report

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ERMS, Validation of PEC, PNEC and Risk by field data (part I)

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REPORT

TITLE

ERMS, Validation of PEC, PNEC and RISK by field data (part I)

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Summary

The objective of this study has been to apply and process available information from the MOD database on benthic ecology to validate model assumptions and outcomes from the ERMS model. In the light of the observed (monitored) effects documented and reported herein, the realism of the model can be assessed for the NOECs, the PECs and Risk.
After a careful selection of fields on the basis of the availability of discharge and monitoring data, the main four fields selected for assessment and later validation are Goliath, SVAN, Vigdis and Norne. These fields are all drilled with either WMB or SBM, and reflect a gradient in grain size.

The experimental validation part of this report has thus been divided into three parts:
Assessment of field *i*) PNECs, *ii*) field PECs and *iii*) field risks and the risk model

Together, these tasks will secure an experimental validation of selected theoretical PNECs and the EIF sediment calculations regarding PEC and risk, i.e. according to all the validation steps described in the EIF concept development The documentation (*i, ii and iii*) may be used to full scale field validation of the ERMS EIF sedimentation calculation. Together these tasks will secure an experimental validation of selected theoretical PNECs and the EIF sediment calculations regarding PEC and risk, i.e. according to all the validation steps described in the EIF concept development. Regarding the validation of the NOECs we suggest a further study including more field data.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Field validation (PNEC, NOEC, PEC, Risk)	Validering felt data (PNEC, NOEC,PEC,Risiko
GROUP 2	Multivariate Analysis	Flervariabel Analyse

Content

1. Objective

The objective of this study has been to apply and process available information from the MOD database on benthic ecology to validate model assumptions and outcomes from the ERMS model calculating EIF sediment relevant parameters. By comparing the calculated (modelled) PECs and risk areas in the light of the observed (monitored) effects, the realism of the EIF model can be assessed. Based on this comparison, suggestions for fine tuning of the final ERMS EIF model can be made in the future, based on the documented field data in this report.

The selected fields have been chosen to reflect a variation in grain size and discharge type (WBM and SBM), although careful selection of the fields has been necessary on the basis of the availability of discharge and monitoring data. Such selection is necessary as grain size and discharge type were expected to be of importance for the PNEC and PEC/Risk evaluation, respectively. For the PEC and risk validation four fields have been selected, Goliath, SVAN, Vigdis and Norne. Goliath and SVAN have been selected because measurements have been carried out at distances considerably closer than the ordinary 250 m distance, and Vigdis and Norne because the (old) ParTrack model in the pre-ERMS project already has been applied on these fields. In addition, Vigdis is a field where SBM has been used. The description of the selected fields is given in Appendix 1.

The report is composed of three parts:

i) Assessment of field PNECs
ii) Assessment of field PECs
iii) Assessment of field risks and the risk model

Together, these tasks will secure an experimental validation of selected theoretical PNECs and the EIF sediment calculations regarding PEC and risk, i.e. according to all the validation steps described in the EIF concept development.

2. Methods

All data has been processed, quality controlled and delivered by Akvaplan- niva. The PECs have been analysed following the guidelines of the Norwegian Pollution Control Authority (SFT). The field PNEC for the field data has been defined as the highest concentration of the toxic stressor where no effect has been *observed* on the benthic fauna. Thus, we will refer to these values as field NOECs (i.e no observed effect concentration) further in the document.

Multivariate methods as Correspondence Analysis (Jongmann et al. 1995), Multidimensional Scaling (Borg & Groenen 1997), Bray-Curtis dissimilarity index (Bray & Curtis, 19957), Principal component Analysis (Wold et al. 1987) and CDI (Massart B. et al. 1996, Massart B, 1997); i.e. Community Disturbance Index, have been applied to find the exact level where the benthic community is reacting to the toxic stressors. Of the multivariate methods only CDI is quantitatively, meaning that the stress level is related to one number, CDI >1. This CDI is used throughout this

report as the main expression for the level of stress in the benthic fauna. A brief presentation of the CDI method is included in Appendix 2.

3. Results

3.1 Assessment of NOECs

The stressors that are subject to validation correspond to the components that are measured in the monitoring and are available in MOD.

3.1.1 Strategy

When one chemical stressor is present in a high concentration, usually many others are present as well. This is related to drilling fluids, the weighting material as well as other discharge chemicals from the platform. This trivial correlation between the toxic stressors puts a demand on the use of field data, as it may be very difficult to relate the effect from only one chemical stressor to the observed changes in the benthic fauna. As a consequence we have developed a strategy that may cope with this problem. The method is as follows:

1) To avoid possible dominance of hydrocarbons in the sediments, fields drilled with water and synthetic based fluids were selected. Furthermore, the fields were supposed to represent a gradient in grain size, see Table 1. This first step revealed the following seven fields as candidates:

Field	TOM (Total Organic Matter) average mg/kg	Pelitt average %	Grain size average µm
Norne 2000	**7,3**	**84,8**	**21**
Njord 1996	**3,9**	**70,0**	**31**
Njord 2000	**4,1**	**60,0**	**44**
Njord 2003	**3,6**	**60,0**	**43**
Goliath 2003	**3,0**	**56,0**	**29**
Vigdis 1999	**3,0**	**26,0**	**40**
Lille Frigg 2000	**1,0**	**5,3**	**84**
NE Frigg 2000	**0,8**	**2,9**	**126**

Table 1: The selected fields and some of their sediment characteristics (average from all stations)

2) The next step is to identify the stations where no effects on benthic fauna are evident. To define “no effect”, several multivariate methods have been used. Multivariate methods, so-called species dependent methods, are considered the most sensitive methods to detect if a disturbance has taken place. To facilitate the reading of this report, all multivariate analysis on the selected fields has been included in the Appendix 3.

3) The next step is then to define the *maximum* concentration of each toxic stressor present in the samples *where no disturbance* of benthic fauna has taken place. For each stressor, we select the highest concentration for each field among the stations where no effect has been observed on the benthic fauna. This value, i.e. the highest value of a chemical stressor observed in the sediment where no effect is observed in the benthic fauna, is abbreviated to NOEC (No Observed Effect Concentration). These field-derived NOECs are shown in Table 2.

	Grain size	TOM	Pelite	THC	NPD	PAH	Decalins
Norne 2000	21	7	85	23	0,09	0,09	1,15
Goliath	29	3	56	3	nm	nm	nm
Njord 1996	*31*	*4*	*70*	*8*	*0,10*	*0,00*	*0,00*
Vigdis 1999	40	3	26	11	0,04	0,06	0,08
Njord 2003	43	4	60	11	0,05	0,11	0,70
Njord 2000	44	4	60	16	0,07	0,13	0,74
Lille Frigg	84	1	5	8	0,05	0,05	0,03
NE Frigg	*126*	*1*	*3*	*6*	*0.01*	*Nm*	*0,02*

	Cd	Pb	Ba	Cr	Cu	Zn	Hg
Norne 2000	0,10	21,97	2994	37,57	11,47	71,57	0,030
Goliath	0,09	16,10	1330	65,50	12,00	48,00	nm
Njord 1996	*0,05*	*16,70*	*298*	*0,00*	*8,93*	*38,10*	*nm*
Vigdis 1999	0,07	5,90	2223	15,90	3,70	16,50	0,012
Njord 2003	0,06	17,59	1276	24,42	7,47	45,38	nm
Njord 2000	0,05	18,67	1964	23,93	8,40	43,07	nm
Lille Frigg	0,02	7,87	727	5,20	2,00	6,83	0,010
NE Frigg	*0,02*	*3,70*	*31*	*6,17*	*0,92*	*2,50*	*0,010*

Table 2 The field derived NOECs (mg/kg dry sediment) and sediment characteristics (average grain size in µm, TOM and pelite in percent) (nm: not measured). The two fileds Njord 1999 and NE Frigg are from baseline studies

A correspondence analysis plot of Table 2 is shown in Figure 1. Note that the two fields analysed as baseline studies are excluded from the anlysis, as their correlation structure is less interesting. The plot in Figure 1 is a so-called biplot where field scores and variable loadings are given in the same plot. Similar fields are plotted together, as e.g. Njord 2000 and Njord 2003. As the plot shows, the field Lille Frigg is the least polluted field, while the highest level of toxic stressors is found at the Norne field in 2000. This conclusion is confirmed from Table 2. All the chemical stressor NOECs are positively correlated and fall together in one group at the same side of the origo, while the parameter grain size falls on the other side of origo compared to the chemical stressors, telling that the NOEC values are negatively correlated with the grain size. From this, we can conclude that the tolerance level for the benthic fauna (the NOEC value) increases with decreasing average grain size.

The observation that the NOEC-value generally is inversely proportional with grain size, is probably related to the fact that a coarse sediment will increase the bioavailability of a metal. The proportion of free metal ions, which for most metals

is the most bioavailable and toxic form, is generally inversely proportional with the amount of organic matter (Bryan and Langston, 1992). Thus coarse sediments, which naturally contain little organic matter, will increase the bioavailability of metals. Several studies have showed a direct relationship between metal concentration in the pore water and sediment toxicity (e.g. Swartz et al., 1985; Kemp and Swartz, 1988; Green et al., 1993). It has also been shown that both macrobenthos (Pesch, 1979; Trannum et al., 2004) and meiofauna (Tietjen, 1980; Austen et al., 1994) have been less affected by metal contamination in mud than in sand.

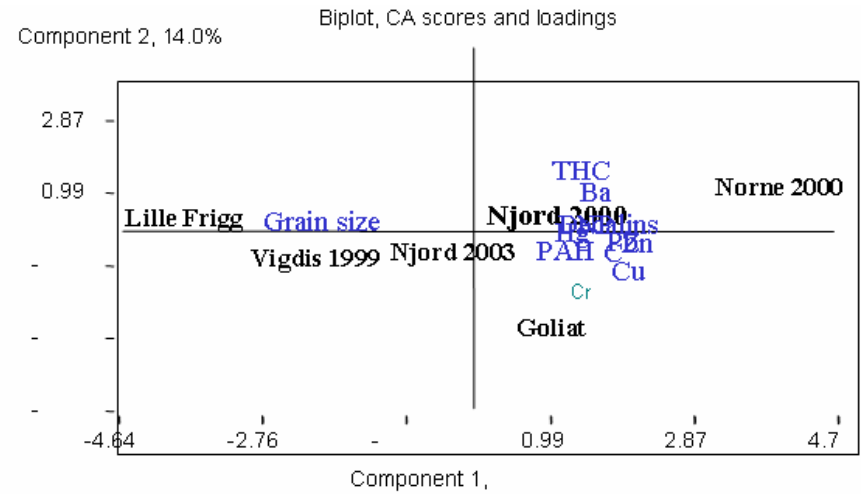

Figure 1 Biplot from the Correspondence analysis of the field derived NOEC data

If we for example look at the NOEC values for Cd in Table 2, we can see that the NOEC value decreases from 0,10 ppm to 0,02 ppm when average grain size increases from 21 µm to 126 µm. This negative correlation between the field NOEC values and the average grain size is illustrated for Cd in Figure 2 (baseline studies not included)

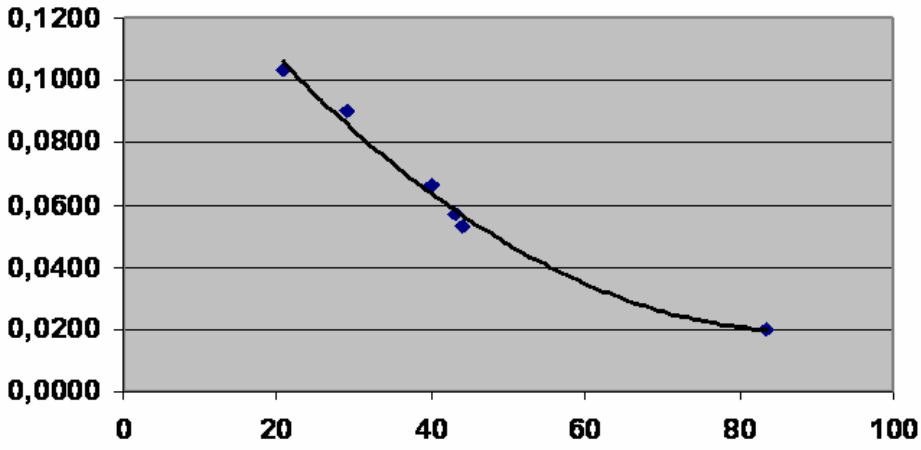

*Figure 2 The correlation between Cd field NOECs (ppm) and average grain size (*µm).

Note that background levels of the chemical stressors also vary with grain size. We tested this for Cd, and as a rule of thumb we found the background levels to be roughly half of the NOEC values.This is illustrated in Figure 3.

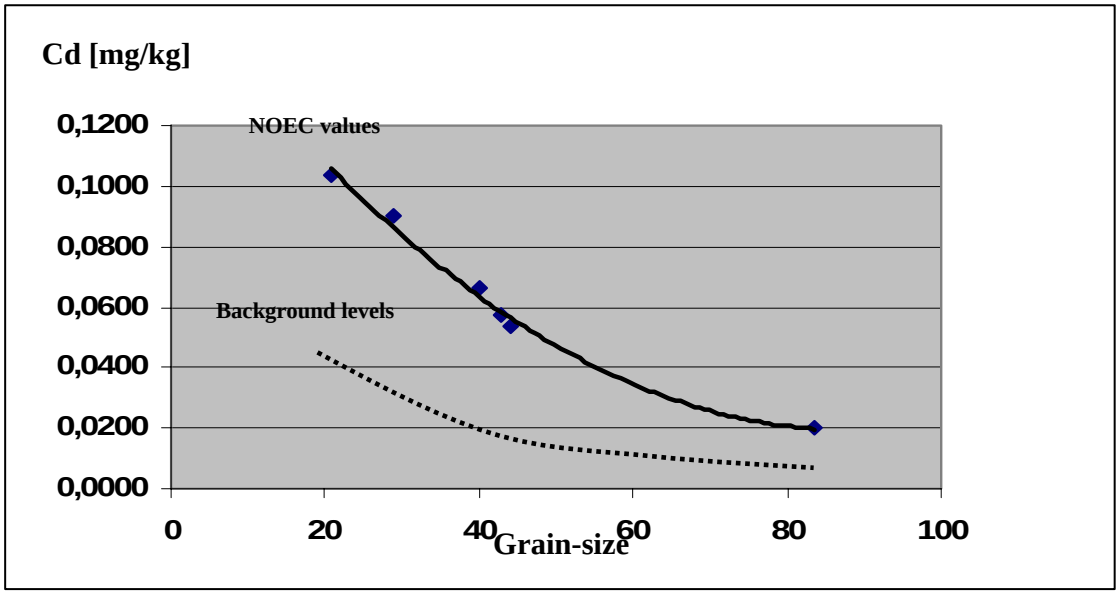

Figure 3. The correlation between Cd field NOECs and Cd background levels at the different grain size intervals.

As the NOEC values in this report only have been based on the selected seven fields, these will be explored more in detailed based on all available data in the MOD (i.e. more than 2000 stations). We refer to the later ERMS report for a more thorough analysis and presentation of field NOECs (Brakstad et al, 2005)..

3.1.2 Field derived non-toxic NOECs

Regarding the non-toxic NOECs (burial and oxygen), these are not available in the MOD database. Consequently, only the evaluation of toxic stress and change in grain size can be done with data from the MOD database.

Regarding oxygen, a measurement of redox potential was performed at the SVAN field (Trannum et al., 2005). At two of the stations closest to the discharge point, suboxic conditions were measured, while all the other sediments were characterized as oxic. Generally, the redox potential was lower 5 cm down in the sediment compared to the surface. There was also a tendency with lowered redox potentials towards the discharge point in the 10º direction (see reference). In the other directions the redox potential was slightly lower at the 75 m station compared to the 125 m station. The lowered potentials closer to the discharge point may indicate higher biodegradation rates. However, it is important to be aware of the fact that the trends are not very strong at the same time as the measurements cannot be interpreted very accurately. There does not appear to be any correlation between the THC content and the redox potential neither at the surface nor at 5 cm sediment depth.

The results of the redox measurements were used in the statistical analyses that were performed to investigate the relationship between the biological and environmental variables. Also the results from the ParTrack modeling were included in these

analyses in order to evaluate possible impacts of burial. According to the modeling the maximum deposition rate was 10 kg/m^2, correspond to approximately 1 mm deposition during the drilling activities. Various statistical methods were used to analyze the correlation between the biological data and the environmental variables, and the results were not very consistent, see Trannum et al., 2005. However, the main conclusion was that trace metals seemed to be of most importance regarding the structuring of the benthic communities, while THC, burial and redox were of less importance.

The ParTrack results were also included in a CCA of the Vigdis field. Burial did not come up as a significant variable, in contrast to chromium, THC and depth, which seemed to be of most importance for the composition of the benthic communities at that field. The maximum burial rate at Vigdis was in the interval 1-3 kg/m^2 during drilling. The CCA of the Vigdis field is presented in Appendix 3.

Regarding the results of the analyses of the impact of burial, it is important to have in mind that the measure of burial is modeled, and not measured in the field. To obtain a more robust conclusion of possible effects of burial, one should use more realistic and accurate data.

3.2 Assessment of PECs

The extension of chemical contamination is presented in the tables in chapter 3.3 below. These areas, together with the reported concentration of the various chemicals, may be used to validate the PEC modelling (when full scale testing of the final ERMS EIF calculation take place). Site specific discharges and dates will be input to the model, and the validation will explore and quantify how the calculated PECs (model outcome) fit with the observed and reported field “PECs” in this report. The observed “field PECs” are the measured concentration of chemical stressors at the time of sampling. The calculation of PECs with the model will be performed by SINTEF separately. The measured concentration levels of all toxic stressors for the fields Vigdis, Norne and Goliat are given in Appendix 4. For a presentation of the SVAN results, please see Trannum et al., 2005.

3.3 Validation of risk and the risk model

In order to calculate the risk, the estimated area having a CDI higher than 1 was calculated at the selected fields. The calculation is based on the area of an asymmetric ellipse. The radius will vary between the different transects. In cases where a CDI higher than 1 is only recorded along one to three transects, half of the length of the distance between the station and the discharge point was used as the radius of the non-disturbed transect(s). For stations having a CDI-value very close to 1, the risk is calculated with this station classified as both disturbed and undisturbed, as CDI indicated the zone transition between the disturbed and undisturbed. The CDI-values that are used as input in the risk calculation is presented in Table 3.

In the traditional monitoring, Akvaplan-niva calculates the area that is classified as contaminated based on the different chemicals in addition to the area that can be classified as disturbed according to the classification in faunal groups. At fields that

have been investigated by Akvaplan-niva these results are included as they may be compared with the area that is classified as disturbed according to the CDI method.

The Goliath field 2003		The NORNE SW field 2000		The Vigdis field 1999	
Name	**CDI**	**Station**	**CDI**	**Station**	**CDI**
GOL1-26	**1,62**	NONW-13	1,78	VGIT-02	10,38
GOL1-14	**1,20**	NOSW-10	1,30	VGPT2-09	4,59
GOL-28	1,05	NOSW-01	1,30	VGPT1-22	3,85
GOL1-1	1,01	NONW-09	1,11	VGIT-03	2,57
GOL1-3	1,00	NONW-12	1,02	VGPT2-16	2,04
GOL1-11	0,96	NOSW-03	0,98	VGPT1-23	1,82
GOL1-4	0,96	NONW-15	0,97	VGPT1-27	1,52
GOL1-23	0,94	NOSW-07	0,97	VGIT-04	1,18
GOL1-10	0,93	NOSW-04	0,93	VGPT2-10	1,03
GOL1-22	0,91	NOSW-13	0,92	VGPT2-18	1,01
GOL1-17	0,88	NONW-03	0,91	VGPT2-12	1,00
GOL1-20	0,87	NONW-11	0,91	VGIT-05	0,99
GOL1-15	0,86	NONW-02	0,90	VGPT1-19	0,99
GOL1-9	0,86	NONW-06	0,88	VGPT2-17	0,98
GOL1-19	0,86	NONW-07	0,88	VGPT2-14	0,95
GOL1-12	0,85	NONW-10	0,87	VGPT1-24	0,92
GOL1-2	0,84	NOSW-11	0,82	VGPT1-25	0,89
GOL1-7	0,82	NOSW-RefB	0,81	VGPT1-28	0,86
GOL-refA	0,80	NOSW-08	0,78	VGPT2-15	0,85
GOL1-21	0,79	NOSW-RefA	0,74	VGPT1-21	0,84
GOL-refB	0,64	NONW-14	0,73	VGPT2-08	0,82
		NOSW-12	0,70	VGIT-01	0,81
				VGIT-06	0,80
				VGPT2-11	0,80
				VGPT2-07	0,79

Table 3. Calculation of Commiunity Disturbance Index for the validation fields Goliath, Vigdis and Norne. CDI < 1 are undisturbed fields. CDI 1.00 -1.2 are fields that may have a very slight disturbed benthic fauna. CDI > 1.2 are fields where pollution induced disturbance has been found. All CDIs correlates well to results found by MDS and CCA.

The risk calculations of the selected field are presented below. Also the calculation of contaminated area is presented to compare the extension of chemical pollution with biological effects.

Goliat

Goliat	NE	SE	SW	NW	Area m^2	Area km^2
THC	12,5	25	12,5	12,5	736	0.007
Ba	125	125	125	125	49087	0.05
Ti	50	50	12,5	25	3682	0.004
Fe, Cr, Cu, Zn	25	50	12,5	25	2209	0.002
Cd, Pb, Al	0	0	0	0	0	0
Li	25	12,5	12,5	12,5	736	0.000
Faunal group B	12.5	50	12.5	12.5	1227	0.001
$Risk_{min}$	25	50	25	50	3927	0.004
$Risk_{max}$	25	50	25	250*	11781	0.012

* CDI=1.002. NE: NorthEast, SE: South East, SW:South West, NW:North West

Vigdis

VGIT	SE	SW	NE	NW	Area m^2	Area km^2
THC	0	0	0	0	0	0
Olefins	2000	125	250	1000	883573	1.99
Ba	1000	125	250	1000	589049	1.10
Other metals	250	125	125	125	73631	0.07
Faunal group B	500	125	125	125	122718	0.12
Faunal group C	250	125	125	125	73631	0.07
Risk	1000	125	250	125	331340	0.33

. NE: NorthEast, SE: South East, SW:South West, NW:North West

VGPT1	SE	SW	NE	NW	Area m^2	Area km^2
THC	250	125	250	125	98175	0,10
Olefins	500	125	250	125	147262	0,15
Ba	1000	125	250	125	245437	0,25
Other metals	250	125	125	125	73631	0,07
Faunal group B	500	125	250	125	147262	0,15
Risk	500	125	250	125	184078	0,18

. NE: NorthEast, SE: South East, SW:South West, NW:North West

VGPT2	SE	SW	NW	NE	Area m^2	Area km^2
THC	250	125	125	125	73631	0,07
Olefins	250	125	125	250	98175	0,10
Ba	1000	125	1000	250	1104466	1,10
Other metals	250	125	125	125	73631	0,07
Faunal group B	250	125	125	250	98175	0,10
$Risk_{min}$	500	125	125	250*	184078	0,18
$Risk_{max}$	500	125	125	1000*	552233	0,55

* CDI= 1.003 at the 1000 m station and 0,988 at the 500 m station. . NE: NorthEast, SE: South East, SW:South West, NW:North West

At Vigdis it is worth noting that the CDI value at the reference station was 1.037. As the faunal composition not indicated any kind of disturbance, the high CDI value is assumed to be caused by the fact that the faunal composition differed from the fauna closer to the discharge point of other reasons than pollution, although the observed change from “natural” fauna is minimal.

Norne

Norne (2000) was investigated by DNV (Norne NW and SW). On this field only the risk values are therefore given. At Norne SW the station grid was modified, and the risk calculation is therefore only done for the NW installation.

Norne NW	NE	SE	SW	NW	Area m^2	Area km^2
Risk	250	250	500	500	441786	0,44

NE: NorthEast, SE: South East, SW:South West, NW:North West

SVAN

The monitoring of the SVAN field was not a part of the ordinary monitoring, and fewer stations were sampled. The outermost station was 1000 m in the 10° direction, but only 125 m in the other directions. As chemical contamination was observed at the outermost stations in one or more directions, the area that is chemically contaminated is therefore expected to be larger than estimated in the table below. However, this is not assumed to be the case regarding the effect measurements on the benthic fauna as the chemical pollution from unknown source(s) seem to be of relatively recent date.

	SE	SW	NW	NE	Area m^2	Area km^2
THC	125	125	125	500	122718	0.12
Ba	125	125	125	1000	220893	0.22
Other metals	125	125	75	175	47124	0.05
Faunal group B	75	32.5	75	75	12665	0.01
CDI	125	125	125	125	47124	0.05

NE: NorthEast, SE: South East, SW:South West, NW:North West

For the selected fields risk areas will be calculated by the EIF sediment model. These model outcome and risk areas will be compared with observed disturbance in benthic communities. At the moment of writing, the model calculation has not yet been performed. Differences between modelled risks and observed disturbance are assumed to be caused by uncertainties in the risk calculations of the model. Empirical relationships between the reported disturbances in the benthic community and measured environmental data (concentration of contaminants in sediment, grain size, TOC) may then be set up to reveal these uncertainties.

4. Conclusion

This report summarizes selected field data for the purpose of final validation of the ERMS EIF sediment model.

Field NOECs[1] have been reported for specific chemical stressors selected from seven different fields. The fields have been selected due to their various average grain size. We found that the NOECs correlate negatively with average grain size. All NOECs increase with decreasing average grain size with average grain sizes lower than 80 µm. Note however that this conclusion is based on rather few fields, and should be verified.

Neither oxygen values nor burial is measured in the ordinary monitoring, which restricts the data available for verification of PNECs for these stressors. However, in the field trial carried out at SVAN, redox measurements were conducted. Suboxic conditions were recorded at one of the stations closest to the well, but according to the statistical analysis this did apparently not influence the fauna. At the SVAN and Vigdis field the ParTrack results were incorporated in the statistical analyses in order to investigate a possible effect of burial. These results showed that the burial rates at those fields, having a maximum value of 10 kg/m^2 during the drilling activities, not seemed to have any impact on the benthic communities. However, it is important to bear in mind that the burial rate refers to modeled rather than measured values.

The field PECs are reported for three fields i) Vigdis 1999, ii) Goliath and iii) Norne. Due to contamination (unknown source) of THC on the SVAN field, this field is less suitable for validation purposes, and the analysis of this field has bee excluded from the report although the area calculation has been included.

The validation of Risk may be done by comparing the model output with the calculated CDI values and the calculated areas of contamination and observed effects on the benthic fauna, given for all stations of Vigdis, Goliath and Norne.

[1] NOECs, No observable Effect Concentration. In practice we have reported the highest level of the chemical stressors we have observed at the **undisturbed** stations of the selected fields.

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6. Appendix 1 Description of selected fields

Sleipner Vest Alfa Nord (SVAN)
SVAN is located in the western part of region II in the North Sea. Statoil is the operator. Drilling was performed from September 2003 to April 2004. Only water based drilling fluid has been used on the field.
The depth at SVAN is 108 m. The sediment is characterised as silt or fine sand. As part of the ERMS program SINTEF and Akvaplan-niva carry out a complex study where the *ParTrack* model is applied as well as a number of sediment and water column sampling, including sampling of benthic fauna on 75 m distance from the discharge point. SINTEF headed a study of the fate of the drilling discharges in the water column during drilling in August 2003, and Akvaplan-niva heads a study on investigation on the effects of the discharges at the sea floor. Biological sampling was performed before the drilling activities, in September 2003, and after the completion of drilling activities, in April 2004.

Goliat
Goliat is located in the sub area "Finnmark West" in region IX in the southern parts of the Barents Sea. Exploratory drilling has been carried out at two wells by Eni Norge AS. However, both wells are now abandoned. During the sampling that was carried out in June 2003, samples were taken in vicinity of both wells, but only the samples from well 1 were processed. At that well, the drilling was performed in September 2000. The top-hole section was drilled with seawater and high viscous sweeps with prehydrated bentonite mud, and ilmenite used as the weighting material. The sections below the top-hole section were drilled with formate based drilling fluid (blend of potassium and sodium formate).
The *ParTrack* model has been applied on Goliat. The benthic sampling was carried out as close as 25 m from the discharge, which is unique in the offshore context. The depth at Goliat is 380 m – 400 m, and the sediment is mainly composed of silt. Since only exploration drilling has been carried out, there are no baseline data available at Goliat.

Vigdis
Vigdis is situated along the slope of the Norwegian Trench in region IV in the North Sea. Norsk Hydro started production in 1997. There are three wells drilled with both water based and synthetic drilling fluids on the field.

The depth at Vigdis is 270 m – 290 m. The sediment is mainly composed of silt.

In a pre-project for verification of the *ParTrack* model, SINTEF used the data from the environmental monitoring at Vigdis in 1999. This was the main reason for using Vigdis in the present project. In order to use the same data, the results from 1999 are used, despite of the fact that the field also was monitored in 2002.

Norne
Norne is situated at Haltenbanken in region VI in the Norwegian Sea. Statoil started production in 1997. The field is composed of five subsea templates; three in south (two for production and one for injection) and two in north (one

for production and one for injection). Only water based drilling fluids have been used.

The depth at Norne is approximately 380 m, and the sediment is composed of silt.

Also Norne was used by SINTEF in the pre-project, which is the main reason for using this field in the present project. However, it was also important to include a field from the Norwegian Sea and a deep water area, which Norne fulfils. The data from the monitoring in 2000 was used in SINTEF's project and also in the present project.

7. Appendix 2 A description of CDI

A combined chemical and biological multivariate approach for assessing the influenced area by discharges from offshore petroleum activity

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ABSTRACT.

Analyses of sediment samples collected around a petroleum production site in the North Sea show that accurate assessment of the extension and quantitative degree of environmental impact from a production site can be achieved by combining information extracted by multivariate analysis of chemical data and faunal benthic data.

Firstly, principal component analysis (PCA) of the chemical variables is used to obtain an initial set of sampling locations (stations) with apparently healthy chemical environment for the benthic communities. Secondly, the benthic profiles from these stations are analyzed by correspondence analysis (CA). This analysis partitions the total variance in the benthic data into two parts: i) variation reflecting the similarity between benthic profiles from all reference stations, and, ii) variation due to the unique species patterns for each community. These two sources of variation reflect natural variation in our terminology. The unique part of the species profiles for the stations in this reference set is used to calculate a statistically upper limit for residual unique variation for a healthy or undisturbed community. Samples from all stations are subsequently fitted to the reference model, and the residual for each sample

compared with the upper limit for an undisturbed community. A statistically based decision can then be made whether or not a sample is similar in species profile to the reference set of healthy communities. If the residual is larger than the upper limit and the chemical variables for the station reveals elevated levels, one can conclude that the community is disturbed because of impact from discharges from the production site..

INTRODUCTION

Benthic macroinvertebrates have been used extensively to assess pollution-induced disturbances from industrial activity. Changes in community structure in the surroundings of an industrial site is taken as a measure of the chemical contamination of the sediment since this fauna integrates chemical interactions of multiple pollutants and is not dependent on route of exposure. Kingston[1] has reviewed the impact of offshore installations on the benthos of the North Sea sediments.

Diversity indices were introduced in the ecological literature almost 30 years ago. Although they have often been criticized since, they are still much used in applied ecological research, and also in pollution impact studies[2]. Several authors[2-4] have reported that the Shannon-Wiener index[5] H_S lacks sensitivity to severe changes in the community structure. It was found that clear changes in diversity indices occur only at approximately 20 times background levels of Ba and 50 times background levels of THC[6]. In a comparison between univariate and multivariate methods for analyzing changes in benthic community structure, it was concluded that multivariate methods were much more sensitive for discriminating between stations[6-7].

The main advantage of using the Shannon-Wiener and other univariate indices, lies in their simple calculation and their quantitative basis. As such, they can be used to get a first quick look at the community data. However, as we will show in this work, these indices are to insensitive to reveal the successive changes in the community structure along a contamination gradient. This means that too much information is lost calculating the Shannon-Wiener and other univariate indices. This is particularly true for the transition from strongly polluted and unpolluted areas.

Hierarchical agglomerative cluster analysis with average linking[8-9] is a frequently used multivariate method in environmental monitoring[6, 10-11]. The most important advantage of cluster analysis is the flexible choice of this distance measure. As such, an environmentally meaningful classification can be obtained. However, due to its non-overlapping and agglomerative character, this clustering technique may sometimes give rise to misleading results. As shown by comparing univariate and multivariate methods, Multidimensional Scaling (MDS) and Correspondence Analysis (CA) are more sensitive than the univariate indices, but they lack a specific quantitative measure

of disturbance such as a statistically determined limit for discriminating between polluted and unpolluted areas, or even better, a continuous measure for quantifying the degree of pollution.

The principal aim of the present study is to present a strategy for selecting and validating a reference set for calculating the community disturbance index (CDI). The CDI as presented in this work is based on a multivariate classification of the stations using correspondence analysis (CA), and not, as earlier described, principal component analysis (PCA)[12]. The result is a table of CDIs, one for each sampling location. The collection of CDIs can be used to generate a contour map showing the degree of disturbance around the platform.

METHODS

Description of the field.

In this investigation we have analyzed the data from the stations around the production site Oseberg East. The sampling locations are shown in Fig.1.

The samples are denoted by a letter and three numbers corresponding to field, angle with direction of main current, distance from platform in meter and the year of the survey. Thus, a sample collected at Oseberg East at a location with the angle 45 degrees to main current direction, at 500 m from the platform in the 2001 survey, is denoted O-45/500-01..

Sample and analysis.

Surveys are conducted in Spring time following directives prepared by the Norwegian State Pollution Control Authority[14-15]. At each station, samples are taken with a Van Veen grab (0.1 m^2) with 5 replicates for analyses of benthic macrofauna and 3 replicates for analyses of sediment variables. For the stations located 10230 m from the production site, 5 additional replicates were taken for the benthic microfauna and two additional replicates were taken for the chemical analyses. The biological samples are extracted using 1 mm mesh sieves and the material fixed in formalin and analyzed in the laboratory. For physical and chemical analyses, sub-samples are taken from the top of the grab, using the upper 5 cm for physical analyses and upper 1 cm for

chemical analyses. In all investigations, we include the concentrations of Ba, Cu, Pb, Zn, Cd, and total hydrocarbon content (THC).

Assessing the species distribution through the Shannon-Wiener index.

The Shannon-Wiener information index is defined as $H_S = -\sum_{i=1}^{n} p_i \log_2 p_i$ where n is the number of species in the sample and $p_i = n_i / \sum_{j=1}^{n} n_j$ is the fraction of the i-th species (n_i is the number of the i-th species in the sample). It is clear that, for the calculation of this index, all species are treated identically, i.e. the index is insensitive to the species identity. Thus, permutations of the dominating species along a gradient, pointing to differing conditions, will go unnoticed.

Short outline of the CDI method.

A good index reflecting the species distribution should at least be sensitive to changes in: i)) the identity of the dominating species, and, (ii) the total and relative number of individuals of each species. A way of achieving these goals is to make use of multivariate techniques. Below, a quantitative index is developed, based on local correspondence analysis (CA) followed by a classification approach.

In a first step, a number of reference stations, i.e. sampling locations where undisturbed communities occur, are selected. In practice this is performed by performing a principal component analysis (PCA) of the chemical variables from all the stations to reveal those stations with non-elevated levels of the chemical variables and combining this knowledge with the positions of the stations in score plots from correspondence analysis (CA). Stations with non-elevated levels of the chemical variables cannot be disturbed by chemical impact and are therefore by definition representing undisturbed communities. However, also stations with moderate increase in level of chemical variables may be undisturbed communities and thus candidates for the refence set representing natural variation. On the other hand, stations far away from the production site with low levels of chemical variables may be biologically different from those closer to the site due to changes in depth, sediments etc. and should not be included in the reference set. These stations are revealed in the CA of the benthic profiles. Typically, so-called reference stations at around 10 000 m from the platform have a different natural composition to those closer to the platform and

are therefore not representative for the sample composition that we want to include in our reference set

Once the unpolluted stations have been selected, the natural variation in the species communities can be modeled by correspondence analysis. The index values for all stations are then obtained through fitting all stations to the model, and calculating a normalized distance to the model through SIMCA classification.

In the next few paragraphs, some more details will be given on all these features.

Selection of reference stations.

In order to model the natural variation in the species distributions, the model should be constructed with information about as many undisturbed communities as possible. In the present work, different ways of finding these undisturbed communities were applied. One approach was to use PCA of the chemical variables and CA for the biological variables to identify the reference set. Another approach we tested was to use a hierarchical clustering technique on the biological data.

Hierarchical clustering with average linking[9] with the Bray-Curtis dissimilarity index[16] as "distance" measure is a widely used technique in environmental surveys. This clustering technique starts by finding the two most similar (i.e. smallest dissimilarity index) samples, and combining them to form a new cluster. The dissimilarity measure between this cluster and a sample *i* is found as the average of the dissimilarities between the samples from which the cluster is constructed and the sample *i*. The method then further proceeds by finding the next two samples (or eventually clusters of original samples) which are most similar. The dissimilarity between this cluster and the other samples is then found in a similar way as above. The same technique is then continued until a final cluster is obtained, grouping all original samples. Generally the results are presented in a tree diagram (dendrogram).

Although this method shows some artifacts (see the Results section), it represents a good starting point for selecting reference stations. Its inherent unidirectional and rigid structure leads to a clear separation between clusters and an objective choice of possibly undisturbed stations. However, due to this same feature, the finally obtained dendrogram can not be seen as an end point.

As an alternative and more robust approach, we looked at the plots obtained by a score plot of the two major components using PCA on the chemical variables and following the same procedure for the benthic profiles using CA. Both PCA and CA were applied to the complete data set (i.e. disturbed and undisturbed stations). Stations with similar chemical variables and species distributions, e.g. the undisturbed community stations, plot closely together in such plots. For the other stations, the distance to the undisturbed cluster is larger, which is an indication of pollution at these stations. There are two possible strategies for selecting the reference stations using PCA of chemical variables and CA for the biological variables. Either we can successively delete stations using PCA of the chemical variables until there is no longer a structure in the score plot, i.e. the stations are randomly spread. This procedure eliminates also stations with rather moderate increase in level of chemical variables. Then we proceed by executing CA on this samples and eliminate samples that are isolated in the CA score plot and at the same time sampled far away from the platform. Then we check the benthic profiles statistically against this “first reference model” and redo the analysis after including stations that are not significantly biologically different from the “first refernce model”. This define the final set of reference stations to be used to calculate the CDI for each sample. In this way stations with moderate increase in chemical variables, but not biologically impacted becomes part of the final reference set. The other way, is to use CA to eliminate stations with different composition due to disturbance or outlying natural variation. Again, the score plot shall show no structure when a homogeneous set of samples is obtained.
In our case, the same result was obtained for both selection strategies. However, combining the information obtained through both approaches may be wise to assure a reliable choice for the reference stations.

CA modeling.

In principle, both principal component analysis[17] (PCA) or correspondence analysis[18] (CA) can be considered for modeling the variation in the non-disturbed communities. As the models are local, i.e. they do not have to stretch large gradients, the difference between both methods is expected to be small. However, since CA was preferred in a number of comparative studies[19-21] only this alternative is retained here.
As CA is described elsewhere, we will only summarize the main features here. However, since the non-reference stations are initially not included in the model, they

have to be *fitted* to it in order to obtain CDI values for all stations. As CA and derived techniques as DCA and CCA have mainly been used as ordination techniques[6,11], this part has not yet been addressed in the literature. This feature is thus discussed in some more detail.

Where possible, the notation used in Jongman et al.(1985)[18] is adopted. However, since we have two sets of data (one for model development, and one for fitting), the subscripts “ref” and “test” are used to differ between reference and test sets.
The species abundance matrix is noted as **Y** ($m \times n$), with the abundances for the different species for one station as columns. Station scores are represented as **X** ($n \times p$, where $p \leq \min(m,n)$), species scores as **U** ($m \times p$). The diagonal matrices **M** ($m \times m$) and **N** ($n \times n$) contain respectively the row- and column-sums of **Y** as diagonal elements.

CA can be regarded as a particular pre-and post treatment of the species abundance matrix, combined with a singular value decomposition (SVD). Generally, the singular value decomposes a matrix **A** ($m \times n$) (the actual form of **A** will be filled in later), as $\mathbf{A} = \mathbf{P}\boldsymbol{\Lambda}^{1/2}\mathbf{Q}^{T}$. Here, $\boldsymbol{\Lambda}(m \times n)$ is a diagonal matrix, containing the eigenvalues of **A**. The matrices **P** ($m \times m$) and **Q** ($n \times n$) are orthonormal.

CA applies an SVD of the matrix $\mathbf{M}_{ref}^{-1/2}\mathbf{Y}_{ref}\mathbf{N}_{ref}^{-1/2}$ in order to obtain the species and station scores:

$$\mathbf{M}_{ref}^{-1/2}\mathbf{Y}_{ref}\mathbf{N}_{ref}^{-1/2} = \mathbf{P}_{ref}\boldsymbol{\Lambda}_{ref}^{1/2}\mathbf{Q}_{ref}^{T} = \mathbf{M}_{ref}^{+1/2}\mathbf{U}_{ref}\mathbf{X}_{ref}^{T}\mathbf{N}_{ref}^{+1/2} \qquad (1)$$

where $\mathbf{U}_{ref}$ and $\mathbf{X}_{ref}$ are defined as $\mathbf{U}_{ref} = \mathbf{M}_{ref}^{-1/2}\,\mathbf{P}_{ref}\boldsymbol{\Lambda}_{ref}^{1/2}$ and $\mathbf{X}_{ref} = \mathbf{N}_{ref}^{-1/2}\,\mathbf{Q}_{ref}^{T}$.

The principal aim CA is data compression, entailing a simpler interpretation of the main features in the data. This is achieved by only retaining the first few dimensions in the models, i.e. by letting $p = a << \min(m,n)$. In most cases, two or three components suffice in order to account for a large amount of variance in the data, and thus the relevant information.

Retaining a smaller number of dimensions in the models involves introducing a residual matrix $\mathbf{E}_{ref}$ ($m \times n$) :

$$\mathbf{M}_{ref}^{-1}\mathbf{Y}_{ref}\mathbf{N}_{ref}^{-1} = \mathbf{U}_{ref}\mathbf{X}_{ref}^{T} + \mathbf{E}_{ref} \quad (2)$$

The aim is to choose *a* in such a way, that all important features in the data are contained in $\mathbf{U}_{ref}\mathbf{X}_{ref}^{T}$, while $\mathbf{E}_{ref}$ only contains noise.

Decisions on the number of components to be retained in the model are based on the eigenvalues, i.e. the diagonal elements contained in $\mathbf{\Lambda}_{ref}$. The value of each $\lambda_{ref,i}$ is in direct relation to the corresponding axes' importance. (The first axes corresponds with the largest eigenvalue, the second axes with the second largest eigenvalue, and so on). The model dimensions can then be chosen in such a way to retain a small number of axes with large eigenvalues, incorporating all major features in the data.

Once the model is calculated, new samples can be fitted to it. However, some complications occur for the choice of $\mathbf{M}_{test}$ to substitute $\mathbf{M}_{ref}$ in eq. 2 It turns out that the only logical choice would be $\mathbf{M}_{test} = \mathbf{M}_{ref}$. n_{test} (a scalar value, since only one station is fitted at a time) is simply given by the row sum for the new sample *i*. An additional problem is encountered when some species occur at non-model stations, which are not present in the model. The choice of the corresponding $\mathbf{M}_{ref,jj}$ value determines how much importance we want to attach to the absence of that particular species at all of the modeling stations. Small values lead to heavy weights for this species *j* in the model, and as such the index will be very sensitive to its presence.

Now $\mathbf{M}_{test}$ and n_{test} are known, the calculations of the station scores for new samples are performed through least-squares fitting ($\mathbf{X}_{test} = \mathbf{X}_{ref}$):

$$\mathbf{U}_{test} = \mathbf{M}_{test}^{-1}\mathbf{Y}_{test}n_{test}^{-1}\mathbf{X}_{test}(\mathbf{X}_{test}^{T}\mathbf{X}_{test})^{-1} \quad (3)$$

$$\mathbf{M}_{test}^{-1}\mathbf{Y}_{test}n_{test}^{-1} = \mathbf{U}_{test}\mathbf{X}_{test}^{T} + \mathbf{E}_{test} \quad (4)$$

SIMCA modeling.

The SIMCA method was initially intended for using a principal component model to describe the variance structure in the reference set[13]. In this work, this principle is extended to CA modeling.

From equation (4), it follows that we can obtain station scores and residuals for each of the stations in reference and test sets. These are subsequently used in a SIMCA classification procedure. Limits for stations scores and residuals are calculated based on the values obtained for the reference set.

In a first step, the residuals for each station (test and reference set) are condensed to a single number, called the residual standard deviation. This can be seen as defining a one dimensional abstract residual direction (RSD), in a space formed by the station scores and this additional direction. For each sample, the non-negative RSD is defined as:

$$RSD_i = \sqrt{\sum_{j=1}^{m} (e_{i,j})^2 / (m-a)} \qquad i = 1 \ldots n_{\text{tot}} \qquad (5)$$

where $m = m_{\text{ref}} = m_{\text{test}}$ and n_{tot} equals the total number of stations . $e_{\text{i,j}}$ is the (i,j) element of $\mathbf{E}_{\text{test}}$. Since this is of the form of a standard deviation, each RSD can be compared with a critical residual standard deviation RSD_{crit}, obtained from all *reference* set samples through an ordinary F-test[13]. In this way, borders for samples can quantitatively r similar to the reference set are obtained in the residual direction.

When a sample is tested against the reference set, the RSD for this sample is compared with the critical RSD for the reference set. The community disturbance index (CDI) is calculated as the ratio between the RSD for the tested sample and the maximum acceptable RSD, RSD_{crit}:

$$CDI_{\text{l}} = RSD_{\text{l}} | / RSD_{\text{crit}} \qquad (7)$$

The CDI index thus condenses the classification result obtained through SIMCA in one single value. Acceptable samples are characterized by CDI values below unity. Higher index values point to dissimilar samples. The hypothesis is that these samples points to contaminated areas.

Pretreatment of the data.

Benthic species with cumulative abundance lower than 5 across all stations in a survey were deleted from the data set. This pretreatment was performed in order to

stabilize the variance pattern in the data, i.e. to avoid noise from the many species with very low or zero count on almost all stations in a survey (ref). The species abundance matrices were subsequently subjected to a square root transformation in order to reduce the problem of heteroscedastic noise (ref). A square root and not a fourth root transformation as often used for benthic count data, suffices in this case, since only a the non-disturbed communities are included in the modeling step.
The chemical variables were pretreated by adding a constant of one and than applying a logarithmic transformation with base 10^{22}.

RESULTS AND DISCUSSION

PCA with the chemical variables of all the sampling locations as input gave the result shown in Figure 2. The samples located at the right (closest to THC) have the most elevated levels of the chemical variables and, thus, are potentially the most disturbed locations.
By gradually deleting the most chemically impacted stations and remodelling by PCA until a homogeneous sample set is obtain, we obtain the potentially chemically impacted sampling locations shown in Table 1. A useful graphic way of obtaining an initial reference set, is to exclude one by one the outlying samples in the CA score plot until the plot shows a homogeneous structure.

Sampling locations between 250 and 1000 m in the main current direction (angle 135 degrees), and, at 250 and 500 m in the direction opposite to the main current direction, and, at 250 and 500 m at 90 degrees angle of the main current direction show elevated chemical levels. The other stations are not chemically impacted and, accordingly, they should in principle be undisturbed in the benthic profile. However, a selection of only these samples may be rather conservative since some of the locations with elevated chemical level may not be biologically changed and therefore should be included in the reference set of biologically undisturbed locations.

Correspondence analysis with the benthic profiles of all samples gave the result shown in Fig.3. The two samples closest to the platform in the main current direction are clearly different from the others. When these two are deleted and a new model is calculated, we obtain the score plot shown in Fig. 4.

We observe that the samples from the locations at 10260 m from the platform in the main current directions are clearly different in the benthic from the others. However, this is a result of these samples being collected far from the others and therefore being biologically different for natural reasons, not as a result of industrial impact since the chemical variables are not showing elevated levels.

Multidimensional scaling (MDS) (Fig. 6) provides almost the same result as correspondence analysis. The two samples closest to the platform in the main current directions and the samples from the reference locations are dissimilat to the rest.

Fig. 6 shows the dendrogram for Oseberg East sampling locations. Three clusters emerge, with one at the left corresponding to the most disturbed communities. It consists of the locations at 250, and 500m in the main current direction. The cluster at the right side contains the least disturbed locations. Note that the reference stations are included although they have quite different composition than the other sampling locations in this group.

If we plot scores and loadings simultaneously in a CA biplot, benthic species corresponding to sampling locations with disturbed benthic communities can be highlighted. Fig.7 shows two dominant species, in the proximity of the two most disturbed sampling locations. These are opportunistic species and indicators of strong chemical impact. If these species are removed, other species are highlighted. By stepwise deletion we can easily pick up the species that contribute strongest to the separation between healthy and polluted locations around a platform.

After removal of the two most disturbed sampling locations and the samples at the reference location at 10260 m, the rest of the samples are collected as a reference set and a CA model is calculated. Figure 8 shows the distance to the CA model for the samples. All the samples are either inside, or just outside the border of the model (the line shown in Figure 8). Thus, the samples may be used as a reference set for undisturbed sampling locations.

Figure 8 shows the samples with elevated level of chemical variables and those with deviating benthic profiles. All locations with deviating benthic profiles show elevated

levels of chemical variables except the two samples taken at the reference locations at 10260 m.

Figure 9 shows good correspondence between CDI and sampling locations with elevated levels on the chemical variables. The locations at 1000 and 2000 m in the main current direction are both borderline cases, while the samples at 250 and 500 m at 45 degrees angle show CDI indicating nondisturbed communities.

The contour plot shows quantitatively the area of disturbed benthic communities although accurate interpolation requires more sample locations. The largest impacted area is, as expected, in the main current direction.

The normal probability plot of calculated Shannon-Wiener indices for the sampling location, reveals only one sample as significantly different in the benthic species profile to classify it as disturbed. All the other samples appears normally distributed, and, thus comply with the null hypothesis that they are undisturbed.

In Table 4, several univariate indices are calculated and compared with CDI. All the univariate indices shows the same pattern, with only one sampling locations being significantly biologically different from the rest and thus qualifying as disturbed.

CDI follows closely the trend of THC, while Shannon-Wiener is almost insensitive to changes in the chemical surroundings (Fig. 11).

CONCLUSIONS

In this work, we have used the distances to multivariate CA models to construct an index providing a sensitive and quantitative discrimination between sampled stations in a contaminated area. The SIMCA modeling approach was extended from principal component analysis to correspondence analysis. In order to separate the effects of natural variability and anthropogenic impact, we select the non-disturbed communities to construct a SIMCA-class (SIMCA: soft independent modeling of class analogies[13]). In this way we take into account the natural spatial variability and the stochastic fluctuation of the species abundances in unpolluted areas. A scaled distance to the

center of this class provides a quantitative measure of the level of stress. An ordinary F-test reveals the statistical significance of this distance measurement. We have shown that our methodology is useful in the quantitative assessment of the extent and severity of sediment contamination.

A disturbance or differences in benthic profiles may occur due to a change in the environment of a community either because of the impact from industrial discharge or a natural cause such as a rather large change in depth. One has to look at the pattern of the residual species profile and/or the chemical profiles in order to conclusively determine whether or not a change in CDI is due to pollution impact.

Contrary to commonly used multivariate methods for analysis of benthic count data, e.g., multidimensional scaling and dendrogram based on Bray-Curtis dissimilarity index, our data-analytical strategy provides a quantitative measure of disturbance.

Furthermore, while the relation between H_S and the chemical surroundings is mostly unclear, the community disturbance index (CDI) correlates well with the chemical profiles.

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Figure Captions:

Figure 1. Sampling grid, angle and distance from production site.

Figure 2. PCA biplot of sampling locations and chemical variables.

Figure 3. Correspondence analysis of benthic data.

Figure 4. Correspondence analysis after removal of the two most disturbed sampling sites,

Figure 5. Multidimensional scaling (MDS) of the benthic data.

Figure 6. Dendrogram using the Bray-Curtis index as dissimililarity measure.

Figure 7. Correspondnece analysis biplot of bethic data.

Figure 8. Residual Standard Deviation (RSD) of reference set of bilogical data.

Figure 9. Contour plot showing the CDI levels around the platform.

Figure 10. Normal probability plot of Shannon-Wiener index for the sampling locations.

Figure 11. Total hydrocarbon content (THC), CDI and Shannon-Wiener for the sampling locations.

Table captions:

Table 1. Sampling locations with meter under sea level and marking of locations with elevated level of chemical variables.

Table 2. Sampling locations with meter under sea level and marking of locations with elevated level of chemical variables and deviating bethic pattern..

Table 3. Sampling locations with meter under sea level and marking of locations with elevated level of chemical variables, deviating bethic pattern, and, the CDI for each sample...

Table 4. Sampling locations, CDI and univariate indices for each sample.

Fig. 1.

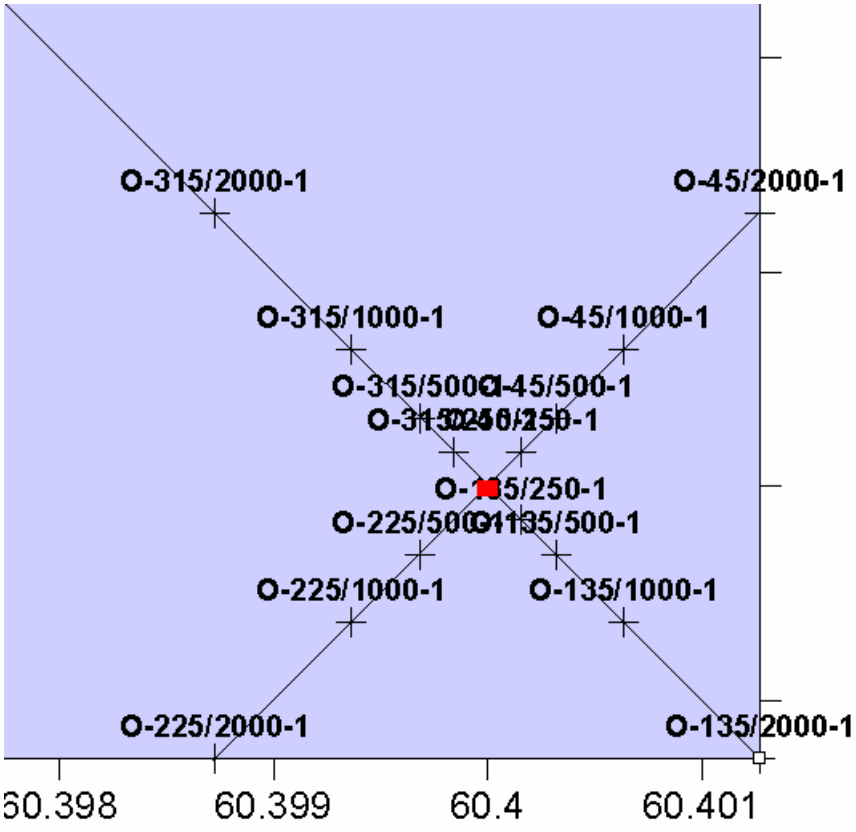

O-315/2000-1
O-45/2000-1
O-315/1000-1
O-45/1000-1
O-45/500-1
O-225/500-1
O-135/500-1
O-225/1000-1
O-135/1000-1
O-225/2000-1
O-135/2000-1
60.398
60.399
60.4
60.401

Fig. 2.

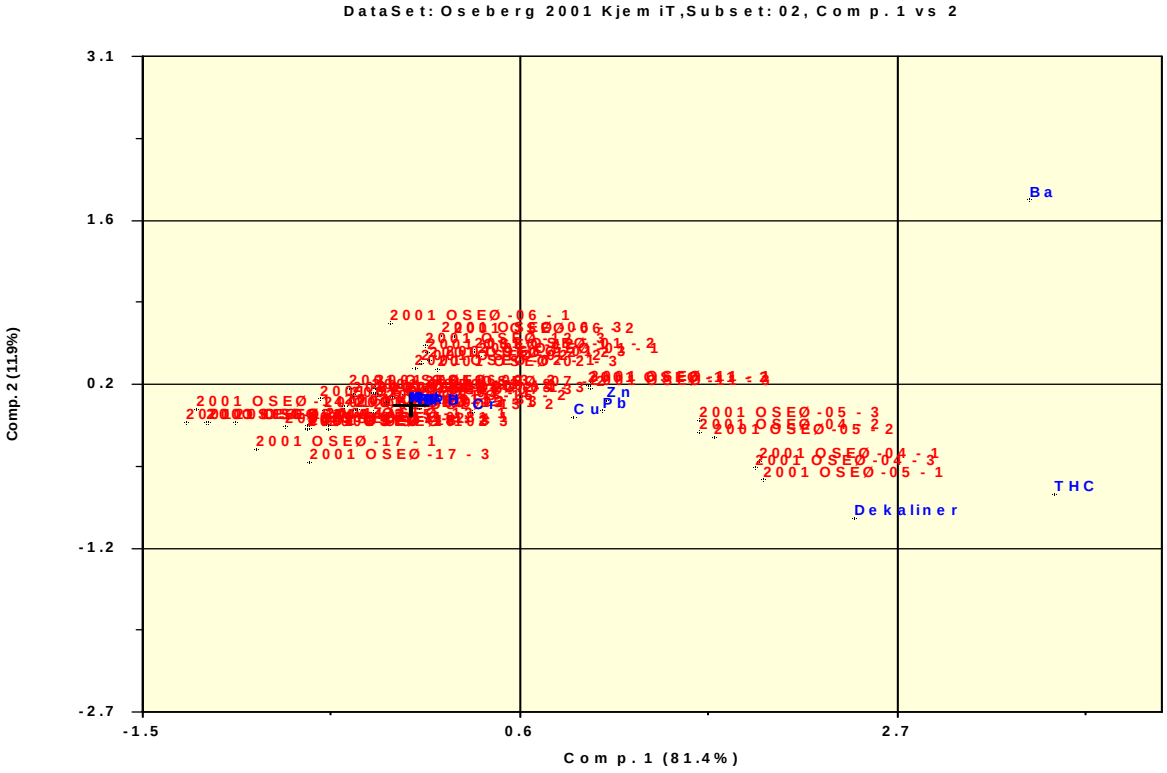

DataSet: Oseberg 2001 KjemiT,Subset: 02, Comp. 1 vs 2
3.1
1.6
0.2
-1.2
-2.7
-1.5
0.6
2.7
Comp. 2 (11.9%)
Comp. 1 (81.4%)
Ba
THC
Dekaliner
Cu
Pb
Zn
2001 OSEØ-06 - 1
2001 OSEØ-17 - 1
2001 OSEØ-17 - 3
2001 OSEØ-05 - 3
2001 OSEØ-05 - 1
2001 OSEØ-04 - 1
2001 OSEØ-04 - 3

Table 1.

	Stations	Angles	Distance	Depth	Poll. CHEM
1	OSEØ-01	45	250	156	
2	OSEØ-02	45	500	156	
3	OSEØ-03	45	1000	159	
4	OSEØ-04	135	250	154	
5	OSEØ-05	135	500	155	
6	OSEØ-06	135	1000	155	
7	OSEØ-07	135	2000	156	
8	OSEØ-08	225	250	154	
9	OSEØ-09	225	500	153	
10	OSEØ-10	225	1000	151	
11	OSEØ-11	315	250	155	
12	OSEØ-12	315	500	155	
13	OSEØ-13	315	1000	155	
14	OSEØ-14A	315	10260	132	
15	OSEØ-14B	315	10260	132	
16	OSEØ-15	45	2000	169	
17	OSEØ-16	135	4000	164	
18	OSEØ-17	225	2000	153	
19	OSEØ-18	315	2000	160	

Fig. 3.

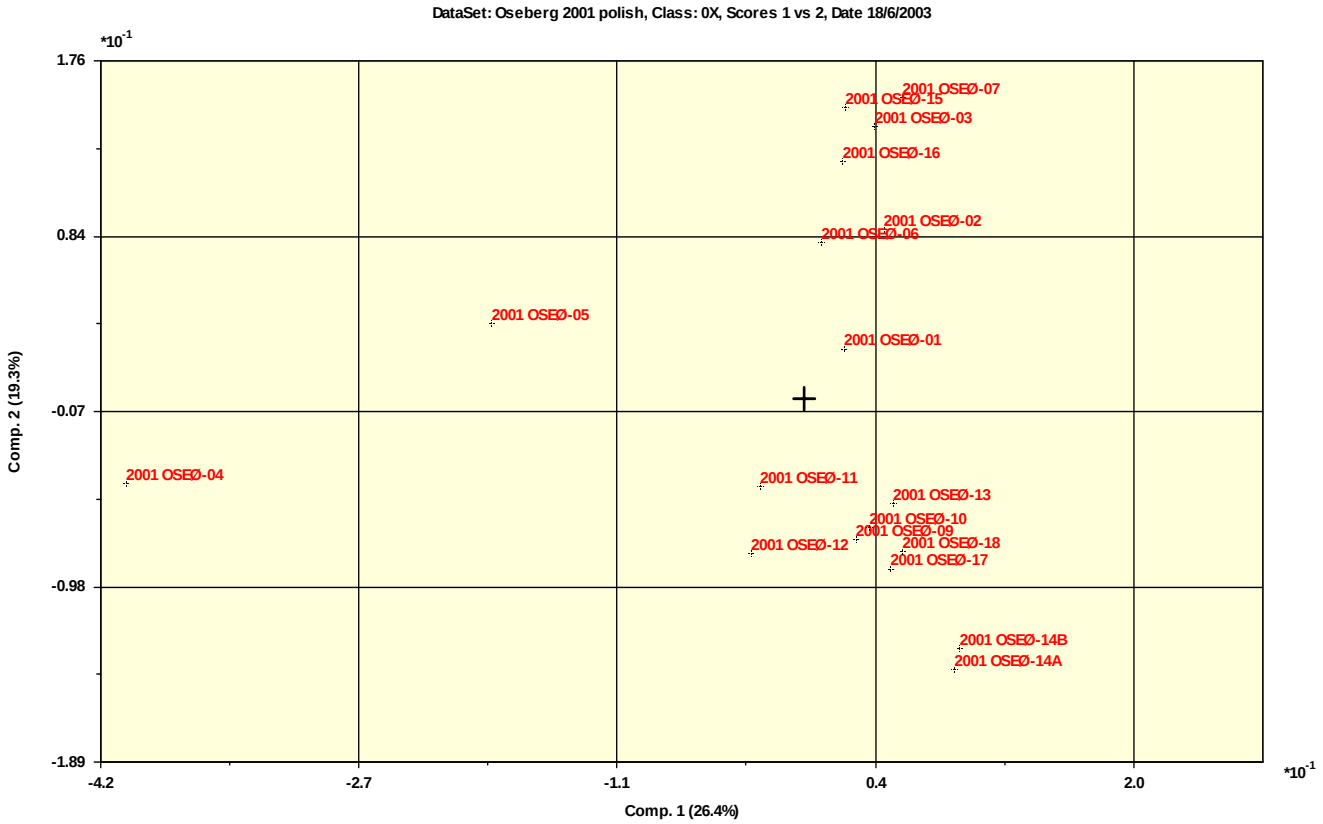

DataSet: Oseberg 2001 polish, Class: 0X, Scores 1 vs 2, Date 18/6/2003
*10-1
1.76
0.84
-0.07
-0.98
-1.89
Comp. 2 (19.3%)
-4.2
-2.7
-1.1
0.4
2.0
*10-1
Comp. 1 (26.4%)
2001 OSEØ-07
2001 OSEØ-15
2001 OSEØ-03
2001 OSEØ-16
2001 OSEØ-02
2001 OSEØ-06
2001 OSEØ-05
2001 OSEØ-01
2001 OSEØ-04
2001 OSEØ-11
2001 OSEØ-13
2001 OSEØ-10
2001 OSEØ-09
2001 OSEØ-12
2001 OSEØ-18
2001 OSEØ-17
2001 OSEØ-14B
2001 OSEØ-14A

Fig. 4.

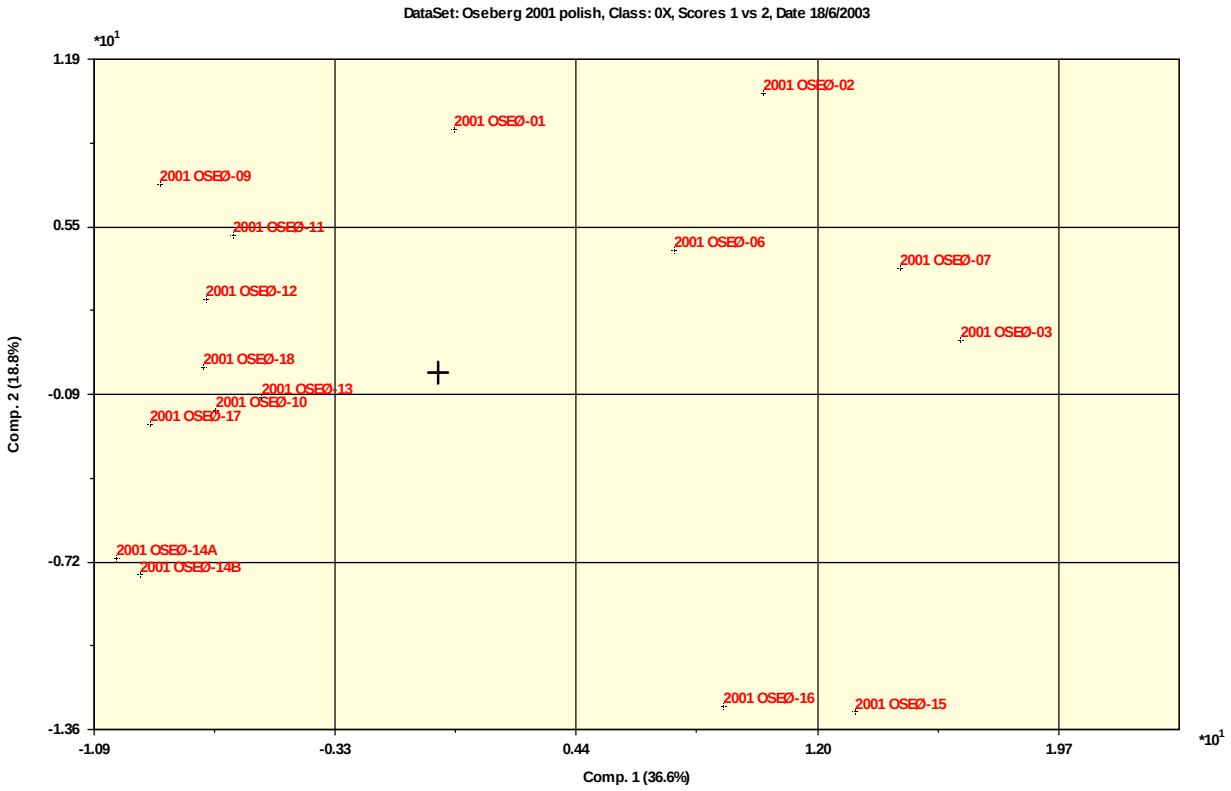

DataSet: Oseberg 2001 polish, Class: 0X, Scores 1 vs 2, Date 18/6/2003
*10^1
1.19
0.55
-0.09
-0.72
-1.36
Comp. 2 (18.8%)
2001 OSEØ-02
2001 OSEØ-01
2001 OSEØ-09
2001 OSEØ-11
2001 OSEØ-06
2001 OSEØ-07
2001 OSEØ-12
2001 OSEØ-03
2001 OSEØ-18
2001 OSEØ-13
2001 OSEØ-10
2001 OSEØ-17
2001 OSEØ-14A
2001 OSEØ-14B
2001 OSEØ-16
2001 OSEØ-15
-1.09
-0.33
0.44
1.20
1.97
*10^1
Comp. 1 (36.6%)

Fig. 5.

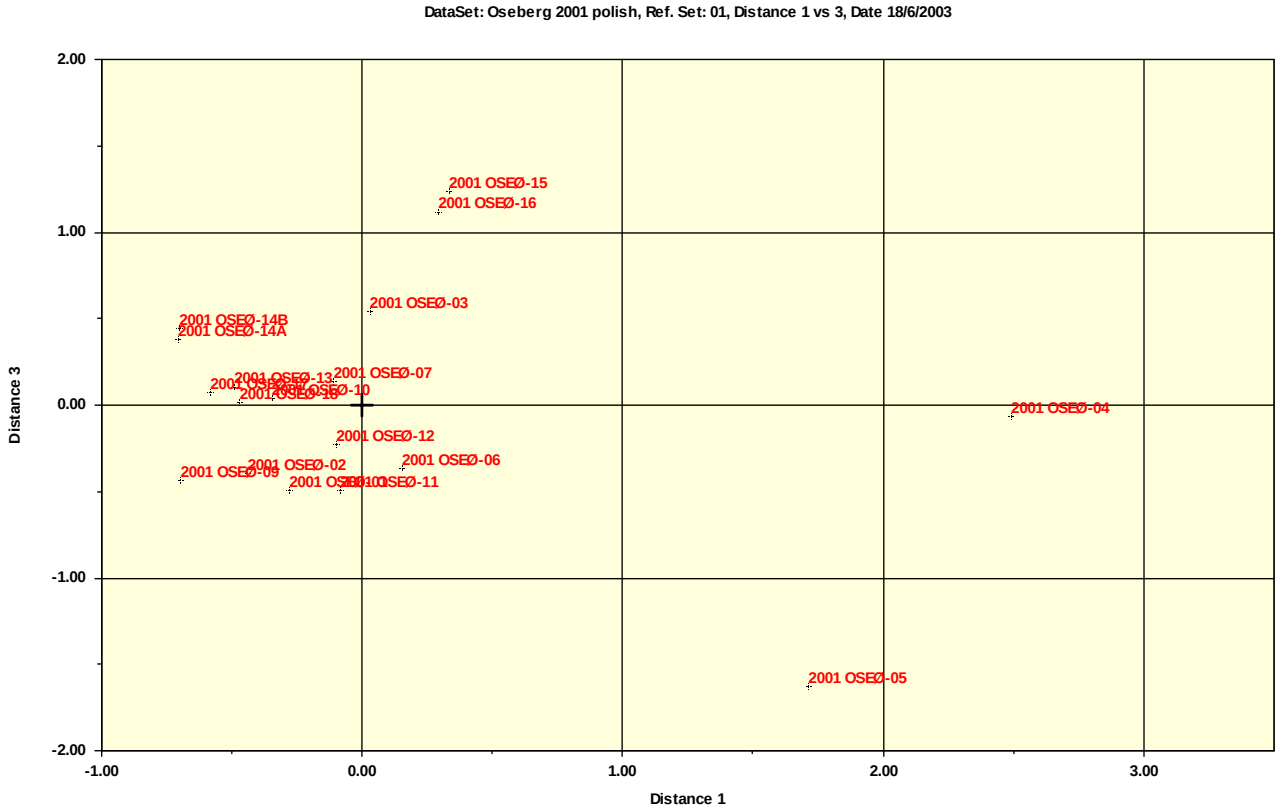

DataSet: Oseberg 2001 polish, Ref. Set: 01, Distance 1 vs 3, Date 18/6/2003
Distance 3
Distance 1
2.00
1.00
0.00
-1.00
-2.00
-1.00
0.00
1.00
2.00
3.00
2001 OSEØ-15
2001 OSEØ-16
2001 OSEØ-03
2001 OSEØ-14B
2001 OSEØ-14A
2001 OSEØ-13
2001 OSEØ-07
2001 OSEØ-10
2001 OSEØ-04
2001 OSEØ-12
2001 OSEØ-02
2001 OSEØ-06
2001 OSEØ-09
2001 OSEØ-11
2001 OSEØ-05

Fig. 6.

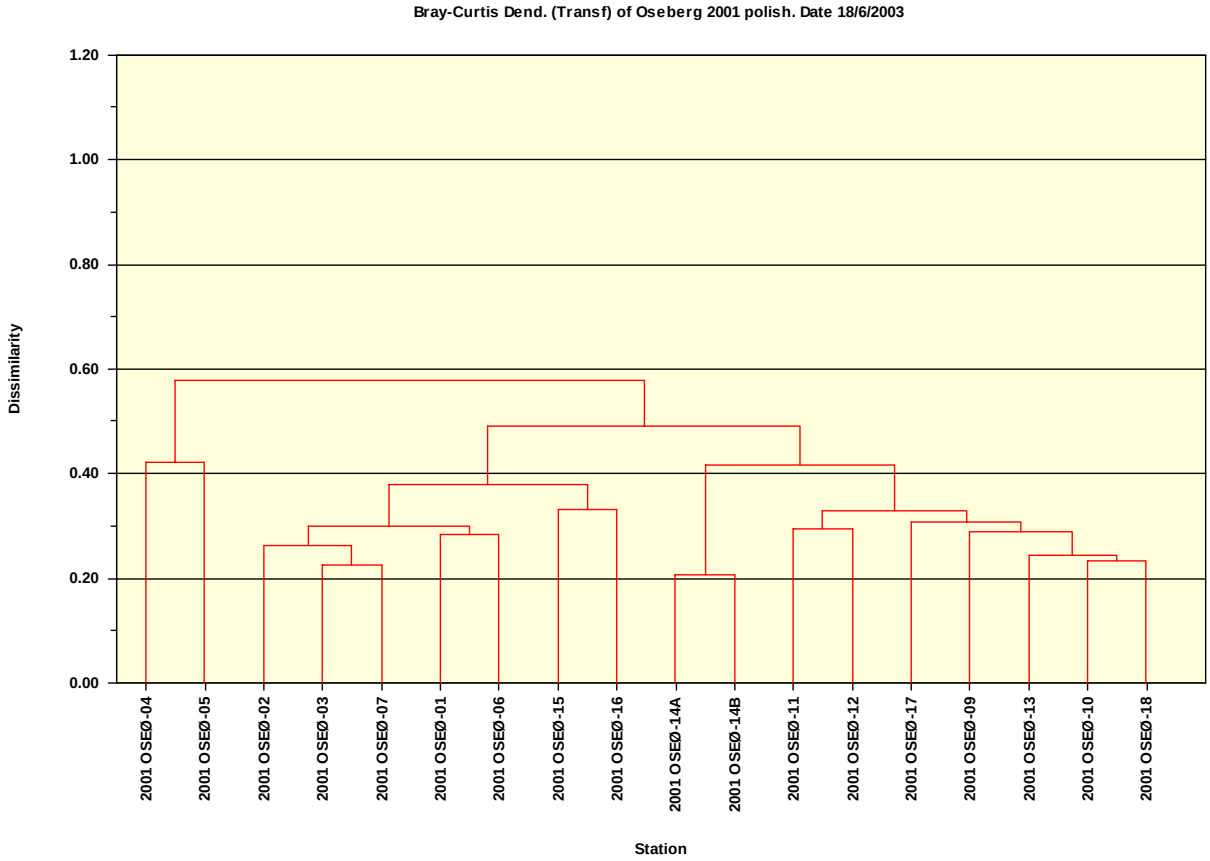

Bray-Curtis Dend. (Transf) of Oseberg 2001 polish. Date 18/6/2003
Dissimilarity
1.20
1.00
0.80
0.60
0.40
0.20
0.00
2001 OSEØ-04
2001 OSEØ-05
2001 OSEØ-02
2001 OSEØ-03
2001 OSEØ-07
2001 OSEØ-01
2001 OSEØ-06
2001 OSEØ-15
2001 OSEØ-16
2001 OSEØ-14A
2001 OSEØ-14B
2001 OSEØ-11
2001 OSEØ-12
2001 OSEØ-17
2001 OSEØ-09
2001 OSEØ-13
2001 OSEØ-10
2001 OSEØ-18
Station

Fig. 7.

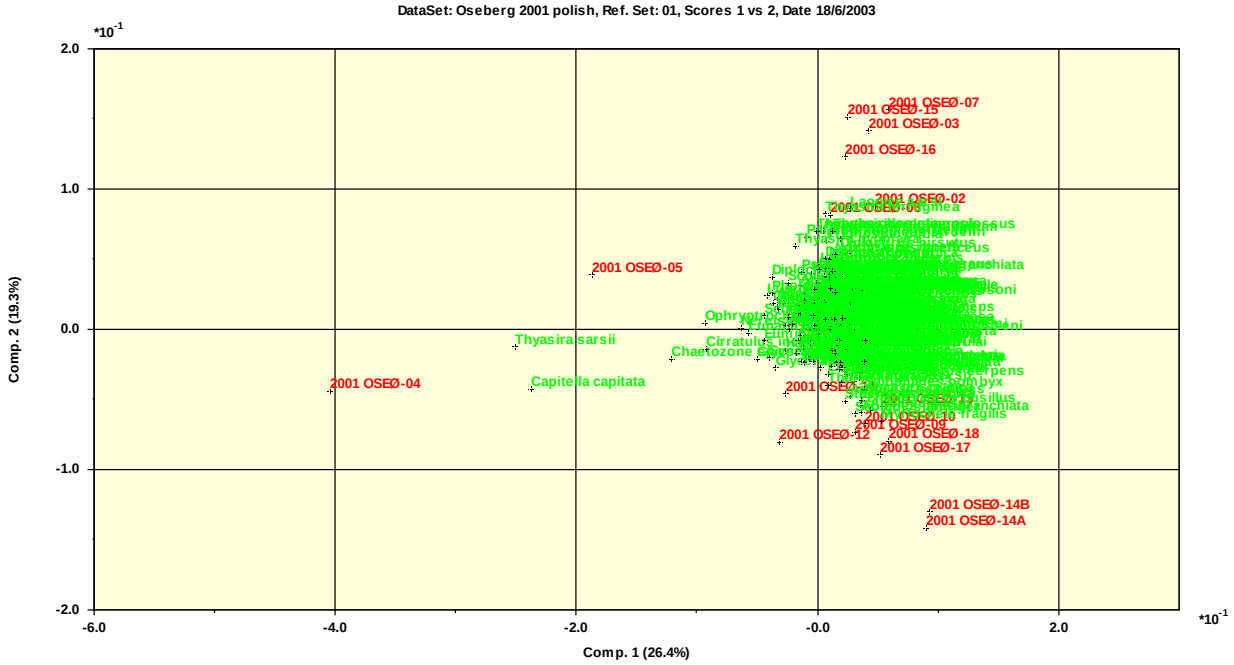

DataSet: Oseberg 2001 polish, Ref. Set: 01, Scores 1 vs 2, Date 18/6/2003
*10-1
2.0
1.0
0.0
-1.0
-2.0
Comp. 2 (19.3%)
-6.0
-4.0
-2.0
-0.0
2.0
*10-1
Comp. 1 (26.4%)
2001 OSEØ-07
2001 OSEØ-15
2001 OSEØ-03
2001 OSEØ-16
2001 OSEØ-02
2001 OSEØ-05
Thyasira sarsii
Capitella capitata
2001 OSEØ-04
2001 OSEØ-12
2001 OSEØ-18
2001 OSEØ-17
2001 OSEØ-14B
2001 OSEØ-14A

Fig. 8.

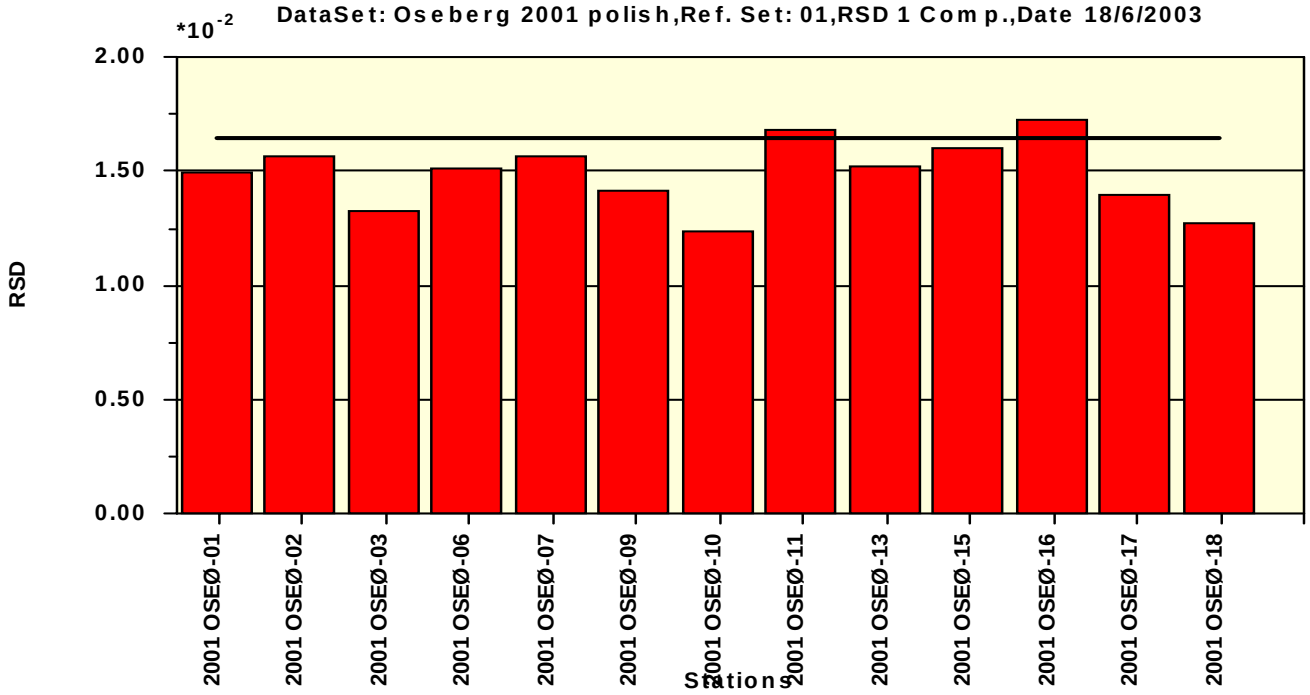

DataSet: Oseberg 2001 polish,Ref. Set: 01,RSD 1 Comp.,Date 18/6/2003
*10-2
2.00
1.50
1.00
0.50
0.00
RSD
2001 OSEØ-01
2001 OSEØ-02
2001 OSEØ-03
2001 OSEØ-06
2001 OSEØ-07
2001 OSEØ-09
2001 OSEØ-10
2001 OSEØ-11
2001 OSEØ-13
2001 OSEØ-15
2001 OSEØ-16
2001 OSEØ-17
2001 OSEØ-18
Stations

Table 2.

	Stations	Angles	Distance	Depth	Elev. CHEM	Dist. BIO
1	OSEØ-01	45	250	156		
2	OSEØ-02	45	500	156		
3	OSEØ-03	45	1000	159		
4	OSEØ-04	135	250	154		
5	OSEØ-05	135	500	155		
6	OSEØ-06	135	1000	155		
7	OSEØ-07	135	2000	156		
8	OSEØ-08	225	250	154		
9	OSEØ-09	225	500	153		
10	OSEØ-10	225	1000	151		
11	OSEØ-11	315	250	155		
12	OSEØ-12	315	500	155		
13	OSEØ-13	315	1000	155		
14	OSEØ-14A	315	10260	132		
15	OSEØ-14B	315	10260	132		
16	OSEØ-15	45	2000	169		
17	OSEØ-16	135	4000	164		
18	OSEØ-17	225	2000	153		
19	OSEØ-18	315	2000	160		

Table 3.

	Stations	Angles	Distance	Depth	Elev. CHEM	Dist. BIO	CDI
1	OSEØ-01	45	250	156			**0,81**
2	OSEØ-02	45	500	156			**0,98**
3	OSEØ-03	45	1000	159			**0,97**
4	OSEØ-04	135	250	154			**3,06**
5	OSEØ-05	135	500	155			**2,50**
6	OSEØ-06	135	1000	155			**1,15**
7	OSEØ-07	135	2000	156			**1,00**
9	OSEØ-09	225	500	153			**0,80**
10	OSEØ-10	225	1000	151			**0,65**
11	OSEØ-11	315	250	155			**1,01**
12	OSEØ-12	315	500	155			**1,04**
13	OSEØ-13	315	1000	155			**0,88**
14	OSEØ-14A	315	10260	132			**0,93**
15	OSEØ-14B	315	10260	132			**0,96**
16	OSEØ-15	45	2000	169			**0,86**
17	OSEØ-16	135	4000	164			**0,86**
18	OSEØ-17	225	2000	153			**0,85**
19	OSEØ-18	315	2000	160			**0,79**

Fig. 9.

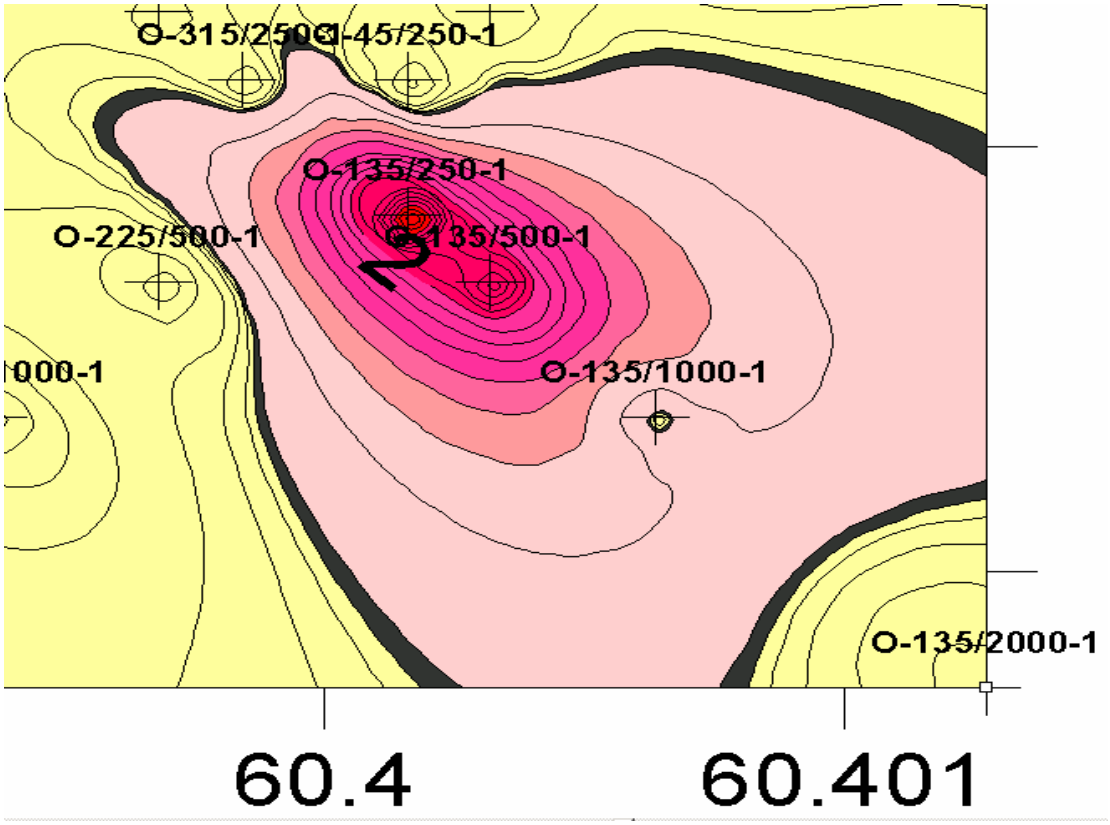

O-315/250
-45/250-1
O-135/250-1
O-225/500-1
135/500-1
000-1
O-135/1000-1
O-135/2000-1
60.4
60.401

Fig. 10.

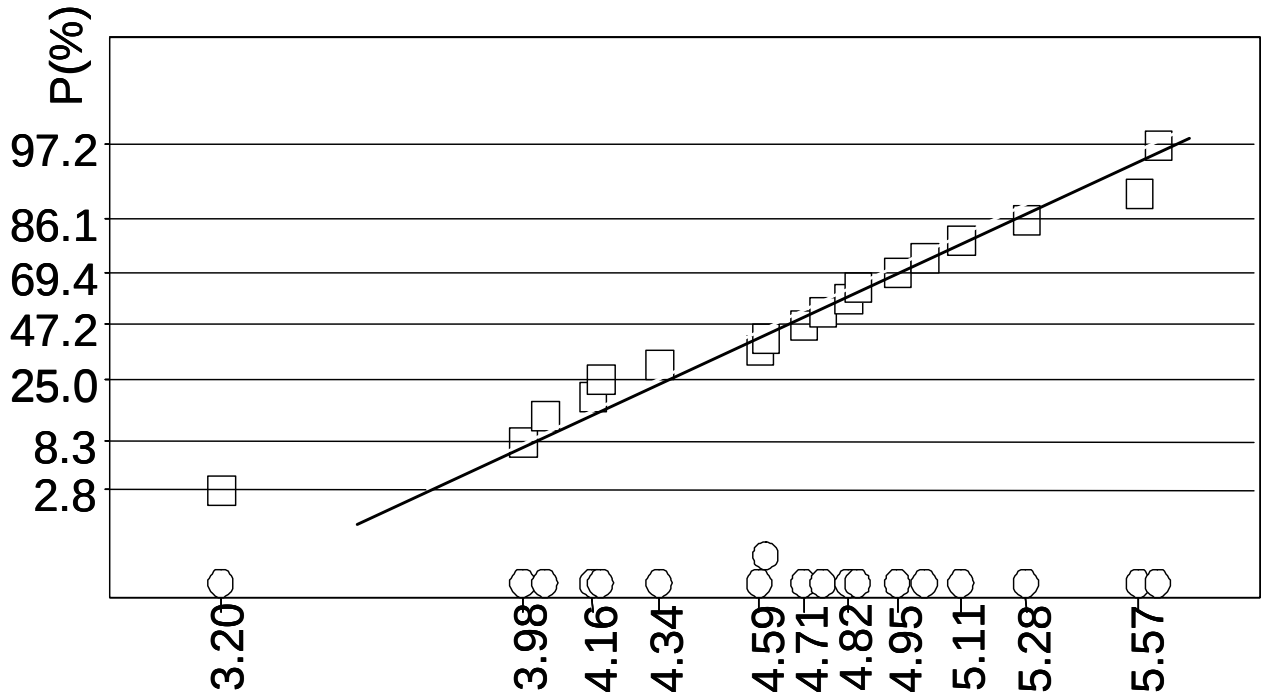
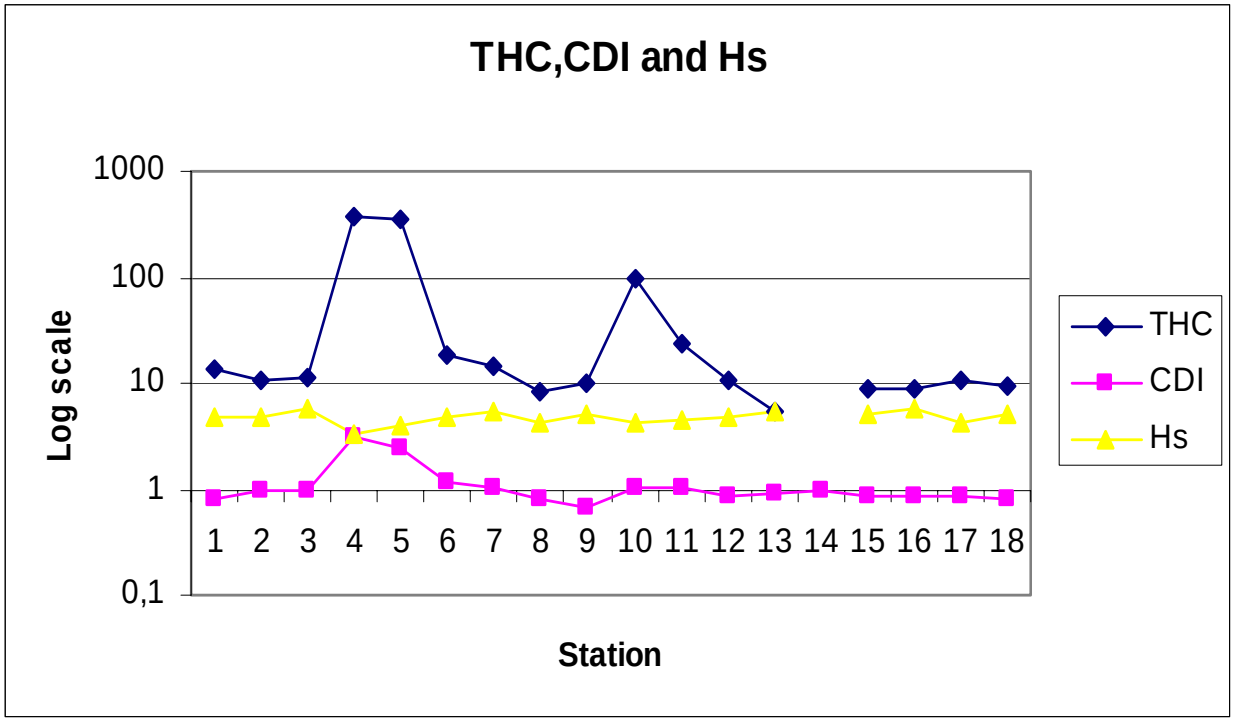

P(%)
97.2
86.1
69.4
47.2
25.0
8.3
2.8
3.20
3.98
4.16
4.34
4.59
4.71
4.82
4.95
5.11
5.28
5.57

Table 4.

Station	Distance	Angles	CDI	Species	Shannon-Wiener	Pielous	Hurlbert
2001 OSEØ-01	250	45	0,81	108	4,6	0,68	32,06
2001 OSEØ-02	500	45	0,98	117	4,8	0,69	33,66
2001 OSEØ-03	1000	45	0,97	126	5,6	0,81	43,05
2001 OSEØ-04	250	135	**3,06**	65	**3,2**	**0,53**	**19,57**
2001 OSEØ-05	500	135	**2,5**	94	4,0	0,61	24,68
2001 OSEØ-06	1000	135	**1,15**	110	4,6	0,68	32,6
2001 OSEØ-07	2000	135	**1**	109	5,3	0,78	40,37
2001 OSEØ-09	500	225	0,8	95	4,2	0,64	29,52
2001 OSEØ-10	1000	225	0,65	90	4,9	0,75	36,55
2001 OSEØ-11	250	315	**1,01**	82	4,2	0,66	28,5
2001 OSEØ-12	500	315	**1,04**	77	4,3	0,69	29,28
2001 OSEØ-13	1000	315	0,88	106	5,1	0,76	38,77
2001 OSEØ-14A	10260	315	0,93	87	4,7	0,73	36,77
2001 OSEØ-14B	10260	315	0,96	93	4,8	0,74	35,81
2001 OSEØ-15	2000	45	0,86	94	5,0	0,77	35,22
2001 OSEØ-16	4000	135	0,86	103	5,6	0,83	44,1
2001 OSEØ-17	2000	225	0,85	76	4,0	0,65	30,25
2001 OSEØ-18	2000	315	0,79	95	5,0	0,75	36,51

Fig. 11.

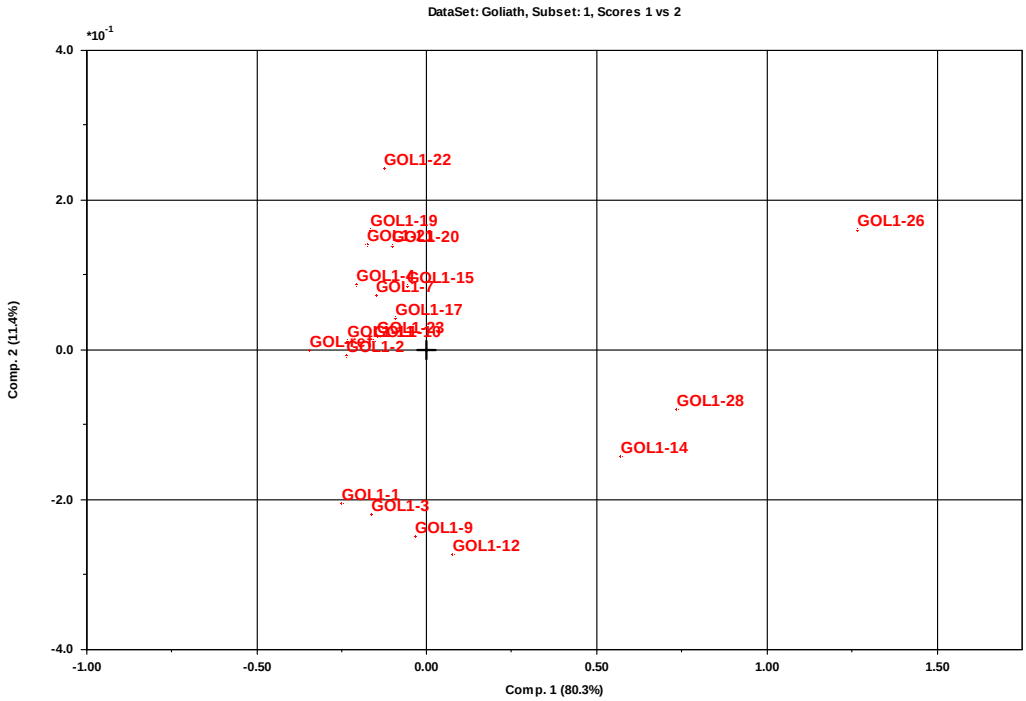

THC,CDI and Hs
Log scale
1000
100
10
1
0,1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
Station
THC
CDI
Hs

8. Appendix 3 Data Analysis of selected fields

In this appendix we have included the data analysis. For the explanation of score plots and loadings plot we refer to the article in Appendix 2, and references therein. A common abbreviation for a principal component is PC.

.

8.4 Goliath



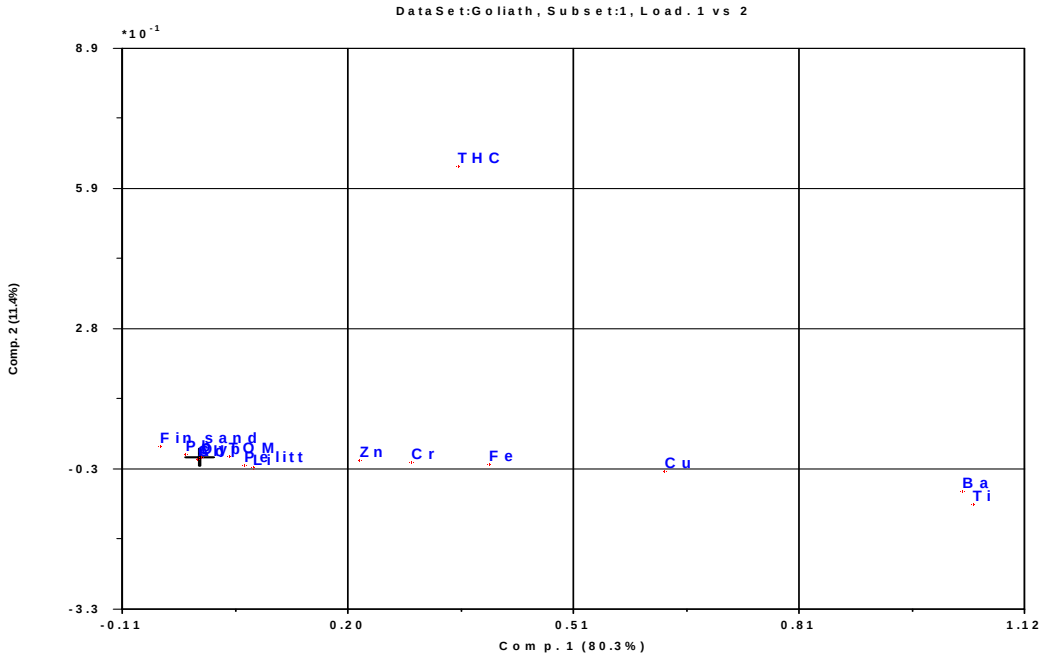


Figure A3_1 . Score- and loadings plot based on chemicals from Goliath

The score plot separates the stations according to similarity. The more similar, the closer are the station located in the plot. The loadings plot give information about the cause of the sample separation in the score plot. E.g., the location of the stations to the right in the score plot is due to elevated concentration of Ba and Ti. The location of the stations in the upper part of the score plot is due to elevated concentration of THC.

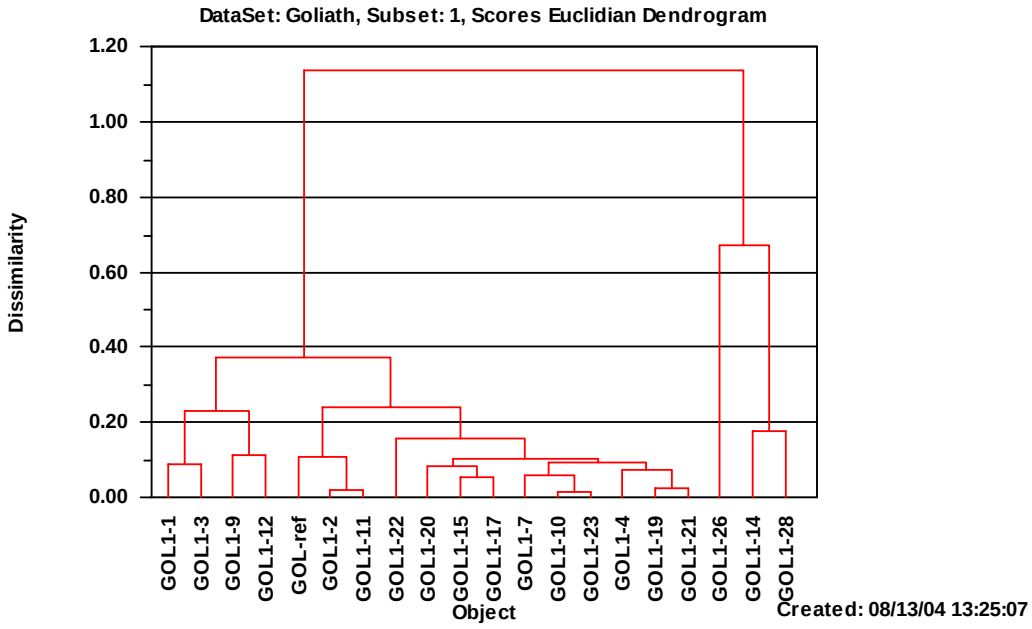


Figure A3_2 Scores dendogram based on PC 1 and 2 (Figure A3_1)

The score- and loadings plots indicate that samples GOL 1-26, GOL 1-14 and GOL 1-28 have slightly elevated levels of some trace elements.

As main differences are along the 1 PC, the level of pollution may be expressed as score value along 1 PC, as shown in Fig.A3_3.

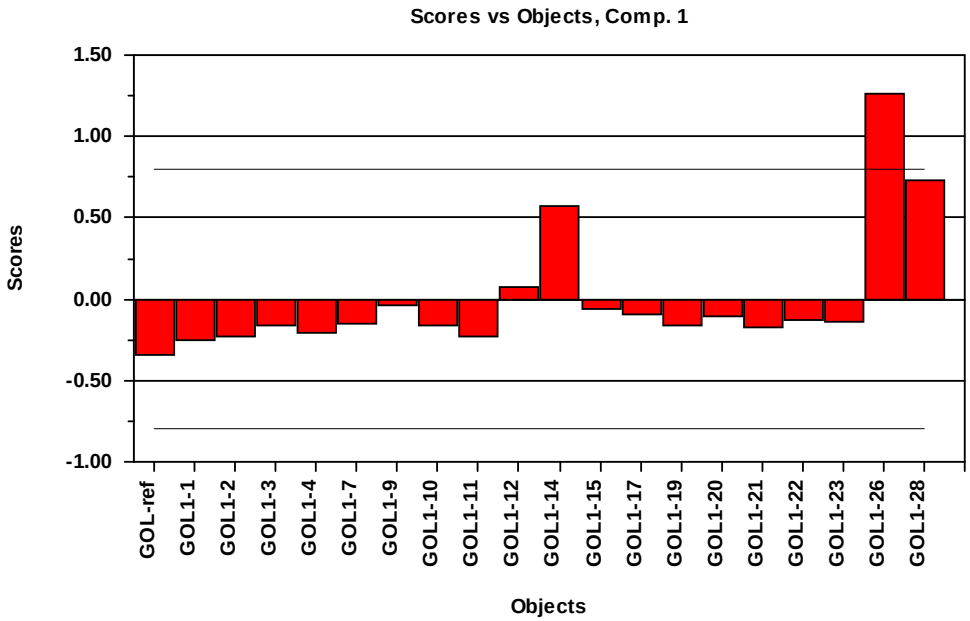


Figure A3_3 Plot of scores along 1 PC

The most important chemicals for the observed score may be expressed as the loadings along 1 PC, as shown in Figure A3_4:

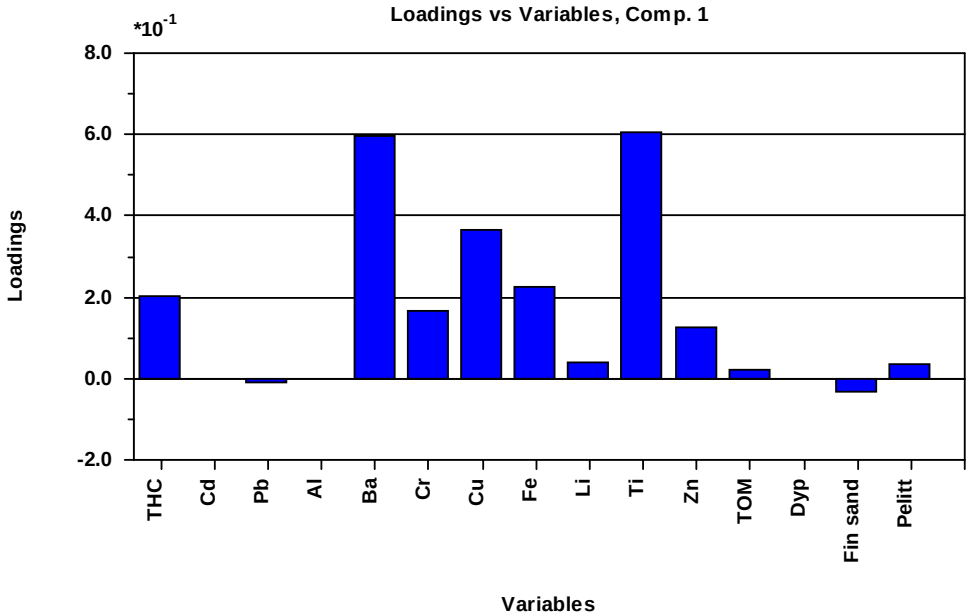


Figure A3_4 Loadings along 1 Principal Component

Again the samples taken at stations 14, 26 and 28 show elevated values of selected chemicals, Ba, Ti and Cu being the most important. All other samples seem to contain pollutant at same levels as the reference station. In particular the THC levels are fairly low for all sediments, .i.e. in the range 1-6 ppm. The stations 1, 3, 9 and 12 have even lower THC values than the level of quantification (i.e. 1 ppm dry sediment).

Candidates for reference station may be all samples except station 14, 26 and 28.

8.4.1 Biology

As a start all samples are inspected by MDS, Bray-Curtis dissimilarity plot, Dendograms, CCA for the selecting of proper reference samples.

All samples except 14, 26 and 28 are modelled as the CDI reference class (i.e. assumed to be undisturbed).

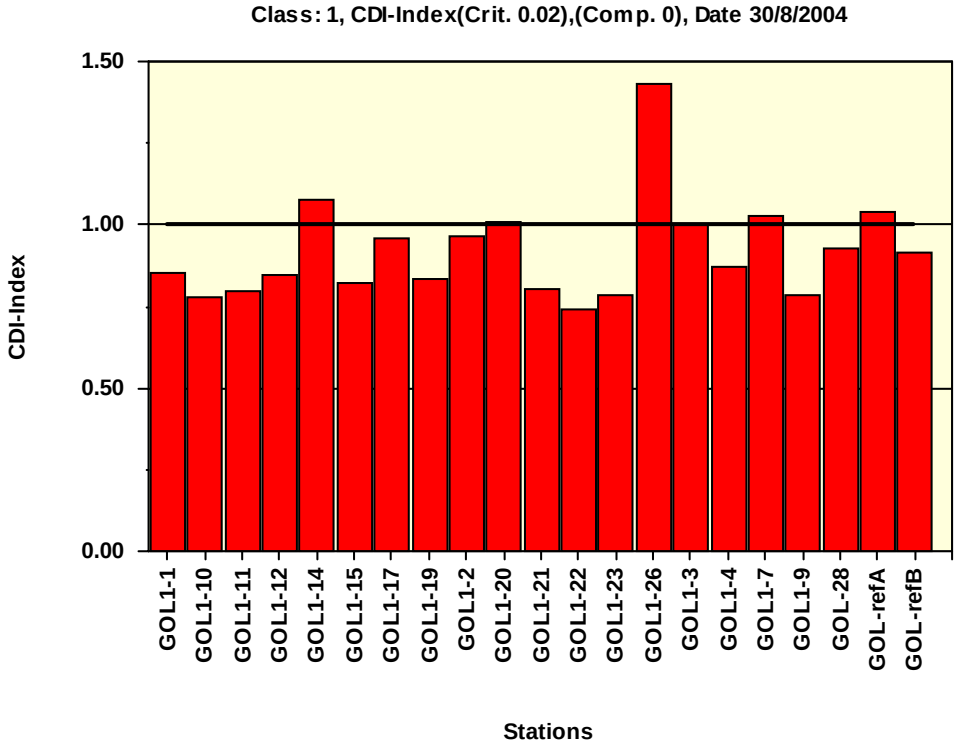


Figure A3_5 CDIs for the stations

Number	Name	RSD	CDI	
1	GOL1-1	0,015	1,009	X
2	GOL1-10	0,014	0,929	
3	GOL1-11	0,014	0,963	
4	GOL1-12	0,013	0,853	
5	GOL1-14	0,018	1,201	X
6	GOL1-15	0,013	0,861	
7	GOL1-17	0,013	0,876	
8	GOL1-19	0,013	0,859	

9	GOL1-2	0,012	0,844	
10	GOL1-20	0,013	0,868	
11	GOL1-21	0,012	0,794	
12	GOL1-22	0,013	0,909	
13	GOL1-23	0,014	0,935	
14	GOL1-26	0,024	1,624	X
15	GOL1-3	0,015	1,002	X
16	GOL1-4	0,014	0,957	
17	GOL1-7	0,012	0,824	
18	GOL1-9	0,013	0,860	
19	GOL-28	0,015	1,053	X
20	GOL-refA	0,012	0,799	
21	GOL-refB	0,009	0,640	

Table A3-2 CDI for all stations

CDI as response, chemicals as independents;

Figure A3_6 shows the cross validated estimations from varying number of Partail Least Squares (PLS) Components in the model. A fair good model explaining 88% of CDI is achieved by using 3 PLS components

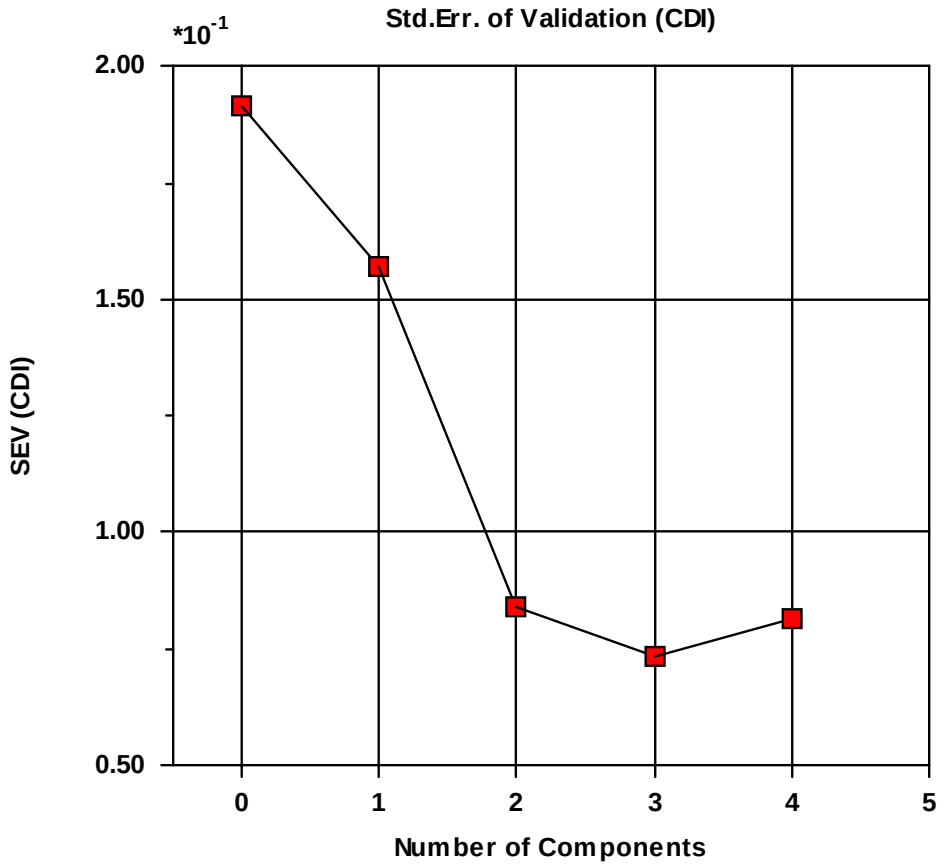


Figure A3_6 Estimation errors (from cross validation) varying number of PLS components in the model (3 components are optimal)

A 3 PLS component regression model was created:

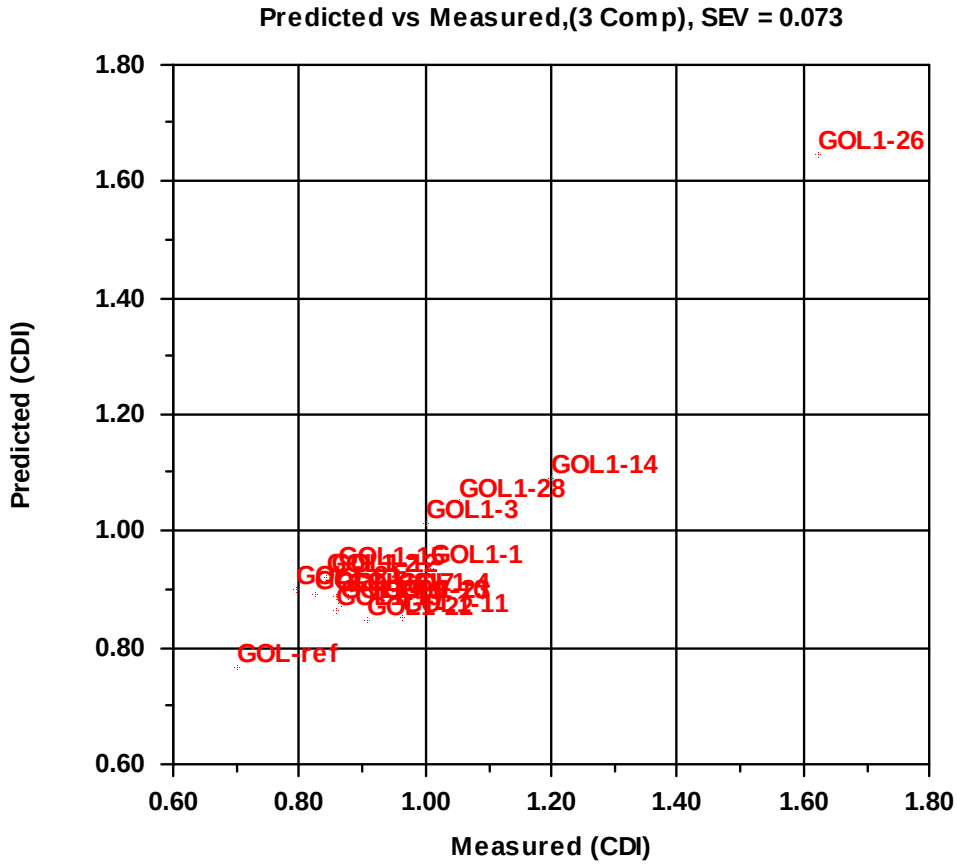


Figure A3_7 CDI based on biology (measured) vs CDI estimated from chemistry

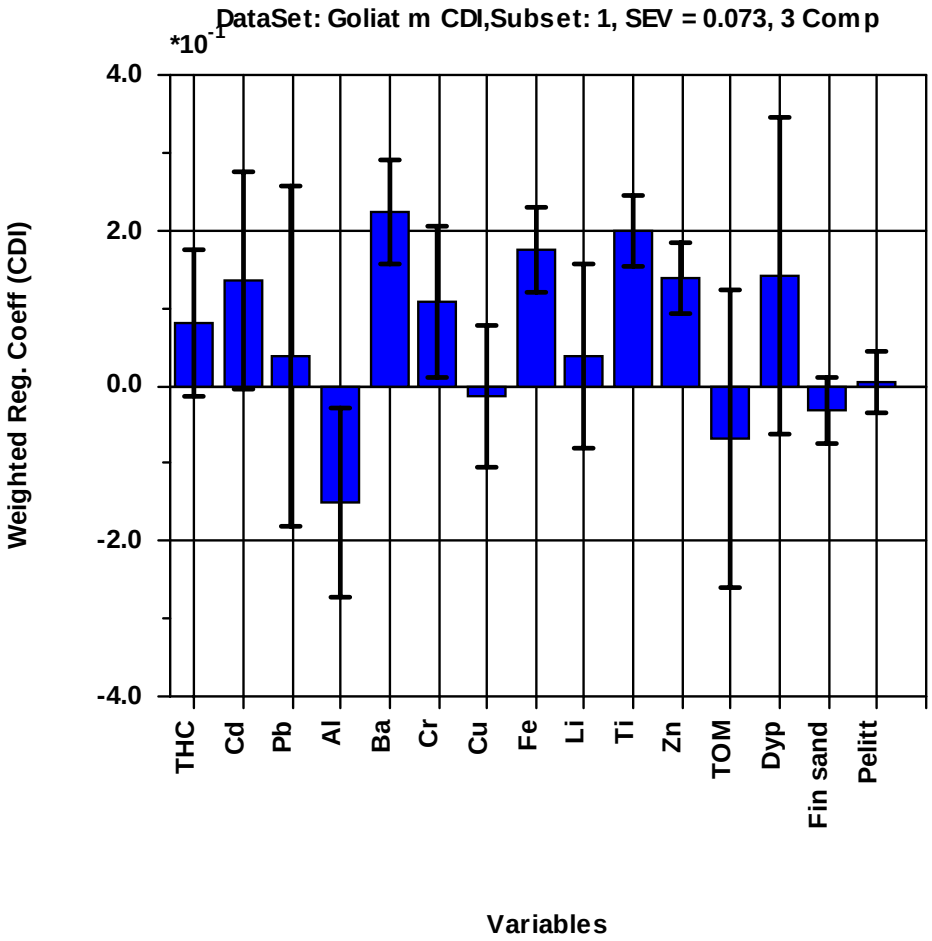


Figure A3_8 Relative importance of stressors to the observed stress in benthic community

8.5 Norne 2000

8.5.1 Chemistry

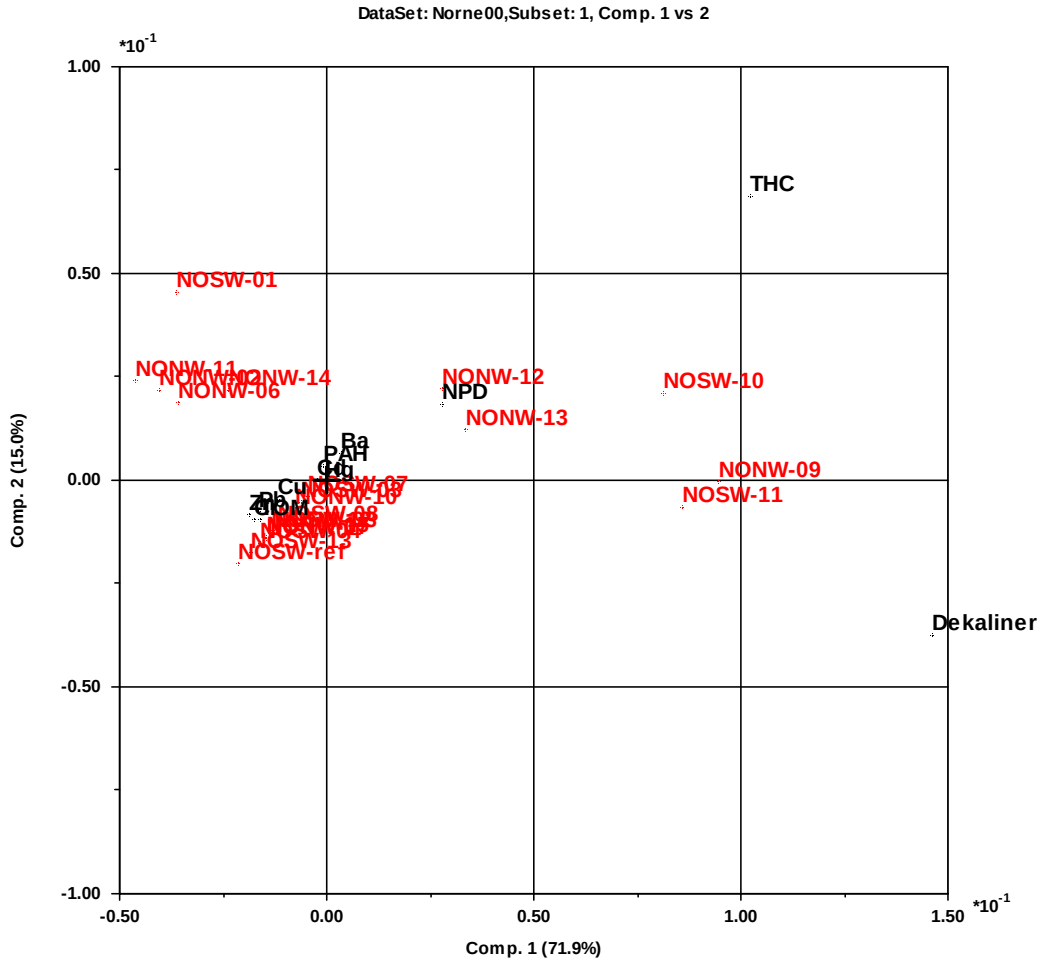


Figure A3-9 B-iplot based on Correspondence Analysis.

Several stations at Norne 2000 have elevated concentrations of in particular NPDs and decalines. The stations located near origo in the CA plot are the ones with lowest concentrations. These stations are the best choice for reference samples. Figure A3-10 shows an expanded version of Figure A3-9, where the names of the reference staions are readable.

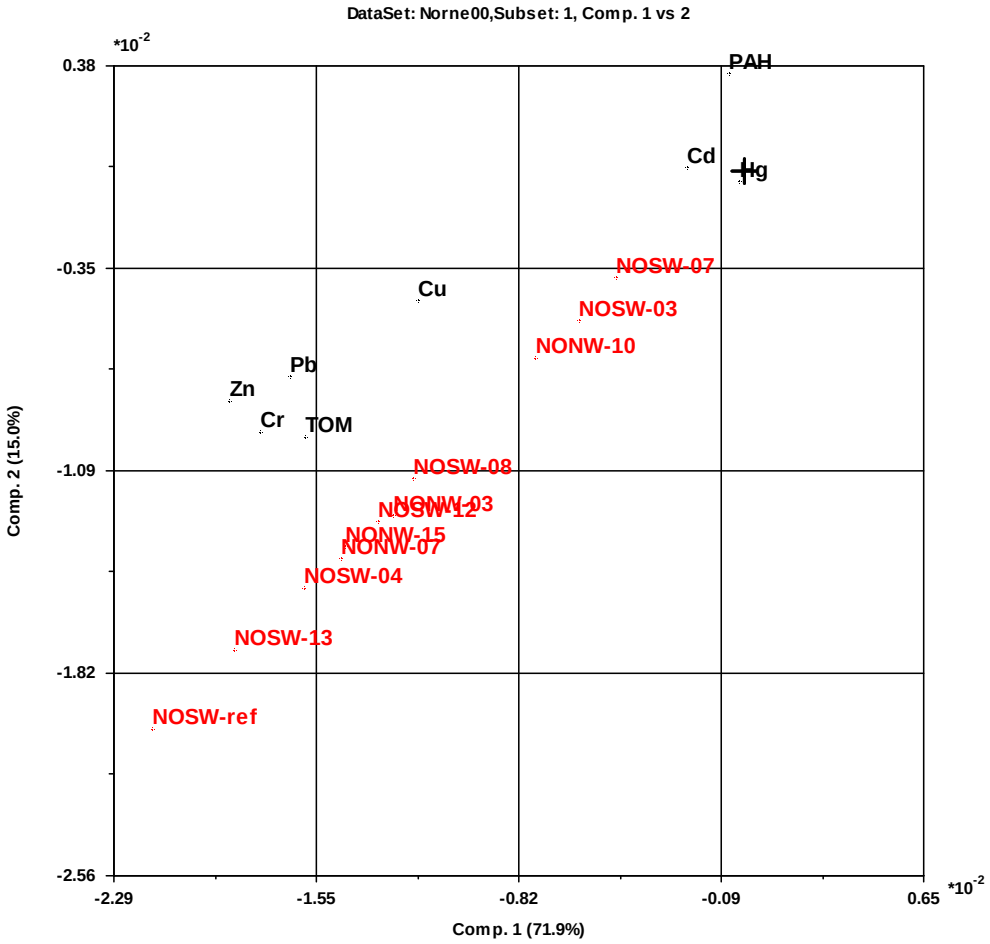


Figure A3_10. The stations around Norne best candidates for references samples (i.e. with lowest concentrations of sediment pollutants).

The 11 best candidate stations for unpolluted reference samples are ; NONW 3,7,10,15 and NOSW 3,4,7,8,12,13,ref.

8.5.2 Biology

The 11 candidate samples were studies by CA.

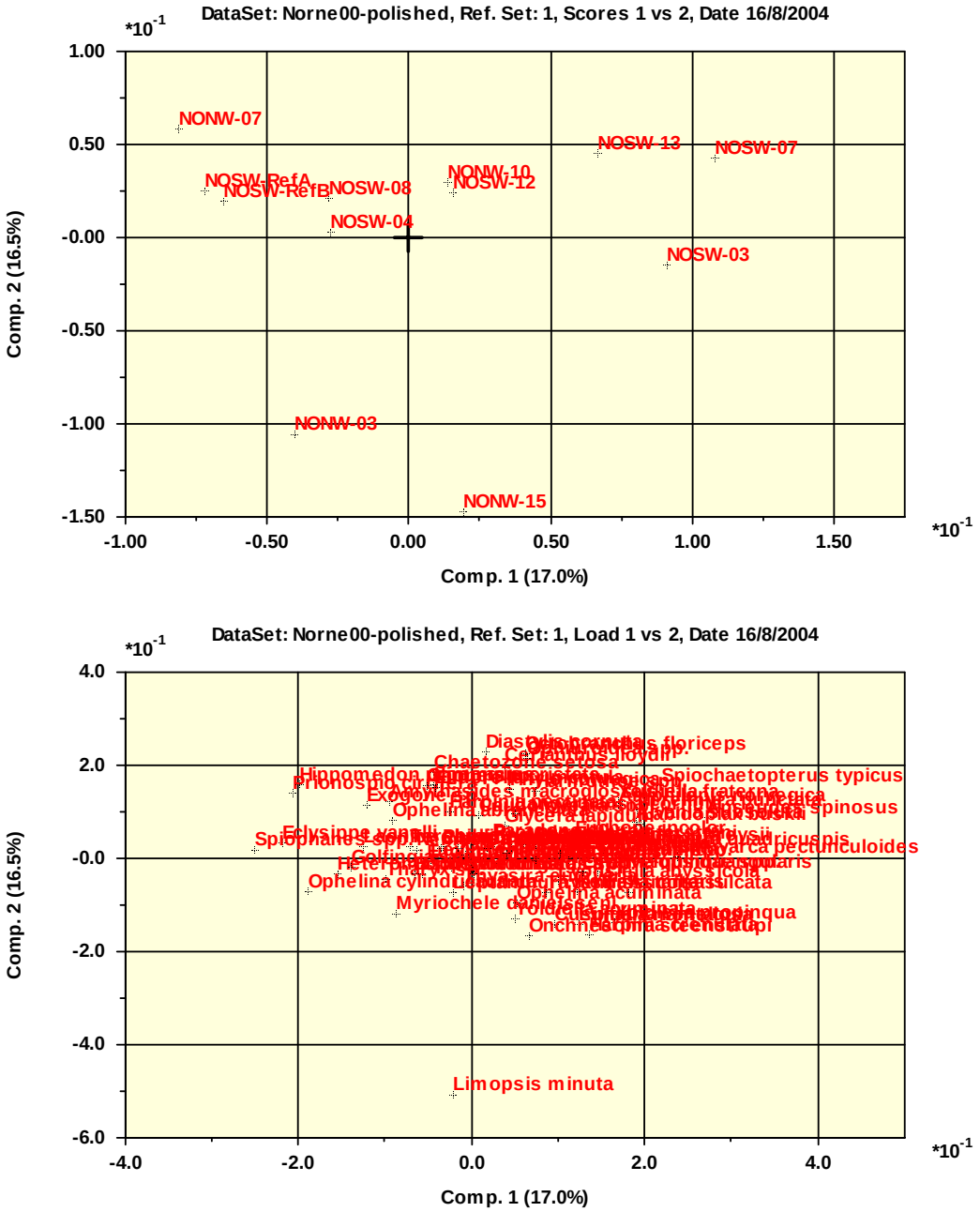


Figure A3_11 Scores- and loadings plot from the Correspondence Analysis

As shown form the CA plot in Figure A3-11 the stations NONW-03 and NONNW-15 are separated from the other samples due to elevated number of the specie *Limopsis minuta*. The two stations do not contain the same distribution of benthic fauna as the other stations, and do not fit into the reference set. The choice is now to exclude the two stations from the reference set, or to exclude the specie *Limopsis minuta.* We do select the options no. two, and reanalyse the data.

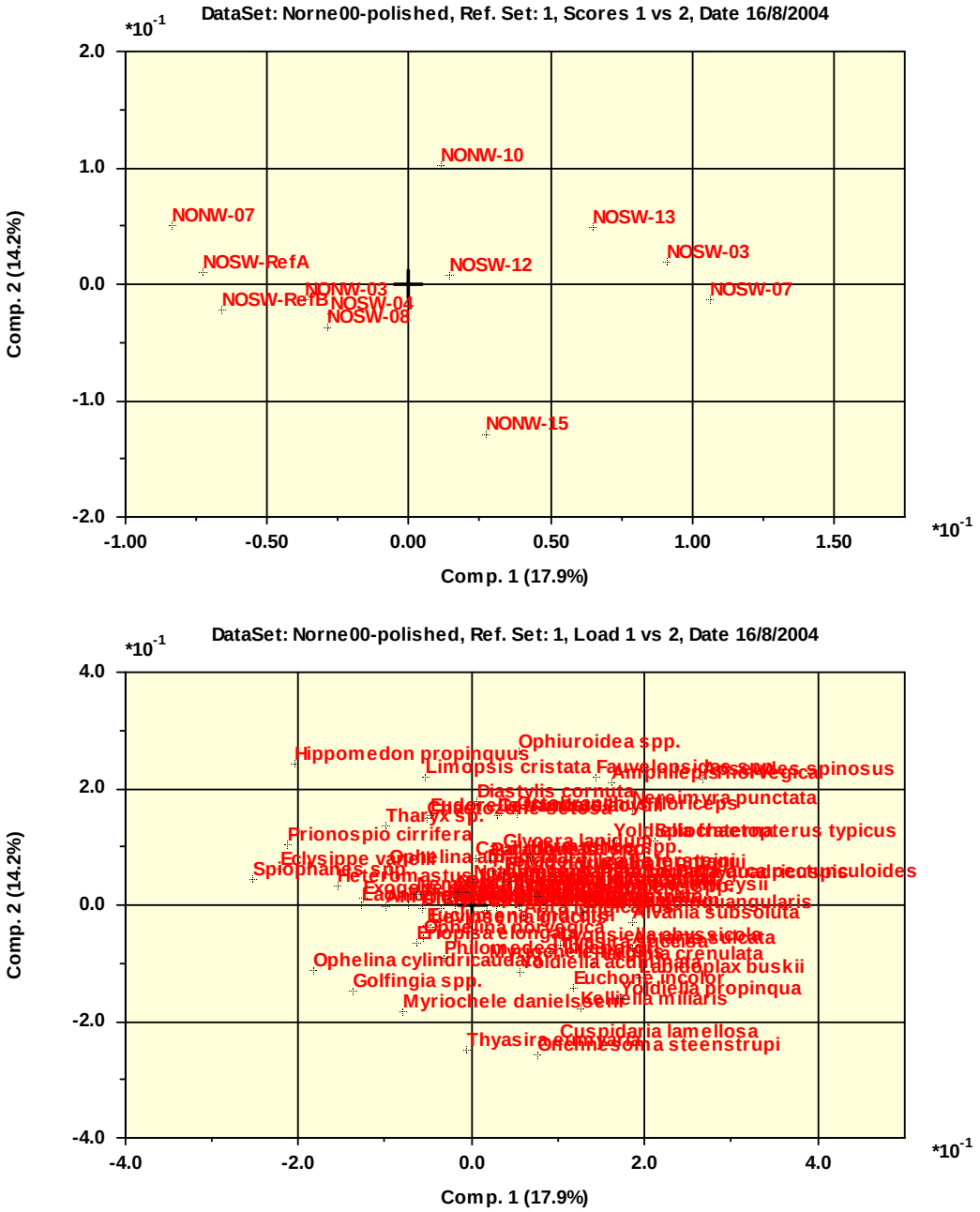


Figure A3_12 Score and loadingsplot of the reference stations after excluding Limopsis minuta.

After excluding *Limopsis minuta* the samples in the reference set plot as expected from a good reference set, i.e. an even distribution of samples and species without any groups being present. Two components do explain close to a third of the variation in the data (32%).

Calculations of CDIs were performed by using a zero component model (as no components were significant). Figure shows the CDI of all station based on the reference samples.

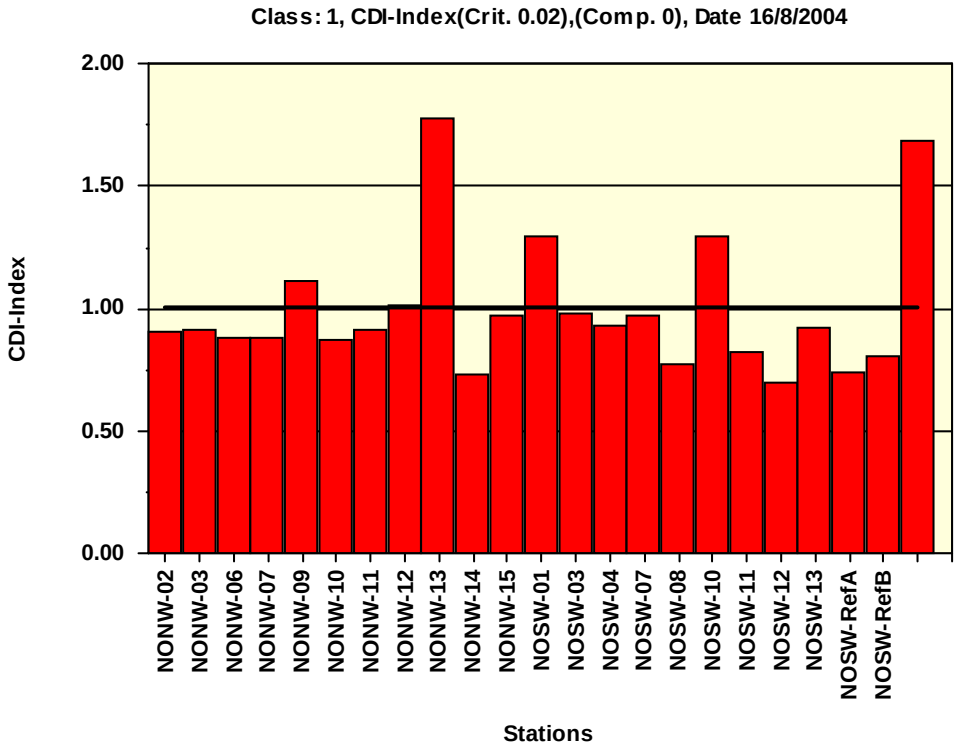


Figure A3-13 CDI indices

Number	Name	RSD	CDI	
1	NONW-02	0,018	0,902	
2	NONW-03	0,018	0,913	
3	NONW-06	0,017	0,884	
4	NONW-07	0,017	0,878	
5	NONW-09	0,022	1,113	X
6	NONW-10	0,017	0,873	
7	NONW-11	0,018	0,911	
8	NONW-12	0,020	1,016	X
9	NONW-13	0,035	1,778	X
10	NONW-14	0,014	0,730	
11	NONW-15	0,019	0,971	
12	NOSW-01	0,025	1,296	X
13	NOSW-03	0,019	0,979	
14	NOSW-04	0,018	0,933	
15	NOSW-07	0,019	0,971	
16	NOSW-08	0,015	0,776	
17	NOSW-10	0,026	1,298	X
18	NOSW-11	0,016	0,824	
19	NOSW-12	0,014	0,696	
20	NOSW-13	0,018	0,920	
21	NOSW-RefA	0,015	0,741	
22	NOSW-RefB	0,016	0,806	

Table A3_3 Calculated CDIs

8.6 Vigdis

8.6.1 Chemistry

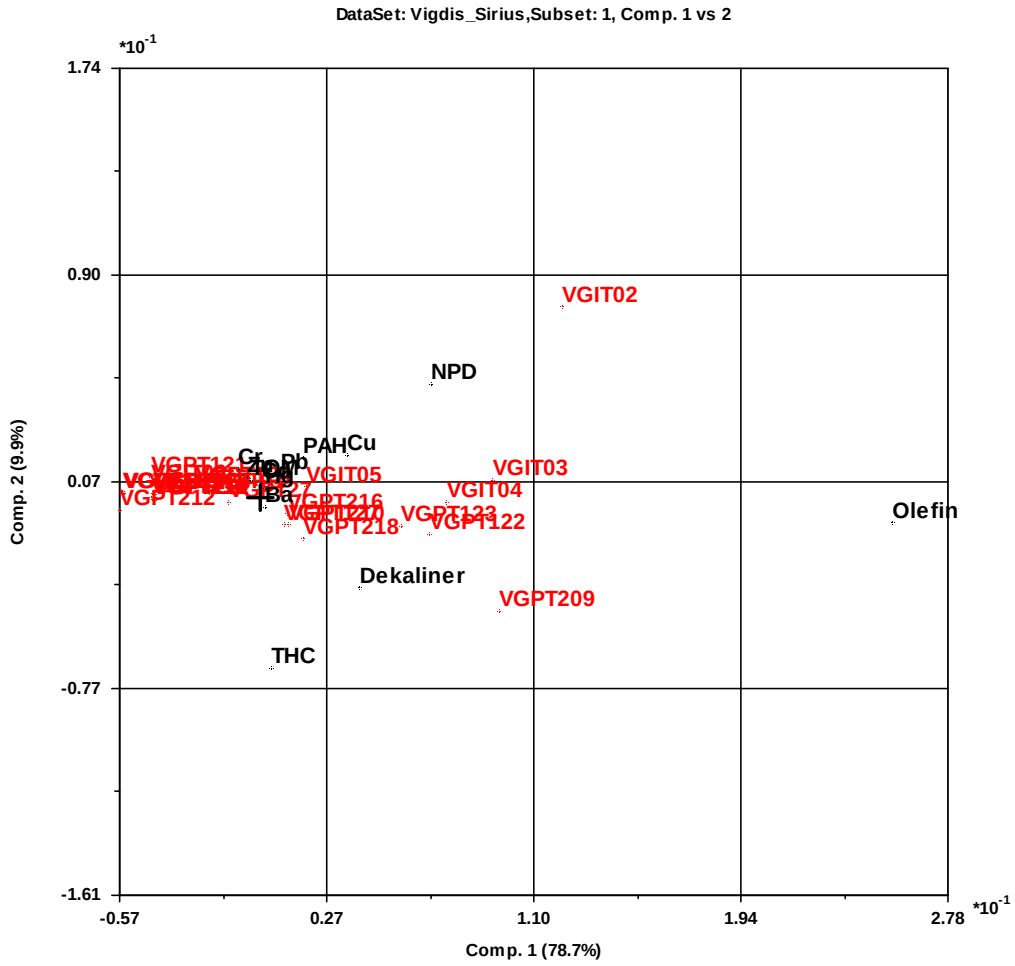


Figure A3_14 CA bi-plot of the Vigdis data.

The biplot in Figure A3_14 shows that the stations VGIT02, 03 and 04 contain elevated levels of NPDs and olefins. VGPT 122, 123 and 209 contain elevated concentrations of olefins, decalins and THC.
Candidates for reference samples from the chemical analysis are all samples except:

- VGIT 02, 03 and 04
- VGPT122 og 23 and VGPT2-09

8.6.2 Biology

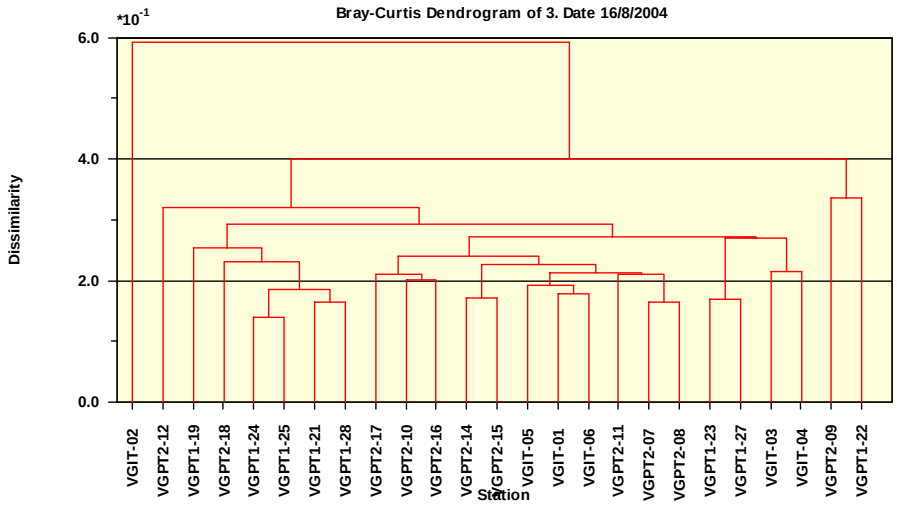


Figure A3_15. Bray-Curtis dissimilariaty dendogram of all samples.

The Bray-Curtis dissimilarity dendiogram (Fig. A3_15) show an unique species distribution of the samples VGIT 02, VPT1-22 and VPt2-09. This is confirmed by the CA biplot shown in Figure A3_16.

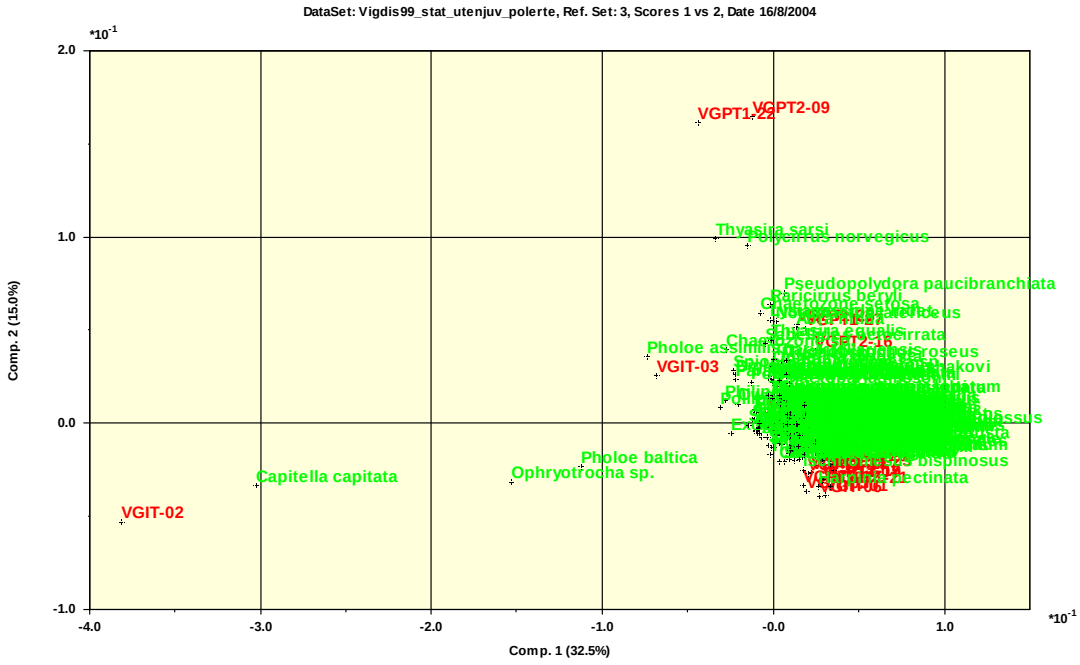


Figure A3_16 CA biplot of benthic fauna Vigdis' 99.

The CA plot in Fig. A3_16 clearly shows that station VGIT-02 are dominated by in particular Capitella Capitata, an opportunistic species very associated with oil

contamination. Also VGPT1-22 and VGPT2-09 have a different benthic fauna than the majority of samples. This procedure was repeated and outlier was excluded until no groups were observed in the scores and loadingsplot. (using n-propability plots)

All samples except the following eight were selected as a reference group:
VGIT 02, 03 VGPT1-17, 22, 23, VGPT2-09,16,27.

Although there seem to be a slight separation in the CA scoreplot (not shown) of the reference samples, no distinct groups are evident. Thus these are good candidates as reference samples, and the CDIs may be calculated.

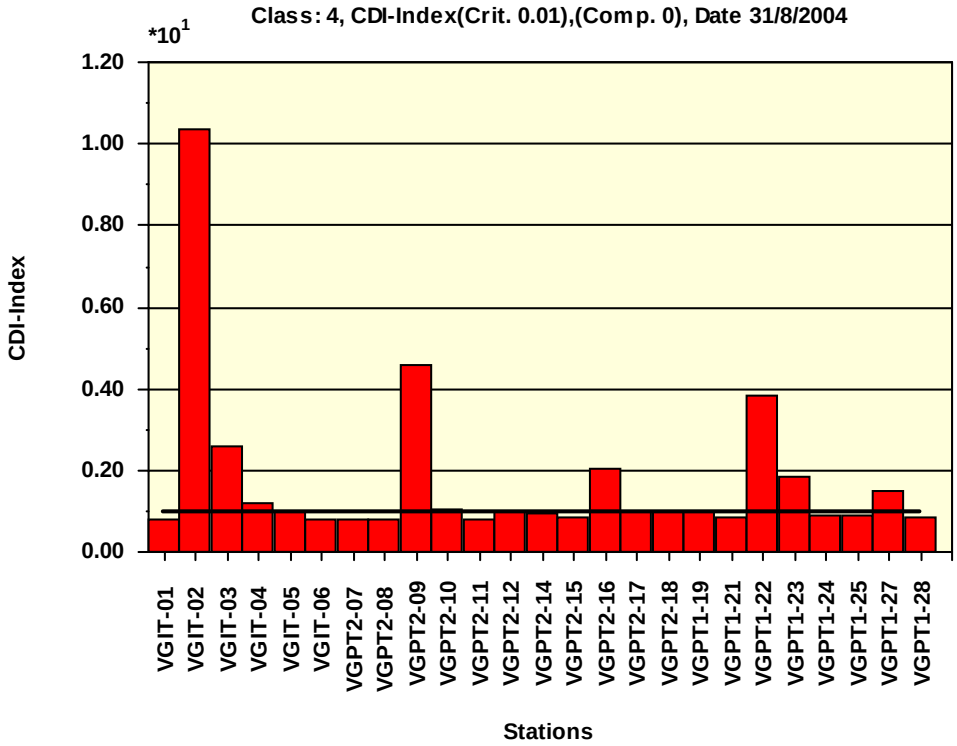


Figure A3_17 CDIs for the Vigdis stations

Name		Residual	Distance	CDI
1	VGIT-01	0,009	0,810	
2	VGIT-02	0,112	10,381	X
3	VGIT-03	0,028	2,568	X
4	VGIT-04	0,013	1,181	X
5	VGIT-05	0,011	0,988	
6	VGIT-06	0,009	0,800	
7	VGPT2-07	0,009	0,791	
8	VGPT2-08	0,009	0,817	
9	VGPT2-09	0,049	4,589	X
10	VGPT2-10	0,011	1,032	X
11	VGPT2-11	0,009	0,798	
12	VGPT2-12	0,011	0,996	
13	VGPT2-14	0,010	0,952	
14	VGPT2-15	0,009	0,850	

15	VGPT2-16	0,022	2,042	X
16	VGPT2-17	0,010	0,975	
17	VGPT2-18	0,011	1,012	X
18	VGPT1-19	0,011	0,985	
19	VGPT1-21	0,009	0,841	
20	VGPT1-22	0,042	3,852	X
21	VGPT1-23	0,020	1,821	X
22	VGPT1-24	0,010	0,919	
23	VGPT1-25	0,010	0,889	
24	VGPT1-27	0,016	1,517	X
25	VGPT1-28	0,009	0,858	

Table A3_4 Calculated CDIs Vigdis

8.6.3 Results of CCA of the Vigdis field, with the ParTrack results included

The ParTrack results are calculated in intervals. When including these results in the analysis, the mean value of the interval was used.

Axes	1	2	3	4	Total inertia
Eigenvalues :	0.507	0.094	0.089	0.058	1.224
Species-environment correlations :	0.973	0.957	0.703	0.906	
Cumulative percentage variance					
of species data :	41.4	49.1	56.4	61.1	
of species-environment relation:	58.4	69.2	79.4	86.1	

Sum of all eigenvalues	1.224
Sum of all canonical eigenvalues	0.869

Marginal Effects

Variable	Var.N	Lambda1
Cr	6	0.23
Cu	3	0.21
Pb	2	0.18
Cd	1	0.16
TOM	10	0.13
THC	8	0.11
Olefin	7	0.08
Depth	11	0.07
Ba	5	0.07
Pelite	9	0.04
Cuttings deposition	12	0.03

Conditional Effects

Variable	Var.N	LambdaA	P	F

Cr	6	0.23	0.008	5.29
THC	8	0.20	0.002	5.50
Depth	11	0.12	0.002	3.82
Cd	1	0.05	0.108	1.67
Olefin	7	0.05	0.108	1.45
TOM	10	0.03	0.386	1.00
Pelite	9	0.02	0.662	0.72
Cu	3	0.02	0.722	0.69
Ba	5	0.02	0.790	0.61
Cuttings deposition	12	0.03	0.586	0.75
Pb	2	0.01	0.820	0.54

Table A3_5 PArtrack results. Some of the parameters are not defined here, but included to make later validation easier (comprehensive details may be found in the Pertrack documentation)

8.7 Njord 1996

No elevation of chemistry, no indication of community disturbance as evident from the 2000 survey figure A3_20. As a result all station from Njord 1996 may be included for calculation of field sNOECs

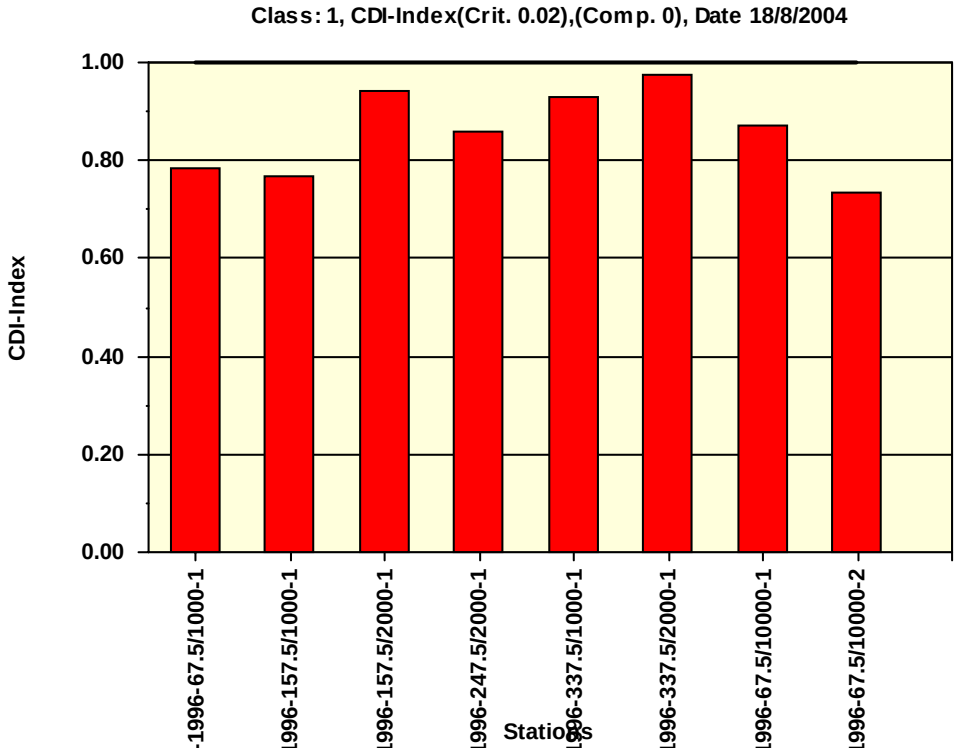


Figure A3_18 CDIs for stations from Njord 1996

8.8 Njord 2000

Biology

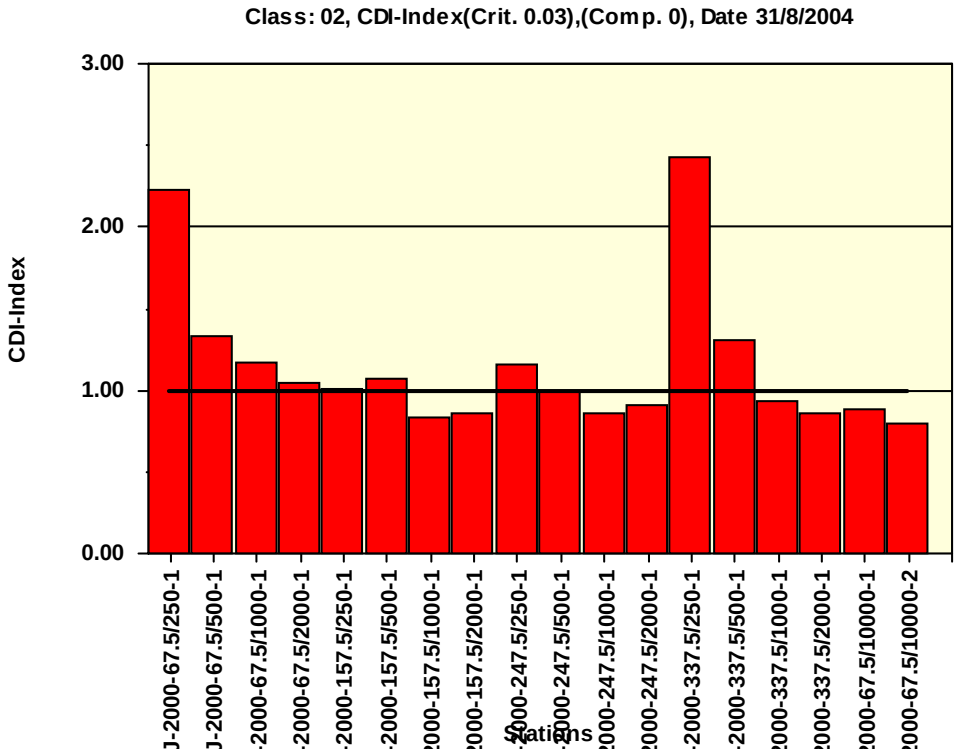


Figure A3-19 CDIs for Njord 2000

Number	Name	RSD	CDI	
1	NJ-2000-67.5/250-1	0,058	2,225	X
2	NJ-2000-67.5/500-1	0,034	1,326	X
3	NJ-2000-67.5/1000-1	0,030	1,170	X
4	NJ-2000-67.5/2000-1	0,027	1,040	X
5	NJ-2000-157.5/250-1	0,026	1,014	X
6	NJ-2000-157.5/500-1	0,028	1,066	X
7	NJ-2000-157.5/1000-1		0,022	0,834
8	NJ-2000-157.5/2000-1		0,022	0,864
9	NJ-2000-247.5/250-1	0,030	1,152	X
10	NJ-2000-247.5/500-1	0,026	0,996	
11	NJ-2000-247.5/1000-1		0,022	0,864
12	NJ-2000-247.5/2000-1		0,024	0,914
13	NJ-2000-337.5/250-1	0,063	2,432	X
14	NJ-2000-337.5/500-1	0,034	1,313	X
15	NJ-2000-337.5/1000-1		0,024	0,930
16	NJ-2000-337.5/2000-1		0,022	0,854
17	NJ-2000-67.5/10000-1		0,023	0,887
18	NJ-2000-67.5/10000-2		0,021	0,799

Table A3_4 Calculated CDIs Njord 2000

8.9 Njord 2003

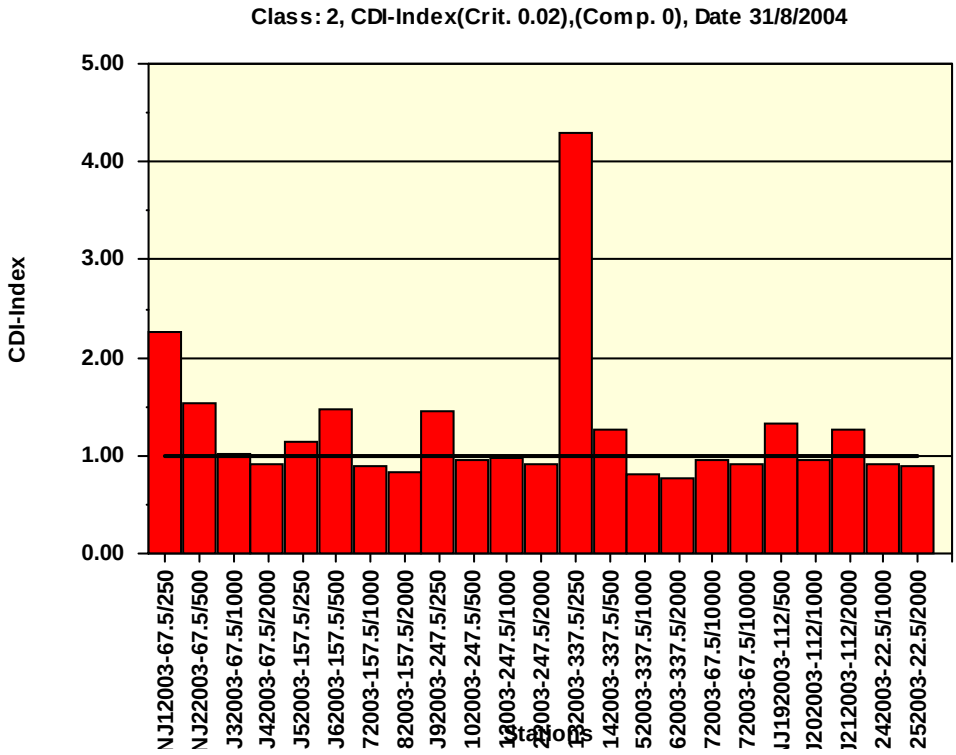


Figure A3_20 CDIs for Njord 2003

Number	Name	RSD	CDI		
1	NJ12003-67.5/250		0,048	2,252	X
2	NJ22003-67.5/500		0,032	1,540	X
3	NJ32003-67.5/1000		0,021	1,019	X
4	NJ42003-67.5/2000		0,019	0,913	
5	NJ52003-157.5/250		0,024	1,139	X
6	NJ62003-157.5/500		0,031	1,466	X
7	NJ72003-157.5/1000		0,019	0,888	
8	NJ82003-157.5/2000		0,017	0,823	
9	NJ92003-247.5/250		0,031	1,459	X
10	NJ102003-247.5/500		0,020	0,954	
11	NJ112003-247.5/1000		0,020	0,967	
12	NJ122003-247.5/2000		0,019	0,913	
13	NJ132003-337.5/250		0,091	4,301	X
14	NJ142003-337.5/500		0,027	1,265	X
15	NJ152003-337.5/1000		0,017	0,814	
16	NJ162003-337.5/2000		0,016	0,770	
17	NJ172003-67.5/10000		0,020	0,965	
18	NJ172003-67.5/10000		0,019	0,904	
19	NJ192003-112/500		0,028	1,322	X

20	NJ202003-112/1000	0,020	0,946	
21	NJ212003-112/2000	0,026	1,256	X
22	NJ242003-22.5/1000	0,019	0,923	
23	NJ252003-22.5/2000	0,019	0,897	

Table A3_5 Calculated CDIs Njord 2003

The high CDI at the station closest to the platform in main current direction may be explained by an accidental release of roughly 30 tonnes oil based drilling fluid roughly two moths prior to sampling.

8.10 NE Frigg

8.10.1 Chemistry

Figure shows the CA biplot based on the chemistry of NE Frigg samples. The samples showing slightly different levels of chemicals are 2000 FRINE-23 and 2000 FRINE-20A. A slightly elevated level of THC is shown for samples 2000 FRINE-23. This sample is taken at 250 m distance in the 105 degree direction. However the levels of THCs are very low at this field, and the differences are close to what may be expected from analytical variation (including sampling). Similarly may be concluded from the reference sample 2000 FRINE-20A, showing slight elevation of levels of Barium and THC. These differences are probably only variation in background levels. There is also a slight increase in % pelite in sample 20A as compared to the other samples.

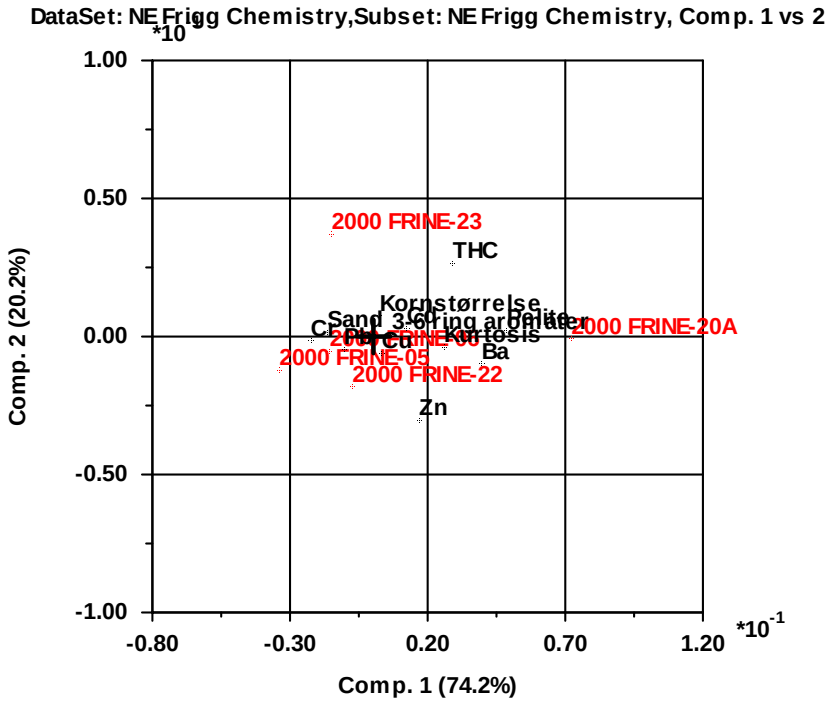


Figure A3_21 Biplot (CA) of samples and data from NE Frigg

8.10.2 Biology

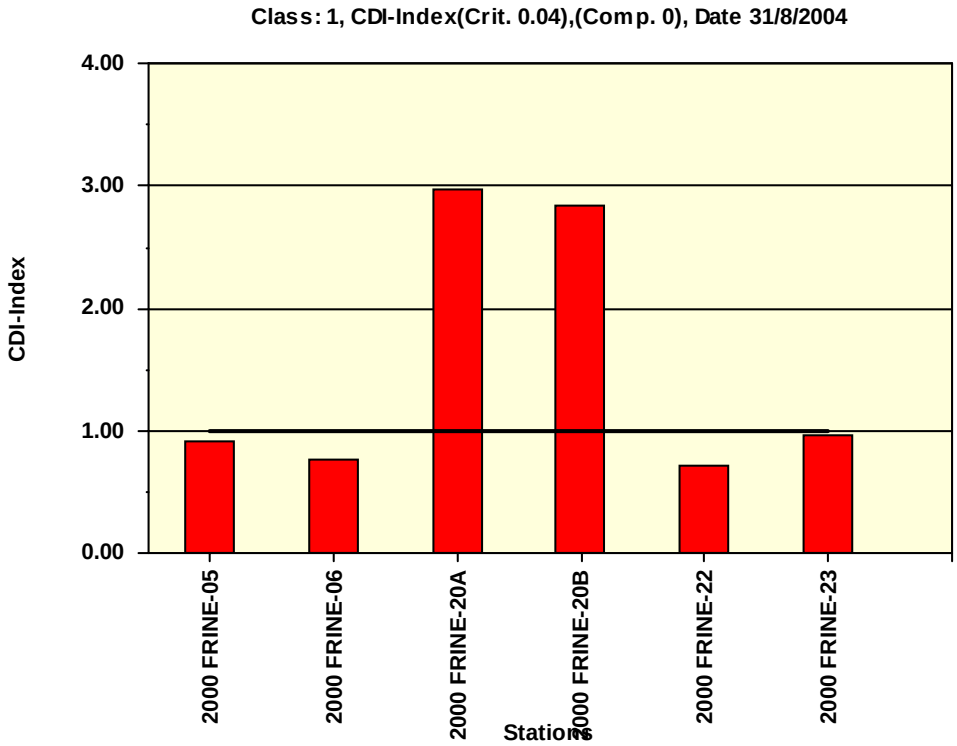


Figure A3_22 Calculated CDIs NE Frigg

Number	Name	RSD	CDI	Residual Distance		Upper/lower limits for the Scores
1	2000 FRINE-05		0,033	0,905		
2	2000 FRINE-06		0,028	0,764		
3	2000 FRINE-20A		0,110	2,973	X	Not due to pollution
4	2000 FRINE-20B		0,105	2,833	X	Not due to pollution
5	2000 FRINE-22		0,027	0,722		
6	2000 FRINE-23		0,036	0,969		

Table A3_6 Calculated CDIs NE Frigg

Figure A3_22 and Table A3_6 suggest that samples 20A and 20B have another distribution of benthic fauna than the other samples. Although these two samples are taken on same depth they are taken almost 10 kilometres away from the other samples. Together with the results from the analysis of chemistry, it is to expect that the difference in benthic fauna **not** is due to pollution. A closer investigation of the benthic fauna support this conclusion, i.e. the sample 20A and B have elevated levels of *Owenia Fusiformis*, a species known to be suppressed by pollution.

8.11 Lille Frigg

8.11.1 Chemistry

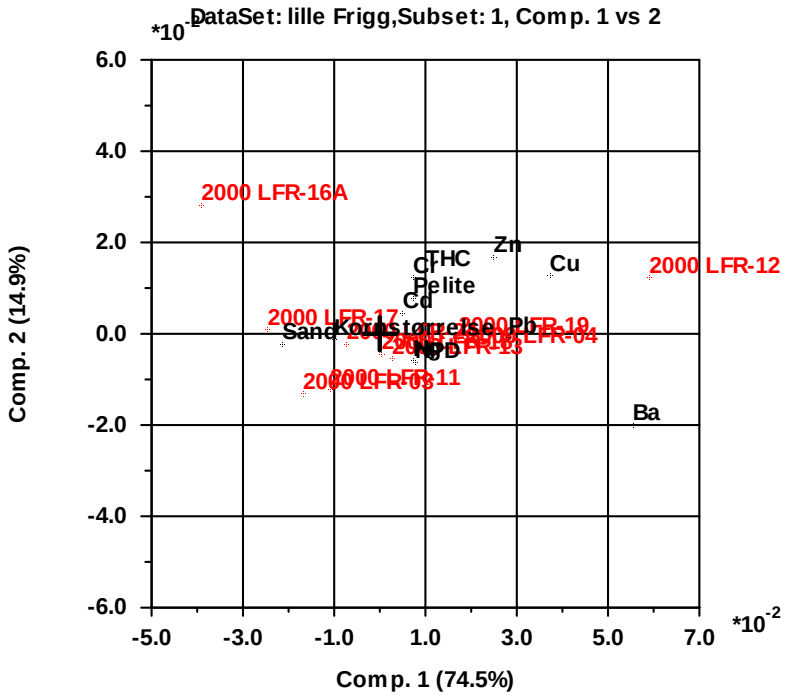


Figure A3_23 Loadings and scores (CA biplot) of Lille Frigg

Figure A3_23 shows slightly elevated levels of all the chemicals (in particular Cu, Ba) in station 2000 LFR-12, and low levels of chemicals in the reference station (in particular relatively low in Ba) in 2000 LFR 16A.
The levels of chemicals are rather low, so the field appear to relativley undisturbed.

8.11.2 Biology

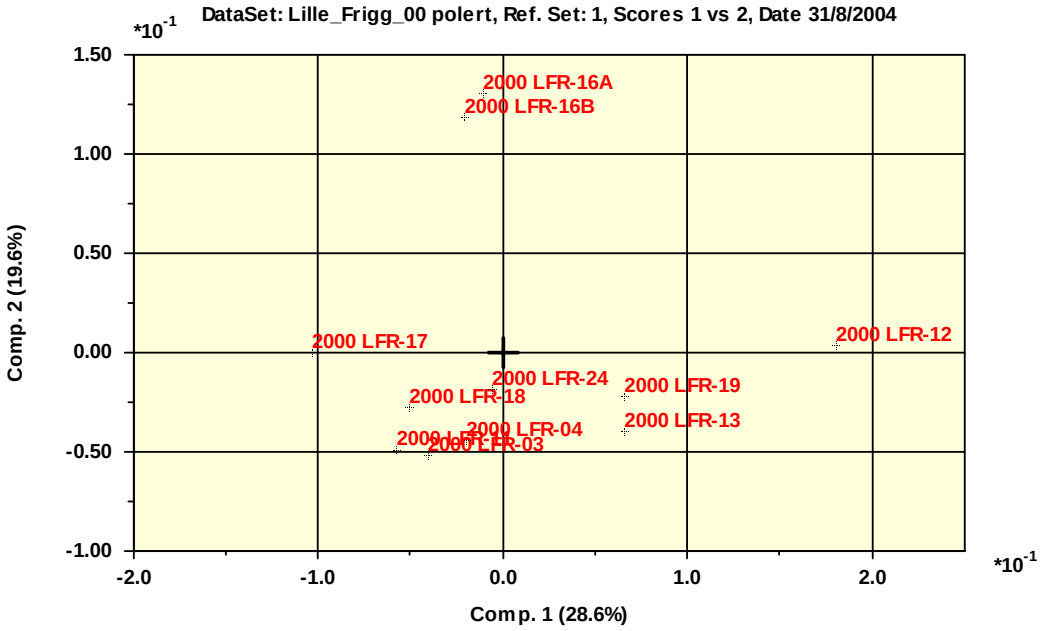


Figure A3_24 CA plot of Lille Frigg benthic fauna data from 2000

The reference stations 16A and 16B taken at 10150 meter distance have another distribution of benthic fauna than the samples takes close to Lille Frigg. After excluding the reference stations from the data model, CA was repeated on the remaining data giving new scores as seen in Fig. A3_25

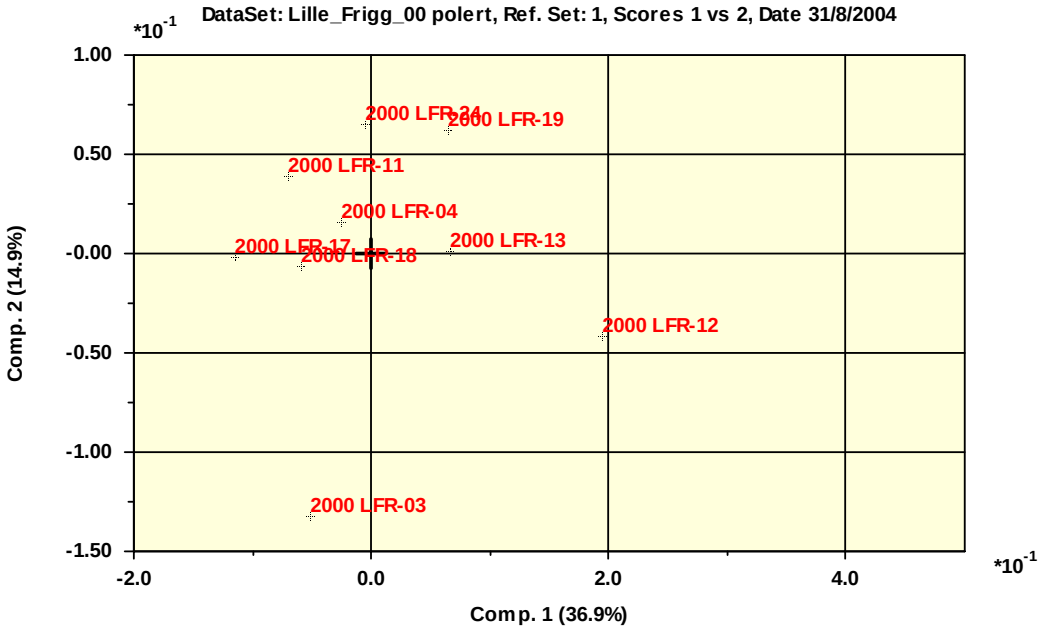


Figure A3_25 CA scores of benthic fauna data from Lille Frigg 2000

Figure shows that sample 03 and 12 separates slightly from the other stations.
By excluding them from the reference data, an even distributed CA plot (i.e. loadings and scores) were achieved. These are shown in Figure A3_26 as a CA bi plot:

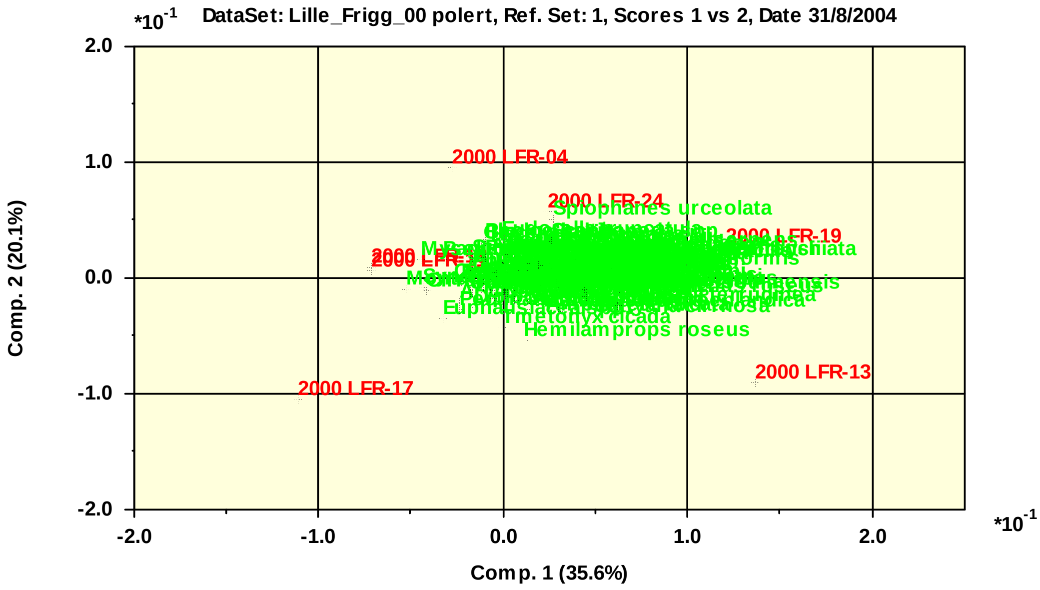


Figure A3_26. CA biplot of station around Lille Frigg selected as reference samples

The CDI were now calculated and are shown in Figure A3_27.

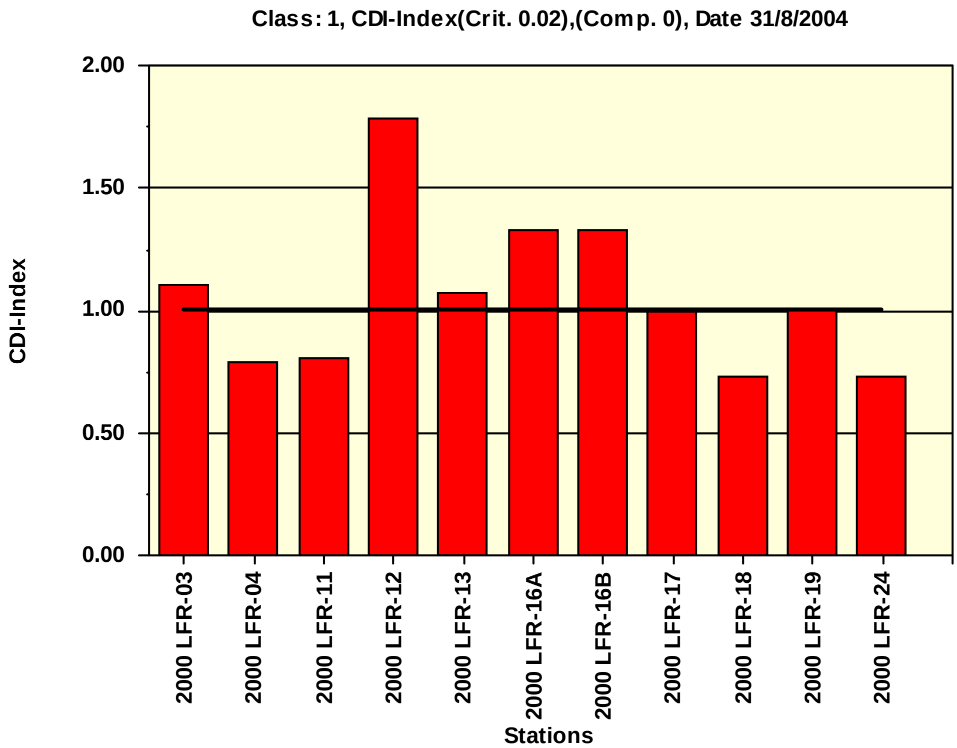


Figure A3_27 CDI for stations at Lille Frigg 2000.

No.	Name	RSD	CDI	
1	2000 LFR-03	0,021	1,107	X

2	2000	LFR-04	0,015	0,790		
3	2000	LFR-11	0,015	0,802		
4	2000	LFR-12	0,034	1,781	X	
5	2000	LFR-13	0,020	1,072	X	
6	2000	LFR-16A		0,025	1,332	X
7	2000	LFR-16B		0,025	1,331	X
8	2000	LFR-17	0,019	0,996		
9	2000	LFR-18	0,014	0,734		
10	2000	LFR-19	0,019	1,005	X	
11	2000	LFR-24	0,014	0,727		

Table A3_7 CDIs for Lille Frigg 2000

The high CDIs for the reference stations is due to another faunal distribution than in the sediments close to Frigg. The benthic fauna is disturbed on station 12 (CDI=1.8), and may be slightly affected at stations 3, 13 and 19.

9. Appendix 4 PECs for Goliath, Vigdis and Norne

9.1 Concentration of toxic stressors Goliath

	THC	*Cd*	*Pb*	*Al*	*Ba*	*Cr*	*Cu*	*Fe*	*Li*	*Ti*	*Zn*	*TOM*
	ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**µg/g**	**µg/g**	**µg/g**	**mg/kg**
GOL-ref	1,25	0,07	12,7	43960	393	40	6,5	17800	15	2370	30	2,35
GOL1-1	0,5	0,07	13,8	45600	459	43	7,9	19400	19	2560	38	3,04
GOL1-2	1,35	0,07	14,0	46700	425	43	8,3	19600	19	2480	36	2,73
GOL1-3	0,5	0,09	15,8	51600	429	51,1	11	23200	24	2670	46	3,06
GOL1-4	1,95	0,06	14,2	46600	430	44	8,4	19900	20	2420	38	3,14
GOL1-7	1,94	0,06	13,9	47700	450	47	8,9	20100	20	2740	38	2,92
GOL1-9	0,5	0,06	13,8	45900	683	44	8,1	21200	19	3780	36	2,95
GOL1-10	1,55	0,06	13,3	48200	475	46	8,3	20200	19	2780	38	2,81
GOL1-11	1,45	0,06	14,3	49000	440	43	7,8	19700	19	2470	37	2,79
GOL1-12	0,5	0,05	14,3	49700	709	52,8	10	23800	22	4210	44	3,26
GOL1-14	1,56	0,05	14,6	47900	1570	58,3	12	28900	22	8600	45	3,15
GOL1-15	2,15	0,06	16,1	49900	513	49	9,4	22100	22	2970	43	3,34
GOL1-17	1,81	0,05	15,1	51400	472	50,5	9,7	23000	23	2820	43	3,38
GOL1-19	2,54	0,05	14,5	47700	493	42	8,0	19300	19	2490	37	2,85
GOL1-20	2,48	0,05	12,6	48700	456	49	9,1	21410	21	2900	40	3,04
GOL1-21	2,37	0,06	15,9	48600	421	46	8,6	20200	21	2520	41	3,38
GOL1-22	3,34	0,05	14,0	48600	503	44	8,3	19800	19	2540	37	3,08
GOL1-23	1,59	0,05	15,0	50700	446	48	9,2	21900	22	2750	42	2,66
GOL1-26	5,92	0,07	14,3	44800	3430	78,6	25	45100	22	19600	60	3,14
GOL1-28	2,10	0,05	12,1	51500	1330	65,5	35,8	30800	21	8850	48	3,07

	Dyp	*Fin sand*	*Pelitt*
	m	**%**	**%**
GOL-ref	377	55,82	38,61
GOL1-1	397	40,38	56,73
GOL1-2	395	42,85	54,34
GOL1-3	397	37,38	61,04
GOL1-4	392	40,47	56,4
GOL1-7	392	40,45	57,6
GOL1-9	390	45,34	50,72
GOL1-10	392	41,81	55,38
GOL1-11	392	45,13	50,49
GOL1-12	394	37,98	60,62
GOL1-14	393	41,1	57,51
GOL1-15	395	39,86	58,27
GOL1-17	396	40,02	58,71
GOL1-19	393	42,83	53,31
GOL1-20	393	42,74	55,17
GOL1-21	394	39,85	58,4
GOL1-22	392	42,23	54,08
GOL1-23	392	44,78	52,77
GOL1-26	393	40,33	57,23
GOL1-28	392	38,19	60,06

Table A4_1 Concentration of chemical stressors Goliath

9.2 Concentration of toxic stressors Vigdis

Enhet	Cd mg/kg	Hg mg/kg	Pb mg/kg	Cu mg/kg	Zn mg/kg	Ba mg/kg	Cr mg/kg
VGIT-01	0,048	-	4,6	2,7	12,1	847	12,1
VGIT-02	0,102	0,02	15,7	20,5	39,6	3035	42,9
VGIT-03	0,05	-	5,4	3,7	13,6	2617	13,6
VGIT-04	0,052	-	4,7	3,1	12,9	1781	11,8
VGIT-05	0,056	-	5,6	3	15	1720	13,3
VGIT-06	0,057	-	4,5	2	13,3	536	12,7
VGPT1-19	0,066	0,012	5,5	3	16,1	423	15,7
VGPT1-21	0,059	-	3,8	2,3	13,6	446	15,9
VGPT1-22	0,09	0,014	10,8	7,9	41,7	3180	23,9
VGPT1-23	0,047	-	7,3	4,3	18,3	2683	18
VGPT1-24	0,066	-	5,5	3	16,5	992	15,2
VGPT1-25	0,063	0,01	4,6	3	14,9	546	14,9
VGPT1-27	0,057	-	5,4	3,7	16,2	1775	15,9
VGPT1-28	0,054	-	4,6	3,3	15,6	643	15,6
VGPT2-7	0,059	-	3,8	2,3	11,6	758	14,3
VGPT2-8	0,052	-	4,4	3	12,6	890	12,6
VGPT2-09	0,049	0,011	8,8	9,7	23,1	3436	23,8
VGPT2-10	0,047	-	4,4	3	13,3	1718	14,6
VGPT2-11	0,048	-	4,4	2,3	12,7	998	12,3
VGPT2-12	0,039	0,007	3,7	2	9,9	538	11,3
VGPT2-14	0,035	-	4,2	1,6	10,7	391	10,4
VGPT2-15	0,046	-	4,6	2	11,7	626	11,7
VGPT2-16	0,046	-	5,3	3,3	13,7	2223	13,4
VGPT2-17	0,049	-	3,8	2,6	13,2	599	14,2
VGPT2-18	0,05	-	5,9	2,6	15,4	699	15,7

Enhet	Dekaliner mg/kg	NPD mg/kg	Olefin mg/kg	PAH mg/kg	THC mg/kg	Pelite %	TOM %	Dypm
VGIT-01	-	-	1,3	-	3,9	19	2,1	280
VGIT-02	0,273	1,549	217	0,21	0,9	24,2	4,6	278
VGIT-03	-	-	118	-	3	19,4	2,5	278
VGIT-04	-	-	56,2	-	4,6	18,5	2,4	279
VGIT-05	-	-	7,3	-	3,6	21,1	2,5	282
VGIT-06	-	-	0,2	-	3,2	19,9	2,4	284
VGPT1-19	0,048	0,039	0,2	0,059	3,9	33,9	2,7	292
VGPT1-21	-	-	0,2	-	2,9	30,6	2,5	289
VGPT1-22	0,278	0,163	76,7	0,079	7,7	28,5	4,3	289
VGPT1-23	-	-	35,1	-	10,8	35	3,4	287
VGPT1-24	-	-	1	-	4	34	3	289
VGPT1-25	0,08	0,035	0,2	0,05	3,2	32	2,9	287
VGPT1-27	-	-	5,5	-	9,2	31,2	3	290
VGPT1-28	-	-	0,2	-	4,9	33,9	3,3	290
VGPT2-7	-	-	2	-	4,5	18,5	2,2	279
VGPT2-8	-	-	0,2	-	4,5	19	1,9	278
VGPT2-09	0,897	0,738	103	0,118	50,6	21,6	3,1	279
VGPT2-10	-	-	5,7	-	7,8	25,2	2,4	280

VGPT2-11	-	-	0,2	-	4,2	17,9	2,2	277
VGPT2-12	0,059	0,03	0,2	0,031	3,3	17,9	2	278
VGPT2-14	-	-	0,2	-	3,6	13,9	2,1	274
VGPT2-15	-	-	0,2	-	3,6	17	2,1	276
VGPT2-16	-	-	5,6	-	6,6	20,5	2,5	280
VGPT2-17	-	-	0,2	-	4,5	30,4	2,5	280
VGPT2-18	-	-	7,1	-	10,9	28,4	2,4	281

Table A4_2 Concentration of chemical stressors Vigdis 1999

9.3 Concentration of toxic stressors Norne

Enhet	Dyp m	Ba mg/kg	Cd mg/kg	Cr mg/kg	Cu mg/kg	Dekaliner mg/kg	Hg mg/kg	NPD mg/kg	PAH mg/kg
NONW-02	378	570	0,06	36,50	10,97	0,61		0,08	0,09
NONW-03	379	327	0,05	37,43	10,60				
NONW-06	382	727	0,05	33,93	10,37	0,80		0,07	0,09
NONW-07	385	556	0,06	35,60	10,53				
NONW-09	380	1059	0,07	29,80	9,00	21,24		0,07	0,06
NONW-10	380	1286	0,09	35,87	11,03				
NONW-11	378	1767	0,10	36,70	11,47	0,46		0,09	0,09
NONW-12	378	3424	0,10	38,47	13,20	4,53	0,03	0,17	0,21
NONW-13	375	1240	0,09	35,30	10,40	5,48		0,08	0,09
NONW-14	375	852	0,10	37,57	10,63	1,15		0,08	0,09
NONW-15	373	786	0,09	31,03	9,07		0,03	0,06	0,08
NOSW-01	374	1014	0,07	32,93	10,00	0,31		0,15	0,12
NOSW-03	375	1921	0,07	29,83	9,30				
NOSW-04	374	732	0,08	36,50	10,93				
NOSW-07	373	2994	0,07	30,63	10,80				
NOSW-08	373	1520	0,07	33,50	10,37				
NOSW-10	371	5903	0,09	31,27	12,43	14,24	0,03	0,83	0,15
NOSW-11	375	1613	0,06	34,37	10,47	21,12		0,11	0,10
NOSW-12	373	950	0,06	32,40	9,50				
NOSW-13	370	796	0,07	31,47	9,53		0,03	0,07	0,08
NOSW-ref	390	191	0,10	36,02	10,32		0,03	0,07	0,12

Enhet	Pb mg/kg	THC mg/kg	Zn mg/kg	Grus %	Kornstørrelse Md	Pelite %	Sand %	TOM %
NONW-02	21,97	14,07	71,57	0,00	5,84	92,46	7,54	6,72
NONW-03	20,87	6,86	68,93	0,00	5,75	88,94	11,06	8,03
NONW-06	19,93	13,93	63,90	0,40	5,46	78,80	20,81	7,12
NONW-07	21,50	5,70	66,70	0,00	5,73	88,12	11,88	7,73
NONW-09	16,53	297,23	56,83	2,74	4,73	61,16	36,10	5,10
NONW-10	21,30	9,96	68,67	0,00	5,81	91,36	8,64	7,82
NONW-11	21,43	12,95	69,20	0,17	5,85	93,03	6,79	8,13
NONW-12	20,47	98,53	75,67	0,00	5,87	93,88	6,12	7,75
NONW-13	20,00	84,57	64,97	0,00	5,65	84,99	15,01	7,34
NONW-14	21,90	22,87	69,73	0,00	5,81	91,42	8,58	6,91
NONW-15	18,50	5,67	63,03	1,46	5,46	78,80	19,74	6,40
NOSW-01	20,77	33,61	77,13	0,00	5,57	82,44	17,56	7,00
NOSW-03	18,77	9,49	57,27	5,19	4,92	64,99	29,82	5,90
NOSW-04	21,50	5,11	69,40	0,00	5,81	91,31	8,69	7,37
NOSW-07	19,47	10,92	60,33	0,66	5,27	73,39	25,95	6,11
NOSW-08	19,87	6,62	65,00	0,52	5,69	86,45	13,02	7,71

NOSW-10	22,27	235,00	64,23	2,02	5,00	66,78	31,20	6,65
NOSW-11	19,80	202,17	67,57	0,00	5,68	86,06	13,94	7,81
NOSW-12	17,33	5,67	67,30	0,69	5,52	80,57	18,74	6,44
NOSW-13	18,97	4,14	60,17	0,16	5,52	80,55	19,29	7,62
NOSW-ref	21,38	3,77	65,86	0,00	5,78	90,08	9,92	8,18