sediment in each box were marked for sediment volume measurements (Table 5).

Table 5: Sediment volume for each core interval analyzed, a full analysis of cores from Location A station 5 and Location B station 2 have been preformed, and chosen intervals from the remaining stations.

	Location A (ml)				**Location B** (ml)	
Depth	*Station 9*		*Station 5*		*Station 9*	*Station 2*
(cm)	Repl. 1	Repl. 2	Repl. 1	Repl. 2	Repl. 1	Repl 1.
0-1	46	-	22	-	38	39
1-2	51	-	52	-	39	11
2-3	-	-	52	-	-	32
3-4	-	-	47	34	-	28
4-6	103	81	85	-	105	56
6-8	-	-	61	35	-	75
8-10	104	109	114	-	19	78

Each section of the sediments was wet-sieved through a 500 µm and a 63 µm sieve, to clean the sample from the mud. The largest fraction, >500 um, was transferred to a labeled container with water and ethanol. The 63-500 µm fraction was wet-split in to eights. 7/8 of the 63-500 µm were transferred to glass vials with a pipette, preserved with ethanol, and labeled. The remaining 1/8 was used for foraminifera analyses.

The entire >500um was studied using a microscope, and all the living (rose Bengal-stained) foraminifera, more than 70% stained with rose Bengal (those stained less were counted as dead), were wet picked, mounted on a faunal slide, and determined. The remaining part of the sample, containing only dead foraminifera, organic material and sediment, were put back in the container with water and ethanol.

Fractions in the 63-500 µm interval were transferred to a “wet-pick-slide” using a pipette. All the living foraminifera (rose bengal-stained), were picked. The picked samples were transferred to a glass vial. A total of 1/8 were analyzed, and only dead foraminifera, organic material and sediment were remaining in the sample.

All the picked species on the faunal slides were counted and determined to species level when possible.

The picked foraminifera were were calculated to individuals per 10 cm^3, with respect to the diameter of the Gemeni corer (8 cm):

$$\frac{counted\ individuals\ of\ each\ species\ at\ each\ depth\ \times\ 8\ cm}{processed\ sample\ (ml)} \times 10$$

The average living depth were calculated for each of the cores (replicate 1):

$$ALD_x = \sum_{i=1x} \frac{(n_i \times D_i)}{N}$$

x = the lowest boundary of the deepest sample included in the calculations
n_i = the number of specimens in interval i
D_i = the midpoint of sample in interval i
N = the total number of individuals for all levels

AMBI is based on species sensitivity/tolerance to an environmental stress gradient, in this case the benthic species sensitivity to increasing TOC and associated biogeochemical modifications of the sediment habitat. Benthic foraminifera are assigned to environmental groups (Alve et al., 2016):

- Group I (G I). "Sensitive species" are sensitive to organic matter enrichment. Their abundance is highest under unimpacted conditions (at lowest TOC values) and drops to zero as organic matter concentration increases.

- Group II (G II). "Indifferent species" are indifferent to organic matter enrichment. They never dominate the assemblage. They occur in low abundance over a broad range of organic matter concentrations, but are absent at very high concentrations.

- Group III (G III). "Tolerant species" are tolerant to excess organic matter enrichment. They may occur at low TOC, their highest frequencies are stimulated by organic enrichment but they are absent at very high organic matter concentrations.

- Group IV (G IV). "2^{nd}-order opportunistic species" show a clear positive response to organic matter enrichment with maximum abundance between the maxima of Groups III and V.

- Group V (G V). "1^{st}-order opportunistic species" show a clear positive response to excess organic matter enrichment with maximum abundance at a higher stress level induced by organic load than species of Group IV. At even higher organic matter concentrations, no foraminifera are able to survive.

4 Results

4.1 Sediment analyses

4.1.1 Grain size

The grain size analyses at Loc A-9 and B-9 are illustrated in Figure 5, the cumulative volume is illustrated with the particle sizes from clay to sand.

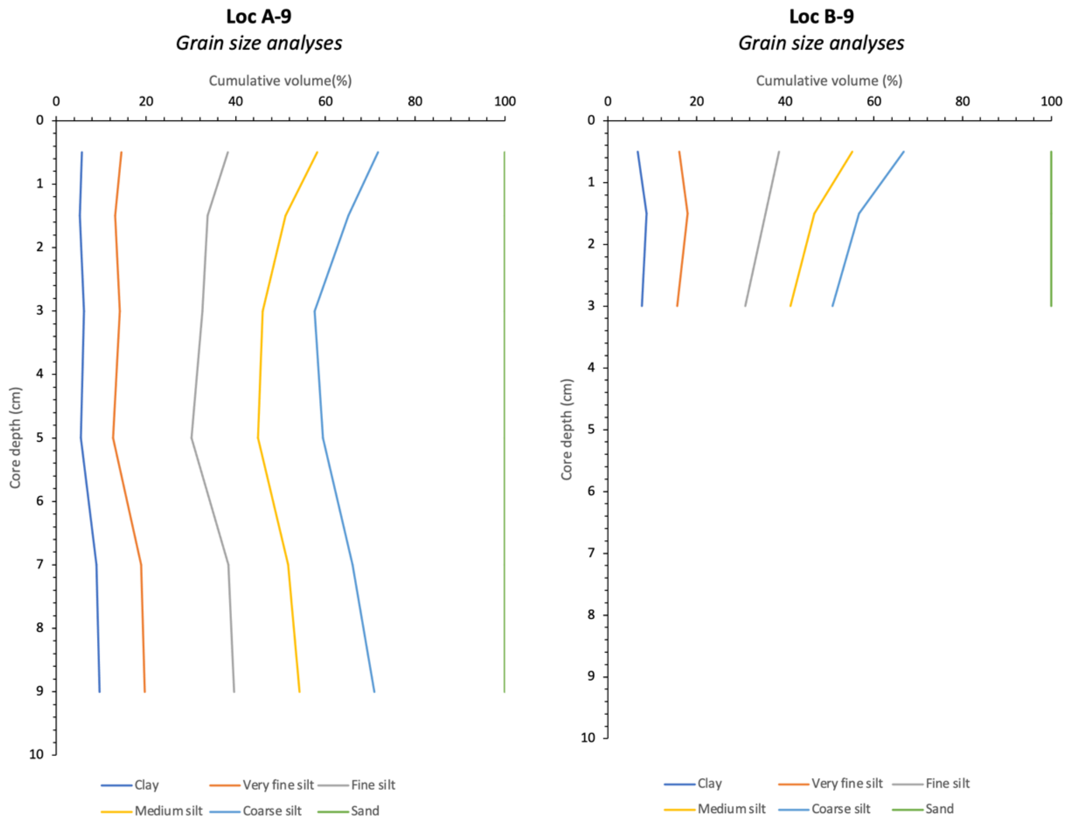

Figure 5: Left: Cumulative volume (%) distribution of grain size classes in core Loc A-9 and core Loc B-9.

The clay content in core Loc A-9 increases from 5% at 0,5 cm to 10% at 9 cm, very fine silt increases from app. 14% at 0,5 cm to 20% at 9 cm. Fine silt decreases from 40% at 0,5 cm to 30% at 5 cm before it increases to 40% at 9 cm. Medium silt decreases from 60% at 0,5 cm to 45% at 5 cm before it increases to 55% at 9 cm. At 0,5 cm coarse silt is at 70% and decreases to 58% at 3 cm before it increases to 70% at 9 cm. Sand is at 100% throughout the core.

The cumulative volume of clay in Loc B-9 is app. 8-9% from 0,5 cm to 3 cm and very fine silt around 16-17%. Fine silt decreases from 40% at 0,5 cm to 30% at 3 cm, and medium silt decreases from 55% at 0,5 cm to 40% at 3 cm. Coarse silt decreases from 65% at 0,5 cm to 50% at 3 cm. Sand is at 100% downcore from 0,5 cm to 3 cm.

4.1.2 Water and carbon content

Total organic carbon (TOC_{63}) and water content in core Loc A-9 and Loc B-9 are illustrated in Figure 6 and Figure 7, they are illustrated with the amount of particle below 63 um.

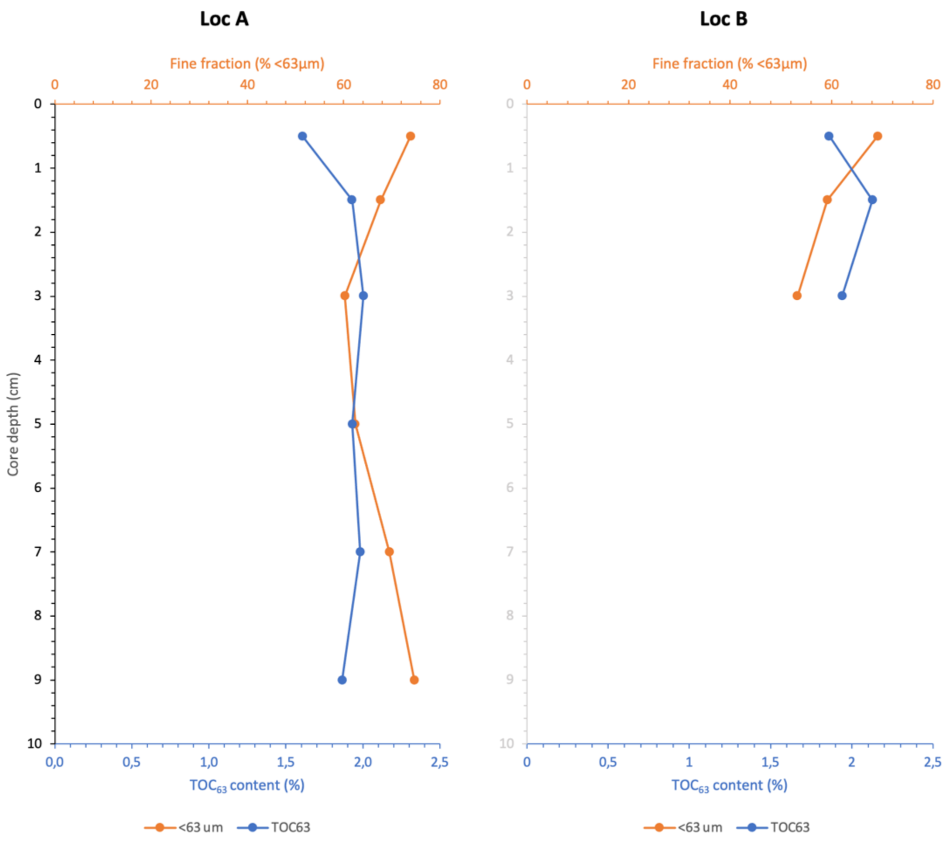

Figure 6: Fine sediment fraction (% <63 um) and total organic carbon (%TOC63) from the cores Loc A-9 and Loc B-9

The amount of TOC in Loc A-9 increases from 1,6% at 0,5 cm to 2,0% at 1,5 cm. From 1,5 cm the amount decreases to 1,9% at 9 cm.

In Loc B-9, TOC increases from 1,9% at 0,5 cm to 2,0% at 1,5 cm. From 1,5 cm to 3 cm it decreases to 1,9%.

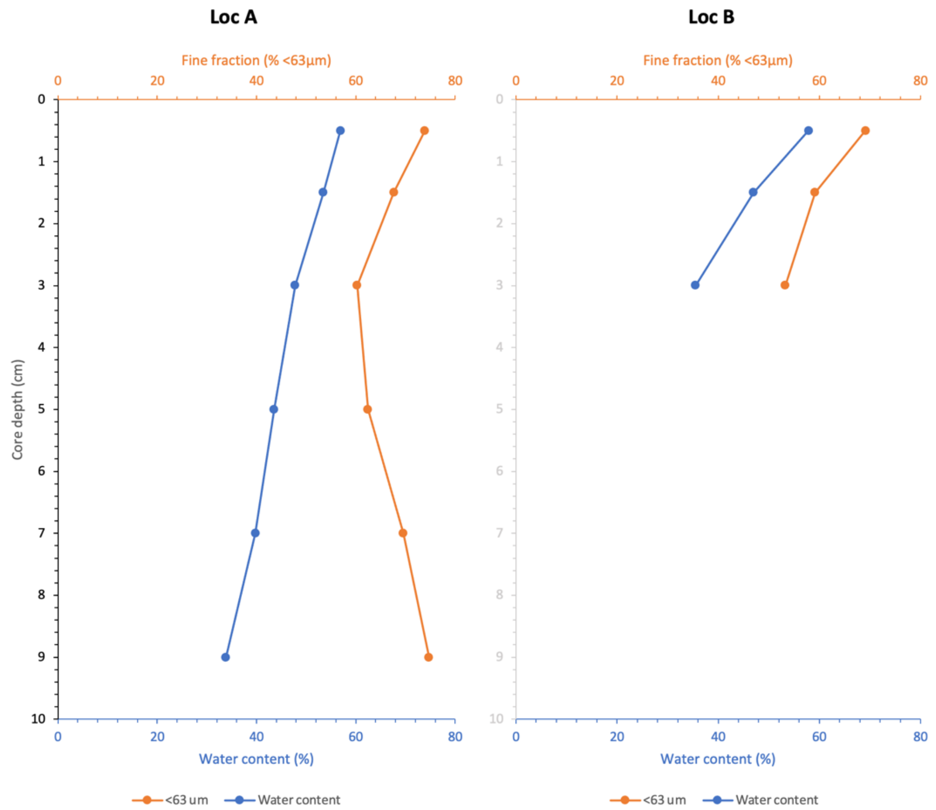

Figure 7: Fine sediment fraction (% <63 um) and water content (%) from the cores Loc A-9 and Loc B-9

The water content in Loc A-9 decreases from 57% at 0,5 cm to 35% at 9 cm.
At 0,5 cm the water content is 58% in Loc B-9 and decreases to 35% at 3 cm.

4.2 Macrofauna

Mean number of macrofaunal species per grab (0.1 m^2) was 38 at location A and 50 at location B. The abundances were more similar with 2500-2800 ind./m^2 in both areas (preliminary data; Kling Michelsen et al. 2020). The dominant species in all samples was the polychaete *Spiochaetopterus typicus* which is a comparably large form that constructs a stiff parchmentlike tube standing vertically in the sediment. The species communities were significantly different between location A and B (Kling Michelsen et al., 2020).

For the assessment of macrofaunal sediment activities based on the traits ‘sediment dwelling depth’ and ‘sediment reworking’ a selection of the most important species was made. All species with sum of mean density for A and B >30 (essentially >30 ind/2 m^2) were chosen, in total 23 species. In addition, ten species of larger and/or deep digging species were included.

The selected species represented more than 90% of the total abundances at each location. A list of the selected species is included in Attachment 1.

The number of species that fits into each trait for Loc A and Loc B is shown in Table 6. It appears that most species are expected to occur in the upper sediment layers (0-1 and 1-5 cm). The number of species decreases rapidly at greater sediment depths and below 15 cm only one species may be found (*Spiochaetopterus typicus*). Most species are classified as surficial modifiers.

The distribution ('abundance') of the traits within the species communities is illustrated in Figure 8. The main pattern was similar among the two locations, but there were somewhat more of both surface and subsurface dwelling fauna and of upward and downward conveyors at location B compared to A.

Table 6: Number of species that fits to each trait for Loc A and Loc B.

	Sediment dwelling depth					**Sediment reworking**				
Depth (cm)	surface	0-1	1-5	5-15	>15	Epi-faunal	Surficial modifier	Upward conv	Down conv	Bio-diffusor
Loc A	8	18	14	8	1	1	14	7	3	6
Loc B	11	21	13	7	1	1	17	7	3	6

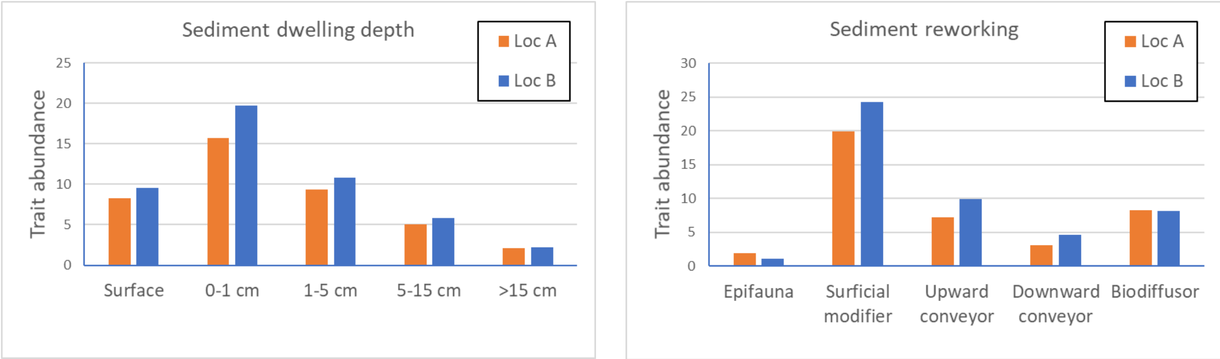

Figure 8: Community composition of the traits 'sediment dwelling depth' and 'sediment reworking' at locations A and B. Each trait category has been calculated as a sum of trait scores for fitted species multiplied by the species' abundances. Species abundances were log-transformed before calculations. Figure from EISA project.

4.3 Foraminifera

4.3.1 Species selection

From the 26 sediment slices analyzed, a total of 24 agglutinated (Loc A: 22, Loc B: 19) and 22 calcareous (Loc A:18, Loc B 17) species were identified (Attachment 2). There will be a primary focus on the dominating agglutinated species, and 6 species will be presented based on; (1) Their dominance throughout the core, (2) a sufficient number of individuals; they must exhibit more than 10% of the total fauna in the sample and (3) if they have any special environment preference which can be useful in the interpretation of the environment. In the top cm of the cores from Loc A, app. 80% the calcareous species shows signs of severe carbonate dissolution and could therefore not be determined.

From the foraminifera analysis, the following species have been selected for further interpretation:
Adercotryma glomerata (Brady, 1878) is a epifaunal to infaunal species (Gooday, 1993; Hunt & Corliss, 1993), belonging to AMBI group 1, meaning it is sensitive to organic matter enrichment. It´s abundance is higest under unimpacted conditions, and drops to zero as organic matter concentration increases (Alve et al., 2016).

Cuneata arctica (Brady, 1881)

Deuterammina grisea (Earland, 1934)

Lagenammina arenulata (Skinner, 1961) is an infaunal species (Gooday, 1986)

Spiroplectammina biformis (Parker & Jones, 1865), an epifaunal/shallow infaunal species (Hunt & Corliss, 1993) in AMBI group 3; tolerant to excess organic matter enrichment. They may occur at low TOC, their highest frequencies are stimulated by organic enrichment but they are absent at very high organic matter concentrations (Alve et al., 2016).

Textularia torquata (Parker, 1952) is an epifaunal/shallow infaunal species (Hunt & Corliss, 1993)

In the cores from Loc A the results are based on an average between the two replicates of each station.

4.3.2 Downcore distribution of foraminifera

The downcore abundance of all living (rose Bengal-stained) benthic foraminifera per 10 cm^3 in the cores from Loc A-5, Loc A-9, Loc B-2 and Loc B-9 are illustrated in Figure 9.

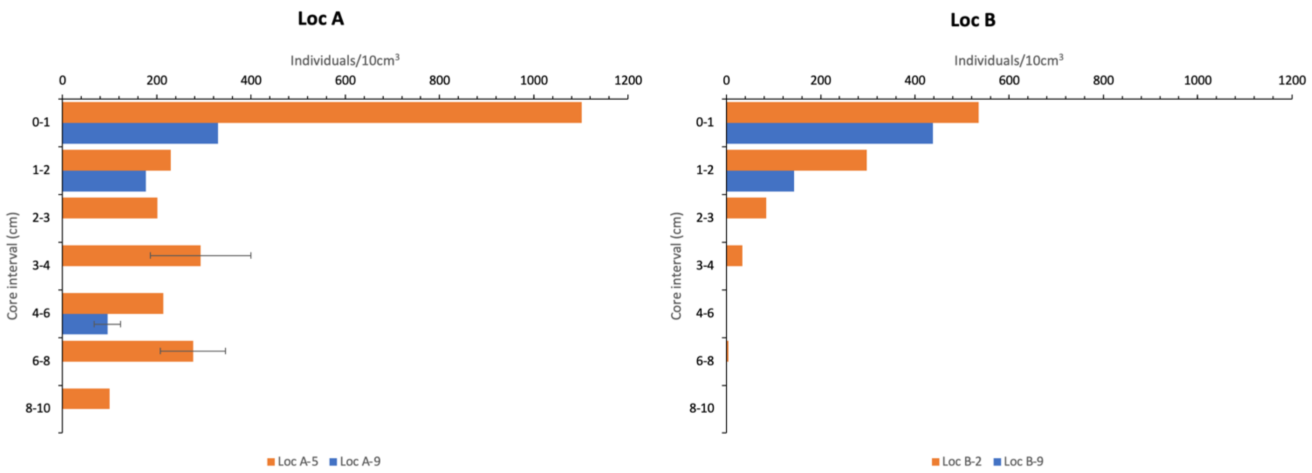

Figure 9: Downcore abundance of benthic foraminifera (individuals per 10 cm^3) in each core interval in the cores from Loc A and Loc B

Core Loc A-5 contains 1102 individuals per 10 cm^3 in the core interval 0-1 cm. In the interval 1-2 cm and 2-3 cm there are around 200 individuals. There is an increase to 300 individuals in the 3-4 cm interval, before it decreases back to 200 at 4-6 cm. At 6-8 cm there is an increase to 280 individuals before it decreases to 100 at 8-10 cm. The average living dept in core Loc A-5 is app. 2.8 cm.

The top interval (0-1 cm) of core Loc A-9 contains 330 living individuals per 10 cm^3. From 1-2 cm there are 180 individuals, and decreases to 100 individuals at 4-6 cm. There are no foraminifera in the 8-10 cm interval. The average living depth in core Loc A-9 is 1.0 cm.

Core Loc B-2 has an average living depth of 1.1 cm. There are 540 living individuals in the top interval (0-1 cm), in the next interval 1-2 cm there are 300. In the interval 2-3 cm there are 85 individuals and decreases to 40 at 3-4 cm. There are no individuals at 4-6 cm, but a slight increase in 6-8 cm with 4 individuals per 10 cm^3. No stained individuals were found in the 8-10 cm interval.

The average living depth of core Loc B-9 is 0.75 cm. At 0-1 cm there are 440 individuals per 10 cm^3, the 1-2 cm interval has 145 individuals. No stained foraminifera were found in the 4-6 cm and 8-10 cm intervals.

4.3.3 Down core distribution of foraminiferal species

The number of living individuals in the cores from Loc A-5 and Loc A-9 of the species *Cuneata arctica* and *Spiroplectammina biformis* are illustrated in Figure 10.

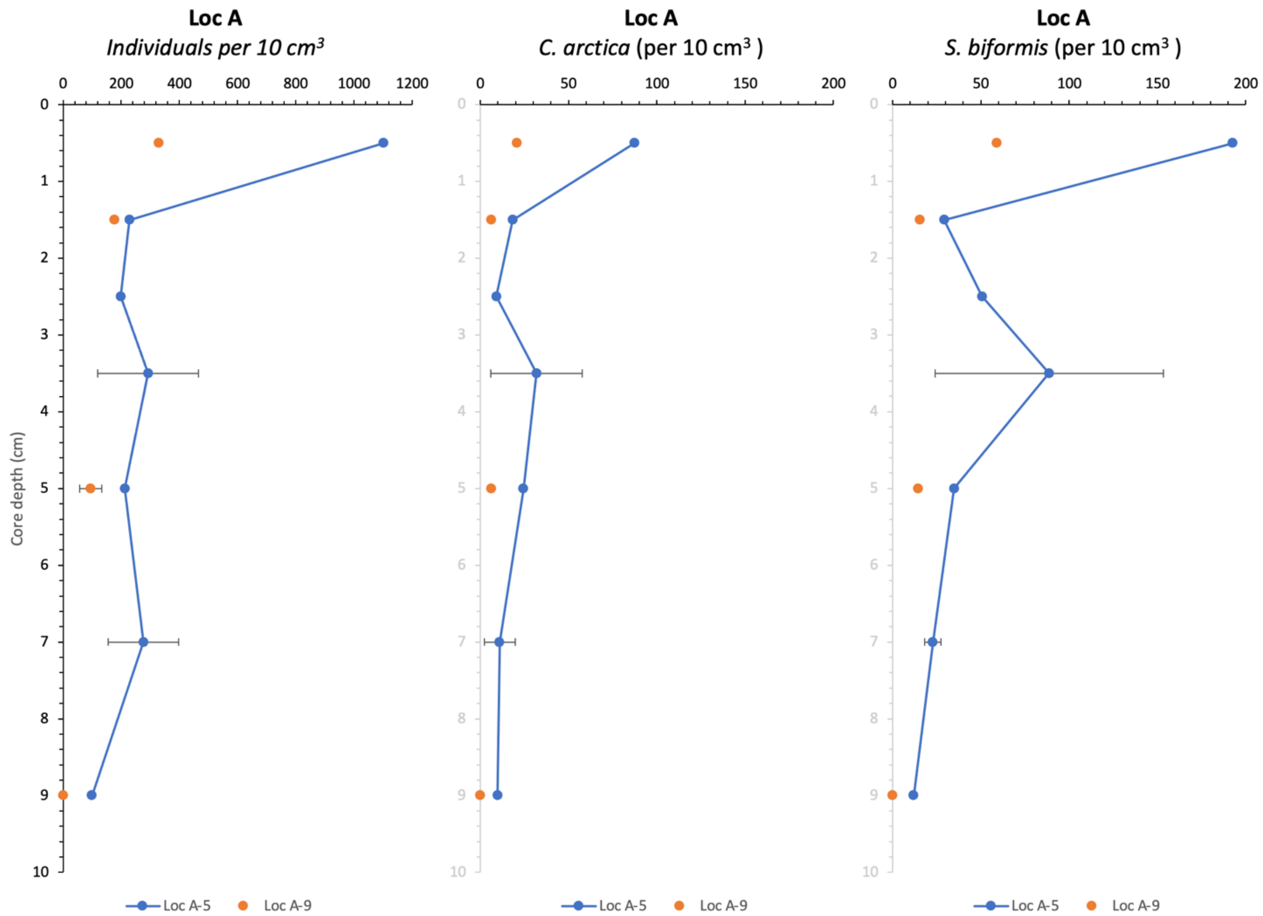

Figure 10: Downcore distribution of individuals per 10 cm³ of the cores Loc A-5 and Loc A-9 (left) and the distribution of the species C. arctica (middle) *and* S. biformis (right) *per 10 cm³. The error bars indicates the variabilities in the replicate sample analysed.*

Cuneata arctica

The decreasing trend of *C. arctica* in Loc A-5 has 90 individuals per 10 cm^3 at 0,5 cm, and 10 at 9 cm. From 2,5 cm it increases from 9 to 40 at 3,5 cm, before it decreases again towards 9 cm. The number of *C. arctica* per 10 cm^3 in Loc A-9 are 20 at 0,5 cm, 6 at 1,5 cm and at 5 cm 7 individuals. In A-9.2 there are 6 individuals at 5 cm and 0 individuals per 10 cm^3 at 9 cm.

Spiroplectammina biformis

Loc A-5 has a decreasing trend from 200 individuals per 10 cm^3 at 0,5 cm to 10 at 9 cm. There is a peak at 3,5 cm, increasing from 30 at 1,5 cm to 90 at 3,5 cm. From 3,5 cm it decreases to 35 at 5 cm.

At 0,5 cm Loc A-9 has 60 individuals per 10 cm^3. At 1,5 cm and 5 cm there are 15 individuals.

Adecrotyma glomerata, Lagenammina arenulata, Deutrammina grisea Textularia torquata in cores from Loc A-5 and Loc A-9 are illustrated in Figure 11.

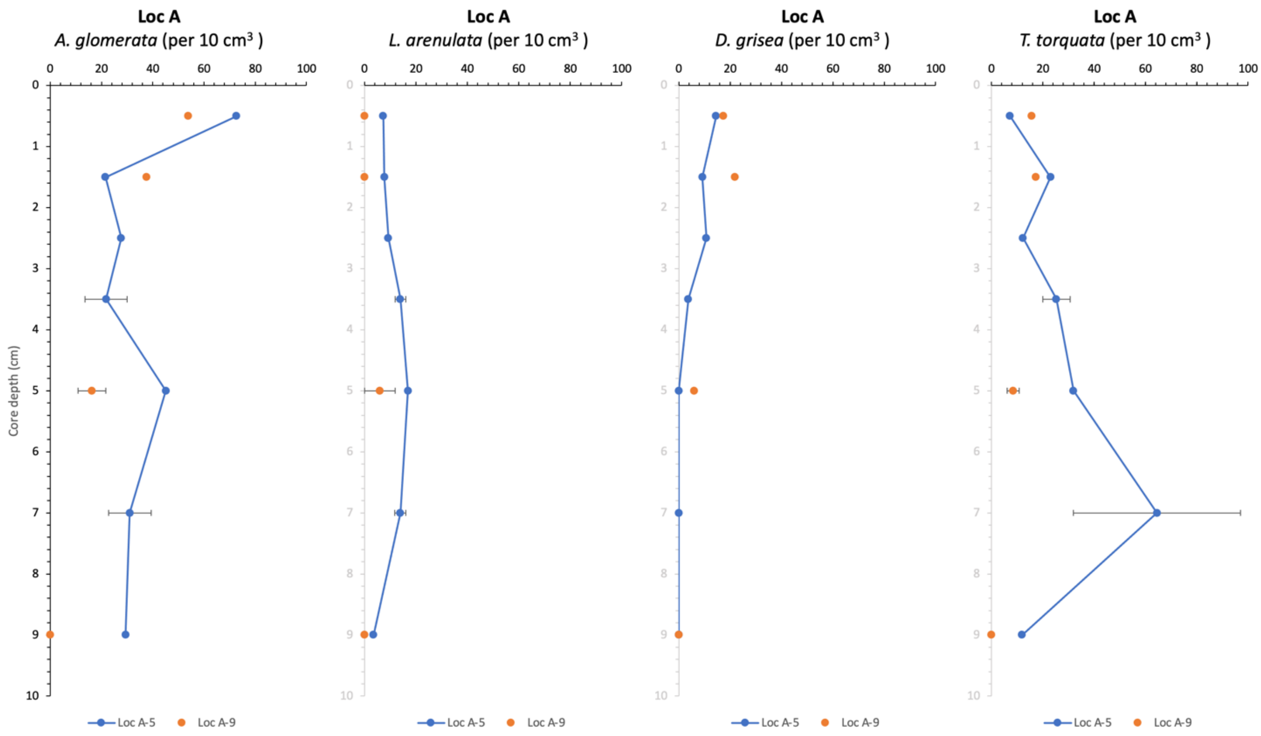

Figure 11: Downcore distribution of the species L. arenulata, S. biformis, T. torquata per 10 cm³ in Loc A-5 and Loc A-9.

Adercotryma glomerata

The general trend of *A. glomerata* for Loc A-5 is decreasing through the core, at the top (0,5 cm) the number of individuals are 75 per 10 cm^3. From 0,5 cm to 3,5 cm it decreases to 20, with an increase between 1,5 cm at 20 to 28 at 2,5 cm. From 20 at 3,5 cm it increases to 45 at 5 cm, and decreases to 30 at 9 cm. Loc A-9 has 50 individuals at the top, 0,5 cm, 40 individuals at 1,5 cm and 15 individuals at 5 cm.

Lagenammina arenulata

From 0,5 cm to 5 cm there is an increasing trend in Loc A-5 from 7 individuals per 10 cm^3 to 17. From 5 cm it decreases from 17 individuals to 4 individuals at 9 cm. Loc A-9 have 6 individuals per 10 cm^3 at 5 cm.

Deuterammina grisea

Loc A-5 has a decreasing trend, from 15 individuals per 10 cm^3 at 0,5 cm it decreases to 0 at 5 cm. From 5 cm it remains at 0 to the bottom (9 cm).

At 0,5 cm the number of *D. grisea* per 10 cm^3 in Loc A-9 are 17, at 1,5 cm it is 22 and 5 cm there are 5 individuals.

Textularia torquata

Loc A-5 has an increasing trend until 7 cm, starting at 10 individuals per 10 cm^3 at 0,5 cm and increasing to 65 at 7 cm. From 1,5 cm to 2,5 cm there is a decrease from 25 to 10 individuals. From 7 cm it decreases from 65 individuals to 10 at 9 cm.

The number of *T. torquata* in Loc A-9 per 10 cm^3 at 0,5 cm are 16, at 1,5 cm it is 17. At 5 cm the number of individuals is 8.

The number of individuals in the cores from Loc B-2 and Loc B-9 of the species *Adecrotyma glomerata, Deuterammina grisea* and *Textularia torquata* are illustrated in Figure 12.

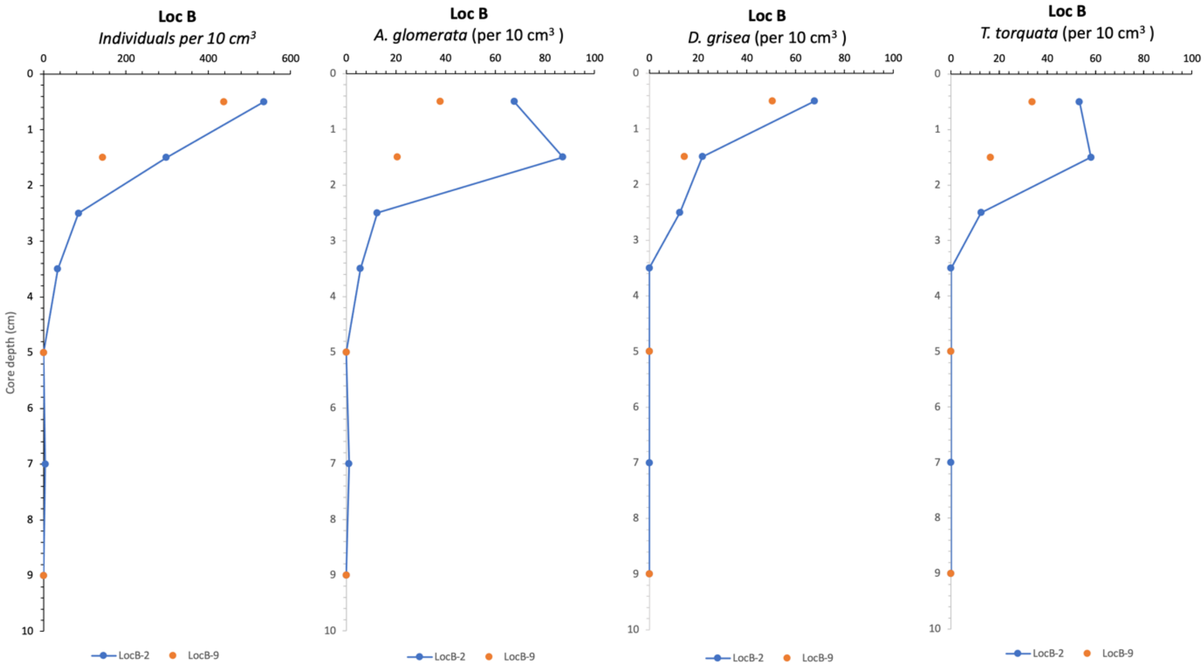

Figure 12: Downcore distribution of individuals per 10 cm^3 of the cores Loc B-2 and Loc B-9 and the distribution of the species A. glomerata, C. arctica and D. grisea per 10 cm^3

Adercotryma glomerata

Loc B-2 has a decreasing trend of *A. glomerata* through the core. The number of individuals per 10 cm^3 at 0,5 cm are 70 and increases to 90 at 1,5 cm. From 1,5 cm it decreases to 0 at 5 cm. From 5 cm to 9 cm it remains around 0.

In Loc B-9 the number of *A. glomerata* per 10 cm^3 at 0,5 cm are 40, at 1,5 cm it is 20, and at 5 cm and 9 cm it is 0.

Deuterammina grisea

From 0,5 cm to 3,5 cm in Loc B-2 *D. grisea* decrease from 70 individuals per 10 cm^3 to 0. From 3,5 cm to 9 cm it remains at 0.

D. grisea has 50 individuals per 10 cm^3 at 0,5 cm in Loc B-9. At 1,5 cm there are 15 individuals, at 5 cm and 9 cm there are 0.

Textularia torquata

In Loc B-2, at 0,5 cm the number of individuals per 10 cm^3 of *T. torquata* is 50. It increases to 60 at 1,5 cm before it decreases to 0 at 3,5 cm. From 3,5 cm it remains at 0 to 9 cm.

At 0,5 cm, in Loc B-9, *T. torquata* has 35 individuals per 10 cm^3, at 1,5 cm there are 16. There are 0 individuals at 5 cm and 9 cm.

Lagenammina arenulata, Spiroplectammina biformis and *Cuneata arctica* in cores from Loc B-2 and Loc B-9 are illustrated in Figure 13.

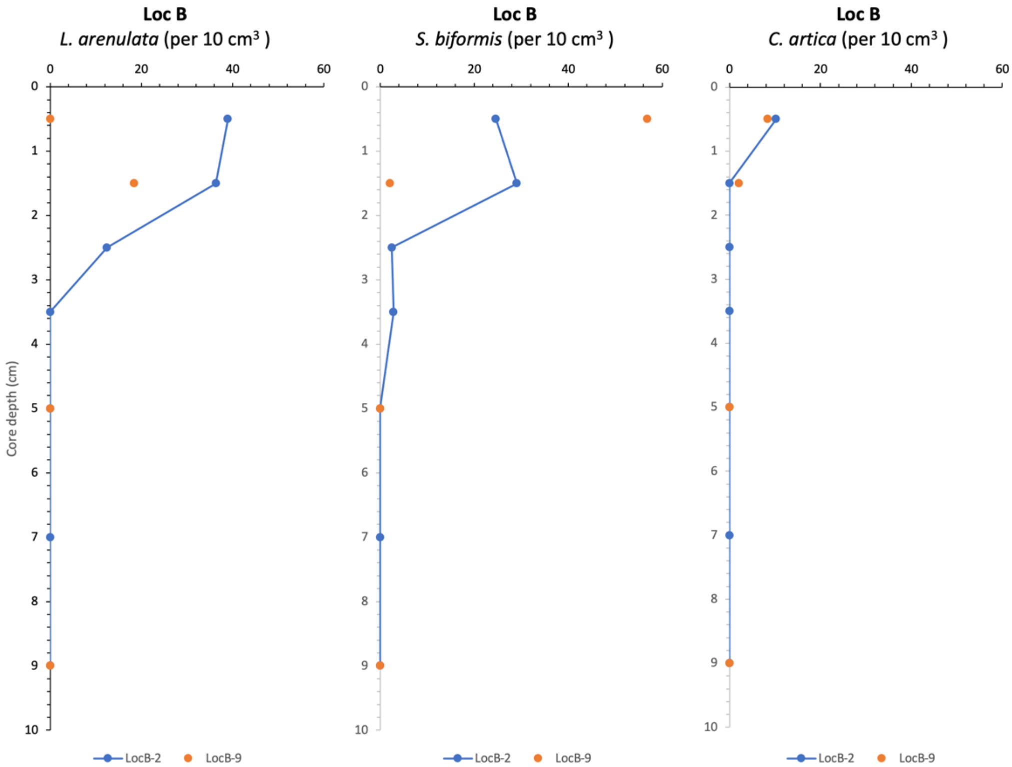

Figure 13: Downcore distribution of the species L. arenulata, S. biformis, T. torquata per 10 cm^3 in Loc B-2 and B-9.

Lagenammina arenulata

From 0,5 cm to 3,5 cm *L. arenulata* decreases from 40 to 0 individuals per 10 cm^3 in Loc B-2. From 3,5 cm to 9 cm it remains at 0.

In Loc B-9 there are 0 individuals at 0,5 cm, 18 at 1,5 cm and 0 individuals per 10 cm^3 at 5 cm and 9 cm.

Spiroplectammina biformis

In Loc B-2 *S. biformis* increases from 25 individuals per 10 cm^3 at 0,5 cm to 30 at 1,5 cm. From 1,5 cm it decreases to 3 individuals, from here it remains stable between 3 and 0 until the bottom at 9 cm.

There are 60 individuals per 10 cm^3 of *S. biformis* at 0,5 cm in Loc B-9. At 1,5 cm there are 2, and at 5 cm and 9 cm there are 0 individuals.

Cuneata arctica

The number of individuals of *C. arctica* per 10 cm^3 in Loc B-2 at 0,5 cm are 10, before it decreases to 0 at 1,5 cm. It remains at 0 until 9 cm.

Loc B-9 has 10 individuals per 10 cm^3 at 0,5 cm and 2 at 1,5 cm. At 5 cm and 9 cm it is 0 individuals per 10 cm^3.

5 Discussion

Location A is located in an area with gravelly sandy mud (Figure 14) and have a high population of snow crabs. There is a decrease in fine-grained sediments in the top 3 cm of the core, and a slight increase in TOC_{63}. This is correlating to the peak of foraminifera at 3.5 cm in Loc A-5.

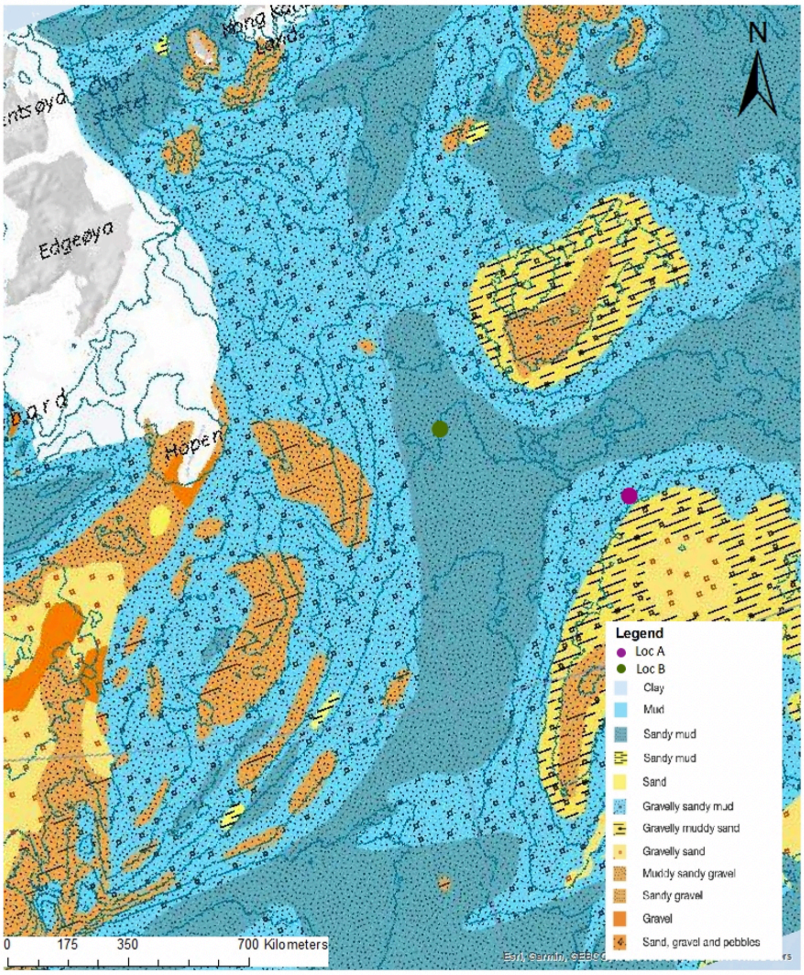

Figure 14: Bottom sediments in the Barents Sea with core locations.

The macrofauna is mostly located in the upper sediment layers in Loc A and the number of species decreases downwards. Considering sediment reworking, most of the species are surficial modifiers, a category that does not contribute much to vertical transport of sediment particles. The convoying species that do result in sediment mixing can make “pockets” with, as well as transport, organic materials and oxygen downcore in the sediments, where smaller organisms such as benthic foraminifera can benefit from and may survive.

The TOC_{63} remains at 1.9-2.0% after 3 cm, as the average TOC values in the Barents Sea is 1,1%, these values are a little higher indicating higher carbon supply at this location. The slow decreasing of water content indicates “looser” sediments, more saturated with water. The slow decreasing water content and the stable TOC_{63} values downcore indicates coarser sediment downcore and/or mixing of sediments, caused either by snow crabs or macrofauna.

Core Loc A-5 have peaks at 3.5 cm and 7 cm, with an average living depth of 2.8 cm. As the average living depth indicates the depth where most of the foraminifera are located, the peaks further downcore indicates livable conditions. This can be seen in the species *C. arctica* and the epifaunal/shallow infaunal *S. biformis*, the epifaunal to shallow infaunal *T. torquata, A. glomerata*, an epifaunal to infaunal species and the infaunal species *L. arenulata*. The foraminifera are moved in the sediments either by self-locomotion because of oxygen and organic matter presence, or bioturbation.

Core Loc A-9 has a lower abundance downcore and doesn't have any prominent down-core peak. The average living depth is 1.0 cm, less than Loc A-5. Core Loc A-9 has a more "normal" trend with the majority of foraminifera in the top cm, decreasing downwards with no individuals below 5 cm. This indicates less disturbance of the sediments, and the difference between the two stations may be explained by internal heterogeneity or physical disturbance from human activity (crab pots etc.) or the snow crab themselves.

The high snow crab area, Loc A shows sows clear signs in changed ecological quality; both snow crabs and macrofauna causes sediment mixing and bioturbation, leading to oxygen- and organic matter-transport downcore. The oxygen and organic matter are factors needed for foraminifera to survive. The foraminifera are transported downcore either by sediment mixing or bioturbation.

Core Loc B consist of sediments from an area of sandy mud and has a low density of snow crabs. There is a decrease in fine-grained sediment and water content, and the TOC_{63} doesn't change much. As the core used for sediment analysis is only 3 cm, it is difficult to give a concrete interpretation further downcore.

As in Loc A, the macrofauna is located in the upper sediment layers, and the result suggest that there is a higher sediment activity from macrofauna in the low-crab area but mainly located in the upper sediment layers. The higher macrofauna activity may be a result of the absence of snow crabs, as the snow crabs feed on a broad type of preys.

The water content decreases faster in core Loc B-9, compared to Loc A-9, indicating less water in the sediments, and more compaction. This implies less sediment mixing in Loc B than Loc A.

The are no foraminifera below 5 cm in the cores from Loc B, and there is a general decrease of individuals downcore. The average living depth in core Loc B-2 is 1.1 cm, but there is a peak of the infaunal species *A. glomerata, T. torquata, L. arenulata and S. biformis* at 1.5 cm. This peak can be explained by the sediment activity from the macrofauna.

In core Loc B-9, with an average living depth of 0.75 cm, *L. arenulata* is the only species that has a peak at 1.5 cm. The rest of the species decrease downcore, with no individuals below 5 cm. The distribution of foraminifera in Loc B-2 and Loc B-9 implies rather normal and undisturbed sediment conditions at Loc B compared to Loc A. As there is no sign of the same downcore mixing at Loc B as Loc A, there is another indication of the snow crabs effect on the sediments at Loc A, and the Lac of them at Loc B.

The top cm of the cores from Loc A indicates carbonate dissolution, app. 80% of all the calcareous test dissolved. The carbonate dissolution can be an explanation of the rich assemblage of agglutinated test in Loc A, with the low water temperature and high atmospheric pressure because of the high latitudes. The high infaunal abundance in Loc A compared to Loc B can also be explained by the position of the polar front (Figure 15). Core Loc A is located away from the polar front with calm bottom currents, allowing accumulation of organic matter. Core Loc B is located on the polar front, with water mixing down to 250 m water depth and much stronger currents affecting the sediments. The position of the polar front, and the water mixing may be a reason why there is no carbonate dissolution at Loc B.

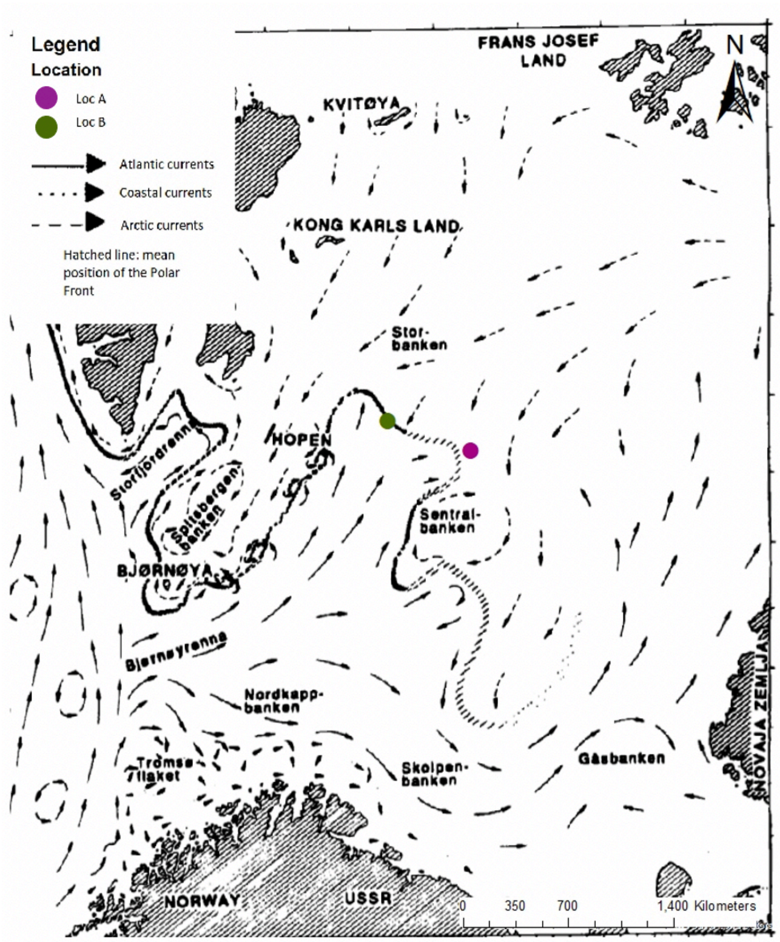

Figure 15: Ocean current and the Polar front in the Barents Sea, with core locations

6 Conclusion

This thesis has studied sediment cores from the Barents Sea, with the purpose to detect the snow crabs impact on benthic foraminifera and the ecological quality. The conclusion is therefore:

- There is evidence of sediment disturbance at location A, the macrofauna shows sediment mixing and the distribution of foraminifera indicates livable conditions downcore.

- The distribution of foraminifera downcore in Loc A indicates access to oxygen and nutrients downcore. This can come from mixing of the sediments by macrofauna and snow brabs, but also the slow bottom current allowing the accumulation of organic matter and carbon dissolution.

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Attachments

Attachment 1. Ten top dominant macrofaunal species (1-10) at location A and location B. x = other common or large-sized species included in the traits analyses. Data from EISA project.

Phylum	Main group		Loc A	Loc B
ANNELIDA	POLYCHAETA	*Chaetozone setosa*	8	x
		Cistenides hyperborea	x	x
		Galathowenia oculata	6	x
		Heteromastus filiformis	7	9
		Leitoscoloplos sp.	x	x
		Levinsenia gracilis	-	x
		Lumbriclymene sp.	x	x
		Lumbrineris mixochaeta	3	4
		Maldane sarsi	x	8
		Nephtys ciliata	x	x
		Nephtys paradoxa	x	x
		Owenia sp.	-	6
		Pholoe assimilis	x	x
		Praxillella gracilis	x	x
		Spiochaetopterus typicus	1	1
		Spiophanes kroyeri	x	3
CRUSTACEA	AMPHIPODA	*Haploops* sp.	-	x
CRUSTACEA	ISOPODA	*Gnathia* sp.	x	x
CRUSTACEA	OSTRACODA	*Philomedes globosus*	5	x
ECHINODERMATA	ASTEROIDEA	Asteroidea juvenil	4	x
		Ctenodiscus crispatus	x	x
ECHINODERMATA	OPHIUROIDEA	*Ophiacantha bidentata*	x	x
		Ophiocten sp.	-	x
		Ophiuroidea, juvenil	x	10
MOLLUSCA	BIVALVIA	*Astarte crenata*	x	x
		Macoma calcarea	x	-
		Mendicula pygmaea	2	2
		Parathyasira dunbari	x	5
		Yoldiella lenticula	x	x
		Yoldiella solidula	10	x
MOLLUSCA	CAUDOFOVEATA	Caudofoveata indet	9	7
VARIA	NEMERTEA	Nemertea indet	x	x
VARIA	SIPUNCULIDA	*Phascolion strombus*	x	x

Attacment 2. Specieslist with known traits; wall structure, microhabitat, AMBI group.

List of species	Wall structure	Microhabitat	AMBI group	References (number refers to microhabitat)
Adercotryma glomerata/wrighti	aggl	Infaunal (1), Epifaunal (2)	1	1. Hunt & Corliss (1993), 2. Gooday (1993)
Ammodiscus gullmarensis	aggl			
Ammotium cassis	aggl	Epifaunal to infaunal (1)		1. Linke & Lutze (1993)
Astrononion gallowayi	calc	Shallow Infaunal (1,2)	2	1. Hunt & Corliss (1993), 2. Wollenburg & Mackesen (1998)
Buccella frigida	calc	Epifaunal (1)	3	1. Corliss (1991)
Buccella sp.	calc	Epifaunal (1)		1. Corliss (1991)
Buccella tenerrima	calc			
Cassidulina sp.	calc			
Cibicides lobatulus	calc	Epifaunal (1)	1	1. Corliss (1991)
Cibicides sp.	calc	Epifaunal (1)		1. Corliss (1991)
Cuneata arctica	aggl			
Deuterammina grahami	aggl			
Deuterammina grisea	aggl			
Discorbinella sp.	calc			
Eggerella europea	aggl			
Elphidium albiumbilicatum	calc		3	
Elphidium excavatum	calc	Epifaunal to infaunal (1), Epifaunal/shallow infaunal (2,3,)	1	1. Linke & Lutze (1993), 2. Hunt & Corliss (1993), 3. Newton & Rowe
Epistominella arctica	calc	Epifaunal (1)		1. Wollenburg and Mackensen (1998)
Epistominella sp.	calc			
Epistominella vitrea	calc		2	
Hippocrepina pusilla	calc			
Hippocrepinella remanei	calc			
Hippocrepinella sp.	calc			

Islandiella norcrossi	calc	Epifaunal (1)	2	1. Corliss (1991)
Labrospira crassimargo	aggl			
Lagenammina arenulata	aggl	Infaunal (1)		1. Gooday (1986)
Lagenammina difflugiformis	aggl	Infaunal (1)	1	1. Gooday (1986)
Lagenammina sp.	aggl	Infaunal (1)		1. Gooday (1986)
Leptohalysis catenata	aggl			
Melonis barleeanus	calc	Intermediate infaunal (1,2,3), Shallow infaunal (3)	3	1. Gooday (1986), 2. Corliss (1991), 3. Wollenburg & Mackensen (1998)
Nonionella turgida	calc	Deep infaunal (1), Epifaunal to infaunal (2)	2	1. Corliss (1991), 2. Schmiedel et al. (1997)
Nonionellina labradorica	calc	Shallow infaunal (1), Infaunal (2)		1. Hunt & Corliss (1993), 2. Newton and Rowe (1995)
Pilulina arguta	aggl			
Portatrochammina karica	aggl			
Quinqueloculina sp.	calc			
Recurvoides contortus	aggl			
Reophax bilocularis	aggl		1	
Reophax dentaliniformis	aggl			
Reophax fusiformis	aggl	Infaunal (1)		1. Hunt and Corliss (1993)
Reophax scorpiurus	aggl		3	
Reophax subfusiformis	aggl		2	
Rosalina williamsoni	calc			
Saccammina sp.	aggl			
Silicosigmoilina groenladica	aggl		2	
Spiroplectammina biformis	aggl	Epifaunal/ shallow infaunal (1)	3	1. Hunt & Corliss (1993)
Stainforthia fusiformis	calc		5	
Textularia earlandi	aggl		3	
Textularia torquata	aggl	Epifaunal/ shallow infaunal (1)		1. Hunt & Corliss (1993)
Trifarina fluens	calc		1	