Conoco Norway Inc.

Baseline Environmental Survey of the Heidrun Field

June 1988

HEIDRUN

Main Report

Norwegian Institute for Water Research NIVA

GEO AGE IKU SINTEF-GRUPPEN NAC AS OCEANOR Oceanographic Company of Norway A/S

NIVA - REPORT

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Abstract: Results from an investigation of the sea bottom sediments at 25 sites in the Heidrun oil and gas field, June 1988, showed that levels of petroleum hydrocarbons and heavy metals were at expected background. At one site elevated barium content seemed to reflect previous exploratory drilling. The sediment fauna was very rich and diverse, and showed no sign of disturbance. A slight faunal gradient from SW to NE reflected a change in sediment grain size distribution.

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1. Heidrunfeltet
2. Oljehydrokarboner
3. Tungmetaller
4. Makrofauna

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2. Petroleum hydrocarbons
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4. Macrofauna

Project leader

Torgeir Bakke

For the Administration

Tor Bokn

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Heiþrún heitir geit   es stendr höllu á (Herjaföþrs)
ok bítr at Lǽráþs limum;
skapker fylla   hón skal ens skíra mjaþar,
knáat sú veig vanask.

Hethrún, the goat   on the hall that stands,
eateth off Læráth's limbs;
the crocks she fills   with clearest mead,
will that drink not e'er be drained.

O - 88113

BASELINE ENVIRONMENTAL SURVEY OF THE HEIDRUN FIELD

JUNE 1988

A report to CONOCO NORWAY INC.
Contract Agreement No GE-139

7. February 1989

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PREFACE

The present document reports the results of the baseline environmental survey performed in June 1988 in the area of the future installations for oil and gas production at the Heidrun field, block 6507/7, at Haltenbanken, Mid-Norway.

NIVA was awarded the contract for the work by CONOCO NORWAY INC. (CNI) on 27 May 1988. Contract Agreement No GE-139 was signed by both parts on 8 June 1988. Field survey was performed from 22 to 28 June 1988.

The contract work has been performed as a joint effort by the following research institutes and consultants:

Continental Shelf and Petroleum Technology Institute, IKU, Trondheim;
GEORGE A/S, Trondheim;
Nordic Analytical Center A/S, NAC, Oslo;
Norwegian Institute for Water Research, NIVA, Oslo;
Oceanographic Company of Norway A/S, OCEANOR, Trondheim.

The Norwegian Institute for Water Research has coordinated the project and been responsible as Contractor for the services.

Oslo, 7. February 1989
Norwegian Institute for Water Research

Torgeir Bakke
Project coordinator and Contract Representative

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EXECUTIVE SUMMARY

Conclusions

The seabed sediments in the Heidrun area were well oxygenated and classified as very fine sand with a content of silt/clay of 26-64 %. The mean organic content was 0.52 %.

The total hydrocarbon (THC) levels were homogenous over the field and ranged between 1 and 10 mg/kg dw by IR analysis and between 0.8 and 9 mg/kg by GC/FID analysis. The NPD content ranged from 3.7 to 30 µg/kg dw by GC/MS analysis. These levels are comparable to uncontaminated sediments at other sites. Bicyclanes, indicating oil based drilling fluids were not detected. The relative composition of n-alkanes and aromatic compounds suggested a predominantly biogenic hydrocarbon origin. The vertical distribution of hydrocarbons in the sediment indicated a slight reduction with depth at one station, and no change at another.

There was no evidence of sites with elevated metal content, except for a high level of barium in one subsample taken in the vicinity of exploratory well 6507/7-4, with 1200 mg/kg against the range of 58-410 mg/kg in all other samples. This may indicate local contamination by drill cuttings. The levels of chemical parameters were not inter-correlated, suggesting an homogenous and uncontaminated sediment.

The Heidrun field contained an homogenous and highly diverse seabed macrofauna community. Diversity was amongst the highest ever recorded around offshore fields, and no sign of environmental disturbance could be detected. There was a weak gradient in fauna composition from southwest to northeast across the field, at least partly a functon of grain size distribution.

The physical, chemical and biological homogeneity of the seabed should enable detection of even small perturbations caused by the future development of the field. In this respect the continous use of 0.5 mm screen for sampling of macrofauna is recommended.

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1. Introduction

The report describes results of the baseline environmental survey of the sea bottom sediments of the Heidrun oil and gas field. The survey was conducted on behalf of Conoco Norway Inc. (CNI) (Contract Agreement no GE-139) by the Norwegian Institute for Water Research (NIVA) in cooperation with the Continental Shelf and

Petroleum Technology Institute IKU, Trondheim, the Oceanographic Company of Norway A/S OCEANOR, Trondheim, Nordic Analytical Center A/S, Oslo, and GEORGE A/S, Trondheim.

The objective was to establish the baseline for future regular surveys. This has been done in such a way as to also allow comparison with results from other fields. It should provide a qualitative and quantitative description of the seabed fauna, the sediment physical characteristics, and the content of major organic and inorganic trace elements of the surficial sediments, and define patterns present in the data.

The work has been performed in the period June 1988 to January 1989.

2. Abbreviated survey log

The sampling survey was performed in the period 22-28 June 1988 from the vessel 'Svanaug Elise'. On 23 June the ship was on location at Heidrun, and after the ARGO positioning system had been calibrated against GPS satellites, sampling of the first station started at 1957 hour. Sampling was performed at 25 stations centered around the sites for the Early Production System (EPS) and the Permanent Platform. The positions of the sampling stations are shown in Figure 4.1, and their basic data given in Table 4.1. Sampling was completed at 0645 hour on 27 June and demobilisation in Trondheim completed by 1200 hour on 28 June.

2.1. Standard sample programme

The standard sampling programme at each station was:

- five acceptable 0.1 m^2 Van Veen grab samples recovered without signs of washout and minimum volume 10 liters. Each grab sample was sieved at 1 and 0.5 mm and preserved in formalin for analysis of fauna.

- three acceptable 0.1 m^2 Smøgen boxcorer samples recovered without disturbed surface, and with thickness larger than that of the oxidised layer (5-7 cm). From each of the boxcores 6 subsamples were taken from the topmost 1-2 cm for analysis of grain size (one sample), organic content (one sample), hydrocarbons (two samples), and heavy metals (two samples).

- on site analysis of redox (Eh) potential at 2 cm sediment depth in one of the boxcorer samples, and description of sediment colour and general appearance.

2.2. Extra samples

At the reference Station 24 the programme included an extra 3 grab samples for for fauna analysis, i.e. a total of 8 grab samples, in order to assess the species number versus the area sampled. At Stations 8 and 10 two extra boxcores were sampled and from each, two subcores were taken to study vertical distribution of hydrocarbons. Also at Stations 8 and 10 six surface subsamples were taken from three extra boxcore samples for hydrocarbon analysis intercalibration.

2.3. Documentation and treatment of samples

The entire volumes of the grab samples for fauna analysis were measured to the nearest 0.5 liter, and the sample was poured onto a hopper table and washed out with a gentle stream of water over a 1 mm sieve and into a 0.5 mm sieve, both with round holes. The subsamples from the two sieves were preserved separately in formalin with rose bengal stain. Thus there were two preserved samples from each of the five grab samples taken from every station.

The box core samples were transferred to a plastic tray, and surface colour (Munsell Colour Code), sediment thickness and general appearance determined. The subsamples for analysis of particle size distribution and organic content were taken with a stainless steel spatula and frozen in plastic bags. The subsamples for hydrocarbon analysis were taken with a Teflon spatula, wrapped in clean aluminium foil, and frozen. The subsamples for metal analysis were taken with a stainless steel spatula and frozen in acid-washed plastic bottles.

2.4. Positioning.

The principal postitioning system used for navigation and station keeping was the ARGO radio link system logging at Skomvær, Træna, Sklinna and Slettringen shore based transmitters. Calibration of the ARGO chain before sampling was by logging against the GPS satellites during a period of satellite cluster passage on 23 June. Positioning was undertaken by North Sea Navigation A/S, Haugesund. For every GPS logging period the ARGO position was verified against the satellite readings. During sampling the position was logged every time the sampler reached bottom, recording date, time and UTM position.

3. Analytical procedures

Particle size distribution was analysed by combined dry sieving for particles larger than 63 µm and electronic particle counting for material below that size down to 2 µm.

Redox potential at 2 cm sediment depth was measured by a platinum electrode (calomel reference and standard Zobell solution) after a few minutes stabilization time in the sediment. The instrument was back-calibrated against a laboratory reference instrument after the survey, and the readings adjusted accordingly.

Total organic content was analysed as loss by combustion after treatment with hydrochloric acid.

Screening analysis for total hydrocarbons was performed on dichloromethane (DCM) extracts of the sediment. After evaporation and dissolution of residue in carbontetrachloride, analysis was performed by use of infrared (IR) detection.

Analysis of total hydrocarbon content (THC) was performed after soxhlet extraction with methanol/pentane and DCM and use of internal standards. The combined pentane and DCM extracts were split into two aliquots one of which was analysed by gas chromatography - flame ionization detection (GC/FID) for quantification of the THC. The other aliquot was separated into aliphatic and aromatic fractions and these were analysed separately by gas chromatography - mass spectrometry (GC/MS) for selected hydrocarbons.

Analysis for trace metal elements was performed on acid extracts after digestion with HNO_3. The elements Ba, Sr, Pb, Cr, Cu, Fe, Ni, V, and Zn were analysed by inductive coupled plasma atomic emission spectrometry (ICP-AES), the elements Cd, Cu, Pb and Cr also by electrothermal atomic adsorption spectrometry (EAA) analysis, and Hg by cold vapour technique.

The macrofauna individuals were sorted from the remaining sediment under a dissecting microscope, identified and enumerated. The list of identified taxa with their densities were used to compute the following community parameters for each station: species number, species richness index, total individual densities, diversity indices, diversity (rarefaction) curves, expected number of species per 100 individuals, dominance and evenness, lists of dominant species ranked after % abundance, number of species per area curves, and correspondence to log-normal distribution. Multivariate techniques (multi-dimensional scaling (MDS) ordination and cluster analysis) were used to group the stations according to faunal similarity, and correlation among fauna and sediment parameters tested. Analysis was done on the complete fauna larger than 0.5 mm and separately on the fraction larger than 1 mm.

4. Main results.

4.1. Sediment characteristics

The sediments were poorly sorted, and the mean diameter (expressed as Φ (phi) mean) ranged from 2.785 (fine sand) at Station 11 to 4.638 (coarse silt) at Station 10. The average Φ mean was 3.835 (very fine sand). The Φ skewness values showed a displacement of the the size distribution towards the finer grains. The fine nature of the sediment was reflected in a high silt/clay or "mud" content ranging from 25.6 % to 64 % with an average of 44.1 %. There was a tendency of more fine grained median values towards the north, probably reflecting the gentle slope towards a bottom depression north of Heidrun. Also the % silt/clay increased in the NE direction.

The average redox (Eh) value was +456 mV ranging from +363 mV at Station 6 to +529 mV at Station 13. These values are typical for well oxygenated sediments, and showed no trends across the sampled field.

4.2. Chemical characterization

The results from the TOC analysis ranged from 0.44% (Station 21) to 0.63% (Station 5) with an average 0.52 ± 0.047%. There was no significant difference between the average TOC levels in the eastern and western regions of the survey area.

The THC level measured by IR ranged from 1.0-10 mg/kg dry weight with a mean value of 4.9 ± 2.5 mg/kg. The levels are typical for a nonpolluted sediment having the physical characteristics described above in section 4.1, and were in good accordance with earlier data from Haltenbanken. The mean value around the EPS was slightly lower than along the Platform transects, but still the total area was regarded as homogenous with respect to IR results.

The THC levels of single samples measured by GC/FID ranged from 0.80 (Station 8) to 8.99 (Station 22) mg/kg (dry weight), with a mean value of 2.92 ± 1.35 mg/kg. These results were in the same range as for North Sea sediments analysed in previous baseline surveys. The mean THC levels for the EPS and Platform sites were regarded as similar. The chromatograms verified that the sampling area represented an homogenous sediment.

The concentrations of normal alkanes in the C_{12}-C_{35} range analysed by GC/FID were comparable to, although in the lower range of, previous background levels for the North Sea. The composition of the normal alkanes suggested a predominantly biogenic input.

The concentrations of isoprenic compounds (pristane and phytane) showed no trend across the Heidrun area, and were similar to North Sea background values. A slight under-representation of pristane relative to phytane could suggest a petrogenic source of sediment hydrocarbons, but this was not substantiated by the composition of the normal alkane and aromatic compounds.

Bicyclanes, being indicative of oil based drilling fluids, were not detected in any of the samples.

The NPD concentrations ranged from 3.7 to 30 µg/kg dry sediment, which is within the range found elsewhere for noncontaminated sediments. The concentrations were in the lower range of background values for North Sea sediments, probably due to evaporative loss of naphthalene in the work-up procedure. Phenanthrenes and dibenzothiophenes were similar to the Haltenbanken baseline survey results for 1985. The concentration of 4-6 ring aromatic compounds were in the higher range of background levels found in the North Sea. The composition of the total PAH (polyaromatic hydrocarbons) indicated no particular influence from petrogenic sources.

The problems identified during the work-up of samples for GC/MS analysis will be addressed through an intercalibration/interprocedural analysis on the additional hydrocarbon samples taken for this purpose during the survey.

At two stations the vertical distribution of hydrocarbons in the sediments was analysed. At Station 10 no change in hydrocarbons with depth was indicated. At Station 8 a slight reduction in THC and a relative increase in biogenic alkane compounds with increasing depth were indicated, but no change in aromatic content.

The results from the trace metal analysis indicated background levels for most elements. Comparison with other noncontaminated sediments where the bioavailable metal content has been determined, verified this suggestion.

The mean content of barium ranged from 65 (Station 24) to 543 (Station 4) mg/kg with an average of 160 ± 80 mg/kg. For one subsample from Station 4 the barium content was 1200 mg/kg. The position of Station 4 in the vicinity of an exploratory well indicated slight contamination from the drilling activity. No indication of contamination at this site was, however, observed for any other element or chemical parameter analysed.

The low barium level at the reference site (Station 24) may reflect natural variability in sediment composition, and should be noted when the limit of significant barium contamination is discussed in future monitoring surveys. Except for this observation, no evidence of zonation within the survey area was present.

For all the remaining metal species no evidence of high concentration zones within the survey area was present. Mercury was not detected in any of the subsamples.

The results were used to define the limits of significant contamination (LSC) for future monitoring surveys. The LSC's from the present very comprehensive Heidrun data material generally showed good to fair agreement with other baseline surveys where similar analytical techniques have been employed.

The low correlation between TOC and the results from the two THC analyses (IR and GC-FID) verified the suggestion of the survey area as being a nonpolluted homogeneous field. The cross-correlation of heavy metal concentrations gave the same result as for TOC and THC. No significant correlation between any of the elements was observed, i.e. no evidence of zonation was present. Correlation of the organic and the inorganic chemical parameters gave similar results. In conclusion, the sediment samples collected in the present survey represented an homogeneous, nondisturbed seabed.

4.3 Biological characterization

A total of 273 macrofauna taxa (species or higher groups) were found in the samples of which 252 were recorded quantitatively, the others only on the basis of presence/absence. The number of taxa of animals larger than 0.5 mm ranged from 71 (Station 20) to 109 (Station 12) with an average of 90. The number of taxa retained on the 1 mm screen was 56-89 % of the total number retained on both screens.

At station 24 the number of taxa sampled from 0.5 m^2 of the seabed was 87 % of the number retrieved from 0.8 m^2. The species-area curve did not level out at 0.8 m^2, suggesting that further effort could have produced several new taxa, and might have been justified.

Total individual densities ranged from 570 per m^2 at Station 21 to 1628 at Station 3, with a mean of 976 ind/m^2. Of the individuals recovered, 20-62 % had passed through the 1 mm screen.

There was no convincing trend in the distribution of species richness or total individual density across the survey area, but total densities correlated positively with number of taxa.

The indices reflecting community diversity all showed that the benthic communities in the area were remarkably diverse and uniform. Shannon-Wiener diversity Hs ranged from 5.47 (Station 5) to 5.93 (Station 12). Diversity of fauna larger than 1 mm was in the range 4.93-5.58, and always less than the corresponding total fauna diversity. This showed that the fauna fraction between 0.5 and 1 mm produced not only more small individuals of already recorded species, but also a substantial number of new taxa. Also the Brillouin index of diversity Hb attained values above 5 for all stations (Tab. 7.3.1). The correlation beween the two indices was strong (Tab. 7.3.5).

The Hurlbert rarefaction diversity curves were all within an extremely narrow range, and classified all stations as highly diverse. The expected number of species per 100 individuals (ES_{100}) ranged from 43.33 (Station 12) to 49.07 (Station 15) for the total fauna, which are among the highest ES_{100} values ever recorded in a soft bottom community. The range in ES_{100} for the fraction larger than 1 mm was slightly less, 36.49-46.03, but still higher than has been found in clean coastal and fjord communities along the coast of Norway.

Dominance was in general low with Simpson index values in the range 0.023-0.035. Evenness was reasonably high both by Pielou's (0.86-0.90) and Heip's index (0.51-0.66). Neither of these indices correlated significantly with the diversity indices Hs, Hb or ES_{100}, suggesting that diversity was primarily a function of species richness. There was no sign of any gradient in any of these community measures across the survey area.

The distribution of species upon the individuals for each station showed good agreement with the theoretical log-normal distribution, and gave no indication of any stations being disturbed.

The ten most abundant species of each station always contained less than 50% of the individuals, reflecting the generally low dominance in the area. A total of 34 taxa were listed among the ten most abundant species, but only 12 occurred on the list at ten or more stations. 7 of these were polychaetes. The most frequently occurring species, the polychaete *Spiophanes kroeyeri*, was on the top ten list at 20 stations only. The even distribution caused small differences in abundance to lead to large changes in ranking of the taxa.

None of the more commonly occurring species showed any strong gradients across the survey area, or any trends in the distribution which convincingly could be linked to any disturbance from the earlier exploratory drilling operations. The dominants comprised species which are known to be sensitive to environmental disturbance, such as the polychaetes *Spiophanes kroeyeri* and *Paramphinome jeffreysi*, and the amphipod *Harpinia pectinata*, as well as species which prosper under such conditions primarily the opportunistic polychaete *Chaetozone setosa*. The latter species had densities ranging from 3 to 49 ind./0.5 m^2 which is comparable to densities found in North Sea baseline studies, and far below densities found at polluted sites. The distribution of *C. setosa* indicated highest densities in the western region around the EPS position, but not in any close relation to the sites of earlier drilling activities. The sipunculan *Golfingia* sp. cf. *minuta* and the two dominant crustaceans *Harpinia pectinata* and *Polycope punctata* had comparable distribution with a slight reduction in the SW direction from EPS, whereas the molluscs *Thyasira pygmaea*, *Limopsis minuta*, *Abra longicallus*, and *Cadulus propinquus* all showed reduced densities at the reference site and highest densities in the centre of the survey area. None of these trends were strong.

The MDS ordination and the cluster analysis gave different groupings of the stations. In the MDS analysis based on the fauna >0.5 mm three groups of stations could be defined with some confidence. These showed a slight SW to NE gradient in fauna similarity and slightly higher heterogeneity in the SW region. The MDS analysis on basis of the >1 mm fraction of the fauna gave essentially the same conclusion. The cluster analysis on the basis of the total fauna showed that all stations were very similar. Some grouping could be defined, but these did not correspond to the MDS groups, nor to any gradient across the Heidrun field. The cluster analysis on the basis of >1 mm fraction also showed great overall station similarity. The station groups that could be defined with any confidence did not correspond to those of the >0.5 mm cluster analysis or the >1 mm MDS groups, and did not reflect any systematic geographical pattern in the survey area. Still all analyses linked together a set of stations: 4, 18, 19, and 25, all except Station 18 being in the centre of the field. They also defined stations 2, 5, 8, and 11 as somewhat atypic, probably for different reasons. Also the reference station 24 was more or less separated from the other stations in these analyses.

Analysis of the sediment characteristics of the station groups defined by the MDS analysis, showed that the silt/clay content differed significantly. This suggested that the SW to NE gradient in fauna similarity was at least partly a function of grain size. The outlying position of the reference Station 24 in the MDS plots was partly explained by the high silt/clay content of the sediments, but the results suggested that distance and greater water depth also separated the reference fauna structure from that of the other stations. The overall results showed that the fauna diversity correlated negatively with % silt/clay.

The correlation of community indices between the total fauna >0.5 mm and the fraction >1 mm was in general positive and significant. Diversity decreased and dominance increased when removing the fraction below 1 mm, but evenness did not change. There was also a 30-90 % similarity in ten top ranked species between the >0.5 mm and the >1 mm fraction. For the MDS analysis there was a good correspondence in station grouping based on the two fractions and both indicated a slight gradient in fauna composition and homogeneity from SW to NE. The cluster analysis gave different groupings, but none of them reflected any convincing systematic trend across the Heidrun area.

The general impression of the fauna: homogenous, high diversity, high evenness, low dominance, and possibly a slight SW to NE gradient, could be concluded on basis of the >1 mm fauna alone, but the smaller fraction contained a range of new species and increased the total diversity, and the two together therefore gives a clearly better baseline for comparison with future surveys than the >1 mm alone.

The Heidrun macrofauna had a narrower range in species richness, density, and diversity than that recorded for the whole of the

Haltenbanken in 1985, but the mean richness and densities were similar. The mean diversity was higher at Heidrun than at Haltenbanken as a whole. At directly comparable stations in the Heidrun area these indices were clearly higher in 1988 than in 1985, some of which is ascribed to procedural differences. Comparison with the baseline conditions at Statfjord and Gullfaks fields is hampered by differences in depth and sediment conditions, primarily causing different species compositions. The general impression is that the Heidrun fauna had lower species richness and density of individuals than the more shallow Statfjord area, but diversity was higher. The Gullfaks field had about the same species richness, but 3 times the individual densities. Still diversity was only slightly lower at Gullfaks than at Heidrun. Comparison with recent baseline surveys in the central North Sea (Gyda and Tommeliten fields) showed that the Heidrun area in general had higher numbers of taxa, slightly lower individual densities, and higher diversity than in the central North Sea.

UTFYLLENDE SAMMENDRAG

Konklusjoner

Havbunnssedimentene i Heidrunområdet var godt oksygenerte og ble klassifisert som 'meget fin sand' med innhold av silt/leire på 26-64 %. Gjennomsnittlig organisk innhold var 0.52 %.

Nivået av totalhydrokarboner (THC) var homogent og lå i området 1-10 mg/kg tørt sediment etter IR-analysen og 0.8-9 mg/kg etter GC/FID-analysen. NPD-innholdet lå mellom 3.7 og 30 µg/kg tørrvekt etter GC/MS-analysen. Dette er på nivå med bakgrunnsverdier fra andre lokaliteter. Bicyclaner, som indikerer forekomst av oljebaserte borevæsker, ble ikke påvist. Den relative sammensetning av normal-alkaner og av aromater indikerte at hydrokarbonene vesentlig var av biogen opprinnelse. Vertikalfordelingen av hydrokarboner i sedimentet på to stasjoner indikerte svak reduksjon med dyp på den ene, og ingen endring med dyp på den andre.

Det var intet tegn på forhøyet nivå av tungmetaller på noen stasjoner, med unntak av bariuminnholdet i en delprøve tatt nær leteboringsbrønn 6507/7-4, målt til 1200 mg/kg mot 58-410 mg/kg i alle de øvrige prøver fra Heidrunområdet. Dette kan indikere lokal kontaminering av borekaks. Nivåene av de ulike kjemiske parametre var ikke korrelert, noe som viser at Heidrunfeltet som sådan hadde et homogent, rent sediment.

Heidrunfeltets makrofauna-samfunn var homogent, og artsmangfoldet (diversiteten) var blant det høyeste som noen gang er målt rundt offshoreinstallasjoner. Ingen tegn til miljøforstyrrelse ble registrert. Det var en svak gradient i faunasammensetning fra sørvest til nordøst over feltet, delvis som funksjon av sedimentets kornstørrelse.

Den fysiske, kjemiske og biologiske homogenitet i sedimentene bør gi et godt utgangspunkt for å kunne påvise selv små miljøendringer som følge av den fremtidige feltutbyggingen på Heidrun. På bakgrunn av resultatene er fortsatt bruk av 0.5 mm sikt for analyse av makrofauna anbefalt.

1. Innledning

Rapporten beskriver resultatene fra basisundersøkelsen av havbunns-sedimentene rundt olje- og gassfeltet Heidrun, Haltenbanken. Undersøkelsen er utført for Conoco Norway Inc. (CNI) (Kontrakt nr

GE-139) av Norsk Institutt for vannforskning i samarbeid med Institutt for Kontinentalsokkelundersøkelser, IKU, Trondheim; OCEANOR A/S, Trondheim; Nordisk Analyse Center A/S, Oslo; og GEORGE A/S, Trondheim.

Formålet var å etablere miljøkunnskapsgrunnlag for sammenlikning med fremtidige regelmessige overvåkings-undersøkelser, og på en slik måte at resultatene også kunne sammenlignes med forholdene på andre utvinnings-felter. Undersøkelsen skulle gi en kvalitativ og kvantitativ beskrivelse av områdets bløtbunnsfauna, sedimentets fysiske karakter, og nivå av de sentrale organiske og uorganiske sporelementer i overflatesedimentene, samt definere eventuelle mønstre i datamaterialet.

Undersøkelsen er gjennomført i perioden juni 1988 til januar 1989.

2. Forkortet toktrapport.

Feltarbeidet ble utført i perioden 22-28 juni 1988 ved bruk av m/s "Svanaug Elise". Skipet var på plass på Heidrunfeltet 23 juni og etter kalibrering av posisjoneringsutstyret (ARGO) mot GPS satelliter startet prøveinnsamlingen kl 1957. Innsamling ble gjort på 25 stasjoner fordelt rundt posisjonene for den fremtidige plattform for tidlig produksjon (EPS) og for den permanente plattformen på Heidrun-feltet. Stasjonenes posisjon er vist på Fig. 4.1 i hovedrapporten og viktige data om stasjonene er gitt i Tabell 4.1. Innsamling ble avsluttet 27 juni kl 0645 og avvikling av toktet var fullført 28 juni kl 1200 i Trondheim.

2.1. Standard prøveinnsamlingsprogram.

Det standardiserte innsamlingsprogram på hver stasjon var følgende:

- fem grabbprøver med en 0.1 m^2 Van Veen grabb godkjent dersom de ikke viste tegn til utvasking av sedimentet og hadde et prøvevolum på minimum 10 liter. Hver prøve ble siktet på 1 og 0.5 mm sikt og fiksert med formalin for analyse av bløtbunns makrofauna.

- tre sedimentprøver tatt med en 0.1 m^2 Smøgen bokscorer (kjerneprøvetaker) godkjent dersom sedimentoverflaten ikke viste tegn til forstyrrelse, og dersom prøvetykkelsen var større enn tykkelsen på sedimentets oksyderte toppsjikt (5-7 cm). Fra hver av disse ble det tatt 6 delprøver fra øverste 1-2 cm for analyse av kornstørrelsesfordeling (en delprøve), innhold av organisk materiale (en delprøve), hydrokarboner (to delprøver) og tungmetaller (to delprøver).

- direkte analyse av redoksforhold (Eh) i 2 cm dyp i sedimentet fra en av bokscorerprøvene, og beskrivelse av bunnmaterialets farge og utseende.

2.2. Ekstra prøver

På referansestasjonen nr. 24 ble det tatt 3 ekstra grabbprøver for fauna-analyse, dvs. totalt 8 prøver, for å fastslå forholdet mellom prøveareal og antall arter funnet. På stasjonene 8 og 10 ble to ekstra bokscorer-prøver tatt for analyse av hydrokarbonenes vertikale fordeling i sedimentet. På de samme to stasjonene ble også seks delprøver tatt fra hver av tre ekstra bokscorer-prøver for interkalibrering av hydrokarbon-analysene.

2.3. Dokumentasjon og prøvebehandling.

Volumet av grabbprøvene ble målt til nærmeste halvliter, og prøven ble overført til spylebord og forsiktig vasket ut med sjøvann gjennom to sikter med runde hull, henholdsvis 1 mm og 0.5 mm i diameter. Delprøvene fra de to siktene ble fiksert separat i formalin tilsatt fagestoffet bengalrosa. Hver av de fem grabbprøvene fra hver stasjon ga derved to prøver klar til videre behandling.

Bokscorer-prøvene ble overført til et plastfat for bestemmelse av overflatefarge (Munsell fargekode), tykkelse og utseende. Delprøvene for analyse av kornstørrelsesfordeling og organisk innhold ble tatt med stålspatel og frosset i plastposer. Delprøvene for hydrokarbon-analyse ble tatt med Teflonspatel og pakket i renset Al- folie og deretter frosset. Delprøvene for metallanalyse ble også tatt med stålspatel og frosset i syrevaskede plastflasker.

2.4. Posisjonering

Hovedposisjoneringssystemet for navigering og for å holde stasjonen ved innsamling var ARGO link-systemet med avlesning av kystsendere på Skomvær, Træna, Sklinna og Slettringen. Kalibrering av ARGO-kjeden ble gjort ved kalibrering mot GPS satellitsignaler i en periode med satellitpassering 23 juni. Ansvar for posisjoneringen ombord lå hos firmaet North Sea Navigation A/S, Haugesund. For hver GPS avlesningsperiode ble ARGO-posisjonen kontrollert mot satellitsignaler. Ved innsamling ble skipets posisjon avlest hver gang prøvetakeren tok bunnen, og dato, tid og UTM koordinater ble notert.

3. Analysemetoder

Kornstørrelsesfordeling ble analysert ved kombinert tørrsikting i størrelsesfraksjoner over 63µm, og ved bruk av partikkelteller på materialet under denne størrelse ned til 2µm.

Redokspotensialet på 2 cm sedimentdyp ble målt ved bruk av platinaelektrode (kalomel referanseelektrode og standard Zobell elektrolyttløsning). Instrumentet ble etterkalibrert mot referanseinstrument på laboratoriet etter fullført tokt og avlesningsverdiene justert etter dette.

Totalt innhold av organisk materiale ble analysert ved glødetap etter behandling med saltsyre.

Oversiktsanalyse av totalmengde hydrokarboner ble gjort på diklormetan(DCM)-ekstrakt av sedimentet. Etter inndamping av ekstraktet og oppløsning i karbontetraklorid ble analysen utført ved infrarød (IR) deteksjon.

Analyse av totalhydrokarboner (THC) ble gjort etter soxhletekstraksjon med metanol og DCM ved bruk av interne standarder. Metanolen ble videre ekstrahert med pentan og det kombinerte pentan-DCM ekstraktet delt i to. En av delene ble analysert ved bruk av gasskromatografi (GC/FID) for THC. Den andre delen ble splittet i alifatisk og aromatisk fraksjon og disse ble hver for seg analysert for utvalgte hydrokarboner ved bruk av gasskromatografimassespektrometri (GC/MS).

Analyse av tungmetaller ble gjort på syrekstrakter av sedimentet etter behandling med HNO_3. Metallene Ba, Sr, Pb, Cr, Cu, Fe, Ni, V, og Zn ble analysert ved bruk av 'inductive coupled plasma atomic emission spectrometry' (ICP-AES), elementene Cd, Cu, Pb, og Cr også ved 'electrothermal atomic adsorption spectrometry' (EEA) analyse, og Hg ved kald-damp teknikk.

All makrofauna ble sortert ut fra sedimentet under disseksjonsmikroskop, identifisert og tellet opp. Artslister med tettheter ble brukt til beregning av følgende samfunnsparametre for hver stasjon: antall arter, indeks for artsrikhet, total individtetthet, indekser og kurver for artsmangfold (diversitet), forventet antall arter pr 100 individer, indekser for dominans og jevnhet, lister over de 10 mest dominante arter pr stasjon rangert etter % forekomst, kurver over antall arter som funksjon av prøveareal, og samsvar med log-normal fordeling av arter på individer. Multivariatanalyse (multidimensional scaling (MDS) ordinering og cluster-analyse) ble brukt for å gruppere stasjonene etter likheter i fauna, og korrelasjonen mellom de ulike fauna- og sedimentparametre ble testet. Disse analysene ble gjort på totalmaterialet og på faunafraksjonen over 1 mm størrelse separat.

4. Hovedresultater

4.1. Sedimentkarakteristikk

Midlere kornstørrelse uttrykt ved Φ (phi)-middelverdi varierte fra 2.785 (fin sand) på Stasjon 11 til 4.638 (grov silt) på Stajon 10. Analysen viste en forfordeling av størrelsesspekteret mot det finkornige. Dette gjenspeilte seg i høyt innhold av silt/leire eller "mudder" som varierte fra 25.6 til 64 %, gjennomsnittlig 44.1 %. Det var en tendens til lavere middelkornstørrelse mot nord i feltet, noe som antakelig gjenspeilte den svake hellingen mot dypere bunn nord for Heidrun. Andelen silt/leire øket også mot nordøst.

Gjennomsnittlig redokspotensial (Eh) var +456 mV med variasjon fra +363 mV på Stasjon 6 til +529 mV på Stasjon 13. Verdiene er typiske for rikt oksygenerte sedimenter, og de viste intet mønster i variasjon over feltet.

4.2. Kjemisk karakterisering.

Resultatene fra TOC analysene varierte mellom 0.44 % (Stasjon 21) og 0.63 % (Stasjon 5) og med gjennomsnitt 0.52 ± 0.047 %. Det var ingen signifikant forskjell i gjennomsnittlig TOC-nivå mellom østlig og vestlig del av feltet.

THC-nivået målt ved IR varierte mellom 1.0 og 10 mg/kg tørt sediment, med middelverdi 4.9 ± 2.5 mg/kg. Disse nivåer er typiske for uforurensede sedimenter av denne type, og de samsvarte godt med tidligere data fra Haltenbanken (IKU 1986). Gjennomsnittsnivået rundt EPS var noe lavere enn nivået i retninger ut fra plattformposisjonen, men området ble likevel betraktet som homogent i THC-nivå etter IR-analysen.

THC-nivået i enkeltprøver analysert ved GC/FID varierte fra 0.80 (Stasjon 8) til 8.99 (Stasjon 22) mg/kg tørt sediment, med gjennomsnitt for feltet på 2.92 ± 1.35 mg/kg. Resultatene tilsvarte bakgrunnsnivå i sedimenter fra Nordsjøen i tidligere undersøkelser. Gjennomsnittlig nivå av THC rundt EPS og plattformposisjonen ble betraktet som like. Kromatogrammene bekreftet at innsamlingsområdet var homogent i sammensetningen av THC.

Konsentrasjonen av normal-alkaner i området C_{12}-C_{35} fra GC/FID ananlysene tilsvarte bakgrunnskonsentrasjoner funnet i Nordsjøen, men lå noe lavt. Alkan-sammensetningen indikerte overveiende biogen tilførsel.

Konsentrasjonen av isoprene hydrokarboner (pristan og phytan) viste ingen klare endringer over Heidrunfeltet og lå på nivå med bakgrunnsverdier funnet i Nordsjøen. En noe lav konsentrasjon av pristan i forhold til phytan kunne indikere petrogen tilførsel av hydrokarboner, men dette ble ikke støttet av sammensetningen av normal-alkaner og aromater.

Forekomst av bicyclaner, som indikerer oljebaserte borevæsker, ble ikke påvist i noen av prøvene.

NPD-konsentrasjonene lå i intervallet 3.7-30 µg/kg tørrvekt, som er innefor normalområdet for rene sedimenter. Konsentrasjonene var noe lave i forhold til bakgrunnsverdier fra Nordsjø-sedimenter, sannsynligvis på grunn av et tap av naftalen gjennom fordampning under opparbeidelsesprosedyren. Fenantren og dibenzothiofen var på samme nivå som i grunnlagsundersøkelsen på Haltenbanken, 1985. Konsentrasjonen av aromater med 4 til 6 ringer lå noe høyt i forhold til normalt bakgrunnsintervall i Nordsjøen. Total PAH(polyaromatiske hydrokarboner)-sammensetning indikerte ingen innflytelse fra petrogene kilder.

De fordampnings-problemer man støtte på under opparbeidelsen av prøvene for GC/MS analyse vil bli nærmere belyst i et interkalibrerings-eksperiment utført på de tilleggsprøvene som ble tatt for dette formål under toktet.

På to av stasjonene ble vertikalfordelingen av hydrokarboner i sedimentets øvre 0-6 cm analysert. På Stasjon 10 fantes ingen endring i mengder eller sammensetning med dyp. På Stasjon 8 var det en svak reduksjon i THC med sedimentdyp og relativ økning i innslag av biogene alkaner. Aromatsammensetningen endret seg ikke nedover i sedimentet.

Resultatene fra tungmetall-analysene indikerte at de fleste elementer lå på bakgrunnsnivå. Sammenlikning med andre rene sedimenter der innholdet av biotilgjengelige metaller er målt, bekreftet dette.

Gjennomsnittsinnholdet av barium varierte fra 65 (Stasjon 24) til 543 (Stasjon 4) mg/kg med gjennomsnitt for hele området på 160 ± 80 mg/kg. I en av delprøvene fra Stasjon 4 var bariuminnholdet 1200 mg/kg. Plasseringen av Stasjon 4 like i nærheten av posisjonen for en av letebrønnene (6507/7-4) indikerte en kontaminering fra boreaktiviteten. Ingen av de andre kjemiske parametre målt på stasjonen indikerte imidlertid noen kontaminering.

Bariuminnholdet på referansestasjonen (Stasjon 24) var meget lavt. Dette reflekterer sannsynligvis en naturlig variasjon i sedimentkarakter, noe man bør ha i tankene når grensen for signifikant kontaminering diskuteres i den fremtidige overvåking. Med unntak av denne observasjon var det ikke tegn til noen barium-sonering i Heidrun-området.

For alle de øvrige tungmetallene var det ikke tegn til høye konsentrasjoner i noen del av undersøkelsesområdet. Kvikksølv ble ikke påvist i det hele tatt i noen av prøvene.

Resultatene ble brukt til å definere grense for signifikant kontaminering (LSC) for hver kjemisk parameter til bruk i fremtidig overvåking. LSC-verdiene fra det meget omfattende materialet fra Heidrun viste godt til rimelig godt samsvar med verdier fra andre sammenlignbare basisundersøkelser.

Den lave korrelasjonen mellom TOC og de to analyser av THC bekreftet intrykket av undersøkelsesområdet som et uforurenset homogent område. det samme gjaldt for innbyrdes korrelasjon mellom metallene og korrelasjon mellom de organiske og uorganiske kjemiparametre. Som konklusjon hevdes at sedimentprøvene tatt i denne undersøkelsen representerer en homogen og uforstyrret havbunn.

4.3. Biologisk karakteristikk

Totalt 273 taxa (arter, evt. høyere grupper der art ikke kunne identifiseres) av makrofauna ble funnet i materialet. Av disse kunne 252 taxa registreres kvantitativt, de øvrige bare som tilstedeværende. Totalt antall taxa funnet pr stasjon varierte fra 71 (Stasjon 20) til 109 (Stasjon 12) med gjennomsnittlig 90 taxa pr stasjon. Antallet taxa funnet på 1 mm sikten var 56-89 % av det totale antall på en stasjon.

På Stasjon 24, der 8 grabbprøver ble tatt, var antallet taxa funnet i de første 5 grabbprøvene 87 % av totalantallet på de 8 prøvene. Kurven over kumulativ økning i antall arter med areal flatet ikke tydelig ut etter 8 grabbprøver, og dette indikerer at ytterligere prøver ville frembragt flere nye arter, og derfor muligens hadde vært berettiget.

Individtettheten varierte fra 570 ind/m^2 på Stasjon 21 til 1628 ind/m^2 på Stasjon 3, gjennomsnittlig 976 ind/m^2. Fra 20 til 62 % av individene passerte 1 mm sikten.

Det var ikke noen overbevisende tendens i utbredelsen av artsrikhet eller total tetthet i undersøkelsesområdet, men de to faunaparametrene var klart positivt korrelert.

Indekser for artsmangfold (diversitet) viste alle at bløtbunnssamfunnet i området var bemerkelsesverdig homogent og mangfoldig. Shannon-Wiener indeks Hs for artsmangfold varierte fra 5.47 (Stasjon 5) til 5.93 (Stasjon 12). Artsmangfold for fauna-fraksjonen større enn 1 mm varierte fra 4.93 til 5.58,og var alltid lavere enn totalt artsmangfold. Dette viser at faunafraksjonen mellom 0.5 og 1 mm frembragte ikke bare små individer av arter som ble holdt igjen på 1 mm sikten, men også et betydelig antall nye arter. Også Brillouins indeks for artsmangfold Hb antok verdier over 5 på alle stasjoner, og korrelasjonen mellom disse to indekser var klart positiv.

Kurver over artsmangfold (Hurlbert) lå for samtlige stasjoner innenfor meget snevre grenser og klassifiserte alle stasjonene som meget mangfoldige. Forventet antall arter pr 100 individer (ES_{100}) større enn 0.5 mm varierte fra 43.33 (Stasjon 12) til 49.07 (Stasjon 15), som er blant de høyeste verdier noen gang målt i et marint bløtbunnssamfunn. ES_{100} verdiene for faunafraksjonen over 1 mm lå noe lavere, fra 36.49 til 46.03, men dette er også høyere enn hva som er funnet i rene kyst og fjordsamfunn på Norskekysten.

Dominansen i faunasamfunnet var generelt lav med Simpson indeksverdi i området 0.022-0.035. Jevnhet var relativt høy både etter Pielous (0.86-0.90) og Heips (0.51-0.66) indekser. Hverken dominans eller jevnhet var korrelert med indeksene for artsmangfold, noe som indikerer at artsmangfoldet i første rekke var funksjon av artsrikhet, og ikke av fordeling av individene på artene. Materialet indikerte ingen gradienter i noen av parametrene for artsmangfold.

Fordelingen av artene etter antall individer på hver stasjon viste rimelig god tilpasning til en teoretisk log-normal fordeling, og ga ikke mistanke om miljøforstyrrelse på noen av stasjonene.

De ti vanligste artene på hver stasjon utgjorde aldri over 50 % av total tetthet, noe som gjenspeiler faunasamfunnets store jevnhet. Totalt 34 taxa forekom på listene over de ti vanligste, men bare 12 av disse var på listen på 10 eller flere stasjoner, og 7 av disse artene var børstemark. Den vanligste arten, børstemarken Spiophanes kroeyeri forekom på listen på bare 20 av de 25 stasjonene. Materialet viste at bare små endringer i tetthet kunne forårsake store forandringer i artenes rangering.

Ingen av de vanlige artene i området viste noen klare gradienter eller andre mønster i utbredelse som kunne knyttes til eventuell belastning fra tidligere boreaktivitet. Blant artene forekom slike som var kjent for å være følsomme for miljøforstyrrelser, f.eks. børstemarkene Spiophanes kroeyeri og Paramphinome jeffreysi og krepsdyret Harpinia pectinata, men også arter som favoriseres av slike forhold, først og fremst børstemarken Chaetozone setosa. Denne arten forekom i tettheter på mellom 3 og 40 ind/0.5 m^2 som er på nivå med tettheter funnet ved basisundersøkelser i Nordsjøen, og langt lavere enn tettheter som er blitt registrert på forurensede lokaliteter. Utbredelsen av C. setosa viste høyest tetthet i de vestlige områder rundt EPS, men ikke sammenfallende med posisjon for tidligere boreaktivitet på feltet.

Utbredelsen av sipunkuliden Golfingia sp. cf. minuta og de to mest vanlige krepsdyrartene Harpinia pectinata og Polycope punctata hadde sammenfallende mønster, med reduksjon i tettheten sørvest for EPS. Muslingene Thyasira pygmaea, Limopsis minuta og Abra longicallus og sjøtannen Cadulus propinquus viste alle sammen lavest tetthet på referanselokaliteten og høyest i sentrum av undersøkelsesområdet. Ingen av disse tendensene i utbredelse var særlig sterke.

De to multivariat-teknikkene benyttet ga forskjellig gruppering av stasjonene. I ordinasjonsanalysen (MDS) basert på samtlige dyr kunne man definere tre noenlunde gyldige grupper i to dimensjoner. Disse ble gjenfunnet i retning fra sørvest til nordøst i Heidrunfeltet og indikerte derfor en gradient i faunasammensetning i denne retning. Videre indikerte analysen at faunaen i feltets sørvestlige del var noe mer heterogen enn mot nordvest. MDS-analysen basert på faunafraksjonen over 1 mm ga samme resultat. Cluster-analysen basert på samtlige dyr viste i utgangspunktet at likheten mellom samtlige stasjoner var stor. Enkelte grupper av stasjoner kunne defineres, men disse samsvarte ikke med grupperingen fra MDS-analysen, heller ikke med noen entydig geografisk stasjonsgruppering i området. Cluster-analysen på basis av faunafraksjonen større enn 1 mm viste også stor generell likhet. De stasjonsgruppene som her kunne defineres samsvarte ikke med cluster-analysen på basis av totalfaunaen, heller ikke med MDS-analysen på 1 mm fraksjonen. Heller ikke her avspeilte grupperingen noe geografisk mønster. Mye tyder på at cluster-analysen på et såvidt homogent materiale påtvinger datasettet grupperinger som ikke er pålitelige. Enkelte fellestrekk i analysene fantes dog. En liten gruppe av stasjoner: 4, 18, 19, og 25 forekom alltid sammen i gruppene. Med unntak av Stasjon 18 ligger disse i sentrum av feltet. Videre ble stasjonene 2, 5, 8 og 11 konsekvent holdt utenfor gruppering, og var derfor noe atypisk i faunasammensetning, antakelig av forskjellige grunner for de forskjellige stasjoners vedkommende. Referansestasjon 24 ble også mer eller mindre klart separert fra de andre stasjonene i disse analysene.

En vurdering av sedimentforhold innen stasjonsgruppene definert i MDS analysene viste at innholdet av silt/leire var signifikant forskjellig. Dette antydet at gradienten i faunasammensetning fra sørvest til nordøst iallfall delvis var funksjon av kornstørrelse. Utskillelsen av referansestasjon 24 i MDS-plottene, kunne delvis forklares ut fra stasjonens høye innhold av silt/leire, men resultatene indikerte også at geografisk avstand og større vanndyp kunne være medvirkende årsaker til et skille mellom referansefaunaen og den øvrige fauna. Resultatene totalt sett viste videre at artsmangfoldet var negativt korrelert med % silt/leire.

Korrelasjonen mellom totalfauna og fraksjonen over 1 mm størrelse m.h.t. samfunnsparametre var jevnt over positiv og signifikant. Artsmangfold minket og dominans øket noe når dyr mindre enn 1 mm ble utelatt fra analysen. Jevnhet forandret seg ikke. Likheten i sammensetning av de 10 mest vanlige artene var fra 30 til 90 %. Grupperingen av stasjoner ved MDS-analyse samsvarte godt, mens cluster-analysen ga klart forskjellig gruppering basert på totalfauna og fraksjonen over 1 mm.

Det generell intrykket av en homogen fauna med høyt artsmangfold, høy jevnhet, lav dominans og en svak gradient i sammensetning fra sørvest til nordøst fikk man av fraksjonen over 1 mm alene. Likevel inneholdt fraksjonen under 1 mm en rekke nye arter og øket det totale artsmangfold, og de to fraksjonene tilsammen gir derfor klart bedre utgangpunkt for påvisning av senere endringer enn fraksjonen over 1 mm alene.

Bløtbunnsfaunaen på Heidrun-feltet hadde smalere spennvidde i artsrikhet, tetthet og artsmangfold enn hva som ble registrert på

Haltenbanken som helhet i grunnlagsundersøkelsen av 1985, men gjennomsnittlig artsrikhet og tetthet var den samme. Gjennomsnittlig nivå av artsmangfold var høyere på Heidrun enn på Haltenbaken som helhet. På de stasjoner som direkte kunne sammenlignes med 1985-undersøkelsen (Stasjon 3 og 24) var disse indekser klart høyere i 1988, men noe av dette må tilskrives forskjeller i undersøkelses-teknikk. Sammmenligning med bakgrunnsforhold på Statfjord- og Gullfaksfeltet er vanskelig på grunn av stor forskjell i vanndyp og sedimenttype, noe som gir forskjellig faunasammensetning. Det generelle inntrykk er at faunaen i Heidrunområdet hadde lavere artsrikhet og individ-tetthet enn i det grunnere Statfjordområdet, men at artsmangfoldet var høyere. Gullfaksfeltet hadde omtrent samme artsrikhet, men tre ganger så høye tettheter som Heidrunfeltet. Likevel var artsmangfoldet bare svakt lavere på Gullfaks. Sammenligning med nyere basisundersøkelser i den midtre del av Nordsjøen (feltene Gyda og Tommeliten) viste at Heidrunfeltet jevnt over hadde høyere artsrikhet, lavere tettheter og høyere artsmangfold enn i den sentrale del av Nordsjøen.

FULL REPORT

CONTENTS

1. INTRODUCTION

This report describes results of the 'baseline' pre-operational environmental survey of the physical, chemical and biological conditions in the sea bottom sediments of the Heidrun oil and gas field at Haltenbanken, Mid-Norway. The survey was conducted on behalf of Conoco Norway Inc. (CNI) (Contract Agreement no GE-139) by the Norwegian Institute for Water Research (NIVA) in cooperation with the following research institutes and consultants:

* Continental Shelf and Petroleum Technology Institute IKU, Trondheim;
* Oceanographic Company of Norway A/S OCEANOR, Trondheim;
* Nordic Analytical Center A/S, Oslo;
* GEORGE A/S, Trondheim.

The objective of the survey was presented by CNI as:

'The marine environment in the vicinity of the proposed Heidrun installations will be monitored to ensure that the Project activities do not cause unneccessary damage to the environment. The objective of this Contract is to establish the baseline for regular surveys and is to be performed in such a way as to allow comparison with results from other fields.'

More specifically the survey should provide a qualitative and quantitative description of the seabed fauna, the sediment physical characteristics, and the content of major organic and inorganic trace elements of the surficial sediments. One should also define and interpret any distribution and other patterns present in the data and possible correlations between physical, chemical and biological features of the seabed. A detailed description of the work to be performed was presented to NIVA by CNI as part of the Contract.

NIVA has been acting as primary contractor and coordinator of the work, and has been responsible for fauna analysis and reporting and for final report preparation. IKU has been responsible for the analysis of organic trace elements, NAC for analysis of the metal elements, and IKU has prepared the subreport for all the chemical analyses. GEORGE has been responsible for coordination of the sampling survey and for reporting of the physical analysis of the sediments. OCEANOR has been responsible for sorting of the fauna samples, for computer analysis of fauna data and partly for species identification (polychaetes).

The work has been performed in the period June 1988 to January 1989.

2. BASIC SEDIMENTOLOGY AND OCEANOGRAPHY

2.1. Topographical setting of the investigated area.

The Heidrun field, situated in block NOR 6507/7, lies about 100 km NW of the shallowest part of Haltenbanken. The western area of Haltenbanken has a fairly gentle topography with waterdepths between 200 and 300 m. The Heidrun field lies in the northern part of this submarine plain. North, east and west of Heidrun the submarine topography is more varied with ridges and troughs. Along the shelf edge to the west of Heidrun lies the southern end of a major terminal moraine system called Skjoldryggen.

The Heidrun field lies on the southern slope of a wide trough, reaching depths of more than 400 m about 5.5 km north of the field. This has sheltered the area from the most severe reworking of surface sediments by icebergs during the later stages of the last glaciation. Icebergs calving within the area made up of the depression may however have grounded and ploughed the sea floor.

The existence of a terminal moraine system along the outer shelf edge is one of the many proofs that the entire continental shelf was glaciated at least once, and the submarine topography of ridges and troughs is the result of the ice sheet's capacity to erode, retransport and deposit large volumes of sediments regardless of grain size and without a gravity-controlled tendency to fill in depressions.

2.2. Marine geology of the investigated area

Geological investigations of the Norwegian continental margin have been undertaken by IKU as a part of a regional mapping program. The results of this survey between latitudes 63^{0}N and 65^{0}N has been summarised by Bugge (1980) and a series of geological maps showing the distribution of seafloor sediments, the Quaternary geology and bedrock geology has been published by IKU. A detailed account of grain-size characteristics of the surface sediments in the Haltenbanken area is given by Holtedahl and Bjerkli (1982). Although these reports describe the marine geology somewhat south of the Heidrun field, there is no evidence to indicate that the origin, the depositional environment or the post-depositional history of the sediments at Heidrun differ significantly from the sediments described in the Haltenbanken region.

The Haltenbanken region has been inundated by several major glaciations during the last 1.5 - 2 million years. The last glaciation was at its height about 18 000 years before present (BP). Radiocarbon dating of shells places the edge of the ice sheet in the vicinity of the shelf break at about 13 000 years BP. During the subsequent period of glacial retreat the edge of the ice sheet reached Haltenbanken by about 12 000 years BP, the outermost skerries at Froan by about 11 000 years BP and the Trondheim region about 10 500 years BP.

The material eroded and transported within the ice sheet was liberated in the form of sediment-laden meltwater, via the melting and capsize of icebergs calved from the edge of the glacier and by ablation at the melting bottom edge of the ice sheet. A pictorial representation of the various processes involved in the release of sediment from a retreating ice sheet is shown below.

The majority of the deposits in the Quaternary sedimentary column in the Haltenbanken region were thus transported and deposited by various glacial processes. Lateglacial and Postglacial modification, reworking and retransport has been modest. Exceptions are the shallowest parts of Haltenbanken, the slopes of the Bank and the uppermost part of the continental slope.

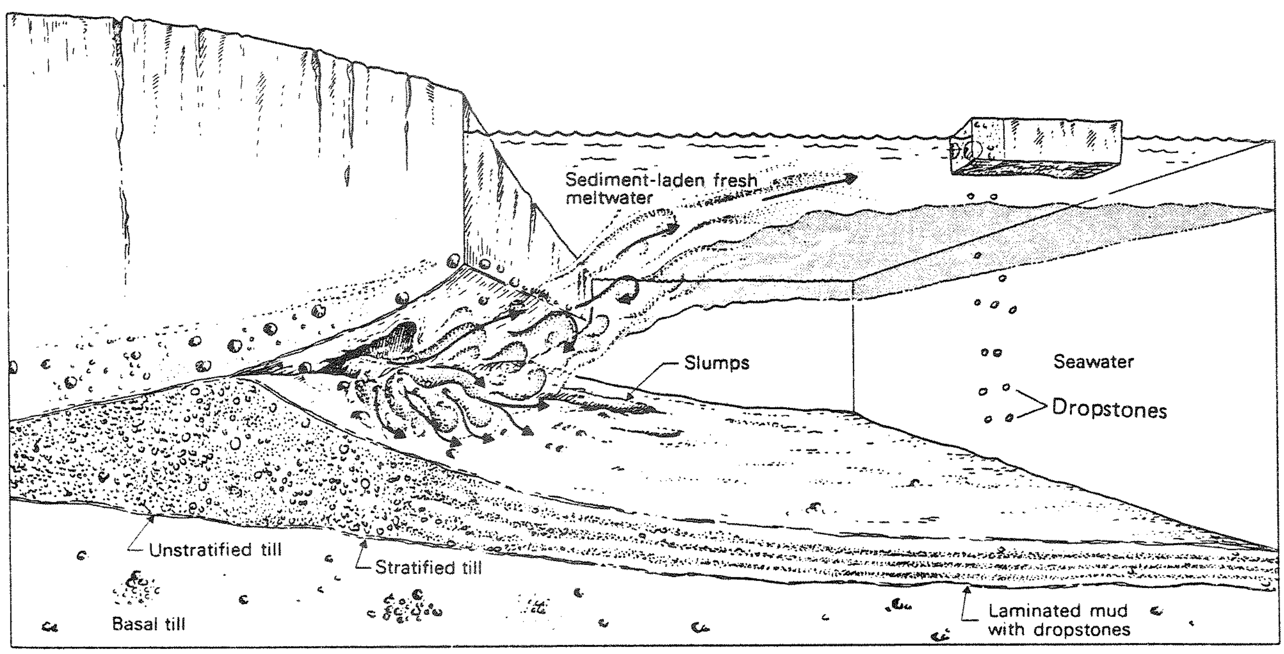


Fig. 2.1. Sediment release from a retreating marine ice sheet (modified after Edwards, 1978).

The shallower parts of Haltenbanken were exposed to severe wave energy during the later part of the last glaciation during a period of lower sea level. The wave erosion resulted in a cover over the bank of an erosional remnant - a lag deposit. This lag deposit is made up of rounded cobbles, stones and boulders. Downslope from the shallower parts of the bank the sea floor is covered by sands and coarse silts winnowed by the wave action further upslope.

Along the upper parts of the continental slope one finds a belt of sands, medium to coarse and well sorted. This sand belt is the result of strong, deep currents following the continental slope in a northerly direction. The fact that current erosion still takes place is evidenced by seafloor photographs showing sharp crested current ripples.

The submarine plain west of Haltenbanken is covered by sediments showing little or no Postglacial or Recent reworking. This includes the investigated area at Heidrun.

It is considered that icebergs were particularly abundant in the waters overlying the deglaciated shelf, and the shedding of ice-rafted material - either through melting or by capsize - is thought to be a major factor in the supply of sediment in this region. The random movement of icebergs and the erratic shedding of ice rafted detritus from such sources can therefore lead to significant and erratic variations in the physical composition of the sediments. This is especially pertinent with respect to the coarser particles (sand, gravel, cobbles) which settle more rapidly and are therefore less exposed to hydrodynamic sorting and dispersion processes.

The present areal distribution of the sediments is the result of processes occurring subsequent to the initial deposition. These processes were largely determined by the hydrologic regime, and partly reflect bathymetric and seafloor topographic characteristics. Consequently, depressions, trenches and other sheltered areas are usually characterised by finegrained sediments, whereas in more exposed areas the finer particles have often been winnowed away.

The seafloor sediments sampled at Heidrun during the present survey reflect the glaciomarine regime of deposition. This regime is demonstrated among other things by the occasional occurrence of stones in the uppermost seafloor sediments. There are no present sedimentary processes that could transport and deposit such coarse particles into the area.

2.3. Physical oceanography.

The water column in the Haltenbanken area is considered to comprise two main components i.e., Atlantic water and the Norwegian coastal water. (A third component, slope water, is sometimes referred to - this being a mixture of Atlantic water and deep water from the Norwegian Sea).

The Atlantic current flows east/northeast from the Faroe-Shetland channel until it is directionally influenced by the Norwegian continental slope at about 63^{0}N. The main flow then follows the slope north/northeast, but one branch runs eastward over the continental margin along a channel between Frøyabanken and Haltenbanken.

The Norwegian coastal water is less dense (salinity less than 35 o/oo) than Atlantic water and flows northwards following the coast, forming a wedge over the Atlantic water. The boundary between the two water masses is seasonally variable and usually reaches its westernmost extension during the summer due to the input of meltwater from the inland.

Several workers have suggested the existence of a gyre of Norwegian coastal water flowing clockwise around Haltenbanken. This gyre would also pass across the Heidrun field. If the suggestion is correct it would imply that the water masses caught in the gyre would stay for a long time over Haltenbanken. This could explain the extremely low levels in particulate matter in water sample filtrates taken from the Haltenbanken area, the water having had time to shed its load of sediments through settling.

Bottom currents in the area are variable in direction and velocity. Current direction varies between east, through north, to west, but is generally to the north and northeast. Current velocities 3 meters above bottom may reach ca. 25 cm/sec. (Maisey and Wøien 1984).

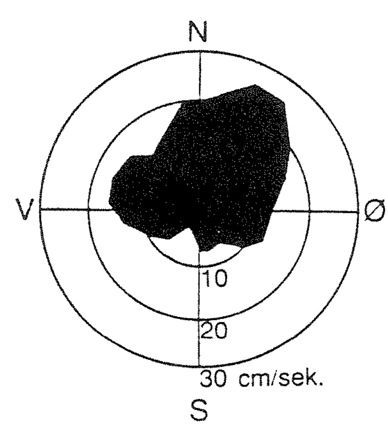


Figure 2.2. Vector diagram showing current velocities and directions maxima measured over a period of 30 days 3 meters above the bottom at Haltenbanken. (from Maisey and Wøien 1984).

3. EXPLORATION ACTIVITY AT HEIDRUN PRIOR TO THE SURVEY

The Heidrun field lies in the northern region of Haltenbanken and about 175 km from the Norwegian coast. The oil and gas reservoir covers an area of about 38 km^2 and lies mainly in Block 6507/7 which is operated by Conoco, and with an extension into Block 6507/8 operated by Statoil.

Concession for Block 6507/7 was given in 1984, and the first exploratory well was finished late the same year. The reservoir was discovered through drilling of well 6507/7-2 in spring 1985. A total of nine exploratory wells have been drilled in the period 1984-1987. The drilling is the prime form of activity which may have had any influence on the sediment chemistry and biology prior to the environmental baseline survey in June 1988. The positions of these wells are indicated in Fig. 4.1. Basic information on the wells is given in Tab. 3.1.

Table 3.1 Overview of exploratory wells drilled in the Heidrun field prior to the environmental survey, June 1988 (Courtesy of Conoco).

Well	Latitude	Longitude	Mud type	Date abandoned	Cuttings volume(m^3)
6507/7-1	65°27'16.75"	07°12'52.60"	Gyp lignite	02.12.84	600
6507/7-2	65°20'12.37"	07°18'34.52"	Gyp polymer	11.06.85	500
6507/7-3	65°19'01.31"	07°17'44.79"	Gyp polymer	18.09.85	500
6507/7-4	65°19'11.56"	07°15'44.99"	Gyp polymer	13.01.86	500
6507/7-5	65°21'30.27"	07°17'35.08"	KCL polymer	05.04.86	700
6507/7-6	65°21'30.03"	07°19'10.34"	KCL polymer	06.09.86	500
6507/7-7	65°17'52.25"	07°18'50.64"	Seawater	09.08.87	250
6507/7-8	65°17'56.68"	07°18'49.87"	KCL polymer	02.08.87	500
6507/7-9	65°19'31.55"	07°19'03.95"	Seawater	09.08.87	40

All wells except number 9 were drilled with seawater down to approx. 1000 m.

About the same time as the environmental survey was conducted, Stolt-Nielsen Seaway A/S performed a soils survey by use of vibrocorer and other penetration equipment down to 6 m in the sediments. This investigation was performed in the southern region of the field, in the vicinity of Stations 7 and 8, but as the work was performed simultaneously with the environmental survey and the effects of such activities on the sediment is regarded as very local, there is no *a priori* reason to believe that the soils survey can have caused any significant disturbance or in other ways interferred with the environmental investigation.

There are no other reports on industrial activities in the Heidrun field which may have had any impact on the elements included in the environmental study.

4. SAMPLING SURVEY

4.1. Sampling positions and position fixing

Sampling was performed in the period 22-28 June 1988 from the vessel 'Svanaug Elise' at 25 stations centered around the sites for the Early Production System and the Permanent Platform. The positions of the sampling stations are shown in Figure 4.1, and their basic features given in Tab. 4.1. Station positions were located by use of the ARGO radio link system logging transmitters at several onshore locations.

During sampling the position was logged by date, time and UTM position coordinates every time the sampler reached the bottom. Further details of positioning procedure is given in the Survey log (Appendix 1).

4.2 Sampling procedure and field measurements

Samples for physical and chemical characterization of the sediment were taken with a 0.1 m^2 Smøgen box corer enabling sediment surface subsampling and Eh measurements to be done on relatively undisturbed samples. Samples for biological analysis were taken by use of a long armed 0.1 m^2 Van Veen grab without extra lead weights.

The standard sampling programme for each station consisted of:

- three box core samples, accepted when having undisturbed surface, depth greater than the thickness of the oxidised layer (5-7 cm) and no sediment wash-out. Each box core sample was transferred to a plastic tray for control and six subsamples were withdrawn from the topmost 1-2 cm for analysis of particle size distribution (PSD), total organic content (TOC), hydrocarbons, and metals.

- five Van Veen grab samples, accepted when having a minimum volume of 10 liters and no sign of sediment wash-out. Each grab sample was poured into a large volumetric cylinder and volume measured to the nearest 0.5 liter. If acceptable, the whole sample was transferred to a hopper table and washed by gentle water jet onto a 1 mm sieve. The material passing this screen was sifted through 0.5 mm. The material from both screens was preserved separately for analysis of macrofauna.

- measurement of Eh by inserting a probe 2 cm into the top sediment of one box core sample from each station, and reading of Eh and temperature taken after about 1 min stabilization period. Details of the procedure is given in Appendix 2.

- Each box core was immediately characterized by colour (Munsell colour code) and apparent sediment composition. The results are presented in Appendix 1,

In addition to the standard sampling programme the following was performed:

- At station 24 (reference station) three additional Van Veen grab samples were collected making a total of 8 grab samples for macrofauna analysis. This was done to make an assessment of the number of species as function of sampled area.

- At stations 8 and 10 five extra box core samples were taken. From each of two of these, two smaller core subsamples were taken to study vertical distribution of hydrocarbons. The subcores were sectioned into 0-1, 1-3, and 3-6 cm sections. From each of the three remaining box cores six standard surface subsamples for hydrocarbons were taken for a hydrocarbon intercalibration exercise.

Table 4.1 Sample station enumeration and location, water depth and total sediment volume sampled for fauna analysis, from the Heidrun field, June 1988.

Station no.	Target	Range	Bearing	UTM Position easting	UTM Position northing	Dept	Fauna volume sampled
1	EPS	5000	234	415317	7242521	320	63.5
2	EPS	2500	234	417379	7243934	330	69.5
3	EPS	1300	234	418368	7244612	335	67.8
4	EPS	515	263	418928	7245294	339	76.0
5	EPS	2500	315	417722	7247162	335	79.5
6	EPS	988	301	418604	7245873	339	66.5
7	EPS	1000	150	419916	7244468	339	71.0
8	EPS	2500	150	420630	7243149	325	62.0
9	EPS	5000	150	421820	7240951	325	66.5
10	EPS	250	73	419681	7245414	340	74.5
11	EPS	500	73	419922	7245480	340	78.5
12	EPS	1000	73	420404	7245613	340	80.0
13	EPS	1815	81	421238	7245589	340	74.0
14	PLATF.	2500	315	419936	7247804	335	74.0
15	PLATF.	1000	315	420967	7246716	338	76.0
16	PLATF.	1000	135	422343	7245265	340	74.5
17	PLATF.	2500	135	423374	7244176	335	72.5
18	PLATF.	5000	135	425094	7242363	320	62.0
19	PLATF.	250	45	421836	7246162	343	74.5
20	PLATF.	500	45	422018	7246334	345	77.5
21	PLATF.	1000	45	422381	7246678	348	69.0
22	PLATF.	2500	45	423469	7247710	340	69.5
23	PLATF.	5000	45	425282	7249429	340	77.5
24	PLATF.	17000	315	411146	7260142	380	80.0 [1])
25	EPS	500	150	419678	7244908	339	74.5

[1]) for 5 grabs. 8 grabs gave 128.5 l.

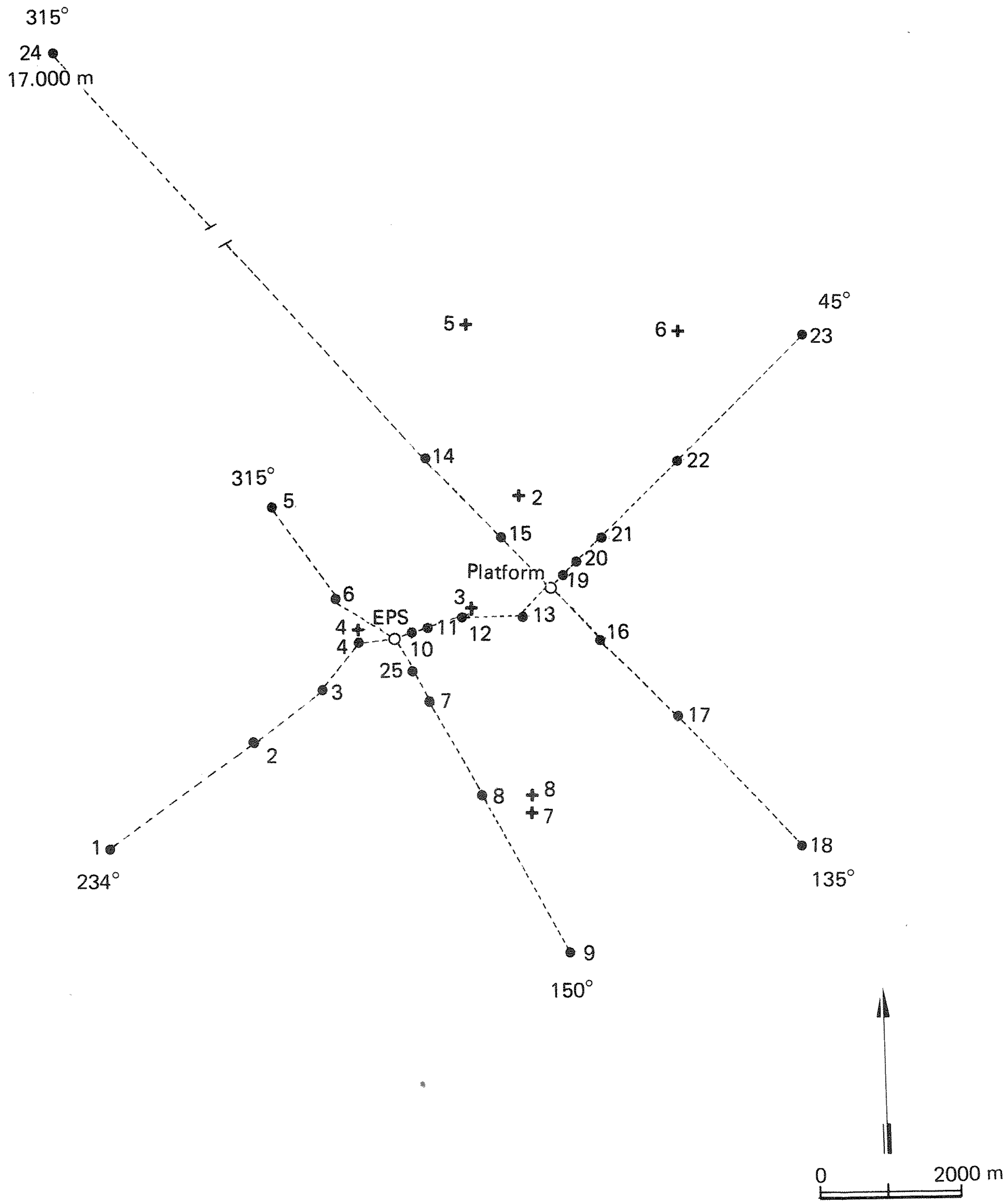


Fig. 4.1. Map of the Heidrun field with position of the Early Production System (EPS), the Permanent Platform, the sampling transects with bearings, sampling stations with identification (●), and existing exploratory wells with number (✚).

5. SAMPLE TREATMENT ON BOARD

The subsamples for PSD and TOC analysis were removed from the core sample with a stainless steel spatula, packed individually in double plastic bags and stored frozen at -20^{0}C.

The samples for hydrocarbon analysis were taken with a Teflon spatula, wrapped individually in clean aluminium foil. These samples were again packed in separate plastic bags and stored frozen. The core subsamples for vertical sectioning from stations 8 and 10 were taken with perspex cylinders of 100 mm diameter, wrapped in aluminium foil, and frozen in a standing position. Sectioning of the samples were performed in the laboratory after slight thawing.

The samples for metal analysis were taken with a stainless steel spatula, transferred individually to acid washed polythene bottles, and stored frozen.

The material for macrofauna analysis retained on the 0.5 and 1 mm sieves was transferred separately to plastic buckets, preserved in 4 % formaldehyde solution with rose bengal stain, and kept cool.

6. SUMMARY OF PROCEDURES FOR LABORATORY ANALYSIS

6.1. Physical analysis

6.1.1 Particle size distribution

PSD analysis was performed by combined dry sieving for the fraction above 63 µm and electronic particle counting below 63 µm. The samples were thawed and gently homogenized, and a subsample of approximately 65 ml was freeze dried for 48 hours. After weight determination the dry sample was shaken for 20 min through a nest of sieves with mesh sizes ranging from 1 mm to 63 µm at Φ (phi: negative $\log_2$ of the particle diameter) intervals of 0.5 (Retsch Lab. Sieving Machine Vibro). The material on each screen was weighed to the nearest 0.001 g.

The material passing the smallest screen was suspended in a known volume of 0.9 % saline solution and the particles counted at volume intervals corresponding to spheric diameters from 2 µm to 63 µm (Φ intervals of 0.5) by use of a Coulter Counter mod. ZB. The % volume of each fraction was converted to % dry weight of the total sediment weight below 63 µm.

The weight of all size fractions were then used to construct cumulative % weight distribution tables for each station. From these tables the following quantities were calculated:

Particle diameter x expressed as Φ (phi) values ($\Phi = -\log_2 x$).

Φ % fractiles from Φ(5) to Φ(95) % defining the Φ limits beyond which a certain % weight of the particles were found.

Median particle diameter MdΦ = the Φ value of the mid- (i.e. 50 %) point of the cumulative % weight curve. This measures the central tendency of the size frequency distribution.

Φ standard deviation estimated as:

$$\sigma\Phi = \frac{\Phi(84)-\Phi(16)}{4} + \frac{\Phi(95)-\Phi(5)}{6.6}$$

$\sigma\Phi$ gives a measure of the spread in particle size around the $Md\Phi$, and thus is a measure of the degree of sorting of the particles.

<u>Φ skewness</u> estimated as:

$$Sk\Phi = \frac{1/2\cdot(\Phi(84) + \Phi(16)) - Md\Phi}{\Phi(84) - \Phi(16)} + \frac{1/2\cdot(\Phi(95) + \Phi(5)) - Md\Phi}{\Phi(95) - \Phi(5)}$$

$Sk\Phi$ describes the symmetry of the spread in distribution around the $Md\Phi$. A completely symmetrical distribution will have $Sk\Phi$ value 0, negative values indicate displacement of the distribution curve towards coarser sediment, and positive $Sk\Phi$ indicates displacement towards finer sediment.

<u>Φ kurtosis</u> estimated as:

$$K\Phi = \frac{\Phi(95) - \Phi(5)}{2.44\cdot(\Phi(75) - \Phi(25))}$$

$K\Phi$ describes the peakedness of the distribution, i.e. how heavy the tails are (expressed by the $\Phi(5)$ and $\Phi(95)$ fractiles) compared to the central portion of the distribution. For a normal distribution the expression above will give a $K\Phi$ value of 1.00.

The complete results of the analysis are presented in Appendix 2.

6.1.2. Redox conditions

Eh was measured by inserting a probe 2 cm into the top of one boxcorer sample from each station. After a period of instrument stabilization of one to a few minutes, the mV and temperature was recorded.

A standard Zobell solution was prepared from two stock solutions; solution A containing 1.86 g KCl and 0.55 g $K_3Fe(CN)_6$ in 250 ml distilled water, solution B containing 1.86 g KCl and 0.17 g $K_4Fe(CN)_6\cdot 3H_2O$ in 250 ml distilled water. Equal parts of solution A and B were mixed every day to prepare a reference Zobell solution. Readings of the reference solution was usually +241 mV with some variance from day to day within 5 mV. This variation could have been caused by inaccuracies when mixing the two stock solutions or variations in temperature.

The correct Eh reading for the standard Zobell solution should have been +430 mV at 25^{0}C. On return to shore the same probe and instrument was tested against a reference instrument under laboratory conditions. The instrument continued to register +241 mV and the recorded values were therefore corrected by adding 189 mV.

Due to a fault in the original cable between the field instrument and probe, the cable was replaced by another one which was soldered to the probe. During the later part of the cruise the instrument failed to provide stable readings. It is believed that this was caused by poor contact at the cable to probe soldering point in certain configurations. This led to unreliable readings from Stations 9, 15, 16, 18 and 21, and in the case of Station 9 and 18 the deck operator has not recorded the readings.

6.2. Chemical analysis

6.2.1. Total organic carbon (TOC) content

Each sediment subsample was homogenized and approx. 5 g was ovendried overnight at 40^{0}C. 200 mg of the dried sample was weighed into a Leco crucible and carbonate was removed by treatment with 10 % HCl. The sample was washed with distilled water to remove HCl traces, and dried overnight at 50^{0}C.

TOC content was determined by heating the sample to 1380^{0}C in a Leco CS 244 carbon analyser. The result was given as percent weight loss during the combustion process. The instrument was calibrated with a Leco standard sample (2.72% TOC), and the repeatability was tested by analysing two of the samples in the analytical sequence twice under similar conditions. These results are included in the TOC results presentation.

6.2.2. Total hydrocarbon (THC) content

In Fig. 6.2.1 a flow chart over the total procedure for soxhlet extraction, work up and analysis of THC, aromatics and alipahtics is given. The different steps in the procedure are discussed in detail in the following. Table 6.2.1 shows the different organic compounds analysed in the present survey and the methods of analysis, respectively.

Table 6.2.1 Organic parameters and respective methods of analysis in the 1988 Heidrun environmental baseline survey.

Parameter	Analytical method
Total hydrocarbon (THC) content (screening)	IR
THC content (accurate measurements)	GC/FID
Aliphatic content, selected compounds	GC/MS
Aromatic content, selected compounds	GC/MS

IR measurements

The procedure given in the Scope of Work for the environmental survey was followed in detail. Samples were homogenized and ovendried at 40^0C to a constant weight. Sediment samples (100.0 ± 0.5 g) were extracted by shaking vigorously for 15 minutes three times with dichloromethane (DCM) (250 + 2 x 100 ml) in an Erlenmeyer flask. After filtration and evaporation of the solvent (rotavapor at room temperature) samples were dissolved in 1 ml carbontetrachloride and eluted through an alumina column (1.0 cm id., 10 g adsorbent) with 45 ml of CCl_4. The sample volume was reduced to approx. 2 ml under a gentle stream of nitrogen, and diluted to 25.0 ml in CCl_4. Samples were analysed by a Perkin Elmer IR instrument at 2930 cm-1 and a North Sea Crude (UK Dept. of Energy standard no. 4) and a diesel fuel oil (UK Dept. of Energy standard no. 3) were used as external standards for quantification. Blank samples were made from the same amount of dichloromethane, following the same work up and analytical procedure as for the real samples.

GC/FID determination

Approx. 200 g of the homogenized sediment subsample was weighed into a thimble and placed in a Soxhlet tube. A solution of internal standards, heptamethylnonane, squalane and the deuterated compounds d_{34}-hexadecane, d_{10}-anthracene, d_{10}-pyrene, d_{12}-chrysene and d_{12}-perylene were added directly to the sediment. The sediment was refluxed with methanol (300 ml) for 24 hours, and further with dichloromethane, DCM, (300 ml) for another 24 hours, after decantation of the methanol.

The methanol solution was placed in a 1 L separation funnel and extracted with three portions of pentane (100 ml each). To achieve good seperation between the pentane and methanol layers, an aliquot of distilled water was added to the funnel. The DCM solution was combined with the pentane washings and the volume of the extract was reduced to approx. 2 ml under vacuum at ambient temperature (20^0C).

For a selected number of samples, one from each site, the resulting extract was split into two aliquots and one of these was used for GC/MS determination of selected aliphatic and aromatic compounds as described below. The volume of the other aliquots and all remaining samples were further reduced to approx. 0.5 ml under a gentle stream of highly purified nitrogen at ambient temperature, and 2 ml of hexane was added to the extracts. The volume was again reduced to approx. 1 ml in order to remove the DCM from the extract. Some of the samples contained small amounts of water (carry-over from the methanol-pentane separation) and to these a small portion of anhydrous sodium sulphate was added to remove the water before their volumes were adjusted to 0.5 ml.

The sample (0.5 ml) was quantitatively applied on a Bond Elut Silica extraction column (500 mg), and the sample vial was washed with three 0.5 ml hexane portions which were also applied on the column. The sample extract was eluted through the column, leaving the polar material adsorbed to the silica. The column was washed with hexane (2x3 ml) to secure that no nonpolar hydrocarbons were left in the system. The volume of the eluate, containing the nonpolar THC fraction was reduced to less than 1 ml under a gentle stream of highly purified nitrogen and determined by weighing of the sample. The samples were stored in darkness at -22^0C until the time of analysis.

THC analysis

The samples were analysed by GC/FID and quantification of THC was performed in a specified boiling point window (C_{12}-C_{35}) by the external standard method. A corresponding base oil planned to be used at the actual field was used as external standard. The analytical equipment and conditions for the THC analyses are given in Table 6.2.2. A chromatogram of the base oil standard is shown in Fig. 6.2.2.

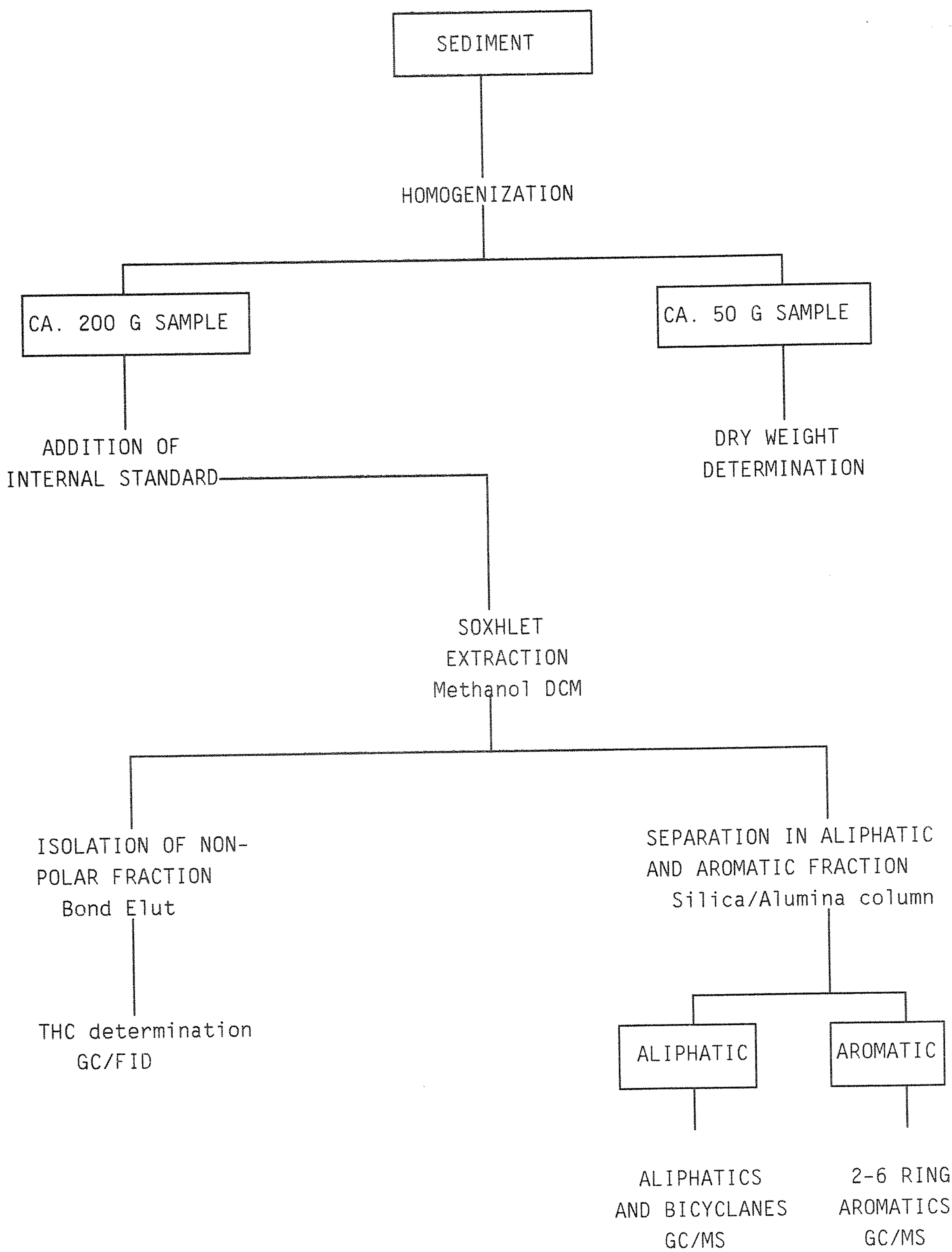


Figure 6.2.1. Flow chart giving the procedure for hydrocarbon analysis.

Table 6.2.2 Analytical equipment and conditions for THC determination.

Gas chromatograph:	Hewlett Packard HP 5710 A
Injector system:	HP 7671A automatic sampler - splitless in 0.60 min.
Injector temperature:	300°C
Carrier gas:	H2 10 PSI inlet pressure
Column:	Durabond DB-5 30 m x 0.25 mm id.
Detector:	FID 300°C
Temperature program:	40°C (2 min.) - 25°C/min - 350°C (4 min.)
Data system:	VG Multichrom, V.1.6 Microvax-based

6.2.3. Aliphatics, aromatics and bicyclanes

The aliquot from the sediment extract bound for GC/MS analysis was left in an open vial and air dried to remove traces of polar solvents. The total extract was applied on a column and separated into an aliphatic and an aromatic fraction. The column, a 50 ml burette, id: 1 cm, contained a bottom layer of activated copper (1-1.5 ml) sealed by two cotton plugs. On top of the copper layer an aluminum oxide layer was placed (Fluka type 5016A, 6 g), and finally, on top of the alumina layer a silica layer was added (Kiselgel 60 70-230 mesh, 3.6 g). The alumina and silica adsorbents were activated in an oven at 200°C overnight prior to this process.

The column was washed with 50 ml of pentane, and the sample applied as 2 ml pentane suspension. The aliphatic fraction was then eluted with pentane (50 ml), and the aromatic fraction with DCM/pentane (1:2, 100 ml). The volumes of the two fractions were reduced to near dryness under a gentle stream of highly purified nitrogen on a hot-plate set at 40°C.

Analysis

Bicyclanes, selected aromatics and aliphatics were determined by GC/MS, using the internal standards named above (section 6.2.2). Selected fragment ions of the actual compounds were monitored, and integration was performed manually by placing the cursor at the beginning and end of the actual peaks. Corresponding average areas from blank samples were subtracted from sample peak areas prior to quantification. Table 6.2.3 gives the analytical equipment and conditions for the GC/MS analysis, while the selected Ion Monitoring program is given in Table 6.2.4.

Table 6.2.3 Analytical equipment and conditions for NPD and bicyclanes analysis

GC:	HP 5710 A with HP 7671 A Automatic sampler
MS:	VG 12-250 quadropol
Computer:	VG 11-250 MS software on Digital PDP 11/24 computer
GC-conditions:	
Injection:	Splitless 300^{0}C in 0,60 min
Column:	Durabond DB -5, 15 m x 0,30 mm
Temp.prog.	60^{0}C (2 min) - 4^0/min - 300^{0}C (5 min)
Carrier gas:	Helium 10 psi
MS-conditions:	
Ionization:	EI 70 EV
Source temp:	200^{0}C
Source pressure:	10-5 Torr

Table 6.2.4 Monitored ions of NPD and bicyclanes.

Compound	Corresponding internal standard	Fragment ion
Aromatic fraction		
Naphthalene	d_{10}-biphenyl	128.1
C_1-naphthalene	"	142.1
C_2-naphthalene	"	156.1
C_3-naphthalene	"	170.1
Phenanthrene	d_{10}-anthracene	178.1
C_1-phenanthrene	"	192.1
C_2-phenanthrene	"	206.1
C_3-phenanthrene	"	220.1
Dibenzothiophene	d_{10}-anthracene	184.1
C_1-dibenzothiophene	"	198.1
C_2-dibenzothiophene	"	212.1
C_3-dibenzothiophene	"	226.1
Pyrene	d_{10}-pyrene	202.1
Fluoranthene	"	202.1
Benz(a)anthracene	d_{10}-chrysene	228.1
Chrysene/triphenylene	"	228.1
Benzo(b/j/k)fluoranthene	d_{12}-perylene	252.1
Benzo(e)pyrene	"	252.1
Benzo(a)pyrene	"	252.1
Perylene	"	252.1
Benzo(ghi)perylene	"	276.1
d_{10}-biphenyl		164.1
d_{10}-anthracene		188.1
d_{10}-pyrene		212.1
d_{12}-chrysene		240.1
d_{12}-perylene		264.1
Aliphatic fraction		
C_5-decalin		208.1
C_6-decalin		222.1
C_7-decalin		236.1
C_8-decalin		250.1
n-alkanes C_9-C_{35}	squalane	130.1
Isoprenoides	"	130.1
	"	113.1
Hexamethylnonane		113.1
Squalane		113.1
d_{34}-hexadecane		130.1

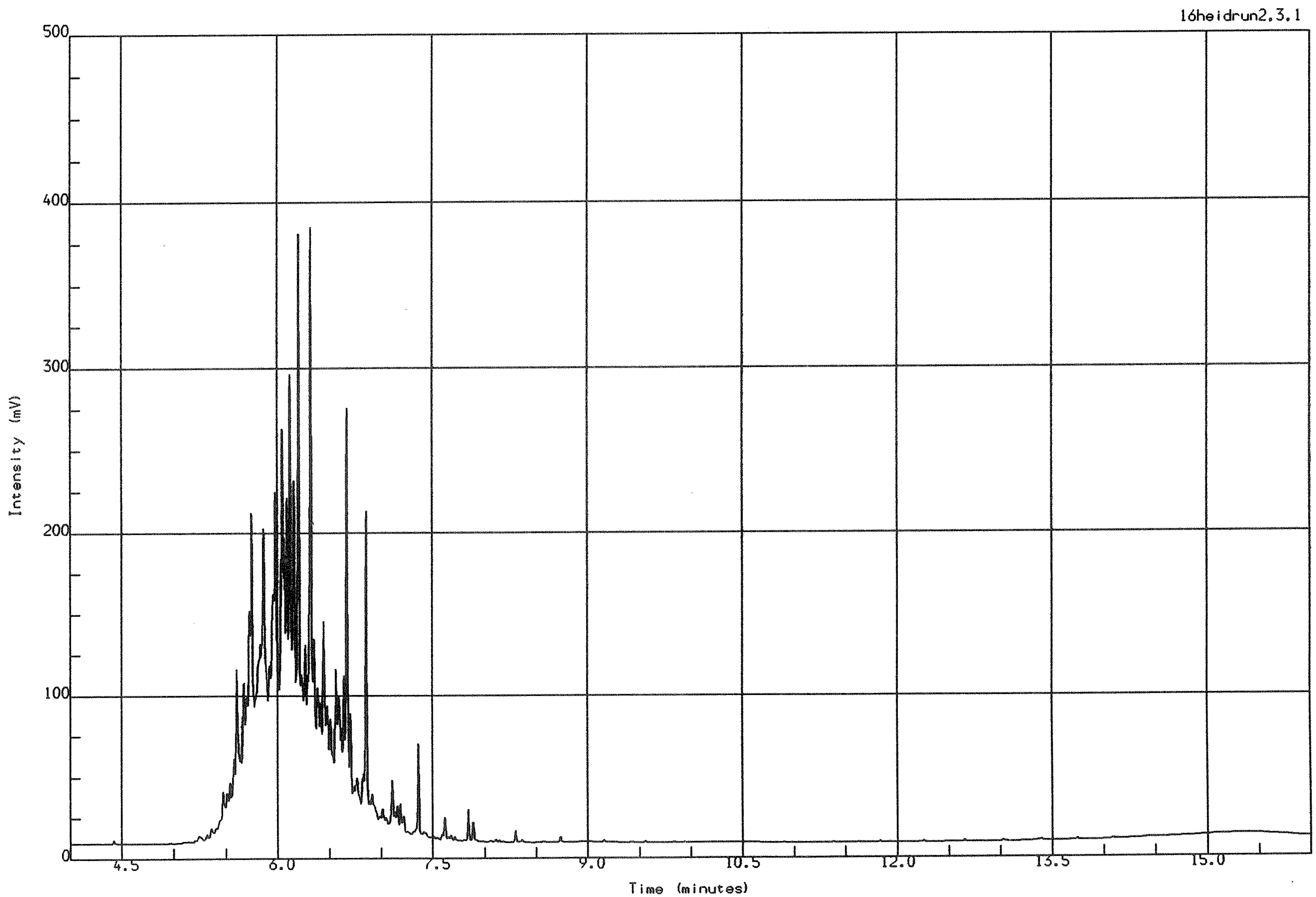


Fig. 6.2.2. THC chromatogram of base oil standard.

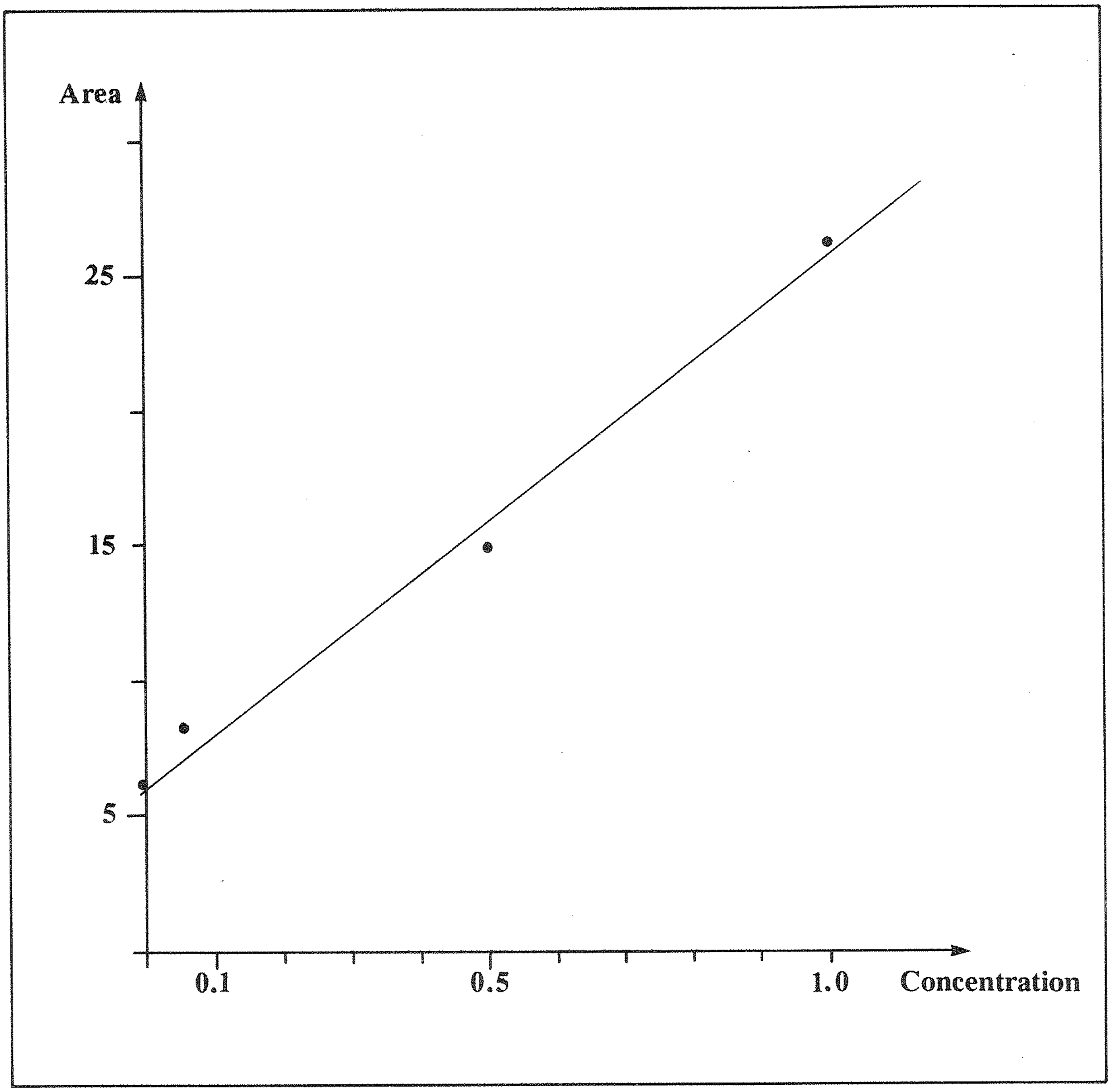


Fig. 6.2.3. Standard curve of base oil for external standard quantification (linear regression coeff: 0,998).

6.2.4. Heavy metal analysis

Heavy metal content in the sediment samples was determined by the procedure described in Norsk Standard 4770. Approximately 50 g of each sample was oven dried for 48 hours at 50^{0}C and dry weight was determined. After homogenisation of the sample, 1,0 g was digested by HNO_3 (20 ml, 7M) in a sealed Duranflask at 120^{0}C for 30 min.

After cooling to ambient temperature, the sample was diluted to 100 ml and the precipitate was allowed to settle. The clear solvent layer was then transferred to polyethylene flasks. The extract was first analysed for content of barium (Ba), strontium (Sr), lead (Pb), chromium (Cr), copper (Cu), iron (Fe), nickel (Ni), vanadium (V) and zinc (Zn) by inductive coupled plasma atomic emission spectrometry (ICP). Due to low concentrations, the content of Cu, Cr and Pb in addition to cadmium (Cd) was also determined by electrothermal atomic adsorbtion spectrometry (EAA). The content of mercury (Hg) was determined by cold vapour technique.

Instrumentation and experimental conditions:

ICP analysis:

ICP-AES: Perkin Elmer Plasma II emission spectrometer

R.F effect	1.0 kW
Nebulizer	1.0 l/mm
Auxillary gas	1.0 l/min
Plasma gas	15 l/min
Pumping speed	1.0 l/min

Selected lines:

Element	Line (nm)	Background correction
Ba	455.40	Automatic
Sr	407.77	Automatic
Cu	324.75	Automatic
Pb	220.35	Automatic
Cr	205.55	Automatic
Zn	213.86	Automatic
Fe	238.20	Automatic
V	282.40	Automatic
Ni	321.60	Automatic

EAA Analysis: **Perkin Elmer mod 5100 AA with Zeeman 600 Graphite furnace.**

Element	Cd	Cu	Pb	Cr
Lamp		Hollow cathode		
Wavelength nm	228.8	324.8	283.3	357.9
Slit nm	0.7	0.7	0.7	0.7

Graphite tube	pyrolytic with platform
Matrix modifier	$(NH_4)H_2PO_4$
Calibration	nonlinear

Cold vapor technique:

Perkin Elmer model 2100 AA with continuous hydride system.

Boronhybride	0,3%$NaBH_4$ + 0,5%NaOH
Hydrochloric acid	416 ml/l
Lamp	Hg EDL
Wavelength	253,7 nm
Slit	0,7 nm

6.2.5. Quality assurance

Hydrocarbons

The limit of detection (LOD) and limit of quantification (LOQ) were determined from the analysis of blank samples, made by work up and analysis of pure solvents after the same procedures as for the different hydrocarbon measurements. Table 6.2.5 shows the results of these experiments. The LOD is defined as the mean hydrocarbon value from three blanks + 3x the standard deviation (significance > 0.95) while the LOQ is defined as mean THC + 10xSD (significance >0.995). The input of hydrocarbons from the solvent and equipment used during the work up and analysis of the sample extracts, represented by the mean results from the blanks, is subtracted from the results presented in this report. An exception from this rule is the TOC results, where no blanks were made.

Table 6.2.5. Limits of detection and quantification (LOD and LOQ) obtained from work up and analysis of solvent blanks (mg input to real samples).

	LOD	LOQ
THC IR	0.43	0.58
THC GC/FID [1])	0.057	0.15
Naphtalenes	0.26	0.56
Phenathrenes	0.41	0.75
Dibenzothiophenes	0.080	0.16
Fluoranthene	0.069	0.17
Pyrene	0.033	0.084
5-ring	not detected in blank samples	
6-ring	not detected in blank samples	
Total n-alkanes	23	56
Total isoprenoides	3.7	9.6

[1]) given as mg/kg dry weight

A Conoco LVT 200 baseoil was used for the quantitative GC/FID analysis (see Section 6.2.2). A 'response area vs. injected amount' standard curve was made from injections of baseoil solutions of 0.1, 0.5, 1.0 and 5.0 mg/ml. This curve is shown in Figure 6.2.3. The repeatability of the GC/FID analysis was tested by analysing a baseoil standard solution 5 times, and determining the uncertainty (standard deviation) in the response (area). The repeatability was found to be within ± 5% of the measured area.

Heavy metals

Standard calibration solutions were used as an internal quality control for every 10th sample analysis. To test the repeatability of the analysis, two selected samples (19 I and 23 III) were analysed 4 times and the percent variation (standard deviation) of the results was determined. The results are given in Table 6.2.6. The recovery of the trace elements from two different samples (NBS 1646 Estuarine sediment and BCR 144 Sewage slugde) was also tested and the results are included in Table 6.2.6. The complete quality control data are given in Appendix 3.

As seen from the table, the recovery is rather poor for some of the elements. Because of the high repeatability of the analysis this effect is not very important. As long as the results obtained in future monitoring surveys are compared either with the present (baseline) or the actual reference site results, this problem can be ignored.

Table 6.2.6. Repeatability and recovery of metal analysis - NS 4770

%SD 4 runs	Cd	Cr	Cu	Pb	Ni	V	Zn	Fe	Ba	Sr	Hg
19 I	11.2	9.1	2.5	6.8	2.8	1.4	3.3	5.1	11.9	3.2	-
23 III	8.0	10	3.7	3.1	2.8	1.6	5.3	3.7	2.0	1.5	-
Recovery											
NBS 1545	106	52.6	83.3	74.5	71.8	53.1	81.8	74.7	104	118	-
BCR 144	-	-	98.2	86.9	93.4	-	88.1	99.1	-	-	131

6.3 Biological analysis

Each sample was washed through a 0.3 mm sieve to remove formaldehyde and any remaining fine sediment. The 0.5 mm and 1 mm fractions were treated separately all the way through to final lists of taxa with attributed densities. All animals were picked out from the samples under a dissection microscope with exception of foraminiferans, nematodes and eggs, which were only recorded by presence/absence. The animals were identified to the lowest taxon possible, usually to the species level, and counted (quantitative taxa). Colonial organisms (e.g. bryozoans, the polychaete Salmacina dysteri). were recorded qualitatively (i.e. by presence/absence). Subsequent to the analysis the animals were preserved in 70 % ethanol and are stored until further notice. The microscope analysis produced a list of taxa for each station and size fraction with densities in the individual grabs as well as total densities at 0.5 m^2 for each taxon. The fauna lists are presented in Appendix 4.

The following features of the fauna from each station have been analysed on the basis of the quantitative taxa. The pelagic copepods were excluded from the analysis. For station 24 the computations are based on data from the first 5 grab samples only, to be comparable to the standard number of samples.

Total number of taxa (S),
Total number of individuals (N),
Shannon- Wiener diversity index (Hs),
Brillouin diversity index (Hb),
Simpson index of dominance (D),
Margalef index of species richness (Ma),
Pielou (J) and Heip (E) measures of evenness,
Hurlbert diversity curves,
Expected number of species (ES_{100}),
Correspondence to the log-normal distribution.

The stations have been grouped according to faunal similarity on the basis of the Bray-Curtis dissimilarity index by group average clustering, and by ordination (Multi-dimensional scaling, MDS). The correlation among the various community parameters, and correlation with sediment characteristics have been analysed. All the calculations were performed on the entire fauna (i.e. larger than 0.5 mm) and separately on the fraction larger than 1 mm.

An account of the biological data analysis procedures is given below.

Shannon-Wiener diversity index (Shannon and Weaver 1963).

The Shannon-Wiener diversity index (or information function) Hs is a measure of the uncertainty in predicting correctly the species of the next individual picked out at random from the community under study. The index summarises in a single value two important aspects of the community: species richness and the evenness in distribution of the individuals amongst the species. Large number of species increases the index value as does increased evenness. Hs is probably the most commonly used of all diversity indices proposed. It is usually expressed as:

$$Hs = -\sum_{i=1}^{s} (pi)\cdot(\log_2 pi)$$

where s is the number of species and pi is the proportion of the total sample belonging to the ith species.

Brillouin index of diversity (Brillouin 1962)

This diversity index is also a measure of information content, but unlike the Shannon-Wiener index estimating the community diversity, Brillouins index is an actual measure of the diversity of the sample unit taken. The index is expressed as:

$$H = \frac{1}{N} \ln \frac{N!}{N_1!\, N_2! \,.....N_s!}$$

where N_i = number of individuals of the ith species
N = total number of individuals in the sample
s = total number of species in the sample

Because the index measures the exact diversity of the sample, it is most appropriately used where the limits of the community cannot be defined, which is the general situation in soft bottom communities.

Simpsons index of dominance (Simpson 1949).

This index is expressed as

$$D = \sum_{i=1}^{s} \left[\frac{n_i}{N}\right]^2$$

where n_i = number of individuals of the ith species
N = total number of individuals
s = total number of species

The index attains a minimum value of 1/N if the individuals are evenly distributed on all species. Maximum value is 1 when all individuals belong to one and the same species.

Margalef index of species richness (Margalef 1958).

This index is expressed as:

$$Ma = \frac{s - 1}{\ln N}$$

Where s is the number of species and N the number of individuals in a sample.

Pielou measure of evenness (Pielou 1966).

This index refers to the evenness in distribution of the individuals amongst the species in a community. This is also a component of the diversity measures. It is usually calculated as the ratio between the actual diversity measured and the theoretical maximum diversity attainable if all the species were equal in abundance. The Pielou index of evenness based on the Shannon-Wiener index is expressed as:

$$J = \frac{Hs}{\log_2 s}$$

Where Hs is the Shannon-Wiener diversity, s the number of species, and $\log_2 s$ the theoretical maximum diversity. The index value will aproach 0 when Hs decreases and has a maximum value of 1 when all species are equal in abundance.

Heip measure of evenness (Heip 1974).

This is a modification of the Pielou index using the ratios between the antilogs of Hs and Hs_{max}. To prevent nonsense values at the extremes of evenness, 1 is subtracted from the enumerator and denominator of the expression:

$$E = \frac{2^{Hs} - 1}{s - 1}$$

This index is said to have better statistical properties than other measures of evenness. It varies between 0 and 1 as does the Pielou index.

Hurlbert rarefaction curves (Hurlbert 1971).

The rarefaction method was developed as a graphical means of assessing relative diversity for samples of differing sizes. It calculates the expected number of species in fractions of the whole sample. This is done for a series of hypothetical subsamples enabling a curve to be constructed which indicates how the expected number of species change as the number of individuals increases. The most commonly used expression today is the Hurlbert (1971) modified version of the Sanders (1968) rarefaction method. It is based on the expression:

$$E(S_n) = \sum_i \left[1 - \frac{\binom{N-N_i}{n}}{\binom{N}{n}} \right]$$

where N = total number of individuals in the sample.
N_i = the number of individuals of the ith species .
n = the toal number of individuals in a sample n/N the size of the whole sample.
ES_n = the expected number of species in a subsample of n individuals

The slope and shape of the rarefaction curves gives a measure of community diversity.

Expected number of species per 100 individuals.

This is an index calculating the number of species one might expect to find in a random subsample of 100 individuals of a sample, and represents in fact the ordinate value of the point with abcissa value 100 on the rarefaction curve. The index thus eases comparison between rarefaction curves by assigning a numerical value to the graphical presentation.

Similarity index

The basis for the multivariate analysis was similarity in fauna structure between every pair of stations according to the Bray-Curtis dissimilarity index (Clifford and Stephenson 1975). This index is expressed by:

$$B = \frac{\sum_{n=1}^{s} | X_{ni} - X_{nj} |}{\sum_{n=1}^{s} (X_{ni} - X_{nj})}$$

where s = number of species compared
X_{ni} = number of individuals of species n at station i
X_{nj} = number of individuals of species n at station j

The abundance (X) values were transformed by root-root transformation

($\sqrt{\sqrt{X}}$) prior to similarity analysis to emphasis the influence of less common species of the samples in the total similarity.

Multivariate analysis

These analyses aimed to distinguish any groupings of the stations on basis of similarity in fauna composition. The similarity matrix between all pairs of stations was the basis for the analysis. The two following methods were applied.

Group average clustering (Lance and Williams 1967). This is an hierarchical technique which first clusters those samples showing the greatest similarity, then computes an overall new similarity matrix regarding already established clusters as units, then performs a new clustering according to the new matrix, and repeating this process until all stations have been clustered. The final cluster pattern is plotted as a dendrogram.

Ordination by non-metric multi-dimensional scaling (MDS) (e.g. Kruskal and Wish 1978). This technique attempts to produce a 'map' of the stations in which the more similar 2 stations are in value of the Bray-Curtis index the nearer they are to each other on the map. The map can be constructed in 2 or more dimensions on the computer, but is projected down to 2 (or sometimes 3) dimensions for graphical presentation and interpretation. It thus follows that the scales of the MDS maps are arbitrary. The degree to which the relations can be adequately represented by (in our analysis) 2 dimensions is expressed by a 'stress' factor given in each instance.

Correlation analysis.

The correlation coefficient measures the degree of correspondence in variation between pairs of fauna and/or environmental characters. The Pearson Product Moment Correlation Coefficient has been applied as expressed by:

$$r = \frac{\Sigma\ (x - \overline{x})\ (y - \overline{y})}{\sqrt{(x - x)^2 (y - y)^2}}$$

where x = the value of character X at station i
y = the value of character Y at station i
$\overline{x}$ = average value of X across all b stations
$\overline{y}$ = average value of Y across all b stations
b = number of stations

The significance of the correlation coefficients was tested on basis of critical values of t according to the expression:

$$t = \frac{r}{\sqrt{(1-r^2)/(b-2)}}$$

and with b-2 degrees of freedom. The levels of rejection were 1 % and 5 %.

7. RESULTS AND DISCUSSION

7.1. Sediment characteristics

7.1.1. Particle size distribution

The results of this analysis are summarised in Table 7.1.1. Full grain size distribution data are given in Appendix 2. The values for sediment Φ (phi) mean ranged from 2.785 (fine sand) at Station 11 to 4.638 (coarse silt) at Station 10. The average Φ mean was 3. 835 (very fine sand). The average Φ standard deviation was 1.631 indicating poorly sorted sediments, and only one station had Φ standard deviation below 1 (0.739, Station 1, moderately sorted). The Φ skewness values were with one exception clearly positive showing a displacement of the the size distribution towards the finer grains. At Station 1 the value was -0.027 reflecting a symmetrical distribution around Φ mean. The Φ kurtosis values were all fairly close to 1 indicating no serious deviation from a normal distribution of size classes. The fine nature of the sediment is reflected in a very high % silt/clay or "mud" content ranging from 25.6 % to 64 % with an average of 44.1 %.

The glaciomarine deposits forming the topmost sea floor sediments at Heidrun demonstrate the random distribution typical for such deposits, especially for the coarser fraction of the particles. Ice rafted detritus usually has a patchy distribution due to icebergs shedding the sediment when overturning or when melting after having been grounded. In addition comes the smooth topography at Heidrun which does not influence the sediment distribution by slope processes or water movement scouring. This random distribution of grain size can be illustrated by the two stations 10 and 11 only 250 m apart having the widest range in Φ mean of all samples.

Still some discrete trends could be seen in the particle size distribution. There was a tendency of more fine grained median values towards the north, probably reflecting the gentle slope towards a bottom depression north of Heidrun. Also the % silt/clay increased in the NE direction. The standard deviation data showed a trend of poorer sorting also in the NE direction, although the poorest sorting was found at the reference station to the NW. There were no clear trends in the skewness or kurtosis values.

Table 7.1.1. Summary of sediment grain size characteristics in the Heidrun field. June 1988.

Station	Phi median	Deviation	Skewness	Kurtosis	% mud
1	3.307	0.739	-0.027	- -	25.6
2	3.568	1.545	0.241	1.232	34.3
3	3.495	1.603	0.244	0.986	32.8
4	3.338	1.601	0.343	1.071	29.3
5	4.414	1.628	0.324	0.770	55.7
6	3.645	1.782	0.155	1.128	39.7
7	3.624	1.663	0.222	1.114	36.7
8	3.528	1.592	0.261	1.114	35.3
9	3.434	1.624	0.263	1.170	30.0
10	4.638	1.510	0.178	1.226	64.0
11	2.785	1.848	0.276	1.137	26.0
12	3.702	1.584	0.423	1.433	43.1
13	3.671	1.584	0.324	1.030	41.2
14	3.536	1.734	0.271	0.947	39.1
15	4.008	1.695	0.259	1.197	50.4
16	4.024	1.643	0.318	1.207	50.9
17	3.760	1.827	0.275	1.185	45.1
18	3.560	1.655	0.394	1.095	39.5
19	3.909	1.721	0.297	1.067	48.1
20	4.598	1.718	0.194	1.105	60.9
21	4.270	1.658	0.235	1.155	54.8
22	4.092	1.619	0.274	1.127	52.2
23	4.238	1.671	0.238	1.087	54.2
24	4.601	1.892	0.177	1.043	59.8
25	4.120	1.643	0.297	1.139	53.1
Max. value	4.638	1.892	0.423	1.433	64.0
Min. value	2.785	0.739	-0.027	0.770	25.6
Average	3.835	1.631	0.260	1.111	44.1

7.1.2. Redox conditions

The average for the total data set was +456 mV ranging from +363 mV at Station 6 to +529 mV at Station 13 (Table 7.1.2). These values are typical for well-oxygenated sediments, and showed no trends across the sampling field.

In comparison the values for Eh at 2cm measured during the 1985 baseline survey gave an average of +503 mV over the whole Haltenbanken region, ranging between +353 and +550 mV. The values for baseline stations corresponding to stations in the present survey are given in Table 7.1.2.

Table 7.1.2. Eh measurements (mV) at 2 cm sediment depth made during the Heidrun field survey, June 1988.

Station number	Corrected values at 2 cm	Corresponding 1985 station number (IKU 1986)	1985 value at at 2 cm (mV)
1	+470		
2	+414		
3	+466	4	+353
4	+476		
5	+516		
6	+363		
7	+459		
8	+411		
9	not determined		
10	+372		
11	+406		
12	+474		
13	+529		
14	+495		
15	rejected		
16	rejected		
17	+378		
18	not determined		
19	+491		
20	+449		
21	rejected		
22	+470		
23	+483		
24	+500	3	+507
25	+496		

7.2 Chemical characterisation of sediments

General remarks

In the discussion of the results from the chemical analysis it is important to recognize whether the observed differences between data sets from different sites are significant or not. In the present survey, the results from each sampling site are given as mean values ± standard deviation. In those cases where results from different sites and areas were compared, the significance of the difference was determined by assuming that the respective values followed a Student-t distribution (Box et al. 1978). The same statistical test was employed in the calculation of limits of significant contamination (LSC) for further monitoring surveys. In general, a significance (p) of more than 0.99 was requested to name two data sets as "significantly different" from each other.

7.2.1 Total organic carbon (TOC) content

General comments

The TOC content of recent, unpolluted sediment is frequently related to the grainsize characteristics; finer sediments contain higher levels of TOC than coarse sediments. The medium and fine grain sandy sediments of the North Sea plateau typically contain TOC concentrations of less than 1 percent (Dicks 1976, Moore 1983, Oppenheimer et. al. 1977). In the environmental survey at Haltenbanken (Bowler & al. 1986) TOC content in the sediments was found to vary from 0.25 to 0.56 w%, with an average of 0.40 w%.

Sources of organic material which may be discharged during drilling operations include drilling fluid components (eg. baseoil, lignosulphonate, emulsifiers), platform discharge and domestic waste. Cuttings may also comprise a significant source of organic carbon, especially when being discharged during drilling through organic rich shales and bitumen-stained sandstone. Sediment TOC contents up to several percent have been found in the close surroundings (inside a few hundred meters) of the point of discharge of North Sea fields (Bowler et al. 1987).

The present survey

The results from the TOC analysis, given in Table 7.2.1, ranged from 0.44% to 0.63% with an average value for the whole field of 0.52 ± 0.047%. Duplicate samples showed agreement within ± 5% (see Table 7.2.1). Compared to the Haltenbanken survey (Bowler et al. 1986) these results were a little higher, but the difference was of poor significance ($0.75<p<0.90$). The values found at the two common sites for the two surveys showed the same trend; 0.51% vs. 0.38% for Station 3 (Station 4 in Bowler et al. 1986) and 0.51% vs. 0.48% for Station 24 (Station 3 in Bowler et al. 1986) It should be noted that a difference in sampling technique was evident for the two surveys. In the present survey efforts were made to limit the subsampling to the 0-1 cm layer. During the 1985 Haltenbanken survey the 0-2 cm layer was defined as the layer to be subsampled. Since the TOC content in general decreases with increasing sediment depth, this may have influenced the result.

Dividing the results into two different data sets, one for the four EPS transects and one for the Platform transects, showed no significant difference between the average TOC levels in these areas. The mean TOC values were 0.51 ± 0.054% and 0.52 ± 0.037% respectively.

7.2.2 Total hydrocarbons (THC) in sediments - screening analysis

General comments

Infrared spectrometry is commonly used as a screening test of the hydrocarbon content of sediments. The method involves measurement of the transmission of IR light at 2930 cm-1, which is a wavelength regarded as selective for determination of hydrocarbon content. However, no separation or isolation step is involved prior to analysis, so interferences with more polar compounds may occur. Previous surveys have shown that hydrocarbon levels in noncontaminated North Sea sediments determined by IR, range below 50 mg/kg.

The present survey

The results from the IR screening analysis of the sediments are given in Table 7.2.2. The THC level measured by IR ranged from 1.0-10 mg/kg dry weight with a mean value of 4.9 ± 2.5 mg/kg. The observed levels are typical for a nonpolluted sediment having the characteristics described in section 7.1, and were in good accordance with the gravimetric THC results from the 1985 Haltenbanken survey (Bowler et al. 1986). Comparison of the two field areas (EPS and Platform transects) showed that the mean value of the EPS sediments was slightly lower than for the sites along the Platform transects, 4.1 ± 2.4 and 6.0 ± 2.2 mg/kg, respectively. However, the significance of this difference was poor and the total area is therefore regarded as homogenous with respect to IR THC results.

7.2.3 Total hydrocarbons (THC) in sediments

General comments

The term "total hydrocarbon", THC, used in the environmental surveys of offshore installations in the North Sea describes the nonpolar hydrocarbon fraction extracted from the sediments and isolated by adsorbtion chromatography. The techniques accepted for extraction, isolation and analysis of THC during environmental surveys in the Norwegian sector of the North Sea are specified by the Guidelines for environmental monitoring of petroleum installations in the Norwegian sector of the North Sea (CMS 1987). To summarize, these include soxhlet, ultrasonic or saponification extraction, isolation by adsorbtion chromatography, and quantification of THC by gas chromatography/flame ionization detection (GC/FID) in the boiling point range C_{12}-C_{35}.

During the previous environmental baseline and monitoring surveys several different analytical techniques have been employed in the THC determination. Consequentially, direct comparison of THC values from different North Sea areas may be difficult. In general, THC background levels in the North Sea area are in the range 0.50-50 mg/kg, with the majority of the values being towards the lower end of the range. THC background levels determined by GC/FID vary from 0.50-20 mg/kg, and are in the lower part of the THC range found elsewhere (Miljøplan and SI 1985,Rygg et al. 1986, Johnsen and Maisey 1987, Johnsen et al. 1987a and b).

In the previous Haltenbanken survey THC was determined by ultrasonic extraction followed by gravimetry/-Iatroscan analysis (Bowler et al. 1986). This method involves gravimetric determination of the total extractable organic matter (EOM) extracted ultrasonically after freeze-drying, followed by Iatroscan-thin layer chromatographic determination of the percent content of aliphatic, aromatic, "medium polarity" amd "high polarity" hydrocarbons. THC was determined as the sum of aliphatic and aromatic fractions. Previous investigations have shown that this method does not give accurate results for extremely low THC levels (in the lower part of the background range) (IKU, unpublished results). This is because of certain linearity problems connected to the Iatroscan detection, giving relatively high THC results for samples containing less than 10 percent THC in the EOM. However, in the Haltenbanken results the mean aliphatic/aromatic content of the EOM was more than 10 percent, meaning that the accuracy of the results in general was acceptable. The average THC content measured in the Haltenbanken survey was 4.0 ± 2.5 mg/kg dry weight.

The present survey

The mean THC levels and their respective standard deviations are given in Fig. 7.2.1 and 7.2.2 (EPS and Platform transects respectively). The common axis between the EPS and Platform site is included in both figures. The detailed results (including all sample replicates) are given in Table 7.2.3. The mean values for the EPS, the Platform and the total Heidrun field samples are also included in the table. The THC levels ranged from 0.80-8.99 mg/kg (dry weight), with a mean value of 2.92 ± 1.35 mg/kg. These results were in the same range as for North Sea sediments analysed in previous environmental surveys. The mean THC levels for the EPS and Platform sites were 2.73 ± 1.14 and 3.15 ± 1.52 mg/kg respectively. The significance of this difference was very poor ($p<0.4$), so the two areas must be regarded as similar in THC content. Comparing the mean THC values of the different sites one by one showed that all the observed differences were of relatively poor significance ($p<0.9$), i.e. the variance in the results was due to natural variations.

Appendix 3, pp 113-137, show THC chromatograms from all sites. The chromatograms verified the above observation of the Heidrun sediments representing an undisturbed area. The qualitative variation in the data was rather low, showing that the sampling area represented an homogenous sediment.

Compared with the results from the Haltenbanken survey (Bowler et al. 1986), the average THC level found in the present survey was slightly lower (2.92 vs. 4.0 mg/kg). However, when the variation in the results was considered, no significant difference between the two data sets was detected. As described above, the gravimetric/Iatroscan determination of THC is not very reliable for low-level background values, meaning that the present analysis probably give a more accurate measurement of the natural THC content in the Heidrun sediments.

7.2.4. Selected hydrocarbons by GC/MS.

The present survey.

The aliphatic and aromatic fraction from the column separation step (cf. Fig. 6.2.1) were analysed by GC/MS for selected aliphatic and aromatic compounds. In addition to the analyses required by the SFT guidelines (CMS 1987), the content of n-alkanes and isoprenoids were determined in the aliphatic fraction. For the aromatic fraction, the number of compounds analysed was extended to include 4-6 ring aromatic hydrocarbons in addition to the NPD (cf. Table 6.2.4).

During the analytical work-up procedure all solvent was evaporated from the sample extract, and it was left in an open vial and air dried to remove traces of polar solvents. This treatment of the sample may have resulted in evaporation of volatile compounds and hence may have influenced the quantitative results.

In previous investigations n-alkanes and isoprenoids have been determined quantitatively by GC, while GC/MS analysis was applied for n-alkane determination in the present investigation. Due to variation in GC/MS response factors and sensitivity problems during the analysis, the aliphatic parameters were also determined from the GC analyses of the nonpolar THC fraction, by using squalane as an internal standard, and these results were used in comparison with previous results.

Conoco Norway have acknowledged the problems identified by IKU during the work-up/analysis of GC/MS samples. In order to clarify the situation and obtain further information on procedural amendments which may be required in future monitoring studies, an intercalibration exercise will be carried out. As a contingency measure, additional hydrocarbon samples were taken at two stations during the Heidrun baseline survey and these will be released to allow the appropriate level of interlaboratory/interprocedural analysis to be undertaken.

Normal alkanes

The chromatograms of THC given in Appendix 3 (pg. 113-137) show the n-alkane homologous series ranging in carbon number for C_{10}-C_{37}. Some variations in the n-alkane profiles were observed both between and within the different stations, but no significant quantitative or qualitative trends were detected for the total survey area. The observed variations are typical for a noncontaminated marine sediment.

Appendix 3, pg. 140-141, shows the alkane profile from GC/FID and GC/MS analysis of sample 1 from the sites 24 (reference) and 25. Comparison of the two methods shows that n-alkanes < C_{17} in the GC/MS traces had a relatively low abundance, and for many of the samples these compounds were detected at concentrations below the limit of quantification (cf. Table 6.2.5). The reasons for this were probably the evaporation and GC/MS sensitivity problems described above.

Because of this effect and the fact that the GC/FID analysis were used for n-alkane and isoprenoidal determination in previous surveys (IOE 1987), the results from the GC/FID analysis of the nonpolar TAC (total n-alkane compound) fraction were used in the comparison of the present results with other North Sea background values. Table 7.2.8 shows the sediment concentrations of n-alkanes at the different sites, ranging from 79 to 382 µg/kg dry sediment. These results were in the lower range compared to other background North Sea sediments (IOE 1987). The table also shows the total concentration of higher n-alkanes, C_{26}-C_{35}, ranging from 57 to 172 µg/kg, also comparable to previous results (IOE 1987). No significant variations were observed between the EPS and Platform field area.

Normal alkane CPI (carbon preference index) values were determined by calculating the ratio of odd to even n-alkanes in the carbon number ranges C_{12}-C_{35} and C_{26}-C_{35}. Higher plants have a predominance of odd carbon numbered C_{27}-C_{33} n-alkanes in their leaf waters (Douglas and Eglinton 1966) and this is often reflected in marine sediments containing material from this source (Farrington and Tripp 1977).

The CPI values given in Table 7.2.9 were relatively high for both carbon number intervals, ranging from 1.07-1.68 and 1.64-2.73 for the intervals C_{12}-C_{35} and C_{26}-C_{35} respectively. This would suggest a considerable hydrocarbon input from biogenic sources.

Isoprenoids

The concentrations of the isoprenoids, pristane and phytane, as measured by GC/FID are shown in Table 7.2.12. As for the n-alkanes, a homogenous distribution over the total Heidrun area was demonstrated. The results were in the same range as observed in the Vanguard baseline survey (IOE 1987) and other baseline surveys in the British sector of the North Sea.

Pristane and phytane are known as constituents of petroleum, but pristane has also been widely found in marine organisms (Quirk et al. 1980). The pristane/phytane ratio has therefore been suggested as a measure for biogenic/petrogenic input to the sediments (IOE 1987). In the present survey, the pristane/phytane ratio ranges from 0.91 to 2.01, which indicated only moderate additional biogenic input of hydrocarbons to the existing petrogenic hydrocarbons in the sediments. Hence, this result was not in accordance with the observations made for n-alkanes and aromatic compounds.

Bicyclic aliphatic compounds - decalines

Bicyclic aliphatic compounds, the decalines, have been suggested as tracers for oil based drilling fluids. The compounds are normally found at very low levels, if detected at all, in North Sea background sediments (Johnsen and Maisey 1987, Johnsen et al. 1987b) In the Heidrun sediments, bicyclanes were not detected in any of the samples, including the blank samples. As a result no limits of detection and quantification could be determined from the present investigation.

Naphthalenes, phenanthrene and dibenzotiophenes - NPD.

The results from the NPD analyses are given in Table 7.2.7. The total NPD content ranged from 3.7 - 30 and 8.3 - 29 µg/kg dry sediment for the EPS and platform sites respectively. This was in the range expected for a natural, noncontaminated sediment. At Station 7 (EPS 135^0/1000 m) the NPD content was lower than at the other locations. This result could not be explained by any of the other chemical, physical or biological parameters determined and was probably due to analytical effects. As examples of the homogeneous NPD distribution over the total field, fragmentograms from Stations 7 and 24 (reference site) are shown in Appendix 3, pg. 142-151.

As mentioned above, the results for naphthalenes were influenced by the evaporative loss of these relatively volatile compounds during the analytical work-up procedure. The internal standard, d_{10}-biphenyl, partly accounted for the loss of the naphthalene homologues, but not for the parent compound itself. The naphthalene results given in Table 7.2.7 will therefore probably not reflect the real naphthalene concentrations in the sediments.

As a result the determined concentrations of naphtalenes were not directly comparable to, and generally lower than the result obtained in the 1985 Haltenbanken environmental baseline survey (Bowler et al. 1986). For the two common sites of the to surveys, Stations 3 and 24 in the present survey, the concentrations of phenanthrenes and dibenzotiophenes were in the same range. The total NPD concentrations were generally in the lower range of concentrations found in North Sea sediments, and this is probably due to the evaporation problems discussed above.

Aromatic compounds from a petrogenic source show a preference for alkylated homologues to parent PAH, while aromatics from combustion sources show preference of parent compound to alkylated homologues. Previous surveys from the North Sea have shown that background PAH levels in the sediments are of a petrogenic origin (Johnsen et al. 1987b). The present results did not show a typical petrogenic composition, and in fact indicated only limited influence of PAH from petrogenic sources. The observation was in accordance with the CPI indices determined from n-alkane profiles.

In addition to the NPDs, the concentrations of 4-6 ring aromatic compounds in the Heidrun sediments were determined. These results are also given in Table 7.2.7. With the exception of pyrene and fluoranthene, which were detected at concentration levels typical for background North Sea sediments, few data from background sediments from other areas of the Norwegian sector of the North Sea are available for comparison. However, the present results were in the higher range of concentrations found previously in the British sector of the North Sea (IOE 1987), but there is no reason to believe that the determined concentrations did not reflect a natural input of aromatic compounds to the Heidrun environment.

7.2.5 Vertical distribution of hydrocarbons at selected sites.

At locations EPS 130^0/250 m and 2500 m (Stations 10 and 8) vertical sectioning of core samples into 0-1, 1-3 and 3-6 cm layers was performed. The sections were analysed for THC content by GC/FID and aliphatic and aromatic compounds by GC/MS. Due to the limited amount of sediment available from the 0-1 cm sections, IR analysis was not performed.

The THC concentrations of the different sediment sections are given in Table 7.2.3. The detected THC levels (1.86-2.83 mg/kg) were in the same range as the levels found at the other sites included in the survey, and the THC concentration found in the upper 0-1 cm section corresponded well with the results from the respective sites in the main analytical programme. No significant difference was observed between the THC concentrations in the different vertical sediment layers, even though the results from Station 8 indicated a decreased THC content with increasing sediment depth.

The total concentrations of n-alkanes and isoprenoids and the CPI indices given in Table 7.2.10 also correlated well with the results from the analysis of the surface sediments. No significent trends of variation with increasing depth were observed for these parameters, with the exception of the CPI values of Station 8 which showed increasing biogenic hydrocarbon input to the two lower sediment layers. The pristane/phytane ratio also showed good correlation with the results from the surface sediment samples.

Table 7.2.11 shows the concentrations of NPD and 4-6 ring aromatic compounds in the vertical sections from Stations 8 and 10. The concentrations of the different compounds and compound classes were within the range found in the surface samples, and no significant change with sediment depth was observed.

7.2.6 Trace metals in sediments

General comments

The content of cadmium, chromium, copper, lead, nickel, vanadium, zinc, iron, barium, strontium and mercury was determined using triplicate subsamples from surface sediments (0-1 cm) from each sampling site. The work up and analysis of the trace elements followed the techniques described by "Norsk Standard NS 4770", which gives the bioavailable metal content of the sediments. In previous surveys, among these the environmental baseline survey at Haltenbanken (Bowler et al. 1986), the total amount of heavy metals has been determined. Calibration studies have shown that the results from these two methods are not directly comparable (IKU unpublished results). The total content of metals in nonpolluted sediments is, as could be expected, much higher than the bioavailable content.

The elements strontium and barium are of particular interest in connection with drilling activities, since they are known as sensitive tracers for drilling fluids. In particular, barium is commonly used as a tracer for distribution of drilling fluids (barite) (Kennicutt et al. 1983, Trocine and Trefry 1983). The other elements included in the present survey were basically limited to a selection of heavy metals which occur as trace impurities in the constituents of the drilling fluids and which may constitute a potential toxicological hazard.

The present survey

The content of the different elements in the Heidrun sediments is given in Table 7.2.4 as mg/kg dry weight. For each site the mean value and SD of the subsamples are given. As seen from the table, mercury was not detected in any of the subsamples. This was in good accordance with observations from other environmental surveys (Johnsen and Maisey 1987, Johnsen et al. 1987b) Because of the differences in the analytical methods, the remaining results were not comparable with the results obtained in the Haltenbanken environmental baseline survey. However, since the hydrocarbon analysis clearly showed that the sediments sampled during the present survey represented a noncontaminated seabed surface, the results from the 1988 survey heavy metal analysis represented true background trace metal levels. Comparison with other noncontaminated sediments where the bioavailable metal content has been determined, verified this suggestion and showed no major differences for the metals included (Johnsen and Maisey 1987, Johnsen et al. 1987b).

The content of barium, which in future monitoring will be of great importance, ranged from 58-410 mg/kg with an average of 160 ± 80 mg/kg. For one subsample, site 4 (EPS 234^0/500m), the barium content was 1200 mg/kg. As a safety precaution this particular sample was reanalysed, but the same barium content was found. No indications of contamination at this site were observed for any other element or chemical parameter analysed. However, Station 4 is positioned only about 100 m from the site of exploratory well 6507/7-4 (cf Fig. 4.1) completed in 1986, and the UTM postiton of the single samples suggested that the sample in question was taken furthest in the direction of the well. The elevated barium content of the subsample could therefore reflect the nearby drilling activity. Another interesting observation from the barium analysis, was that the level at the reference site (Station 24) was lower than for some of the other sites, 65 ± 5.1 mg/kg. This may reflect natural variability in the sediment composition, and should be noted when the limit of significant barium contamination is discussed in future monitoring surveys. Except for this observation, no evidence of zonation within the survey area was present.

For all the remaining elements included, no evidence of high concentration zones within the survey area was found. This is in good accordance with the results obtained in the Haltenbanken environmental baseline survey, which as described earlier included two of the actual Heidrun sampling sites (3 and 24). In Table 7.2.4, the total mean and standard deviation from all subsamples are given, and from these results the limits of significant contamination for future monitoring surveys was determined (Box et al., 1978). These are given in Table 7.2.5. Compared to other baseline surveys where similar analytical techniques have been employed, the LSC's from the very comprehensive Heidrun data material generally showed good to fair agreement.

7.2.7 Correlation of the chemical parameters

As discussed in sections 7.2.2 and 7.2.3, the THC results determined by IR and GC/FID were slightly higher in the Platform (NE) area of the field than in the EPS (SW) area. It was emphasized that these differences were of poor significance, and that the total field was regarded as homogeneous. Table 7.2.6 gives the correlation coefficients from cross-correlation of all chemical parameters determined in the present survey. The low correlation between TOC and the two THC results verified the suggestion of the survey area as being a nonpolluted homogeneous field. No evidence or zonation was observed for the TOC or THC content in the sediments.

For the comparison of the present results with future environmental monitoring surveys, the limit of significant contamination (LSC) of the different contaminants was calculated from all subsamples. These are included in Table 7.2.5. The LSC's were determined by assuming that the natural contents of TOC and THC in sediments followed a Student-t distribution (Box et al., 1978). In future surveys, these results should be used in the discussion of contamination together with reference site results from the actual survey.

In this connection it is important to note that the LSC values for IR determination ($p>0.95$) and GC/FID determination ($p>0.95$ and $p>0.99$) of

THC in fact were lower than the maximum THC levels detected in the present survey. The reason for this was that one or two of the measured THC values were somewhat higher than the rest, although they still represented natural variation in sediment composition. Hence, these results fell outside the confidence limits described by the mean THC values and their respective standard deviations, even though these confidence limits described the data with a very high degree of certainty. In future surveys this should be kept in mind, and care must be taken in interpretation when the LSCs are used for a decision on whether or not a particular site is contaminated.

The cross-correlation of heavy metal concentrations gave the same result as for TOC and THC. No significant correlation between any of the elements was observed, i.e. no evidence of zonation was present. Correlation of the organic and the inorganic chemical parameters gave similar results. In conclusion, the sediment samples collected in the present survey represented an homogeneous, nondisturbed seabed.

Table 7.2.1 Total organic carbon (TOC) content in sediments (% weight) from the Heidrun field, June 1988.

Sampling site	Position	TOC%	Mean ± SD
1	EPS 230^0/5000	0.49	
2	EPS 234^0/2500	0.45	
3	EPS 234^0/1500	0.51	
4	EPS 234^0/500	0.51	
5	EPS 315^0/2500	0.63	
6	EPS 315^0/1000	0.46	
7	EPS 135^0/1000	0.47	
8	EPS 135^0/2500	0.47	
9	EPS 135^0/5000	0.46/0.44*)	
10	EPS 73^0/250	0.55	
11	EPS 73^0/500	0.47	
12	EPS 73^0/1000	0.59	
13	EPS 73^0/1750	0.55	EPS 0.51±0.054
14	P 315^0/2500	0.54	
15	P 315^0/1000	0.57	
16	P 135^0/1000	0.52	
17	P 135^0/2500	0.54	
18	P 135^0/5000	0.51/0.52*)	
19	P 45^0/250	0.58	
20	P 45^0/500	0.50	
21	P 45^0/1000	0.44	
22	P 45^0/2500	0.51	
23	P 45^0/5000	0.52	
24	REF P 315^0/17 km	0.53	P 0.52±0.037
25	EPS 135^0/500	0.54	
TOTAL			0.52±0.047

*) Repeatability test. Duplicate analysis of selected samples.

Table 7.2.2 Hydrocarbon content in Heidrun sediments, June 1988, mg/kg dry weight. IR analysis. (Average of blank samples has been subtracted from the results).

Site	Position	Content	Site	Position	Content
1	EPS 230^0/5000	6.1	14	P 315^0/2500	4.3
2	EPS 234^0/2500	2.3	15	P 315^0/1000	6.5
3	EPS 234^0/1500	3.3	16	P 135^0/1000	4.9
4	EPS 234^0/500	8.7	17	P 135^0/2500	10.0
5	EPS 315^0/2500	3.2	18	P 135^0/5000	8.5
6	EPS 315^0/1000	9.5	19	P 45^0/250	7.2
7	EPS 135^0/1000	1.0	20	P 45^0/500	7.7
8	EPS 135^0/2500	3.1	21	P 45^0/1000	3.2
9	EPS 135^0/5000	3.5	22	P 45^0/2500	3.1
10	EPS 73^0/250	2.9	23	P 45^0/5000	4.6
11	EPS 73^0/500	3.0	24	REF P 315^0/17 km	5.6
12	EPS 73^0/1000	2.9	25	EPS 135^0/500	3.4
13	EPS 73^0/1750	4.1			

Average of blank samples 0.37

EPS	Mean ±SD	4.1±2.4
P	Mean ±SD	6.0±2.2
TOTAL	Mean ±SD	4.9±2.5

Table 7.2.3 Total hydrocarbon content in Heidrun sediments - GC/FID. (mg/kg dry weight). Standard analysis and vertical sections of cores, June 1988.

Site no.	Position	Replicate no.			Mean ±SD
		1	2	3	
1	EPS 230°/5000	3.08	1.75	2.03	2.29±0.70
2	EPS 234°/2500	2.12	2.36	1.63	2.04±0.37
3	EPS 234°/1500	1.64	2.76	1.42	1.94±0.72
4	EPS 234°/500	3.82	7.53	4.38	5.91±1.56
5	EPS 315°/2500	3.52	3.56	2.10	3.02±0.83
6	EPS 315°/1000	3.52	3.32	3.58	3.44±0.13
7	EPS 135°/1000	2.10	3.20	2.59	2.63±0.55
8	EPS 135°/2500	2.62	0.80	0.87	1.48±1.03
9	EPS 135°/5000	1.74	2.64	2.88	2.42±0.60
10	EPS 73°/250	1.61	2.95	2.37	2.31±0.67
11	EPS 73°/500	3.08	2.91	2.33	2.77±0.39
12	EPS 73°/1000	1.85	2.36	3.01	2.40±0.58
13	EPS 73°/1750	2.61	3.00	2.47	2.69±0.27
14	P 315°/2500	2.50	3.75	2.90	3.05±0.63
15	P 315°/1000	3.60	2.50	4.99	3.72±1.24
16	P 135°/1000	1.87	2.64	1.19	1.90±0.72
17	P 135°/2500	1.78	1.92	2.29	2.00±0.26
18	P 135°/5000	1.86	1.57	2.12	1.85±0.39
19	P 45°/250	3.00	1.94	3.01	2.65±0.61
20	P 45°/500	2.85	2.00	3.69	2.85±0.81
21	P 45°/1000	2.98	1.76	2.02	2.35±0.64
22	P 45°/2500	8.99	2.83	4.55	5.46±3.18
23	P 45°/5000	4.24	4.43	3.50	4.05±0.49
24	REF P 315°/17 km	4.87	5.71	4.42	5.00±0.65
25	EPS 135°/500	5.02	2.90	2.80	3.54±1.25
EPS	Mean ±SD				2.73 ± 1.14
P	Mean ±SD				3.15 ± 1.52
All sites	Mean ±SD				2.92 ± 1.35

Site no.	Vertical section:	0-1 cm	1-3 cm	3-6 cm
8		2.83	2.24	1.86
10		2.22	2.19	2.40

Table 7.2.4. Concentration of heavy metals in Heidrun sediments, June 1988. (mg/kg dry weight).

Site	Position	Cd mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Ni mg/kg	V mg/kg	Zn mg/kg	Fe mg/kg	Ba mg/kg	Sr mg/kg	Hg mg/kg
1	EPS 234°/5000	0.072	33	9.0	16	17	27	30	12.2	82	210	<0.1
		0.081	21	7.8	18	17	30	35	14.8	97	230	<0.1
		0.066	20	6.4	15	15	30	31	12.8	71	210	<0.1
Mean ±SD		0.073±0.0095	25±7.2	7.7±1.3	16±1.5	16±1.2	29±1.7	32±2.6	13.3±1.36	83±13	220±12	
2	EPS 234°/2500	0.075	20	6.9	11	18	31	33	14.7	58	220	<0.1
		0.082	21	7.5	19	16	33	40	15.6	104	270	<0.1
		0.11	24	7.9	20	20	37	41	16.2	110	270	<0.1
Mean ±SD		0.089±0.08	22±2.1	7.4±0.50	17±4.9	18±2.0	34±3.1	35±4.4	15.5±0.75	91±28	250±29	
3	EPS 234°/1300	0.083	27	9.1	16	17	37	38	16.3	130	270	<0.1
		0.099	25	9.8	22	21	42	47	18.4	140	300	<0.1
		0.069	26	9.0	16	21	35	42	16.9	63	280	<0.1
Mean ±SD		0.084±0.015	26±1.0	9.3±0.44	18±3.5	20±2.3	38±3.6	42±4.5	17.2±1.08	110±42	280±15	
4	EPS 263°/515	0.081	23	9.3	16	18	35	46	16.5	1200	290	<0.1
		0.096	24	9.3	17	21	36	41	16.4	260	280	<0.1
		0.095	26	9.0	15	20	31	37	15.2	170	260	<0.1
Mean ±SD		0.09±0.0083	24±1.5	9.2±0.7	16±0.1	20±1.6	34±2.6	41±4.6	16.0±0.72	543±543	280±15	
5	EPS 315°/2500	0.11	31	12	20	29	50	56	22.2	104	370	<0.1
		0.11	29	12	29	26	51	56	22.1	110	370	<0.1
		0.10	28	11	29	27	53	56	22.2	94	370	<0.1
Mean ±SD		0.11±0.057	29±1.5	12±0.57	26±5.2	27±1.5	51±1.5	56	22.2±0.058	100±81	370	
6	EPS 301°/988	0.090	26	9.6	12	20	38	43	17.0	160	280	<0.1
		0.11	25	9.8	11	19	40	44	17.2	91	260	<0.1
		0.075	24	10.5	10	23	40	45	18.1	96	280	<0.1
Mean ±SD		0.092±0.018	25±1.0	10±0.47	11±1.0	21±2.1	39±1.2	44±1.0	17.4±0.59	120±38	270±12	

Table 7.2.4 *Cont.*

Site	Position	Cd mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Ni mg/kg	V mg/kg	Zn mg/kg	Fe mg/kg	Ba mg/kg	Sr mg/kg	Hg mg/kg
7	EPS 150°/1000	0.064	23	10.0	12	18	38	43	17.6	90	260	<0.1
		0.080	25	9.4	13	19	40	45	17.5	160	280	<0.1
		0.073	23	8.8	19	19	37	41	16.9	140	260	<0.1
Mean ±SD		0.072±0.0082	24±1.2	9.4±0.6	15±3.8	19±0.58	38±1.5	43±2.0	17.3±0.38	130±36	270±12	
8	EPS 150°/2500	0.088	27	8.5	13	19	32	36	15.0	300	250	<0.1
		0.073	18	6.4	17	18	36	39	16.1	320	220	<0.1
		0.084	25	8.5	10	18	33	39	15.7	340	250	<0.1
Mean ±SD		0.080±0.0061	23±4.7	7.8±1.2	13±3.5	18±0.58	34±2.1	38±1.7	15.6±0.54	320±20	240±17	
9	EPS 150°/5000	0.078	26	8.5	15	15	34	35	15.3	92	230	<0.1
		0.067	23	7.6	15	17	30	36	14.9	200	230	<0.1
		0.068	23	8.1	17	18	32	36	14.9	110	230	<0.1
Mean ±SD		0.078±0.010	24±1.7	7.9±0.83	16±1.2	17±1.5	32±2.0	36±0.58	15.0±0.23	130±58	230	
10	EPS 73°/250	0.064	28	8.8	17	19	36	44	17.9	120	290	<0.1
		0.086	28	9.7	17	21	39	47	18.1	150	300	<0.1
		0.066	25	9.2	18	20	36	45	16.9	220	290	<0.1
Mean ±SD		0.072±0.012	27±1.7	9.2±0.45	17±0.58	20±1.0	37±1.7	45±1.5	17.6±0.64	160±51	290±5.8	
11	EPS 73°/500	0.072	25	8.6	17	19	36	40	17.4	160	250	<0.1
		0.086	25	10.0	18	23	38	46	19.0	140	310	<0.1
		0.078	27	8.8	18	19	37	42	17.7	170	260	<0.1
Mean ±SD		0.079±0.007	26±1.2	9.1±0.76	18±0.58	20±2.3	37±1.0	43±3.1	18.0±0.85	160±15	270±32	
12	EPS 73°/1000	0.086	28	9.9	18	21	40	45	19.0	260	300	<0.1
		0.078	30	9.5	18	23	42	46	20.2	170	310	<0.1
		0.098	27	10.3	19	18	42	46	19.6	190	320	<0.1
Mean ±SD		0.087±0.01	28±1.5	9.9±0.4	18±0.58	21±2.5	41±1.2	46±0.58	19.6±0.6	210±47	310±10	

Table 7.2.4 *Cont.*

Site	Position	Cd mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Ni mg/kg	V mg/kg	Zn mg/kg	Fe mg/kg	Ba mg/kg	Sr mg/kg	Hg mg/kg
13	EPS 81°/1815	0.082	27	9.0	16	21	37	42	16.8	140	270	<0.1
		0.076	28	9.8	16	21	41	48	18.0	98	290	<0.1
		0.072	26	9.0	15	19	37	43	17.6	120	270	<0.1
Mean ±SD		0.077±0.005	27±1.0	8.9±0.12	16±0.58	20±1.2	38±2.3	44±3.2	17.5±0.61	120±21	280±12	
14	P 315°/2500	0.102	28	10.0	20	23	40	48	18.8	140	300	<0.1
		0.088	25	9.8	22	24	41	48	18.2	130	310	<0.1
		0.090	25	8.8	18	19	37	44	17.0	150	280	<0.1
Mean ±SD		0.093±0.0076	26±1.7	9.5±0.64	20±2.0	22±2.6	39±2.1	47±2.3	18.0±0.92	140±10	300±15	
15	P 315°/1000	0.064	25	8.5	16	20	35	45	16.5	100	270	<0.1
		0.098	22	8.8	18	19	36	45	16.8	220	270	<0.1
		0.088	26	8.5	14	20	36	43	16.3	190	280	<0.1
Mean ±SD		0.080±0.014	24±2.1	8.6±0.17	16±2.0	20±0.58	36±0.58	44±1.2	16.5±0.3	170±62	270±5.8	
16	P 135°/1000	0.078	21	8.6	20	21	35	45	16.3	200	270	<0.1
		0.078	22	8.2	17	18	34	43	16.0	250	260	<0.1
		0.078	21	7.8	16	17	33	42	15.2	190	260	<0.1
Mean ±SD		0.078	21±0.58	8.3±0.50	18±2.1	19±2.1	34±1.0	43±1.5	15.8±0.57	210±32	260±5.8	
17	P 135°/2500	0.076	23	7.9	18	18	31	41	14.7	400	260	<0.1
		0.073	23	7.9	17	20	32	42	15.1	190	230	<0.1
		0.13	20	8.1	16	17	32	40	14.4	410	280	<0.1
Mean ±SD		0.093±0.032	22±1.7	8.0±0.12	11±1.0	18±1.5	32±0.58	41±1.0	14.4±0.35	330±120	260±25	

Table 7.2.4 *Cont.*

Site	Position	Cd mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Ni mg/kg	V mg/kg	Zn mg/kg	Fe mg/kg	Ba mg/kg	Sr mg/kg	Hg mg/kg
18	P 135°/5000	0.093	22	7.3	19	16	29	39	13.7	200	240	<0.1
		0.074	16	6.3	14	17	29	35	13.2	240	230	<0.1
		0.066	21	6.8	12	16	28	36	13.4	160	220	<0.1
Mean ±SD		0.084±0.0096	20±3.2	6.8±0.5	15±3.6	16±0.58	29±0.58	37±2.1	13.4±0.25	200±40	230±10	
19	P 45°/250	0.096	20	8.5	20	18	34	44	16.0	330	290	<0.1
		0.080	21	8.1	18	18	34	43	15.9	260	280	<0.1
		0.080	20	7.6	14	15	32	40	15.0	310	270	<0.1
Mean ±SD		0.085±0.0092	20±0.58	8.1±0.45	17±3.1	17±1.7	33±1.2	42±2.1	15.6±0.55	300±36	280±10	
20	P 45°/500	0.100	23	8.6	15	20	36	45	16.8	240	280	<0.1
		0.100	25	8.5	14	19	35	43	16.0	89	270	<0.1
		0.094	24	9.3	22	21	38	46	17.3	270	310	<0.1
Mean ±SD		0.098±0.0035	24±1.0	8.8±0.44	17±4.4	20±1.0	37±2.1	45±1.5	16.7±0.66	200±97	290±21	
21	P 45°/1000	0.056	21	8.9	16	15	32	43	15.0	150	260	<0.1
		0.060	19	7.7	15	19	32	41	15.3	95	260	<0.1
		0.068	20	7.8	14	17	32	40	15.1	210	260	<0.1
Mean ±SD		0.068±0.017	20±1.0	8.0±0.49	15±1.0	17±2.0	32	41±1.5	15.1±0.15	150±58	260	
22	P 45°/2500	0.106	23	8.5	17	18	36	45	16.3	110	290	<0.1
		0.080	23	8.6	16	21	35	44	16.5	210	260	<0.1
		0.074	24	8.4	17	19	36	45	16.6	170	290	<0.1
Mean ±SD		0.087±0.017	24±0.58	8.5±0.1	17±0.58	19±1.5	36±0.58	45±0.58	16.5±0.15	160±50	280±17	

Table 7.2.4 *Cont.*

Site	Position	Cd mg/kg	Cr mg/kg	Cu mg/kg	Pb mg/kg	Ni mg/kg	V mg/kg	Zn mg/kg	Fe mg/kg	Ba mg/kg	Sr mg/kg	Hg mg/kg
23	P 45°/5000	0.074	21	8.5	17	20	36	45	16.8	83	270	<0.1
		0.078	24	9.0	19	22	38	51	18.1	85	290	<0.1
		0.078	22	8.5	16	21	37	46	17.0	78	280	<0.1
Mean ±SD		0.077±0.0023	22±1.5	8.7±0.29	17±1.5	21±1.0	37±1.0	44±2.6	16.9±0.64	82±3.6	280±10	
24	Ref.	0.099	28	9.5	15	23	38	50	17.7	64	300	<0.1
		0.096	24	10.1	22	24	41	55	19.3	71	320	<0.1
		0.080	24	9.1	15	19	38	48	17.9	61	310	<0.1
Mean ±SD		0.092±0.01	25±2.3	8.9±0.5	18±1.7	20±0.58	34±1.7	44±2.1	16.1±0.89	65±5.1	310±10	
25	P 150°/500	0.088	25	9.4	19	20	35	45	16.8	140	290	<0.1
		0.082	23	8.9	19	20	35	46	16.4	210	280	<0.1
		0.062	19	8.4	16	19	32	42	15.1	97	260	<0.1
Mean ±SD		0.072±0.014	22±3.1	8.9±0.5	18±1.7	20±0.58	34±1.7	44±2.1	16.1±0.89	150±57	280±15	
Total Mean ±SD		0.081±0.011	24±2.5	8.8±1.0	17±2.6	20±2.3	35±4.5	43±4.8	16.8±1.87	160±80	270±31	

Table 7.2.5 Limits of significant contamination TOC, THC and heavy metals, Heidrun field, June 1988.

	LSC mg/kg dry weight P>0.95	P>0.995
TOC	0.60 *)	0.64 *)
THC IR	9.1	12
THC GC/FID	5.17	6.51
Cd	0.098	1.1
Cr	28	31
Cu	10.4	11.5
Pb	21	24
Ni	24	26
V	43	47
Zn	51	56
Fe	20	22
Ba	290	370
Sr	320	350
Hg	-	-

*) given as percent of dry weight

Table 7.2.6. Cross correlation between TOC, THC and heavy metals.

Correlations:	CD	CR	CU	PB	NI	V	FE	ZN	BA	SR	HG
CD	1.0000 (25) P= .	.3758 (25) P= .032	.4770 (25) P= .008	.4593 (25) P= .010	.6422 (25) P= .000	.5562 (25) P= .002	.4972 (25) P= .006	.5202 (25) P= .004	.1696 (25) P= .209	.6060 (25) P= .001	.0000 (25) P= .500
CR	.3758 (25) P= .032	1.0000 (25) P= .	.8079 (25) P= .000	.4397 (25) P= .014	.7160 (25) P= .000	.7632 (25) P= .000	.7723 (25) P= .000	.4989 (25) P= .006	-.2235 (25) P= .141	.6242 (25) P= .000	.0000 (25) P= .500
CU	.4770 (25) P= .008	.8079 (25) P= .000	1.0000 (25) P= .	.5113 (25) P= .004	.8894 (25) P= .000	.9334 (25) P= .000	.9255 (25) P= .000	.8097 (25) P= .000	-.1879 (25) P= .184	.8674 (25) P= .000	.0000 (25) P= .500
PB	.4593 (25) P= .010	.4397 (25) P= .014	.5113 (25) P= .004	1.0000 (25) P= .	.6649 (25) P= .000	.6002 (25) P= .001	.5990 (25) P= .001	.5991 (25) P= .001	-.1571 (25) P= .227	.7123 (25) P= .000	.0000 (25) P= .500
NI	.6422 (25) P= .000	.7160 (25) P= .000	.8894 (25) P= .000	.6649 (25) P= .000	1.0000 (25) P= .	.9331 (25) P= .000	.9194 (25) P= .000	.8977 (25) P= .000	-.2181 (25) P= .147	.9082 (25) P= .000	.0000 (25) P= .500
V	.5562 (25) P= .002	.7632 (25) P= .000	.9334 (25) P= .000	.6002 (25) P= .001	.9331 (25) P= .000	1.0000 (25) P= .	.9779 (25) P= .000	.8570 (25) P= .000	-.2871 (25) P= .082	.9080 (25) P= .000	.0000 (25) P= .500
ZN	.5202 (25) P= .004	.4989 (25) P= .006	.8097 (25) P= .000	.5991 (25) P= .001	.8977 (25) P= .000	.8570 (25) P= .000	1.0000 (25) P= .	1.0000 (25) P= .000	-.2074 (25) P= .160	.9449 (25) P= .000	.0000 (25) P= .500
ZN	.5202 (25) P= .004	.4989 (25) P= .006	.8097 (25) P= .000	.5991 (25) P= .001	.8977 (25) P= .000	.8570 (25) P= .000	.8752 (25) P= .000	1.0000 (25) P= .	-.2074 (25) P= .160	.9449 (25) P= .000	.0000 (25) P= .500
BA	.1696 (25) P= .209	-.2235 (25) P= .141	-.1879 (25) P= .184	-.1571 (25) P= .227	-.2181 (25) P= .147	-.2871 (25) P= .082	-.2531 (25) P= .111	-.2074 (25) P= .160	1.0000 (25) P= .	-.1290 (25) P= .269	.0000 (25) P= .500

Table 7.2.6 Cont.

Correlations:	CD	CR	CU	PB	NI	V	FE	ZN	BA	SR	HG
SR	.6060 (25) P= .001	.6242 (25) P= .000	.8674 (25) P= .000	.7123 (25) P= .000	.9082 (25) P= .000	.9080 (25) P= .000	.9222 (25) P= .000	.9449 (25) P= .000	-.1290 (25) P= .269	1.0000 (25) P= .	.0000 (25) P= .500
HG	.0000 (25) P= .500	.0000 (25) P= .500	.0000 (25) P= .500	.0000 (25) P= .500	.0000 (25) P= .500	.0000 (25) P= .500	.0000 (25) P= .500	.0000 (25) P= .500	.0000 (25) P= .500	.0000 (25) P= .500	1.0000 (25) P= .
THC	.2947 (25) P= .076	.1443 (25) P= .246	.3458 (25) P= .045	.0694 (25) P= .371	.3716 (25) P= .034	.2324 (25) P= .132	.2650 (25) P= .100	.4487 (25) P= .012	.0784 (25) P= .355	.3676 (25) P= .035	.0000 (25) P= .500
TOC	.4570 (25) P= .011	.4388 (25) P= .014	.4810 (25) P= .007	.6842 (25) P= .000	.5639 (25) P= .002	.5245 (25) P= .004	.5326 (25) P= .003	.6167 (25) P= .001	.0795 (25) P= .353	.6825 (25) P= .000	.0000 (25) P= .500
IR	.3504 (25) P= .043	-.2713 (25) P= .095	-.2013 (25) P= .167	-.2679 (25) P= .098	-.1544 (25) P= .231	-.3107 (25) P= .065	-.3570 (25) P= .040	-.1460 (25) P= .243	.4532 (25) P= .011	-.1801 (25) P= .195	.0000 (25) P= .500

Table 7.2.7 *Concentrations µg/kg dry weight of 2-6 ring aromatic hydrocarbons in Heidrun sediments, EPS (site 1-13 and 25).*

Site Compounds	1*	2	3	4	5	6	7	8	9*	10	11	12	13	25
Naphthalene	0.52	0.046	0.44	3.7	1)	1)	0.047	0.065	0.20	0.78	0.39	0.064	0.56	0.27
C_1-homolog	0.71	1)	1)	0.89	1)	1)	1)	0.026	0.16	0.19	1)	1)	0.14	0.10
C_2-homolog	1.7	1.5	1)	3.7	0.22	1)	1)	0.17	2.04	0.83	0.7	1)	1.0	0.68
C_3-homolog	1.33	3.1	1)	3.0	0.67	1)	1)	1)	2.0	0.85	0.80	1)	1.0	1.3
Total	4.04±4.22	4.6	0.44	11	0.89	1)	1)	1)	4.6	2.6	2.1	1)	2.7	2.4
Phenanthrene	4.2	6.5	4.3	11	3.7	6.5	1.1	3.3	5.0	5.6	3.8	2.9	6.3	4.4
C_1-homolog	5.7	8.5	5.5	5.2	9.1	3.7	0.74	8.6	7.2	3.8	5.0	3.6	7.9	5.9
C_2-homolog	2.8	2.7	1.6	0.82	2.1	3.0	1.1	3.7	2.6	4.7	2.5	2.7	1.6	3.5
C_3-homolog	1.1	0.87	0.35	1.2	0.43	1)	0.44	1.1	0.63	2.2	1.6	1.3	0.26	1.7
Total	14±3.7	19	12	18	15	13	3.4	17	15±7.0	16	13	11	16	16
Dibenzothiophene	0.26	0.47	0.19	0.40	0.16	0.10	0.057	0.18	0.17	0.49	0.31	0.18	0.21	0.30
C_1-homolog	0.21	0.42	0.16	0.12	0.44	0.24	0.033	0.41	0.34	0.18	0.40	0.18	0.27	0.34
C_2-homolog	0.25	0.29	0.10	1)	0.12	0.73	0.23	0.45	0.33	0.39	0.44	0.25	0.16	0.41
C_3-homolog	0.12	0.082	0.036	1)	0.052	1)	1)	0.16	0.12	0.31	0.25	0.21	0.050	0.28
Total	0.80±0.12	1.3	0.49	0.52	0.77	1.1	0.32	1.2	1.1±0.63	1.4	1.4	0.82	0.69	1.3
Total NPD	19	[illegible]	13	30	17	14	3.7	18	20	20	17	12	19	20

Mean NPD content EPS: 18 ± 6.0

1) not detected.

Table 7.2.7 cont. *Concentrations µg/kg dry weight of 2-6 ring aromatic hydrocarbons in Heidrun sediments, EPS (site 1-13 and 25).*

Site Compounds	1*	2	3	4	5	6	7	8	9*	10	11	12	13	25
Fluoranthene	4.6±0.62	3.8	4.1	30	5.2	22	2.1	3.8	5.1±0.73	5.7	3.6	3.6	3.1	4.6
Pyrene	2.8±0.24	2.8	2.8	28	3.7	13	1.6	2.8	3.0±0.56	4.3	2.8	3.1	2.4	2.9
Benz-a-anthracene	0.28±0.20	0.68	0.64	13	1.3	5.1	0.38	0.67	0.2±0.11	1.1	0.35	0.54	0.46	0.51
Chrysene/Triphenylene	5.0±1.9	0.36	1.7	55	6.0	25	3.0	4.1	4.9±0.93	6.0	3.9	4.5	5.0	3.7
Benzo-b/j/k pyrene	17±3.7	71	19	8.8	8.1	13	0.46	6.7	4.7±3.7	9.8	6.6	18	24	30
Benzo-(e)-pyrene	5.9±1.5	25	6.6	26	18	10	1.4	7.4	6.2±2.7	6.3	5.2	6.8	22	8.6
Benzo-(a)-pyrene	1)	0.55	0.27	6.6	2.2	2.1	0.16	0.39	0.20	1.2	1)	0.94	3.5	1)
Perylene	0.15	1.1	0.32	2.3	3.5	1.4	0.15	0.33	0.35	0.5	1)	0.44	3.0	0.32
Benzo-(g h i)-perylene	2.8±4.2	16	6.6	1)	1)	14	1)	0.21	1)	0.14	1.5	12	1.5	17

Table 7.2.7 *Concentration in mg/kg dry weight of 2 - 6 ring aromatic hydrocarbons in Heidrun sediments, platform site (site 14 - 24).*

Site	14	15	16	17	18	19	20	21	22	23*	24
Compounds											
Naphthalene	0.65	1)	0.21	0.56	1)	1)	1)	1)	1)	0.95	0.18
C_1-homolog	0.16	0.082	0.082	0.067	1)	1)	1)	1)	1)	1.1	1)
C_2-homolog	0.95	1.1	0.21	1)	1)	1)	1)	1)	1)	3.0	1)
C_3-homolog	1.9	1.6	0.50	1)	1)	0.78	0.94	1)	1)	3.1	1)
Total	3.6	2.8	1.0	0.86	1)	0.78	0.94	1)	1)	8.2	1)
Phenanthrene	5.7	6.4	3.7	4.6	6.6	4.4	4.1	3.5	6.0	8.6±4.9	5.2±2.4
C_1-homolog	6.9	12	11	4.1	5.1	7.2	7.2	3.7	2.5	8.1±3.7	6.4±0.95
C_2-homolog	2.0	3.9	3.9	1.2	1.2	3.7	2.7	0.79	0.35	2.2±0.54	1.9±1.6
C_3-homolog	0.78	1.3	1.4	0.36	0.28	1.3	1.7	0.22	1)	0.54±0.13	0.55±0.63
Total	15	24	20	10	13	17	16	8.2	8.9	19±9.0	1.4±3.2
Dibenzothiophene	0.21	0.40	0.22	0.20	0.28	0.22	0.26	0.084	0.056	0.55±0.38	0.22±0.093
C_1-homolog	0.49	0.57	0.51	0.23	0.18	0.50	0.46	1)	1)	0.55±0.31	0.24±0.15
C_2-homolog	0.66	0.51	0.68	0.20	0.083	0.63	0.40	1)	1)	0.47±0.26	0.57[1]
C_3-homolog	1)	0.14	0.15	0.083	0.038	0.24	0.23	0.036	1)	0.11±0.022	0.10±0.13
Total	1.3	1.6	1.6	0.71	0.58	1.6	1.4	1)	1)	1.5±0.86	0.75±0.62
Total NPD	20	28	23	12	14	19	18	8.3	9.0	29	15

Mean NPD content Platform site: 18 ± 6.9

Table 7.2.7 cont. *Concentration in mg/kg dry weight of 2 - 6 ring aromatic hydrocarbons in Heidrun sediments, platform site (site 14 - 24).*

Site / Compounds	14	15	16	17	18	19	20	21	22	23*	24*
Fluoranthene	3.5	5.7	4.4	3.3	5.3	4.5	3.4	2.6	3.8	4.4±0.70	4.6±1.3
Pyrene	2.3	3.8	2.8	2.2	3.2	2.9	2.5	2.4	1.9	3.2±0.24	3.2±0.13
Benz-a-anthracene	0.65	0.86	1.1	0.050	0.038	0.84	0.55	0.10	0.093	0.35±0.18	5.0±0.72
Chrysene/ triphenylene	5.0	5.7	4.4	3.0	4.5	4.5	3.4	3.3	7.9	0.29±0.39	4.9±0.36
Benzo-b/j/k- pyrene	1.1	18	35	4.8	15	19	13	2.6	67	5.0±3.5	21±18
Benzo-e-pyrene	0.58	9.3	11	2.3	9.8	9.6	4.6	12	35	7.3±1.6	7.8±3.1
Benzo-a-pyrene	0.060	0.74	1.3	1)	0.27	1.6	0.54	1)	1)	0.72	1)
Perylene	1)	0.50	1.2	1)	1)	2.3	1.3	0.16	0.12	0.53	0.68
Benzo-(g,h,i)- perylene	0.89	0.40	18	0.19	0.17	1.6	7.1	1)	8.7	1)	11

Table 7.2.8. Concentrations of normal alkanes in Heidrun sediments from GC and GC/MS analysis (µg/kg dry weight). Platform and EPS sites separated.

Site	Total n-alkanes			
	$nC_{12}-nC_{35}$		$nC_{26}-nC_{35}$	
	GC/MS	GC	GC/MS	GC
14	26	79	14	1)
15	81	183	27	85
16	185	263	116	132
17	104	163	44	73
18	18	229	2.7	77
19	12	217	4.2	103
20	11	1)	4.3	1)
21	309	169	171	91
22	39	201	1)	78
23	66	112±25	0.22	57±9.8
24	117±69	187±15	7.6	91±12
Mean ± SD	88±88	166±70	67±27	76±32

Site	Total n-alkanes			
	$nC_{12}-nC_{35}$		$nC_{26}-nC_{35}$	
	GC/MS	GC	GC/MS	GC
1	90±70	192±173	43±39	92±108
2	86	382	44	172
3	211	238	75	122
4	23	147	3.4	72
5	12	167	0.45	92
6	115	167	62	90
7	253	207	219	100
8	43	259	1)	80
9	58±11	210±55	1.2	92±11
10	43	181	2.7	102
11	62	165	4.5	74
12	123	229	72	111
13	41	289	18	1)
25	170	235	9.7	94
Mean ± SD	95±72	219±62	43±43	99±32

1) not detected

Table 7.2.9. Carbon preference indices (CPIs) for the Heidrun field sediment n-alkane content. Results from GC and GC/MS analyses. Platform and EPS sites separated.

Site	nC_{12}-nC_{35}		nC_{26}-nC_{35}	
	GC/MS	GC	GC/MS	GC
14	1.21	1.50	0.41	1)
15	0.522	1.37	1)	1.87
16	2.73	1.40	2.61	2.06
17	2.03	1.34	2.34	2.02
18	1.50	1.07	1)	1.99
19	5.21	1.48	2.34	2.20
20	4.76	1.35	1)	1.96
21	1.06	1.68	0.526	2.73
22	0.864	1.54	1)	2.01
23	1.75	1.49±0.048	1)	2.02±0.14
24	2.93±1.93	1.45±0.14	3.00	2.0±0.17

Site	nC_{12}-nC_{35}		nC_{26}-nC_{35}	
	GC/MS	GC	GC/MS	GC
1	2.18	1.09±0.072	2.25	1.69±0.454
2	3.36	1.24	1.57	2.22
3	1.75	1.54	1.15	2.19
4	1.19	1.28	1)	1.64
5	3.69	1.52	1)	2.02
6	3.21	1.45	3.8	1.95
7	1.12	1.29	1.03	1.85
8	1.23	1.18	1)	2.13
9	2.27±1.17	1.46±0.072	1)	2.17±0.070
10	2.24	1.50	1)	2.13
11	1.82	1.41	0.678	2.00
12	1.94	1.47	1.40	2.20
13	0.56	1.43	0.0859	2.29
25	2.14	1.30	4.03	2.05

1) not detected

Table 7.2.10. Concentation of n-alkanes in Heidrun field sediments from vertical sectioning of core samples (A), and carbon preference indices (CPIs) for the n-alkane content of the core samples (B).

A

Sample		Total n-alkanes			
		nC_{12}-nC_{35}		nC_{26}-nC_{35}	
		GC/MS	GC	GC/MS	GC
Site 8:	0-1 cm	252	211	3.8	54
	1-3 cm	2107	242	148	67
	3-6 cm	102	246	4.3	51
Site 10:	0-1 cm	151	410	7.2	65
	1-3 cm	1)	272	1)	74
	3-6 cm	116	211	7.1	82

B

Sample		GC/MS	GC	GC/MS	GC
Site 8:	0-1 cm	1.37	1.11	1.00	1.86
	1-3 cm	1.37	1.42	0.71	2.30
	3-6 cm	2.43	1.35	1.32	2.43
Site 10:	0-1 cm	1.29	1.32	0.95	1.98
	1-3 cm	1)	1.36	1)	2.08
	3-6 cm	2.16	1.32	1.59	2.06

1) not detected

Table 7.2.11. Concentration of aromatic compounds (µg/kg dry weight) in vertical sections of core samples. Results from GC/MS analysis.

Site Compound	8			10		
	0-1 cm	1-3 cm	3-6 cm	0-1 cm	1-3 cm	3-6 cm
Naphthalene	0.09	1)	0.053	1)	0.61	1)
C_1-homolog	1)	1)	1)	1)	0.47	1)
C_2-homolog	0.24	1)	0.67	0.21	3.88	1)
C_3-homolog	0.64	1)	1.66	0.42	7.12	1)
Total	0.97	1)	2.4	0.63	12	1)
Phenanthrene	4.2	2.0	6.0	6.1	1)	3.9
C_1-homolog	5.6	3.3	4.1	2.6	1)	6.4
C_2-homolog	3.8	3.1	0.85	2.5	1.2	3.4
C_3-homolog	2.0	2.3	0.36	0.93	0.24	2.0
Total	16	11	11	12	1.4	16
Dibenzothiphenes	0.30	0.097	0.38	0.31	1.4	0.24
C_1-homolog	0.52	0.23	0.29	0.29	1.3	0.48
C_2-homolog	1.0	0.46	0.15	0.22	0.90	0.56
C_3-homolog	0.54	0.38	0.062	0.072	1)	0.35
Total	2.4	1.2	0.88	0.89	3.6	1.6
Total NPD	19	12	14	14	17	18
Fluroranthene	3.6	2.9	2.2	4.8	4.6	3.9
Pyrene	2.6	2.7	1.9	3.2	2.9	4.0
Benz(a)anthracene	0.69	0.84	0.11	0.73	0.30	0.86
Chrysene/ Triphenylene	3.3	3.3	1.8	5.4	5.5	4.5
Benzo(b/j/k) pyrene	42	1)	19	48	22	56
Benzo-e-pyrene	15	1)	9.9	17	7.0	22
Benzo-a-pyrene	4.3	12	0.86	3.6	0.83	5.3
Perylene	2.7	8.7	1.0	1.9	0.58	3.1
Benz(ghi) perylene	17	1)	3.0	2.5	3.6	19

Table 7.2.12. The isoprenoid content (µg/kg dry sediment) of the Heidrun field, June 1988. EPS site and Platform site respectively. Results from the GC and GC/MS analysis. The ratio pristane/phytane is calculated from the GC results.

EPS site

Station	Pristane		Phytane		ratio
	GC	GC/MS	GC	GC/MS	pri/phy
1	6.07±6.0	11.10	6.28±6.28	6.16	0.967
2	13.1	1)	6.51	1)	2.01
3	6.47	3.12	1)	1)	1)
4	5.04	1)	1)	1)	1)
5	1)	1)	1)	1)	1)
6	4.64	1)	1)	1)	1)
7	4.77	1)	1)	1)	1)
8	13.5	1.14	14.8	1.42	0.912
9	9.06±7.19	1.78	6.04±5.57	3.01	1.50
10	4.23	13.1	1)	0.154	1)
11	5.78	3.89	1)	1)	1)
12	10.3	1.26	1)	1)	1)
13	10.9	1)	11.0	1)	0.991
25	9.75	5.19	7.99	2.92	1.22

Permanent Platform site:

Station	Pristane		Phytane		ratio
	GC	GC/MS	GC	GC/MS	pri/phy
14	2.45	1)	1)	1)	1)
15	10.3	6.99	1)	1)	1)
16	6.67	1.41	1)	1)	1)
17	1)	1)	1)	1.12	1)
18	7.69	1)	1)	1)	1)
19	9.94	1)	1)	1)	1)
20	4.73	1)	1)	1)	1)
21	10.7	1)	9.03	1)	1.18
22	7.74	1)	6.48	2.02	1.19
23	3.59±2.51	3.79	3.44±2.42	2.85	1.04
24	4.02±0.40	1)	3.52±0.178	1)	1.14

1) Not detected

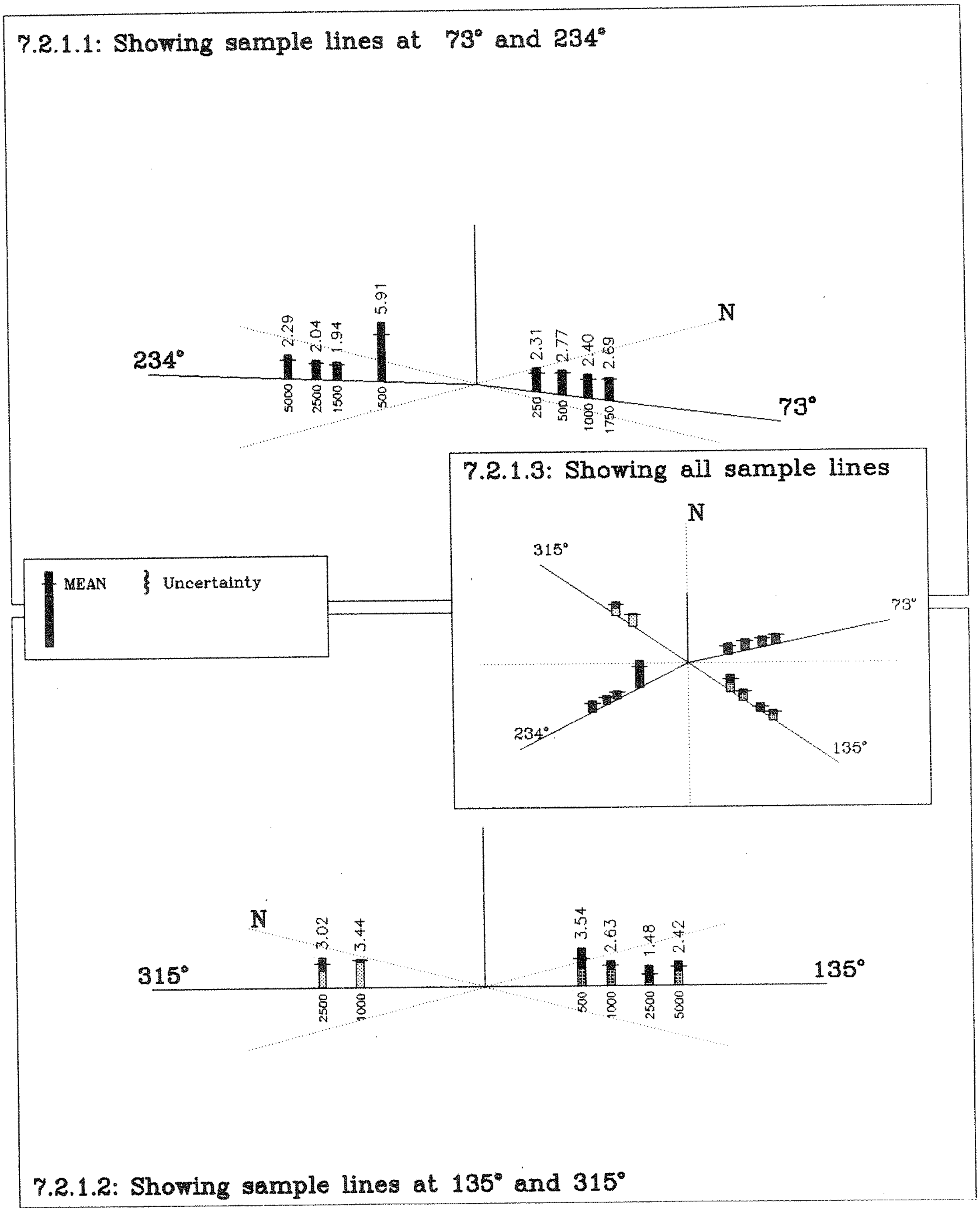


Fig. 7.2.1. THC content in Heidrun sediments around EPS (mg/kg dry weight). All distances given in metres on a logarithmic scale.

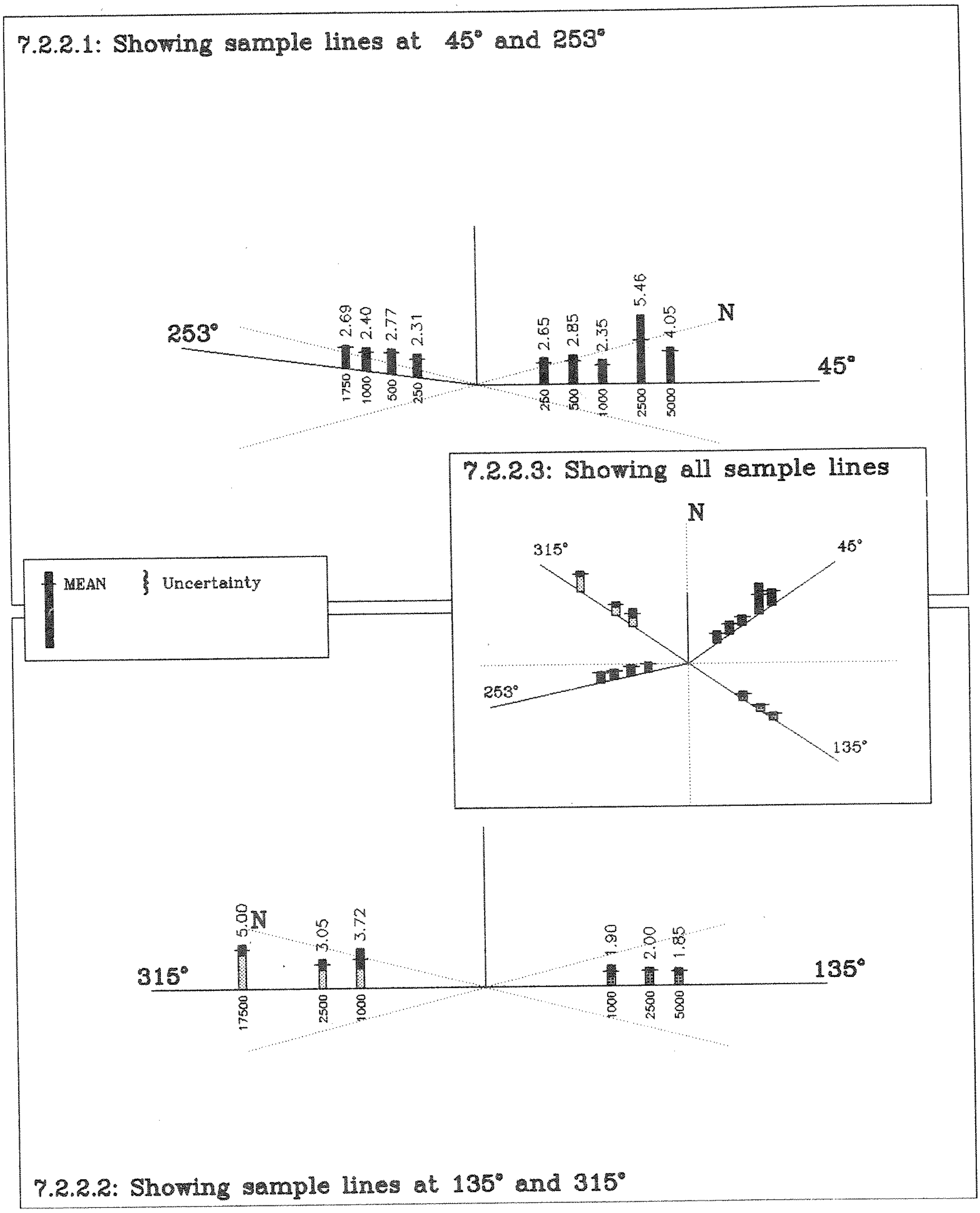


Fig. 7.2.2. THC content in Heidrun sediments around the platform site (mg/kg dry weight). All distances given in metres on a logarithmic scale.

7.3. Biological characterisation of the sediments

7.3.1. Number of taxa.

A total of 273 taxa were found in the samples of which 252 were recorded quantitatively, the others only on the basis of presence-/absence. The bryozoans (13 species) and foraminiferans (not further identified) dominated the taxa recorded qualitatively. For the Bryozoans a selected set of specimens representing the various forms were transferred to a specialist in Copenhagen for species verification. A list of which samples these specimens came from is given in Appendix 4 (pg 195). The Poriferans (sponges) are only recorded as Porifera indet., but were completely dominated by one species, Thenea abyssorum, a typical cold- and deepwater species.

The number of quantitative taxa retained on the 0.5 mm screen was high and ranged from 71 (for the 0.5 m^2 area sampled) at Station 20 to 109 at Station 12 (Table 7.3.1). The median number of quantitative taxa per station was 90 (Table 7.3.2). The median number of taxa larger than 1 mm was 66 (Table 7.3.2.), and the number of taxa retained on the 1 mm screen was 56-89 % (average 73 %) of the total number retained on both screens.

As expected, the Margalef index of species richness correlated strongly with number of taxa (cf, Tab 7.3.5), and ranged from 12.19 (Station 20) to 16.48 (Station 12), with an average of 14.34 (Table 7.3.1. and 7.3.2.). Corresponding average for the 1 mm fraction was 11.55.

There were no convincing trends in distribution of species richness over the survey area, neither according to the number of taxa nor to the Margalef index values (Fig. 7.3.1 to 7.3.2), but a slight reduction in number was found at Stations 20 and 21 NE of the future Platform position.

The phylum Annelida dominated the species lists with up to 8 of the 10 most common taxa (Table 7.3.3, Stations 1-3). At 18 of the 25 stations the most abundant species was an annelid. Other groups being ranked as the most abundant were sipunculids (Golfingia spp. cf. minuta, Stations 11, 15, 16, 22, and 23), ascidians (Station 17), and bivalves (Limopsis minuta, Station 20).

7.3.2. Species versus area curve

Figure 7.3.10 shows the increase in number of taxa recorded with increased sample area from 0.1 to 0.5 m^2 (to 0.8 m^2 at the reference station 24). Most stations sampled did not tend to reach an asymptotic level of species richness after 0.5 m^2 sampled. The species-area curve for Station 24 was in the lower range of the distribution of curves. It did not reach any asymptotic value at 0.8 m^2, indicating that further sampling effort could have produced several new taxa, and might have been justified. This is in accordance with the very high diversity of the Heidrun benthic fauna (see below).

The number of taxa caught in 0.5 m^2 at station 24 was 87 % of the number retrieved from 0.8 m^2. Since the shape of the curve for Station 24 would reasonably conform with those from the bulk of the other stations up to 0.5 m^2 area (Figure 7.3.10), it suggests that this relationship could hold for the other stations too, and hence that the standard sampling programme in general would recover about 80 % of the total number of taxa one might catch by increasing the effort to 8 grab hauls per station.

7.3.3. Total fauna densities

Total number of individuals per m^2 ranged from 570 at Station 21 to 1628 at Station 3, with an average of 976 ind/m^2 across the survey area (Table 7.3.2). From the table it can be inferred that 20-62 % (average 44 %) of the individuals which would have been retained on the 0.5 mm screen alone passed through the 1 mm screen.

There was no convincing trend in distribution of total number of individuals across the survey area (Fig 7.3.3 and 7.3.4), but the densities were lowest at the stations having the lowest number of taxa. Total densities correlated positively with number of taxa (Tab. 7.3.5). Neither S nor N correlated significantly with sediment volume sampled (Tab. 7.3.5). Hence, although the total volume of sediment analysed per station ranged from 62 to 80 liters (Tab. 4.1), larger volumes did not produce more species or larger number of individuals. This is probably because increased sample volume did not produce more of the biologically active surface layer, only more of the clay layer beneath which had very few animals.

7.3.4. Diversity, equitability (evenness), dominance

The indices reflecting community diversity all showed that the benthic communities in the area were remarkably diverse and uniform. The indices for diversity and evenness were high and dominance low at all stations.

The Shannon-Wiener information index Hs for the total fauna was remarkably stable and attained values between 5.47 and 5.93 (Table 7.3.1 and 7.3.2). Highest value was found at Station 12 and the lowest at Station 5. The HS values for the size fraction above 1 mm was in the range 4.93-5.58, and always less than the corresponding total fauna diversity. This reflected the fact that inclusion of the fauna fraction between 0.5 and 1 mm produced not only more small individuals of already recorded species, but also a substantial number of new taxa.

Also the Brillouin index of diversity Hb attained values above 5 for all stations (Tab. 7.3.1). The values were slightly lower than the corresponding Hs values, which is expected since Hb calculates the real diversity of the 5-grab sample, whereas Hs estimates community diversity. The correlation beween the two indices was strong (Tab. 7.3.5).

There was no gradient in Hs or Hb across the survey area (Fig. 7.3.5 and 7.3.6).

Relative diversity was also compared among stations by use of Hurlbert rarefaction curves. Highest total fauna diversity (Fig 7.3.11, steepest slope) was found at Station 11, and lowest at Station 2, but all the curves had the same shape and lay within an extremely narrow range. The pattern was similar for the fraction larger than 1 mm (Fig. 7.3.12), and the fact that the highest and lowest slope was represented by other stations than for the total fauna, is considered coincidental. In the figures is also indicated an empirical classification diagram for the position of rarefaction curves from clean to perturbed coastal and fjord locations in Norway (from Rygg 1984). This diagram classifies all the Heidrun stations as highly diverse.

The expected number of species per 100 individuals (ES_{100}) ranged from 43.33 (Station 12) to 49.07 (Station 15) for the total fauna (Tab. 7.3.1), and correlated significantly with HS and HB (Tab 7.3.5). To our knowledge these are among the most extreme ES_{100} values ever recorded in a soft bottom community. An ES_{100} value close to 50 implies that every second individual encountered in a sample of 100 can be expected to represent a new species. The corresponding range in ES_{100} for the fraction larger than 1 mm was slightly less: 36.49-46.03 (Tab. 7.3.2), but is also higher than has been found in clean coastal and fjord communities along the coast of Norway (e.g. Rygg 1984, Molvær and Bakke 1985).

Dominance was in general low with Simpson index values in the range 0.022 to 0.035 (Tab. 7.3.1 and 7.3.2). Evenness was reasonably high both by Pielou's index J (0.86-0.90) and Heip's index E (0.51-0.66). Neither of these indices correlated significantly with the diversity indices HS, HB or ES_{100}, suggesting that differences in diversity primarily were a function of species richness. ES_{100}, dominance, and evenness showed no trends or systematic changes across the survey area (Figs. 7.3.7 to 7.3.9).

7.3.5. Rank abundance of dominants.

The ten most abundant species for each station have been tabulated in Tab. 7.3.3. A total of 34 taxa (of the total fauna) were recorded among the ten most abundant at any one station (Tab. 7.3.4). When the fraction between 0.5 and 1 mm was excluded another 5 species were added to the top ranked, and four of these were bivalves.

Of the 34 taxa in Tab 7.3.4, only 12 occurred on the list at 10 or more stations and 7 of these were polychaetes. The most frequently occurring species, the polychaete Spiophanes kroeyeri, was on the top ten list at 20 stations. This fairly strong variability in ranking among the stations reflected the low dominance in the fauna, and only small differences in abundance could cause large changes in ranking. Cumulative % abundance (Table 7.3.3) showed that the ten most abundant species contributed to less than 50 % (35.4-46.2 %) of the total individual density, which is consistent with an overall low dominance, high equitability, and high ES_{100} values.

The distribution of some of the species in Table 7.3.4 are presented in Figs. 7.3.13 to 7.3.25 primarily as a basis for future comparison. None of them showed any strong gradients over the survey area, and there were no trends in the distribution which convincingly could be linked to any disturbance from the earlier exploratory drilling operations at Heidrun.

The most frequent species, Spiophanes kroeyeri (Fig 7.3.13), a spionid polychaete, is a tube dwelling cosmopolitan inhabiting soft sediments from shallow water to at least 1600 m depth. As spionids in general, S. kroeyeri is considered a surface deposit feeder (Fauchald and Jumars 1979), and is regarded as non-tolerant to pollution (Rygg 1985). It occurred at all stations in the area and at densities ranging from 8 to 53 ind./0.5 m^2. The densities were slightly reduced in the center of the field and along the 150^0 transect from EPS. Reduced densities along this transect was also found for other polychaetes analysed (Figs 7.3.14 to 7.3.18), especially the lumbrinerid Augeneria tentaculata (Fig. 7.3.14) and the amphinomid Paramphinome jeffreysi (Fig. 7.3.15). The latter, also a species regarded as sensitive to pollution (Rygg 1985), had maximum distribution along the main SW-NE transect, but with slight reduction around the EPS. The opposite trend with least densities along this transect was shown by Spiochaetopterus typicus (Fig. 7.3.16), a large tube dwelling chaetopterid which also is a conspicuous member of the polychaete fauna over the whole of the Barents sea (Mileikovskii 1965).

The cirratulid polychaete Chaetozone setosa, by several regarded as a secondary opportunist around North Sea platforms (Hobbs 1987), had densities ranging from 3 to 49 ind./0.5 m^2 which is comparable to densities found in North Sea baseline studies (e.g. Hobbs 1987), and far below densities found at pollution. The distribution (Fig 7.3.17) indicated highest densities in the western region of the survey area. It was ranked as most abundant species at five stations (2, 5, 7, 13, and 25) around EPS, but not in any close relation to the sites of earlier drilling activities.

The most common onuphid polychaete Sarsonuphis fiordica had a fairly even distribution in the area (Fig 7.3.18). This is a characteristic inhabitant of the deeper fjords in Norway (Fauchald 1982).

The sipunculans were represented by two species frequently among the top dominants: Golfingia sp. cf. minuta, and Oncnesoma steenstrupi. Golfingia was most common and showed a gradient in distribution across the area with highest densities in the NE region (Fig 7.3.19). The species identification of the present Golfingia is uncertain even though it morphologically resembles G. minuta most closely, especially due to the known depth distribution (<50 m) of G. minuta proper (Gibbs 1977).

Two species of crustaceans were represented among the dominants: the ostracod Polycope punctata (Fig. 7.3.20), and the amphipod Harpinia pectinata (Fig. 7.3.21), the latter suggested by Rygg (1985) to be non-tolerant to pollution. Both species showed the same trend as

Golfingia with reduced densities along the 234^0 transect from the EPS.

Four molluscs occurred frequently among the dominants: the bivalves Thyasira pygmea (Fig. 7.3.22), Limopsis minuta (Fig. 7.3.23), and Abra longicallus (Fig. 7.3.24), and the scaphopod Cadulus propincuus (Fig. 7.3.25) These are all common inhabitats of deeper soft bottom areas along the coast of Norway. L. minuta is a very common inhabitant of the outer Norwegian shelf region. These molluscs showed resonably similar distribution: reduced densities at the reference station, possibly a function of depth difference (cf Tab. 4.1), and highest densities in the center of the survey area. These trends were, however, not strong.

The species described above comprise both pollutant sensitive and pollutant tolerant forms. Their recorded distribution in the Heidrun area was not particularly scattered, and the possibility of detecting future changes due to industrial and other activities in the area should be good.

7.3.6. Log-normal distribution

Plotting of the distribution of species upon the individuals for each station (Fig. 7.3.26) suggested good agreement with the theoretical log normal distribution of individuals among species. The distributions were in general similar to the pattern of undisturbed communities demonstrated by Pearson et. al. (1983). The distribution comprised at most 6 geometric classes of densities ($\log_2$-basis). None of the stations showed the spread towards higher classes, or the reduction in number of species in the lower classes, which has been suggested by these authors to be indicative of disturbance (e.g. organic enrichment). These graphs should therefore be a good baseline for future comparisons. According to Pearson et. al. (1983) the species found in geometric classes 3-5 (here 8-62 ind/m^2) would be those one should be particularly aware of in looking for future responses to disturbance. In the present material these would in general be the species listed in Table 7.3.4 (top ranked).

7.3.7. Station similarity, cluster analysis, ordination.

The similarity among the stations has been analysed on the total fauna and the >1 mm fractions separately as well as the two fractions combined.

Fig. 7.3.27a shows the dendrogram for the cluster analysis of the total fauna (>0.5 mm) from all stations. The level of similarity was high as is shown by the fact that all stations are clustered at level 0.638 or higher of the Bray-Curtis index. One larger cluster of 10 stations (group B in Fig. 7.3.27a) was discerned, and three other stations (group A) were loosely clustered to this again. At the same or higher level of similarity three pairs of stations were clustered: 3 and 16, 14 and 17 and 9 and 24. MDS ordination based on the same Bray-Curtis similarities at two dimensions is shown in Fig. 7.3.27b. The two-dimensional plot gave a least stress coefficient of 0.236, which indicates that ordination in three or more dimensions is required to attain an accurate reflection of the similarities between the station pairs. In the MDS plot, however, one can discern two reasonably well defined station groups I and II, and possibly one loose grouping III.

As is seen in Fig. 7.3.27b, where the cluster station groups or pairs are indicated on the MDS plot, the two types of analysis did not give corresponding station groupings. There was some overlap in as much as stations 18, 19, 20, 23, and 25 were grouped in both analyses, but together with other stations. Furthermore, both analyses defined stations 2, 8, 5 and 11 as somewhat atypic. Also in both analyses the reference station 24 was at the extreme of the groupings although included in group I of the MDS plot.

When the groups are encircled on the station map (Fig. 7.3.28), none of the analyses defined station groups that corresponded to any clear directional gradient or geographical pattern. The only trend was a slight SW to NE gradient in the position of the MDS groups. Also the more loosely defined group III of the MDS plot suggests that the SW region of the field is slightly more heterogenous in fauna composition than the NE region.

For the >1.0 mm fraction all stations clustered at index value 0.550 or higher (Fig. 7.3.29a). Here too the dendrogram was characterized by a high degree of chaining (one station after another is added to a grouping), but at level 0.670 four station groups could be discerned. These groups were not similar to those found on the basis of the total fauna, but one group of stations: 4, 13, 18, 19, and 25 were in the same cluster as for the total fauna. One should also note that the reference station 24 is even more isolated here than based on the total fauna.

The MDS ordination on the basis of the >1 mm fraction (Fig. 7.3.29b) gave a least stress coefficient of 0.238, also here showing that reflection in two dimensions gave less than desired discrimination. The plot was generally similar to the total fauna MDS. Four station groups might be defined with reasonable confidence, two of which corresponded to groups I and II of the total fauna analysis. The third and fourth group could also be discerned as two defined subgroups of station group III of the total fauna. Also on basis of the >1 mm fraction stations 2, 5, 8, and 11 were defined as atypic. The comparison indicates that most of the information of the stations utilized by the MDS analysis is contained in the >1 mm fraction alone.

Encircling the cluster groups based on the >1 mm fraction on the MDS plot showed that the two analyses did not correspond (Fig. 7.3.29b). Demarcation of the cluster and MDS station groups on the station map (Fig 7.3.29) did not give any clear directional gradient, but the MDS groups were more or less orientated along a SW to NE axis also on basis of the >1 mm fraction.

The reasons for the lack of correspondence beween cluster and MDS analyses on the basis of the same set of similarities could be several, but is presumably a consequence of the different computational procedures of the analyses. Clustering of highly similar units tends to force these into groupings built around those pairs of units which happen to be the most similar. Small differences among the units could therefore override general trends in the data set. This would give the haphazard pattern found when the station groups are identified on the map (Figs. 7.3.28a and 7.3.30a).

The MDS grouping of the stations gave a more consistent pattern, although the groups were not very well defined in two dimensions according to the degree of stress. Still the groups based on total and >1 mm fractions corresponded. They indicated a slight SW to NE gradient in the fauna across the area, and somewhat more homogenous fauna in the NE than the SW direction. The gradient corresponds to the weak gradients in distribution found for some of the more common species (cf chapter 7.3.5), and correlated to the sediment characteristics (chapter 7.3.9).

Stations 2, 5, 8 and 11, and especially 2 and 11, were separated from other stations and from each other. The cause for this is not obvious from the species list. Station 2 and 5 had Chaetozone setosa as dominants, but so had stations 7, 13 and 25. Station 11 had the lowest Φ mean of all stations, i.e. most coarse sediment, and the highest Hurlbert diversity (Fig. 7.3.11). Any plausible reason why Station 8 should stand out, especially in the MDS analysis, has not been found.

The general separation of the reference station 24 from the others in the cluster and MDS analyses should also be noted. Although number of taxa and individual densities at station 24 was in the lower range of the field as a whole the station did not show any extremes in community parameters. A comparison of the most abundant species, however, (Tab. 7.3.3) indicated a slight shift in fauna composition when moving to Station 24, as the most abundant species in general were those somewhat lower on the list of the overall most common species in the Heidrun field (Tab. 7.3.4). The slight difference could be a function of difference in sediment features, depth and distance (cf Chapter 7.3.9).

7.3.8. Comparison of the >0.5 mm and >1 mm fauna

The basis for separating the fauna into 'total fauna larger than 0.5 mm' and the 'fraction larger than 1 mm' was twofold. Firstly, the separation enables direct comparison with investigations performed in other offshore fields, some of which have used 0.5 mm and some 1 mm screens in sieving. Secondly, the material enables evaluation of the cost-effectiveness of using the 0.5 mm sieve which demands a considerably larger effort in sample treatment and analysis than use of 1 mm sieves, balanced against e.g. the alternative to use the same amount of work in analysing a larger number of grab samples at 1 mm.

The analysis showed that there was a considerable difference between the total fauna and the >1 mm fraction. Number of taxa on the 1 mm screen was only 56-89 % of the total number recovered from both screens, and number of individuals 20-62 % less. The correlation of community indices between the two fractions across all stations was in general positive and significant (Tab. 7.3.6), but only at the 5 % level except for total densities (1 % level). The % similarity in ten top ranked species (cf. Table 7.3.3) between total fauna and the >1 mm fraction ranged from 30 to 90 %, with an average of 63 %. The change in evenness by either index was not changed significantly when omitting the animals smaller than 1 mm, but diversity decreased by all indices ($p<0.01$) and dominance increased ($p<0.01$).

Fig. 7.3.31 shows the dendrogram of a cluster analysis of the total fauna and 1 mm fraction combined for all stations. With no exception the two adjoint units combine at higher similarity level than any 'between station' similarity. It is obvious from this analysis that the 1 mm fraction expresses most of the information on faunal composition contained in the total fauna. This result corroborates the MDS analyses which gave largely the same plots for total fauna and the

1 mm fraction. Incidentally it weakens the reliance upon the station groups formed in the cluster analyses. The lack of correspondence among these analyses appears to be due to differences between the total fauna and 1 mm fraction rather than spatial structures in the fauna, reflecting the susceptibility of cluster analysis to minor variation in the units.

The general impression of the fauna of the Heidrun area: homogenous with a high number of species compared to total densities, high diversity, high evenness, low dominance, and a slight SW to NE gradient, could be concluded on basis of the >1 mm fauna alone, and in this respect inclusion of the fraction between 1 and 0.5 mm would seem an overshoot. Still the smaller fraction contained a range of new species and increased the total diversity, and the two together therefore gives a clearly better baseline for comparison with future surveys than the >1 mm alone.

7.3.9. Correlation between fauna, sediment characters, and level of possible contaminants.

Two basic sediment features have been shown frequently to influence soft bottom fauna composition: the content of particles in the silt/clay fraction (< 63 µm) and the content of organic matter. Table 7.3.5 shows that % mud (silt/clay) correlated negatively with the two diversity indices Hs and Hb for the total fauna i.e. lowest diversity was found at the stations with highest mud content. No other community parameter correlated significantly with mud content, although the table indicates negative relation with both number of taxa and individual densities. The % organic content, total hydrocarbons by IR, and by GC/FID did not correlate significantly with any of the fauna parameters.

By linking the % mud to each element in the station grouping of the MDS ordination on the basis of total fauna, it was shown that mean mud content differed between the station groups (Table 7.3.7). The difference was significant between group I and III indicating that one of the important factors underlying the grouping by ordination was the sediment composition which tended to increase in silt/clay content in the NE direction of the survey area.

The outlying position of the reference Station 24 in the MDS plots can also partly be explained by the silt/clay content. The % mud content at Station 24 (Table 7.3.7) was significantly higher ($p<0.01$) than the mean of the other stations in in the MDS group I. The fact that

Stations 10 and 20 with even higher mud content did not occupy the same extreme position in the MDS plots, shows that other factors must also have separated the reference fauna from that of the other stations, the most obvious being the geographical separation (15 km from the nearest station) and the difference in depth (380 m as opposed to the range 320-348 m for the others).

7.3.10 Comparison with other investigations

The basis for comparison with earlier investigations in the Heidrun area is weak as only two of the stations in the Haltenbanken baseline investigation of 1985 (Bowler et al. 1986) were taken in the Heidrun area. Also slightly different sampling procedures were applied in the two surveys, and the material has been analysed by different scientists. The 1985 investigation was based on sieving at 1 mm screen only, but the total area sampled for each station (0.5 m^2) was the same both years.

In Table 7.3.8 the basic fauna characters are compared for these two investigations. The number of taxa recorded per station had a wider range in 1985 than in the present study, which is expected since the geographical area covered was far greater in 1985. The depth range was also larger. Still the mean number of taxa per station was almost the same both years. Individual densities showed the same trend: the range in 1985 was clearly larger, whereas mean densities were about the same in both years.

At both the comparable stations in the Heidrun area the number of taxa recorded at 1 mm was about twice as high in 1988 as in 1985, and the individual densities 3-4 times as high.

The range in Shannon-Wiener diversity (both years on $\log_2$ basis) was also greatest in 1985, but the mean diversity found for the Heidrun field was clearly larger than that of the Haltenbanken as a whole. A clear elevation in diversity was also found from 1985 to 1988 on the comparable stations, which again, since Hs is a function of S and N, could be an effect of procedure differences. Overall mean evenness (Pielou) was slightly higher in 1988 than in 1985, but the two comparable stations showed the opposite trend with slight reduction in evenness from 1985 to 1988.

At Station 3/1988 the dominant species was the same as in 1985: *Spiophanes kroeyeri*. At station 24/1988 *Spiochaetopterus typicus* had replaced two other polychaete species: *Nothria opalina*? and *Clymenura*

(=Leichone) borealis. L. borealis appeared at modest density in 1988, N. opalina were not present in 1988, but may have been misidentified (given the questionmark in Bowler et al. (1986)).

The change in species richness and total densities is considerable over 3 years in an area which gives an overall expression of faunal homogeneity, the more so since sampling surveys were done at approximately the same time both years (May 1985 and June 1988). Although a natural faunal shift over time may have happened, some of the change from 1985 to 1988 could relate to differences in sampling, possibly also in work up procedures between the two years. In 1985 a heavily loaded boxcorer was used and the upper ca. 10 cm of the sediment was carved off for sieving. In 1988 no extra weight was applied on the Van Veen grab and the total sample was sieved. This could cause differences in sampling efficiency by several means: different shock wave in front of the sampler, different penetration depth, different relative efficiency in sampling the various depth strata of the sediment, etc.

Comparison of the Heidrun fauna with baseline conditions for the nearest oil fields in the northern North Sea (e.g. Statfjord, Gullfaks) is also difficult because the latter have far less water depth and coarser sediment. The sediment at Statfjord at about 150 m depth,is characterised as medium sand and with a silt/clay content of less than 10 % (IOE 1985). At Gullfaks the silt/clay content ranges around 1-3 % (Miljøplan and SI 1985). Hence the sediment community at Heidrun must be expected to be different. Still an attempt has been made to compare the present findings with the conditions at the outer (>3 km), presumably undisturbed, sites around the Statfjord platforms in 1984 (IOE 1985: Tab. 7.5), as the two investigations are based on the same procedures.

The number of taxa recorded at Statfjord in 1984 ranged from 136 to 177 per station, compared to 72-106 at Heidrun (Tab. 7.3.8), hence nearly twice as many taxa were recorded at Statfjord with approximately the same level of resolution in species identification. The total densities were in the range 1900 to 3300 ind/0.5 m^2 compared to 285-814 at Heidrun, i.e. 5-10 times higher. The Hs diversity was in the range 4.97 to 5.82 which is close to the Heidrun range of 5.47-5.88. Brillouin diversity, Pielou and Heip evenness was clearly less at Statfjord than at Heidrun. So the general impression is that the Heidrun fauna had lower density of species and individuals than the more shallow Statfjord area, but diversity was higher both in relative and, for some indices, in absolute terms.

The range in number of taxa larger than 1 mm (per 0.2 m^2) found as baseline for the Gullfaks area was 51-86 (Tab.7.3.8), which is similar to the range of a corresponding area at Heidrun (cf. Fig. 7.3.10). Individual densities per 0.5 m^2 ranged from 548 to 1545 which is 3 times the densites at Heidrun, but still the Hs diversity at Gullfaks (range 4.36-5.36) was only slightly less than at Heidrun.

Comparison with some recent baseline surveys in the central North Sea: the Gyda (Levell 1987) and Tommeliten (Hobbs 1987) fields, show that the Heidrun area in general had higher number of taxa, slightly lower individual densities, and higher diversity than in the central North Sea (Tab. 7.3.8).

Table 7.3.1. Sediment community parameters of the Heidrun field, June 1988

Station no	Fauna size fraction	Number of taxa	Individuals/0.5 mm^2	Shannon-Wiener diversity	Brillouin diversity	Pielou evenness	Heip evenness	Simpson dominance	ES_{100}	Margaleff species richness
1	0.5	79	400	5.64	5.22	0.89	0.63	0.027	45.79	13.02
1	1.0	54	199	5.01	4.50	0.87	0.59	0.047	38.72	10.01
2	0.5	82	508	5.50	5.15	0.87	0.55	0.034	43.52	13.00
2	1.0	66	275	5.40	4.92	0.89	0.63	0.032	42.69	11.57
3	0.5	105	814	5.87	5.57	0.87	0.55	0.024	48.09	15.52
3	1.0	72	333	5.48	5.03	0.89	0.61	0.031	43.91	12.22
4	0.5	98	641	5.75	5.42	0.87	0.54	0.026	46.18	15.01
4	1.0	55	244	5.29	4.76	0.87	0.71	0.042	44.01	9.82
5	0.5	81	374	5.47	5.10	0.88	0.54	0.035	45.70	13.50
5	1.0	52	150	5.13	4.50	0.90	0.67	0.043	42.95	10.18
6	0.5	94	565	5.68	5.32	0.87	0.54	0.030	45.83	14.68
6	1.0	66	278	5.15	4.68	0.85	0.53	0.051	41.56	11.55
7	0.5	90	488	5.71	5.32	0.88	0.58	0.027	46.32	14.38
7	1.0	65	286	5.27	4.82	0.88	0.59	0.037	40.63	11.32
8	0.5	87	403	5.71	5.27	0.89	0.60	0.027	46.93	14.34
8	1.0	71	279	5.43	4.93	0.88	0.60	0.034	44.19	12.43
9	0.5	98	508	5.88	5.47	0.89	0.60	0.023	48.95	15.57
9	1.0	75	314	5.52	5.04	0.89	0.61	0.030	44.10	12.87
10	0.5	77	333	5.50	5.04	0.88	0.58	0.031	43.78	13.09
10	1.0	48	190	4.93	4.43	0.88	0.63	0.047	36.49	8.96
11	0.5	87	326	5.72	5.21	0.89	0.60	0.027	48.29	14.86
11	1.0	59	193	5.06	4.51	0.86	0.56	0.044	40.23	11.02
12	0.5	109	702	5.93	5.59	0.88	0.56	0.022	43.33	16.48
12	1.0	67	338	5.43	4.99	0.87	0.64	0.033	42.75	11.33
13	0.5	85	465	5.79	5.39	0.90	0.65	0.024	47.89	13.68
13	1.0	64	242	5.48	4.95	0.91	0.69	0.030	44.96	11.48

cont.

Table 7.3.1 cont.

Station no	Fauna size fraction	Number of taxa	Individuals/0.5 mm^2	Shannon-Wiener diversity	Brillouin diversity	Pielou evenness	Heip evenness	Simpson dominance	ES_{100}	Margaleff species richness
14	0.5	94	514	5.72	5.33	0.87	0.56	0.029	47.12	14.89
14	1.0	72	327	5.37	4.93	0.87	0.57	0.039	43.46	12.26
15	0.5	87	353	5.78	5.29	0.90	0.63	0.025	49.07	14.66
15	1.0	63	180	5.31	4.69	0.89	0.62	0.038	46.03	11.94
16	0.5	103	681	5.75	5.42	0.86	0.52	0.028	46.37	15.64
16	1.0	72	341	5.30	4.87	0.86	0.54	0.042	42.05	12.17
17	0.5	91	502	5.64	5.25	0.87	0.54	0.033	46.53	14.47
17	1.0	74	370	5.20	4.80	0.84	0.49	0.047	40.82	12.34
18	0.5	101	564	5.73	5.36	0.86	0.52	0.030	46.86	15.79
18	1.0	90	450	5.54	5.14	0.85	0.51	0.035	44.65	14.57
19	0.5	97	494	5.85	5.43	0.89	0.59	0.025	49.02	15.48
19	1.0	74	282	5.58	5.06	0.90	0.64	0.028	45.94	12.94
20	0.5	71	312	5.50	5.03	0.89	0.63	0.032	45.00	12.19
20	1.0	54	207	5.04	4.54	0.88	0.60	0.047	39.35	9.94
21	0.5	71	285	5.55	5.05	0.90	0.66	0.029	45.80	12.38
21	1.0	54	158	5.21	4.58	0.90	0.68	0.038	43.28	10.47
22	0.5	94	555	5.75	5.38	0.88	0.57	0.029	47.57	14.72
22	1.0	69	295	5.16	4.71	0.85	0.51	0.050	41.31	11.96
23	0.5	85	417	5.80	5.36	0.90	0.65	0.024	48.41	13.92
23	1.0	67	262	5.48	4.97	0.90	0.66	0.031	44.95	11.85
24	0.5	78	347	5.58	5.12	0.89	0.61	0.031	45.99	13.16
24	1.0	63	207	5.14	4.58	0.86	0.55	0.052	43.23	11.63
25	0.5	91	638	5.68	5.36	0.87	0.56	0.028	45.26	13.94
25	1.0	71	347	5.42	5.00	0.88	0.60	0.033	42.58	11.97

Table. 7.3.2. Basic statistics of sediment community parameters for the Heidrun field survey stations, June 1988

Parameter [1]		Mean	Median	Stdev.	Min.	Max.
0.5 mm	S	89	90	10.15	71	109
	N	488	494	137	285	814
	Hs	5.70	5.72	0.13	5.47	5.93
	Hb	5.30	5.32	0.15	5.03	5.59
	J	0.88	0.88	0.01	0.86	0.90
	D	0.028	0.028	0.003	0.022	0.035
	ES_{100}	46.54	46.37	1.64	43.33	49.07
	E	0.58	0.58	0.04	0.51	0.66
	Ma	14.34	14.47	1.13	12.19	16.48
1.0 mm	S	65	66	9.34	48	90
	N	270	278	74.00	150	450
	Hs	5.29	5.30	0.18	4.93	5.58
	Hb	4.80	4.82	0.21	4.43	5.14
	J	0.88	0.88	0.02	0.84	0.91
	D	0.039	0.038	0.007	0.028	0.052
	ES_{100}	42.59	42.95	2.30	36.49	46.03
	E	0.60	0.60	0.06	0.49	0.71
	Ma	11.55	11.63	1.19	8.96	14.57

[1]) S: number of taxa, N: density/0.5 m^2, Hs: Shannon-Wiener diversity, Hb: Brillouin diversity, J: Pielou evenness, D: Simpson dominance, ES_{100}: expected no. of taxa per 100 ind. E: Heip evenness, Ma: Margaleff species richness.

Table. 7.3.3. The 10 numerically dominant species for stations in the Heidrun field, June 1988.

Taxon 1 mm.	Density	%	Cum. %	Taxon 0.5 mm.	Density	%	Cum. %
Station 1.							
Sarsonuphis fiordica	23	11.6	11.6	Sarsonuphis fiordica	25	6.2	6.2
Lumbrineris sp. (cf. scopa)	21	10.6	22.2	Chaetozone setosa	23	5.8	12.0
Molgulidae indet.	11	5.5	27.7	Lumbrineris sp. (cf. scopa)	23	5.8	17.8
Nucula tumidula	10	5.0	32.7	Paramphinome jeffreysi	17	4.3	22.1
Paramphinome jeffreysi	8	4.0	36.7	Nucula tumidula	15	3.8	25.9
Abra longicallus	7	3.5	40.2	Spiophanes kroeyeri	15	3.8	29.7
Tharyx cf. marioni	7	3.5	43.7	?Paradoneis lyra	13	3.3	33.0
Chaetozone setosa	7	3.5	47.2	Notomastus latericus	13	3.3	36.3
Leichone borealis	7	3.5	50.4	Thyasira obsoleta	12	3.0	39.3
Yoldiella cf. acuminata	6	3.2	53.6	Terebellides stroemi	12	3.0	42.3
Station 2.							
Nucula tumidula	16	5.8	5.8	Chaetozone setosa	49	9.6	9.6
Spiophanes kroeyeri	15	5.5	11.3	Spiophanes kroeyeri	47	9.3	18.9
Sarsonuphis quadricuspis	15	5.5	16.8	?Paradoneis lyra	21	4.1	23.0
Sarsonuphis fiordica	15	5.5	22.3	Sarsonuphis fiordica	18	3.5	26.5
Chaetozone setosa	14	5.1	27.4	Nucula tumidula	17	3.3	29.8
Lumbrineris sp. (cf. scopa)	14	5.1	32.5	Cadulus propinquus	16	3.1	32.9
Bathyarca pectunculoides	13	4.7	37.2	Paramphinome jeffreysi	16	3.1	36.0
Terebellides stroemi	11	4.0	41.2	Lumbrineris sp. (cf. scopa)	16	3.1	39.1
Cuspidaria lamellosa	10	3.6	44.8	Sarsonuphis quadricuspis	15	3.0	42.1
Spiochaetopterus typicus	9	3.3	48.1	Terebellides stroemi	15	3.0	45.1
Station 3.							
Lumbrineris sp. (cf. scopa)	24	7.2	7.2	Spiophanes kroeyeri	53	6.5	6.5
Spiophanes kroeyeri	22	6.6	13.8	?Paradoneis lyra	42	5.2	11.7
Onuphis qadricuspis	18	5.4	19.2	Chaetozone setosa	39	4.8	16.5
Sarsonuphis fiordica	18	5.4	24.6	Lumbrineris sp. (cf. scopa)	32	3.9	20.4
Porifera indet.	16	4.8	29.4	Terebellides stroemi	31	3.8	24.2
Bathyarca pectunculoides	15	4.5	33.9	Sabellidae indet.	31	3.8	28.0
Golfingia cf. minuta	14	4.2	38.1	Porifera indet.	25	3.1	31.1
Eclysippe vanelli	11	3.3	41.4	Golfingia cf. minuta	25	3.1	34.2
Molgulidae indet.	11	3.3	44.7	Eclysippe vanelli	24	2.9	37.1
Limopsis minuta	9	2.7	47.4	Paramphinome jeffreysi	22	2.7	39.8
Station 4.							
Porifera indet.	26	10.7	10.7	Terebellides stroemi	43	6.7	6.7
Lumbrineris sp. (cf. scopa)	24	9.8	17.0	Polycope punctata	34	5.3	12.0
Abra longicallus	17	7.0	24.0	Porifera indet.	29	4.5	16.5
Nucula tumidula	15	6.1	30.1	Lumbrineris sp. (cf. scopa)	29	4.5	21.0
Sarsonuphis fiordica	11	4.5	34.6	Chaetozone setosa	27	4.2	25.2
Bathyarca pectunculoides	10	4.1	38.7	Spiophanes kroeyeri	24	3.7	28.9
Yoldiella cf. acuminata	8	3.3	42.0	?Paradoneis lyra	20	3.1	32.0
Paramphinome jeffreysi	7	2.9	44.9	Abra longicallus	19	3.0	35.0
Augeneria tentaculata	7	2.9	47.8	Caudofov./Solenogas. ind.	18	2.8	37.8
Leichone borealis	6	2.5	50.3	Thyasira pygmaea	18	2.8	40.6
Station 5.							
Limopsis minuta	21	14.0	14.0	Chaetozone setosa	44	11.8	11.8
Spiochaetopterus typicus	8	5.3	19.3	Limopsis minuta	24	6.4	18.2
Sarsonuphis fiordica	8	5.3	24.6	Spiophanes kroeyeri	19	5.0	23.2
Porifera indet.	7	4.7	29.3	Thyasira obsoleta	16	4.3	27.5
Molgulidae indet.	7	4.7	34.0	Cadulus propinquus	14	3.7	31.2
Nucula tumidula	6	4.0	38.0	Spiochaetopterus typicus	12	3.2	34.4
Chaetozone setosa	6	4.0	42.0	Ophelina sp. (juv.)	11	3.0	37.4
Lumbrineris sp. (cf. scopa)	6	4.0	46.0	Eclysippe vanelli	10	2.7	40.1
Abra longicallus	5	3.3	49.3	Terebellides stroemi	10	2.7	42.8
Yoldiella cf. acuminata	4	2.7	52.0	?Paradoneis lyra	9	2.4	45.2

Taxon (1 mm.)	Density	%	Cum. %	Taxon (0.5 mm.)	Density	%	Cum. %
Station 6.							
Spiochaetoperus typicus	45	16.2	16.2	Spiochaetopterus typicus	57	10:1	10.1
Sarsonuphis fiordica	25	9.0	25.2	Thyasira pygmaea	25	4.4	14.5
Lumbrineris sp. (cf. scopa)	16	5.8	31.0	Lumbrineris sp.(cf. fragilis)	25	4.4	18.9
Nucula tumidula	12	4.3	35.3	Lumbrineris sp. (cf. scopa)	21	3.7	22.6
Abra longicallus	11	4.0	39.3	Sabellidae indet.	21	3.7	26.3
Onchnesoma steenstrupi	11	4.0	43.3	Nucula tumidula	20	3.5	29.8
Paramphinome jeffreysi	9	3.2	46.5	Thyasira obsoleta	20	3.5	33.3
Golfingia cf. minuta	9	3.2	49.7	Onchnesoma steenstrupi	20	3.5	36.8
Limopsis minuta	8	2.9	52.6	Chaetozone setosa	18	3.2	40.0
Bathyarca pectunculoides	7	2.5	55.1	Abra longicallus	16	2.8	42.8
Station 7.							
Lumbrineris sp. (cf. scopa)	23	8.0	8.0	Chaetozone setosa	34	7.0	7.0
Chaetozone setosa	22	7.7	15.7	Lumbrineris sp. (cf. scopa)	27	5.5	12.5
Porifera indet.	16	5.6	21.3	Paramphinome jeffreysi	22	4.5	17.0
Bathyarca pectunculoides	16	5.6	26.9	Bathyarca pectunculoides	19	3.9	20.9
Nucula tumidula	15	5.2	32.1	Terebellides stroemi	19	3.9	24.8
Paramphinome jeffreysi	14	4.9	37.0	Spiophanes kroeyeri	18	3.7	28.5
Sarsonuphis fiordica	13	4.5	41.5	Porifera indet.	16	3.3	31.8
Golfingia cf. minuta	12	4.2	45.7	Entalina quinquangularis	16	3.3	35.1
Cuspidaria lamellosa	8	2.8	48.5	Cadulus propinquus	15	3.1	38.2
Abra longicallus	8	2.8	51.3	Nucula tumidula	15	3.1	41.3
Station 8.							
Sarsonuphis fiordica	27	9.7	9.7	Sarsonuphis fiordica	28	6.9	6.9
Spiophanes kroeyeri	18	6.5	16.2	Spiophanes kroeyeri	23	5.7	12.6
Lumbrineris sp. (cf. scopa)	18	6.5	22.7	Chaetozone setosa	18	4.5	17.1
Limopsis minuta	12	4.3	27.0	Lumbrineris sp. (cf. scopa)	18	4.5	21.6
Molgulidae indet.	12	4.3	31.3	Cadulus propinquus	17	4.2	25.8
Nucula tumidula	11	3.9	35.2	?Paradoneis lyra	15	3.7	29.5
Chaetozone setosa	10	3.6	38.8	Nucula tumidula	12	3.0	32.5
Sarsonuphis quadricuspis	10	3.6	42.4	Limopsis minuta	12	3.0	35.5
Abra longicallus	9	3.2	45.6	Eriopisa elongata	12	3.0	38.5
Yoldiella cf. acuminata	7	2.5	48.1	Harpinia pectinata	12	3.0	41.5
Station 9.							
Onuphis qadricuspis	20	6.4	6.4	?Paradoneis lyra	26	5.1	5.1
Chaetozone setosa	16	5.1	11.5	Thyasira obsoleta	24	4.7	9.8
?Paradoneis lyra	15	4.8	16.3	Chaetozone setosa	21	4.1	13.9
Sarsonuphis fiordica	15	4.8	21.1	Sarsonuphis quadricuspis	20	3.9	17.8
Abra longicallus	14	4.5	25.6	Onchnesoma steenstrupi	20	3.9	21.7
Spiochaetopterus typicus	14	4.5	30.1	Spiochaetopterus typicus	17	3.3	25.0
Onchnesoma steenstrupi	14	4.5	34.6	Thyasira pygmaea	16	3.1	28.1
Limopsis minuta	13	4.1	38.7	Cadulus propinquus	15	3.0	31.1
Spiophanes kroeyeri	12	3.8	42.5	Limopsis minuta	15	3.0	34.1
Lumbrineris sp. (cf. scopa)	11	3.5	46.0	Sarsonuphis fiordica	15	3.0	37.1
Station 10.							
Lumbrineris sp. (cf. scopa)	26	13.7	13.7	Lumbrineris sp. (cf. scopa)	27	8.1	8.1
Porifera indet.	12	6.1	19.8	Terebellides stroemi	18	5.4	13.5
Golfingia cf. minuta	11	5.8	25.6	Chaetozone setosa	17	5.1	18.6
Limopsis minuta	9	4.7	30.3	Golfingia cf. minuta	15	4.5	23.1
Paramphinome jeffreysi	9	4.7	35.0	Porifera indet.	14	4.2	27.3
Sarsonuphis fiordica	9	4.7	39.7	Thyasira obsoleta	14	4.2	31.5
Chaetozone setosa	8	4.2	43.9	Spiophanes kroeyeri	13	3.9	35.4
Leichone borealis	8	4.2	48.1	Limopsis minuta	12	3.6	39.0
Terebellides stroemi	8	4.2	52.3	Thyasira pygmaea	12	3.6	42.6
Molgulidae indet.	8	4.2	56.5	Leichone borealis	12	3.6	46.2

Taxon 1 mm.	Density	%	Cum. %	Taxon 0.5 mm.	Density	%	Cum. %
Station 11.							
Golfingia cf. minuta	17	8.8	8.8	Golfingia cf. minuta	20	6.1	6.1
Limopsis minuta	15	7.8	16.6	Molgulidae indet.	20	6.1	12.2
Molgulidae indet.	15	7.8	24.4	Limopsis minuta	15	4.6	16.8
Paramphinome jeffreysi	13	6.7	31.1	Thyasira pygmaea	15	4.6	21.4
Sarsonuphis fiordica	13	6.7	37.8	Abra longicallus	13	4.0	25.4
Lumbrineris sp. (cf. scopa)	13	6.7	44.5	Paramphinome jeffreysi	13	4.0	29.4
Nucula tumidula	9	4.7	49.2	Sarsonuphis fiordica	13	4.0	33.4
Abra longicallus	9	4.7	53.9	Lumbrineris sp. (cf. scopa)	13	4.0	37.4
Spiophanes kroeyeri	7	3.6	57.5	Nucula tumidula	10	3.1	40.5
Spiochaectoperus typicus	6	3.1	60.6	Cadulus propinquus	9	2.8	43.3
Station 12.							
Sarsonuphis fiordica	25	7.4	7.4	Lumbrineris sp. (cf. scopa)	36	5.1	5.1
Lumbrineris sp. (cf. scopa)	24	7.1	14.5	Chaetozone setosa	29	4.1	9.2
Limopsis minuta	21	6.2	20.7	Sarsonuphis fiordica	28	4.0	13.2
Porifera indet.	20	5.9	26.6	Terebellides stroemi	26	3.7	16.9
Augeneria tentaculata	15	4.4	31.0	Limopsis minuta	24	3.4	20.3
Nucula tumidula	13	3.8	34.8	Spiophanes kroeyeri	24	3.4	23.7
Abra longicallus	12	3.6	38.4	Onchnesoma steenstrupi	22	3.1	26.8
Paramphinome jeffreysi	11	3.3	41.7	Augeneria tentaculata	21	3.0	29.8
Eclysippe vanelli	11	3.3	45.0	Porifera indet.	20	2.8	32.6
Golfingia cf. minuta	11	3.3	48.3	Cadulus propinquus	20	2.8	35.4
Station 13.							
Lumbrineris sp. (cf. scopa)	19	7.9	7.9	Chaetozone setosa	28	6.0	6.0
Goldfingia minuta	15	6.2	14.1	Lumbrineris sp. (cf. scopa)	22	4.7	10.7
Sarsonuphis fiordica	12	5.0	19.1	Golfingia cf. minuta	20	4.3	15.0
Spiochaetopterus typicus	10	4.1	23.2	Paramphinome jeffreysi	19	4.0	19.0
Chaetozone setosa	10	4.1	27.3	Thyasira pygmaea	16	3.4	22.4
Abra longicallus	9	3.7	31.0	Onchnesoma steenstrupi	16	3.4	25.8
Molgulidae indet.	9	3.7	34.7	Sarsonuphis fiordica	14	3.0	28.8
Paramphinome jeffreysi	8	3.3	38.0	Eclysippe vanelli	14	3.0	31.8
Yoldiella cf. acuminata	7	2.9	40.9	?Paradoneis lyra	13	2.8	34.6
Augeneria tentaculata	7	2.9	43.8	Polycope punctata	13	2.8	37.4
Station 14.							
Spiochaetopterus typicus	39	11.9	11.9	Spiochaetopterus typicus	44	8.6	8.6
Lumbrineris sp. (cf. scopa)	26	8.0	19.9	Spiophanes kroeyeri	32	6.2	14.8
Spiophanes kroeyeri	22	6.7	26.6	Lumbrineris sp. (cf. scopa)	31	6.0	20.8
Sarsonuphis fiordica	13	4.0	30.6	Chaetozone setosa	23	4.5	25.3
Golfingia cf. minuta	13	4.0	34.6	Thyasira pygmaea	21	4.1	29.4
Chaetozone setosa	12	3.7	38.3	Golfingia cf. minuta	17	3.3	32.7
Nucula tumidula	10	3.1	41.4	Onchnesoma steenstrupi	17	3.3	36.0
Parvicardium minimum	8	2.4	43.8	Cadulus propinquus	16	3.1	39.1
Augeneria tentaculata	8	2.4	46.2	Sarsonuphis fiordica	13	2.5	41.6
Onchnesoma steenstrupi	8	2.4	48.6	Harpinia pectinata	13	2.5	44.1
Station 15.							
Lumbrineris sp. (cf. scopa)	16	8.9	8.9	Golfingia cf. minuta	21	5.9	5.9
Golfingia cf. minuta	15	8.3	17.2	Lumbrineris sp. (cf. scopa)	19	5.4	11.3
Sarsonuphis fiordica	14	7.8	25.0	Thyasira pygmaea	18	5.1	16.4
Spiochaetopterus typicus	13	7.2	32.2	Spiochaetopterus typicus	15	4.2	20.6
Limopsis minuta	8	4.4	36.6	Sarsonuphis fiordica	15	4.2	24.8
Leichone borealis	6	3.3	39.9	Onchnesoma steenstrupi	15	4.2	29.0
Sarsonuphis quadricuspis	6	3.3	43.2	Terebellides stroemi	11	3.1	32.1
Molgulidae indet.	6	3.3	46.5	Spiophanes kroeyeri	10	2.8	34.9
Paramphinome jeffreysi	5	2.8	49.3	Molgulidae indet.	10	2.8	37.7
Chlamys sulcata	4	2.2	51.5	Limopsis minuta	9	2.5	40.2

Taxon 1 mm.	Density	%	Cum. %	Taxon 0.5 mm.	Density	%	Cum. %
Station 16.							
Golfingia cf. minuta	46	13.5	13.5	Golfingia cf. minuta	55	8.1	8.1
Spiophanes kroeyeri	23	6.7	20.2	Spiophanes kroeyeri	41	6.0	14.1
Lumbrineris sp. (cf. scopa)	19	5.6	25.8	Sabellidae indet.	37	5.4	19.5
Sarsonuphis fiordica	17	5.0	30.8	?Paradoneis lyra	29	4.3	23.8
Limopsis minuta	15	4.4	35.2	Terebellides stroemi	28	4.1	27.9
Molgulidae indet.	15	4.4	39.6	Cadulus propinquus	22	3.2	31.1
Augeneria tentaculata	14	4.1	43.7	Paramphinome jeffreysi	21	3.1	34.2
Leichone borealis	11	3.2	46.9	Chaetozone setosa	20	2.9	37.1
?Paradoneis lyra	10	2.9	49.8	Lumbrineris sp. (cf. scopa)	20	2.9	40.0
Spiochaetopterus typicus	9	2.6	52.4	Limopsis minuta	19	2.8	42.8
Station 17.							
Molgulidae indet.	48	13.0	13.0	Molgulidae indet.	54	10.8	10.8
Sarsonuphis fiordica	37	10.0	23.0	Sarsonuphis fiordica	37	7.4	18.2
Spiochaetopterus typicus	31	8.4	31.4	Spiochaetopterus typicus	31	6.2	24.4
Golfingia cf. minuta	17	4.6	36.0	Limopsis minuta	18	3.6	28.0
Limopsis minuta	15	4.1	40.1	Golfingia cf. minuta	17	3.4	31.4
Spiophanes kroeyeri	13	3.5	43.6	Cadulus propinquus	15	3.0	34.4
Nucula tumidula	12	3.2	46.8	Nucula tumidula	14	2.8	37.2
Lumbrineris sp. (cf. scopa)	12	3.2	50.0	Thyasira pygmaea	14	2.8	40.0
Augeneria tentaculata	11	3.0	53.0	Spiophanes kroeyeri	13	2.6	42.6
Chaetozone setosa	9	2.4	55.4	Lumbrineris sp. (cf. scopa)	12	2.4	45.0
Station 18.							
Spiophanes kroeyeri	43	9.6	9.6	Spiophanes kroeyeri	50	8.9	8.9
Spiochaetopterus typicus	29	6.4	16.0	Spiochaetopterus typicus	31	5.5	14.4
Sarsonuphis fiordica	29	6.4	22.4	Sarsonuphis fiordica	30	5.3	19.7
?Paradoneis lyra	25	5.6	28.0	?Paradoneis lyra	27	4.8	24.5
Golfingia cf. minuta	24	5.3	33.4	Golfingia cf. minuta	26	4.6	29.1
Eclysippe vanelli	19	4.0	37.4	Eclysippe vanelli	21	3.7	32.8
Chaetozone setosa	16	3.6	41.0	Bathyarca pectunculoides	19	3.4	36.2
Bathyarca pectunculoides	15	3.3	44.3	Chaetozone setosa	18	3.2	39.4
Lumbrineris sp. (cf. scopa)	14	3.1	47.4	Lumbrineris sp. (cf. scopa)	16	2.8	42.2
Abra longicallus	13	2.9	50.3	Thyasira pygmaea	15	2.7	44.9
Station 19.							
Sarsonuphis fiordica	20	7.1	7.1	Spiophanes kroeyeri	35	7.1	7.1
Golfingia cf. minuta	15	5.3	12.4	Chaetozone setosa	26	5.3	12.4
Spiochaetopterus typicus	13	4.6	17.0	Golfingia cf. minuta	23	4.7	17.1
Spiophanes kroeyeri	12	4.3	21.3	Sarsonuphis fiordica	21	4.3	21.4
Molgulidae indet.	12	4.3	25.6	Spiochaetopterus typicus	16	3.2	24.6
Abra longicallus	11	3.9	29.5	Polycope punctata	16	3.2	27.8
Bathyarca pectunculoides	10	3.5	33.0	Bathyarca pectunculoides	15	3.0	30.8
Chaetozone setosa	10	3.5	36.5	Paramphinome jeffreysi	15	3.0	33.8
Lumbrineris sp. (cf. scopa)	10	3.5	40.0	Augeneria tentaculata	14	2.8	36.6
Leichone borealis	8	2.8	42.8	Onchnesoma steenstrupi	14	2.8	39.4
Station 20.							
Limopsis minuta	28	13.5	13.5	Limopsis minuta	29	9.3	9.3
Golfingia cf. minuta	18	8.7	22.2	Golfingia cf. minuta	25	8.0	17.3
Augeneria tentaculata	11	5.3	27.5	Onchnesoma steenstrupi	17	5.4	22.7
Spiochaetopterus typicus	10	4.8	32.2	Augeneria tentaculata	12	3.8	26.5
Sarsonuphis fiordica	9	4.3	36.6	Cadulus propinquus	11	3.5	30.0
Lumbrineris sp. (cf. scopa)	9	4.3	40.9	Sarsonuphis fiordica	11	3.5	33.5
Onchnesoma steenstrupi	9	4.3	45.2	Spiophanes kroeyeri	10	3.2	36.7
Paramphinome jeffreysi	8	3.9	49.1	Spiochaetopterus typicus	10	3.2	39.9
Spiophanes kroeyeri	7	3.4	52.5	Lumbrineris sp. (cf. scopa)	9	2.9	42.8
Leichone borealis	7	3.4	55.9	Bathyarca pectunculoides	8	2.6	45.4

Taxon 1 mm.	Density	%	Cum. %	Taxon 0.5 mm.	Density	%	Cum. %
Station 21.							
Paramphinome jeffreysi	17	10.8	10.8	Paramphinome jeffreysi	23	8.1	8.1
Sarsonuphis fiordica	12	7.6	18.4	Chaetozone setosa	15	5.6	13.7
Chaetozone setosa	8	5.1	23.5	Thyasira obsoleta	13	4.6	18.3
Lumbrineris sp. (cf. scopa)	8	5.1	28.6	Sarsonuphis fiordica	13	4.6	22.9
Notomastus latericus	7	4.4	33.0	Notomastus latericus	11	3.9	26.8
Abra longicallus	6	3.8	36.8	Onchnesoma steenstrupi	11	3.9	30.7
Augeneria tentaculata	6	3.8	40.6	Spiophanes kroeyeri	10	3.5	34.2
Onchnesoma steenstrupi	6	3.8	44.4	Eclysippe vanelli	10	3.5	37.7
Nucula tumidula	5	3.2	47.6	Golfingia cf. minuta	10	3.5	41.2
Golfingia cf. minuta	5	3.2	50.8	Thyasira pygmaea	9	3.2	44.4
Station 22.							
Golfingia cf. minuta	46	15.6	15.6	Golfingia cf. minuta	56	10.1	10.1
Sarsonuphis fiordica	26	8.8	24.4	Spiophanes kroeyeri	28	5.0	15.1
Molgulidae indet.	18	6.1	30.5	Sarsonuphis fiordica	28	5.0	20.1
Spiophanes kroeyeri	16	5.4	35.9	Molgulidae indet.	22	4.0	24.1
Spiochaetopterus typicus	13	4.4	40.3	Eclysippe vanelli	17	3.1	27.2
Sarsonuphis quadricuspis	11	3.7	44.0	Thyasira obsoleta	16	2.9	30.1
Augeneria tentaculata	9	3.1	47.1	Harpinia pectinaria	16	2.9	33.0
Abra longicallus	8	2.7	49.8	Thyasira pygmaea	15	2.7	35.7
Bathyarca pectunculoides	7	2.4	52.2	Bathyarca pectunculoides	14	2.5	38.2
Onchnesoma steenstrupi	7	2.4	54.6	Spiochaetopterus typicus	14	2.5	40.7
Station 23.							
Golfingia cf. minuta	19	7.3	7.3	Porifera indet.	24	5.8	5.8
Porifera indet.	16	6.1	13.4	Golfingia cf. minuta	22	5.3	11.1
Molgulidae indet.	16	6.1	19.5	Cadulus propincuus	16	3.8	14.9
Sarsonuphis fiordica	13	5.0	24.5	Molgulidae indet.	16	3.8	18.7
Lumbrineris sp. (cf. scopa)	11	4.2	28.7	Chaetozone setosa	15	3.6	22.3
Augeneria tentaculata	11	4.2	32.9	Spiophanes kroeyeri	13	3.1	25.4
Nucula tumidula	9	3.4	36.3	Sarsonuphis fiordica	13	3.1	28.5
Spiophanes kroeyeri	9	3.4	39.7	Terebellides stroemi	13	3.1	31.6
Apseudes spinosus	9	3.4	43.1	Thyasira pygmaea	12	2.9	34.5
Terebellides stroemi	8	3.1	46.2	Lumbrineris sp. (cf. scopa)	12	2.9	37.4
Station 24.							
Spiochaetopterus typicus	36	17.4	17.4	Spiochaetopterus typicus	33	9.5	9.5
Molgulidae indet.	14	6.8	24.2	Thyasira obsoleta	18	5.2	14.7
Onchnesoma steenstrupi	11	5.3	29.5	Onchnesoma steenstrupi	17	4.9	19.6
Sarsonuphis fiordica	10	4.8	34.3	Harpinia pectinata	16	4.6	24.2
Lumbrineris sp. (cf. scopa)	10	4.8	39.1	Lumbrineris sp. (cf. scopa)	15	4.3	28.5
Thyasira obsoleta	7	3.4	42.5	Molgulidae indet.	15	4.3	32.8
Eriopisa elongata	7	3.4	45.9	Ophelina sp. (juv.)	12	3.5	36.3
Harpinia pectinata	7	3.4	49.3	Golfingia cf. minuta	12	3.5	39.8
Parvicardium minimum	5	2.4	51.7	Levinsensia gracilis	10	2.9	42.7
Notomastus latericus	5	2.4	54.1	Sarsonuphis fiordica	10	2.9	45.6
Station 25.							
Porifera indet.	24	6.9	6.9	Chaetozone setosa	46	7.2	7.2
Sarsonuphis fiordica	20	5.8	12.7	Spiophanes kroeyeri	35	5.5	12.7
Augeneria tentaculata	20	5.8	18.5	Porifera indet.	29	4.5	17.2
Golfingia cf. minuta	20	5.8	24.3	Terebellides stroemi	29	4.5	21.7
Spiophanes kroeyeri	17	4.9	29.2	Golfingia cf. minuta	28	4.4	26.1
Chaetozone setosa	17	4.9	34.1	?Paradoneis lyra	27	4.2	30.3
Lumbrineris sp. (cf. scopa)	17	4.9	39.0	Augeneria tentaculata	23	3.6	33.9
Limopsis minuta	14	4.0	43.0	Lumbrineris sp. (cf. scopa)	22	3.4	37.3
Terebellides stroemi	14	4.0	47.0	Thyasira granulosa	21	3.3	40.6
?Paradoneis lyra	11	3.2	50.2	Sarsonuphis fiordica	21	3.3	43.9

Taxon 1 mm.	Density	%	Cum. %	Taxon 0.5 mm.	Density	%	Cum. %
Station 24 (8 grabs)							
Spiochaetopterus typicus	46	14.6	14.6	Spiochaetopterus typicus	48	8.1	8.1
Sarsonuphis fiordica	19	6.3	20.9	Thyasira obsoleta	35	5.9	14.0
Lumbrineris sp. (cf. scopa)	17	5.4	26.3	Lumbrineris sp. (cf. scopa)	26	4.4	18.4
Molgulidae indet.	17	5.4	31.7	?Paradoneis lyra	24	4.0	22.4
Onchnesoma steenstrupi	13	4.1	35.8	Golfingia cf. minuta	23	3.9	26.3
Golfingia cf. minuta	12	3.8	39.6	Onchnesoma steenstrupi	22	3.7	30.0
Thyasira obsoleta	10	3.2	42.8	Harpinia pectinata	21	3.5	33.5
Chlamys sulcata	9	2.9	45.7	Levinsenia gracilis	19	3.2	36.7
Eriopisa elongata	8	2.5	48.2	Sarsonuphis fiordica	19	3.2	39.9
Nucula tumidula	7	2.2	50.4	Molgulidae indet.	18	3.0	42.9

Table 7.3.4. The most abundant taxa in the Heidrun field (>5 mm) ranked according to frequency of occurrence in Table 7.3.3.

Taxon	number of stations where present on the top ten list
Spiophanes kroeyeri	20
Sarsonuphis fiordica	19
Chaetozone setosa	18
Lumbrineris sp. (cf. scopa)	18
Golfingia cf. minuta	16
Thyasira pygmea	13
Terebellides stroemi	12
Cadulus propinquus	12
Spiochaetoptereus typicus	11
?Paradoneis lyra	11
Limopsis minuta	10
Oncnesoma steenstrupi	10
Paramphinome jeffreysi	9
Thyasira obsoleta	8
Nucula tumidula	7
Porifera indet.	7
Eclysippe vanelli	6
Molgulidae indet.	6
Bathyarca pectunculoides	5
Augeneria tentaculata	4
Harpinia pectinata	4
Sabellidae indet.	3
Polycope punctata	3
Abra longicallus	3
Sarsonuphis quadricuspis	2
Notomastus latericus	2
Ophelina sp.	2
Caudofoveata/Solenogastres indet.	1
Entalina quinquangularis	1
Eriopisa elongata	1
Leichone borealis	1
Levinsenia gracilis	1
Lumbrineris sp. (cf. fragilis)	1
Thyasira granulosa	1

Table 7.3.5. Correlation matrix for selected sediment characters and fauna community parameters. The significance of the coefficients is indicated: *: p<0.05, **: p<0.01.

0.5 mm fraction

	grab volume	% mud	% org	S	N	Hs	Hb	J	D	ES_{100}	E
%mud	0.476										
%org	0.576*	0.443									
S	-0.234	-0.458	0.082								
N	-0.189	-0.347	0.076	0.850**							
Hs	-0.170	-0.487*	0.002	0.760**	0.529*						
Hb	-0.200	-0.488*	0.087	0.899**	0.820**	0.909**					
J	0.230	0.183	-0.086	-0.625*	-0.636*	-0.054	-0.325				
D	0.082	0.403	0.040	-0.419	-0.305	-0.856**	-0.711*	-0.313			
ES_{100}	-0.047	-0.325	0.065	0.442	0.055	0.821**	0.569*	0.229	-0.676*		
E	0.159	0.177	-0.136	-0.676*	-0.694*	-0.039	-0.353	0.901**	-0.327	0.241	
Ma	-0.210	-0.461	0.072	0.950**	0.647*	0.798**	0.822**	-0.517*	-0.443	0.621*	-0.563*

1.0 mm fraction

	grab volume	% mud	% org	S	N	Hs	Hb	J	D	ES_{100}	E
%mud	0.476										
%org	0.576*	0.443									
S	-0.488*	-0.299	-0.119								
N	-0.423	-0.280	-0.048	0.868**							
Hs	-0.367	-0.334	-0.054	0.765**	0.588*						
Hb	-0.388	-0.342	-0.114	0.687*	0.596*	0.894**					
J	0.213	0.193	0.239	-0.302	-0.368	0.209	-0.015				
D	0.219	0.302	0.007	-0.391	-0.296	-0.826**	-0.778**	-0.539*			
ES_{100}	-0.203	-0.192	-0.017	0.543*	0.180	0.801**	0.600*	0.201	-0.527*		
E	0.266	0.069	0.151	-0.572*	-0.571*	0.082	0.063	0.733**	-0.438	0.164	
Ma	-0.465	-0.275	-0.130	0.972**	0.728**	0.774**	0.658*	-0.242	-0.398	0.666*	-0.525*

Table 7.3.6. Correlation of community parameters for the >0.5 mm versus >1.0 mm fraction of the Heidrun field sediment fauna, June 1988.

Parameter	Correlation coeff.
S	0.714*
N	0.728**
Hs	0.592*
Hb	0.665*
J	0.350
D	0.474
ES_{100}	0.513*
E	0.533*
Ma	0.689*

* $p < 0.05$
** $p < 0.01$

Table 7.3.7 The mean content of silt/clay (<63 µm, wt.%) for the station groups defined in the MDS ordination analysis (>0.5 mm). The Heidrun field survey, June 1988.

MDS group no.	Stations in the group	% silt/clay (mud) mean ± st.dev.
I	16, 18, 19, 20, 21, 22, 23, 24, 25	52.6 ± 6.8
II	13, 15, 17	45.6 ± 4.6
III	1, 3, 4, 6, 7, 9, 10, 12, 14,	37.8 ± 11.4
	Station 24 alone	59.8

Table 7.3.8. Comparison of Heidrun community parameters, June 1988, with values from other Norwegian offshore fields.

	S	N/0.5m^2	HS	J	Overall dominant
> 1 mm fauna					
Heidrun 1988 mean	65	270	5.29	0.88	Spiophanes
Heidrun 1988 range	48-90	150-450	4.93-5.58	0.84-0.91	kroeyeri
Halten Bank 1985 mean[1]	58	255	4.41	0.76	Onuphis
Halten Bank 1985 range	25-98	39-719	2.31-5.89	0.43-0.97	quadri-cuspis
Station 3-88	72	333	5.48	0.89	Spioph. kroeyeri
Station 4-85 [1]	35	86	4.83	0.94	Spioph. kroeyeri
Station 24-88	63	207	5.14	0.86	Spiochae-topterus typicus
Station 3-85 [1]	39	77	4.96	0.94	Nothria opalina? Clymenura borealis
Gullfaks 1984 [2]	51-86	548-1545	4.56-5.36	0.77-0-87	-
Gyda 1987 [3]	32-50	268-618	4.25-4.96	0.82-0.89	-
Tommeliten 1987 [4]	39-55	328-438	4.20-5.24	0.79-0.88	-
> 0.5 mm					
Statfjord 1984 [5] outer stations	136-177	1891-3306	4.97-5.82	0.70-0.80	-
Heidrun	71-109	285-814	5.47-5.93	0.86-0.90	-

1 Bowler et al. 1986

2 Miljøplan and SI 1985

3 Levell 1987

4 Hobbs 1987

5 IOE 1985

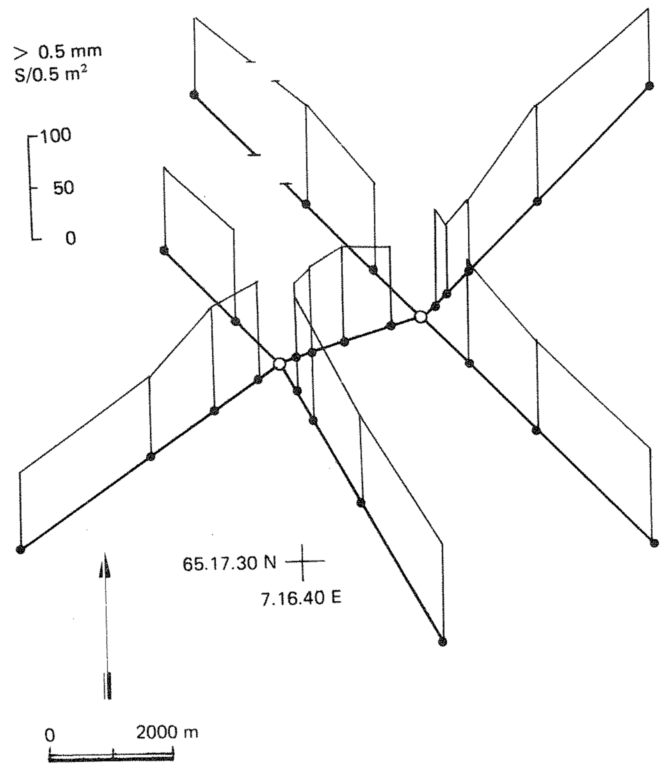


Fig. 7.3.1. Distribution of number of quantitative fauna taxa >0,5 mm along the sampling transects in the Heidrun field, June 1988.

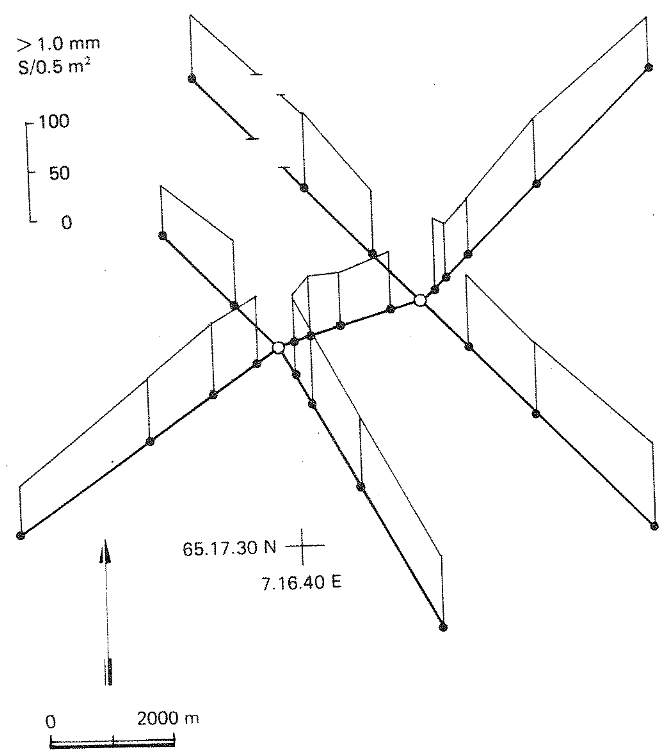


Fig. 7.3.2. Distribution of number of quantitative fauna taxa >1 mm along the sampling transects in the Heidrun field, June 1988.

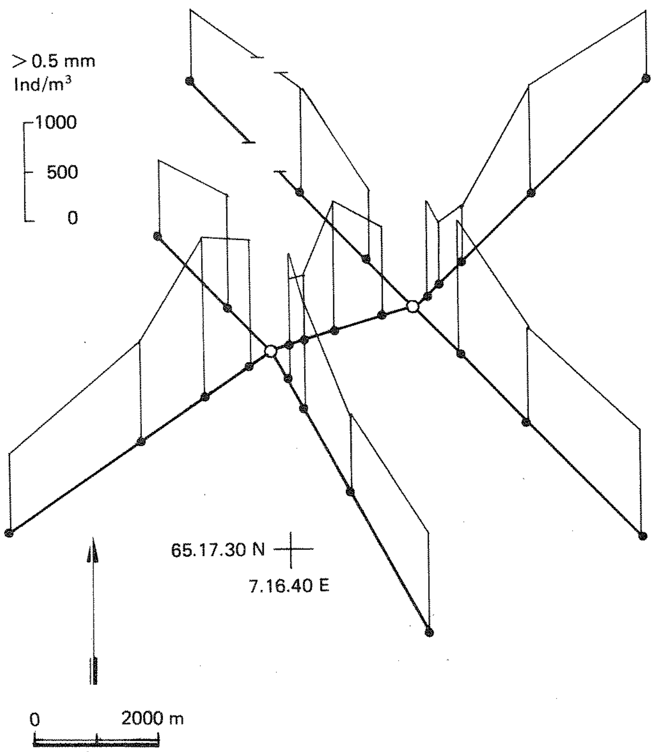


Fig. 7.3.3. Individual densities of animals >0,5 mm along the sampling transects in the Heidrun field, June 1988.

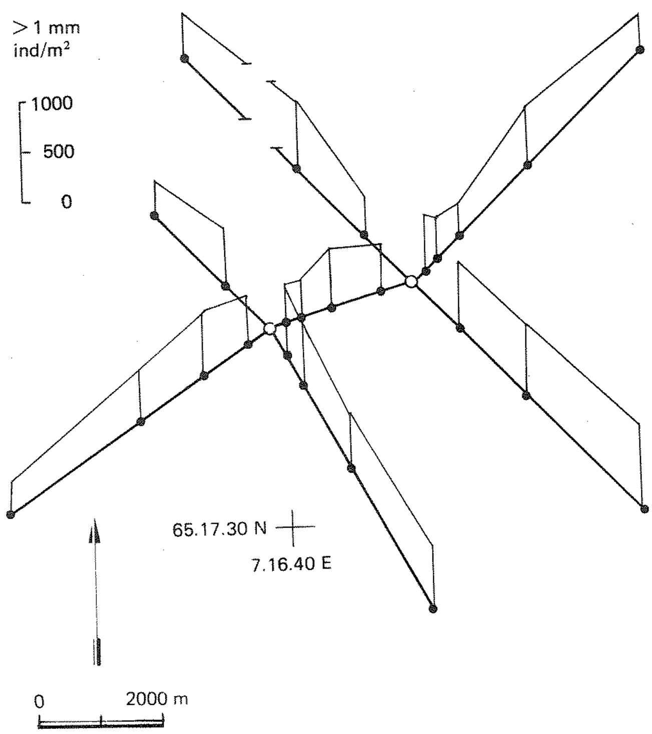


Fig. 7.3.4. Individual densities of animals >1 mm along the sampling transects in the Heidrun field, June 1988.

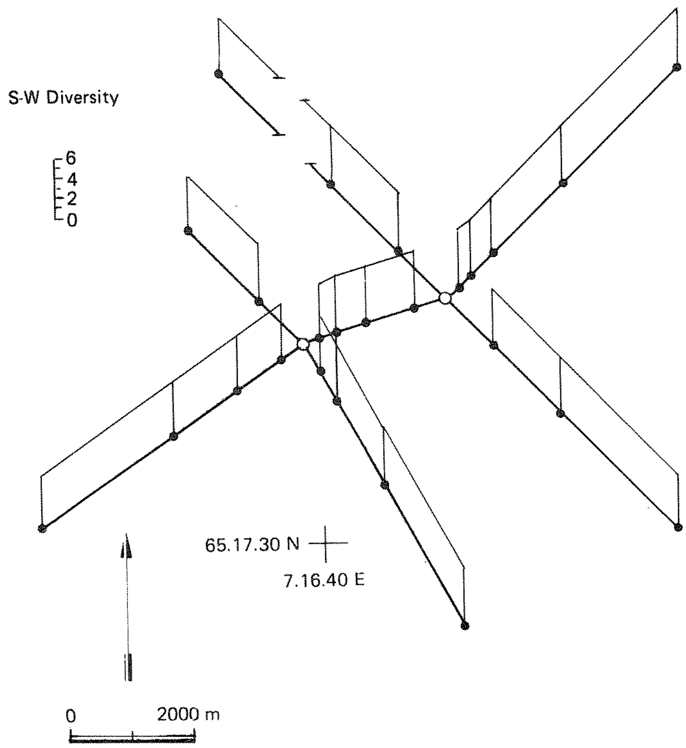


Fig. 7.3.5. Shannon-Wiener diversity values for fauna >0,5 mm along the sampling transects in the Heidrun field, June 1988.

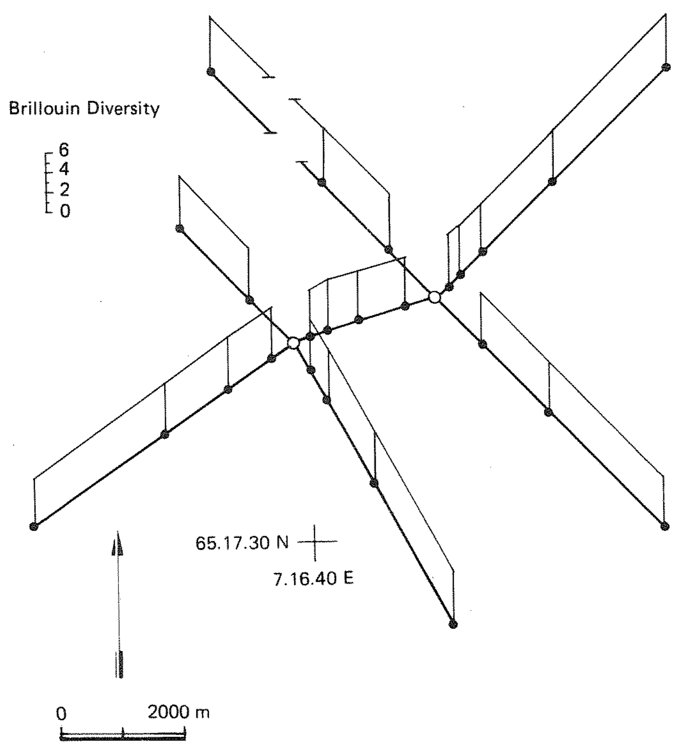


Fig. 7.3.6. Brillouin diversity values for fauna >0,5 mm along the the sampling transects in the Heidrun field, June 1988.

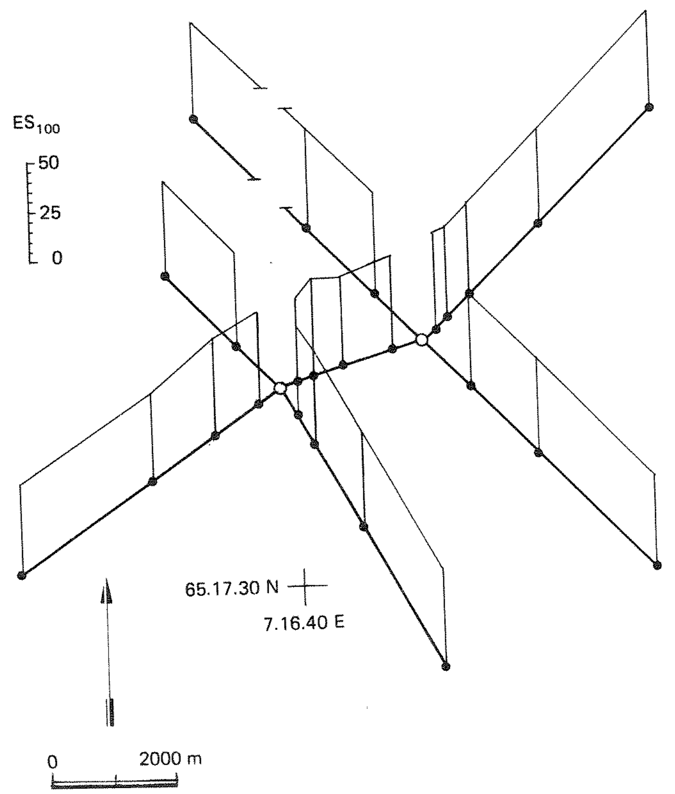


Fig. 7.3.7. Expected number of taxa per 100 individuals for fauna >0,5 mm along the sampling transects in the Heidrun field, June 1988.

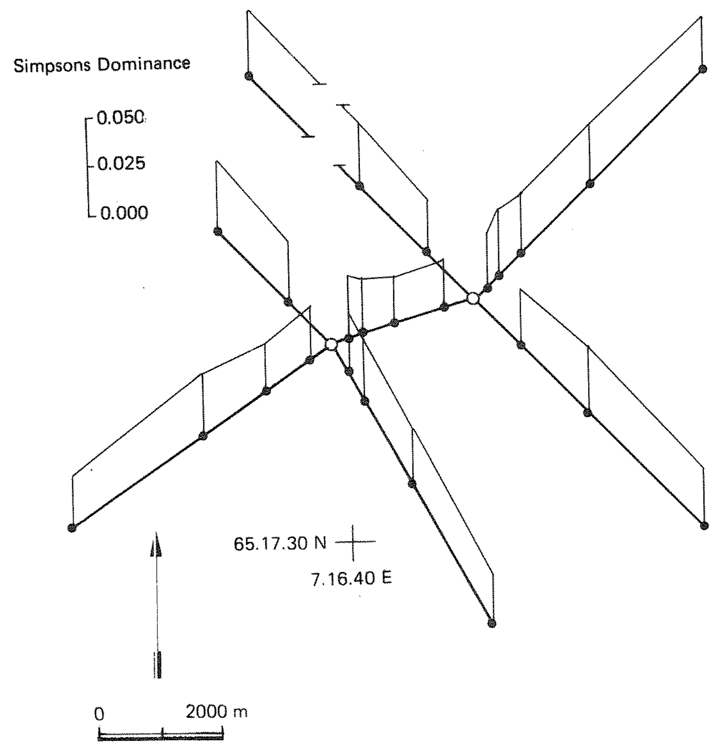


Fig. 7.3.8. Simpsons dominance index values for fauna >0,5 mm along the sampling transects in the Heidrun field, June 1988.

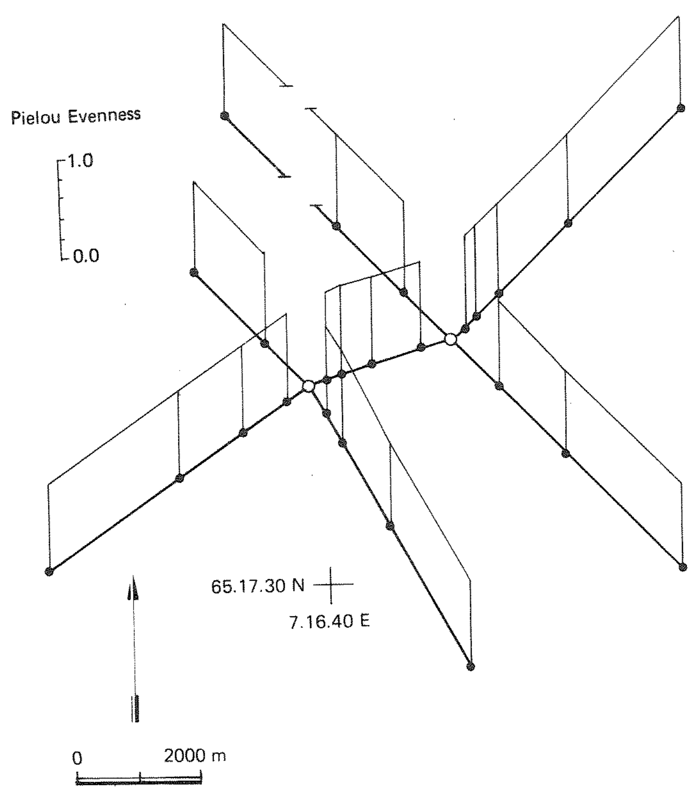


Fig. 7.3.9. Pielou evenness values for fauna >0,5 mm along the sampling transects in the Heidrun field, June 1988.

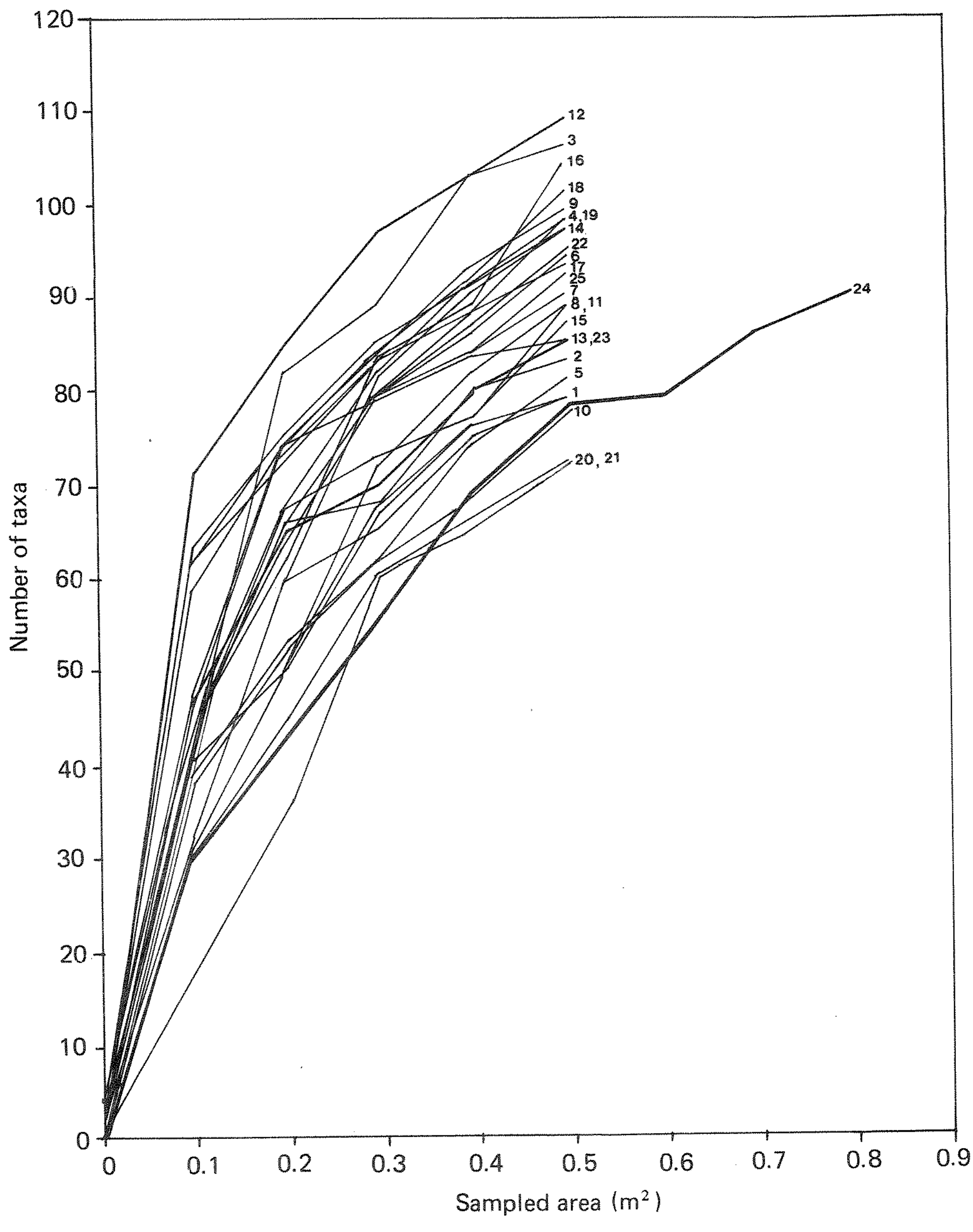


Fig. 7.3.10. Cumulative increase in number of quantitative taxa >0,5 mm with sampled area for the individual sampling stations at Heidrun, June 1988. Station numbers are given.

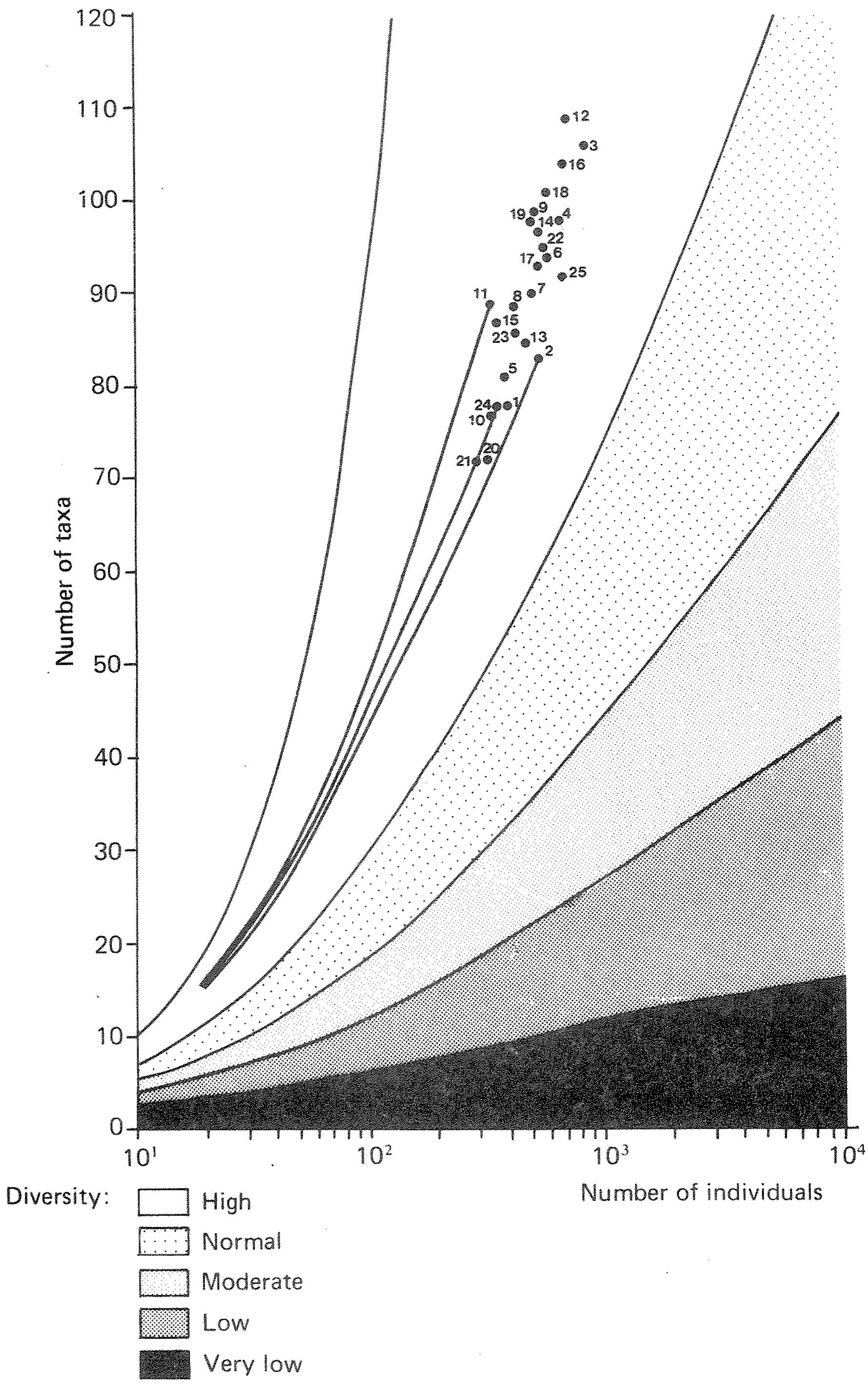


Fig. 7.3.11. Hurlbert rarefaction curves for the fauna >0,5 mm in the Heidrun field, June 1988. For clarity only the extreme curves and that of the reference Station 24 have been drawn, for the other stations only the end point of the curve is indicated. The classification refers to the diversity range found in a large number of coastal and fjord localities in Norway (from Rygg, 1984).

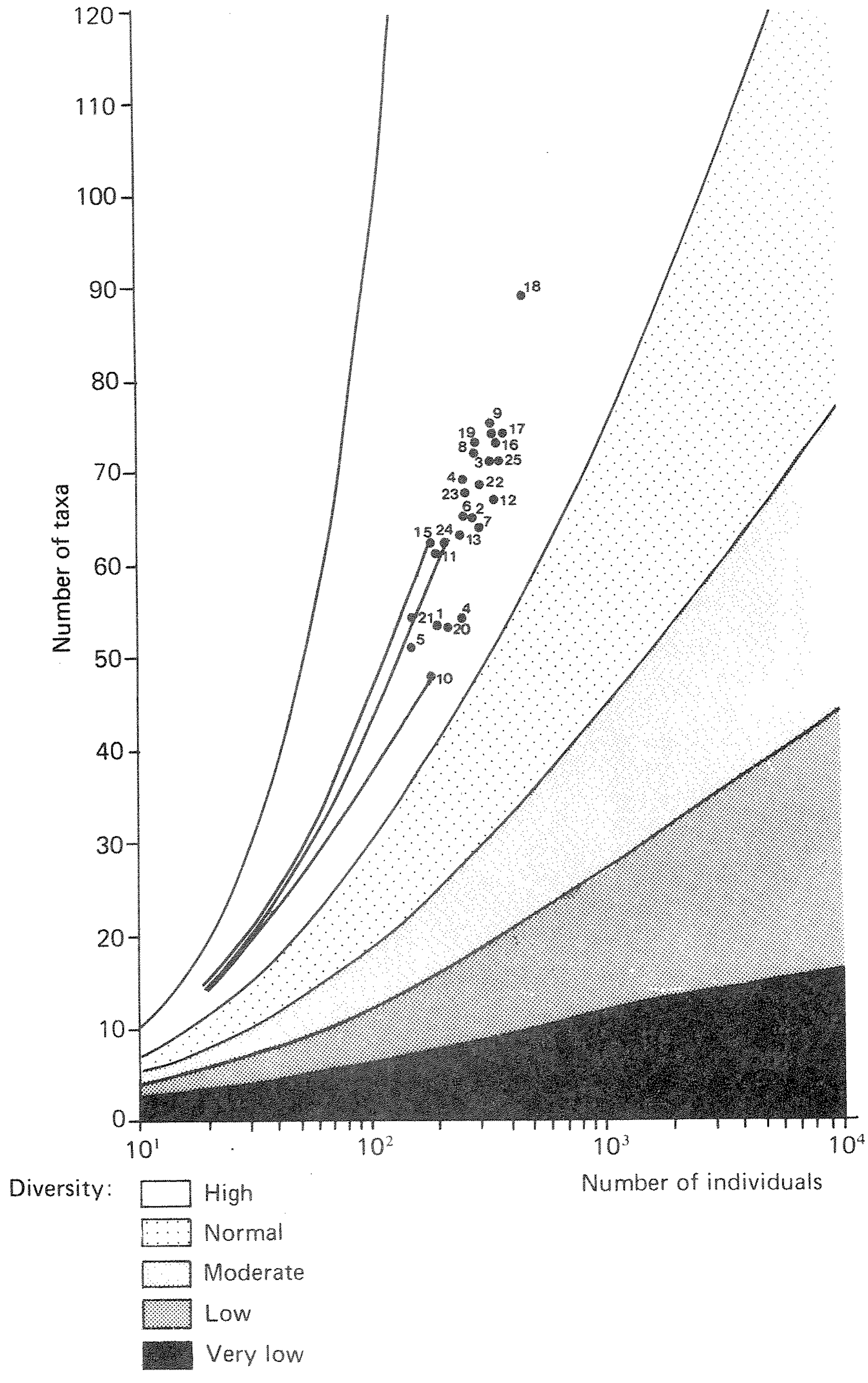


Fig. 7.3.12. Hurlbert rarefaction curves for the fauna >1 mm in the Heidrun field, June 1988. For clarity only the extreme curves and that of the reference station 24 have been drawn, for the other stations only the end point of the curve is indicated. The classification refers to the diversity range found in a large number of coastal and fjord localities in Norway (from Rygg, 1984).

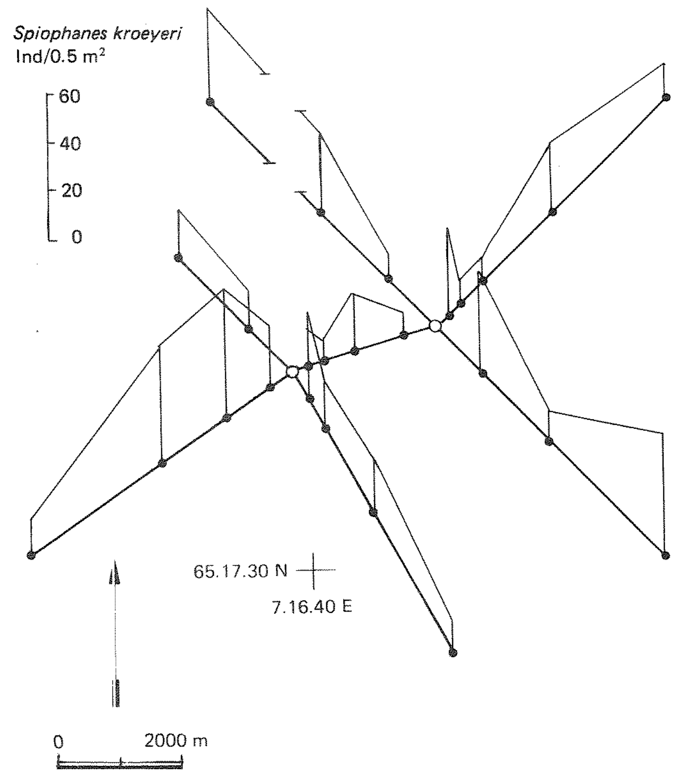


Fig. 7.3.13. Distribution of Spiophanes kroeyeri in the Heidrun field, June 1988.

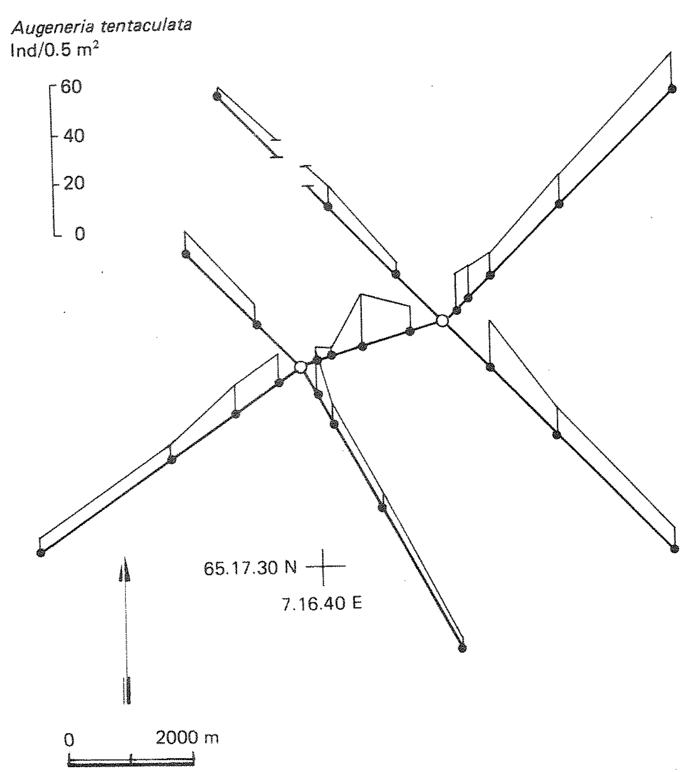


Fig. 7.3.14. Distribution of Augeneria tentaculata in the Heidrun field, June 1988.

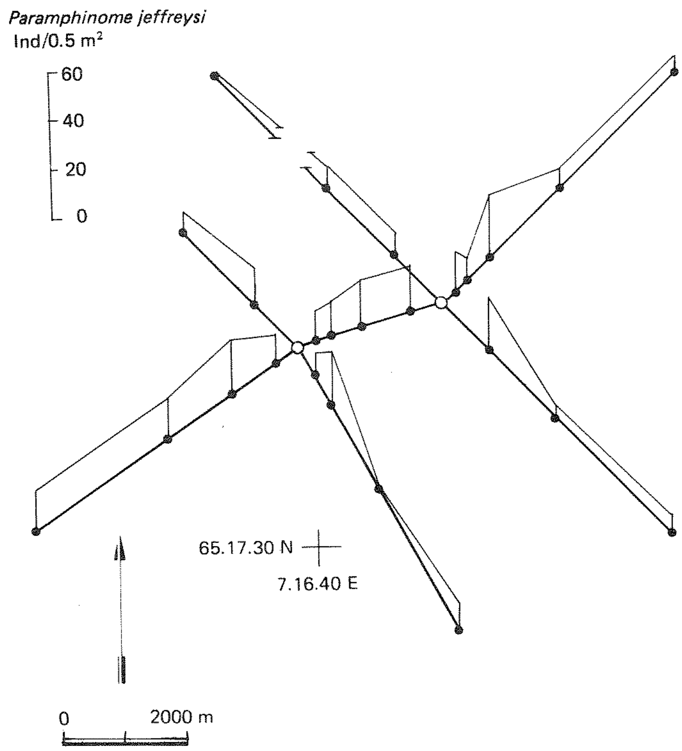


Fig. 7.3.15. Distribution of Paramphinome jeffreysi in the Heidrun field, June 1988.

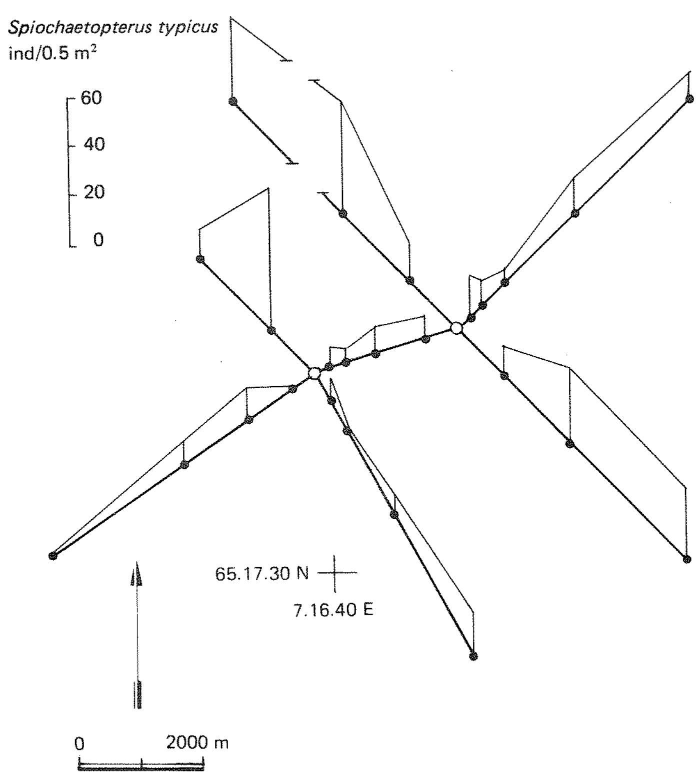


Fig. 7.3.16. Distribution of Spiochaetopterus typicus in the Heidrun field, June 1988.

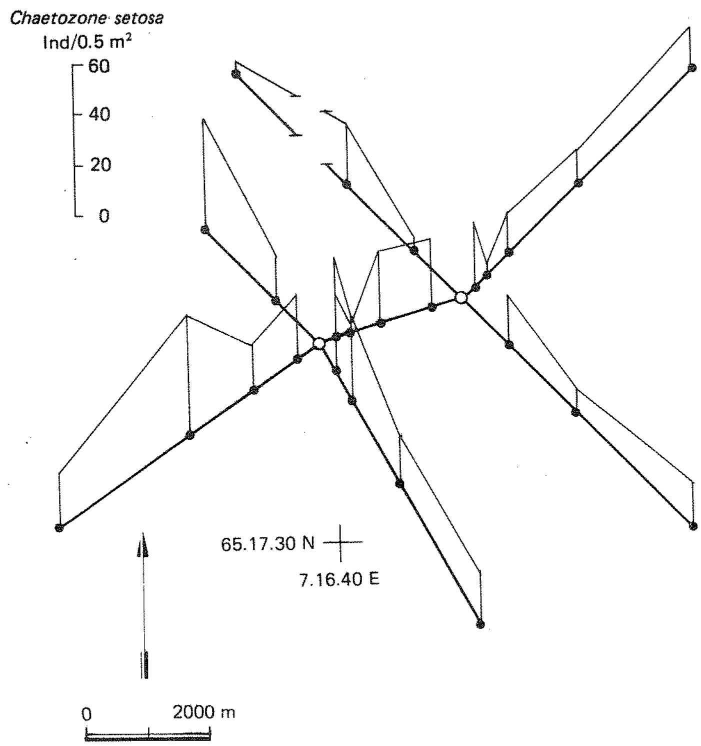


Fig. 7.3.17. Distribution of Chaetozone setosa in the Heidrun field, June 1988.

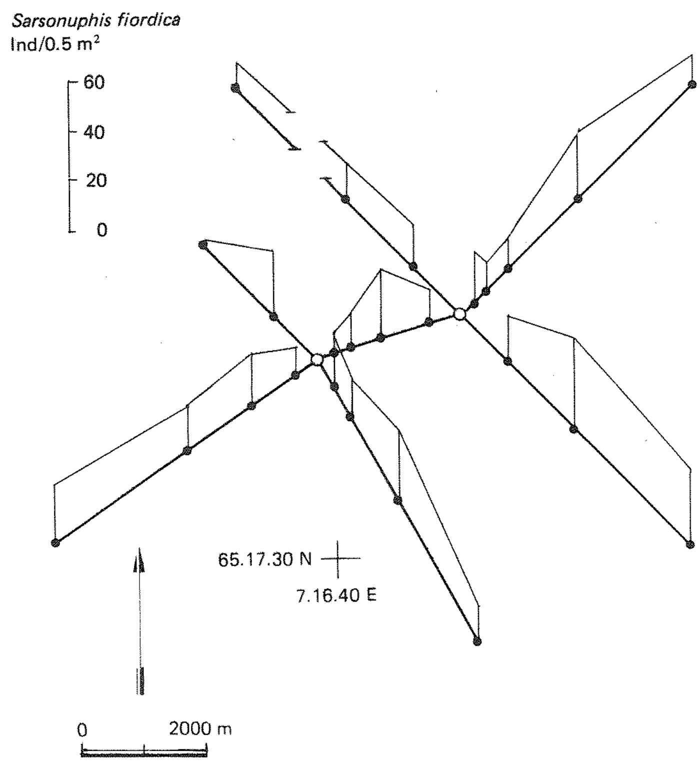


Fig. 7.3.18. Distribution of Sarsonuphis fiordica in the Heidrun field, June 1988.

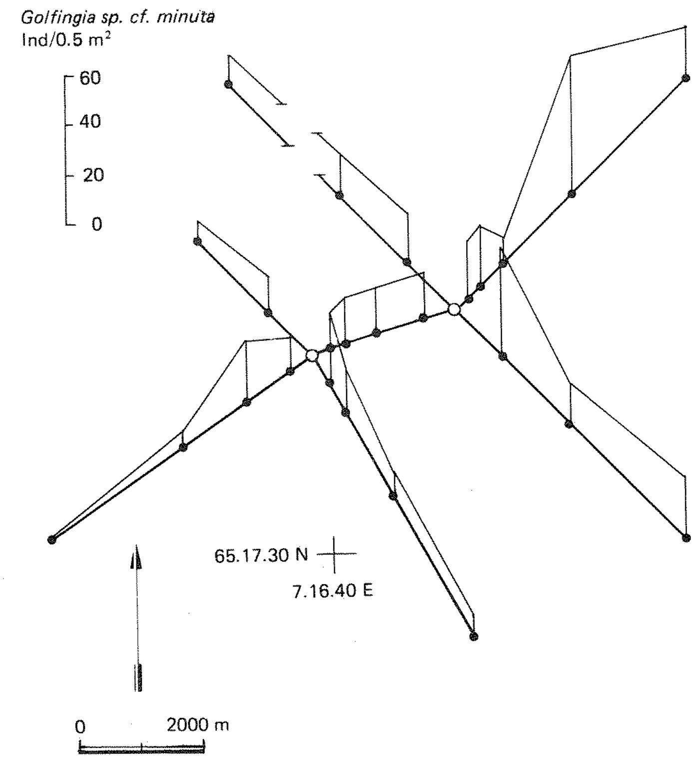


Fig. 7.3.19. Distribution of <u>Goldfingia</u> sp. cf. <u>minuta</u> in the Heidrun field, June 1988.

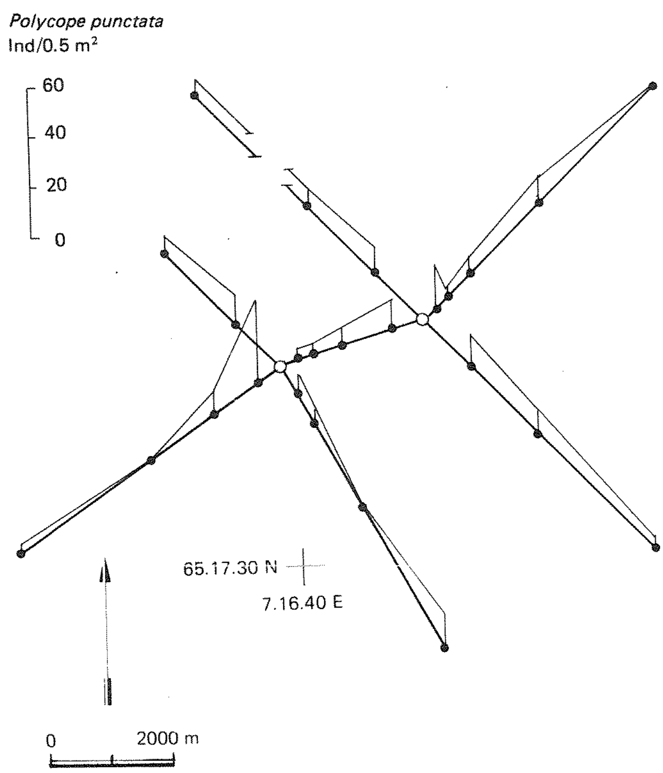


Fig. 7.3.20. Distribution of <u>Polycope</u> <u>punctata</u> in the Heidrun field, June 1988.

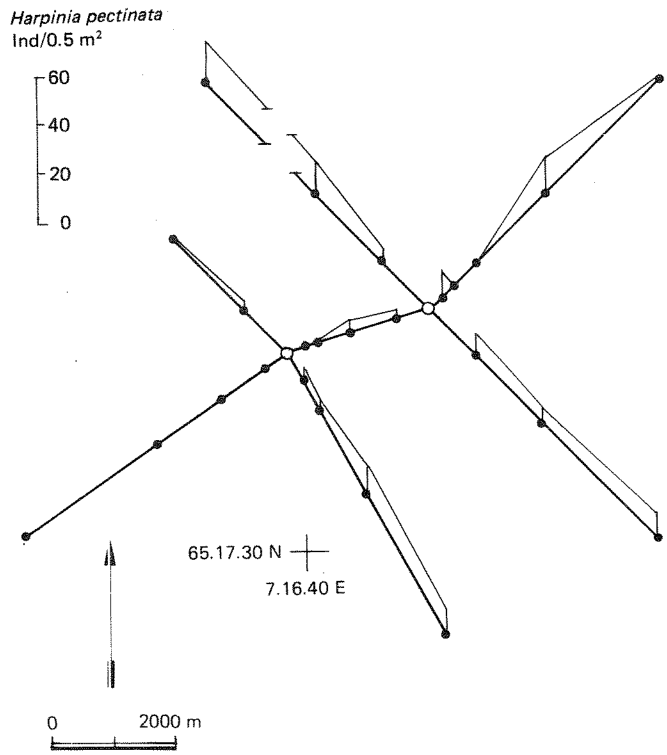


Fig. 7.3.21. Distribution of Harpinia pectinata in the Heidrun field, June 1988.

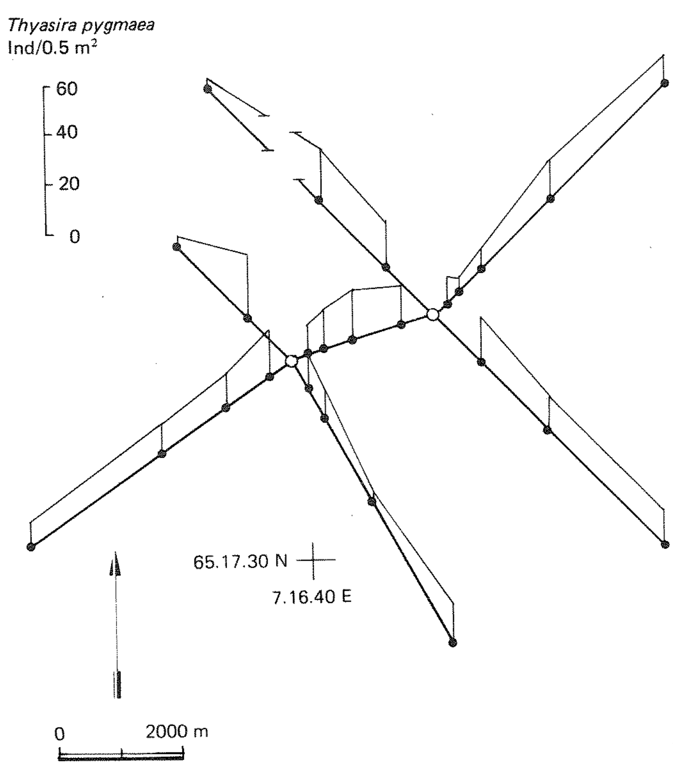


Fig. 7.3.22. Distribution of Thyasira pygmaea in the Heidrun field, June 1988.

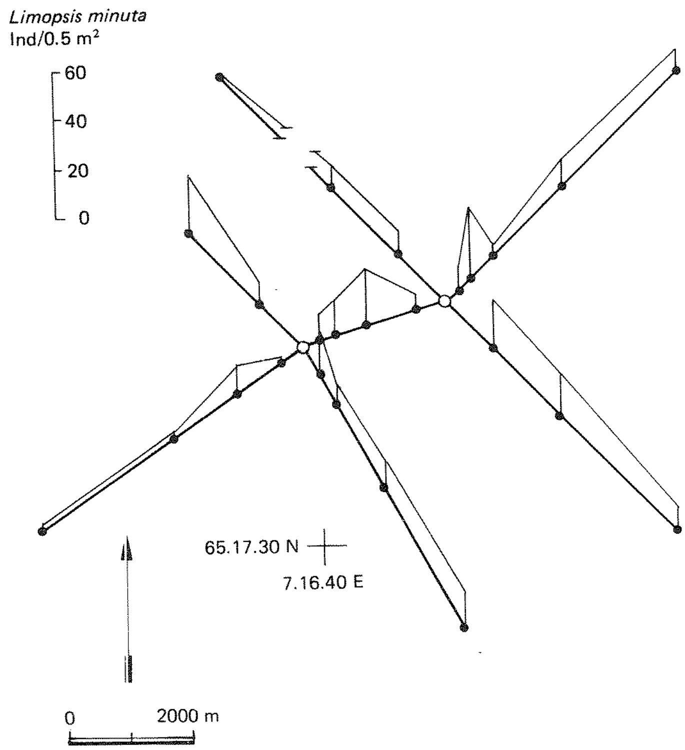


Fig. 7.3.23. Distribution of Limopsis minuta in the Heidrun field, June 1988.

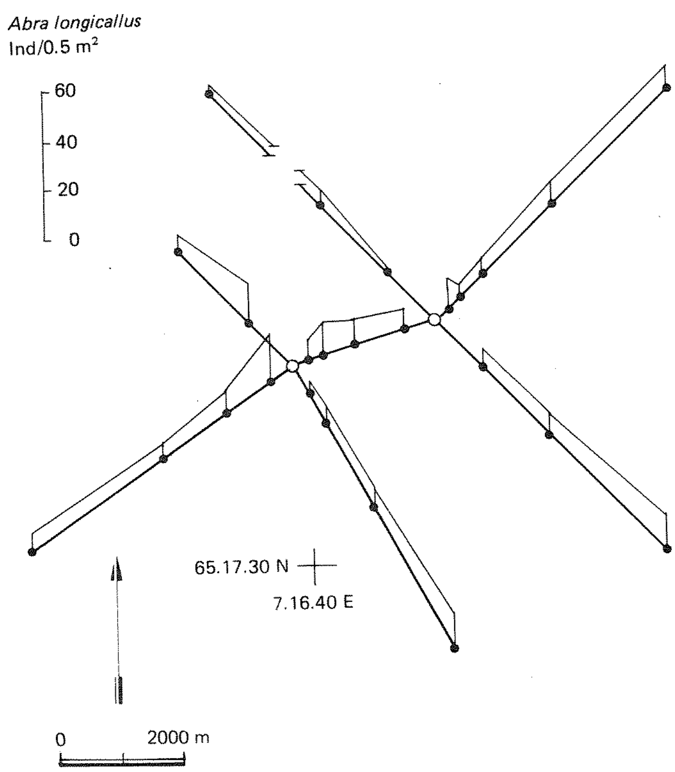


Fig. 7.3.24. Distribution of Abra longicallus in the Heidrun field, June 1988.

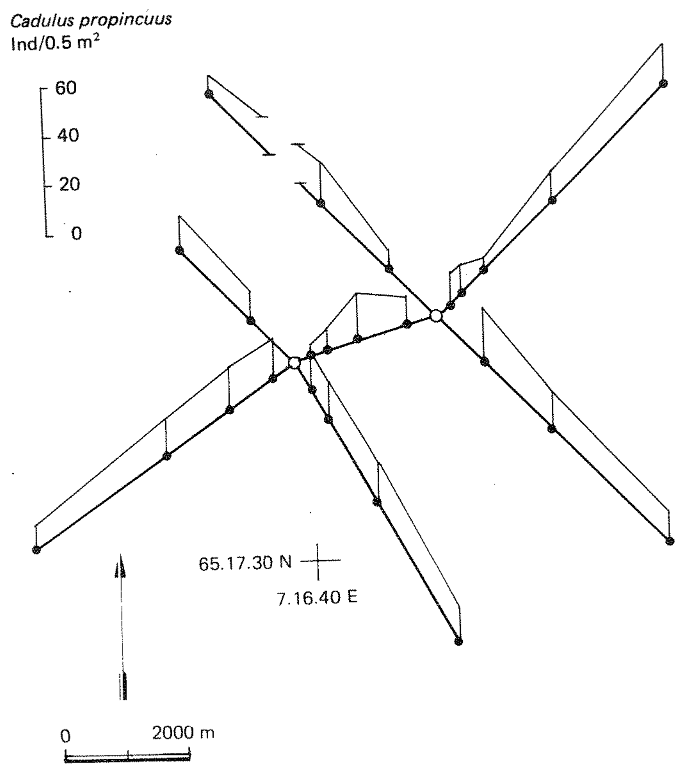
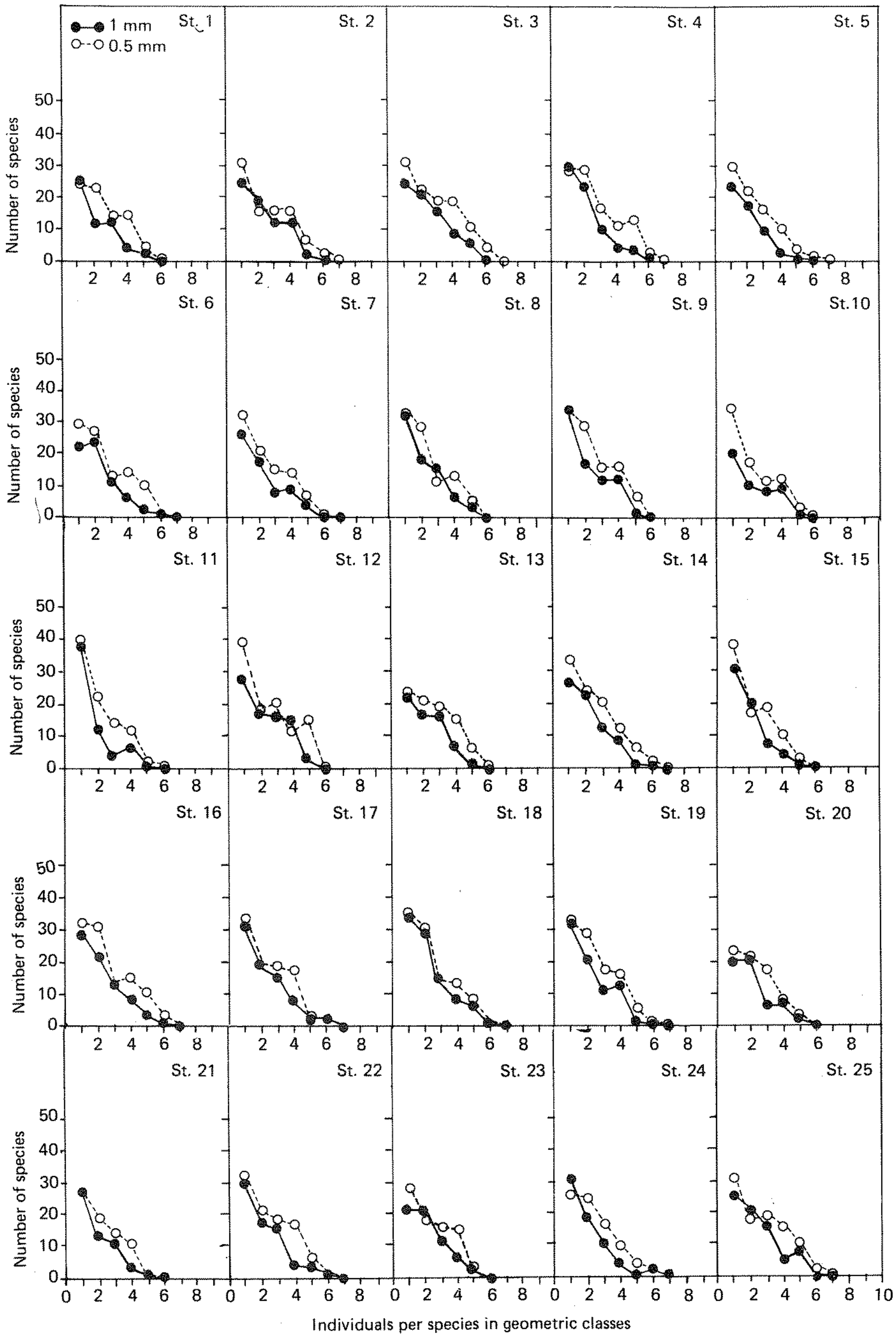
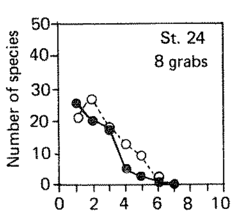


Fig. 7.3.25 Distribution of Cadulus propincuus in the Heidrun field, June 1988.





Classes
1: 1
2: 2-3
3: 4-7
4: 8-15
5: 16-31
6: 32-63
7: 64-127

Fig. 7.3.26. Distribution of quantitative taxa >0,5 mm according to their individual densities in geometric classes. The ordinate gives the number of taxa in each geometric class.

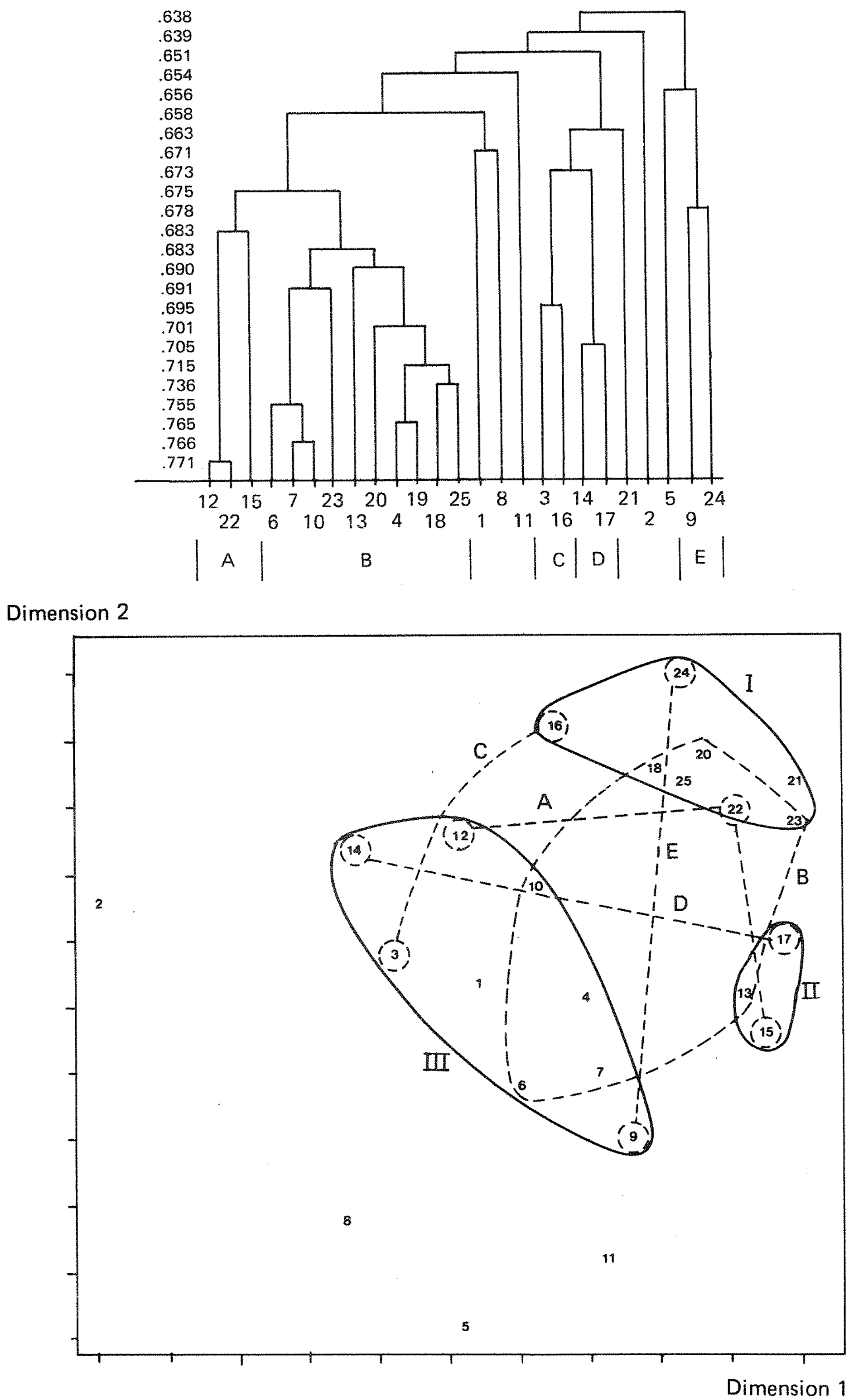


Fig. 7.3.27. Result of the multivariate analysis of the fauna >0,5 mm. a: Cluster analysis of stations on the basis of the Bray-Curtis index of dissimilarity (ordinate values). Reasonable groups of stations are identified (A - E). b: MDS plot in two dimensions of station similarity, stress coefficient 0,236 (Station 18 and 19 have same position). Reasonable groups of stations (I -III) are encircled (solid line). The groups A - E from the cluster analysis are indicated (hatched lines).

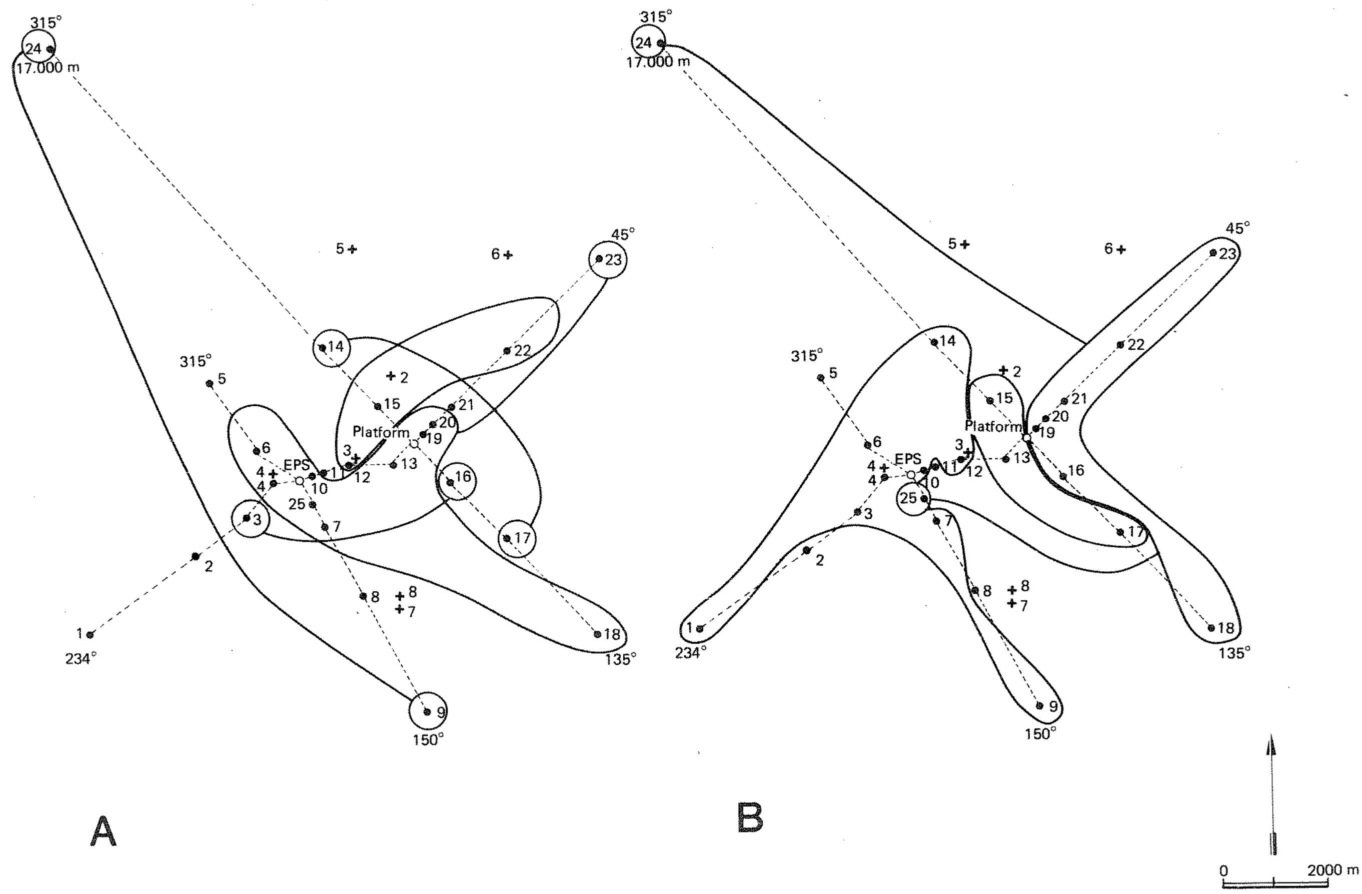


Fig. 7.3.28. Map of the Heidrun area with groups of stations from the multivariate analysis indicated. Fauna >0,5 mm. A: based on the cluster analysis. B: based on the MDS analysis.

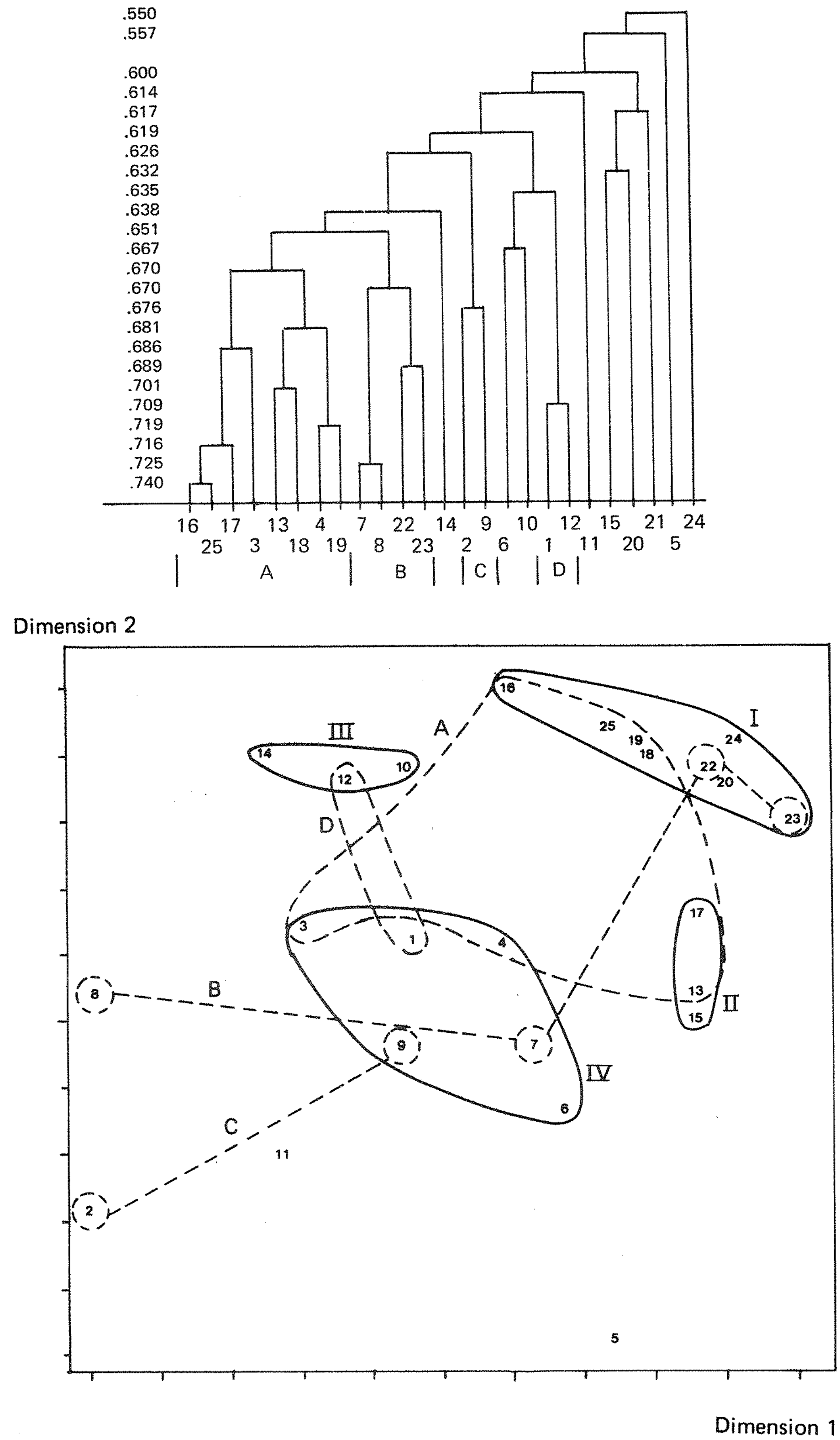


Fig. 7.3.29. Result of the multivariate analysis of the fauna >1 mm. a: Cluster analysis of stations on the basis of the Bray-Curtis index of dissimilarity (ordinate values). Reasonable groups of stations are identified (A - D). b: MDS plot in two dimensions of station similarity, stress coefficient 0,238 (Station 20 and 21 have the same position). Reasonable groups of stations (I - IV) are encircled (solid line). The groups A -D from the cluster analysis are indicated (hatched lines).

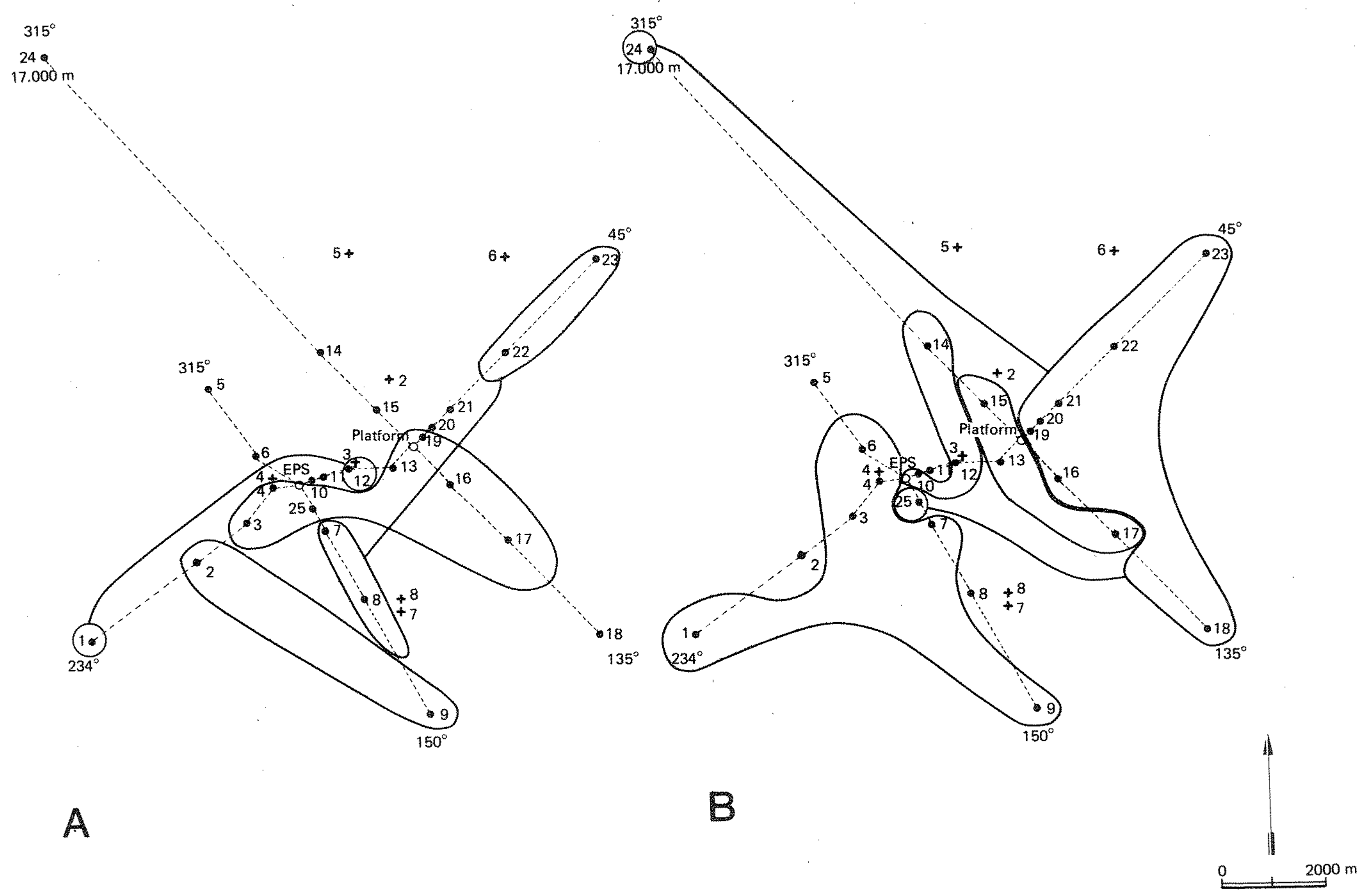


Fig. 7.3.30. Map of the Heidrun area with groups of stations from the multivariate analysis indicated. Fauna >1 mm. A: based on the cluster analysis. B: based on the MDS analysis.

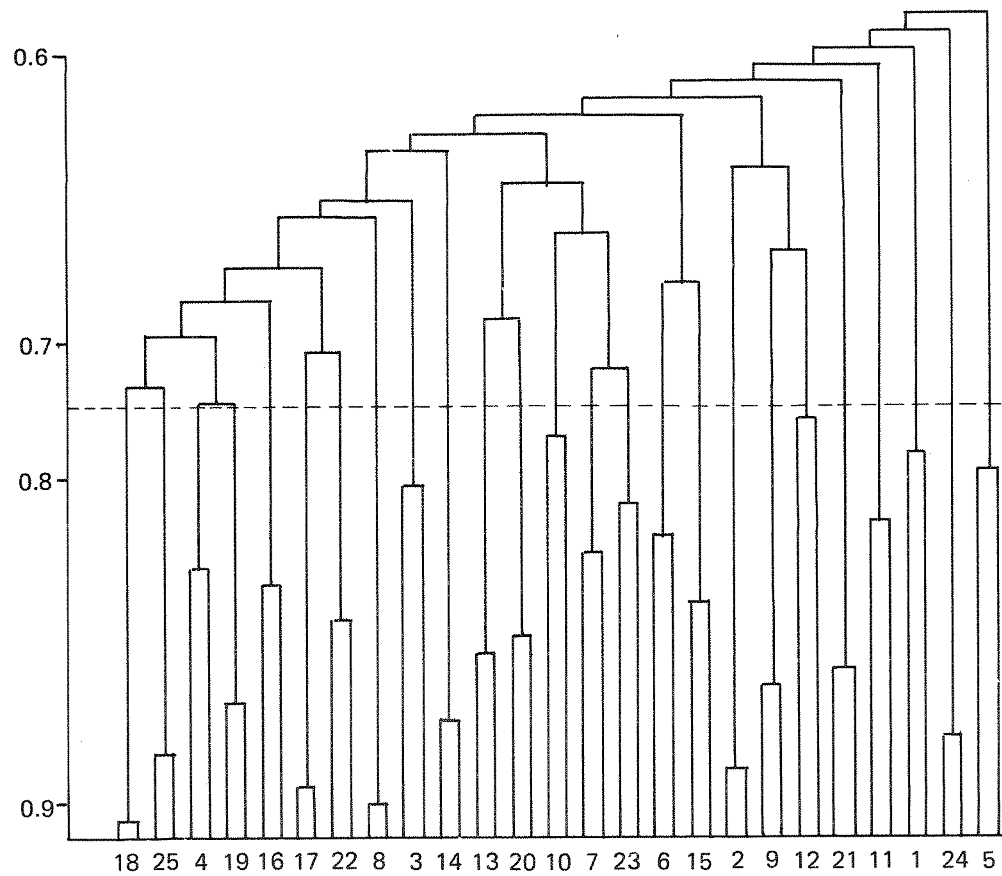


Fig. 7.3.31. Cluster analysis of the two fauna fractions (>0.5 mm and >1 mm) at all stations on the basis of the Bray-Curtis index of dissimilarity (ordinate values). As all corresponding pairs of fractions are clustered before any 'between station' clustering, only the station identification is given on the abcissa.

8. CONCLUSIONS

1. The sediments in the Heidrun area were poorly sorted with a median grain size ranging from fine sand to coarse silt, predominantly described as very fine sand. The content of silt and clay was high (26-64 %). A tendency of somewhat finer sediments towards N-NE of the field could be discerned. The sediments were well oxygenated and no indications of suboxic or anoxic areas were detected. The total organic content of the sediments was on an average 0.52 % and with small and non-systematic variation across the field.

2. The content of hydrocarbons in the upper 1 cm of the seabed was in the lower range of typical values for comparable uncontaminated sediments, except for 4-6 ring aromatics which were in the higher part of the background range. The levels were considered to be homogenous over the field. The concentration of total hydrocarbons from the IR analysis ranged from 1 to 10 mg/kg dw. (mean 4.9 mg/kg). The levels of THC based on GC/FID analysis ranged from 0.8 to 9 mg/kg dw. (mean 2.9 mg/kg). The concentrations of NPD ranged from 3.7 to 30 µg/kg dw. The relative composition of the n-alkanes and the aromatics indicated a predominantly biogenic origin. The vertical distribution of hydrocarbons in the sediments (two sites only) suggested no clear gradient in levels or composition.

3. There was no evidence of any sites with elevated concentrations of trace metals. In comparison with other non-contaminated sediments the trace metal concentrations at Heidrun are regarded as true background levels. Mercury was not detected in any of the samples. Barium, being indicative of drill cuttings discharges, ranged from 58 to 410 mg/kg dw. One subsample, taken in the vicinity of exploratory well 6507/7-4 contained 1200 mg/kg of barium, which may indicate local contamination by drill cuttings. However, no other organic or inorganic elements indicated contamination at this site.

4. No significant correlation was found between the chemical parameters analysed. This supports the impression of an homogenous and uncontaminated seabed sediment in the Heidrun area.

5. The 'limits of significant contamination' (LSC) values for the chemical parameters have been computed as a basis for future appraisal of contamination.

6. The Heidrun field contained an homogenous and highly diverse seabed macrofauna community. Diversity measures were among the highest recorded around offshore fields, dominance was low and equitability high. No signs of environmental disturbance could be detected by community parameters or distribution of species.

7. There were no systematic trends or gradients in the community parameters across the survey area, but multivariate analysis revealed a slight gradient in fauna composition from SW to NE. This gradient was at least partly a function of the silt/clay content of the sediment. A slightly more heterogenous fauna in the SW region was also indicated. Furthermore, the multivariate analyses separated the reference station slightly from the bulk of the stations on the basis of fauna composition, most likely a function of sediment silt/clay content, but also of distance and depth difference. Still the overall similarity and homogeneity of the fauna was striking.

8. The detailed impression of the macrofauna described in this report could be gained by analysis of the fauna larger than 1 mm alone, and inclusion of the animals smaller than 1 mm in size in the analysis did not change this impression. Still the 0.5-1 mm size fraction contained a range of new taxa and the inclusion of this fraction increased the overall diversity and homogeneity. Macrofauna analysis on the basis of sieving at 0.5 mm screen is therefore recommended as cost-effective in future surveys at Heidrun.

9. The physical, chemical and biological homogeneity of the seabed around Heidrun should provide a very good baseline for detection and appraisal of even small environmental perturbations caused by the development of the oil and gas field.

9. LIST OF TABLES.

Table 7.3.4. The most abundant taxa in the Heidrun field (>5 mm) ranked according to frequency of occurrence in Table 7.3.3.

Table 7.3.5. Correlation matrix for selected sediment characters and fauna community parameters. The significance of the coefficients is indicated: *: p<0,05, **: p<0,01.

Table 7.3.6. Correlation of community parameters for the >0,5 mm versus >1,0 mm fraction of the Heidrun field sediment fauna, June 1988.

Table 7.3.7. The mean content of silt/clay (<63µm, wt.%) for the station groups defined in the MDS ordination analysis (>0,5 mm). The Heidrun field survey, June 1988.

Table 7.3.8. Comparison of Heidrun community parameters, June 1988, with values from other Norwegian offshore fields.

10. LIST OF FIGURES

Fig. 7.3.5. Shannon-Wiener diversity values for fauna >0,5 mm along the sampling transects in the Heidrun field, June 1988.

Fig. 7.3.6. Brillouin diversity values for fauna >0,5 mm along the sampling transects in the Heidrun field, June 1988.

Fig. 7.3.7. Expected number of taxa per 100 individuals for fauna >0,5 mm along the sampling transects in the Heidrun field, June 1988.

Fig. 7.3.8. Simpsons dominance index values for fauna >0,5 mm along the sampling transects in the Heidrun field, June 1988.

Fig. 7.3.9. Pielou evenness values for fauna >0,5 mm along the sampling transects in the Heidrun field, June 1988.

Fig. 7.3.10. Cumulative increase in number of quantitative taxa >0,5 mm with sampled area for the individual sampling stations at Heidrun, June 1988. Station numbers are given.

Fig. 7.3.11. Hurlbert rarefaction curves for the fauna >0,5 mm in the Heidrun field, June 1988. For clarity only the extreme curves and that of the reference Station 24 have been drawn, for the other stations only the end point of the curve is indicated. The classification refers to the diversity range found in a large number of coastal and fjord localities in Norway (from Rygg, 1984).

Fig. 7.3.12. Hurlbert rarefaction curves for the fauna >1 mm in the Heidrun field, June 1988. For clarity only the extreme curves and that of the reference station 24 have been drawn, for the other stations only the end point of the curve is indicated. The classification refers to the diversity range found in a large number of coastal and fjord localities in Norway (from Rygg, 1984).

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Fig. 7.3.15. Distribution of Paramphinome jeffreysi in the Heidrun field, June 1988.

Fig. 7.3.16. Distribution of Spiochaetopterus typicus in the Heidrun field, June 1988.

Fig. 7.3.17. Distribution of Chaetozone setosa in the Heidrun field, June 1988.

Fig. 7.3.18. Distribution of Sarsonuphis fiordica in the Heidrun field, June 1988.

Fig. 7.3.19. Distribution of Goldfingia sp. cf. minuta in the Heidrun field, June 1988.

Fig. 7.3.20. Distribution of Polycope punctata in the Heidrun field, June 1988.

Fig. 7.3.21. Distribution of Harpinia pectinata in the Heidrun field, June 1988.

Fig. 7.3.22. Distribution of Thyasira pygmaea in the Heidrun field, June 1988.

Fig. 7.3.23. Distribution of Limopsis minuta in the Heidrun field, June 1988.

Fig. 7.3.24. Distribution of Abra longicallus in the Heidrun field, June 1988.

Fig. 7.3.25 Distribution of Cadulus propincuus in the Heidrun field, June 1988.

Fig. 7.3.26. Distribution of quantitative taxa >0,5 mm according to their individual densities in geometric classes. The ordinate gives the number of taxa in each geometric class.

Fig. 7.3.27. Result of the multivariate analysis of the fauna >0,5 mm. a: Cluster analysis of stations on the basis of the Bray-Curtis index of dissimilarity (ordinate values). Reasonable groups of stations are identified (A - E). b: MDS plot in two dimensions of station similarity, stress coefficient 0,236 (Station 18 and 19 have same position). Reasonable groups of stations (I -III) are encircled (solid line). The groups A - E from the cluster analysis are indicated (hatched lines).

Fig. 7.3.28. Map of the Heidrun area with groups of stations from the multivariate analysis indicated. Fauna >0,5 mm. A: based on the cluster analysis. B: based on the MDS analysis.

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