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Field experiment on thin-layer capping in Ormefjorden and Eidangerfjorden; Benthic community analyses 2009-2011

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REPORT

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Abstract

As part of the work towards a remediation plan for the Grenlandfjord area, thin cap test fields were established at 30 and 100 m depth in the outer Grenlandfjord in September 2009. One field was treated with crushed limestone, one field was treated with clay dredged from a nearby location and two fields were treated with a mixture of dredged clay and activated carbon (AC). The test fields and appropriate reference locations were surveyed with a sediment profile camera (SPI) every spring and autumn from May 2009 to May 2011. The benthic habitat quality index (BHQ) determined from picture analyses showed *good* conditions at all fields before cap placement and a change to *less good* at both fields treated with AC by the end of the investigation period. Full macrofaunal analyses were performed in October 2009 and November 2011 and characterized in accordance with standard community analyses and multivariate statistical methods (PERMANOVA). The analyses showed that both fields treated with AC were significantly depleted compared to the respective reference fields, and that they experienced a negative trend from 2009 to 2010. Neither the coarse limestone material (up to gravel size) nor the dredged clay without AC added had significant effects on number of species, biomass or the BQI index. Continued monitoring is recommended for fields treated with limestone and activated carbon.

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1. Tiltak	1. Remediation
2. Dioksiner	2. Dioxins
3. Bunnfauna	3. Benthic macrofauna
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Field experiment on thin-layer capping in Ormefjorden and Eidangerfjorden

Benthic community analyses 2009-2011

Preface

The present report has been prepared by a group of investigators from Stockholm University (SU), University of Gothenburg (GU) and the Norwegian Institute for Water Research (NIVA). The report is a contribution to the research projects THINC, OPTICAP and CARBOCAP. OPTICAP and THINC were funded by the Norwegian Research Council (NFR) and Hydro. Additional funding and active participation was offered by Klima- og forurensingsdirektoratet (Klif) and OPTICAP project partners Hydro, Norsk Avfallshåndtering (NOAH), Agder Marine, Secora and Hustadmarmor. CARBOCAP was funded by the Swedish Research Council FORMAS and the Swedish Governmental Agency for Innovation Systems VINNOVA.

The three projects had common objectives in developing a method to prevent or reduce risk of spreading of pollutants from historically contaminated sediments to marine water and biota. Within all three projects, field experiments were considered important supplements to smaller scale laboratory and mesocosm experiments, but the resource requirements associated with field experiments at large depths are high. Therefore the OPTICAP/THINC joint capping operation carried out in the Grenlandfjords in September 2009 was a prerequisite for this unique field experiment. Agder Marine, Secora, NOAH and Hydro participated with ships, materials and expertise in this operation lead by Espen Eek, NGI. NIVA had a primary responsibility for the field investigations and six surveys in the Grenlandfjord area with FF Trygve Braarud during the period October 2008 - May 2011. SU was responsible for the fauna investigations. The taxonomic work performed by co-authors Göran Samuelsson and Caroline Raymond, SU under the superveillance of Stefan Agrenius, UG.

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Summary

In order to reduce transfer of dioxin from sediment to biota, thin layer capping is tested at four different sites in the Grenlandfjord area. Three fields have been established at 30 m depth in Ormefjorden and 1 field at 100 m depth in Eidangerfjorden. The applied test materials were gravel (<5 mm fraction) from the limestone quarry at Langøya in the Oslofjord and a marine, silty clay with or without added activated carbon (AC). The clay was dredged from a nearby fjord location and AC was added before deposition at the test fields (Eek et al., 2011). The main objectives of the work presented in this report were to monitor and describe changes in the benthic habitat and macrobenthic communities as a result of the capping operations in September 2009.

All test fields and near-by reference locations were surveyed with an SPI-camera at 6 month intervals during the period May 2009-May 2011. The investigation in October 2009 showed that thin caps had been successfully placed with maximum thickness of 1.8-4.7 cm and fairly even distribution of cap material inside the fields. The thickness of the cap layers was confirmed by control measurements of vertical distribution of mercury which was small in the cap materials compared to test field sediments.

The SPI images indicated bioturbation impacts down to 3-5 cm depth. Below this depth, the sediments had an even grey colour and organisms were rarely detected. This was confirmed by the redox-potential profiles which showed decreasing potentials from 300-400 mV at the sediment-water interface to typical values 0-100 mV and little variation with depth below 5 cm. The cap materials were all mineral materials with low content of labile organic carbon, and as expected, neither the redoxpotential nor the O_2-microelectrode profiles showed any clear effects of cap placement.

For each survey, 20-50 SPI-images/field were analysed to provide a Benthic Habitat Quality (BHQ) index. In May 2009, before cap placement, the BHQ-index showed *good* conditions at all fields and no significant difference between any of the fields. After cap placement the BHQ was more variable, but significant differences between test- and reference-fields were not observed until May 2011 when the habitat at both fields treated with active carbon was *less good* and significantly different from the respective reference fields. At the other fields, BHQ in May 2011was similar to or better than the BHQ determined before cap treatment.

Full macrofaunal investigations were performed on all test fields in October 2009 and November 2010. This investigation confirmed the BHQ data in the respect that adverse effects of capping were observed in the clay-AC fields only. The negative development at the clay-AC field between 2009 and 2010 was confirmed in Ormefjorden, but less clearly in Eidangerfjorden. The effects in the clay-AC fields showed up as statistically significant differences from the control field in multivariate community analyses (PERMANOVA) and univariate analyses of fauna variables such as abundance, species richness, biomass and the BQI diversity index.

Results from the limestone gravel and the clay capping treatments indicate that macrofauna can withstand remediation using thin layer capping at this thickness level. As a substrate for benthic communities, the clay was very similar to the pre-cap sediment in all respects and longterm changes are not likely to occur. The limestone gravel represented, however, a substantial change in substrate and long-term community changes may occur as result of the shape, size and mineral composition of the added cap material.

Continued monitoring is recommended to assess the pace of recovery at the clay-AC fields and potential long-term community development at the limestone gravel field.

Sammendrag

For å redusere biotilgjengelighet av dioksiner i sedimentene er det gjennomført en prøveutlegging på fire testfelt i de ytre Grenlandsfordene (Eek et al., 2011). Tre felt på 100x100 m er etablert på 30 m dyp i Ormefjorden og dekket med hhv grus (<5mm) fra kalksteinsbruddet på Langøya i Oslofjorden, marin leire mudret fra en nærliggende lokalitet i Ormefjorden og samme mudrete leire iblandet aktivt kull (AC). I tillegg er et større felt på 200x200 m på 100 m dyp i Eidangerfjorden dekket med mudret leire iblandet aktivt kull. Målsettingen med undersøkelsene beskrevet i denne rapporten var å overvåke og beskrive eventuelle endringer i bentisk habitat og bunnfauna som følge av tildekkingene som ble utført i september 2009.

Prøvefeltene og nærliggende referensefelt ble undersøkt med SPI-kamera hver 6. måned fra mai 2009 til mai 2011. Undersøkelsen i oktober 2009 viste relativt jevne lag tildekkingsmaterialer på alle feltene med maks tykkelse fra 1,8 til 4,7 cm. Lagtykkelsen ble bekreftet med kontrollmålinger av vertikalfordelingen av kvikksølv som var liten i tildekkingsmaterialene sammenlignet med sedimentene på testfeltene.

Habitatene ble beskrevet på grunnlag av SPI-bilder og målinger av vertikalprofiler av oksygen (O_2) og redokspotensialer. Disse viste generelt oksygen ned til 5-10 mm under sediment-vann grenseflaten, klare spor av bioturbasjon ned til 3-5 cm dyp, og ingen spor av hydrogensulfid i de øvre 10 cm av sedimentene. Tynnsjikt-tildekkingen ga ingen vesentlige endringer i oksygen- og redoksforholdene, noe som var ventet som følge av at tildekkingen ble utført med materialer med lavt innhold av nedbrytbart organisk materiale.

For hvert tokt ble det analysert 20-40 bilder/felt for bestemmelse av en BHQ (Benthic Habitat Quality) -indeks. I mai 2009 viste indeksen *gode* forhold på alle feltene og ingen signifikante forskjeller mellom noen av feltene. Indeksen varierte noe etter etablering av feltene, men signifikante forskjeller mellom test- og referense-felt ble først observert i mai 2011 da tilstanden på begge feltene behandlet med aktivt kull ble karakterisert som *mindre god* og signifikant dårligere enn de respektive referensefeltene. På de øvrige feltene var BHQ uendret eller bedre enn før tildekkingen.

Full makrofauna-undersøkelse ble utført i oktober 2009 og november 2010. Undersøkelsene viste samfunn preget av forstyrrelse på begge feltene behandlet med aktivt kull. Den negative utviklingen observert med SPI-kameraet fra 2009 til 2010 ble bekreftet på 30 m-feltet i Ormefjorden, men ikke like klart på 100 m-feltet i Eidangerfjorden. Effektene av behandlingen med aktivt kull iblandet leire viste seg som statistisk signifikante avvik fra referensefeltene i en multivariat samfunnsanalyse (PERMANOVA) og univariate analyser av fauna-parametrene individtetthet, artsrikdom, biomasse og BQI diversitetsindeks.

Resultatene for kalksteinsgrusen og mudret leire uten tilsetting av aktivt karbon viste at faunaen har god evne til å motstå utlegging av tynnsjikt med disse materialene og lagtykkelse mindre enn 5 cm. Som substrat betraktet, er mudret leire så lik det opprinnelige substratet som mulig og det er ikke grunn til å forvente langsiktige endringer av faunasamfunnet på dette feltet. Kalksteinsgrusen representerte imidlertid en stor endring av substratet, og det kan ikke utelukkes at samfunnet på dette feltet vil kunne endre seg over tid som følge av de nye sedimentpartiklenes form, størrelse, og mineralsammensetning.

Overvåkingen av testfeltene anbefales forlenget for å få mer kunnskap om tidsaspektet for rekolonisering på feltene med aktivt kull, og for å øke kunnskapen med hensyn til den langsiktige utviklingen av samfunnet på kalksteinfeltet.

Introduction

The primary objective of thin capping is to develop a method to reduce the release of contaminants from sediments to fjord water and biota. As a supplement to theoretical modeling and small scale laboratory and mesocosm experiments a field experiment was considered necessary to test out the technical challenges of cap placement and real world cap performance.

Benthic communities are sensitive to sedimentation rates and hypersedimentation triggered by natural events such as floods and storms may lead to a loss of species diversity. Based on a definition of maximum 5% loss of macrofaunal species, Smit et al. (2008) found a no-effect level of sediment burial of 6.3 mm. In experimental work, however, Trannum et al. (2010) found negligible effects on benthic communities treated with up to 24 mm layers of natural sediments with similar shapes and grain size distribution as the original sediments. Screening tests with 2 cm layers of several cap materials proposed for capping in the Grenlandfjord area showed that thin caps can significantly reduce the abundance and the diversity of the benthic species (Näslund et al., submitted). Although materials used in the test fields were selected based on a least harmful effect approach, the 1-5 cm caps placed in the experimental plots in the Grenlandfjord area in September 2009 (Eek and Schaanning, 2010) exceeded the no-effect layer thickness, and some loss of benthic species is likely to occur. Therefore, the two important objectives of the field experiment addressed in this report were

- how is the benthic community affected by cap placement, and if affected,
- how fast and to which state will the communities recover.

Sediment Profile Images (SPI) is a technique that provides a picture of a vertical profile across the sediment-water interface (typically 0-20 cm). SPI was first used for mapping and identification of appropriate test plots in October 2008 and May 2009, then in order to assess the success of the cap placement in October 2009 and finally in order to observe and compare the effects of the capping treatments on the benthic fauna and cap erosion in follow-up investigations conducted at 6-months intervals until May 2011.

Collection of macrofauna for taxonomy determinations were done in October 2009, shortly after cap placement, and repeated one year later in November 2010. At both occasions the faunal investigations were supplemented with investigations of biogeochemical processes, and bioaccumulation and release of Hg and dioxins in box core samples transplanted from the field to the laboratory at the Solbergstrand Marine Research Station.

1. Material and methods

1.1 Test field establishment

The test fields (**Table 1**, **Figure 1**) were established in September 2009 in the outer Grenlandfjord area. The outer fjords area separated from the Frierfjord by a shallow sill at Breivik and from Skagerrak by deep sill at 55 m depth. The hydrography is characterized by outflowing brackish water from Skienselva and Frierfjorden which maintains a typical 2 m layer with brackish water, an intermediate layer with increasing salinitiy to about 30 PSU at 20 m depth and 34 PSU at 55 m depth. Below this depth the water is fairly homogeneous down to maximum depths of about 120 m. Further details on field co-ordinates and depth transects are given in 0

In Ormefjorden, 3 fields of 10 000 m^2 at 24-32 m depth were treated with crushed limestone supplied from NOAH, Langøya (FO1), silty-clay sediments suction-dredged at 10-20 m depth in a nearby location (FO2) and sediments dredged from the same location amended with 2 kg m^{-2} activated carbon (FO3). A fourth field was left untreated for control (FO4). At the dredging site, the moderately contaminated top layer (ca 1 m) was suctioned off and shipped to land-deposit before dredging sediments for the capping operation (Eek et al., 2011).

In Eidangerfjorden, 1 field of 40,000 m^2 (FE5) at 92-96 m depth was capped with dredged clay amended with activated carbon (AC) in a similar way as done in FO3. In Eidangerfjorden one untreated reference location located at 85 m depth to the north of the test field (FE6) was used as reference field in 2009. In 2010 a second reference field at 90-100 m depth (FE7) was used in addition to FE6.

Trawling is a regular activity in Eidangerfjorden. In understanding with the local fishermen, FE5 is not trawled during the field experiment and FE6 is beyond reach of the trawling gear due to topographic restrictions. The second reference field FE7 is located at the same depth as the activated carbon treated plot, but may occasionally be affected by trawling gear. Further information about the cap placement is given in Eek et al., 2011.

Table 1. Field name and treatments

Fjord	Field	Treatments	T	Depth range (m)	Typical depth (m)	Field Area (m^2)
Ormefjorden	FO1	Gravel of crushed limestone	GR	29-32	30	10,000
Ormefjorden	FO2	Dredged clay	CL	24-31	30	10,000
Ormefjorden	FO3	Dredged clay with AC	AC	24-28	26	10,000
Ormefjorden	FO4	Reference	REF	-	30	-
Eidangerfjorden	FE5	Dredged clay with AC	AC	92-96	95	40,000
Eidangerfjorden	FE6	Reference	REF1	-	85	-
Eidangerfjorden	FE7	Reference 2010 only	REF2	-	100	-

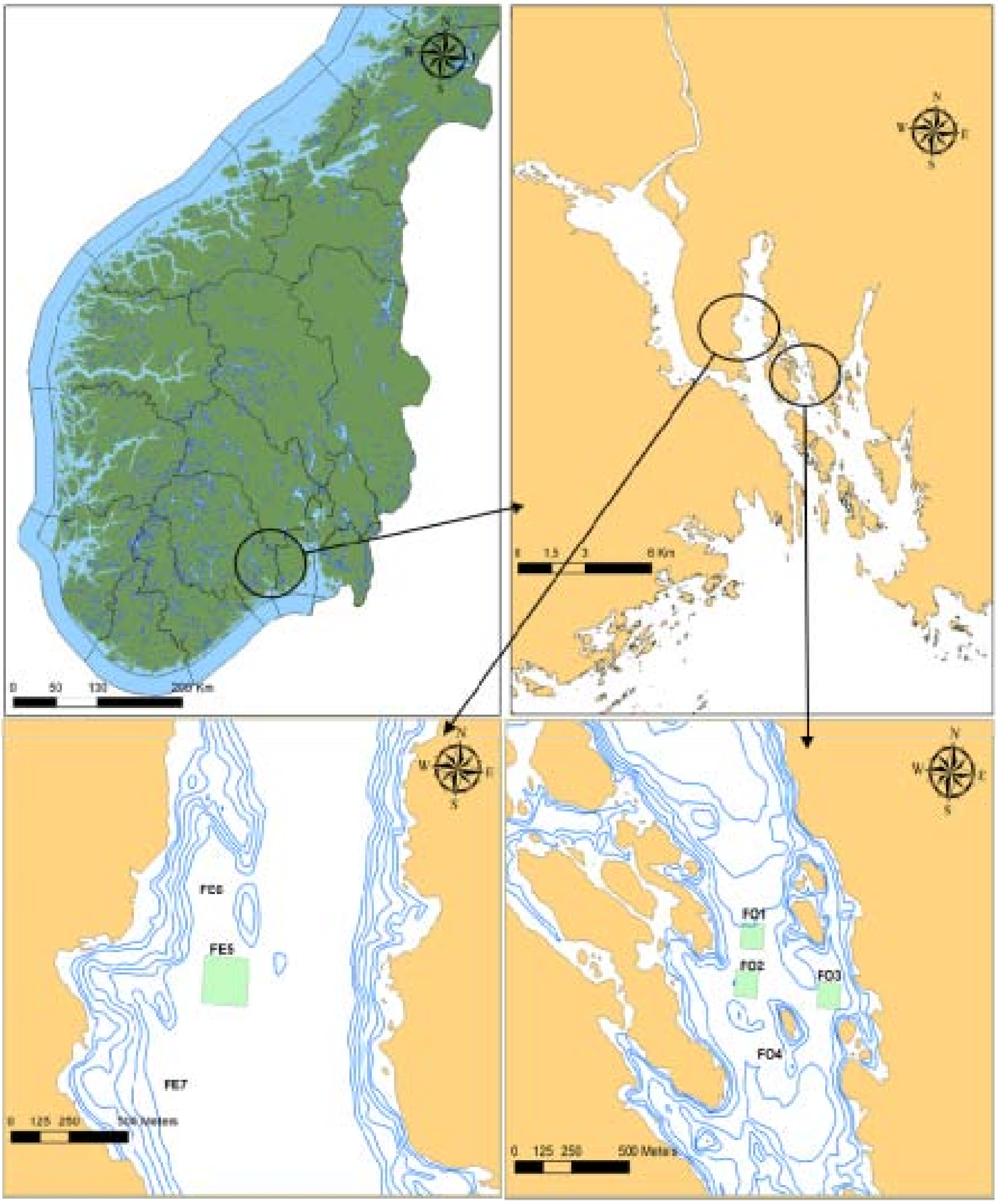


Figure 1. Map showing outhern Norway, the Grenlandfjord area, and the test plots in Eidangerfjorden (low left) and Ormefjorden (low right).

1.2 SPI

A digital CMOS camera (Canon D50), was used to take vertical *in situ* photos through a prism (26 x 17,3 cm) as described in **Figure 2 (**Nilsson & Rosenberg, 1997). After each deployment, the sediment profile images (SPI) were transferred to a computer and stored. SPI image enhancement and measurement was done in Adobe Photoshop Extended CS4. The depth of the apparent redox potential discontinuity (aRPD) was measured as the distance from the sediment surface to the borderline between rusty brown and green to grey or sometimes even black sediment. In each image the mean aRPD was calculated as the area of aRPD coverage divided by the width of the image, and the benthic habitat quality (BHQ) index was calculated (Nilsson & Rosenberg, 1997). This index parameterises surface structures (faecal, tubes, feeding pit and mounds), sub-surface structures (infauna, burrows, oxic voids) and the aRPD. Each of these properties (surface structure, subsurface structure and aRPD) is scoring up to 5p to a total of 15p as the highest score in an image. The BHQ index is a quick method which allows sampling of a higher number of stations compared to quantitative macrofauna analyses. It is related to the faunal successional stages in the Pearson-Rosenberg model (**Figure 2**) (Pearson and Rosenberg 1978, Nilsson & Rosenberg, 2006).

In this particular investigation, the changes in colour gradients at the sediment surface imposed by the cap materials might alter the preconditions for determining aRPD and hence affect the BHQ index. The depth of the aRPD is determined from color change. Adding a few cm of light coloured sand or black carbon

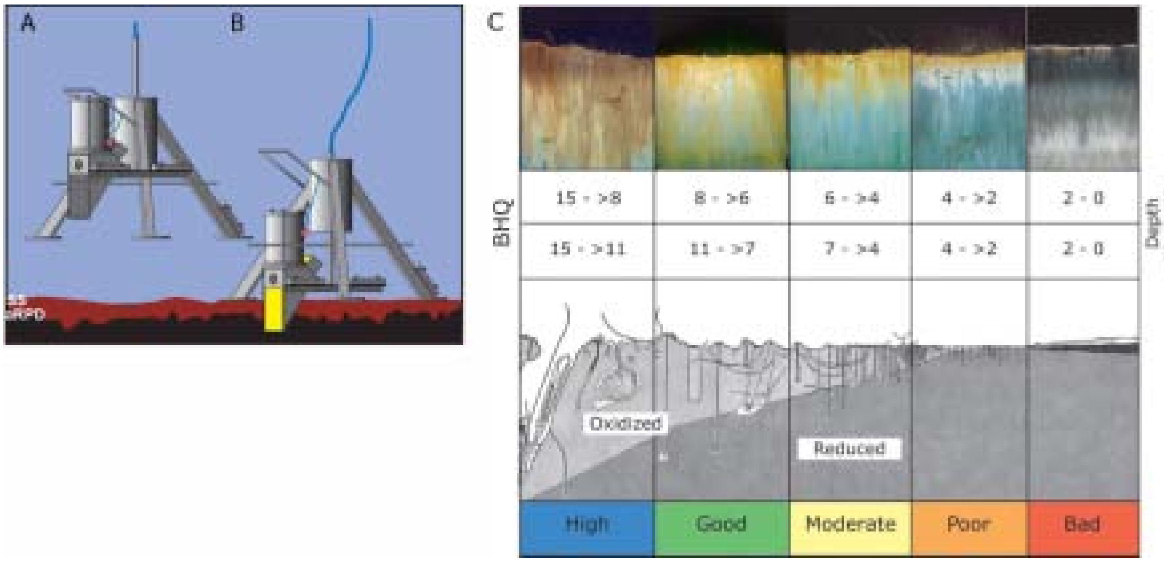


Figure 2. Diagram of a sediment profile camera in operation. (A) The sediment profile camera just above the sediment surface. (B) The prism has penetrated the sediment surface and the image is exposed. Sediment surface (SS) and the apparent redox potential discontinuity (aRPD) is marked in the line drawing. (C) Model of the faunal successional stages along a gradient of increasing disturbance from left to right (after Pearson and Rosenberg, 1978). Sediment profile images (colours enhanced) are shown on the top where brownish colour indicates oxidized conditions and black reduced conditions, and the benthic habitat quality (BHQ) indices (Nilsson & Rosenberg 1997) are presented for depths >20m and ≤20m. Figure modified from (Rosenberg et al. 2004).

material made it difficult to correctly determine the distance from the surface to the depth of the color shift. Therefore, two indexes were determined. The ordinary BHQ in accordance with the standard criteria and a BHQ* which was determined similarly but without adding the points obtained for aRPD. The objective was to avoid artifacts of the cap materials and improve comparison between fields and times. For the total of 204 stations analysed in the present study, the mean BHQ differed from BHQ* by 2.8 points.

1.3 Oxygen microelectrode measurements

Oxygen microelectrode profiles were measured 07.-08.01.2010 in sub-cores drawn from two box core samples from each field transferred to the benthic mesocosm at Solbergstrand 15.10.2009 (further details are given in separate report on dioxin bioavailability).

The oxygen profile at the sediment-water interface was recorded on a Unisense™ Clark-type microelectrode (OX-50) with an internal reference and a guard cathode (Revsbech, 1989). The electrodes were connected to a picoammeter and output displayed on an online PC using Profix™ software. The measurements were performed in 10 mm (ID) core sub-samples drawn from each box and mounted on a laboratory stand and a micromanipulator. Before measurements a two-point calibration was performed in well aerated seawater and anoxic sediment. The motor driving the electrode was set to steps of 200 µm with resting time 7 sec. before each measurement.

1.4 Redox potential measurements

Redox potentials were measured in sediment cores sampled during the field work. The potentials were measured with eleven platinum electrodes inserted simultaneously through premade ports at 1 cm distance in a 6 cm (ID) sediment core. After a fixed time interval (10 minutes) rest potentials were read against a common calomel reference electrode inserted in the water on top of the core. The instrument and electrical circuits was tested using ZoBell’s solution. Temperature was measured with an automatic temperature compensation probe. The readings were compensated for temperature according to Langmuir (1971) and Bates (1973). The redox potential (Eh) was calculated by addition of the half-cell potential of the calomel electrode to the recorded potential.

1.5 Macrofauna

1.5.1 Methods

Benthic macrofauna was sampled with a van Veen grab with a sampling area of ca. 0.1 m^2. The grab sample positions were pre-determined and localized with DGPS in the coordinate system WGS-84. In October 2009 three replicate grabs were taken per field (n=3) (Figure 1.). In November 2010 five replicate grabs were taken per field (n=5). The samples were immediately sieved through a 1 mm mesh size sieve and conserved in 4% formaldehyde (buffered with hexamethylene tetramine) and stored for 3 months prior to taxonomy identification. All specimens for the major taxonomic groups were with few exceptions identified to species level. Species within the groups Nemertea and Turbellaria were identified only to higher taxonomic level. Abundance (number of individuals) and biomass (g wet weight) were determined for each taxon (see Appendix C).

1.5.2 Ecological state assessment

Samples were classed by ecological status using Benthic Quality Index (BQI) in the modified version described by Leonardsson et al. (2009), and Shannon-Wiener index (H’) (Klassifiseringsveileder, 2008). BQI is not normally used in Norway, but in a recent field capping study in the Trondheim harbour the BQI index was found to perform well compared with the Shannon-Wiener index H' and the Norwegian Quality Index (NQI) (Cornelissen et al, 2011).

The development of the Benthic Quality Index (BQI) (Rosenberg et al., 2004) was commissioned by the Swedish Environmental Protection Agency according to The European Union Water Framework Directive (WFD) (European Commission, 2003), in order to divide the ecological status into five categories: *I) High*, *II) Good*, *III) Moderate*, *IV) Poor* or *V) Bad* (Rosenberg et al 2004; Leonardsson et al., 2009). The boundary values between the five categories vary for different water areas.

The BQI takes into account the specific species resistance to ecological disturbances, where each species has an individual sensitivity value based on empirical data. Calculation of BQI is based on the relative abundance of sensitive and tolerant species, the total number of species in the sample and to some respect the total abundance in the sample.

$$BQI = \left[\sum_{i=1}^{S_{classified}} \left(\frac{N_i}{N_{classified}} \times Sensitivity\ value_i\right)\right] \times \log_{10}(S+1) \times \left(\frac{N_{total}}{N_{total}+5}\right)$$

where $S_{classified}$ is the number of taxa having a sensitivity value, N_i is the number of individuals of taxon *i*, $N_{classified}$ is the total number of individuals of taxa having a sensitivity value, the *Sensitivity value*$_i$ is the sensitivity value for taxon *i*, *S* is the total number of taxa, and N_{total} is the total number of individuals in the sample (0.1 m^2) (Formula and description text from Leonardsson et al, 2009). In this study we used the boundary values for Kattegat-Skagerrak for depths larger than 20 meters, in order to assess ecological status.

Ecological state assessment was also done according to the Shannon-Wiener index (H’) calculated in PRIMER, for each sample (see Appendix A.):

$H' = -\Sigma\ (p_i) * (\ln_2 p_i)$

where p_i = proportion of individuals in the sample belonging to species *i*. The principle difference between BQI and H’ is that H’ does not take species sensitivity into consideration. Class boundaries are given in **Table 2**.

Table 2. Classification criteria based on Shannon-Wiener index (H’). From Klassifiseringsveileder, 2009.

Classification	I Very good	II Good	III Moderate	IV Bad	V Very Bad
Values (H')	> 3.8	3.0 - 3.8	1.9 - 3.0	0.9 - 1.9	< 0.9

1.5.3 Statistical methods

The benthic macrofauna community is strongly variable among fjords depending on factors such as depth, water exchange, current regime, organic carbon input, salinity, light etc.. Therefore, the experiments at 30 m depth in Ormefjorden and at 100 m depth in Eidangerfjorden were treated separately in all statistical analyses.

Differences among capping treatments were analyzed with permutational analysis of variance (PERMANOVA) (Anderson 2001, McArdle and Anderson 2001) using PRIMER 6 + PERMANOVA statistical software package (Plymouth Laboratories, England). The variables total abundance, species richness, total biomass and BQI were analyzed using univariate statistics. Benthic community data (number of individuals identified of each species/taxon) were analyzed with multivariate statistics in order to detect groupings and significant differences in benthic communities between treatments.

Benthic community data were fourth-root transformed. Bray-Curtis dissimilarity index was used for benthic community data and Euclidian distance for the univariate variables (abundance, species richness, biomass and BQI). Parameters that did not show homoscedasticity, were Log(x+1) transformed before statistical analysis. The significance level for all statistical tests were set at $\alpha = 0.05$.

Compared to the commonly used ANOVA (or MANOVA, if multiple variables are included), PERMANOVA offers the advantages of using other distance measurements than Euclidian (e.g., Bray-Curtis dissimilarity) and of calculating probability values using permutations, instead of relying on tabled P-values (which requires that data is normally distributed). The Bray-Curtis dissimilarity integrates both taxa and their respective abundances to calculate dissimilarity between samples. If data is normally distributed and Euclidian distance measurement is used, the resulting P-values are in principle identical to those obtained in a traditional ANOVA.

Post-hoc pair-wise tests were carried out using the same PERMANOVA procedures (equivalent to Dunnet’s post-hoc test in a traditional ANOVA), to reveal differences between the levels of the two factors “Year” and “Treatment”. For Year the two levels are *2009* and *2010*, and for Treatment the levels are *REF*, *AC* for Eidangerfjorden and *REF*, *AC*, *CL* and *GR* for Ormefjorden. In addition to the two-factor analyses, one-factor PERMANOVA tests and subsequent pairwise post-hoc tests were made to discriminate between treatments in the separate years (and between years for each treatment). For this pairwise test Monte-Carlo sampling was used since the number of unique permutations was low. However, these one-factor analyses are subordinated the statistically stronger two-factor PERMANOVA tests. The main conclusions should be based on the results from the main tests with complementary information available from the subordinated (i.e. “post-hoc”) one-factor analyses.

From the multivariate matrix of benthic community data, non-metric multidimensional (nMDS) scaling plots (with Bray-Curtis similarity index as distance measure) were also created to visualize relative similarities of the benthic communities in a 2-dimensional graph (one for each fjord).

In order to increase the detail level in the figures all species were assigned to one of the five groups Polychaeta, Mollusca, Crustacea, Echinodermata and Varia (including Cnidaria, Nemertea, Phoronida, Platyhelminthes, Sipuncula). Complete species lists are given in Appendix C. Statistical analyses, however, were performed on ungrouped data.

2. Habitat description

2.1 Layer thickness

Time series of selected images from each field (**Figure 3**) showed a brownish surface layer typically extending down to 3-5cm thick and a second less clear transition towards a uniform grey sediment at about 10 cm depth. This seemed to be a persistent feature at the reference fields both in Ormefjorden (**Figure 3**A) and Eidangerfjorden (**Figure 3**E). In October 2009 the brownish top layer is replaced with the added cap materials in FO1-3 and FE5, but is clearly present again in May 2010 and subsequent surveys. The brownish material is probably a mixture of riverine detritus, fresh algae material produced in the surface layer and sediments resuspended from shallow areas and basin slopes. Because of smearing, a superficious analyses easily overestimated the downwards extension of the brownish layer as well as the black activated carbon on FO3 and FE5. Careful image analyses gave maximum layer thickness ranging from 1.96 to 5.89 cm and median layer thickness from 1.08 to 4.05 cm (**Table 3**). The material was fairly well confined to within the predefined boundaries at FO3 and FO4 (**Figure 4**). At FO3 cap material was found to the south and west of the predefined field boundaries and at FE5 added materials were identified as far as 300 m south of the defined field boundary (**Figure 6**). Further analyses and details on cap thickness are discussed in Eek et al. (2011).

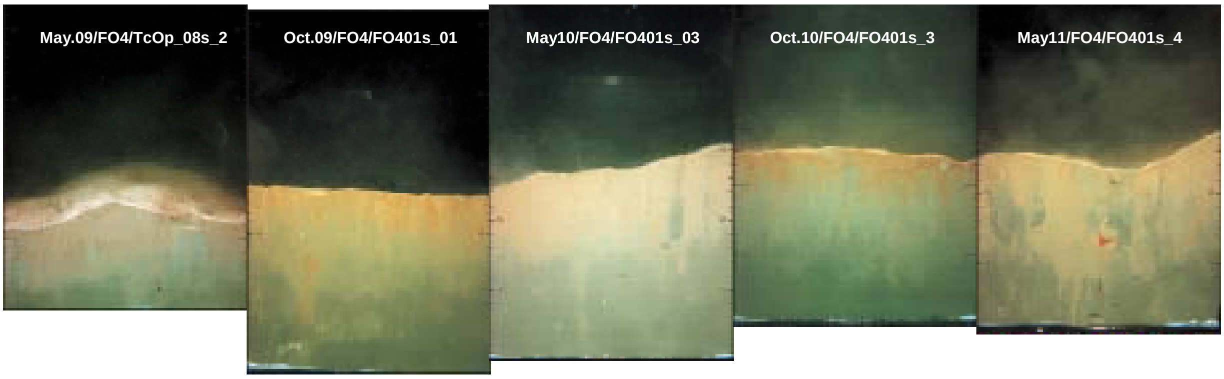
Table 3. Cap layer thickness analysed from SPI images in October 2009. n = number of analysed images at each field.

Field	Treatment	n	min	max	median	mean	Std.dev
FO1	NOAH limestone	24	0,75	4,73	1,78	2,08	1,12
FO2	Dredged silty clay	25	2,54	5,89	4,05	3,93	0,85
FO3	AC -dredged silty clay	24	0	1,96	1,08	1,05	0,50
FE5	AC -dredged silty clay	47	0	3,69	1,28	1,31	0,50

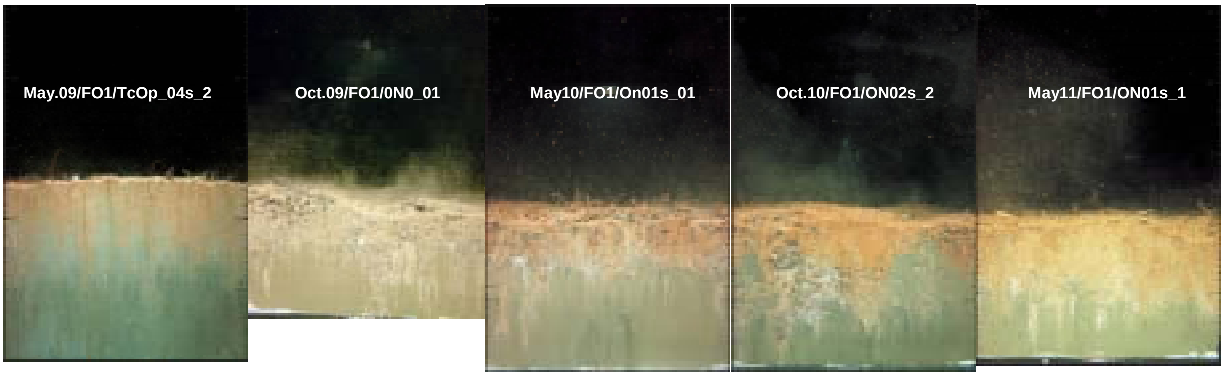
2.2 Mercury as tracer for cap thickness and recontamination

SPI was the primary tool used to distinguish between the added cap materials and the pre-cap sediments. SPI gives a high number of control points at which the cap thickness can be considered, but the identification of the boundary between the old sediment and the cap is not always easy to identify. This problem tends to increase with time after cap placement (**Figure 3**). Processes such as resuspension, bioturbation, lateral transport and sedimentation contribute to a gradual recontamination of the cap layers which may be better addressed more directly by chemical analyses of contaminants or particle tracers characteristic for the pre-cap sediment.

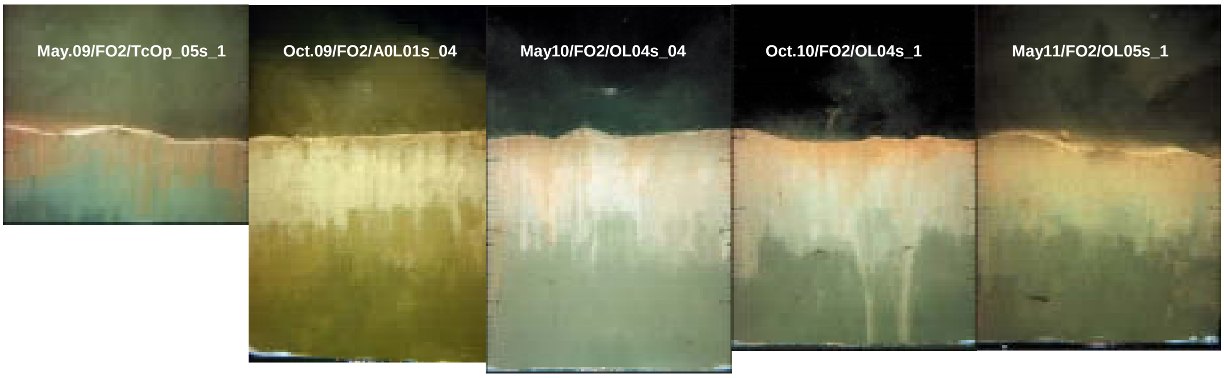
In addition to dioxins, the sediments in the Grenlandfjord are generally contaminated with mercury (Hg). Hg is more easily analysed than dioxins and it was therefore decided to use this metal as a tracer for the pre-cap sediments. The analyses were considered as an SPI-supplement for determination of cap thickness in October 2010 and recontamination of the top layer during the first year.



A) FO4, Ormefjorden reference field.

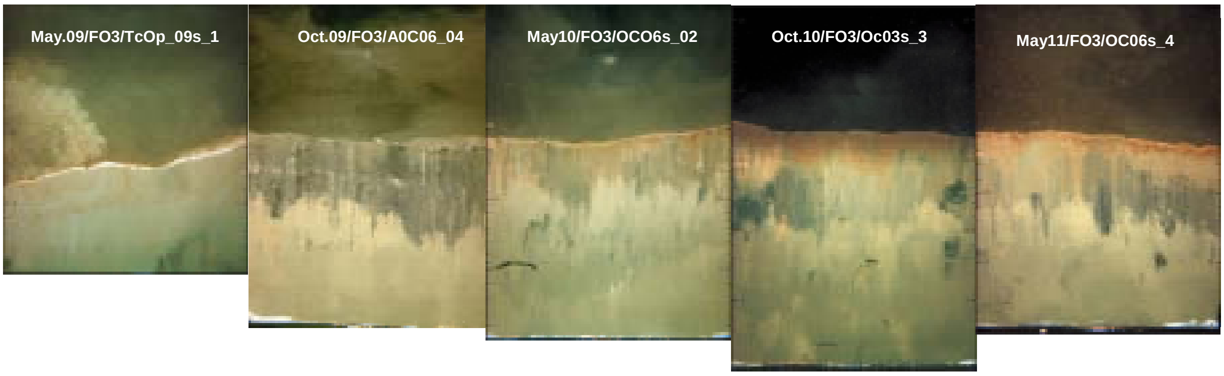


B) FO1, Ormefjorden NOAH (gravel)

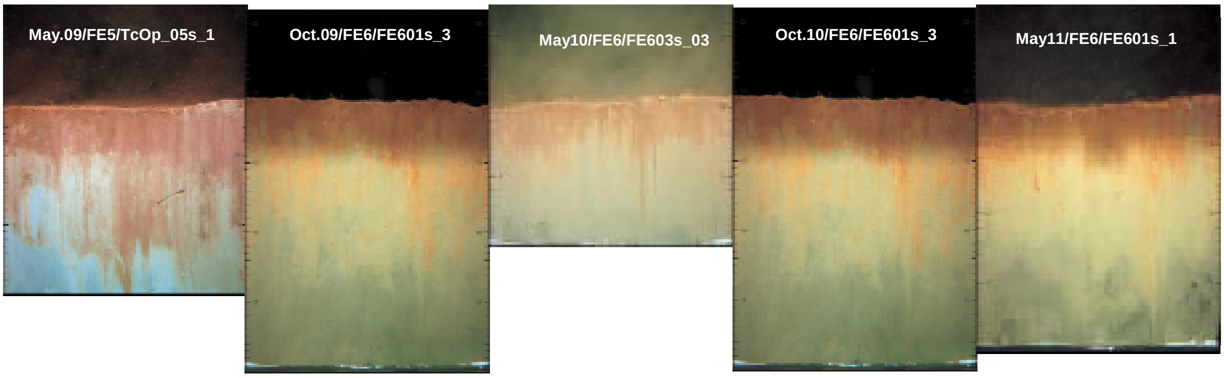


C) FO2, Ormefjorden dredged clay

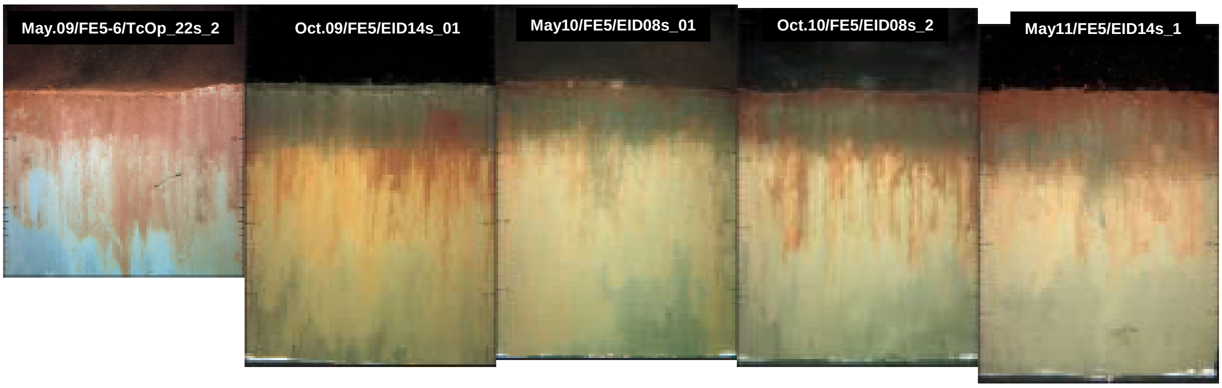
Figure 3. Continues next page…..



D) FO3, Ormefjorden Clay with activated carbon



E) FE6, Eidangerfjorden Reference field



F) FE5, Eidangerfjorden Dredged clay with activated carbon

Figure 3. SPI images from test fields in Ormefjorden (A-D) and Eidangerfjorden (E-F). Each plate displays a selected image from each survey in respectively May 2009, October 2009, May 2010, October 2010 and May 2011.

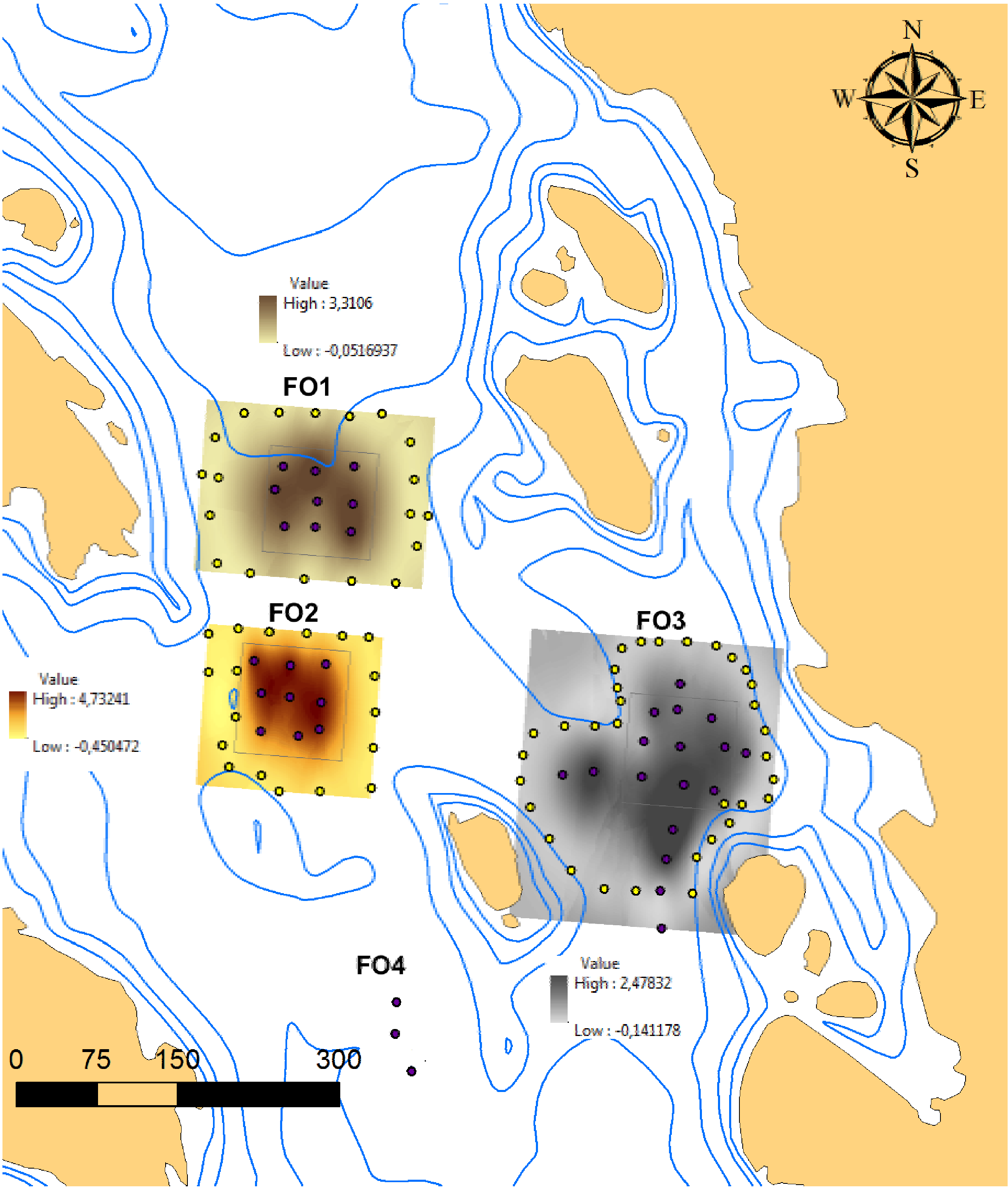


Figure 4. Thin cap material on the seabed in Ormefjorden in October 2009 as determined with SPI and modeled in ArcGIS using kriging. Dark points show SPI-stations. Yellow points are boundary points set to zero. Maximum layer thickness (cm) is indicated on separate color-scales for each field.

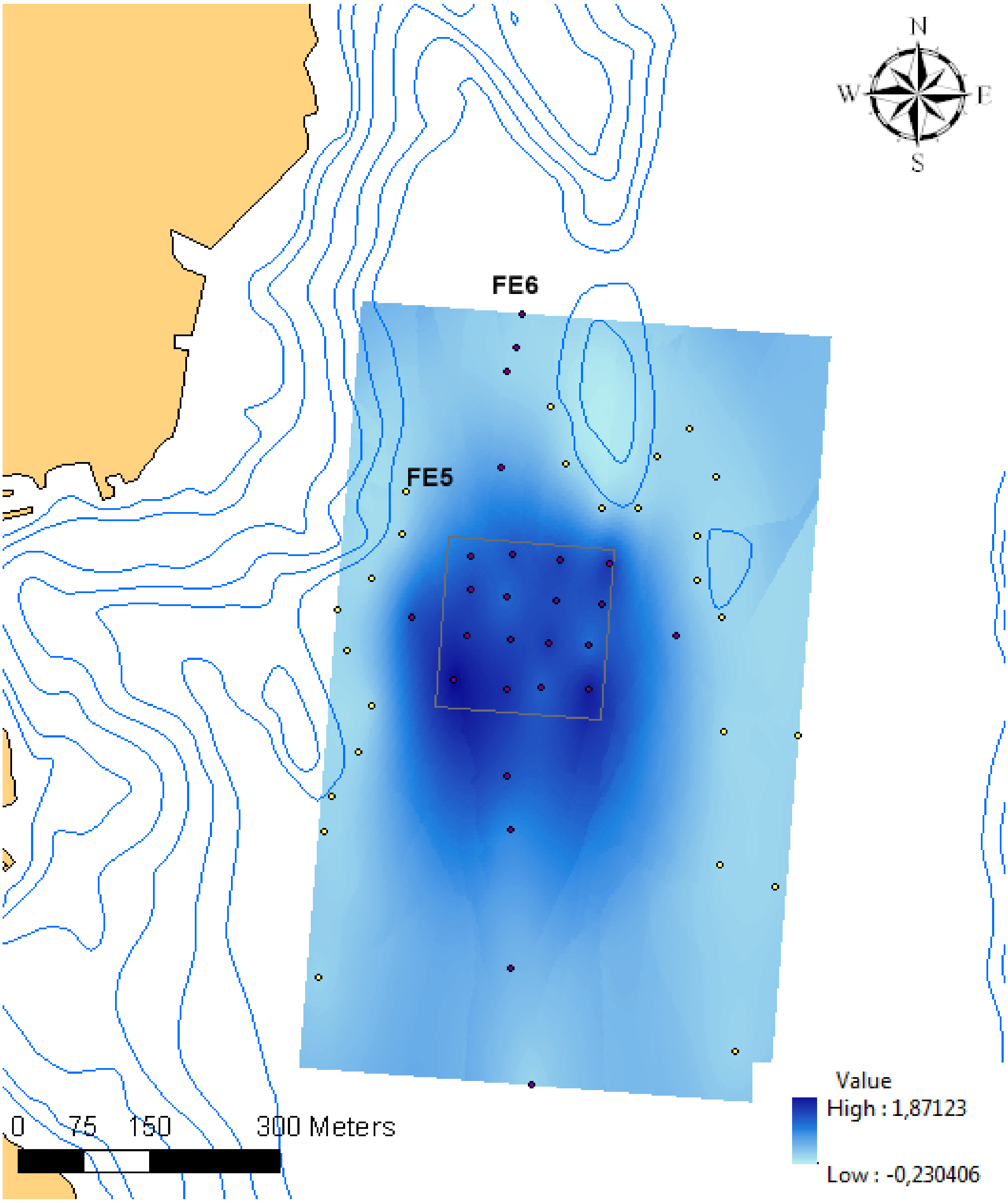


Figure 5. Thin cap material on the seabed in October 2009 as determined with SPI and modeled in ArcGIS using kriging. Dark points show SPI-stations. Yellow points are boundary points set to zero. Maximum layer thickness (cm) is indicated on color-scale inserted.

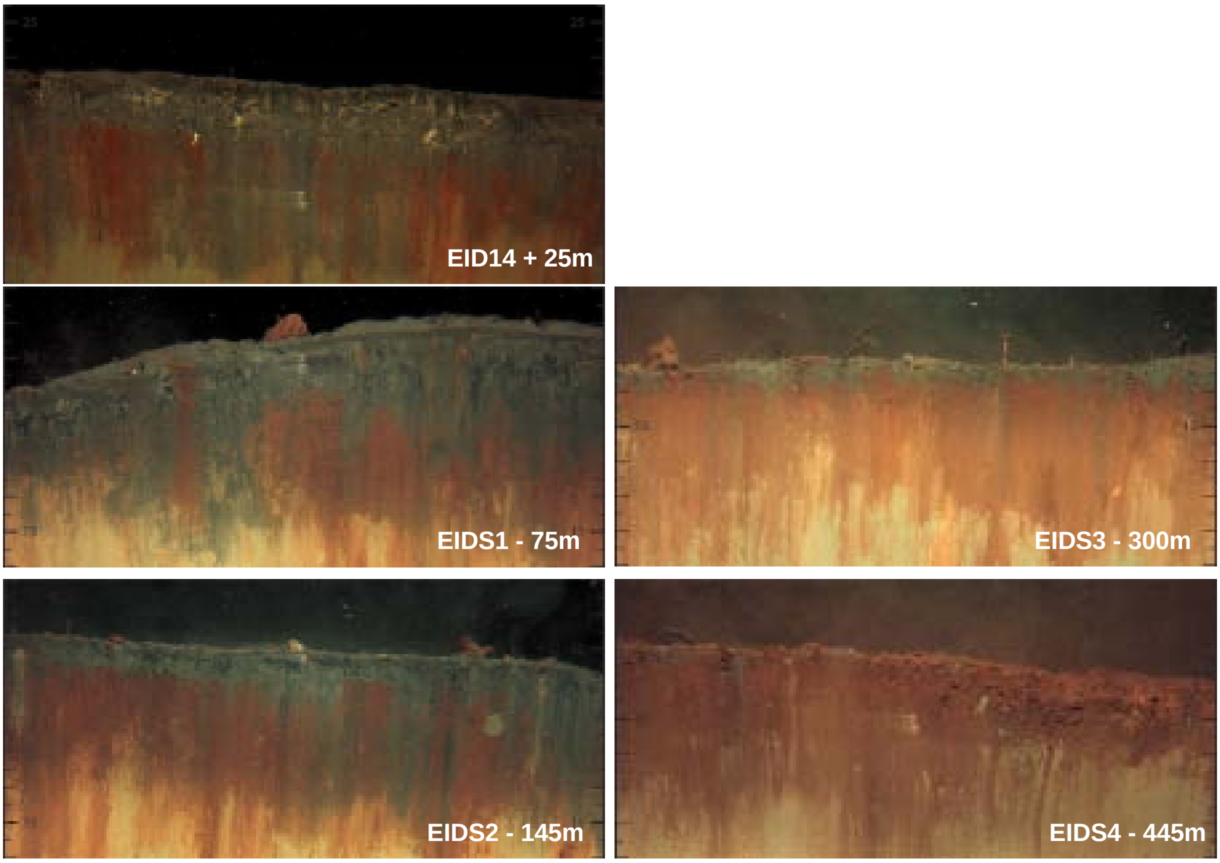


Figure 6. SPI images along a gradient extending up to 445 south of the southern bouandary of FE5.

The concentrations of Hg increased with depth at all stations (**Figure 7**). However, at all fields treated with thin caps, concentrations within the top few cm were lower than the lower 95% confidence limit calculated from the analyses at the reference fields in 2009. The analyses performed in 2010 generally confirmed the data from 2009 showing lowered concentrations of mercury down to

- 2 cm depth at Clay AC at 30 m depth (FO3).
- 2 cm depth at Clay AC at 100 m depth (FE5).
- 3 cm depth at Clay at 30 m depth (FO2).
- 4 cm depth at NOAH at 30 m depth (FO1).

This was reasonably consistent with the SPI-images (**Table 3**) which showed mean layer thickness of

- 1.05 cm at FO3.
- 1.31 cm at FE5.
- 2.08 cm at FO1.
- 4.05 cm at FO1.

The chemical analyses confirmed the thickness of the cap layers measured more accurately from a much higher number of stations analysed by the SPI images.

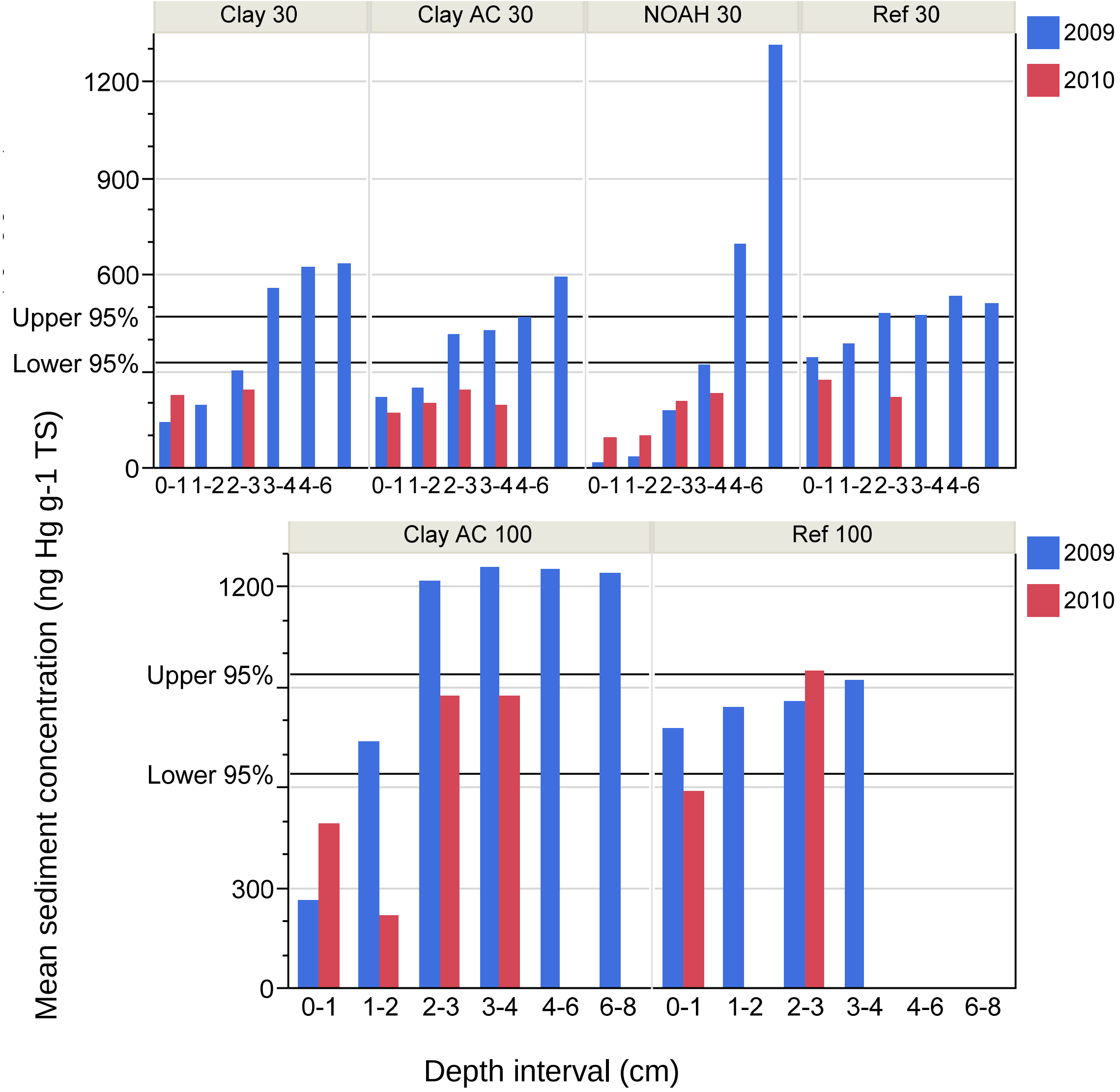


Figure 7. Concentrations of mercury in sediments from variously treated fields in Ormefjorden (upper diagram) and Eidangerfjorden (lower diagram) determined in boxcore samples collected in 2009 and 2010. Inserted reference lines shows 95% confidence limits calculated for the respective reference fields (Ref 30 in upper diagram and Ref 100 in lower diagram).

2.3 BHQ index

Because of the uncertainties with regard to determination of aRPD shortly after cap placement, two indices (BHQ, BHQ*) were determined throughout all surveys (see ch. 1.2). The uncertainty applied to aRPD and BHQ only and will decrease with time.

The time trend for the BHQ*-index (**Figure 8**) showed no clear trend at the reference stations FE6 and FO4. At FE6 typical BHQ* was 5-6. At FO4 typical BHQ* was about 4-5. At the two fields treated with clay and AC (FE5 and FO3), the figure shows a general decrease from about 6 in May 2009 to typical values of 2-5 in November 2010 and May 2011. At FO1 and FO2 BHQ* was about 6 before cap placement and in May 2011, but with several lower scores of typical 3-5 at intermediate surveys.

In May 2009, before the capping operation, the BHQ index at the sites of the planned test fields ranged from 8.3-11.0 in Eidangerfjorden and 7.0-10.3 in Ormefjorden (**Table 4**). According to the classification shown in **Figure 2** this corresponded to a *good* benthic habitat and the statistical comparison (ANOVA, Tukey-Kramer HSD, α= 0.05) showed no significant difference between any of the test fields. The mean

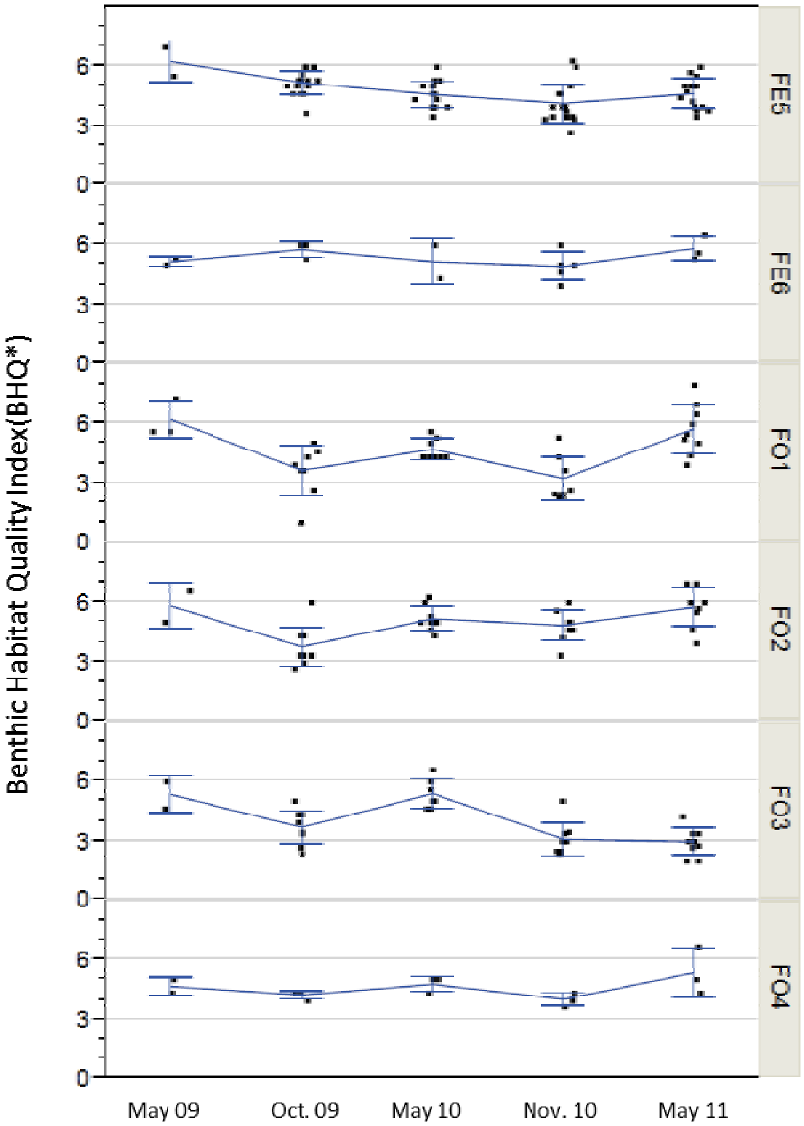


Figure 8. Benthic habitat quality index (BHQ*) determined at each field during the period May 2009 to May 2011. The index was here determined without the scores normally assigned for RPD-layer (see text). Vertical bars = 2 standard deviations.

BHQ was slightly lower in Ormefjorden (8.3) than in Eidangerfjorden (9.4) and it may also be noted that the reference field FO4 had lower BHQ (7.5) than the other fields in Ormefjorden (8.3-9.1).

Shortly after placement of the cap, FO1 had a low score, but in May 2010 BHQ showed *good* habitats at all fields. These data should however be considered with care because of the difficulties involved in the determination of RPD-scores at the capped fields. In November 2010 low scores gave *less good* conditions at FE5 (BHQ = 4.6) and FO3 (BHQ = 4.7). This trend was confirmed in May 2011 when these two fields again had the two lowest BHQ indexes. The statistical analyses showed that FE5 was significantly different from FE 6 both in November 2010 and May 2011. FO3, however, was significantly lower than FO4 in May 2011, only.

Thus, the BHQ index showed that in May 2011, 1.5 years after cap placement, the BHQ-index at the reference fields (FO4 and FE6) were similar to or slightly higher than in May 2009. The fields treated with coarse NOAH limestone (FO1) or clay (FO2) had higher BHQ index than in May 2009 and at the reference field (FO4), but the differences were not significant. However, both fields treated with clay and AC (FE5 and FO3) had obtained BHQ indices which were significantly lower than the corresponding reference fields and a decline in benthic habitat quality from *good* to *less good*.

Table 4. Mean BHQ index determined at test and reference fields before and after cap placement in September 2009 at FE5, FO1, FO2 and FO3. Colours show habitat classification. Green = *good*, yellow = *less good*. Letters show result of statistical analyses (ANOVA, Tukey-Kramer HSD, α=0.05) performed comparing all data at each occasion. Fields not connected by the same letter are significantly different.

	May 2009		Oct. 2009		May 2010		November 2010		May 2011	
FE5	A	10,0	A	9,1	A	7,7	C	4,4	B C	6,6
FE6	**A**	**8,8**	**A B**	**8,9**	**A**	**8,3**	**A**	**7,7**	**A**	**8,8**
FO1	A	9,1	B	6,8	A	7,9	B C	5,7	A	9,8
FO2	A	8,3	A B	7,7	A	8,8	A B	6,8	A	9,1
FO3	A	8,3	B	7,3	A	8,0	C	4,7	C	5,7
FO4	**A**	**7,5**	**A B**	**7,1**	**A**	**7,8**	**A B C**	**6,3**	**A B**	**8,4**

Table 5. Mean BHQ* index determined at test and reference fields before and after cap placement in September 2009 at FE5, FO1, FO2 and FO3. Letters show result of statistical analyses (ANOVA, Tukey-Kramer HSD, α=0.05) performed comparing all data at each occasion. Fields not connected by the same letter are significantly different.

	May 2009		Oct. 2009		May 2010		November 2010		May 2011	
FE5	A	6,3	A	5,2	A	4,6	A B	4,1	B	4,6
FE6	A	5,2	A	5,8	A	5,2	A	4,9	A B	5,8
FO1	A	6,2	B	3,6	A	4,7	B	3,2	A B	5,8
FO2	A	5,8	B	3,7	A	5,2	A	4,8	A	5,8
FO3	A	5,3	B	3,6	A	5,4	B	3,1	C	2,9
FO4	A	4,7	A B	4,2	A	4,8	A B	4,0	A B	5,4

2.4 Oxygen and redox potential profiles

2.4.1 Dissolved O_2

In Ormefjorden, the boxcores with uncapped sediments from reference field FO4, dissolved O_2 was observed to penetrate down to 7 - 10 mm (**Figure 9**). In boxcores with sediments from the fields treated with dredged clay (FO2) and dredged clay with AC (FO3), penetration of O_2 ranged was 4 - 8 mm. (The microelectrodes could not be used in sediments from FO1 because the fragile tip of the electrodes would break against the large grains of the added limestone cap material.) In Eidangerfjorden the downward penetration of O_2 was 7-14 mm in boxcores with sediment from the reference field (FE6) and 9-11 mm in the boxcores with sediments from the field treated with dredged clay and AC.

Thus, the microelectrode measurements did not reveal any clear difference between the O_2-profiles in capped and control sediments. The profiles are sensitive to changes in grain size and degradable organic carbon. In the mesocosm experiment (Näslund et al., 2011) improved O_2 penetration was observed in caps with large grain size and low concentration of organic carbon (sand, hyperite), but because of the fragile equipment this could not be confirmed in the samples from the limestone-gravel FO1. Improved penetration in coarse cap materials are likely to be a short-term effect because bioturbation and sedimentation of new, more fine grained material will slowly fill in the gaps between large particles. The remaining fields (FO2, FO3 and FE5) were all treated with dredged clay which was quite similar to the control sediments both with regard to organic carbon and grain size, and impacts on O_2 penetration was not expected. The measurements also confirmed that the activated carbon added at FO3 and FE5 had marginal effects on the O_2 penetration.

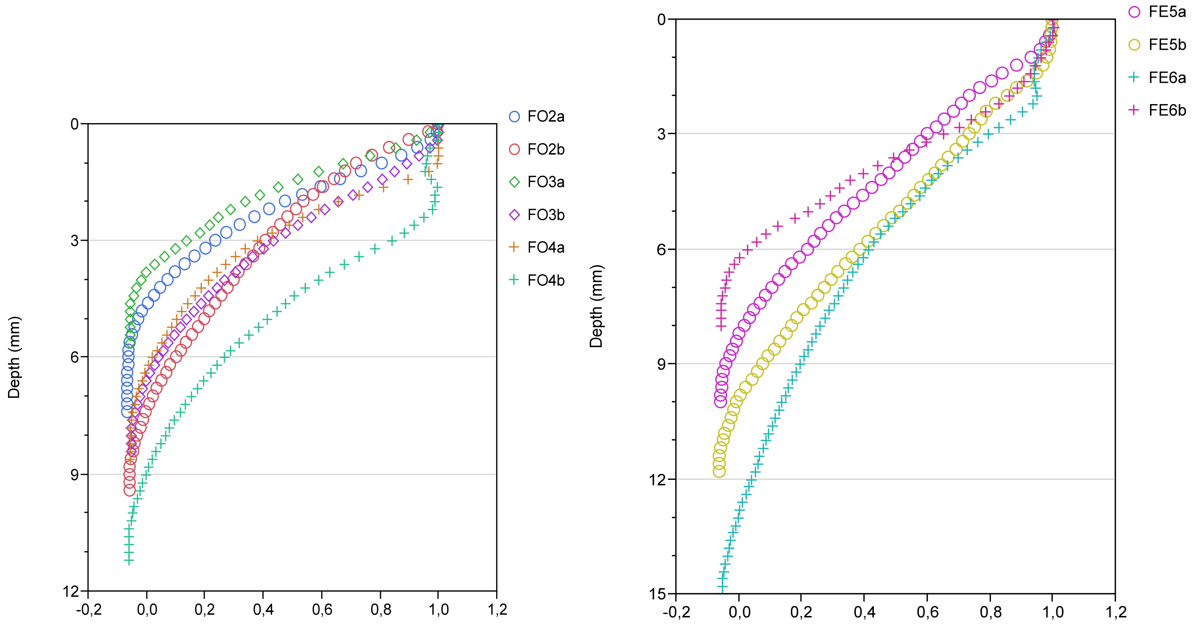


Figure 9. Vertical profiles of dissolved oxygen (O_2) in sediment boxes from Ormefjorden (left) and Eidangerfjorden (right). Unit = oxygen saturation.

2.4.2 Redox potentials

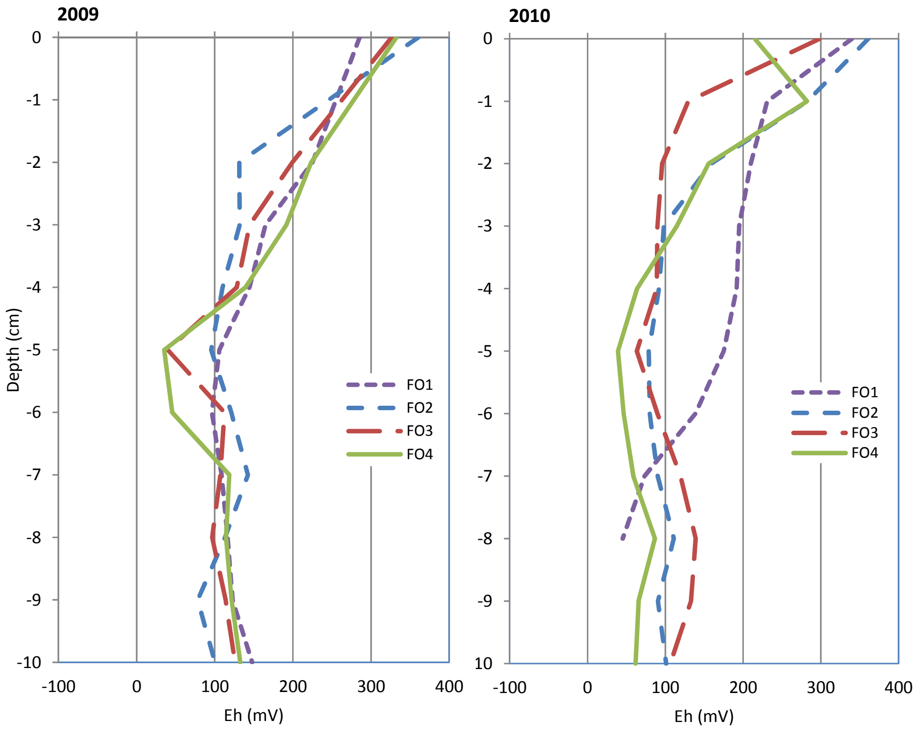
The redox potentials in Ormefjorden showed a general decline from 200-400 mV in the surface layer and transition to more stable recordings of typical 0-200 mV at about 5 cm depth (**Figure 10**).

At the sediment–water interface the redoxpotentials are controlled by the presence of oxygen. Below the surface O_2 is rapidly depleted (**Figure 9**) and electroactive redox couples such as Fe^{3+}/Fe^{2+} and Mn^{4+}/Mn^{2+} ubiquitously present in pore waters of marine sediments are frequently assumed to control intermediate E_h-levels (typical 0-200 mV). The absence of low potentials (<0mV) through the top 10 cm of the sediments, gave no evidence for presence of hydrogen sulphide in the pore water due to carbon sedimentation and insufficient deep water exchange. Irrigation by benthic organisms is frequently assumed to be the most important factor maintaining the E_h-gradient within the surface layer of the sediments.

In 2010 the mean redox profile from the clay-AC field (FO3) shows a slightly more reduced sediment layer in the top three cm compared to the reference field (FO4). Active carbon is inert and not likely to stimulate heterotrophic activity, but decay of dead animals might produce such deviation. The deviation was observed in replicate cores and therefore difficult to disregard as a random variation produced by one large animal. The redox profile rather indicated a general increase of the oxygen deficiency FO3 which was consistent with the reduced state of the macrofauna community at this field in 2010 (see chap.3).

In Eidangerfjorden a more pronounced transition was observed at about 5 cm depth (**Figure 10**), which may reflect differences between the two locations with regard physical factors, carbon loading and bioturbators.

Redox in Ormefjorden



Redox in Eidangerfjorden

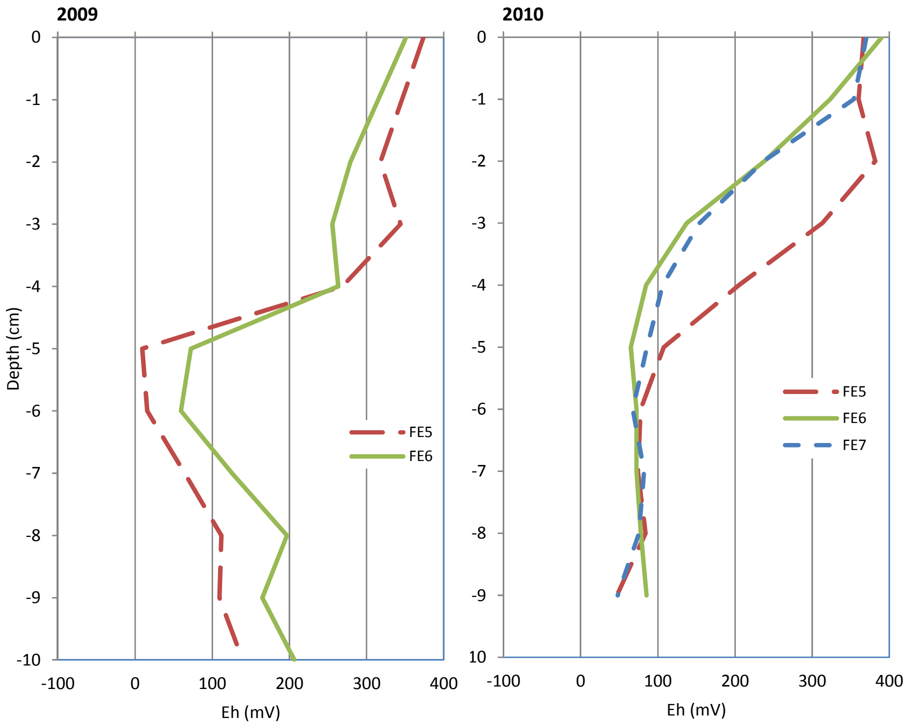


Figure 10. Redox potential profiles measured in sediments cores from Ormefjorden (top) and Eidangerfjorden (bottom) in October 2009 (left) and November 2010 (right). Mean profile measured in 3 cores from each field.

3. Macrofauna

A total of 4437 benthic organisms from 159 species were included in the analyses, where 1253 specimens (from 116 species) were from the 18 samples taken in 2009, and 3,184 specimens (from 123 species) were from the 35 samples taken in 2010.

3.1 Abundance

In Ormefjorden, total abundance varied from less than 100 ind. m^{-2} in the activated carbon capped field FO3 in 2010 to more than 900 ind. m^{-2} in the gravel capped field FO1 in 2010 (**Figure 11**a).

In Eidangerfjorden, the variation in abundance was smaller, from almost 700 ind. m^{-2} in the activated carbon field FE5 2009 to ca 1200 ind. m^{-2} in the two reference fields (FE6 and FE7) 2010 (**Figure 11**b). Polychaetes and molluscs were the dominant taxonomic groups. Echinoderms were also abundant in Ormefjorden, but not in Eidangerfjorden. Abundances of echinoderms, with the brittle stars (*Amphiura* sp.*)* as the most numerous taxa, were strongly reduced in the activated carbon fields, primarily in Ormefjorden but also at FE5 in Eidangerfjorden compared with FE6.

Ormefjorden showed very low numbers of crustaceans, only 36 specimens over the two years, in average 1.1 ind. per sample (10 ind. m^{-2}). More than half of these (20 specimens) were found in the reference field FO4. 10 were found in gravel FO1, 5 in clay FO2 and only one single specimen of the deep digging *Calliannassa subteranea* in the activated carbon field FO3 the first year. In comparison Eidangerfjorden had 143 crustaceans, an average of 6.8 ind. per sample (59 ind.m^{-2}).

The PERMANOVA analyses revealed significant differences between fields in both Ormefjorden (p=0.001) and Eidangerfjorden (p=0.014) and Year*Field interactions in Ormefjorden (**Table 7**a). The post-hoc tests (**Table 7b**) showed lower abundance in the clay-AC capped field FE5 compared to both reference fields FE6 (p=0.011) and FE7 (p=0.042), which were not different from each other (p=0.822). In Ormefjorden, abundance was lower (p<0.001) at the clay-AC field FO3 than at the reference field FO4 and decreased (p=0.007) from 2009 to 2010 (**Table 7**c and **Figure 11**). The clay capped field FO2 had higher abundance than the reference field in 2009 (p=0.008), and the limestone gravel field (FO1) was not significantly different from the reference field neither in 2009 nor in 2010. Divergent development in the different plots can explain the significant Year*Field interaction in Ormefjorden, where the severe drop in the AC field between 2009 and 2010 describes a development quite different from the stable or increasing trends for the other treatments.

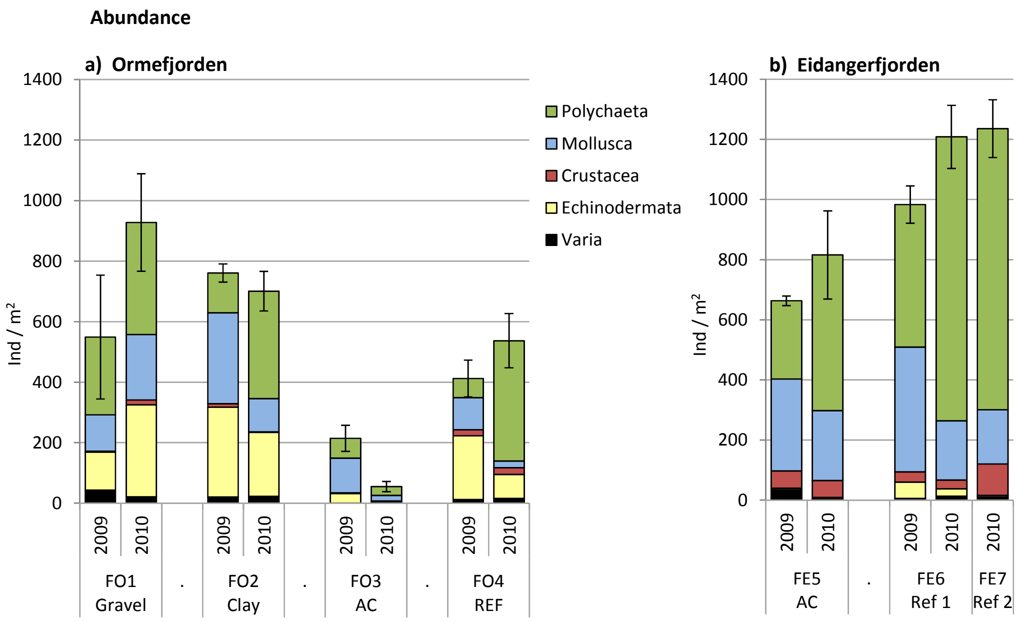


Figure 11. Macrofauna abundance (mean ± SE) at test fields in the Grenland fjord area surveyed in 2009 and 2010.

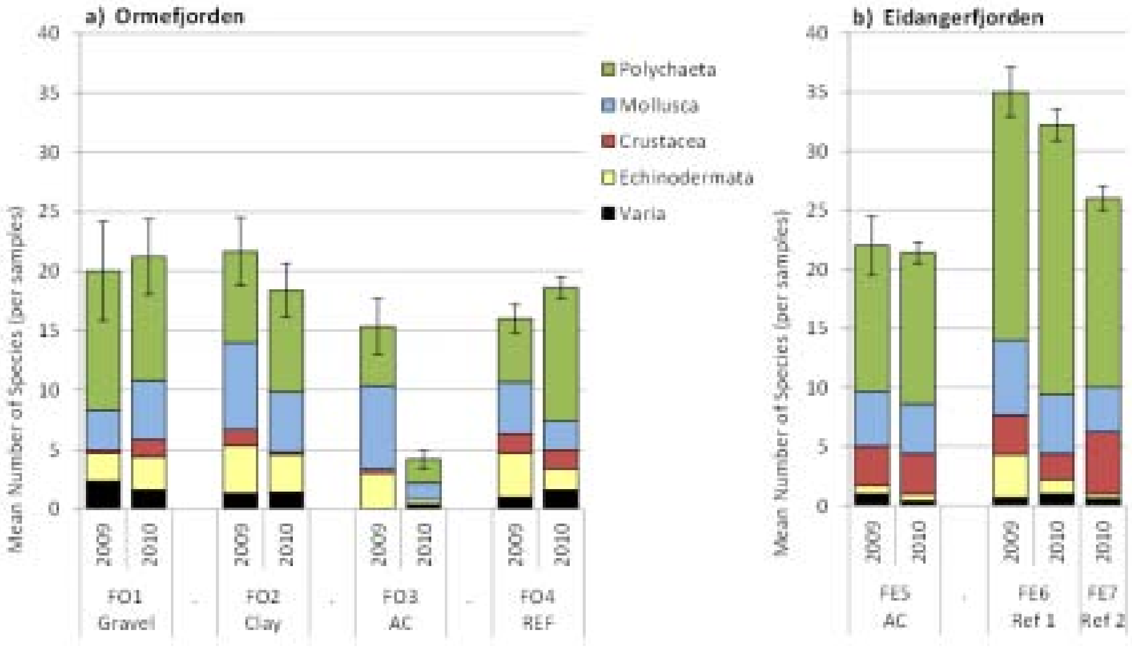


Figure 12. The number of macrofauna species/sample (mean ± SE) in samples collected in 2009 and 2010 in the test fields in the Grenland fjord area.

3.2 Number of species

The number of species (**Figure 12**) varied from 3-7/sample at the clay-AC field FO3 in 2010 to 32-39/sample at the reference field FE6 in Eidangerfjorden in 2009. The reference fields showed higher number of species in Eidangerfjorden (23-39 /sample) than in Ormefjorden (14-21 /sample).

Polychaete worms were almost always the largest group in both fjords, followed by molluscs. Molluscs appeared little affected by the clay-AC treatment compared to the relatively large reduction in numbers of polychaetes and echinoderms. The large bioturbating sea urchin *Brissopsis lyrifera* decreased from 0.7/sample in the reference fields to 0.4/sample at FO3 and 0.1/sample at FE5. Low numbers of crustacean species were seen in Ormefjorden, and benthic amphipods were almost absent.

The PERMANOVA analyses (**Table 7a**) showed significantly different number of species between the test fields in both Ormefjorden and Eidangerfjorden and significant Year*Field interactions in Ormefjorden. In Eidangerfjorden, the two reference sites FE6 and FE7 were different ($p=0.013$) from each other (**Table 7b**), with lower number of taxa at the deepest location (FE7). However, the clay-AC capped sediments at FE5 had fewer taxa ($p\leq0.037$) than both reference fields (**Figure 12**b, **Table 7b and c**). In Ormefjorden the number of species was lower ($p=0.001$) in the clay-AC capped field FO3 than in the reference field FO4 (**Table 7b**) and decreased ($p=0.002$) from 2009 to 2010 (**Table 7c**). Capping with limestone gravel (FO1) or clay (FO2) gave no significant effects on the number of species (**Table 7**b,**c**).

3.3 Biomass

The total biomass of macrofauna (**Figure 13**) varied from ca 10 g m^{-2} (wet weight) in the clay-AC capped FE5 in Eidangerfjorden in 2009 to more than 180 g m^{-2} in the clay capped FO2 in both 2009 and 2010.

The PERMANOVA analyses showed a significant difference between the test fields in both fjords and a significant Year*Field interaction in Ormefjorden (**Table 7a**). The post-hoc test showed that in Eidangerfjorden the biomass was lower ($p=0.009$) in the clay-AC capped FE5 than in the reference field FE6, but not compared to the deeper REF2 (**Table 7b**), and primarily in 2009 ($p=0.036$) (**Table 7**c). In Ormefjorden, significant differences were only found in pairwise comparisons among the three capped fields (FO2>FO1 and FO2>FO3), and not between any one of the capped fields and the reference field (FO4) (**Table 7**b). However, the biomass at the clay-AC field FO3 decreased ($p=0.021$) from 2009 to 2010 to become less than ($p=0.044$) the biomass at the reference field FO4 (**Table 7**c).

The sea urchins *Brissopsis lyrifera* and *Echinocardium cordatum* frequently constituted a large fraction of the total as well as of the Echinoderm biomass. Thus, the loss of biomass at FO3 from 2009 to 2010 was primarily a result of a reduction from 2 to 0.2 sea urchins/sample. An opposite development was found at the limestone gravel field FO with the recurrence of 1.4 sea urchins/sample in 2010 compared to complete absence shortly after the capping operation in 2009.

3.4 Ecological status

In Ormefjorden, at the reference field FO4 and the fields capped with clay and gravel, the BQI-index varied between 8 and 10 and no clear difference was found between 2009 and 2010. This BQI correspond to a *moderate* ecological status (**Figure 14**, **Table 6**). At the clay-AC field FO3, however, the index decreased from 8 in 2009 (*moderate* ecological status) to 2.5 in 2010 (*bad* ecological status). Similarly, the Shannon-Wiener index showed *bad* ecological status on the clay/AC field FO3 in 2010 compared to *good* status on all other field assessments in Ormefjorden.

In Eidangerfjorden BQI >12 corresponded to *good* or *high* ecological status for all samples collected at the FE5, FE6 and FE7. Both BQI and H' indices showed class I (high/very good) both years at the initial reference location (FE6) and class II (good) both years at the clay/AC field (FE5) and the second reference station (FE7) added in 2010.

The PERMANOVA analyses revealed significant differences in BQI between the fields (p=0.001) in both Eidangerfjorden and Ormefjorden (**Table 7a**). In addition Ormefjorden provided significant effects of Year (p=0.002) and Year*Field interactions (p=0.001). In Eidangerfjorden, the post-hoc test (**Table 7**b) showed lower BQI (p=0.048) at FE7 than at FE6, but both reference fields had higher BQI (p≤0.007) than the clay AC field FE5. Thus, although the diversity indices showed *good* or *very good*/*high* ecological status on all fields in Eidangerfjorden, the statistical analyses revealed a significant impact of the clay-AC cap both in 2009 and 2010. In Ormefjorden, however, the clay-AC field was not different from the reference field in 2009, but a major decline from 2009 to 2010 (p=0.003) resulted in different BQI (p=0.001) at the clay-AC and reference fields in Ormefjorden in 2010 (**Table 7**c). At the limestone gravel (FO1) and clay (FO2) fields BQI was not different (p≥0.191) from the BQI at the reference field FO4 neither in 2009 nor 2010.

The significant Year*Field interaction for all univariate parameters in Ormefjorden, appeared to result from the severe development at the AC field between 2009 and 2010 which was quite different from the stable or increasing trends at the other fields.

Table 6. Ecological status based on median BQI and Shannon-Wiener indices. Classification and colour coding: Class I) High or Very good, Class II) Good, Class III) Moderate, Class IV) Poor or Bad, Class V) Bad or Very bad
Note that class numbers are identical, but phrases are different, in the two classification systems (see ch.1.5.2).

		BQI 2009	H'(log2) 2009	BQI 2010	H'(log2) 2010
FE5	Clay/AC	13,7	3,73	13,0	3,57
FE6	REF1	15,9	4,20	15,8	4,26
FE7	REF2			14,9	3,78
FO1	Limest. gravel	9,67	3,54	10,5	3,22
FO2	Clay	11,1	3,58	9,24	3,11
FO3	Clay/AC	8,18	3,51	2,21	1,58
FO4	REF	8,74	3,05	9,65	3,10

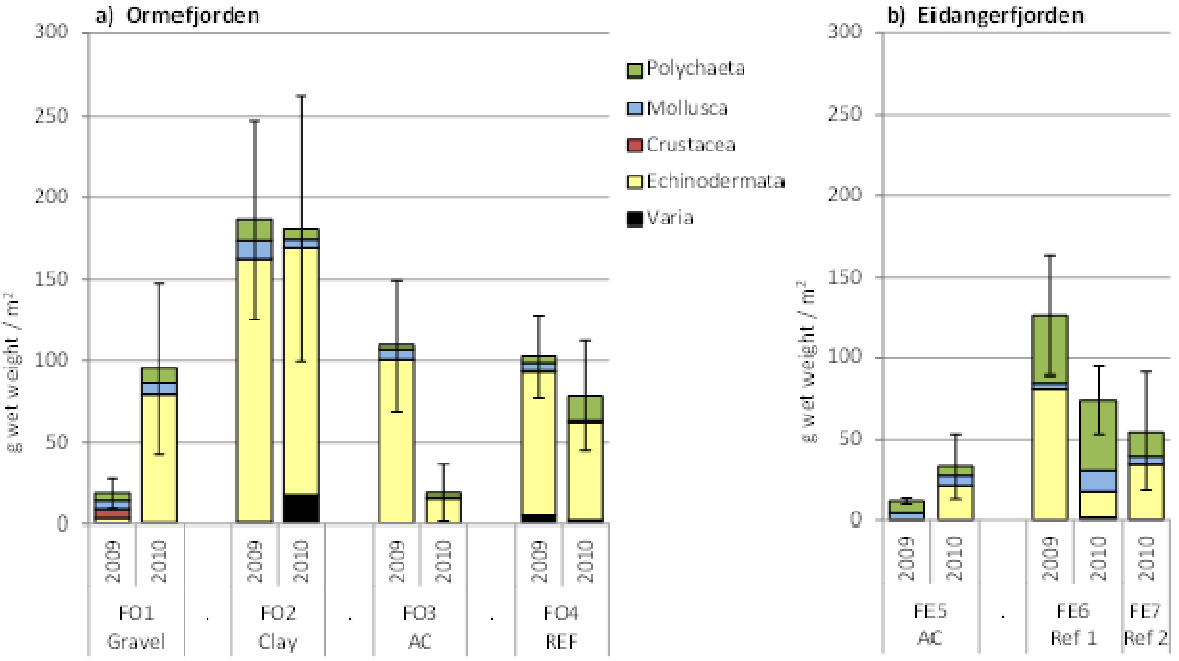


Figure 13 Macrofaunal biomass (mean ± SE) at the test fields in the Grenland fjord area surveyed in 2009 and 2010.

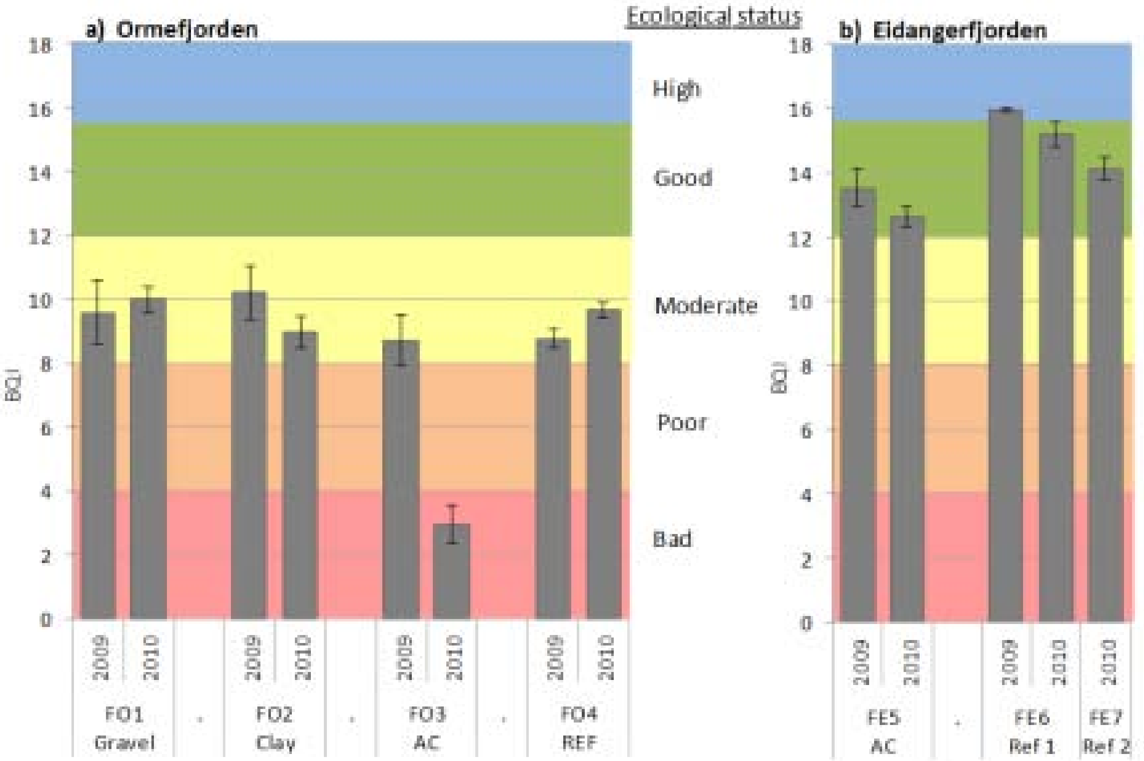


Figure 14. BQI index (mean ± SE) in the test fields in the Grenland fjord area surveyed in 2009 and 2010.

Table 7. Results from PERMANOVA analyses. Compilation of relevant p-values, for all statistical analyses of four univariate endpoints (*total abundance, species richness, total biomass* and *BQI*) and the multivariate *benthic community*. p-values <0.05 are shown in bold, red numbers and considered evidence for a significant effect of the cap on benthic variables

a. Two-factor PERMANOVA analyses			**p-values**				
Fjord	Factor	df	Abundance	Species Richness	Biomass	BQI	Benthic Community
Eidangerfjorden	Year	1	0.137	0.258	0.599	0.057	**0.001**
	Field	2	**0.014**	**0.001**	**0.046**	**0.001**	**0.001**
	Year*Field[1]	1	0.752	0.515	0.217	0.887	**0.014**
Ormefjorden	Year	1	0.375	0.119	0.192	**0.002**	**0.001**
	Field	3	**0.001**	**0.002**	**0.017**	**0.001**	**0.001**
	Year*Field	3	**0.002**	**0.042**	**0.017**	**0.001**	**0.001**

b. Post-hoc pairwise tests		**p-values**				
Fjord	Pairwise comparison	Abundance	Species Richness	Biomass	BQI	Benthic Community
Eidangerfjorden	**AC** (FE5) vs **REF1** (FE6)	**0.011**	**0.001**	**0.009**	**0.002**	**0.001**
	AC (FE5) vs **REF2** (FE7)	**0.042**	**0.037**	0.563	**0.019**	**0.014**
	REF1 (FE6) vs **REF2** (FE7)	0.822	**0.013**	0.660	**0.037**	**0.002**
Ormefjorden	**GR** (FO1) vs **REF** (FO4)	0.245	0.215	0.149	0.289	**0.001**
	CL (FO2) vs **REF** (FO4)	**0.008**	0.132	0.199	0.432	**0.021**
	AC (FO3) vs **REF** (FO4)	**0.001**	**0.001**	0.085	**0.001**	**0.001**

c. Post-hoc pairwise tests (one-factor)			**p-values[2]**				
Fjord	Pairwise comparison		Abundance	Species Richness	Biomass	BQI	Benthic Community
Eidangerfjorden	**AC** (FE5) vs **REF1** (FE6)	2009	**0.005**	**0.016**	**0.036**	**0.019**	0.100
	AC (FE5) vs **REF1** (FE6)	2010	0.057	**0.001**	0.198	**0.002**	**0.003**
	AC (FE5) vs **REF2** (FE7)	2010	0.052	**0.015**	0.638	**0.021**	**0.038**
	REF1 (FE6) vs **REF2** (FE7)	2010	0.852	**0.003**	0.650	0.067	**0.006**
	2009 vs 2010	**AC** (FE5)	0.478	0.736	0.458	0.196	**0.003**
	2009 vs 2010	**REF1** (FE6)	0.166	0.287	0.245	0.165	**0.034**
Ormefjorden	**GR** (FO1) vs **REF** (FO4)	2009	0.854	0.387	0.078	0.488	**0.039**
	GR (FO1) vs **REF** (FO4)	2010	0.074	0.409	0.811	0.529	**0.010**
	CL (FO2) vs **REF** (FO4)	2009	**0.010**	0.127	0.377	0.191	0.226
	CL (FO2) vs **REF** (FO4)	2010	0.167	1.000	0.259	0.248	**0.028**
	AC (FO3) vs **REF** (FO4)	2009	**0.042**	0.902	0.902	0.946	**0.021**
	AC (FO3) vs **REF** (FO4)	2010	**0.001**	**0.001**	**0.044**	**0.001**	**0.025**
	2009 vs 2010	**AC** (FO3)	**0.007**	**0.002**	**0.021**	**0.003**	0.062
	2009 vs 2010	**CL** (FO2)	0.446	0.437	0.688	0.215	0.129
	2009 vs 2010	**GR** (FO1)	0.186	0.823	0.116	0.703	0.135
	2009 vs 2010	**REF** (FO4)	0.400	0.109	0.403	0.082	**0.020**

[1] Term has one or more empty cells, since field FE7 was not introduced in 2009.

[2] Monte Carlo sampling.

3.5 Multivariate analyses

The non-metric multidimensional scaling plot (nMDS) in Eidangerfjorden (**Figure 15**) showed a fairly clear separation between all year*field groups, and a major separation between the clay-AC field (AC FE5 2009 and AC FE5 2010) in the lower part of the diagram and the reference fields (REF1 FE6 and REF2 FE7) in the upper part. The two-factor PERMANOVA analyses of benthic community (**Table 7a**) confirmed the separation in the plot by showing significant effects of Fields (p=0.001) and Year (p=0.001). The post-hoc test indicated that the significant Year*Field interaction (p=0.014) resulted from the lack of difference between FE5 and FE6 in 2009 (p=0.100), but diverged significantly ($p \leq 0.034$) to become different in 2010 (p=0.003). Thus, the development from 2009 to 2010 gave no evidence for recovery of the benthic community at FE5.

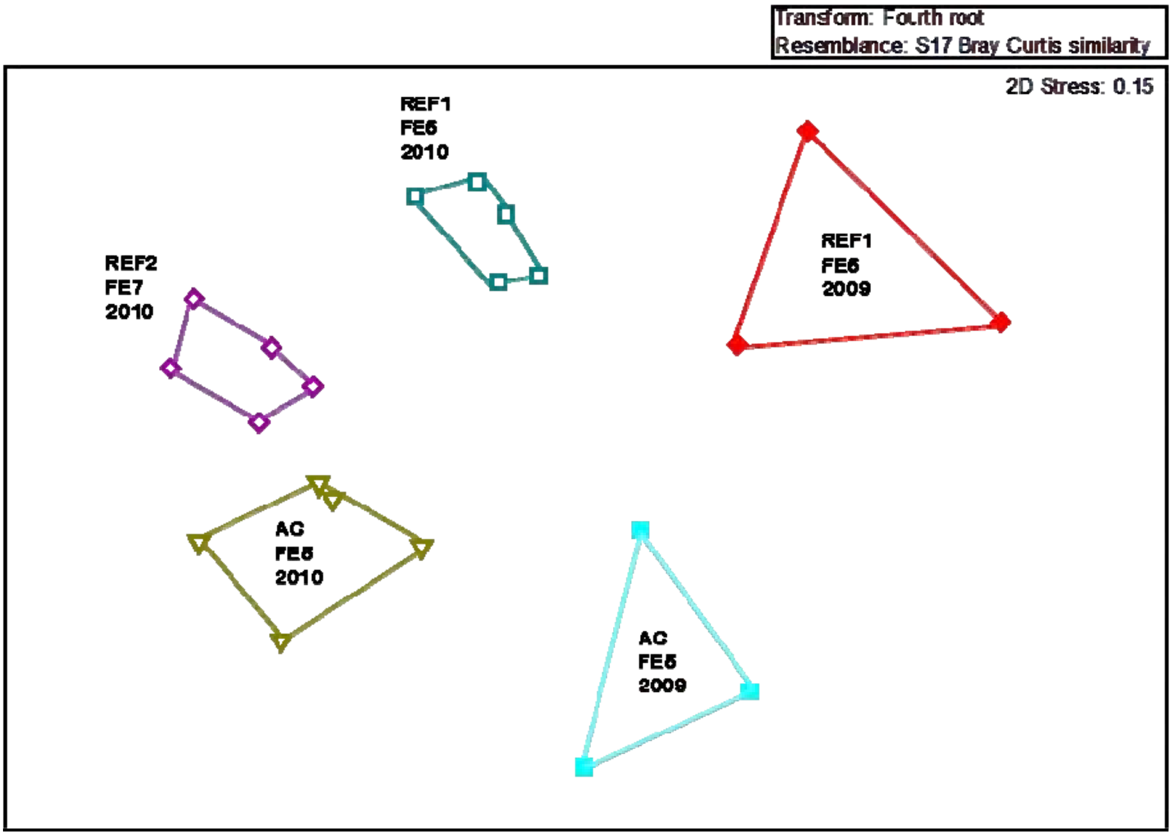


Figure 15. MDS plot showing similarity between the macrobenthic communities analysed in each sample in Eidangerfjorden in 2009 (3 replicates) and 2010 (5 replicates). AC, activated carbon treatment at ca 96 meters depth; REF1, reference field at ca 85 m, sampled in 2009 and 2010; REF2, reference field at ca 100 m, sampled in 2010.

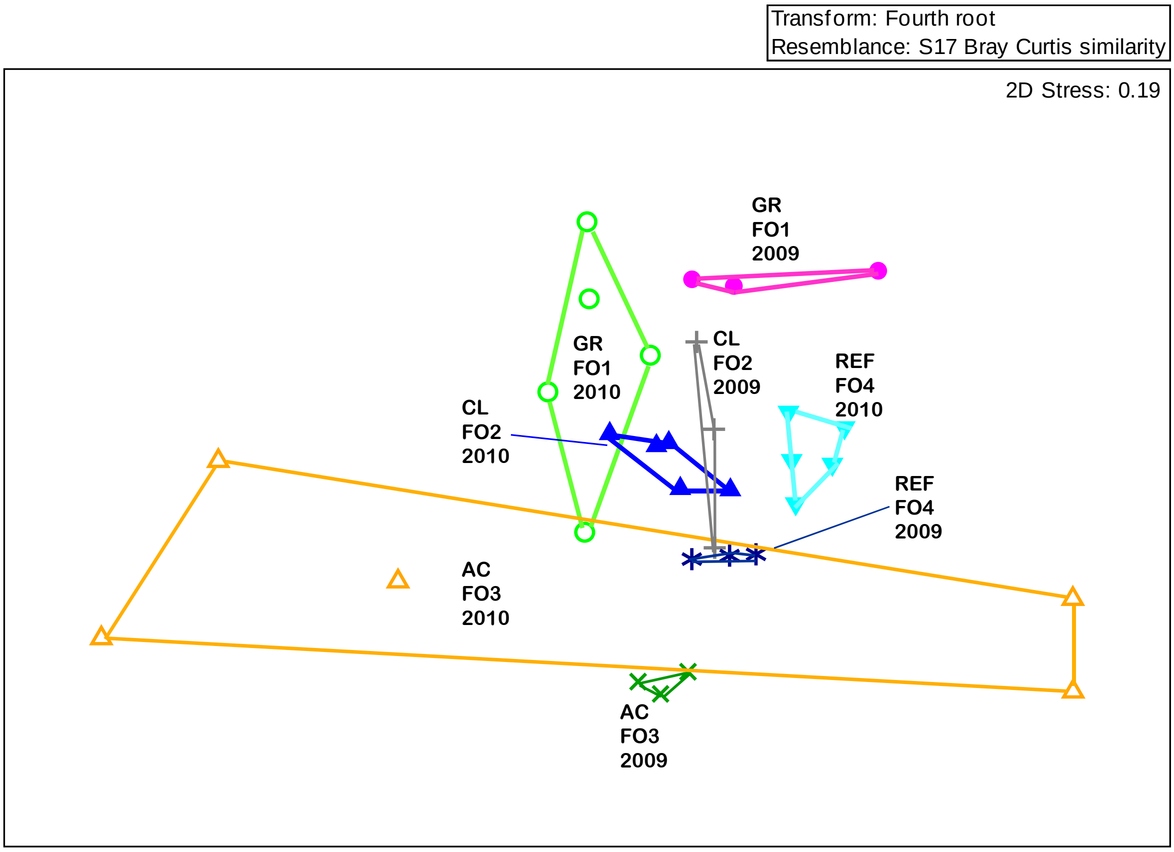


Figure 16. MDS plot showing similarity between the macrobenthic communities analysed in each sample in Ormefjorden in 2009 (3 replicates) and 2010 (5 replicates). GR, limestone gravel treatment field at 30 meters depth; CL, clay capped field at ca 30m; AC, activated carbon treatment at 28 meters; REF, reference field at ca 30 m; REF2, reference field at ca 100 m, sampled in 2010.

In the nMDS-plot for Ormefjorden (**Figure 16**), all eight samples from the clay cap field FO2 are grouped close together near the center of the diagram with the reference samples (FO4) 2010 to the right, and gravel samples (FO1) forming a semicircular group above and to the left. Compared to this cluster, the samples from the clay-AC cap FO3 field was clearly displaced downwards in the diagram both in 2009 and 2010. Also the reference samples (FO4) from 2009 occurred in the lower part of the diagram. The PERMANOVA analyses (**Table 7**a) showed significant effects (p=0.001) of both Field and Year as well as Year*Field interactions, and the post-hoc analyses (**Table 7**b) showed that the benthic community in all thin cap treatments was significantly different from the benthic community in the reference field (p≤0.021). The analyses seemed to suggest that because the clay field community (FO2) was different from the reference field community (FO4) in 2010 only, the significant change of the reference field community from 2009 to 2010 was the main reason for the diverging development and the Year*field interaction.

4. Discussion

The field sites were not sampled for macrofauna analyses before cap placements and there is a possibility that the reference fields had an inherently different fauna compared to the cap treatments. The habitat quality index (BHQ) was, however, determined from SPI-images taken in May 2009. These data showed that in both fjords, before capping BHQ was lower at the reference field than at the fields selected for capping, but the differences were not statistically significant (Table 4). After capping the BHQ index varied considerably, but comparison of the initial and final surveys showed that in Eidangerfjorden BHQ had not changed at the reference field, but it had decreased from 10.0 to 6.6 at the clay-AC field, which corresponded to a decrease of the benthic habitat quality from *good* to *less good*. In Ormefjorden, BHQ increased at the reference field from 7.5 in May 2009 to 8.4 in May 2011, but the classification remained unchanged *good*. Also the clay and limestone gravel fields showed increased BHQ index, but unchanged classification as *good* benthic habitats (Table 4). At the clay-AC field, however, BHQ decreased from 8.3 to 5.7 which corresponded to a change from *good* to *less good* benthic habitat. It may be added that in May 2011, the benthic habitat quality index at both clay-AC fields was significantly different from the index at the respective reference fields. Thus, the SPI-investigation and picture analyses showed that during the first 20 months after cap placement, the quality of the benthic habitat remained more or less unchanged at the reference fields and at the clay and limestone gravel fields, but declined slowly at both clay-AC fields.

The multivariate analysis of the macrofauna communities (PERMANOVA) showed that all sediments treated with thin caps were significantly different from the communities at the respective reference fields. For the clay-AC fields the difference was clearly a result of loss of individuals, species and diversity compared to the reference fields. At the limestone gravel and clay fields in Ormefjorden, however, these parameters were consistently higher than at the reference field. Thus, even though the PERMANOVA analyses showed significantly different communities it could not be concluded that capping had had a negative effect at these two fields. The reference field in Ormefjorden was the only field at which the benthic community changed significantly from 2009 to 2010 (**Table 7**c) and the MDS plot indicated a development away from the clay-AC field towards greater similarity to the clay and limestone gravel fields, at least in the vertical direction. Also, the univariate parameters showed a simultaneous increase of abundance and number of taxa at (**Figure 11** and **Figure 12**) and an improved ($p=0.082$) BQI index. As showed above, before capping the BHQ index was low at the reference field in Ormefjorden. Therefore the significant positive deviations of the macrofaunal communities at the clay and limestone gravel fields were more likely a result of inherent differences, rather than a positive effect of capping.

In the sediments with clay-AC cap in Ormefjorden, the benthic community was significantly different from the reference sediments both years. The MDS-plot showed increased heterogeneity in 2010 compared to 2009, and the univariate parameters declined from 2009 to 2010 with regard to number of species, individuals and diversity as well as a major decrease of biomass. In Eidangerfjorden, the benthic communities at the clay-AC and REF1 diverged to become significantly different in 2010 and the univariate tests showed a significant decrease in abundance, species richness and diversity compared to both reference fields and a lower biomass compared to REF1. This clearly showed adverse effects of the clay-AC cap.

The observed changes at the clay-AC fields seemed to confirm the results from the mesocosm experiment reported by Näslund et al., 2011. In this experiment, 14 species survived for five months in boxes treated with a 2 mm layer of activated carbon as compared to 16-24 species in boxes treated with 2 cm clay or sand and 27 species in control boxes with no cap (**Table 8**). PERMANOVA analyses of the benthic communities showed no significant difference between the treatments shown in the table, but the number of species was significantly reduced compared to control in all but the sand treatment. The hyperite was a crushed stone material which with respect to sharp edges and particle size was not unlike the limestone gravel used in the field experiment. As shown in the table, more species survived in the sand and hyperite than in the clay treatments. When comparing mesocosm and field experiments it is important to keep in mind the very limited recruitement in the mesocosm compared to field where recolonisation will take place. The good performance of the limestone material in the field experiment and the sand and hyperite treatments in the mesocosm, should therefore be considered with care. Only prolonged field investigations would be able to reveal wether or not particle size and shapes are factors which become important in the long-term development of community structure. Because of the continuous input of new, organic carbon from the water column, the low concentration of organic carbon in the added mineral materials is less likely to be an important factor in this respect. In spite of the much smaller thickness of the added AC-layer, activated carbon had significant effects at several of the experimental end points and was therefore ranked to be more harmful than the clay and sand treatments, as confirmed in the field experiment.

Table 8. Number of species retrieved in four replicate box-core samples five months after cap placement (Data from Näslund et al., 2011).

Cap material (thickness)	Number of species		Std.dev.
Control	27,0	±	5,7
Clay suspended (2 cm)	16,5	±	2,9
Clay cut (2 cm)	17,3	±	4,1
Sand (2 cm)	23,3	±	3,8
Hyperite sand (2 cm)	19,3	±	1,0
Active carbon (2 mm)	14,3	±	5,0

The effects of the clay-AC cap were observed in both fjords, and no evidence was found for recovery during the investigation period. The gravel- and clay-caps without AC had no significant effects on the benthic communities. It should also be added that both of the latter caps were thicker than the clay-AC caps (**Table 3**). It follows that AC was the primary factor explaining the negative impact on the benthic communities observed in both clay-AC test fields.

The mechanism explaining the effects of active carbon is beyond the scope of this work. One hypothesis could be that labile organic substances, which represent important food items for deposit feeders, also bind to active carbon and thereby reduce food availability for deposit feeders. A closer consideration of the species composition provide some support for this hypothesis. The species lists for the clay-AC field in Ormefjorden was dominated almost exclusively by carnivores, suspension feeders or mussels feeding on symbiotic bacteria living in their gills. The opportunistic deposit feeder *Scalibregma inflatum* was hardly present at the clay-AC fields in 2010 with two individuals identified in Ormefjorden and one in Eidangerfjorden compared to 16-137 individuals at each of the other fields (FO1, FO2, FO4, FE6 and FE7). The brittle star *Amphiura* sp and the sea urchin *Brissopsis lyrifera* were the dominant echinoderms in both fjords. Both species were clearly depleted with a total of 6 brittle stars and 4 sea urchins at the two fields treated with clay-AC as compared to 130 brittle stars and 13 sea urchins at the reference fields and 411 brittle stars and 15 sea urchins at the clay and limestone gravel treatments. Loss of sea urchins has been linked to reduced ecosystem productivity (Lohrer et al., 2004), and due to their size and bulldozing bioturbation activity, sea urchins may be considered key species with a potential impact on the remaining community structure and function (Widdicombe et al., 2004). Also *Amphiura* sp may be considered a key species (e.g. Solan and Kennedy, 2002), and was for instance found to account for up to 80% of the total flux of O_2 into the sediment (Vopel, 2003). Thus, it seems likely that the loss of brittle stars and sea urchins in the first place may lead to cascading effects on the community level.

The fact that the ecological status of an aquatic system is temporarily decreased following a remediation action is common and not surprising. The key questions are 1) will the benthic community recover to a satisfactory ecological status after the initial disruption, and 2) how long will it take for the recovery, i.e. recolonization and establishment of a normal benthic fauna. The present study shows that the placement of thin caps of different materials is possible. It also shows that a cap made of crushed limestone or clay had little effect on the benthic community, compared to a cap with clay amended with activated carbon which had a significant impact on the macrofauna, especially in the more shallow and less diverse community in Ormefjorden. A capping experiment in the field of such amplitude and at such depths has never been conducted before. Results are promising from a technical point of view, and other investigations will conclude on the main purpose of dioxin retention by the thin caps. From an ecological perspective, however, the harmful effect of capping with activated carbon on the benthic community and ecological status cannot be neglected. Such initial adverse effects may be acceptable if the community recovers after a few years. It is therefore very important to continue monitoring the benthic fauna in order to observe if and how fast the benthic fauna recovers. A continued monitoring is also recommendable in order to follow the long-term development of the benthic community at the limestone gravel test field as result of major substrate changes with respect to particle size, shape and mineral composition.

5. Conclusions

The thin cap field experiment has shown significant effects of active carbon on benthic habitats and macrofaunal communities at 30 m and 100 m depth. The effects persisted throughout the investigation period.

Effects of active carbon on the benthic ecosystem have previously been found in a box core experiment reported by Näslund et al., 2011.

Effects of dredged clay were not severe during the first 20 months after cap placement and future divergence of the benthic community at this field is not expected due to the similarity between the cap material and the test field sediments.

Effects of crushed limestone gravel were not severe during the first 20 months after cap placement, but future divergence of the benthic community at this substrate cannot be ruled out due to substantial change of particle size, shape and mineral composition.

Continued monitoring is recommended to assess the

- the pace of recovery at the clay-AC fields and
- potential long-term development of the benthic community at the limestone gravel field

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Appendix A. Macrofauna univariate results

Year	Field	Sample	Treatment	Sp. Richness	Abundance	Biomass	BQI `	H'(log2)
Oct. 2009	FE5	A	AC	24	75	15.35	13.65	3.73
	FE5	B	AC	17	81	10.59	12.44	3.26
	FE5	C	AC	25	76	9.78	14.45	3.77
	FE6	A	REF1	34	109	182.50	15.87	4.31
	FE6	B	REF1	39	129	56.39	16.11	4.20
	FE6	C	REF1	32	106	140.86	15.91	3.89
	FO1	A	GR	22	70	20.88	9.67	3.54
	FO1	B	GR	12	20	1.89	7.79	3.45
	FO1	C	GR	26	102	33.62	11.30	4.16
	FO2	A	CL	24	95	243.64	11.06	3.58
	FO2	B	CL	16	88	64.06	8.51	2.77
	FO2	C	CL	25	83	250.42	11.06	3.82
	FO3	A	AC	20	35	165.69	10.26	4.10
	FO3	B	AC	13	19	31.95	7.68	3.51
	FO3	C	AC	13	21	130.40	8.18	3.42
	FO4	A	REF	18	62	53.99	9.29	3.12
	FO4	B	REF	14	43	137.56	8.28	2.52
	FO4	C	REF	15	39	116.29	8.74	3.05
Nov. 2010	FE5	A	AC	23	51	114.29	12.41	3.92
	FE5	B	AC	22	130	10.46	13.58	3.12
	FE5	C	AC	23	109	16.87	13.58	3.57
	FE5	D	AC	19	57	10.67	12.36	3.64
	FE5	E	AC	19	127	14.50	13.02	2.98
	FE6	A	REF1	34	114	111.58	15.84	4.47
	FE6	B	REF1	29	111	22.12	14.57	3.94
	FE6	C	REF1	35	146	128.75	16.65	4.44
	FE6	D	REF1	29	173	75.26	15.40	3.84
	FE6	E	REF1	34	158	34.21	16.23	4.26
	FE7	A	REF2	24	155	13.43	14.51	3.48
	FE7	B	REF2	26	146	16.91	15.04	3.71
	FE7	C	REF2	23	100	11.88	13.58	3.79
	FE7	D	REF2	29	159	199.31	15.75	3.78
	FE7	E	REF2	26	158	32.87	14.86	3.86
	FO1	A	GR	26	146	22.63	10.75	3.53
	FO1	B	GR	28	144	91.14	10.46	3.64
	FO1	C	GR	24	120	37.87	10.57	3.22
	FO1	D	GR	11	52	26.21	8.67	3.01
	FO1	E	GR	17	77	298.37	9.51	2.66
	FO2	A	CL	13	105	58.26	7.54	2.41
	FO2	B	CL	20	80	89.59	9.99	3.48
	FO2	C	CL	26	91	471.74	9.97	3.51
	FO2	D	CL	18	66	248.37	9.24	3.11
	FO2	E	CL	15	65	36.83	8.22	2.30
	FO3	A	AC	3	4	0.77	2.20	1.50
	FO3	B	AC	5	6	3.36	3.74	2.25
	FO3	C	AC	3	3	0.95	1.69	1.58
	FO3	D	AC	3	5	0.77	2.21	1.52
	FO3	E	AC	7	14	89.63	4.97	2.41
	FO4	A	REF	17	57	79.30	9.65	3.10
	FO4	B	REF	21	95	23.92	9.80	2.56
	FO4	C	REF	17	35	7.44	9.27	3.62
	FO4	D	REF	17	75	84.38	9.08	2.88
	FO4	E	REF	20	50	198.67	10.57	3.67

Appendix B. Macrofauna stations, sediment and water description

Year	Field	Station	Date	Latitud	Longitud	Depth	Sediment type	Sample area (m^2)	Sample vol. (L)	Salinity (PSU)	Temp. (^{o}C)	O^2 (ml/L)	O^2 (ml/L)*
2009	FO1	A	2009-10-13	59.058167	9.749267	30	Silty clay	0.1166	19	33.5	13.8	6.02	6.01
	FO1	B	2009-10-13	59.058033	9.749483	30	Silty clay	0.1166	19				
	FO1	C	2009-10-13	59.058384	9.749100	30	Silty clay	0.1166	19				
2010	FO1	A	2010-11-09	59.058548	9.748565	31.5	Silty clay	0.1162	19	33.4	12.1	6.27	
	FO1	B	2010-11-09	59.058350	9.748907	30.8	Silty clay	0.1162	19				
	FO1	C	2010-11-09	59.058357	9.749910	30.2	Silty clay	0.1162	19				
	FO1	D	2010-11-09	59.058121	9.749491	30.1	Silty clay	0.1162	19				
	FO1	E	2010-11-09	59.057922	9.749264	29.5	Silty clay	0.1162	19				
2009	FO2	A	2009-10-13	59.056534	9.749000	30	Muddy clay	0.1166	19	33.4	14.2	6.42	6.26
	FO2	B	2009-10-13	59.056366	9.748716	30	Muddy clay	0.1166	19				
	FO2	C	2009-10-13	59.056683	9.749434	30	Muddy clay	0.1166	19				
2010	FO2	A	2010-11-08	59.056732	9.748728	30.4	Muddy clay	0.1162	19	33.4	12.2	5.92	
	FO2	B	2010-11-08	59.056664	9.749291	30.2	Muddy clay	0.1162	19				
	FO2	C	2010-08-09	59.056370	9.749452	30.5	Muddy clay	0.1162	19				
	FO2	D	2010-11-08	59.056255	9.749799	30.2	Muddy clay	0.1162	19				
	FO2	E	2010-11-08	59.056168	9.748919	29.5	Muddy clay	0.1162	19				
2009	FO3	A	2009-10-13	59.056366	9.755433	28	Muddy clay, Silty clay	0.1166	19	33.2	14.9	6.25	6.48
	FO3	B	2009-10-13	59.056217	9.755533	29	Muddy clay, Silty clay	0.1166	19				
	FO3	C	2009-10-13	59.056534	9.755150	28	Muddy clay, Silty clay	0.1166	19				
2010	FO3	A	2010-11-08	59.056633	9.754948	25	Muddy clay, Silty clay	0.1162	19	33.3	12.2	7.3	
	FO3	B	2010-11-08	59.056564	9.756216	25.5	Muddy clay, Silty clay	0.1162	19				
	FO3	C	2010-11-08	59.056450	9.755422	26	Muddy clay, Silty clay	0.1162	19				
	FO3	D	2010-11-08	59.056118	9.755065	27	Muddy clay, Silty clay	0.1162	19				
	FO3	E	2010-11-08	59.056103	9.756096	26	Muddy clay, Silty clay	0.1162	19				
2009	FO4	A	2009-10-14	59.053749	9.751284	30	Muddy clay, Silty clay	0.1166	19	33.6	13.9	6.14	5.9
	FO4	B	2009-10-14	59.053482	9.751616	30	Muddy clay, Silty clay	0.1166	19				
	FO4	C	2009-10-14	59.054050	9.751266	30	Muddy clay, Silty clay	0.1166	19				
2010	FO4	A	2010-11-08	59.053917	9.751545	30	Muddy clay, Silty clay	0.1162	19	33.4	12.2	6.5	
	FO4	B	2010-11-08	59.054031	9.751346	30.2	Muddy clay, Silty clay	0.1162	19				
	FO4	C	2010-11-08	59.053799	9.751755	29.4	Muddy clay, Silty clay	0.1162	19				
	FO4	D	2010-11-08	59.053741	9.750966	29.8	Muddy clay, Silty clay	0.1162	19				
	FO4	E	2010-11-08	59.053463	9.751545	29.6	Muddy clay, Silty clay	0.1162	19				
2009	FE5	A	2009-10-14	59.075184	9.703450	95	Silty mud	0.1166	19	34	12	6.76	6.55

	FE5	B	2009-10-14	59.074917	9.703484	95	Silty mud	0.1166	19				
	FE5	C	2009-10-14	59.075432	9.703466	95	Silty mud	0.1166	19				
2010	FE5	A	2010-11-09	59.075699	9.702343	93.4	Silty mud	0.1162	19	34.5	7.5	5.11	
	FE5	B	2010-11-09	59.075741	9.703950	95	Silty mud	0.1162	19				
	FE5	C	2010-11-09	59.071874	9.704304	95.2	Silty mud	0.1162	19				
	FE5	D	2010-11-09	59.074612	9.702631	95.1	Silty mud	0.1162	19				
	FE5	E	2010-11-09	59.074596	9.704390	95	Silty mud	0.1162	19				
2009	FE6	A	2009-10-14	59.078182	9.702683	80	Muddy silt	0.1166	19	34.1	10.7	6.41	6.39
	FE6	B	2009-10-14	59.078434	9.702817	79	Muddy silt	0.1166	19				
	FE6	C	2009-10-14	59.077900	9.702633	80	Muddy silt	0.1166	19				
2010	FE6	A	2010-11-09	59.078476	9.702438	79	Muddy silt	0.1162	19	34.5	7.6	5.43	
	FE6	B	2010-11-09	59.078255	9.702950	80	Muddy silt	0.1162	19				
	FE6	C	2010-11-09	59.078106	9.702379	81	Muddy silt	0.1162	19				
	FE6	D	2010-11-09	59.077908	9.702932	83	Muddy silt	0.1162	19				
	FE6	E	2010-11-09	59.077782	9.702516	83	Muddy silt	0.1162	19				
2010	FE7	A	2010-11-09	59.068501	9.704017	96.1	Silty mud	0.1162	19	34.5	7.5	5.4	
	FE7	B	2010-11-09	59.068352	9.706402	98	Silty mud	0.1162	19				
	FE7	C	2010-11-09	59.067905	9.704871	97.5	Silty mud	0.1162	19				
	FE7	D	2010-11-09	59.067425	9.706175	98	Silty mud	0.1162	19				
	FE7	E	2010-11-09	59.067287	9.704285	96	Silty mud	0.1162	19				

* Only year 2009

Appendix C. Species list

Field FO1 (Gravel)		2009						2010									
		FO1:A		FO1:B		FO1:C		FO1:A		FO1:B		FO1:C		FO1:D		FO1:E	
Phylum	Taxa	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
Annelida	Abyssoninoe hibernica					1	< 0.005									1	< 0.005
Annelida	Ampharete baltica															3	0.02
Annelida	Anobothrus gracilis									1	0.03	1	0.03	4	< 0.005		
Annelida	Brada villosa									1	< 0.005	1	< 0.005				
Annelida	Chaetopterus norvegicus													1	2.45		
Annelida	Chaetozone setosa	1	< 0.005			3	< 0.005			1	0.01	2	0.02				
Annelida	Diplocirrus glaucus	1	0.01			3	0.01	2	0.01					9	0.02		
Annelida	Eclysippe eliasoni							4	< 0.005								
Annelida	Euchone papillosa							1	< 0.005			3	< 0.005				
Annelida	Galathowenia oculata					5	0.01	14	0.15	16	0.13	1	< 0.005				
Annelida	Glycera alba	2	0.01	2	0.01	5	0.06	1	0.06	1	0.01			2	0.09		
Annelida	Goniada maculata			1	0.05							2	0.06				
Annelida	Heteromastus filiformis	1	< 0.005			9	0.01			1	< 0.005						
Annelida	Laonice bahusiensis					1	0.02										
Annelida	Lipobranchius jeffreysii							1	0.02							1	0.05
Annelida	Lumbriclymene minor							1	< 0.005								
Annelida	Magelona minuta	1	< 0.005														
Annelida	Maldane sarsi					4	0.23			1	0.04						
Annelida	Nephtys incisa											1	0.04				
Annelida	Ophiodromus flexuosus					1	< 0.005	1	0.02								
Annelida	Owenia fusiformis					1	0.19			1	0.01						
Annelida	Pectinaria auricoma											4	0.01	1	< 0.005	1	< 0.005
Annelida	Pectinaria koreni											2	0.07			2	0.57
Annelida	Pholoe baltica			1	< 0.005	1	0.01					1	< 0.005	6	0.01		
Annelida	Pholoe pallida	1	< 0.005														
Annelida	Pilargis verrucosa			1	0.03												
Annelida	Podarkeopsis helgolandicus					1	0.01										
Annelida	Polydora spp.					1	< 0.005	29	0.01	31	0.01	4	< 0.005				
Annelida	Praxillella praetermissa	1	< 0.005	1	< 0.005	2	< 0.005			3	0.08						
Annelida	Prionospio cirrifera							1	< 0.005								
Annelida	Prionospio fallax	9	0.01	3	< 0.005	11	0.01										

Annelida	Prionospio multibranchiata	1	< 0.005														
Annelida	Rhodine loveni									1	0.02						
Annelida	Sabellidae (juv)									1	< 0.005						
Annelida	Scalibregma inflatum	2	0.4			5	0.41			4	0.02	17	0.36	7	0.08	7	0.03
Annelida	Spiophanes kroeyeri											2	0.02				
Annelida	Terebellides stroemi													1	< 0.005		
Annelida	Tharyx killariensis	2	< 0.005	2	< 0.005												
Annelida	Trichobranchus roseus					3	0.03	6	0.02	4	0.03						
Arthropoda	Ampelisca gibba									1	< 0.005						
Arthropoda	Ampelisca macrocephala							1	< 0.005								
Arthropoda	Callianassa subterranea															3	0.07
Arthropoda	Diastylis boecki							1	0.01	1	0.01					1	< 0.005
Arthropoda	Eriopisa elongata															1	< 0.005
Arthropoda	Pagurus bernhardus					1	2.08										
Cnidaria	Anthozoa							1	< 0.005			1	0.03				
Cnidaria	Cerianthus lloydii									1	< 0.005						
Cnidaria	Edwardsiidae	1	< 0.005					2	0.06	3	< 0.005	1	< 0.005				
Echinodermata	Amphiura spp (arm weight)		0.58		0.01		0.04		0.46		0.58		1.52		0.11		2.41
Echinodermata	Amphiura chiajei (discs)	2	0.03			5	0.01	3	0.06	5	0.05	1	0.1			2	0.27
Echinodermata	Amphiura filiformis (discs)	17	0.28	2	0.01	16	0.05	24	0.21	22	0.27	50	1.1	14	0.16	42	2.06
Echinodermata	Brissopsis lyrifera									1	5.82					5	28.51
Echinodermata	Echinocardium cordatum									1	2.21						
Echinodermata	Labidoplax buskii					1	0.01	5	0.01								
Echinodermata	Luidia sarsi	1	0.01														
Echinodermata	Ophiuridae (juv)															2	< 0.005
Mollusca	Antalis entalis											1	0.64			1	0.54
Mollusca	Cerastoderma glaucum							1	0.05	1	< 0.005						
Mollusca	Chaetoderma nitidulum							1	0.1								
Mollusca	Corbula gibba	14	0.8	2	< 0.005	7	0.63	3	0.17	11	0.51	7	0.29	4	0.04	1	0.02
Mollusca	Cylichna cylindracea	1	0.02									1	0.01				
Mollusca	Ennucula tenuis							5	0.43	2	0.24						
Mollusca	Hyala vitrea			3	0.01	2	< 0.005			1	< 0.005	9	0.03			3	< 0.005
Mollusca	Mysella bidentata											5	< 0.005				
Mollusca	Nucula nitidosa							2	0.1								
Mollusca	Philine scabra							1	0.01	3	0.05	1	< 0.005	3	0.07		
Mollusca	Polinices montagui	1	0.08														
Mollusca	Polinices pulchella	2	0.05														
Mollusca	Thyasira flexuosa	7	0.1			3	0.04	33	0.49	24	0.42	2	0.03				

Nemertea	Cerebratulus spp.	1	< 0.005					2	0.15								
Nemertea	Nemertea			1	< 0.005	9	0.01									1	0.09
Sipuncula	Golfingia spp.	1	0.01	1	0.07												
Sipuncula	Phascolion strombus					1	0.02										

Field FO2 (Clay)		2009						2010									
		FO2:A		FO2:B		FO2:C		FO2:A		FO2:B		FO2:C		FO2:D		FO2:E	
Phylum	Taxa	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
Annelida	Abyssoninoe hibernica	3	0.06	1	0.01	8	0.21	1	0.03	1	0.02	1	0.04			1	<0.005
Annelida	Ampharete finmarchica									4	0.01						
Annelida	Chaetopterus norvegicus															1	0.12
Annelida	Chaetozone setosa															1	<0.005
Annelida	Diplocirrus glaucus	4	0.03			3	0.02	1	0.01	3	<0.005	1	<0.005	2	0.02		
Annelida	Eunoe nodosa											1	<0.005				
Annelida	Gattyana cirrhosa											2	<0.005				
Annelida	Glycera alba			1	0.01			3	0.07			1	<0.005	1	0.02	1	0.02
Annelida	Glycera rouxii	1	0.08							1	0.22						
Annelida	Goniada maculata													2	0.12		
Annelida	Heteromastus filiformis	1	<0.005													1	<0.005
Annelida	Laonice bahusiensis	1	0.01														
Annelida	Nephtys incisa					1	0.07	3	0.38	2	0.29	2	0.24	2	0.35	1	0.18
Annelida	Ophiodromus flexuosus													1	<0.005		
Annelida	Pectinaria auricoma	1	0.01	3	0.16												
Annelida	Pectinaria belgica	2	<0.005			2	1.53							1	0.44		
Annelida	Pectinaria koreni											2	0.13				
Annelida	Phyllodoce groenlandica							1	<0.005								
Annelida	Polydora spp.	1	<0.005					9	<0.005			2	<0.005				
Annelida	Polyphysia crassa			3	0.84	1	0.9										
Annelida	Praxillella praetermissa	1	0.03														
Annelida	Prionospio fallax									3	<0.005						
Annelida	Psamathe fusca													1	<0.005		
Annelida	Scalibregma inflatum	1	<0.005					53	0.28	18	0.1	21	0.08	6	0.03	39	0.14
Annelida	Spiophanes kroeyeri	1	0.04	2	0.01	1	0.01			2	0.04	1	0.05				
Annelida	Terebellides stroemi	3	0.03							1	0.01					4	0.02
Annelida	Trichobranchus roseus											1	0.02				
Arthropoda	Callianassa subterranea	1	<0.005	1	0.01	1	0.01										
Arthropoda	Eriopisa elongata					1	<0.005			1	<0.005						

Cnidaria	Edwardsiidae			1	0.01	1	<0.005			4	0.06	1	0.02	1	<0.005		
Echinodermata	Amphiura spp (arm weight)		0.7		1.56		1.05		0.12		1.36		0.57		1.46		0.12
Echinodermata	Amphiura chiajei (discs)	2	0.13	4	0.23	1	0.11			4	0.38			4	0.68		
Echinodermata	Amphiura filiformis (discs)	23	0.22	41	0.75	24	0.49	18	0.2	21	0.66	27	0.58	29	1.21	8	0.21
Echinodermata	Brissopsis lyrifera	2	25.51			2	17.49	1	4.71	1	6.07	1	7.52	1	6.48	1	2.85
Echinodermata	Echinocardium cordatum					2	5.3					3	9.82	2	7.95		
Echinodermata	Echinocardium flavescens			1	2.99												
Echinodermata	Luidia sarsi	1	<0.005														
Echinodermata	Mesothuria intestinalis											1	34.7				
Echinodermata	Trachythyone elongata			1	0.03					1	0.49						
Mollusca	Abra nitida					1	0.01					1	0.06				
Mollusca	Antalis entalis					1	0.68										
Mollusca	Chaetoderma nitidulum	1	0.03	1	0.06							2	0.14				
Mollusca	Corbula gibba	7	1	13	0.5	10	0.63	6	0.54	6	0.43	9	0.5	5	0.05	2	0.33
Mollusca	Cuspidaria obesa					1	0.08										
Mollusca	Cylichna cylindracea					3	0.05			1	0.02						
Mollusca	Ennucula tenuis													1	0.08		
Mollusca	Hyala vitrea	19	0.05	2	0.01	4	0.01			3	<0.005	1	<0.005			1	<0.005
Mollusca	Montacuta tenella					3	<0.005										
Mollusca	Myrtea spinifera											1	0.03				
Mollusca	Mysella bidentata					2	<0.005										
Mollusca	Nucula nitidosa	13	0.35	8	0.27	2	0.09					2	0.03	3	0.17	2	0.14
Mollusca	Phaxas pellucida											2	0.03				
Mollusca	Philine scabra	1	0.01			3	0.05	1	0.06	1	0.01	1	<0.005				
Mollusca	Polinices pulchella					1	0.15					1	0.14			1	0.07
Mollusca	Thyasira flexuosa	4	0.03	5	0.02			7	0.21			3	0.08				
Mollusca	Thyasira sarsii													1	<0.005		
Nemertea	Cerebratulus spp.													3	9.78		
Sipuncula	Golfingia spp.	1	0.06			4	0.24	1	0.15	2	0.22					1	0.06

Field FO3 (AC)		2009						2010									
		FO3:A		FO3:B		FO3:C		FO3:A		FO3:B		FO3:C		FO3:D		FO3:E	
Phylum	Taxa	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
Annelida	Abyssoninoe hibernica	1	0.02													5	0.12
Annelida	Chaetopterus norvegicus															1	1.11
Annelida	Cossura longocirrata	1	<0.005														
Annelida	Diplocirrus glaucus	1	0.01														

Annelida	Glycera alba															1	<0.005
Annelida	Goniada maculata															1	0.02
Annelida	Heteromastus filiformis	1	0.01	1	<0.005												
Annelida	Nephtys incisa	3	0.25	4	0.33			2	0.06	2	0.19						
Annelida	Notomastus latericeus									1	0.14						
Annelida	Polycirrus spp.	2	0.01			1	0.01										
Annelida	Scalibregma inflatum	1	0.01	1	0.03	2	0.18							2	0.03		
Annelida	Spiophanes kroeyeri							1	0.01	1	0.03						
Annelida	Trichobranchus roseus	1	0.01	2	0.03	1	0.03										
Arthropoda	Callianassa subterranea					1	0.02										
Echinodermata	Amphiura spp (arm weight)								0.01								
Echinodermata	Amphiura filiformis (discs)			1	<0.005	1	<0.005	1	0.01								
Echinodermata	Brissopsis lyrifera	1	8.79			1	9.25									1	8.84
Echinodermata	Echinocardium cordatum	2	8.58	1	3.24	1	5.3										
Echinodermata	Luidia sarsi	2	0.01			1	<0.005										
Mollusca	Abra nitida	1	<0.005	2	0.04							1	0.08				
Mollusca	Corbula gibba	3	0.73	1	<0.005	1	0.33									4	0.31
Mollusca	Cylichna cylindracea	2	0.02	1	0.01	5	0.05			1	0.02						
Mollusca	Hyala vitrea	5	0.02	2	0.01	2	0.01										
Mollusca	Montacuta ferruginosa	3	<0.005	1	<0.005	1	<0.005										
Mollusca	Montacuta tenella	2	0.01			3	0.01										
Mollusca	Nucula sulcata	1	0.79														
Mollusca	Parvicardium minimum	1	<0.005														
Mollusca	Philine scabra			1	0.01									2	0.05		
Mollusca	Polinices pulchella	1	0.03	1	<0.005												
Mollusca	Thyasira sarsii											1	0.01	1	0.01	1	0.01
Nemertea	Cerebratulus spp.											1	0.02				
Sipuncula	Golfingia spp.									1	0.01						

Field FO4 (Reference)		2009						2010									
		FO4:A		FO4:B		FO4:C		FO4:A		FO4:B		FO4:C		FO4:D		FO4:E	
Phylum	Taxa	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
Annelida	Abyssoninoe hibernica			4	0.08	1	0.03	3	0.1	3	0.07			2	0.09		
Annelida	Chaetopterus norvegicus									1	1.37						
Annelida	Chaetozone setosa							1	<0.005								
Annelida	Diplocirrus glaucus	1	0.01	1	0.01			4	0.04	5	0.04	2	<0.005	2	<0.005	2	<0.005
Annelida	Glycera alba							1	0.05	1	0.01			2	0.07		

Annelida	Goniada maculata			1	0.06	1	0.07	1	0.02								
Annelida	Heteromastus filiformis									1	0.02	2	0.01				
Annelida	Lipobranchius jeffreysii	1	0.82														
Annelida	Maldanidae									1	0.02						
Annelida	Nephtys incisa	1	0.09	1	0.02	1	0.09	1	0.07	1	<0.005	2	0.17	1	0.16	1	0.08
Annelida	Ophiodromus flexuosus							1	0.04	2	0.03	1	0.02	2	0.06	2	0.04
Annelida	Pectinaria auricoma									1	<0.005	2	0.01				
Annelida	Pectinaria belgica							4	4.29			1	<0.005				
Annelida	Pholoe baltica											1	<0.005	1	<0.005	1	0.01
Annelida	Podarkeopsis helgolandicus					1	0.01										
Annelida	Polycirrus sp.	1	0.02														
Annelida	Polydora sp.							1	<0.005								
Annelida	Praxillella affinis													2	0.07		
Annelida	Praxillella praetermissa	2	0.07					3	0.09							2	0.07
Annelida	Scalibregma inflatum							23	0.09	56	0.21	10	0.12	35	0.53	8	0.05
Annelida	Scolelepis tridentata									1	<0.005						
Annelida	Spiophanes kroeyeri	2	0.05			2	0.03	2	0.03	2	0.06	2	0.03	2	0.03	3	0.06
Annelida	Streblosoma bairdi									1	0.05	1	0.05	1	0.07	2	0.01
Annelida	Terebellides stroemi			1	0.01					6	0.03			8	0.09	1	0.02
Arthropoda	Callianassa subterranea	1	0.12	2	0.04	1	0.02			1	0.01	3	0.12	3	0.08	3	0.13
Arthropoda	Diastylis laevis															1	0.02
Arthropoda	Eriopisa elongata	3	0.01							1	<0.005						
Arthropoda	Oedicerotidae									1	<0.005						
Cnidaria	Edwardsiidae											1	<0.005			1	<0.005
Echinodermata	Amphiura spp (arm weight)		0.66		1.25		0.3		0.1		0.03		0.04		0.39		0.27
Echinodermata	Amphiura chiajei (discs)	1	0.02	1	0.04	1	0.01										
Echinodermata	Amphiura filiformis (discs)	24	0.29	24	0.48	17	0.21	8	0.14	7	0.07	3	0.05	9	0.2	14	0.23
Echinodermata	Brissopsis lyrifera	1	3.18	1	7.89	2	11.07							1	7.69	1	14.72
Echinodermata	Echinocardium cordatum			1	5.36			1	3.95							2	7.12
Echinodermata	Luidia sarsi	1	0.01														
Mollusca	Abra nitida	1	0.04	1	0.06												
Mollusca	Cerastoderma glaucum													1	<0.005	1	0.07
Mollusca	Chaetoderma nitidulum			1	0.07	1	0.05										
Mollusca	Corbula gibba	12	0.61	3	0.58	3	0.19			1	<0.005						
Mollusca	Cylichna cylindracea	4	0.05			3	0.04									2	0.03
Mollusca	Hyala vitrea	2	<0.005			2	0.01	1	<0.005							1	<0.005
Mollusca	Mysia undata							1	0.12								
Mollusca	Nucula nitidosa	2	0.02					1	0.07			1	0.08				

Mollusca	Philine scabra					2	0.01			1	0.01					1	0.04
Mollusca	Thyasira flexuosa											1	<0.005				
Nemertea	Nemertea					1	1.42			1	0.72	1	0.02	1	0.09		
Sipuncula	Golfingia spp.	2	0.22	1	0.09							1	0.12	2	0.17	1	0.1

Field FE5 (AC)		2009						2010									
		FE5:A		FE5:B		FE5:C		FE5:A		FE5:B		FE5:C		FE5:D		FE5:E	
Phylum	Taxa	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
Annelida	Abyssoninoe hibernica			1	0.09												
Annelida	Bylgides elegans											2	0.02				
Annelida	Caulleriella bioculata							1	<0.005	1	<0.005						
Annelida	Ceratocephale loveni	2	0.05	5	0.12	1	0.01	4	0.05	3	0.06	3	0.02	1	<0.005	2	0.03
Annelida	Chaetoparia nilssoni	1	<0.005									1	0.01				
Annelida	Chaetozone setosa	2	0.01	10	0.08			1	<0.005	5	<0.005	4	0.02	2	0.02	4	0.02
Annelida	Cirratulus caudatus	2	0.02	4	0.03	1	0.02	3	0.02	4	0.04	3	0.02	6	0.16	4	0.04
Annelida	Diplocirrus glaucus			1	0.01	1	0.01			1	<0.005					1	<0.005
Annelida	Euchone papillosa					2	0.02	1	<0.005	2	0.01					1	<0.005
Annelida	Galathowenia oculata									1	<0.005			1	<0.005		
Annelida	Gattyana amondseni											1	0.01				
Annelida	Glycera alba			1	0.02			2	0.09	2	0.06	3	0.18	1	<0.005	4	0.29
Annelida	Glycera rouxii											1	0.53				
Annelida	Glycinde nordmanni											1	0.02				
Annelida	Goniada maculata									1	<0.005			1	0.03	1	0.02
Annelida	Harmothoe sp.											1	0.01				
Annelida	Heteromastus filiformis	2	0.01			2	<0.005	4	0.01	4	<0.005	4	0.01	1	<0.005	3	<0.005
Annelida	Melinna cristata	2	0.03														
Annelida	Neoamphitrite affinis	1	0.01														
Annelida	Neoamphitrite grayi	1	0.61														
Annelida	Nephtys incisa															1	<0.005
Annelida	Ophiodromus flexuosus							1	0.04								
Annelida	Paramphinome jeffreysi	1	0.01	6	0.03	3	0.02			56	0.21	24	0.07	9	0.03	55	0.2
Annelida	Phyllodoce rosea					1	0.01										
Annelida	Phylo norvegica					1	0.37										
Annelida	Pista cristata	1	0.07	2	0.28			1	0.03								
Annelida	Polydora sp.													1	<0.005		
Annelida	Polynoidae (juv)									2	<0.005			1	<0.005	1	<0.005
Annelida	Praxillella affinis	1	<0.005														

Annelida	Prionospio dubia	1	0.01	1	<0.005												
Annelida	Rhodine loveni	2	0.18			1	0.03	2	0.09			1	0.02			2	0.04
Annelida	Scalibregma inflatum			2	0.06	1	0.02					1	0.01				
Annelida	Scoletoma fragilis													1	0.24		
Annelida	Spiophanes kroeyeri	7	0.16	7	0.1	10	0.13	5	0.05	14	0.09	9	0.04	2	0.02	15	0.16
Annelida	Terebellides stroemi					1	<0.005										
Arthropoda	Arrhis phyllonyx							1	0.02			3	0.07	6	0.14	3	0.06
Arthropoda	Campylaspis costata					1	<0.005										
Arthropoda	Diastylis boecki			1	0.01												
Arthropoda	Diastyloides serratus					6	0.01					1	<0.005				
Arthropoda	Eudorella emarginata							1	<0.005	3	<0.005			3	0.02	2	<0.005
Arthropoda	Gnathia spp.			1	<0.005												
Arthropoda	Leptostylis longimana					1	<0.005										
Arthropoda	Leucon nasica					1	<0.005	1	<0.005	2	<0.005			2	0.01	2	<0.005
Arthropoda	Lysianassidae									1	<0.005						
Arthropoda	Monoculodes carinatus									1	<0.005						
Arthropoda	Philomedes brenda	2	<0.005			4	0.01					1	<0.005				
Arthropoda	Tanaidacea	2	<0.005			1	<0.005										
Echinodermata	Amphiura spp (arm weight)								<0.005								
Echinodermata	Amphiura chiajei (discs)							1	<0.005								
Echinodermata	Amphiura filiformis (discs)					1	<0.005	1	<0.005								
Echinodermata	Brissopsis lyrifera							1	12.11								
Echinodermata	Ophiocten affinis					1	0.08										
Mollusca	Abra nitida	1	<0.005	1	0.01	3	<0.005	13	0.55	2	0.08	9	0.23	13	0.38	13	0.37
Mollusca	Cerastoderma glaucum							1	0.02								
Mollusca	Corbula gibba	1	0.01														
Mollusca	Ennucula tenuis	1	<0.005														
Mollusca	Hyala vitrea	3	0.01														
Mollusca	Mysella bidentata	1	<0.005														
Mollusca	Nudibranchia									1	0.02						
Mollusca	Philine scabra							3	0.05	3	0.03	4	0.06	1	0.02	1	0.03
Mollusca	Thyasira equalis	22	0.43	28	0.34	18	0.18	1	0.05	17	0.5	27	0.54	3	0.09	12	0.39
Mollusca	Thyasira sarsii					1	<0.005										
Mollusca	Yoldiella philippiana	10	0.13	5	0.04	12	0.17	1	0.02	4	0.06	4	0.03	2	0.05		
Nemertea	Cerebratulus spp.							1	0.04								
Platyhelminthes	Turbellaria											1	0.03				
Sipuncula	Phascolion strombus	6	<0.005	5	<0.005	1	<0.005										

Field FE6 (Reference 1)		2009						2010									
		FE6:A		FE6:B		FE6:C		FE6:A		FE6:B		FE6:C		FE6:D		FE6:E	
Phylum	Taxa	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
Annelida	Abyssoninoe hibernica	3	0.12	4	0.13	2	0.07	3	0.07	2	0.03	5	0.16	6	0.42	2	0.08
Annelida	Anobothrus gracilis											1	0.01			1	<0.005
Annelida	Brada villosa									2	0.01	1	<0.005	2	0.07	6	0.18
Annelida	Bylgides elegans									1	<0.005						
Annelida	Ceratocephale loveni					3	0.03	4	0.05	2	0.04	4	0.04	3	0.04	2	<0.005
Annelida	Chaetozone setosa	1	0.01			1	<0.005	13	0.07	1	<0.005	12	0.05	7	0.04	11	0.05
Annelida	Cirratulus caudatus	4	0.04	2	0.02	4	0.04	2	0.01	9	0.09	15	0.13	20	0.25	11	0.15
Annelida	Diplocirrus glaucus	2	0.02	3	0.01	1	0.01	1	0.01	5	0.03	1	0.01	1	0.01	3	0.01
Annelida	Eclysippe eliasoni	2	<0.005			1	0.01	1	<0.005	2	0.01	3	<0.005	1	<0.005	1	<0.005
Annelida	Euchone papillosa			1	<0.005	1	0.02	2	<0.005							1	<0.005
Annelida	Eumida bahusiensis													1	<0.005		
Annelida	Galathowenia oculata					1	<0.005					3	0.02				
Annelida	Gattyana amondseni			1	<0.005												
Annelida	Glycera alba	1	0.02			4	0.16	2	0.03	3	0.08	4	0.12	3	0.06	3	0.02
Annelida	Glycera rouxii	2	0.38							2	0.47	1	1.08				
Annelida	Glycinde nordmanni					1	0.01										
Annelida	Glyphohesione klatti			1	0.01												
Annelida	Goniada maculata							1	0.04	1	0.05			2	0.07	1	0.01
Annelida	Harmothoe sp.							1	<0.005								
Annelida	Heteromastus filiformis	4	0.02	3	0.01	1	<0.005	7	0.02	11	0.03	9	0.02	5	0.01	8	0.02
Annelida	Iphitime hartmanae	1	0.08														
Annelida	Lipobranchius jeffreysii			2	1.08			6	1.64	2	0.53	5	1.4	3	1.62	5	1.2
Annelida	Maldane sarsi			3	0.01												
Annelida	Melinna cristata	3	0.03					1	0.03								
Annelida	Neoamphitrite affinis					1	2.36							4	4.32		
Annelida	Nereiphylla lutea	1	0.01									1	<0.005				
Annelida	Notomastus latericeus	1	0.06	1	0.03												
Annelida	Ophelina norvegica															1	0.02
Annelida	Ophiodromus flexuosus									1	<0.005	2	0.04			1	0.01
Annelida	Paramphinome jeffreysi			3	0.02	3	0.01	13	0.04	33	0.13	14	0.05	46	0.15	20	0.06
Annelida	Paramphitrite tetrabranchia	1	0.03	1	0.01	1	0.04					3	0.09			3	0.05
Annelida	Pectinaria belgica			1	1.67												
Annelida	Pectinaria koreni									1	0.01			1	0.04		
Annelida	Pholoe baltica							1	<0.005	1	<0.005						

Annelida	Pholoe pallida							1	<0.005								
Annelida	Phyllodoce rosea			1	<0.005												
Annelida	Phyllodocidae (juv)											1	<0.005				
Annelida	Pista cristata	3	1.04			3	0.03							1	0.12	1	0.03
Annelida	Polycirrus sp.	1	0.1														
Annelida	Polydora sp.															1	<0.005
Annelida	Polynoidae	1	<0.005	1	<0.005			2	0.01			1	<0.005				
Annelida	Praxillella affinis	1	<0.005	1	<0.005												
Annelida	Prionospio cirrifera							1	<0.005	1	<0.005	1	<0.005				
Annelida	Prionospio dubia			2	0.02												
Annelida	Prionospio fallax							4	0.02								
Annelida	Proclea graffii	1	<0.005														
Annelida	Rhodine loveni			1	0.09	1	0.01	3	0.24	2	0.38	4	0.08			1	0.06
Annelida	Scalibregma inflatum							2	0.12	3	0.01	5	0.03	4	0.01	2	0.02
Annelida	Scoletoma fragilis			1	0.52												
Annelida	Sosane sulcata	1	0.01			1	<0.005										
Annelida	Spiophanes kroeyeri	17	0.1	9	0.07	22	0.14	11	0.05	3	0.04	12	0.05	17	0.06	25	0.08
Annelida	Streblosoma bairdi	8	2.6	6	2.34	5	0.73	6	3.35	3	0.37	13	3.07	4	0.28	5	0.88
Annelida	Terebellides stroemi			1	<0.005			1	0.04			1	0.02				
Annelida	Tharyx killariensis			1	0.01												
Annelida	Trichobranchus roseus															1	0.01
Arthropoda	Ampelisca gibba	1	0.01	2	<0.005	1	<0.005										
Arthropoda	Ampelisca macrocephala									3	0.01						
Arthropoda	Aora gracilis															2	<0.005
Arthropoda	Arrhis phyllonyx													2	0.05		
Arthropoda	Callianassa subterranea											1	<0.005				
Arthropoda	Campylaspis costata			1	<0.005												
Arthropoda	Diastylis boecki							1	<0.005							1	<0.005
Arthropoda	Diastyloides biplicatus													1	<0.005		
Arthropoda	Diastyloides serratus															1	<0.005
Arthropoda	Eriopisa elongata									2	0.03						
Arthropoda	Gnathia spp.			2	<0.005												
Arthropoda	Harpinia antennaria					1	<0.005										
Arthropoda	Harpinia crenulata	1	<0.005														
Arthropoda	Leucothoe lilljeborgii					1	<0.005							2	<0.005		
Arthropoda	Lysianassidae			1	0.02												
Arthropoda	Westwoodilla caecula					1	0.01					1	0.01				
Echinodermata	Amphiura spp (arm weight)								0.06		<0.005				0.1		0.21

Echinodermata	Amphiura chiajei (discs)	3	0.01	1	<0.005			2	0.07	1	<0.005			4	0.07	5	0.15
Echinodermata	Amphiura filiformis (discs)	2	0.01	1	<0.005	2	<0.005										
Echinodermata	Brissopsis lyrifera	4	16.08			1	12.46	1	3.98			1	4.45				
Echinodermata	Echinocardium flavescens			2	<0.005												
Echinodermata	Luidia sarsi	1	<0.005	1	<0.005												
Echinodermata	Spatangidae (juv)					1	<0.005										
Mollusca	Abra nitida	2	0.01	13	0.02	1	0.01			4	0.08	1	0.01	3	0.09	1	<0.005
Mollusca	Chaetoderma nitidulum					1	<0.005			1	0.01						
Mollusca	Cuspidaria spp.			1	0.01												
Mollusca	Ennucula tenuis	7	0.23	3	0.21	1	0.01	2	0.13			1	0.19	1	<0.005	3	0.21
Mollusca	Hyala vitrea			1	<0.005												
Mollusca	Montacuta tenella	2	0.01														
Mollusca	Nudibranchia							1	0.01								
Mollusca	Philine aperta			2	0.01												
Mollusca	Philine scabra	1	0.01					1	0.09			1	0.08			1	0.01
Mollusca	Pseudamussium peslutrae	1	0.02					1	2.56			2	3				
Mollusca	Thyasira equalis	21	0.18	36	0.15	23	0.11	10	0.13	8	0.09	13	0.3	21	0.33	18	0.26
Mollusca	Yoldiella philippiana	4	0.01	11	0.03	14	0.1	5	0.04	1	<0.005	1	<0.005	5	0.04	8	0.07
Nemertea	Cerebratulus spp.							1	0.02			2	0.41	2	0.46	2	0.08
Nemertea	Nemertea			1	<0.005												
Platyhelminthes	Turbellaria													1	0.01		
Sipuncula	Phascolion strombus					1	<0.005										

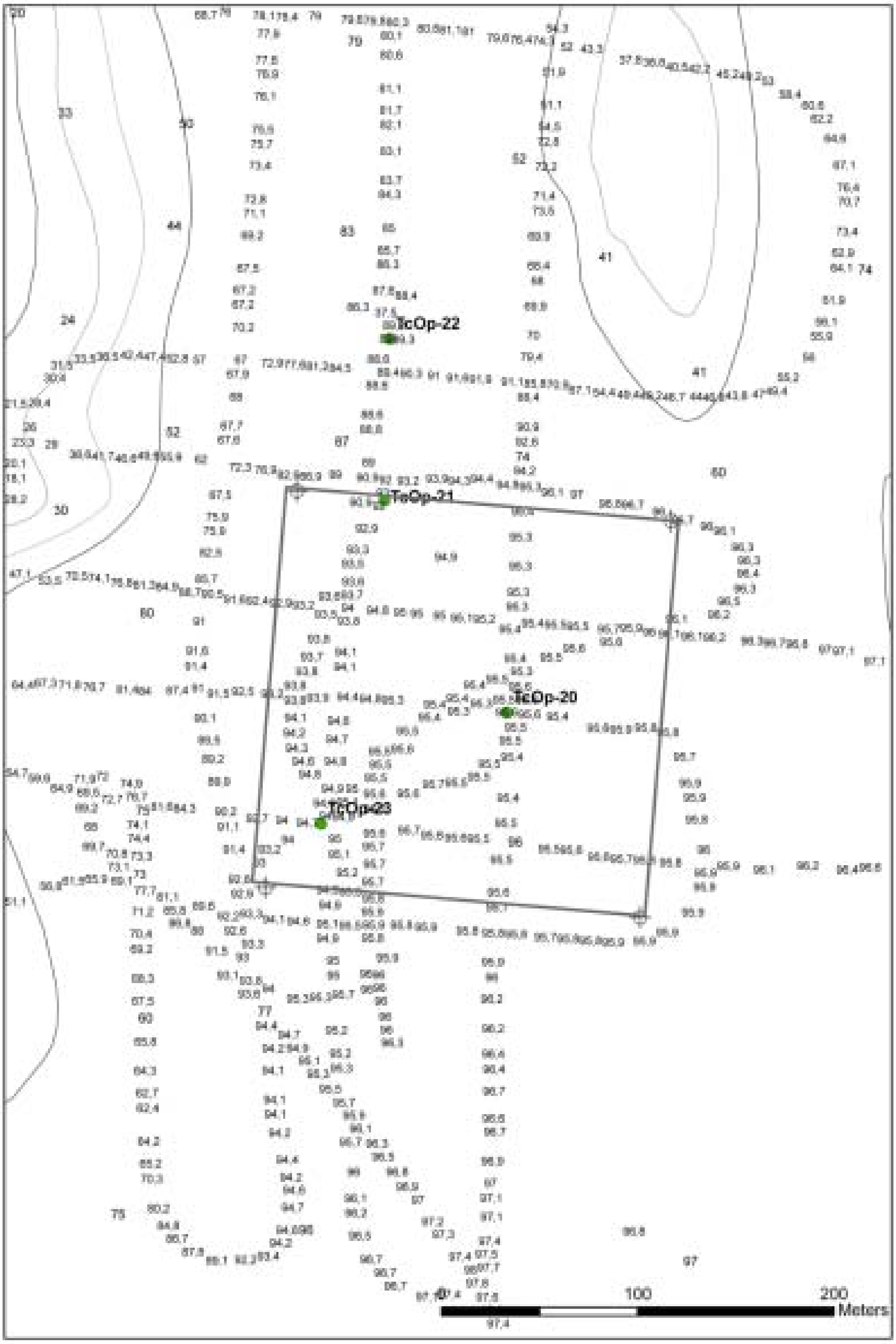
Field FE7 (Reference2)		2010									
		FE7:A		FE7:B		FE7:C		FE7:D		FE7:E	
Phylum	Taxa	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
Annelida	Anobothrus gracilis					1	<0.005				
Annelida	Cirratulus caudatus	11	0.15	12	0.19	9	0.16	20	0.25	17	0.36
Annelida	Bylgides elegans	1	0.03					2	0.01		
Annelida	Ceratocephale loveni	2	0.05	14	0.28	2	0.04	8	0.06	5	0.04
Annelida	Chaetoparia nilssoni	1	<0.005								
Annelida	Chaetozone setosa	30	0.2	31	0.2	20	0.17	48	0.25	28	0.23
Annelida	Diplocirrus glaucus			1	<0.005						
Annelida	Euchone papillosa							1	<0.005		
Annelida	Galathowenia oculata							1	<0.005	4	0.01
Annelida	Glycera alba	3	0.05					2	0.02	3	0.24
Annelida	Glycera rouxii	1	0.18					1	0.13	1	1.46
Annelida	Goniada maculata	2	0.05	2	0.11	2	0.05	1	<0.005	1	<0.005

Annelida	Heteromastus filiformis	9	0.04	3	<0.005	17	0.04	3	0.01	11	0.03
Annelida	Lipobranchius jeffreysii					1	0.09				
Annelida	Melinna cristata	1	<0.005	1	0.07			1	0.02	1	<0.005
Annelida	Nereimyra punctata							1	<0.005		
Annelida	Ophelina norvegica					1	0.06				
Annelida	Paramphinome jeffreysi	27	0.08	13	0.03	2	<0.005	5	0.01	20	0.06
Annelida	Pectinaria koreni	1	<0.005	2	<0.005						
Annelida	Phylo norvegica			1	0.06						
Annelida	Pista cristata							3	0.56		
Annelida	Polydora sp.									1	<0.005
Annelida	Polynoidae			1	0.01					2	<0.005
Annelida	Prionospio cirrifera			2	<0.005	4	0.02	7	0.01	2	<0.005
Annelida	Rhodine loveni					1	0.06	2	0.17	2	0.15
Annelida	Scalibregma inflatum	1	0.03	5	0.2	8	0.16	4	0.13	5	0.17
Annelida	Sige fusigera			1	<0.005			2	<0.005		
Annelida	Spiophanes kroeyeri	35	0.33	16	0.31	10	0.15	7	0.13	8	0.12
Annelida	Streblosoma bairdi							2	0.22		
Annelida	Terebellides stroemi	2	0.03							1	0.04
Arthropoda	Arrhis phyllonyx	7	0.14	1	0.01	5	0.11	3	0.08	1	0.01
Arthropoda	Callianassa subterranea			1	<0.005						
Arthropoda	Campylaspis costata			1	<0.005						
Arthropoda	Diastyloides serratus	2	<0.005	1	<0.005						
Arthropoda	Eriopisa elongata			1	<0.005			2	0.01	1	<0.005
Arthropoda	Eudorella emarginata	6	<0.005	2	<0.005			2	<0.005	3	<0.005
Arthropoda	Leucon nasica	5	<0.005	3	0.01	3	0.01	5	0.02	2	<0.005
Arthropoda	Leucothoe lilljeborgii			1	<0.005						
Arthropoda	Lysianassidae					1	<0.005				
Arthropoda	Phoxocephalidae					1	<0.005				
Arthropoda	Westwoodilla caecula	1	<0.005								
Echinodermata	Brissopsis lyrifera							1	19.84		
Echinodermata	Ophiuridae					2	0.03				
Mollusca	Abra nitida	2	0.04	5	0.17	3	0.05	3	0.05	9	0.19
Mollusca	Ennucula tenuis	1	0.04								
Mollusca	Philine scabra					1	0.01	3	0.16	2	0.11
Mollusca	Pseudamussium peslutrae							1	0.72		
Mollusca	Thyasira equalis	3	0.08	23	0.18	1	0.03	18	0.27	23	0.46
Mollusca	Yoldiella philippiana	1	<0.005			2	0.03			4	0.05
Nemertea	Cerebratulus spp.			2	0.08	3	0.09			1	0.05

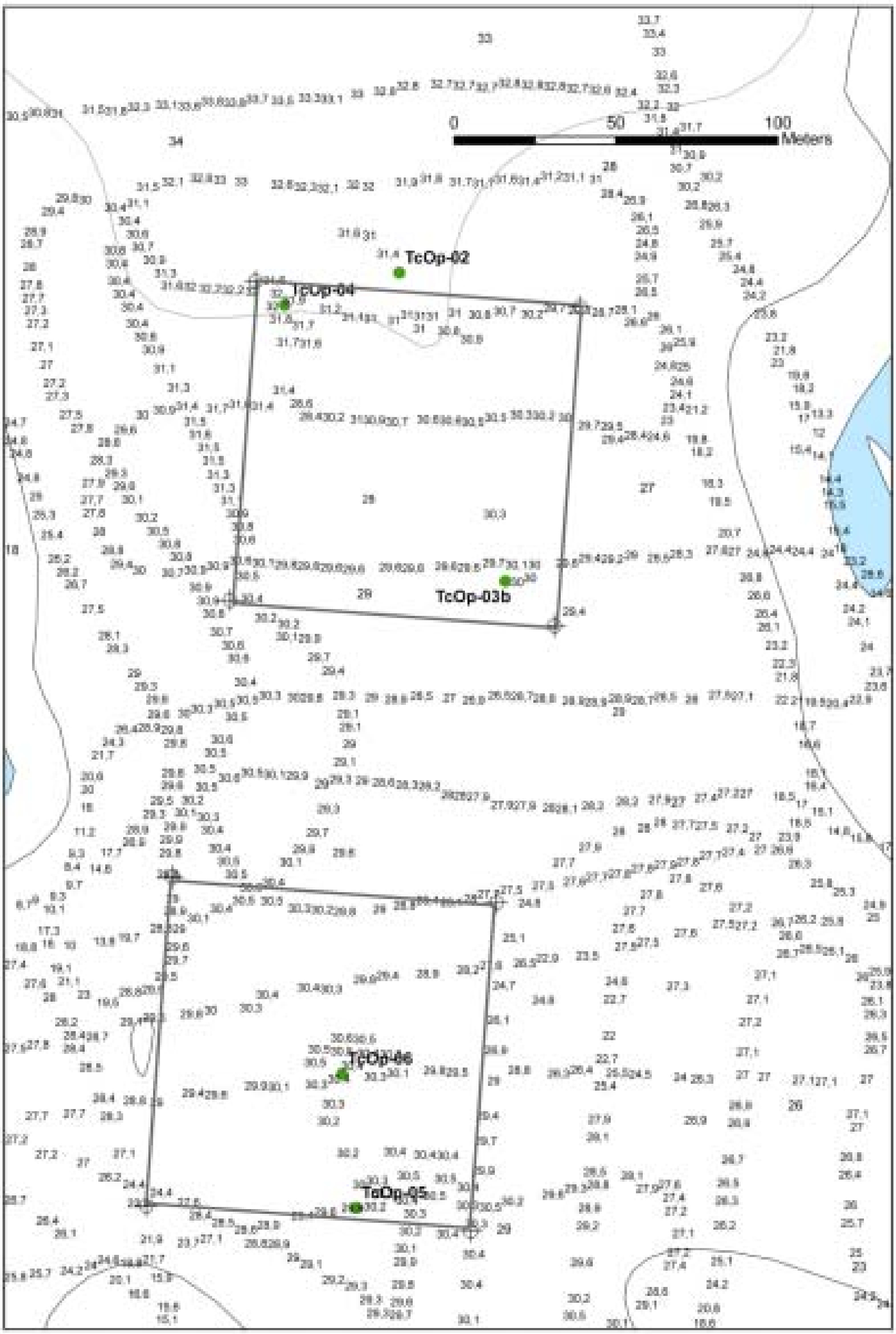
Appendix D. Field locations and depth transects

Co-ordinates of Grenland test fields, RV Trygve Braarud, October 2008

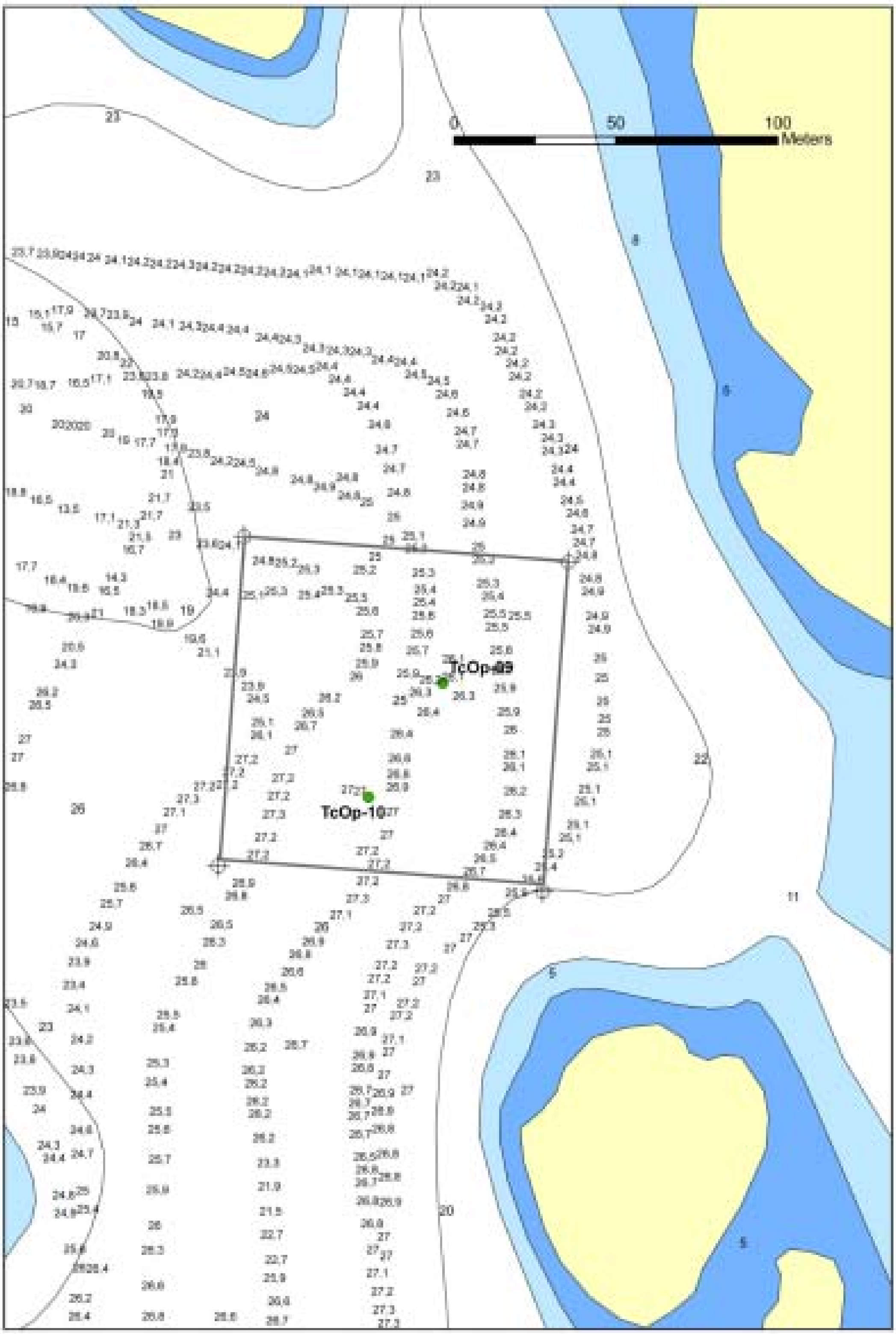
Fjord		Field	Corner	Latitud	Longitud
Eidangerfj	1 Eid	FE4	A	59.076111	9.701667
Eidangerfj	1 Eid	FE4	B	59.076111	9.705000
Eidangerfj	1 Eid	FE4	C	59.074306	9.701667
Eidangerfj	1 Eid	FE4	D	59.074306	9.705000
Ormefj	1 Orm	FO1	A	59.058611	9.748417
Ormefj	1 Orm	FO1	B	59.058611	9.750167
Ormefj	1 Orm	FO1	C	59.057722	9.748417
Ormefj	1 Orm	FO1	D	59.057722	9.750167
Ormefj	2 Orm	FO2	A	59.056944	9.748222
Ormefj	2 Orm	FO2	B	59.056944	9.749972
Ormefj	2 Orm	FO2	C	59.056028	9.748222
Ormefj	2 Orm	FO2	D	59.056028	9.749972
Ormefj	3 Orm	FO3	A	59.056778	9.754556
Ormefj	3 Orm	FO3	B	59.056778	9.756306
Ormefj	3 Orm	FO3	C	59.055861	9.754556
Ormefj	3 Orm	FO3	D	59.055861	9.756306



Depth transects at FE5, RV Trygve Braarud, October 2008.



Depth transects at FO1 and FO2, RV Trygve Braarud, October 2008.



Depth transects at FO3, RV Trygve Braarud, October 2008.

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