Husky Energy

REPORT

REPORT TITLE

White Rose

Environmental Effects Monitoring Program

2006

Volume 1

SUBMITTED TO

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Environmental Effects Monitoring Report on Sediment, Benthic Invertebrates and Commercial Fish.

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Executive Summary

The White Rose Environmental Effects Monitoring (EEM) program (Husky Energy 2004) was established to fulfill a commitment made in the White Rose Environmental Impact Statement (EIS) (Husky Oil 2000). This commitment was subsequently integrated into Decision 2001.01 (C-NOPB 2001) as a condition of project approval. The design of the EEM program drew on information provided in the White Rose EIS (Husky Oil 2000), drill cuttings and produced water dispersion modelling for White Rose (Hodgins and Hodgins 2000), the White Rose Baseline Characterization program (Husky Energy 2001; 2003), stakeholder consultations and consultations with regulatory agencies. The program was designed with input from an expert advisory group that included Leslie Grattan (Environmental Planning Consultant), Dr. Roger Green (University of Western Ontario), Dr. Douglas Holdway (University of Ontario Institute of Technology), Mary Catherine O'Brien (Manager at Tors Cove Fisheries Ltd), Dr. Paul Snelgrove (Memorial University) and Dr. Len Zedel (Memorial University). The main goals of the program are to assess effects predictions made in the EIS and determine the zone of influence of project contaminants. The term "contamination" is used in this report to indicate elevated levels of a chemical as compared to background levels (GESAMP 1993).

Volumes 1 and 2 of this report provide the results of the third year of sampling for the EEM program, which was conducted in the summer of 2006. Findings are related to results of sampling conducted under the first and second year EEM programs (Husky Energy 2005; 2006) and the Baseline Characterization program (Husky Energy 2001; 2003).

In 2006, seafloor sediments were sampled at 31 locations along transect lines radiating from the centre of the development and 13 locations surrounding the Northern, Central and Southern drill centres. An additional 14 stations were sampled in the vicinity of two potential drill centres located to the northwest of the Central drill centre. Physical and chemical analyses were conducted on sediment samples. Toxicity tests that characterized whether sediments were toxic to bacteria and a marine amphipod (crustacean) species were performed. In addition, benthic invertebrate infaunal species (species living in sediment) were identified and enumerated.

Samples of a common flatfish species (American plaice) and a commercial shellfish species (snow crab) were collected in the Study Area and in four Reference Areas located approximately 28 km from the centre of the development. These samples were analyzed for chemical body burden and taste. Analyses were also performed on a variety of American plaice health indices.

As in previous years, few project-related effects were noted for the 2006 EEM Program. For sediment, no project-related effects were identified for metals other than barium. However, concentrations of hydrocarbons and barium were elevated by drilling activity near drill centres. Sulphur and, to some extent, sulphide and fines levels were elevated near drill centres. Elevated concentrations of hydrocarbons and barium at White Rose are within the range of levels observed at other offshore oil and gas developments.

Sediment contamination did not extend beyond the 9 km zone of influence predicted by drill cuttings modelling (Hodgins and Hodgins 2000). Hydrocarbon contamination extended to 6 km from source and barium contamination extended to 2 km. Any contamination from sulphur was limited to within 1 km and increased sulphide levels were noted only in the immediate vicinity (0.5 km) of drill centres. Previously, there has been no change in fines with distance from drill centres and future monitoring programs will determine if the elevated fines levels observed in 2006 can be attributed to a project activity.

Weak directional effects were noted for both hydrocarbon and barium contamination, with dispersion primarily to the southeast within 1 km of the Southern and Central drill centres. This is consistent with current records at White Rose for 2003 and 2004 (Husky Energy 2005) and with Hodgins and Hodgins (2000), who noted that currents at White Rose are generally dominated by wind and tide, with a weak mean flow to the south.

In 2006 and in previous years, there were no detectable project effects on many benthic invertebrate community summary measures including standing crop, richness, diversity and evenness. However, total abundance, overall community composition, polychaete dominance, Paraonidae (Polychaeta) abundance and Amphipoda abundance were affected by project activity. The zone of effects on benthic invertebrates extended to 1 to 5 km from source, beyond the 500-m zone of effects predicted in the White Rose EIS. Nevertheless, the spatial extent of the benthic invertebrate response in 2006 appears to be generally consistent with the recent literature on effects on benthos from offshore oil developments.

For commercial fish, metal and hydrocarbon body burdens for both species were unaffected by project activity. Plaice and crab tissue were not tainted by sediment contamination in the Study Area and the general health of plaice in the Study Area, as measured through various indices, was similar to that measured in Reference Areas. Results for both plaice and crab are consistent with EIS predictions.

Conclusion

Overall, project-effects at White Rose in 2006 remained limited. The spatial extent and magnitude of sediment contamination were within the ranges predicted in the EIS. However, effects on benthic invertebrates were noted and the spatial extent of these exceeded EIS predictions by 0.5 to 5 km. Nevertheless, these effects were consistent with recent literature on effects on benthic invertebrates from offshore oil development. Sediment contamination and effects on benthos were not coupled with effects on commercial fish. No tissue contamination was noted for crab and plaice. Neither resource was tainted, and plaice health was similar between White Rose and more distant Reference Areas.

Based on results obtained to date, it is recommended that the next EEM sampling program take place in 2008.

Acknowledgements

The White Rose EEM program (2006) was led by Jacques Whitford (St. John's, Newfoundland and Labrador) under contract to Husky Energy and under the direction of Francine Wight (Husky Energy).

Jacques Whitford led data collection, with participants including Matthew Hynes, Barry Wicks, Darroch Taylor, Harold Boland, Todd Bath and Joseph Roberts. Fugro Jacques Geosurvey's Inc. provided geopositional services for sediment collections. Benthic invertebrate sorting, identification and enumeration was led by Patricia Pocklington of Arenicola Marine (Wolfville, Nova Scotia). Chemical analyses of sediment and tissues were conducted by Maxxam Analytics (Halifax, Nova Scotia and St. John's, Newfoundland and Labrador). Particle size analysis was conducted by Jacques Whitford. Sediment toxicity was supervised by Trudy Toms of Jacques Whitford - Laboratory Division. Fish and shellfish taste tests were performed at the Marine Institute of Memorial University of Newfoundland. Fish health indicator analyses were supervised by Dr. Anne Mathieu of Oceans Ltd. (St. John's, Newfoundland and Labrador). Sediment quality, body burden and fish health data were analyzed by Dr. Michael Paine of Paine, Ledge and Associates (North Vancouver, British Columbia). Project management was executed by Dr. Elisabeth DeBlois. The Jacques Whitford analysis and reporting team included Dr. Elisabeth DeBlois, Beverley Best and Stephen Rowe. Sandra Whiteway and Ellen Tracy (Jacques Whitford) and the White Rose Advisory Group reviewed the document before final printing.

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1.0 Purpose

1.1 Project Setting and Field Layout

Husky Energy, with its joint-venture partner Petro-Canada, is developing the White Rose oilfield on the Grand Banks, offshore Newfoundland. The field is approximately 350 km east-southeast of St. John's, Newfoundland, and 50 km from both the Terra Nova and Hibernia fields (Figure 1-1). To date, development wells have been drilled at three drill centres: the Northern, Central and Southern drill centres (Figure 1-2).

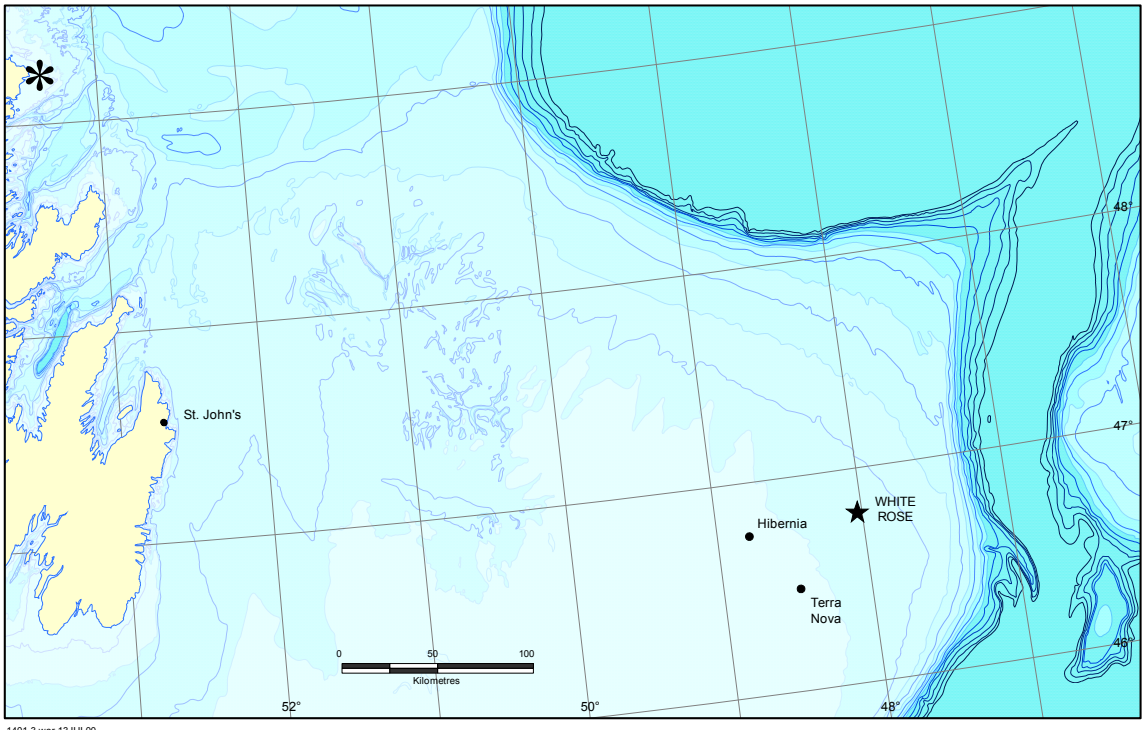

Figure 1-1 Location of the White Rose Oilfield

1.2 Project Commitments

Husky Energy committed in its EIS (Part One of the White Rose Oilfield Comprehensive Study (Husky Oil 2000)) to develop and implement a comprehensive EEM program for the marine receiving environment. This commitment was integrated into Decision 2001.01 (C-NOPB 2001) as a condition of project approval.

Also, as noted in Condition 38 of Decision 2001.01 (C-NOPB 2001), Husky Energy committed, in its application to the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB), to make the results of its EEM program available to interested parties and the general public. The C-NLOPB also noted in correspondence to the White Rose Public Hearings Commissioner, that Husky Energy stated its intent to make both EEM program reports and environmental compliance monitoring information "publicly available to interested stakeholders in a timely manner".

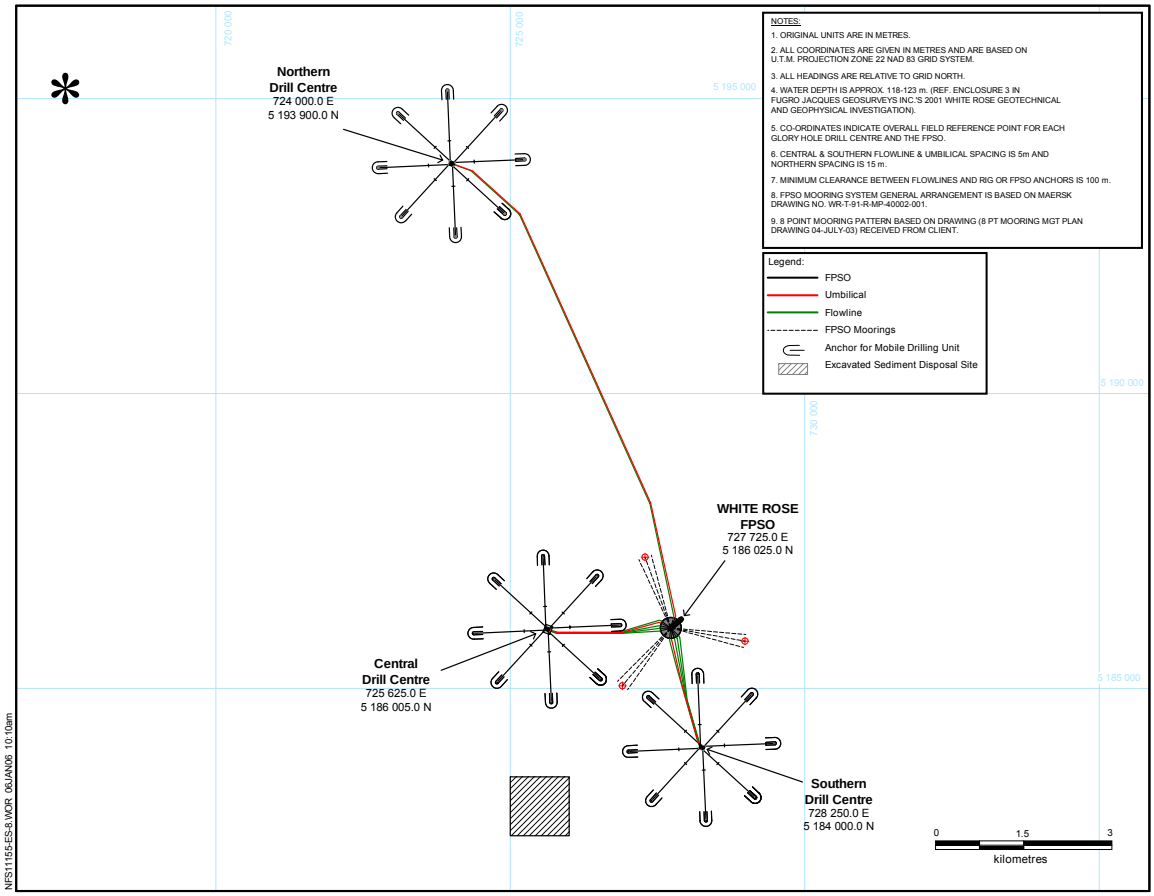

Figure 1-2 White Rose Field Layout

1.3 EEM Program Design

Husky Energy submitted an EEM program design to the C-NLOPB in May 2004, and this design was approved for implementation in July 2004. The design drew on information provided in the White Rose EIS (Husky Oil 2000), drill cuttings and produced water dispersion modelling for White Rose (Hodgins and Hodgins 2000), the White Rose Baseline Characterization program carried out in 2000 and 2002 (Husky Energy 2001; 2003), stakeholder consultations and consultations with regulatory agencies.

The program was designed with the input an expert advisory group that included Leslie Grattan (Environmental Planning Consultant), Dr. Roger Green (University of Western Ontario), Dr. Douglas Holdway (University of Ontario Institute of Technology), Mary Catherine O'Brien (Manager at Tors Cove Fisheries Ltd.), Dr. Paul Snelgrove (Memorial University) and Dr. Len Zedel (Memorial University). The White Rose Advisory Group (WRAG) continues to provide input on interpretation of EEM results and on program refinements, as required. In 2006, fishing interests on the WRAG were represented by by Jaimie Coady of the Fish, Food and Allied Workers Union (FFAW). WRAG comments on the 2006 EEM program are provided in Appendix A.

1.4 EEM Program Objectives

The EEM program is intended to provide the primary means to determine and quantify project-induced change in the surrounding environment. Where such change occurs, the EEM program enables the evaluation of effects and, therefore, assists in identifying the appropriate modifications to, or mitigation of, project activities or discharges. Such operational EEM programs also provide information for the C-NLOPB to consider during its periodic reviews of the Offshore Waste Treatment Guidelines (NEB et al. 2002).

Objectives to be met by the EEM program are to:

- confirm the zone of influence of project contaminants;
- test biological effects predictions made in the EIS (Husky Oil 2000);
- provide feedback to Husky Energy for project management decisions requiring modification of operations practices where/when necessary;
- provide a scientifically-defensible synthesis, analysis and interpretation of data; and
- be cost-effective, making optimal use of personnel, technology and equipment.

1.5 White Rose EIS Predictions

The White Rose EIS assessed the significance of effects on Valued Ecosystem Components (VECs). VECs addressed within the context of the Husky Energy EEM program are Fish and Fish Habitat and Commercial Fisheries (Husky Oil 2000). As such, predictions on physical and chemical characteristics of sediment and water, and predictions on benthos, fish and fisheries apply to the EEM program.

In general, development operations at White Rose were expected to have the greatest effects on near-field sediment physical and chemical characteristics through release of drill cuttings, while regular operations were expect to have the greatest effect on physical and chemical characteristics of water, through release of produced water. The zone of influence[1] for these two waste streams was not expected to extend beyond approximately 9 km and 3 km from source for drill cuttings and produced water, respectively (Hodgins and Hodgins 2000). Effects of other waste streams (see Section 2 for details) on physical and chemical characteristics of sediment and water were considered small relative to effects of drill cuttings and produced water discharge.

Effects of drill cuttings on benthos were expected to be low to high in magnitude[2] within approximately 500 m, with overall effects low in magnitude. However, direct effects to fish populations, rather than benthos (on which some fish feed), as a result of drill cuttings discharge were expected to be unlikely. Effects resulting from contaminant uptake by individual fish (including taint) were expected to range from negligible to low in magnitude and be limited to within 500 m of the point of discharge.

[1] The zone of influence is defined as the zone where project-related physical and chemical alterations might occur.

[2] Low = Affects 0 to 10 percent of individuals in the affected area; medium = affects 10 to 25 percent of individuals; high = affects more than 25% of individuals.

Effects of produced water (and other liquid waste streams) on physical and chemical characteristics of water were expected to be localized near the point of discharge. Liquid waste streams were not expected to have any effect on physical and chemical characteristics of sediment or benthos. Direct effects on adult fish were expected to be negligible.

Given predictions on effects on sediment and water quality, anticipated effects on Fish and Fish Habitat and Commercial Fisheries were assessed as non-significant in the White Rose EIS (Husky Oil 2000).

Further details on environmental assessment methodologies can be obtained from the White Rose EIS (Husky Oil 2000). For the purpose of the EEM program, testable hypotheses that draw on effects predictions are developed in Section 1.7.

1.6 EEM Program Components

The two primary objectives of the White Rose EEM (Section 1.4) are to determine the zone of influence of project contaminants and test biological effects predictions made in the EIS. As such, the program will ultimately be divided into three components, dealing with effects on Sediment Quality, Water Quality and Commercial Fish species. The Water Quality Component of the White Rose EEM program is currently under development (see Husky Energy 2004, 2005b) and is not dealt with in this report. Assessment of Sediment Quality includes measurement of alterations in chemical and physical characteristics, measurement of sediment toxicity and assessment of benthic community structure. These three sets of measurements are commonly known as the Sediment Quality Triad (SQT) (Chapman 1992; Chapman et al. 1987; 1991; Long and Chapman 1985). Assessment of effects on Commercial Fish species includes measurement of body burden, taint, morphometric and life history characteristics for snow crab and American plaice and measurement of various health indices for American plaice. Components of the 2006 EEM program for White Rose are shown in Figure 1-3. Further details on the selection of monitoring variables are provided in the White Rose EEM Program Design document (Husky Energy 2004).

1.7 Monitoring Hypotheses

Monitoring, or null (H0), hypotheses have been established as part of the White Rose EEM program. Null hypotheses are an analysis and reporting construct established to assess effects predictions. Null hypotheses (H0) will always state “no effects”, even if effects have been predicted as part of the EIS. Therefore, rejection of a null hypothesis does not necessarily invalidate EIS predictions, nor should such predictions be considered a “compliance” target in this context.

The following monitoring hypotheses apply to the Sediment Quality and Commercial Fish Components of the White Rose EEM program:

- Sediment Quality:
    - H0: There will be no change in SQT variables with distance or direction from project discharge sources over time.

- Commercial Fish:

  - H0(1): Project discharges will not result in taint of snow crab and American plaice resources sampled within the White Rose Study Area, as measured using taste panels.

  - H0(2): Project discharges will not result in adverse effects to fish health within the White Rose Study Area, as measured using histopathology, haematology and MFO induction.

No hypotheses were developed for American plaice and snow crab body burden and morphometrics and life history characteristics, as these tests were considered to be supporting tests, providing information to aid in the interpretation of results of other monitoring variables (taste tests and health).

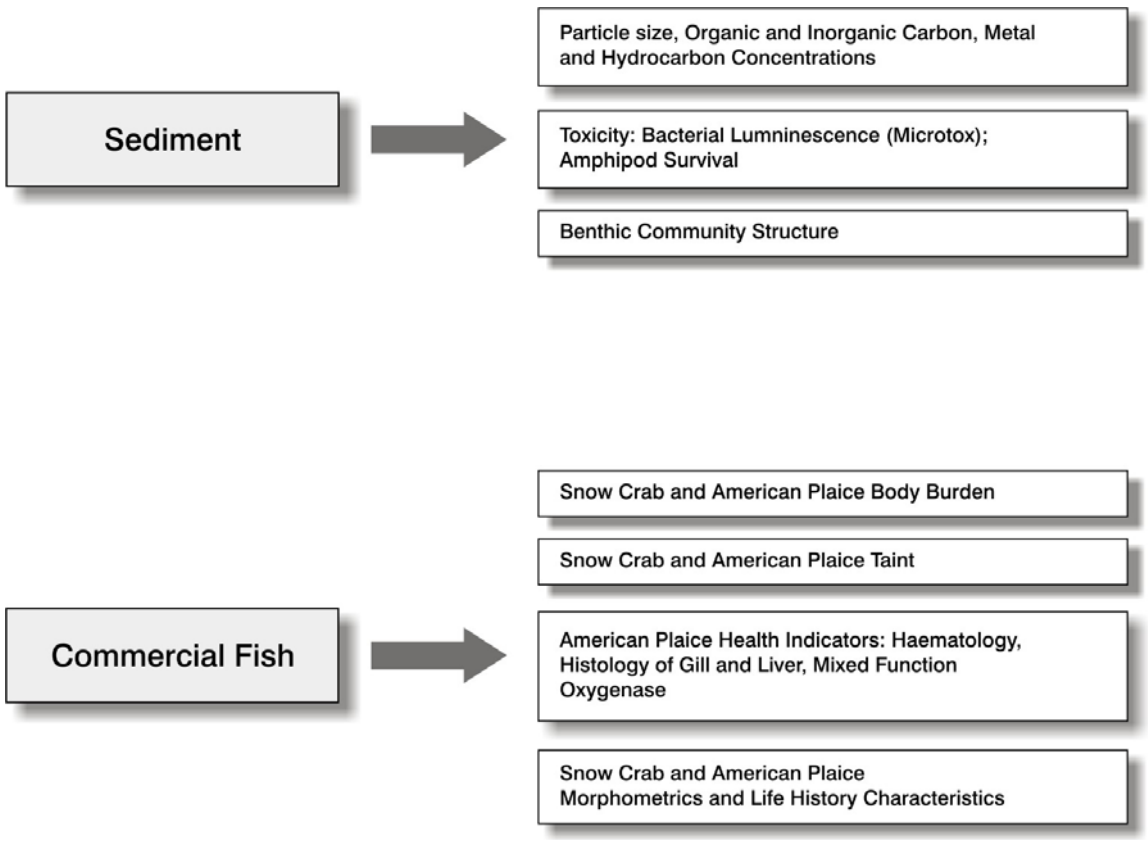

Figure 1-3 EEM Program Components

1.8 Sampling Design

In the Baseline Characterization ("baseline") and the EEM programs, sediment was sampled at discrete stations located at varying distances from drill centres, while commercial fish were sampled in the vicinity of the drill centres (Study Area) and at more distant Reference Areas (with no intermediate distances). The sediment sampling design is commonly referred to as a gradient design while the commercial fish design is a control-impact design (see Husky Energy 2004 for details).

There are some differences between sediment stations sampled for baseline (2000) and for EEM programs (2004, 2005 and 2006). A total of 48 sediment stations were sampled during baseline (Figure 1-4), 56 stations were sampled for the 2004 EEM program (Figure 1-5), 44 stations were sampled for the 2005 EEM program (Figure 1-6) and 59 stations were sampled in 2006 (Figure 1-7); 37 stations were common to all sampling programs. As part of EEM program design (Husky Energy 2004), some redundant stations in the immediate vicinity of drill centres were eliminated for the EEM programs. These stations were sampled during baseline because the final location of drill centres had not been established. Two remote reference stations located 35 km south-southeast and 85 km northwest of White Rose were eliminated for the EEM programs because of their distance from the development and because sediment chemistry results from baseline sampling showed that the northwest reference station might not be comparable to other stations. Two 18-km stations were eliminated because of redundancies with other stations (see Husky Energy 2004 for details).

Station additions for the EEM programs included four reference stations at 28 km from the centre of the development, one station along the north axis at approximately 8 km from the centre of the development, three drill centre stations located approximately 300 m from each of the Northern, Central and Southern drill centres. However, in 2005, one of these stations (station S5) could not be sampled because of drilling activity at the Southern drill centre. In 2004, six drill centre stations were sampled at 1 km from the proposed location of each of more northerly and more southerly drill centres (see Figure 1-5). Since there are no immediate plans to drill at these centres, these stations were not sampled in the 2005 and 2006 program. Similarly, 14 'West' stations were sampled in 2006 around the proposed location of the West-Alpha and West-Bravo drill centres located to the northwest of the Central drill centre (Figure 1-7). Table 1-1 provides a summary of changes between baseline and EEM sampling years, as well as stations name changes that were proposed in the EEM design document to simplify reporting of results.

For American plaice and snow crab, sampling for the baseline program (2000 and 2002) occurred in the White Rose Study Area and in one Reference Area located 85 km northwest of White Rose. For the EEM program, this Reference Area was replaced with four Reference Areas located roughly 28 km northwest, northeast, southwest and southeast of the development. Figures 1-8 to 1-10 provide trawl locations for the 2004, 2005 and 2006 EEM programs. The fisheries exclusion zone in 2004 was larger to accommodate possible drilling at the NN and SS drill centres. Additional information on differences between the baseline program and the EEM programs can be found in the White Rose EEM design document (Husky Energy 2004).

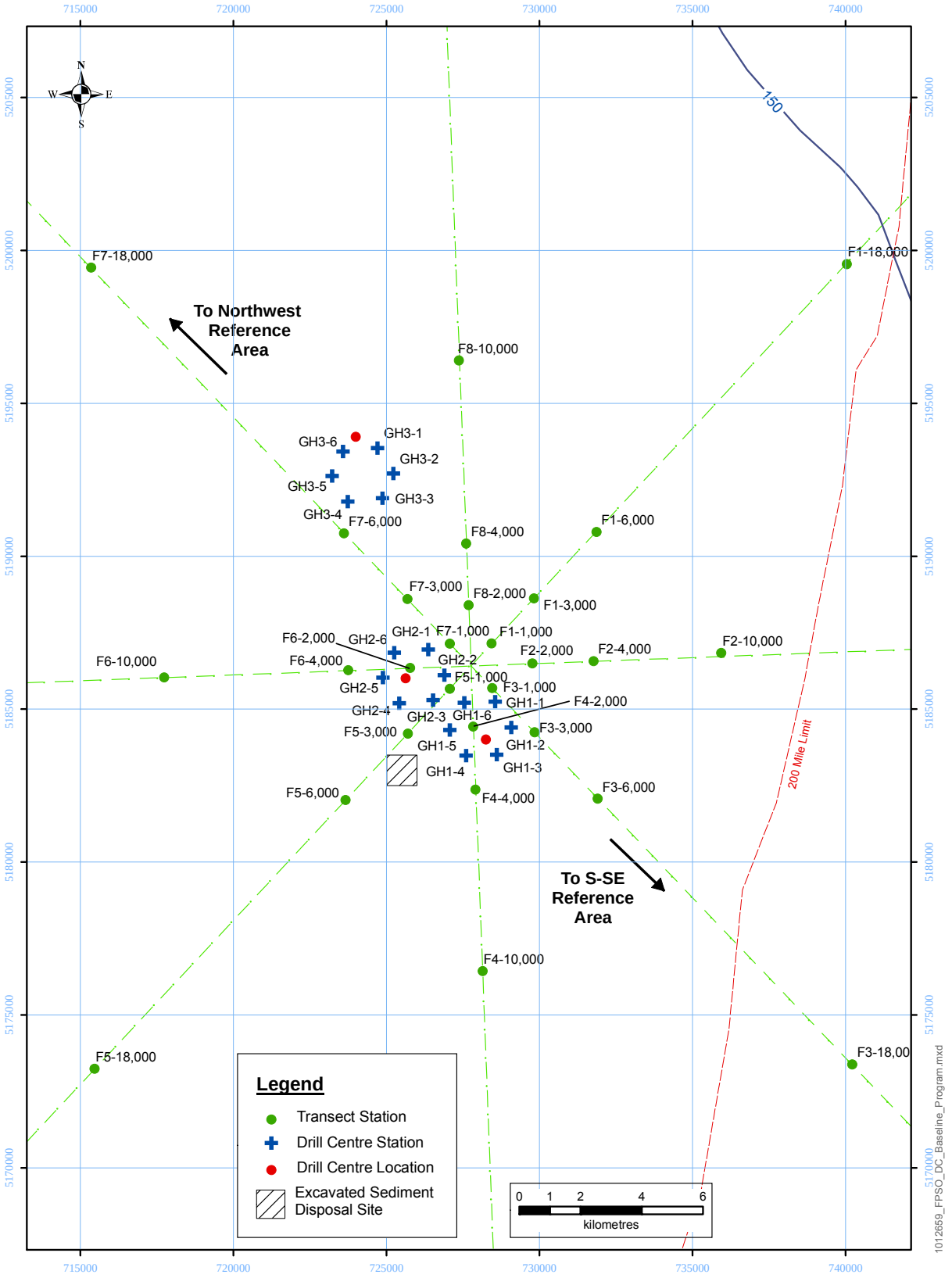

Figure 1-4 Baseline Program Sediment Stations

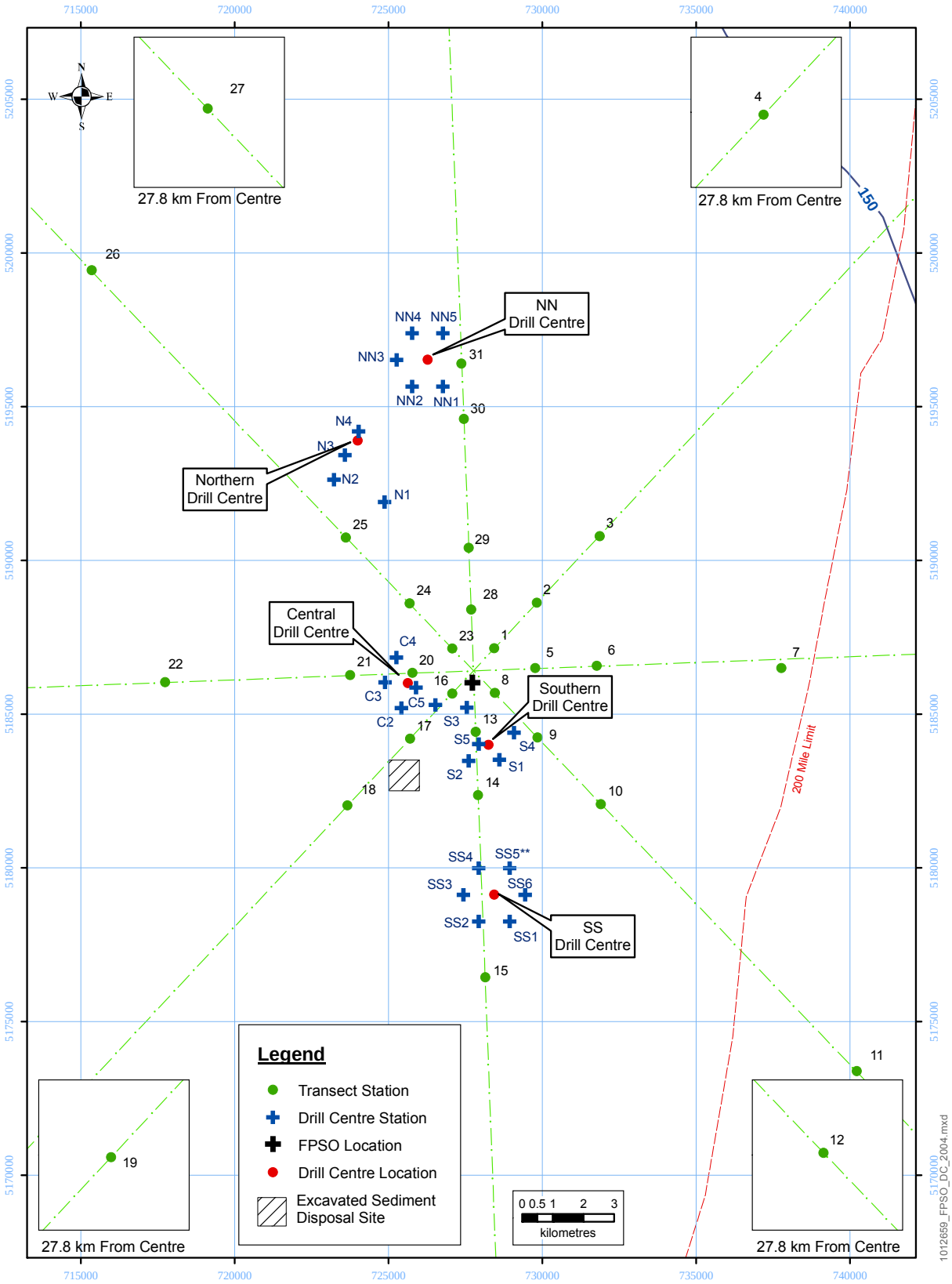

Figure 1-5 2004 EEM Program Sediment Stations

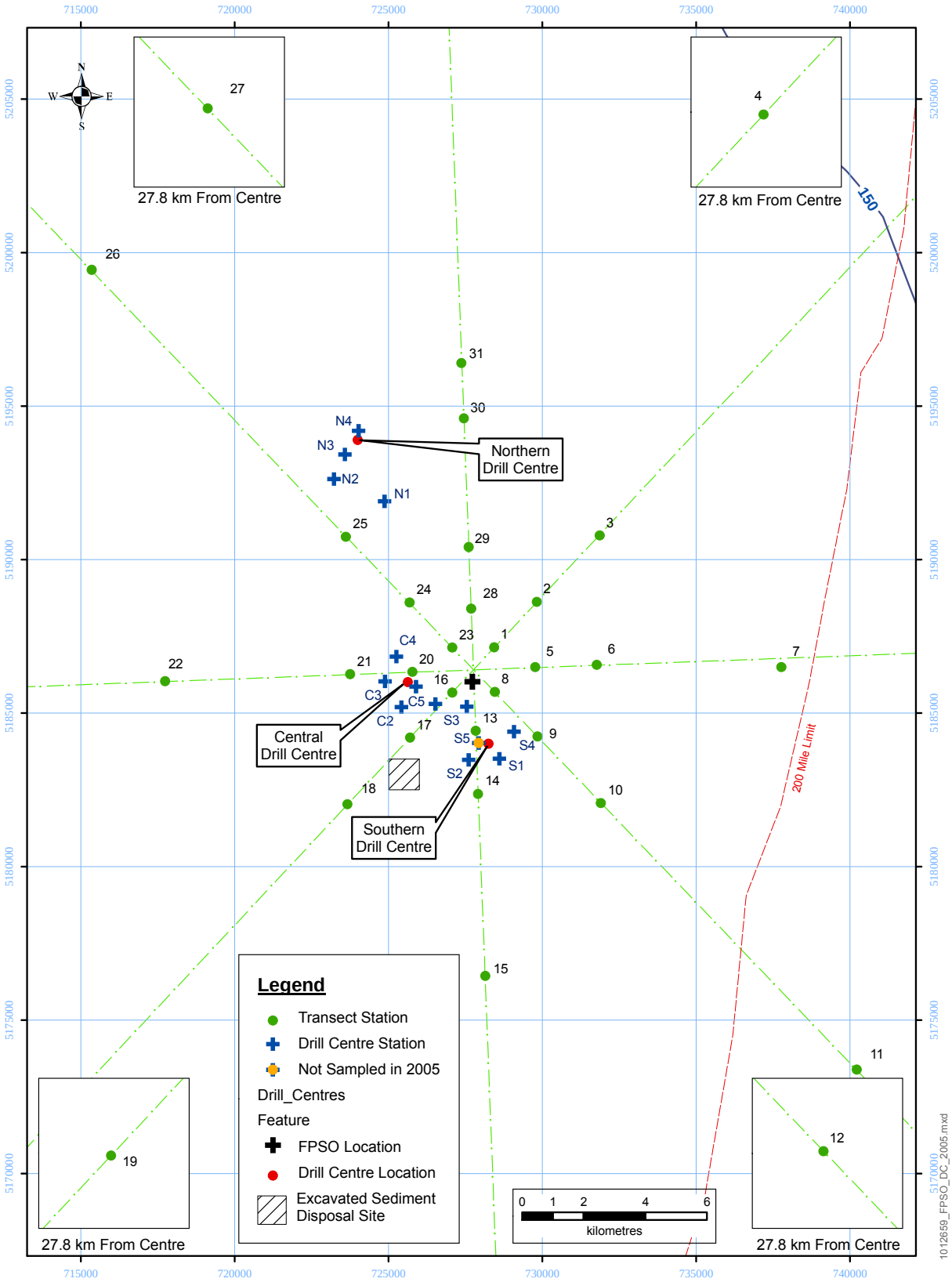

Figure 1-6 2005 EEM Program Sediment Stations

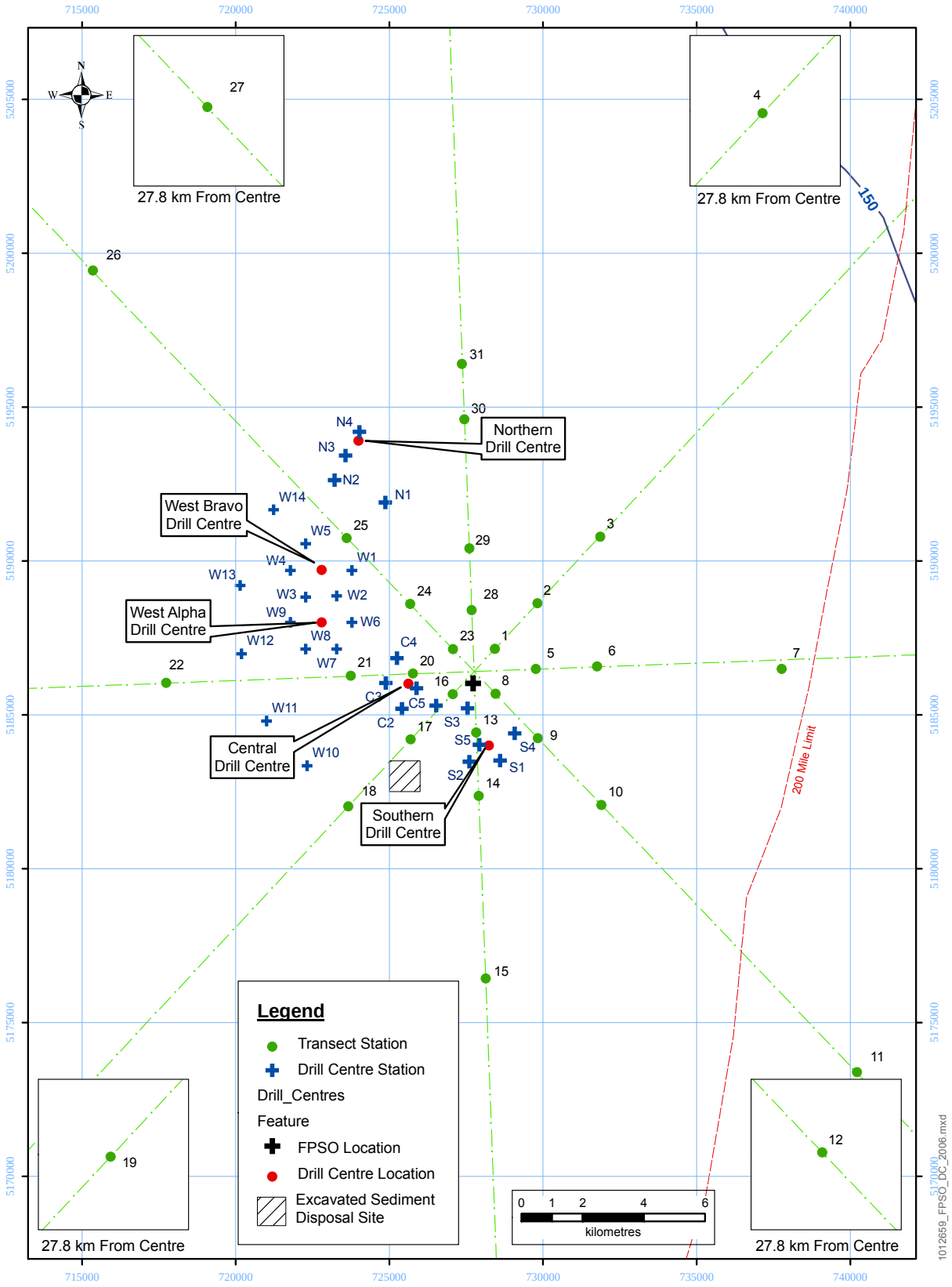

Figure 1-7 2006 EEM Program Sediment Stations

Table 1-1 Table of Concordance Between Baseline and EEM Stations

EEM Station Name	Baseline Station Name	EEM Station Name	Baseline Station Name
1	F1-1,000	N3	GH3-6
2	F1-3,000	N4	Not Sampled
3	F1-6,000	NN1**	Not Sampled
4	Not Sampled	NN2**	Not Sampled
5	F2-2,000	NN3**	Not Sampled
6	F2-4,000	NN4**	Not Sampled
7	F2-10,000	NN5**	Not Sampled
8	F3-1,000	NN6**	Not Sampled
9	F3-3,000	S1	GH1-3
10	F3-6,000	S2	GH1-4
11	F3-18,000	S3	GH1-6
12	Not Sampled	S4	GH1-2
13	F4-2,000	S5*	Not Sampled
14	F4-4,000	SS1**	Not Sampled
15	F4-10,000	SS2**	Not Sampled
16	F5-1,000	SS3**	Not Sampled
17	F5-3,000	SS4**	Not Sampled
18	F5-6,000	SS5**	Not Sampled
19	Not Sampled	SS6**	Not Sampled
20	F6-2,000	Deleted	GH1-1
21	F6-4,000	Deleted	GH1-5
22	F6-10,000	Deleted	GH2-1
23	F7-1,000	Deleted	GH2-2
24	F7-3,000	Deleted	GH3-1
25	F7-6,000	Deleted	GH3-2
26	F7-18,000	Deleted	GH3-4
27	Not Sampled	W1***	Not Sampled
28	F8-2,000	W2***	Not Sampled
29	F8-4,000	W3***	Not Sampled
30	F8-10,000	W4***	Not Sampled
31	Not Sampled	W5***	Not Sampled
Deleted	F1-18,000	W6***	Not Sampled
Deleted	F5-18,000	W7***	Not Sampled
Deleted	SS and NW Reference	W8***	Not Sampled
C1	GH2-3	W9***	Not Sampled
C2	GH2-4	W10***	Not Sampled
C3	GH2-5	W11***	Not Sampled
C4	GH2-6	W12***	Not Sampled
C5	Not Sampled	W13***	Not Sampled
N1	GH3-3	W14***	Not Sampled
N2	GH3-5		

Notes:
- * Not sampled in 2005 because of drilling activity at the Southern drill centre
- **Not sampled in 2005 and 2006 (see text)
- ***Not sampled in 2004 and 2005 (see text)

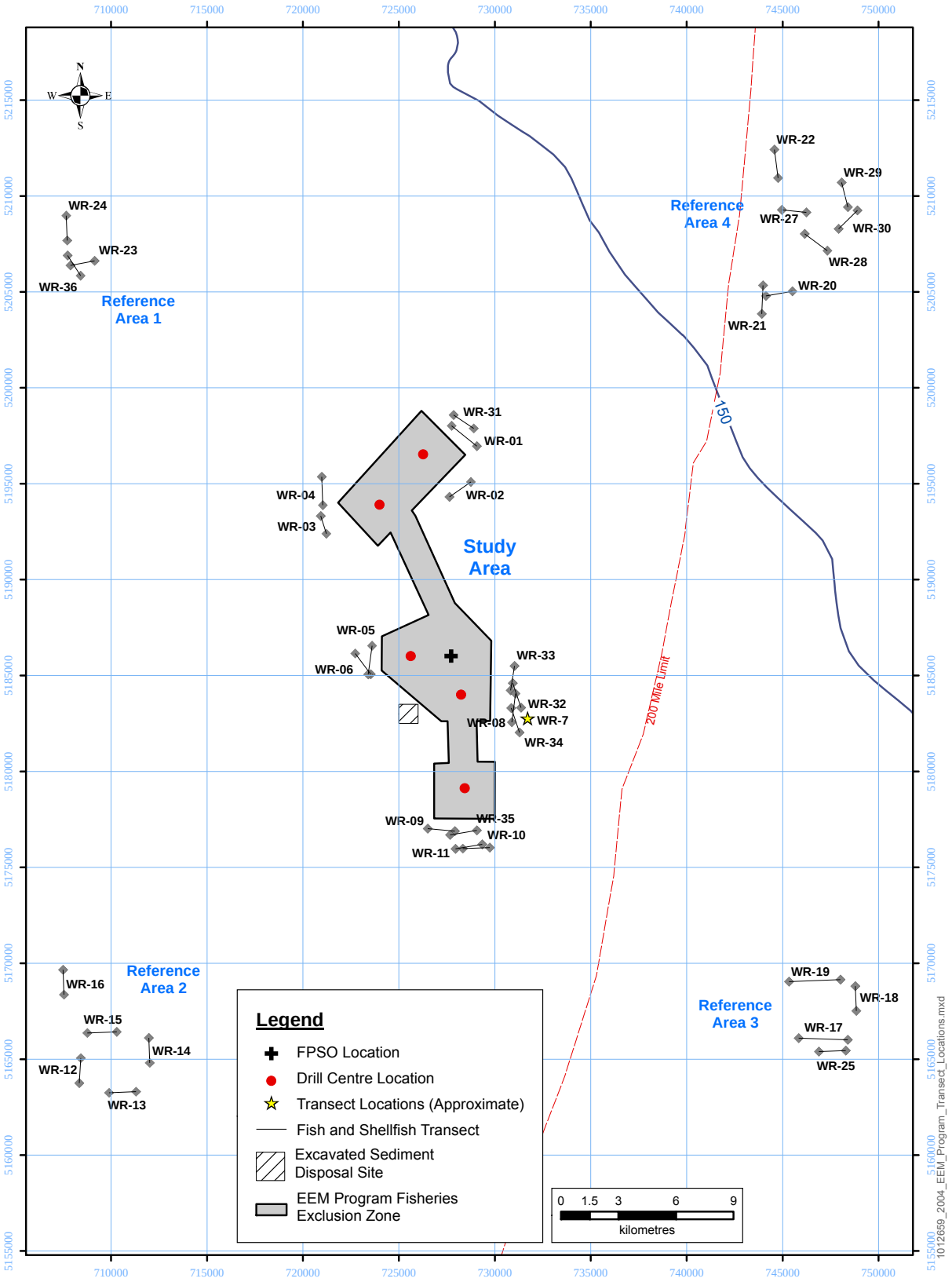

Figure 1-8 2004 EEM Program Transect Locations

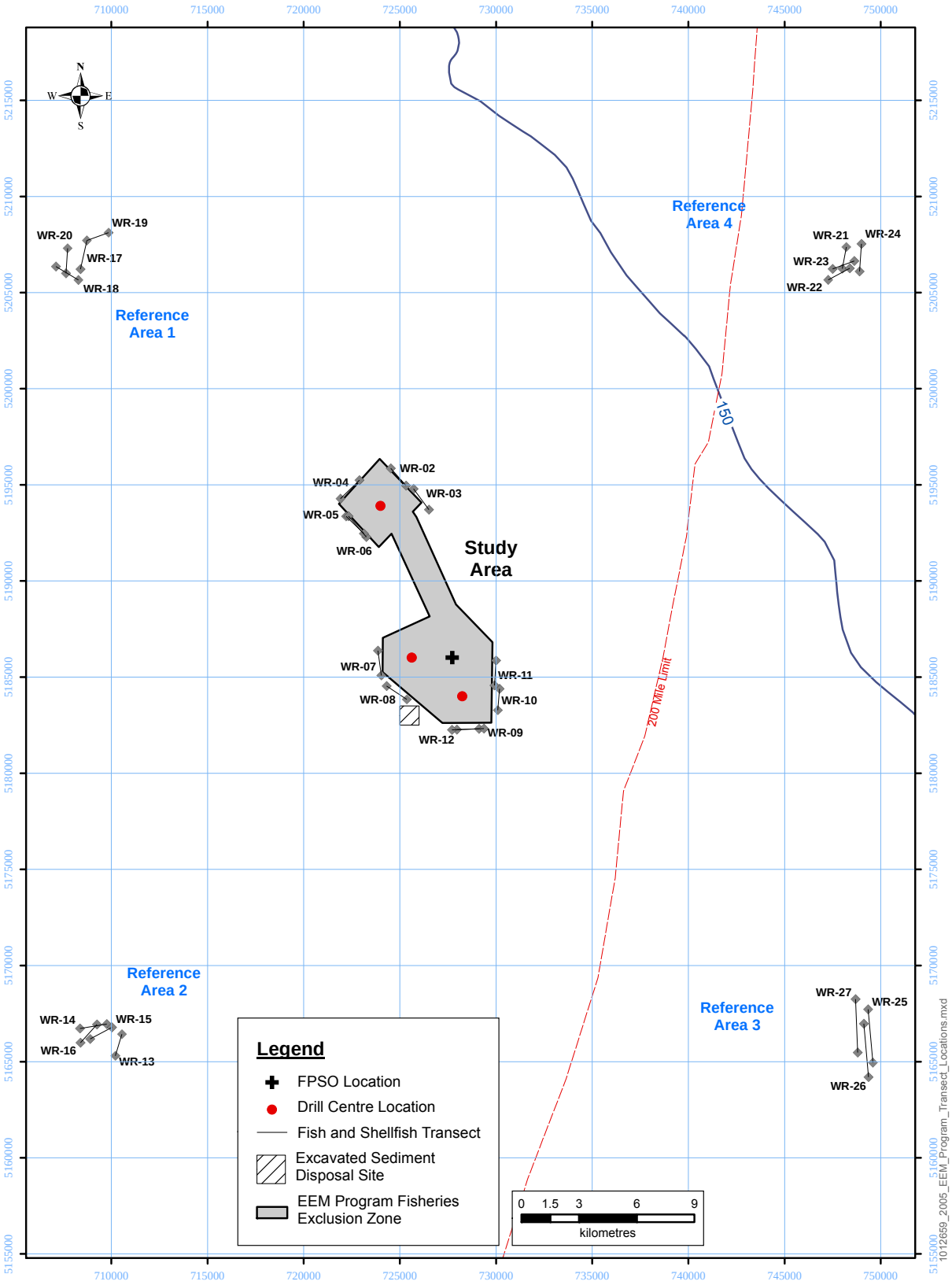

Figure 1-9 2005 EEM Program Transect Locations

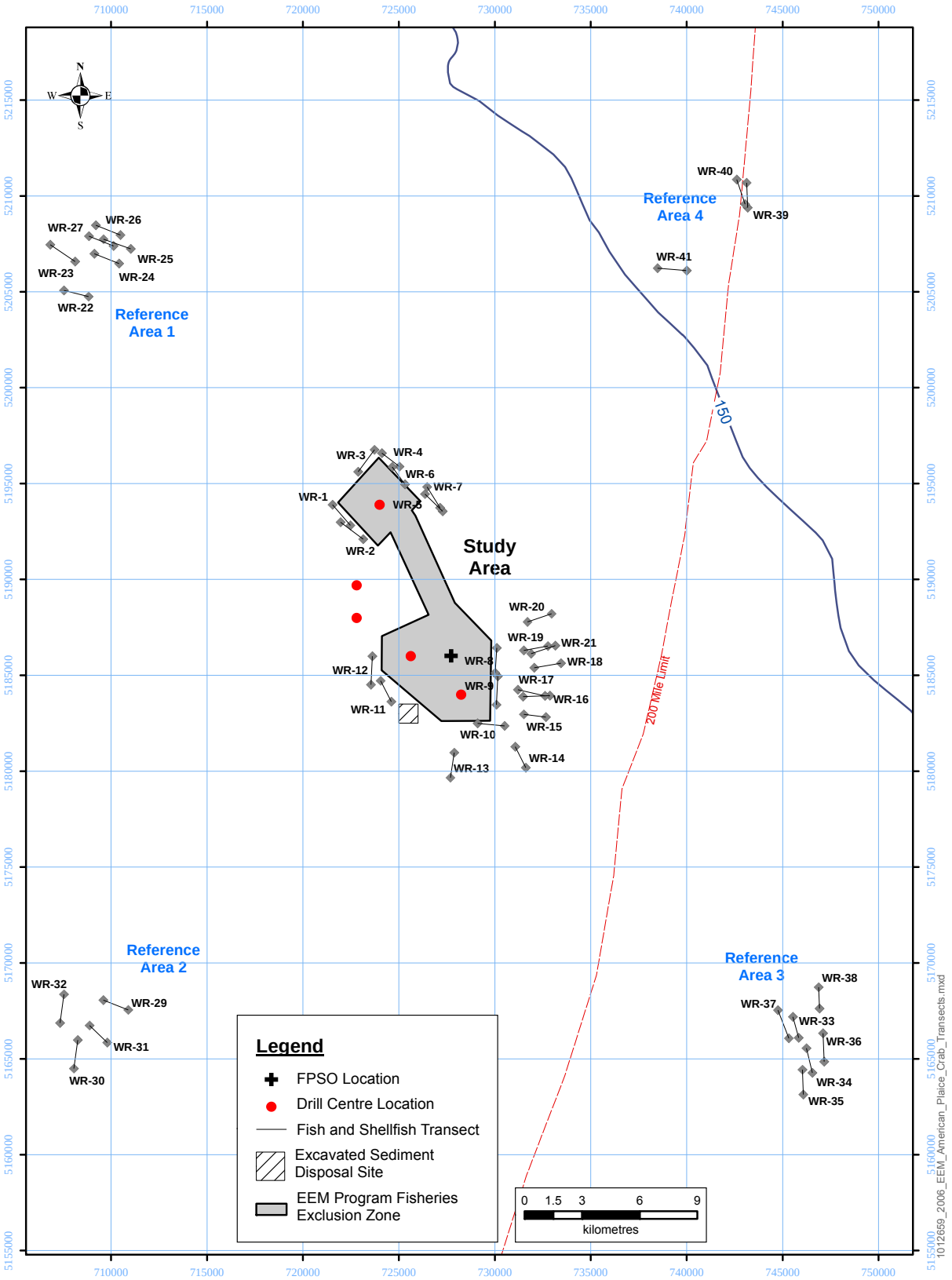

Figure 1-10 2006 EEM Program Transect Locations

2.0 Scope

This document, *White Rose Environmental Effects Monitoring Program 2006 (Volume 1)*, provides summary results, analysis and interpretation for the White Rose 2006 EEM program. Presentation of results has been structured to provide a logical sequence of information on the physical and chemical environment, benthos and commercially important species that prey on these food sources. Where feasible; results from the baseline and the 2004 and 2005 EEM programs are compared to 2006 results. Since analysis results are often highly technical, a summary of findings section is included at the end of each results section. The discussion section of the report provides interpretation of results and an overall assessment of potential project effects with respect to monitoring hypotheses (Section 1.7). The discussion also includes recommendations for future EEM programs based on findings in 2006.

Most methods are provided in *Volume 1*. However, some more detailed methods as well as ancillary analyses are included in Appendices (*White Rose Environmental Effects Monitoring Program 2006 (Volume 2))*. Raw data and other information supporting *Volume 1* are also provided in *Volume 2*.

2.1 Background Material

The executive summary and discussion section of this document are written for a general audience. The methods and results sections assume a certain level of understanding of EEM survey design and statistical analysis. References to statistical methods used are provided in the reference section of the document (*Volume 1*). The most useful references, as well as other standard references are provided below. In addition to these, the EEM program draws on a number of general readings from the biochemical, biomedical, agriculture and hydrological literature.

Armsworthy, S.L., P.J. Cranford and K. Lee (eds.). *Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Technologies.* Battelle Press, Columbus, Ohio.

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van Belle, G. 2002. *Statistical Rules of Thumb.* John Wiley & Sons, New York, NY. 221 pp. (more recent rules of thumb are posted at http://www.vanbelle.org).

3.0 Acronyms

The following acronyms are used in this report.

Acronym	Definition
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
AR	Among Reference Areas
BC	Bray-Curtis (measure of similarity)
BS	Between Study Areas
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CCME	Canadian Council of Ministers of the Environment
CI	Confidence Interval
CL	Confidence Limit
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
C-NOPB	Canada-Newfoundland Offshore Petroleum Board
CV	Coefficient of Variation
DFO	Fisheries and Oceans Canada
EBM	Exaggerated Battlement Method
EEM	Environmental Effects Monitoring
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EROD	7-ethoxyresorufin O-deethylase
FFAW	Fish, Food and Allied Workers Union
FPSO	Floating, Production, Storage and Offloading Facility
HC	Hydrocarbon
ISQG	Interim Sediment Quality Guidelines
LEC	Lowest Effective Concentration
LOWESS	Locally Weighted Scatter-plot Smoothers
MDL	Method Detection Limit
MDS	Multidimensional Scaling
MFO	Mixed Function Oxygenase
MS	Variance (Mean Square)
MS(AR)	Variance Among Reference Areas
MSE	Variance Among Replicates within Areas
MT	Metric Tonne
NMDS	Non-Metric Multidimensional Scaling
PAH	Polycyclic Aromatic Hydrocarbon
PC	Principal Component
PCA	Principal Component Analysis
PEL	Probable Effects Levels
QA/QC	Quality Assurance/Quality Control
RDL	Reportable Detection Limit
RM	Repeated Measures
ROV	Remotely Operated Vehicle
SBM	Synthetic-Based Mud
SD	Standard Deviation
SE	Standard Error

Acronym	Definition
SQT	Sediment Quality Triad
SR	Study versus Reference Areas
TEL	Threshold Effects Levels
TOC	Total Organic Carbon
UCM	Unresolved Complex Mixture
VEC	Valued Ecosystem Component
WBM	Water-Based Mud
WRAG	White Rose Advisory Group
ZOE	Zone of Effects – Zone where biological effects can be measured
ZOI	Zone of Influence – Zone of chemical contamination

4.0 Project Discharges

4.1 Introduction

This section reports on both drilling and production activities in the White Rose field and also summarizes the authorized discharges and spills associated with these operations.

The purpose of this section is to provide context for the interpretation of the results from the EEM program.

4.2 Project Activities

Activities associated with the White Rose Development Project to date fall into four general categories:

- Construction and installation operations were completed in Fall 2005. For more details, refer to the 2005 EEM Report (Husky Energy 2006);
- Drilling operations including completions, delineation and exploration (ongoing for the foreseeable future by one or more drill rigs);
- *SeaRose* Floating Production Storage and Offloading (FPSO) platform operations (ongoing for the foreseeable future); and
- Supply vessel operations (ongoing for the foreseeable future).

In mid-November of 2005, production operations (i.e. oil and gas production, storage and offloading to a tanker) began at the White Rose field once hook up, commissioning and introduction of hydrocarbons (HCs) to the FPSO *SeaRose* were completed.

Development drilling from the drill rig *GSF Grand Banks* continued in 2006 as did normal supply and standby vessel operations. Delineation and exploration drilling operations from the drill rig *Rowan Gorilla VI* took place between September and October 2005 and between April 14 and June 25 2006.

4.2.1 Drilling and Completions Operations

As mentioned, drilling activities continued throughout 2006. Husky Energy employs both water-based muds (WBMs) and synthetic fluid-based drill muds (SBMs) in its drilling programs. WBMs are used for the upper two drill hole sections, which is riserless drilling, while SBMs are used in deeper hole sections, especially during directional drilling operations, where drilling conditions are more difficult and hole stability is critical to safety and success.

There have been a number of continuous improvement initiatives undertaken in chemical management for the drilling side of the White Rose operation. In 2006, the drilling group undertook a "*Total Fluids Management*" approach for White Rose drilling operation. This includes both chemical and mechanical best available technology (BAT) to reduce the discharge volumes and overall environmental footprint from drilling operations.

The *"Total Fluids Management"* approach has facilitated a number of drilling fluid formulation changes and maintenance of the *Lowest Effective Concentration (LEC)* focus in all drilling products. This approach is extremely focused on reduction of overall chemical discharge to the environment. This has also facilitated operational procedural changes in some cases, primarily the replacement of the traditional barite and bentonite sweep mud with Viscosified NaCl Brine for riserless or drilling in the first two hole sections of each well.

The traditional prehydrated Bentonite/Barite sweep mud formulation was replaced with NaCl Brine viscosified with guar gum for riserless drilling in November of 2005. The rationale behind the change was to minimize the amount of debris in the glory hole to improve Remotely Operated Vehicle (ROV) visibility, eliminate visible on water phenomenon and minimize the overall discharge of chemicals to the ocean. Since its introduction in November of 2005, the viscosified NaCl Brine has been used in the first two hole sections of every well for the White Rose development.

The use of viscosified NaCl Brine at a weight of 1200 kg/m³ has proved to be effective in reducing the amount of debris in the glory hole and in turn has made ROV operations more efficient. Table 4.1 below, outlines the difference in volume of product discharged between three traditional wells, using barite and bentonite, and three viscosified NaCl brine wells which use NaCl salt and guar gum. The viscosified NaCl brine reduces the volume of product discharged to the ocean by 48%. The result of the toxicity studies has indicated the LC_{50}[3] is approximately the same for both systems; however the environmental load has been reduced by almost half.

Table 4-1 Volume of Traditional Bentonite/Barite Sweep Mud versus Viscosified NaCl Brine in Riserless drilling

Product	Traditional Wells Volume Discharged (kg) (E-18 1, E-18 2, E-18 3)	Viscosified NaCl Brine Wells Volume Discharged (kg) (E-18 4, E-18 5, E-18 6)
Barite	248,000	n/a
Bentonite	215,000	n/a
NaCl Salt	n/a	210,000
Guar Gum	n/a	10,000
Total Volume Discharged	463,000	220,000
Toxicity LC_{50}	>5% (50,000 mg/L)	>5% (50,000 mg/L)

4.2.1.1 Drilling Mud and Completion Fluids Discharges

Table 4.2 summarizes the volumes by year and drill centre of drill cuttings and WBMs discharged during development drilling activities. The months during which drilling activities took place are also indicated.

[3] LC_{50}: The concentration of the chemical that kills 50% of the test animals in a given time.

Table 4-2 Cuttings and WBM Discharges from 2003 to September 2006

Year	Drill Center	Months with Drilling Activity												Total Cuttings Discharged (Tons)	Total Muds Discharged (m^3)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
2003	Northern													N/A	N/A
	Central													N/A	N/A
	Southern													1,476	1,588
2004	Northern													682	456
	Central													655	473
	Southern													537	761
2005	Northern													N/A	N/A
	Central													1,748	1,674
	Southern													552	783
2006	Northern													N/A	N/A
	Central													1,749	1282
	Southern													638	932
Total Discharge at Northern Drill Centre														682	456
Total Discharge at Central Drill Centre														4,152	3,429
Total Discharge at Southern Drill Centre														3,203	4,064
Total Field Discharge														8,037	7,949

Table 4.3 summarizes the volumes by year and drill centre of drill cuttings and SBMs discharged during development drilling activities. The months during which drilling activities took place are also indicated.

Table 4-3 Cuttings and SBM discharges from 2003 to September 2006

Year	Drill Center	Months with Drilling Activity												Total Cuttings Discharged (Tons)	Total Solids Discharged (Tons)	Total Base Oil Discharged (m^3)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
2003	Northern													N/A	N/A	N/A
	Central													N/A	N/A	N/A
	Southern													416	957	228
2004	Northern													350	473.1	35
	Central													253	1,197	141
	Southern													1,193	3,358	512
2005	Northern													N/A	N/A	N/A
	Central													1,291	2,382	482
	Southern													741	1464	157
2006	Northern													N/A	N/A	N/A
	Central													1,268	3,163	335
	Southern													1,028	1,927	185
Total Discharge at Northern Drill Centre														350	473	35
Total Discharge at Central Drill Centre														2,812	6,742	958
Total Discharge at Southern Drill Centre														3,378	7,706	1,082
Total Field Discharge														6,540	14,921	2,075

On completion, a well bore needs to be cleaned of residual cuttings. This is done by flushing with “completion fluids” consisting of primarily sodium chloride or potassium formate brines. Table 4.4 summarizes the volumes of completion fluids discharged during the well completions by year and drill centre. The months during which these activities took place are also indicated.

Table 4-4 Completion Fluid discharges from 2003 to September 2006

Year	Drill Center	Months with Drilling Activity												Total Completion Fluids Discharged (m^3)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2003	Northern													N/A
	Central													N/A
	Southern													N/A
2004	Northern													N/A
	Central													N/A
	Southern													1619
2005	Northern													N/A
	Central													1,015.96
	Southern													1,372
2006	Northern													N/A
	Central													901.1
	Southern													476
Total Discharge at Northern Drill Centre														0
Total Discharge at Central Drill Centre														1917.06
Total Discharge at Southern Drill Centre														3467
Total Field Discharge														5,384.06

4.2.1.2 Other Discharges from Drilling Operations

From drilling operations between October 2005 and September 2006, a total of 115.8 m³ of bilge water has been discharged. All bilge water is treated in an oily water separator prior to release to reduce hydrocarbon content to 15 ppm or less (in accordance with Offshore Waste Treatment Guidelines (NEB 2002)). In total 1.7 kg of dissolved and dispersed hydrocarbons were released to the ocean from bilge water. Similarly, all deck drainage is collected and treated to reduce hydrocarbon content to 15ppm or less. There has been approximately 2249.5 m³ of deck drainage reported during this period which represents a transfer of 33.7 kg of dispersed hydrocarbons to the ocean.

Water and ethylene glycols are discharged routinely during function testing of a seabed blowout preventer and subsea flowline valves. In total, over the reporting period, approximately 109 m³ of water and glycols have been discharged from these sources, of which approximately 34.9 m³, or 32% of the total volume, has been the active ingredients. Note that these discharges are from the semi-submersible drill rig *GSF Grandbanks* that has its blow out preventer on the sea floor, in contrast to a jack-up rig with its blow out preventer on the platform and hence no discharges to sea.

4.2.2 FPSO Production Operations

The primary points of hydrocarbon discharge to seawater for the *SeaRose* FPSO are from the bilge and the slops tanks. While discharge from the bilge is permitted under the OWTG, following a separation process to reduce the oil in water content to less than 15pmm, bilge water on the *SeaRose* FPSO is typically directed towards the slops tanks prior to discharge. Between November 2005 and October 2006, 36 m³ of bilge was released from the SeaRose bilge separation system representing 150.5g (4.8ppm) of dispersed hydrocarbons to the ocean.

Slops tanks are reservoirs for collecting both rainwater (washed over the production facility from open and closed drains) and bilge water. Contents of the slops tanks undergo oil/water separation before discharging (to a level of less than 15 ppm hydrocarbon as per the OWTG). Between November 2005 and September 2006, a total of 3302.5 m^3 of water was released from the slops tanks representing 19.9 kg (6 ppm) of dispersed hydrocarbons to the ocean.

Seawater is pumped aboard the *SeaRose* FPSO and is circulated around equipment as cooling water to reduce operating temperatures. Approximately 9840 m^3 is discharged from the cooling water system daily. To prevent biofouling within the lines, cooling water is treated with chlorine and is managed such that the residual chlorine level at discharge is 0.5 ppm or less. Between November 2005 and October 2006, the monthly average concentration of chlorine prior to release was 0.2 ppm.

4.2.3 Supply Vessel Operations

All facilities and operations offshore are supported by supply and standby vessels. Normal vessel operations involve discharge of treated sewage and bilge water that contains 15 ppm or less of dissolved and dispersed oil and are released in accordance with MARPOL (73/78) requirements.

5.0 Sediment Component

5.1 Field Collection

The Sediment Component of the 2006 EEM Program was conducted from August 14 to 18, 2006, using the offshore supply vessel *Maersk Placentia*. Sampling dates for the baseline program and EEM programs are summarized in Table 5-1. Sediment stations for the baseline and EEM programs are shown in Figures 1-4 to 1-7 (Section 1). More details on the baseline survey can be found Section 1 and in Husky Energy (2001). More details on the year 1 and year 2 EEM programs can be found in Husky Energy (2005; 2006). Geographic coordinates and distances to drill centres for EEM stations sampled in 2006 are provided in Appendix B-1.

Table 5-1 Date of Field Programs

Trip	Date
Baseline Program	September 9 to September 19, 2000
EEM Program Year 1	September 26 to October 11, 2004
EEM Program Year 2	September 16 to September 22, 2005
EEM Program Year 3	August 14 to August 18, 2006

Sediment samples were collected using a large-volume corer (mouth diameter = 35.6 cm, depth = 61 cm) designed to mechanically take an undisturbed sediment sample over approximately 0.1 m^2 (0.0995 m^2) of seabed (Figures 5-1 and 5-2). Three cores were performed at each station to collect sufficient sediment volume for assessment of sediment physical and chemical characteristics, toxicity and benthic community structure (SQT components; see Section 1). Sediment samples collected for physical and chemical analyses, as well as for archive, were a composite from the top of all three cores (Figure 5-3). Sediment was sampled with a stainless steel spoon at the surface of the cores but at least 2 cm away from the corer walls (i.e. over an areas of approximately 0.078 m^2) and down to a depth of approximately 0.5 to 1 cm. Most of these samples were stored in pre-labelled 250-mL glass jars at -20°C. However, sediment for sulphide analysis was stored at 4°C. Sediment samples collected for toxicity were taken from the top 7.5 cm of one core and stored at 4°C, in the dark, in a 4-L pail (amphipod toxicity) and a Whirl-Pak (bacterial luminescence). Sediment samples for benthic community structure analysis were collected from the top 15 cm of two cores and stored in two separate 11-L pails[4]. These samples were preserved with approximately 1 L of 10% buffered formalin. Benthic invertebrate counts from these two samples were later pooled for analysis.

[4] Those chemistry samples collected from the same core as benthic community samples made up approximately 3% of the volume of sediment sampled for benthic community analysis.

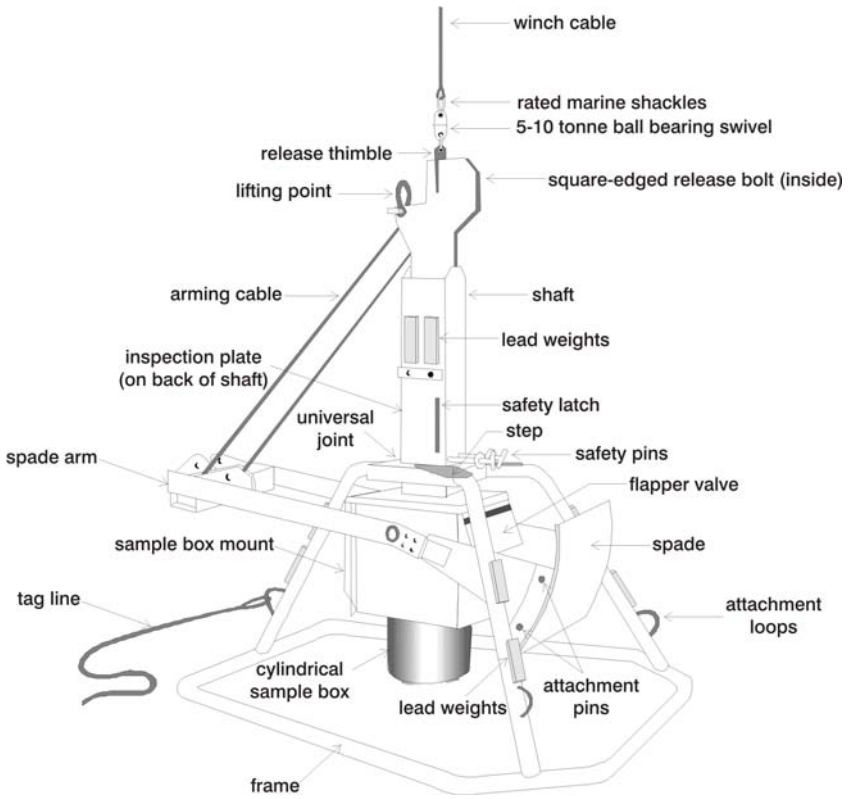


Figure 5-1 Sediment Corer Diagram

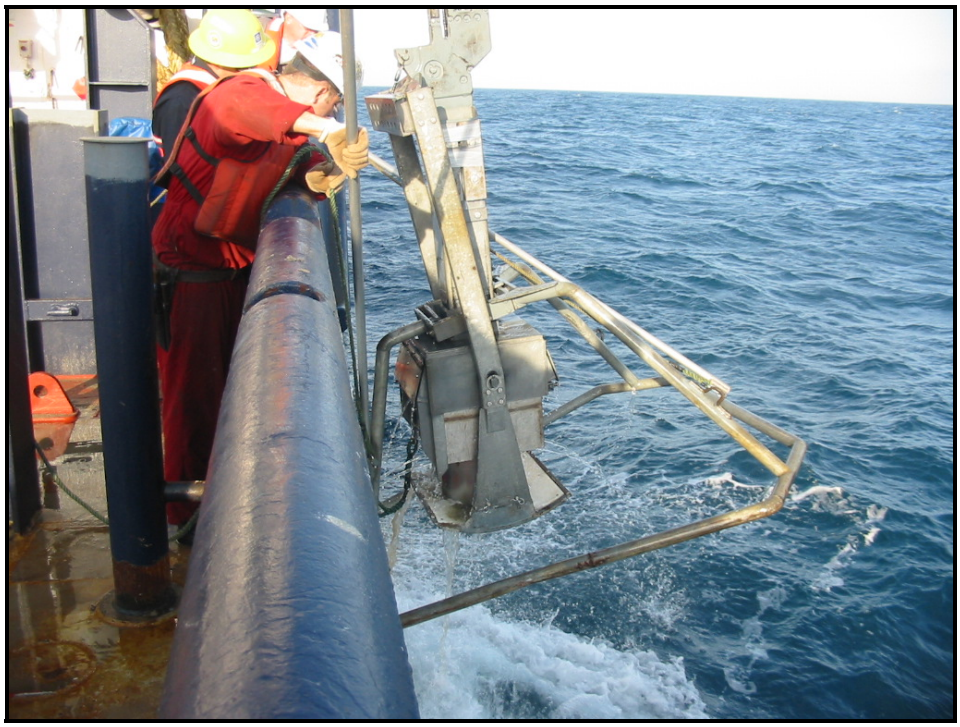
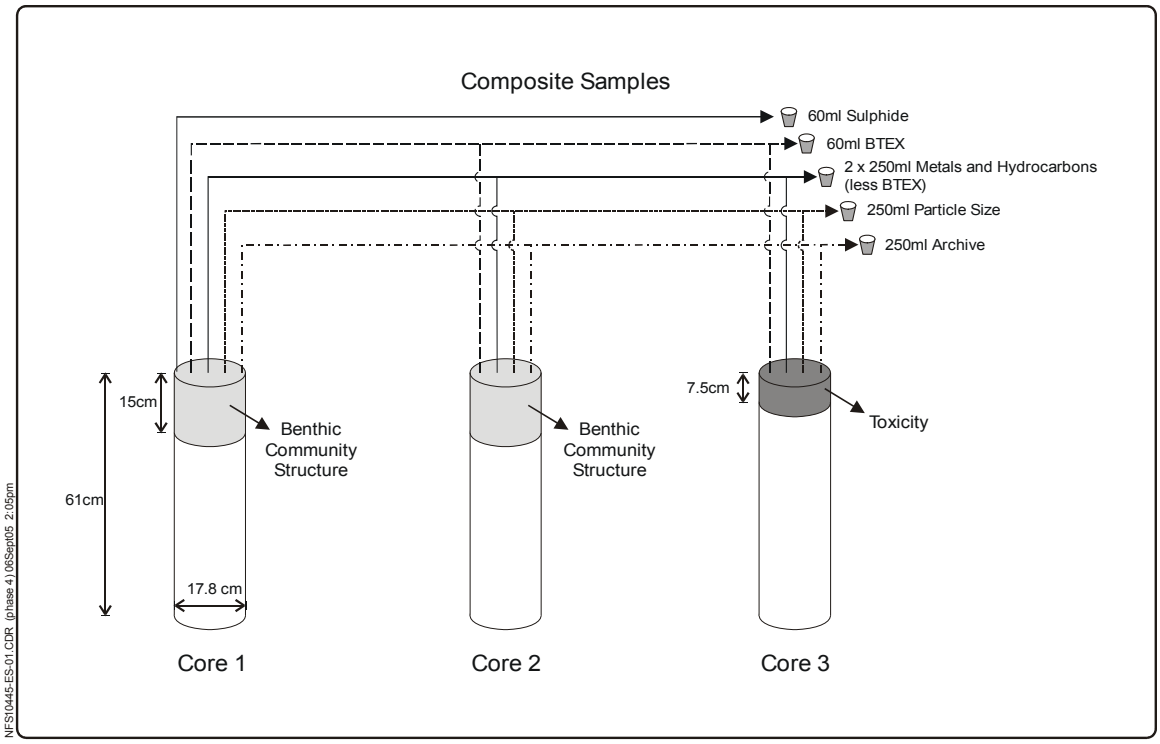


Figure 5-2 Sediment Corer



Source: Modified from Petro-Canada

Figure 5-3 Allocation of Samples from Cores

Sediment chemistry field blanks composed of clean sediment obtained from Maxxam Analytics were collected for stations 9, 20 and W14. Blank vials were opened as soon the core samples from these three stations were brought on board the vessel and remained opened until chemistry samples from these stations were processed. Blank vials were then sealed and stored with other chemistry samples. Field duplicates were collected for sediment chemistry at stations 11, 13, 20, N2 and W13. Both field blanks and field duplicates were assigned randomly to stations.

The following Quality Assurance/Quality Control (QA/QC) protocols were followed for collection of samples to ensure sample integrity and prevent onboard contamination. Core samples were immediately covered with clean, plastic-lined metal covers and moved to a working area near the laboratory facility. Sampling personnel were supplied with new latex gloves for each station. The laboratory facility and sampling tools were washed with isopropanol then rinsed with distilled water between each station to prevent cross-contamination between stations. Processed samples were transferred to cold storage within one hour of collection.

5.2 Laboratory Analysis

5.2.1 Physical and Chemical Characteristics

Sediment samples were processed for particle size, hydrocarbons (HCs) and metal concentration (Tables 5-2 and 5-3). Particle size analysis was conducted by Jacques Whitford in St. John's, Newfoundland and Labrador. HC and metal analyses were conducted by Maxxam Analytics in Halifax, Nova Scotia. Methods summaries from both these laboratories are provided in Appendices B-2 and B-3, respectively.

Table 5-2 Particle Size Classification

Size Classification (Wentworth)	Size Range (mm)	PHI Scale Range
Gravel	2 to 64	-1.000 to -6.000
Sand	0.063 to 2	3.989 to -1.000
Silt	0.002 to 0.063	8.966 to 3.989
Clay	< 0.002	< 8.986

Note: - Silt + clay fractions are referred to as "fines"

Table 5-3 Sediment Chemistry Variables (2000, 2004, 2005 and 2006)

Variables	Method	2000 RDL	2004 RDL	2005 RDL	2006 RDL	Units
HCs						
Benzene	Calculated	0.025	0.025	0.025	0.03	mg/kg
Toluene	Calculated	0.025	0.025	0.025	0.03	mg/kg
Ethylbenzene	Calculated	0.025	0.025	0.025	0.03	mg/kg
Xylenes	Calculated	0.05	0.05	0.05	0.05	mg/kg
C_6-C_{10}	Calculated	2.5	2.5	2.5	4	mg/kg
>C_{10}-C_{21}	GC/FID	0.25	0.25	0.3	0.3	mg/kg
>C_{21}-C_{32}	GC/FID	0.25	0.25	0.3	0.3	mg/kg
PAHs						
1-Chloronaphthalene	GC/FID	NA	0.05	0.05	0.05	mg/kg
2-Chloronaphthalene	GC/FID	NA	0.05	0.05	0.05	mg/kg
1-Methylnaphthalene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
2-Methylnaphthalene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Acenaphthene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Acenaphthylene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Anthracene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Benz[*a*]anthracene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Benzo[*a*]pyrene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Benzo[*b*]fluoranthene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Benzo[*ghi*]perylene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Benzo[*k*]fluoranthene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Chrysene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Dibenz[*a,h*]anthracene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Fluoranthene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Fluorene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Indeno[1,2,3-*cd*]pyrene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Naphthalene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Perylene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Phenanthrene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Pyrene	GC/FID	0.05	0.05	0.05	0.05	mg/kg
Carbon						
Total Carbon	LECO	0.1	0.2	0.2	0.2	g/kg
Total Organic Carbon	LECO	0.1	0.2	0.2	0.2	g/kg
Total Inorganic Carbon	By Diff	0.2	0.3	0.2	0.2	g/kg
Metals						
Aluminum	ICP-MS	10	10	10	10	mg/kg
Antimony	ICP-MS	2	2	2	2	mg/kg
Arsenic	ICP-MS	2	2	2	2	mg/kg
Barium	ICP-MS	5	5	5	5	mg/kg
Beryllium	ICP-MS	5	2	2	2	mg/kg
Cadmium	GFAAS	0.05	0.05	0.05	0.05	mg/kg
Chromium	ICP-MS	2	2	2	2	mg/kg
Cobalt	ICP-MS	1	1	1	1	mg/kg
Copper	ICP-MS	2	2	2	2	mg/kg
Iron	ICP-MS	20	50	50	50	mg/kg
Lead	ICP-MS	0.5	0.5	0.5	0.5	mg/kg

Variables	Method	2000 RDL	2004 RDL	2005 RDL	2006 RDL	Units
Lithium	ICP-MS	5	2	2	2	mg/kg
Manganese	ICP-MS	2	2	2	2	mg/kg
Mercury	CVAA	0.01	0.01	0.01	0.01	mg/kg
Molybdenum	ICP-MS	2	2	2	2	mg/kg
Nickel	ICP-MS	2	2	2	2	mg/kg
Selenium	ICP-MS	2	2	2	2	mg/kg
Strontium	ICP-MS	5	5	5	5	mg/kg
Thallium	ICP-MS	0.1	0.1	0.1	0.1	mg/kg
Tin	ICP-MS	2	2	2	2	mg/kg
Uranium	ICP-MS	0.1	0.1	0.1	0.1	mg/kg
Vanadium	ICP-MS	2	2	2	2	mg/kg
Zinc	ICP-MS	2	5	2	5	mg/kg
Other						
Ammonia (as N)	COBAS	NA	0.25	0.3	0.3	mg/kg
Sulphide	SM4500	NA	2	0.2	0.2	mg/kg
Sulphur	LECO	NA	0.02	0.02	0.002	%(w)
Moisture	Grav.	0.1	0.1	0.1	1	%

Notes:
- The acronym EQL (Estimated Quantification Limit) was used in previous years instead of RDL (Reportable Detection Limit). The two terms are fully interchangeable and relate solely to the merger between Phillip Analytics and Maxxam Analytics and the various terminologies used by these two laboratories
- The RDL is the lowest concentration that can be detected reliably within specified limits of precision and accuracy during routine laboratory operating conditions. RDLs may vary from year to year because instruments are checked for precision and accuracy every year as part of QA/QC procedures[5]
- NA = Not Analyzed

Within the HCs, benzene, toluene, ethylbenzene and xylenes (BTEX) are aromatic (cyclic) organic compounds, which are detected in the C_6-C_{10} range commonly referred to as the gasoline range. >C_{10}-C_{21} is referred to as the fuel range and is the range where lightweight fuels like diesel will be detected. The >C_{21}-C_{32} range is where lubricating oils (i.e., motor oil and grease), crude oil and, in some cases, bunker C oil, would be detected. HCs in all ranges include both aromatic (ring), n-alkane (straight chain) and isoalkane (branched chain) compounds. Polycyclic aromatic hydrocarbons (PAHs) are a diverse class of organic compounds that are composed of two or more fused aromatic benzene rings.

Gas chromatography is used to extract concentrations of HCs over the C_6-C_{32} range (see Appendix B-3). When complex HC mixtures are separated by chromatography, the more unique compounds such as the n-alkanes separate as individual peaks. Isoalkanes, on the other hand, are such a diverse group with so little difference in physical characteristics that they tend not to separate into distinct peaks in the chromatogram but rather form a “hump” in the chromatogram. This hump is often referred to as the Unresolved Complex Mixture (UCM). The drill mud base oil (PureDrill IA35-LV) used at White Rose is a synthetic isoalkane fluid consisting of molecules ranging from >C_{10}-C_{21}. Most of the components of PureDrill IA35-LV form an UCM that starts around the retention time of C11 n-alkane (2.25 min) and ends around the same time as C_{21} n-alkanes (approximately 7.4 min) (Figure 5-4). The highest peaks in a chromatogram of PureDrill IA35-LV have retention times similar to those of n-alkanes of C_{17}-C_{18} size.

[5] Typically, Maxxam Analytics sets the RDL at 2 to 10 times the MDL (Method Detection Limit) calculated using the EPA (U.S. Environmental Protection Agency) protocol. The 2 to 10 times MDL factor for RDL established by Maxxam Analytics is based on a number of considerations including details of the analytical method and known or anticipated matrix effects.

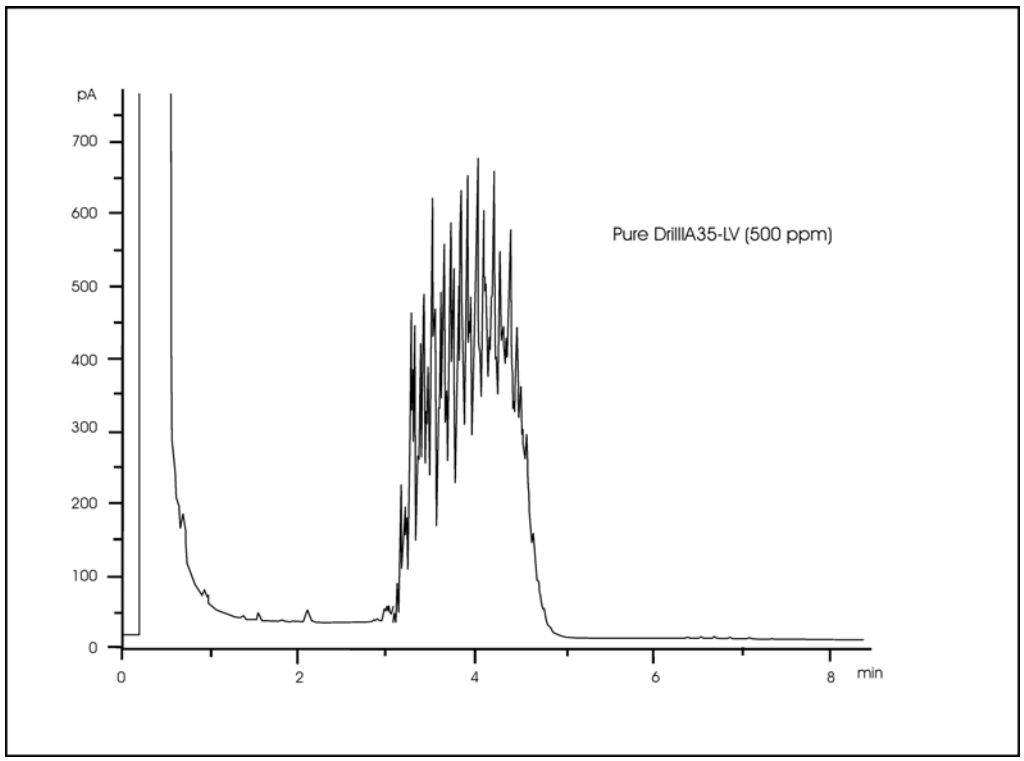


Figure 5-4 Gas Chromatogram Trace for PureDrill IA35-LV

5.2.2 Toxicity

Jacques Whitford's Environmental Laboratory Division in St. John's, Newfoundland and Labrador, conducted the sediment toxicity analyses. All sediment samples were examined using the amphipod survival bioassay and the bacterial luminescence assay (Microtox). Both bioassays used whole sediment as the test matrix. Tests with lethal endpoints, in this case amphipod survival, measure survival over a defined exposure period. Tests with sublethal endpoints measure physiological functions of the test organism, such as metabolism, fertilization and growth, over a defined exposure period. Bacterial luminescence, in this case, was used as a measure of metabolism. Tests that rely on sublethal endpoints are a potential gauge of the long-term effects.

Amphipod survival tests were conducted according to Environment Canada (1998) protocols using the marine amphipod *Rhepoxynius abronius* obtained from West Beach, Whidbey Island, Washington State (USA). *R. abronius* is a standard and widely use test species. Although it is not native to the East Coast, related species in the family Phoxocephalidae were among the more abundant amphipods in White Rose benthic invertebrate communities. Tests involved four to five replicate 1-L test chambers with approximately 2 cm of sediment and approximately 800 mL of overlying water (Figure 5-5).

Figure 5-5 Amphipod Survival Test

Each test container was set up with 20 test organisms and maintained for 10 days under appropriate test conditions, after which survival was recorded. An additional test container was used for water quality monitoring only. Negative control sediment was tested concurrently, since negative controls provide a baseline response to which test organisms can be compared. Negative control sediment, known to support a viable population, was obtained from the collection site for the test organisms. A positive (toxic) control in aqueous solution was tested for each batch of test organisms received. Positive controls provide a measure of precision for a particular test, monitor seasonal and batch resistance to a specific toxicant, as well as standardize results to which the results for other samples may be tentatively compared. Ancillary testing of total ammonia and sulphides in overlying water was conducted by an ammonia ion selective probe and colorimetric determination, respectively.

Samples were processed within six weeks of sample collection, meeting the storage time requirements recommended by Environment Canada guidelines (Environment Canada 1998).

The bacterial luminescence test was performed with *Vibrio fishcheri*. This bacterium emits light as a result of normal metabolic activities. The Microtox assay was conducted according to the Environment Canada (2002) Reference Method using the large volume solid phase assay. Analysis was conducted on a Model 500 Photometer with a computer interface. A geometric series of sediment concentrations was set up using Azur solid phase diluent. The actual number of concentrations was dependent on the degree of reduction in bioluminescence observed. Negative (clean) and positive (toxic) controls were run concurrently with the test samples. Reduction of light after 15 minutes was used to measure toxicity. Data interpretation for 2004, 2005 and 2006 was conducted as outlined in Environment Canada's (2002) Reference Method. Data from the 2000 (baseline) program were reexamined using the criteria outlined in Environment Canada (2002) because analyses in 2000 were conducted using earlier Environment Canada guidelines (small volume solid phase assay; Environment Canada 1992). Reinterpretation of 2000 data using Environmental Canada (2002) did not alter any of the 2000 interpretations.

All Microtox tests were initiated within six weeks of sample collection, meeting sediment storage time requirements recommended by Environment Canada guidelines (Environment 2002).

5.2.2.1 Results Interpretation

The statistical endpoint for the amphipod toxicity test is the determination of whether the biological endpoint (percent survival) differs statistically from the control or reference sample, calculated using the Dunnett's Test with the TOXCALC computer program (Tidepool Scientific Software 1994). The statistical endpoint for the bacterial luminescence toxicity test is the determination of whether the biological endpoint (bioluminescence) for the sample is significantly different from the negative control (0%), calculated as the IC_{50}[6] value.

Sample toxicity was assessed using standard toxicity testing statistical programs coupled with interpretation guidelines and direction provided by Environment Canada (K. Doe, pers. comm.). The amphipod survival tests results for sediments were considered toxic if the endpoint (mortality) exhibited a greater than a 30% reduction in survival as compared to negative control sediment; and the result was statistically significantly different than mortality in the negative control sediment. Amphipod survival was also compared to Reference Station sediment (stations 4, 12, 19 and 27). In this case, the amphipod survival test results for sediments were considered toxic if the endpoint (mortality) exhibited a greater than a 20% reduction in survival when compared to Reference Station sediment; and the result was statistically significantly different than mortality in the reference sediment.

For the bacterial luminescence assay, as noted in above, Environment Canada has published a new reference method for Solid Phase Microtox Testing. The new reference method (Environment Canada 2002) contains new interim guidelines for assessing Microtox toxicity. Sediments with levels of silt/clay greater than 20% are considered to have failed this sediment toxicity test (are toxic) if the IC_{50} is less than 1,000 mg/L as dry solids.

[6] An IC50 (50% inhibitory concentration) is the molar concentration of an agonist which produces 50% of the maximum possible inhibitory response to that agonist.

For any test sediment from a particular station which is comprised of less than 20% fines and that has an IC_{50} (dry weight) of ≥ 1,000 mg/L (dry weight), the IC_{50} of this sediment must be compared against a sample of "clean" reference sediment or negative control sediment (artificial or natural) with a percent fines content that does not differ by more than 30% from that of the test sediment. Based on this comparison, the test sediment is judged to have failed the sediment toxicity test if, and only if, both of the following two conditions apply:

1. its IC_{50} is more than 50% lower than that determined for the sample reference sediment or negative control sediment; and

2. the IC_{50}s for the test sediment and reference sediment or negative control sediment differ significantly.

5.2.3 Benthic Community Structure

All 2006 samples were provided whole to Arenicola Marine Limited (Wolfville, Nova Scotia). Individual cores samples were processed separately but data were pooled for data analysis (see Section 5.3.2).

Sandy samples were washed through a 0.5 mm sieve. Samples with larger proportions of coarse material (gravel and shell) were elutriated and sieved by directing a high volume (1 L/s) flow of freshwater into the sample, tilting the sample bucket and catching the overflow on a 0.5 mm sieve. This washing removed the silt/clay and finer sand fractions from the samples. The procedure was adjusted to leave coarser sediment fractions in the pail. The flow suspended the less dense organisms (e.g., polychaetes) and separated small gastropods and clams which, with a suitable balance of flow in and out of the bucket, could be separated as well. Elutriation was continued until the water leaving the pail was free of organisms and when no additional heavier organisms could be seen after close examination of the sediment. Usually, larger organisms such as scallops and propeller clams were separated manually as they were found. Barnacles and sponges were scraped off rocks. With coarser sediments such as gravels, which were occasionally encountered, a 1.2 cm mesh in combination with the 0.5 mm screen was used to aid in separating the organisms. Organisms were placed in 70% alcohol after sieving.

All samples were sorted under a stereomicroscope at 6.4x magnification, with a final scan at 16x. After sorting, substrate from 10% of samples was reexamined by a different sorter to determine sorting efficiency. Efficiency levels of 95% or better were achieved (i.e. the first sorter recovered 95% or more of the organisms recovered by both sorters combined). Wet weight biomass (g/sample) was estimated by weighing animals to the nearest milligram at the time of sorting after blotting to remove surface water. None of the samples were subsampled.

Organisms were identified to the lowest practical taxonomic level, typically to species, using conventional literature for the groups involved (Appendix B-4). All organisms were identified by Patricia Pocklington, a specialist in marine benthic invertebrate taxonomy.

Benthic invertebrate samples for 2004 and 2005 were also processed by Arenicola Marine Limited. Benthic invertebrate samples from 2000 were processed by Pat Stewart

of Envirosphere Limited Methods and the level of taxonomy were similar to those used for the 2004 to 2006 samples (see Husky Energy 2001 for details).

5.3 Data Analysis

5.3.1 General Approach

Analyses of sediment quality data included:

- analyses of correlations among variables for 2006 and between these variables and distances from drill centres and depth;
- comparison of distance-depth relationships among years (2000, 2004, 2005 and 2006); and
- integrated assessment of multi-year relationships between benthic invertebrate community variables and sediment physical and chemical characteristics.

The distance relationships tested "attenuation with distance" hypotheses; the integrated assessment tested "concentration-response" relationships.

Given the large and complex multivariate sediment quality data set, there were reasonable alternatives available at almost every step in analyses. The general approach was to use different approaches (e.g., parametric versus non-parametric analyses; use of exposure/concentration versus distance as *X* in regression) as opposed to minor variations of the same analysis. Suggestions from external reviews of past reports were also incorporated whenever possible. Specific analyses are described below and in Appendix B-5.

Statistical significance was defined based on the standard α level ($p \leq 0.05$). However, emphasis was on:

- results significant at $p \leq 0.01$ and especially $p \leq 0.001$;
- strong correlations (i.e., $|r|$ or $|r_s| > 0.5$ and especially > 0.7); and
- large spatial differences, especially those attributable to potential project effects.

The White Rose program and data analyses, particularly for the multi-year data set, were powerful enough to detect some small natural and project-related effects at $p \leq 0.05$ of lesser environmental or practical relevance. These results were always reported for interested readers. However, there were many cases where strong/large natural and project-related effects were observed at low *p* (i.e., << 0.05), and it is reasonable to place the emphasis on these less equivocal and usually more relevant results.

Correlations were used as general measures of the strength of relationships (not necessarily a measure of cause-effect or environmental interest) between variables. When correlations were high (greater than 0.7 or less than –0.7 for physical and chemical characteristics, and greater than 0.5 or less than –0.5 for invertebrate community variables), parametric regressions predicting *Y* from *X* were usually provided. Any definition of "large" differences will be subjective and differ among variables. The

basic approach used in this report was to ask if extreme values of some *Y* variable were more likely to occur at extreme values of *X* variables of interest (e.g., distances from drill centres; concentrations of drilling mud tracers; after versus before drilling).

All log transformations were $\log_{10}$ rather than natural log ($\log_e$) transformations. Analyses were conducted using SYSTAT 11.

5.3.1.1 Analysis of 2006 Data

For analysis of 2006 data, the first step was to calculate summary statistics and any multivariate summary measures required for further analyses. Spearman non-parametric rank correlations (r_S) within and among SQT components were then calculated and tested. Spearman r_S are parametric or Pearson correlations (r) between the ranks of two variables. In many cases, the correlations within SQT components were tests of redundancy of variables expected to be related for statistical or natural reasons, rather than tests of meaningful environmental relationships.

Multiple regression/partial correlation analyses assessing relationships between SQT variables (*Y*) and distance and depth (*X*) were then conducted. Both *Y* and *X* variables were rank-transformed (rank-rank regression or correlation). The distance measure used was distance to the nearest active drill centre (Min *d*). The Northern, Central and Southern drill centres, but not the proposed West drill centres, were treated as "active" in analysis of 2006 data. Min *d* was a useful summary distance measure, particularly for plotting distance relationships in two dimensions. In the past, regressions on distances from each drill centre were also conducted. However, these regressions were rarely more effective or informative than simpler regressions on Min *d*. Furthermore, the addition of 14 West stations around the proposed West Alpha and West Bravo drill centres in 2006 substantially increased correlations among distances from each drill centre, and between these distances and depth. When *X* variables are correlated, variances of slope estimates are inflated and results may not be robust. In contrast, parametric and non-parametric correlations between Min *d* and depth were near 0. The Repeated Measures (RM) comparisons among years (Section 5.3.1.2) provided a better assessment of effects from each drill centre.

The rank-based correlation and regression analyses were useful for cases where *Y* values were less than RDL, and/or either *Y* or *X* values were extreme. In these cases, parametric analyses would not be appropriate without deleting some data. The rank-based analyses were able to use all the data and could be applied to almost any data set and analysis.

The rank-based analyses addressed the qualitative question: was *Y* more likely to increase, decrease or remain the same as *X* increased? In some cases, this was the only appropriate or relevant question. However, in other cases, more quantitative parametric models were of interest for distance relationships. For these analyses, the basic model was a linear regression of *Y* on Min *d* (= *X*), with Min *d* and often *Y* log-transformed. Then, hockey-stick or threshold models, with Min *d* as *X* were fit. Hockey-stick models assume that *Y* increases or decreases with increasing distance (*X*) (the "shaft" of the hockey stick) up to some threshold distance (X_T) and then does not vary with *X* (the "blade"). The hockey-stick regressions were useful for defining zones of influence or effects (threshold distances (X_T)), or in some cases, indicating that zones of influence or effects could not or should not be defined.

To assess the hockey-stick models, the basic question was "did adding a threshold significantly reduce the residual or error variance of regression estimates relative to the simple bivariate *Y-X* model?" (see Appendix B-5 for the test used).

The various distance models used did not directly test for directional effects. Distances from the Central and Southern drill centres were also strongly positively correlated, which made it difficult to statistically separate their effects (i.e., effects of the two drill centres were confounded). To address these issues, bubble plots (spatial distributions, with symbol sizes proportional to *Y* levels) were used for selected variables. Centroids (centres of *Y* value distributions; Section 5.3.1.2) were also calculated and compared among sample years for the same purposes.

5.3.1.2 Comparison Among Years

The Repeated Measures (RM) regression model described in Appendix B-5 was used to compare regressions on depth and distances from each drill centre (*X* variables) among years. The RM approach can only be used to analyze stations re-sampled every year. For most variables, emphasis was on the 37 stations sampled in all four years, which allowed a comparison to baseline (2000). However, some chemistry variables were not measured in 2000, so analyses were also conducted on the 42 stations sampled in 2004, 2005 and 2006. Reference Stations 4 and 19, sampled in 2004, 2005 and 2006, were excluded from these three-year RM analyses because depths at these stations were extreme and would have a large influence on any analysis of depth effects. For the RM analyses, distances were log-transformed, some *Y* variables were log-transformed, and depth was not transformed. Correlations among depth and distance variables for the stations used in RM analyses were weaker than for the larger set of stations sampled in 2006, so confounding of *X* variables was not a serious issue.

The subsets of stations sampled in all four years, or in all three EEM years (2004 to 2006) when data were not available for 2000, were also used for two other purposes. Mean values and variances (Standard Deviation, SD) of *Y* were plotted against year to qualitatively assess net changes over the entire data set over time. Centroids for *Y* variables were calculated for each year. Appendix B-5 provides detailed methods for calculation of centroids, which removed any effects of natural/methodological differences over time occurring at all or most stations. Basic questions were:

1. Where was the location of the "average *Y* value" (*Y* centroid) relative to the location of the "average station" (sampling centroid)?

2. Did *Y* centroid locations change in response to the onset of drilling at the Northern and Southern drill centres prior to 2004, and the onset of drilling at the Central drill centre between 2004 and 2005?

Centroids were particularly useful for assessing cumulative drilling effects from all active centres, and directional and other spatial effects unrelated to distance or drilling activity.

There was evidence from the RM regressions that relationships between some *Y* variables and distances from active drill centres changed in strength from 2004 to 2006 (i.e., effects increased or decreased). Therefore, for selected *Y* variables, threshold distances (X_T) were compared between 2004, 2005 and 2006 to qualitatively assess if the zone of influence had changed. These analyses included all stations sampled within

each year. The distance measure used was distance from the nearest active drill centre (Northern and Southern in 2004; Northern, Central and Southern in 2005 and 2006).

5.3.2 Physical and Chemical Characteristics

5.3.2.1 Groups of Variables

Physical and chemical sediment characteristics were divided into four groups of related variables:

- sediment particle size and total organic carbon (TOC) content;
- known drilling mud tracers and constituents (barium, $>C_{10}$-C_{21} HCs and, possibly $>C_{21}$-C_{32} HCs);
- metals other than barium; and
- other variables (ammonia, sulphide, sulphur, redox).

Sediment particle size was expressed as % contributions of gravel, sand and fines (silt + clay). Both fines and TOC content could be altered by drilling activity. Water-based drilling muds (WBMs) and synthetic-based muds (SBMs) and drill cuttings are finer than the predominantly sand substrate on the Grand Banks, and SBMs have a higher organic carbon content than natural substrates. Particle size, as a physical habitat variable, and TOC, as an indicator of food availability for deposit and filter feeders, can also affect benthic invertebrate communities.

Barium, as barium sulphate (barite), is a constituent of both WBMs and SBMs. SBMs have elevated concentrations of $>C_{10}$-C_{21} HCs, which rarely or never occur at detectable levels in natural sediments on the Grand Banks. $>C_{21}$-C_{32} HCs are not a major constituent of SBMs but could originate from other anthropogenic sources (e.g., deck discharges). However, when $>C_{10}$-C_{21} HC concentrations are high, there is also an analytical "spill-over" effect, with some $>C_{10}$-C_{21} HCs appearing as $>C_{21}$-C_{32} HCs.

Metals other than barium, several of which (e.g., aluminum, iron) occur naturally at high concentrations in marine sediments, were primarily treated as "reference" metals, or indicators of the natural variance of barium concentrations that might be expected in the absence of drilling.

Sulphur, as sulphate in barite, is an important constituent of drilling muds, but also occurs naturally at high levels. Ammonia and sulphide levels are typically high, and redox levels low, in sediments where decomposition or degradation of natural or synthetic organic matter is extensive. High ammonia, sulphur and sulphide levels, and low redox levels, can adversely affect toxicity test organisms and *in-situ* invertebrate communities.

5.3.2.2 Statistical Analysis

For analysis of 2006 data, Spearman rank correlations (r_s) were calculated within and among groups of sediment physical and chemical variables. Rank-rank distance-depth regressions were also tested. In these analyses, *Y* values less than RDL were treated as

tied for the lowest rank. Parametric distance-depth and hockey-stick models were also tested for the two tracers (barium and >C_{10}-C_{21} HCs), which were strongly affected by distance from the drill centres.

Barium, fines and TOC levels, and concentrations of metals other than barium (i.e., Metals Principal Component 1 (PC1) scores; see below), were compared among years in RM regression models based on the 37 stations sampled in all four years (2000, 2004, 2005, 2006). These *Y* variables, plus ammonia, sulphur (not measured in 2000) and >C_{10}-C_{21} HCs (not detected in 2000) were also analyzed in RM regression models based on the 42 stations sampled from 2004 to 2006 (stations 4 and 19 excluded). All *Y* variables except Metals PC1 were log-transformed. Estimates of the zones of influence (threshold distances: X_T) for the two tracers (barium, >C_{10}-C_{21} HCs) were also compared among the three EEM years (2004 to 2006).

Principal Components Analysis (PCA[7]) was used to derive a summary measure of concentrations of metals other than barium for analyses of 2006 and multi-year data. Metals analyzed were aluminum, chromium, iron, lead, manganese, strontium, uranium and vanadium. These metals were detected in every sample in all four sample years. Zinc was detected in every sample in 2000 and 2005, when RDLs were 2 mg/kg, but was not detected in 10 (of 56) samples from 2004 and 28 (of 59) samples from 2006 when RDLs were 5 mg/kg. In the past, zinc was included in the Metals PCA. However, with RDLs differing among years, and many values less than RDL in 2006, zinc was deleted from the PCA. Rank correlations between zinc concentrations and Metals PC1 scores were calculated within each year to determine if zinc concentrations were generally higher where concentrations of other metals were higher (i.e., to determine if zinc "behaved" like other metals).

In 2000 and 2004, RDLs for >C_{10}-C_{21} HCs were reported as 0.25 mg/kg. In 2005 and 2006, RDLs were reported as 0.3 mg/kg. The change in RDL was simply rounding to better reflect the precision of the measurements; the analytical method did not change. For statistical analyses, all concentrations less than the 2005 and 2006 RDL of 0.3 mg/kg were set at ½ that RDL (0.15 mg/kg).

In 2004, there were four sulphur values less than RDL of 0.02%. In 2005, there was one sulphur concentration less than 0.02%. In 2006, there were eight values less than 0.02%, but the RDL for 2006 was lower than in previous years (0.002% instead of 0.02%). Six of the 2006 values were between 0.017 and 0.019% and two were lower than 0.017% (0.007% and 0.012%). All of these values less than 0.02% were set at 0.02% for comparisons among years.

[7] PCA identifies the major axis of covariance (PC1) among the original variables (i.e., concentrations of the eight metals), which is also the major axis of variance among samples (i.e., stations). The minor axis (PC2) is the axis accounting for the largest amount of remaining covariance among variables and variance among samples that is independent of (uncorrelated with) PC1. Positions of samples along the PC axes can be expressed as scores (weighted averages of original variable values), and the scores used for further analyses. The scores are standardized, so that the overall mean is 0 with SD = 1. Metal concentrations were log-transformed prior to conducting the PCA. The sediment metal and other PCAs in this report were based on correlation rather than covariance matrices. The sediment metal and other PCAs in this report were based on correlation rather than covariance matrices. All 205 samples from all years were included in a single PCA.

5.3.3 Toxicity

No analyses of results for bacterial toxicity tests were conducted because all samples were non-toxic, with IC_{50} greater than the highest concentration tested (98,600 mg/kg in 2000; 197,000 mg/kg in 2004 to 2006).

In 2006, there were three sediment samples toxic to amphipods and one other sample with low survival (less than 70% versus more than 80% for all other 2006 samples). Rank correlations between amphipod survival in toxicity tests, distances from the drill centres and sediment physical and chemical characteristics were calculated. Characteristics of the four stations with low amphipod survival were also compared with overall medians to determine if the four samples were "unusual" in some respect.

5.3.4 Benthic Community Structure

5.3.4.1 Groups of Variables

Benthic community variables analyzed were:

- total abundance and standing crop (wet weight of all invertebrates recovered);
- taxonomic richness, diversity and evenness;
- multivariate community composition measures (see Section 5.3.4.2); and
- absolute abundances (i.e., numbers) of Paraonidae (Polychaeta), Spionidae (Polychaeta), Tellinidae (Bivalvia) and Amphipoda.

Paraonidae, Spionidae and Tellinidae were the three most abundant taxa. They were analyzed separately to assess which taxa could be responsible for previously observed reductions in total abundance and changes in community composition near drill centres and at high $>C_{10}$-C_{21} concentrations in 2005 (Husky Energy 2006). Amphipods were relatively rare, but are generally considered sensitive and were also reduced in abundance near drill centres and at high $>C_{10}$-C_{21} HC concentrations in 2005 (Husky Energy 2006).

Nemerteans, nematodes, oligochaetes, ostracods and copepods were excluded from all variables except standing crop. These small organisms are poorly recovered with the 0.5 mm mesh used. Most of the excluded organisms would have made a negligible contribution to standing crop because of their small size[8].

5.3.4.2 Statistical Analysis

Preliminary Analysis

For all analyses of invertebrate communities, abundances of each taxon in the two cores collected at each station were summed (i.e., variable values were "per station" rather than "per sample"). Genera and species within families (or occasionally higher

[8] In some environments, usually neashore, nermerteans and oligochaetes can make some contribution to standing crop when they are abundant and larger organisms (for instance, echinoderms) are rare or absent.

taxonomic levels) were pooled and families were used as the basic taxonomic unit for analyses. For the White Rose samples, there was good agreement at the family level between the taxonomist used in 2000 and the taxonomist used in 2004, 2005 and 2006. At lower taxonomic levels (i.e., genus and species), there were some differences, predominantly attributable to differences in the taxonomic level that the two taxonomists were willing to use, especially for juveniles, and differences in the treatment of uncertain identifications. Appendix B-4 provides abundances of lower-level taxa (usually species) for the 2006 samples. Family assignments of lower-level taxa were standardized by first using families from Gosner (1971), a general East coast reference. Assignments were then updated using Kozloff (1987), a general West coast reference. Most taxa collected are found on both the East and West coasts, and family-level taxonomy has not changed much in the last few decades.

Richness (S) was the number of taxa (families) per station. Diversity was Simpson's D calculated using:

$$D = 1/\Sigma p_i^2$$

where p_i is the abundance of the ith taxon as a proportion of total abundance. D is the number of "dominant taxa", with higher values indicating greater diversity. Simpson's evenness (E) is then D/S, the number of dominant taxa relative to the total number of taxa. Although evenness is calculated from diversity, diversity is defined as a function of richness and evenness (i.e., $D = S \times E$).

Non-metric multidimensional scaling (NMDS) was used to derive summary community composition measures. NMDS can be considered a non-parametric analogue of PCA; Clarke (1993) discusses methods and applications. First, abundances of each taxon (family) were expressed as a percent of total abundance. Second, Bray-Curtis (B-C) distances were calculated between all possible pairs of stations. These B-C distances are the percentage of invertebrates not shared between stations (percent differences); percent similarities would be 100 minus B-C distances. Third, B-C distances were subjected to NMDS. NMDS iteratively finds the k-dimensional solution (i.e., set of axes) that best reproduces the original pair-wise distance matrix. The stress coefficient, which ranges from 0 (perfect fit to original matrix) to 1 (no fit), can be used to assess the adequacy of the NMDS solution. All 205 stations sampled in 2000, 2004, 2005 and 2006 were included in the NMDS, since all stations were included in some analysis.

Positions of stations along the NMDS axes (Multidimensional Scores, NMDS1, NMDS2 etc.) were then used as summary measures for further analyses. In SYSTAT (the statistical software used for NMDS), NMDS solutions and axes are rotated to principal axes so that variance is greatest along NMDS1 (i.e., NMDS1 is the major axis of variance, and NMDS2 is the secondary axis of variance and orthogonal to (uncorrelated) with NMDS1). Rotation to principal axes is a useful approach for generating uncorrelated variables for further analysis and identifying the primary axis of variance in community composition (NMDS1). However, other rotations can be used without altering distances among stations and may be informative. More generally, differences along both NMDS1 and NMDS2 (i.e., distances among stations) need to be jointly considered when assessing effects on overall community composition.

Statistical Analysis

Summary statistics for invertebrate community variables were calculated over all 59 stations sampled in 2006. Rank correlations (r_s) among the variables were also calculated.

Rank correlations between invertebrate community variables and sediment physical and chemical characteristics were also calculated for 2006 samples. Benthic community variable values for the four stations with low amphipod survival in toxicity tests were also tabulated, to determine if the laboratory effects were associated with field effects.

Rank-rank distance-depth relationships were analyzed, followed by more specific parametric regression analysis when warranted. The RM regression model described in Section 5.3.1.2 was used to compare invertebrate community variables among years. Threshold distances for selected variables were compared among post-drilling years (2004, 2005 and 2006). For biological variables, the threshold distances are referred to as zones of effects (ZOE) rather than zones of influence (ZOI).

For parametric analyses, all variables except NMDS scores were log-transformed. Log (Y + 1) transformations were used for Paraonidae and Amphipoda when abundances of 0 occurred.

5.3.5 Concentration-Response Relationships

A concentration-response approach was used to assess relationships between invertebrate community variables (biological response or Y) and sediment $>C_{10}$-C_{21} HC concentrations (X) over the three post-drilling years (2004, 2005 and 2006). Using $>C_{10}$-C_{21} HCs as an X variable addressed some problems with analysis of distance effects. The spatial distribution of $>C_{10}$-C_{21} HC concentrations will incorporate directional and other non-distance and localized project effects, especially around individual drill centres. A single tracer X variable may also be a simpler and better predictor of community Y variable values than one or more distance X variables. Threshold tracer concentrations below which effects do not occur may also be of interest.

The first step was to calculate and compare rank correlations between invertebrate community variables (Y) and $>C_{10}$-C_{21} HCs (X) among the three EEM years using van Belle tests (Appendix B-5). The next step was to assess alternative parametric concentration-response models for community variables most strongly correlated with $>C_{10}$-C_{21} HC concentrations. In most cases, and as for distance, the models assessed were bivariate linear regressions versus hockey-stick models with a threshold concentration added. LOWESS (Locally Weighted Scatter-plot Smoothers) trend lines (see Appendix B-5 for details) were used for plots of community variables versus $>C_{10}$-C_{21} HC concentrations to suggest the most appropriate parametric relationship, if any. For parametric analyses, $>C_{10}$-C_{21} HC concentrations and all community variables except NMDS1 and NMDS2 were log transformed.

5.4 Results

5.4.1 Physical and Chemical Characteristics

Table 5-4 provides summary statistics for sediment physical and chemical characteristics occurring at or above RDL in 2000, 2004, 2005 and 2006. All variables measured on sediment are provided in Table 5-3. Toluene was detected at levels close to RDL in one sample in 2005 and was not detected in other years. $>C_{10}$-C_{21} and $>C_{21}$-C_{32} HCs have been detected in 2004, 2005 and 2006, but not in 2000. With the exception of naphthalene, which was detected in 2000, PAHs have never been detected in sediment samples. Commonly detected metals in all four sampling years include: aluminum, barium, chromium, iron, lead, manganese, strontium, uranium and vanadium.

Table 5-4 Summary Statistics for Physical and Chemical Characteristics (2000, 2004, 2005 and 2006)

Variable	Year	*n*	*n*<RDL	Min	Max	Median	Mean	SD	CV
Toluene	2005	44	43	<0.03	0.04	<0.03			
$>C_{10}$-C_{21}	2004	56	11	<0.25	275.0	0.7			
	2005	44	5	0.3	260.0	1			
	2006	59	14	<0.3	570.0	0.7			
$>C_{21}$-C_{32}	2004	56	45	<0.25	0.92	<0.25			
	2005	44	19	0.3	1.7	0.3			
	2006	59	1	<0.3	6.0	0.6			
Naphthalene	2000	46	45	<0.05	0.07	<0.05			
Total Carbon (g/kg)	2000	46	0	0.7	1.3	1.0	0.99	0.12	12
	2004	56	0	0.7	1.4	1.1	1.05	0.12	11
	2005	44	0	0.9	1.7	1.0	1.07	0.15	14
	2006	59	0	0.6	1.7	1.0	1.05	0.24	23
Total Inorganic Carbon (g/kg)	2000	46	6	<0.1	0.4	0.1			
	2004	56	52	<0.3	0.5	<0.3			
	2005	44	24	<0.2	0.7	<0.2			
	2006	59	39	<0.2	0.9	<0.2			
Total Organic Carbon (g/kg)	2000	46	0	0.6	1.0	0.9	0.85	0.09	11
	2004	56	0	0.6	1.2	1.0	0.94	0.10	11
	2005	44	0	0.6	1.1	0.9	0.89	0.09	10
	2006	59	0	0.4	1.2	0.8	0.85	0.12	14
Aluminum	2000	46	0	6400	11000	8250	8243	651	8
	2004	56	0	6500	9500	8300	8173	709	9
	2005	44	0	5700	14000	8350	8502	1123	13
	2006	59	0	6300	13000	8400	8463	885	10
Arsenic	2000	46	33	<2	2	<2			
Barium	2000	46	0	120	210	160	163.7	19.4	12
	2004	56	0	110	1400	160	203.4	177.7	87
	2005	44	0	93	810	170	210.5	116.2	55
	2006	59	0	110	3100	170	297.8	470.6	158
Cadmium	2004	56	38	<0.05	0.08	<0.05			
	2005	44	35	<0.05	0.07	<0.05			
	2006	59	47	<0.05	0.06	<0.05			
Chromium	2000	46	0	3	4	3	3.5	0.5	15
	2004	56	0	3	7	4	3.8	0.7	18
	2005	44	0	2.8	5.5	3.6	3.7	0.6	16
	2006	59	0	2.6	5.8	3.7	3.8	0.6	15
Cobalt	2000	46	44	<1	1	<1			
	2004	56	50	<1	1	<1			
Copper	2000	46	41	<2	4	<2			
	2004	56	19	<2	3	<2			
	2005	44	40	<2	2.9	<2			
	2006	59	50	<2	3.6	<2			
Iron	2000	46	0	1100	2300	1400	1461	244	17
	2004	56	0	850	2400	1500	1489	315	21
	2005	44	0	1100	2900	1600	1677	399	24

Variable	Year	*n*	*n*<RDL	Min	Max	Median	Mean	SD	CV
Iron	2006	59	0	1100	2900	1600	1605	288	18
Lead	2000	46	0	2.1	5.1	2.7	2.79	0.44	16
	2004	56	0	2.0	4.0	2.8	2.75	0.33	12
	2005	44	0	1.8	5.9	2.8	2.98	0.63	21
	2006	59	0	2.1	9.5	2.7	3.05	1.27	42
Lithium	2004	56	31	<2	2.0	<2			
	2006	59	58	<2	2.3	<2			
Manganese	2000	46	0	25	70	36	38.7	10.1	26
	2004	56	0	17	82	38	40.1	12.7	32
	2005	44	0	22	96	41	45.6	16.1	35
	2006	59	0	29	82	43	45.8	11.3	25
Nickel	2000	46	44	<2	2.0	<2			
	2004	56	54	<2	2.0	<2			
	2005	44	43	<2	2.0	<2			
	2006	59	58	<2	2.2	<2			
Strontium	2000	46	0	37	60	47	47.5	3.5	7
	2004	56	0	34	64	46	47.0	4.9	10
	2005	44	0	30	75	49	49.2	6.4	13
	2006	59	0	33	77	46	48.4	7.7	16
Thallium	2000	46	1	<0.1	0.1	0.1			
	2004	56	0	0.1	0.1	0.1	0.10	0.00	0
	2005	44	40	<0.1	0.12	<0.1			
	2006	59	57	<0.1	0.12	<0.1			
Uranium	2000	46	0	0.2	0.3	0.2	0.20	0.02	10
	2004	56	0	0.2	0.3	0.2	0.21	0.02	11
	2005	44	0	0.13	0.29	0.21	0.22	0.04	17
	2006	59	0	0.15	0.33	0.2	0.21	0.04	18
Vanadium	2000	46	0	5	8	6	6.4	0.7	11
	2004	56	0	4	7	6	5.7	0.8	13
	2005	44	0	4.5	9.2	5.7	5.8	0.9	16
	2006	59	0	4.5	9.4	5.5	5.6	0.7	13
Zinc	2000	46	0	4	14	6	6.4	2.3	35
	2004	56	10	<5	9	<5			
	2005	44	0	4.9	10.0	7.1	7.0	1.1	15
	2006	59	28	<5	9.4	5.0			
% Clay	2000	46	0	0.29	0.83	0.62	0.61	0.12	20
	2004	56	0	0.14	1.02	0.61	0.60	0.17	28
	2005	44	0	0.01	1.14	0.57	0.58	0.22	38
	2006	59	0	0.02	0.80	0.34	0.37	0.18	48
% Gravel	2000	46	0	0.00	2.30	0.55	0.67	0.54	81
	2004	56	0	0.00	5.60	0.80	1.09	1.09	100
	2005	44	0	0.00	11.2	0.65	1.32	1.94	146
	2006	59	0	0.10	13.5	0.5	1.37	2.46	179
% Sand	2000	46	0	96.63	99.12	98.46	98.32	0.55	1
	2004	56	0	92.62	98.59	97.64	97.35	1.21	1
	2005	44	0	87.74	98.98	98.09	97.45	1.91	2
	2006	59	0	85.20	99.30	98.20	97.34	2.47	3
% Silt	2000	46	0	0.15	0.94	0.39	0.42	0.14	34
	2004	56	0	0.47	2.41	0.88	0.95	0.37	39
	2005	44	0	0.12	1.81	0.64	0.65	0.31	48
	2006	59	0	0.29	2.20	0.87	0.93	0.36	39
Moisture (%)	2000	46	0	14	22	19	18.46	1.56	8
	2004	56	0	16	23	18	18.50	1.49	8
	2005	44	0	17	20	18	18.36	0.89	5
	2006	59	0	17	22	19	19.00	0.96	5
Ammonia	2000	NA							
	2004	56	0	2.17	64.60	7.10	9.23	9.00	98
	2005	44	0	2.30	49.00	7.25	8.49	7.16	84
	2006	59	0	1.90	9.60	3.20	3.48	1.26	36
Sulphide	2000	NA							
	2004	56	53	<2	3.0	<2			
	2005	44	31	<0.2	1.0	<0.2			
	2006	59	0	0.2	20.7	0.5	1.03	2.72	263
Sulphur (%)	2000	NA							
	2004	56	1	<0.02	0.082	0.027			

Variable	Year	*n*	*n*<RDL	Min	Max	Median	Mean	SD	CV
Sulphur (%)	2005	44	1	<0.02	0.048	0.025	0.030	0.010	24
	2006	59	0	0.007	0.066	0.025	0.0300	0.0100	39

Notes: - All units are mg/kg except where indicated
- 2000 data exclude the two remote Reference Stations; ammonia, sulphur and sulphides were not measured in 2000
- Means and SDs are reported to one more significant digit than what is given for RDL (see Table 5-3)

5.4.1.1 Correlations Within and Among Groups of Variables (2006)

Sediments sampled in 2006 (and previous years) were predominantly (usually more than 90%) sand (Table 5-4). One or both of the " "non-sand" components, gravel and fines, was expected to be negatively correlated with sand content, since percentages of the three particle size categories sum to 100%. Gravel content, which was usually the major non-sand component by weight and varied among stations from 0.1 to 13.5%, was strongly negatively correlated with sand content (Table 5-5). Fines content varied over a narrow range (0.5 to 3%), and was negatively correlated with sand content and uncorrelated with gravel content. Based on these correlations, sand and gravel content were considered redundant, and sand content was eliminated from further analyses.

Table 5-5 Spearman Rank Correlations (r_s) Among Particle Size Categories and TOC (2006)

	% fines	% sand	% gravel
% sand	**–0.462*** **		
% gravel	0.024	**–0.825*** **	
TOC	0.202	–0.033	0.043

Note: - $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in bold)

TOC levels in sediments collected in 2006 were low (0.4 to 1.2 g/kg) and did not vary widely among stations. TOC levels were weakly and not significantly positively correlated with fines content (Table 5-5). Organic matter (i.e., TOC) should be associated with finer particles, but the expected positive correlation between the two variables has rarely been significant over the narrow range of TOC and fines values in the White Rose area.

Concentrations of the two primary drilling mud tracers, barium and $>C_{10}$-C_{21} HCs, were strongly and significantly positively correlated (Table 5-6). This correlation was expected, since both WBMs and SBMs were used and barium is a constituent of both types of muds. $>C_{21}$-C_{32} HC concentrations were positively correlated with concentrations of both barium and $>C_{10}$-C_{21} HCs, indicating that detectable $>C_{21}$-C_{32} HC concentrations were more likely to occur where concentrations of the two primary tracers were high. $>C_{21}$-C_{32} HCs were not included in further analyses, because $>C_{21}$-C_{32} HC concentrations were correlated with $>C_{10}$-C_{21} HC concentrations, may represent analytical "spill-over" of the latter HC group and were generally low (<0.3 to 6 mg/kg).

Table 5-6 Spearman Rank Correlations (r_s) Among Barium and HC Concentrations (2006)

	Barium	$>C_{10}$-C_{21} HCs
$>C_{10}$-C_{21} HCs	**0.757*** **	
$>C_{21}$-C_{32} HCs	**0.574*** **	**0.643*** **

Note: - $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in bold)

Concentrations of the eight other frequently detected metals in sediments collected in 2000, 2004, 2005 and 2006 were positively correlated with each other and with the first Principal Component (Metals PC1) derived from these concentrations (Table 5-7). Metals PC1 accounted for more than 50% of the total variance among the 205 samples and was used as a summary measure of "total" metals concentrations for further analyses. The secondary axes of variance (PC2 and PC3) accounted for minimal variance and were not analyzed further.

Table 5-7 Correlations (*r*) Between Concentrations of Frequently Detected Metals and PCs Derived from these Concentrations (2000, 2004, 2005, 2006)

Metal	Correlation (*r*) with:		
	PC1	PC2	PC3
Iron	**0.906**	0.286	0.060
Aluminum	**0.857**	−0.140	0.016
Manganese	**0.848**	0.354	0.057
Strontium	**0.835**	−0.485	0.023
Vanadium	**0.734**	0.233	0.133
Chromium	**0.728**	0.230	0.267
Lead	**0.588**	**−0.728**	0.057
Uranium	**0.588**	0.095	**−0.786**
% variance	59.2	13.8	9.0

Notes:
- Metals are listed in descending order of their correlation with PC1
- $|r| \geq 0.5$ in bold
- Concentrations were $\log_{10}$ transformed prior to deriving PC
- n = 205 stations: 59 in 2006; 44 in 2005, 56 in 2004, 46 in 2000

Zinc concentrations were significantly positively correlated with Metals PC1 scores in all four sample years, although the correlations were relatively weak except in 2005 (Table 5-8). With zinc concentrations exceeding 10 mg/kg (twice the current RDL) only in baseline (2000; Table 5-4), zinc concentrations either did not vary, or co-varied over a narrow range with concentrations of other more frequently detected metals.

Table 5-8 Correlations (*r*) Between Zinc Concentrations and Metals PC1 Scores (2000, 2004, 2005, 2006)

Year	No. Stations	r_s between Zinc and Metals PC1
2000	46	**0.320***
2004	56	**0.424****
2005	44	0.909***
2006	59	0.462***

Note: - $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in bold)

Metals PC1 scores were significantly positively correlated with barium concentrations, which will naturally co-vary with concentrations of other metals (e.g., as in 2000; Husky Energy 2001) (Table 5-9). However, the natural covariance between barium concentrations and concentrations of other metals was smaller than the covariance of barium and $>C_{10}$-C_{21} HC concentrations (compare correlations in Table 5-9). Metals PC1 scores were less strongly correlated with $>C_{10}$-C_{21} HCs than with barium.

Table 5-9 Spearman Rank Correlations (r_s) Among Chemistry Variables (2006)

	Barium	>C_{10}-C_{21} HCs	Metals PC1	Ammonia	Sulphur	Sulphide
>C_{10}-C_{21} HCs	**0.757*** **					
Metals PC1	**0.545*** **	0.337*				
Ammonia	0.100	0.143	0.178			
Sulphur	**0.548*** **	**0.529*** **	0.032	0.006		
Sulphide	0.302*	0.332*	0.377**	0.011	0.105	
Redox	0.119	–0.047	–0.047	–0.175	0.028	–0.288*

Note: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)

Ammonia levels were uncorrelated with tracer, metal, sulphur, sulphide and redox levels (Table 5-9). Sulphur levels increased with increasing tracer concentrations, suggesting that drilling and drill cutting discharges elevated sulphur (presumably sulphate from barium sulphate) concentrations. Sulphide concentrations were less strongly, but still significantly, positively correlated with tracer concentrations. Sulphide concentrations were also significantly, although weakly, positively correlated with metal concentrations (Metals PC1) and negatively correlated with redox concentrations. Divalent metals such as iron, manganese, chromium and lead are often bound to sulphides (Newman and Under 2003). Redox levels should be lower where concentrations of sulphides (a reducing agent) are higher. Finally, in 2006, redox levels were uncorrelated with tracer levels. In 2005, redox levels were strongly correlated with both tracer levels and distances from the drill centres (Husky Energy 2006).

Concentrations of barium and other metals were significantly positively correlated with sediment fines and TOC content (Table 5-10). These correlations presumably reflected a natural tendency for metals to sorb to finer organic particles, rather than drilling discharge effects. Note that >C_{10}-C_{21} HCs were not significantly correlated with either fines or TOC levels. Other variables were also not significantly correlated with fines or TOC levels. Stronger correlations for some variables would normally be expected, but fines and TOC levels were low and varied little among stations.

Table 5-10 Spearman Rank Correlations (r_s) Between Chemistry Variables, Fines and TOC (2006)

Chemistry variable	Correlation (r_s) with:	
	% fines	TOC
Barium	**0.536*** **	0.365**
>C_{10}-C_{21} HCs	0.150	0.263
Metals PC1	0.393**	**0.435*** **
Ammonia	–0.007	0.159
Sulphur	0.243	0.152
Sulphide	0.139	0.251
Redox	0.211	0.032

Note: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)

5.4.1.2 Depth and Distance Effects (2006)

Table 5-11 provides results of rank-rank regressions of sediment physical and chemical characteristics on depth and distance from the nearest active drill centre, with Northern, Central and Southern drill centres, but not the West drill centres, treated as active. Overall multiple correlations (R) for the regression models with both depth and distance as X variables can range from 0 to 1. Partial correlations (r) for each X variable can range from −1 to 1, and provide the correlation between each X variable and Y with the

effects of other *X* variables held constant or removed. For bivariate rank-rank regressions on a single *X* variable, *r* will be equal to the Spearman rank correlation (r_s).

Table 5-11 Results of Rank-Rank Regressions of Physical and Chemical Characteristics on Depth and Distances from the Drill Centres (2006)

Y Variable	*X*=Depth & distance from nearest drill centre (Min *d*)			*X*=Depth	*X*=Min *d*
	Overall *R*	Partial *r*		r_s	r_s
		Depth	Min *d*		
Barium	**0.819*** **	0.109	**–0.815*** **	0.140	**–0.817*** **
>C_{10}-C_{21} HCs	**0.890*** **	–0.398**	**–0.888*** **	–0.115	**–0.867*** **
% fines	0.457**	0.227	–0.398**	0.245	–0.407**
% gravel	0.144	0.014	0.144	0.000	0.143
TOC	0.338*	0.261*	–0.206	0.274*	–0.223
Metals PC1	0.433**	0.226	–0.369**	0.244	–0.380**
Ammonia	0.130	–0.067	–0.118	–0.056	–0.119
Sulphur	**0.537*** **	–0.102	**–0.536*** **	–0.036	**–0.530*** **
Sulphide	0.331*	–0.009	–0.331*	0.023	–0.331*
Redox	0.185	0.185	0.019	0.184	0.001

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Min *d* = distance from the nearest drill centre
- All *Y* and *X* variables were rank-transformed

Tracers

Barium and >C_{10}-C_{21} HC concentrations decreased significantly with distance from the drill centres (negative *r* or r_s in Table 5-11). For both tracers, partial *r* for distance in the multiple regressions were similar to *r* (=r_s for rank-rank regression) for bivariate regressions on distance. In 2006, barium concentrations were uncorrelated with depth in both multiple and bivariate regressions. However, >C_{10}-C_{21} HC concentrations were significantly and negatively correlated with depth in the multiple but not bivariate regression (Table 5-11). The apparent depth effects on >C_{10}-C_{21} HCs were ignored in further analyses of much stronger distance effects (see below).

In parametric models for barium and >C_{10}-C_{21} HCs, adding a threshold distance value (X_T) to regressions of both variables on distance from the nearest drill centre significantly reduced error variances relative to bivariate regressions (Table 5-12). Figure 5-6 plots the hockey-stick relationships (solid lines) and individual station values.

Table 5-12 provides parameter estimates for the hockey-stick relationships for the two tracers, plotted in Figure 5-6. Estimates of threshold distances can be considered zones of influence (ZOI). Barium concentrations reached estimated background levels (156 mg/kg dry) at 1.9 km from the nearest drill centre. >C_{10}-C_{21} HC concentrations reached background levels (effectively RDL of 0.3 mg/kg dry) at 5.9 km. Therefore, >C_{10}-C_{21} HC contamination was spatially more extensive than barium contamination. The distance gradient (slope of the shaft) was also steeper for >C_{10}-C_{21} HCs than for barium.

Table 5-12 Results for Parametric Distance Models for Barium, >C_{10}-C_{21} HCs and Redox (2006)

Result/Estimate	Barium	>C_{10}-C_{21} HCs
Bivariate regression on distance from nearest drill centre		
r	–0.693***	–0.850***
Hockey-stick (threshold) model		
Overall *R*	0.815***	0.887***
p for adding threshold (X_T)	<0.001	<0.001
antilog *a* (blade or background *Y* value as mg/kg dry)	**156**	**0.19**
95% CI	**138 to 177**	**0.11 to 0.34**
b (slope of shaft)	**–0.995**	**–2.07**
95% CI	**–1.260 to –0.730**	**–2.40 to –1.74**
antilog X_T (threshold distance in km)	**1.9**	**5.9**
95% CI	**1.4 to 2.6**	**4.2 to 8.5**

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Bivariate regressions = regressions of *Y* on distance to the nearest drill centre (*X*)
- *X* variables for the hockey-stick model were distance from the nearest drill centre plus the threshold distance (X_T)
- All *Y* and *X* variables were log-transformed

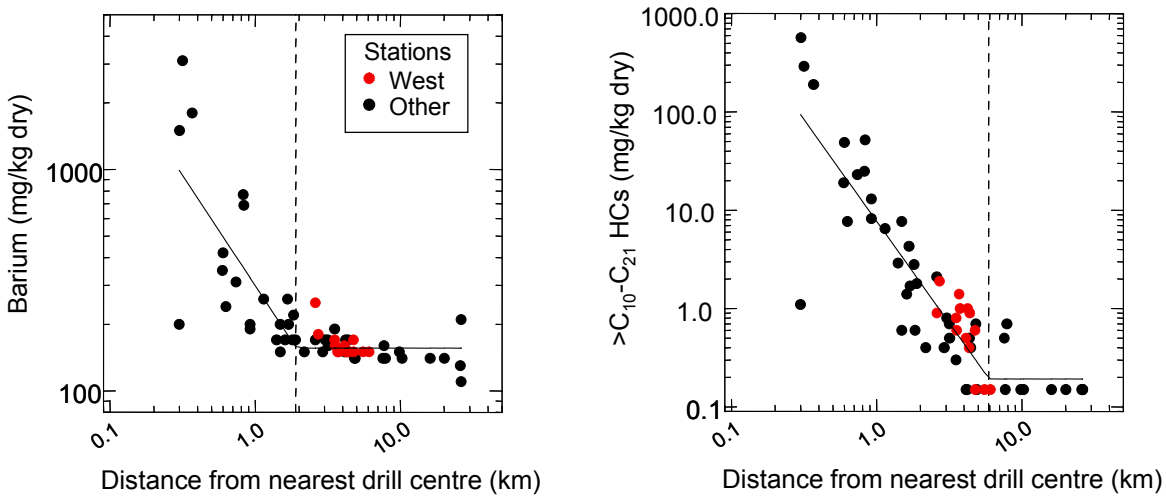


Figure 5-6 Barium and >C_{10}-C_{21} HCs versus Distance from the Nearest Drill Centre (2006)

Variances about the hockey-stick regressions in Figure 5-6 were wide within 1 km of drill centres for barium and within 0.5 km for >C_{10}-C_{21} HCs. These are the stations at which differences among drill centres ("which drill centre is nearest?"), plus directional and other localized spatial effects, were important. Variances about the hockey-stick model for barium also increased for Reference Stations, located more than 20 km from drill centres, a common occurrence at distances greater than estimated threshold distances for many variables. These remote stations were separated by more than 50 km and natural differences (variances) usually increase with increasing distance among samples.

Concentrations of barium were greatest at several stations within 1 km of the Central and Southern drill centres but were not markedly above background near the Northern drill centre (Figure 5-7). Concentrations were greater to the south and east around the Central and Southern drill centres than to the north or west. The spatial distribution of $>C_{10}$-C_{21} HCs was similar, but with more extensive contamination (effectively any concentration above RDL of 0.3 mg/kg) (Figure 5-8). Concentrations around the Central and Southern drill centres were greater to the south and east than in other directions. There did not appear to be any decrease in $>C_{10}$-C_{21} HC concentrations from the southwest to the northeast along the gradient of increasing depth. Distance effects overwhelmed any depth effects.

In Figure 5-6 and other depth and distance plots, the 14 West stations added in 2006 are plotted as red symbols to distinguish them from the 45 previously monitored EEM stations (black circles). Tracer concentrations for the West stations fit the hockey-stick relationships well, indicating that tracer concentrations at these stations were approximately what one would expect based on distance from the nearest of the three active drill centres (usually the Central drill centre) (see also Figures 5-7 and 5-8). The same statement can be made for other variables significantly correlated with distance.

Particle Size and TOC

Over all stations, fines content decreased significantly with increasing distance from the nearest drill centre and increased with increasing depth (Table 5-11). The depth effects were not significant, although they have been significant and stronger than distance effects in past years (Husky Energy 2006; see also Section 5.4.1.3). As Figure 5-9 indicates, there was a relatively continuous decrease in fines content (from less than 2% to approximately 1%) with increasing distance from the drill centres for most stations, potential evidence of effects of discharge of fine drill cuttings near drill centres. However, the most extreme value (3% fines) in 2006 occurred at the Station 4, the deepest and most remote station; and fines content at Station 4 was also higher than fines content at all or most stations in 2004 and 2005 (Husky Energy 2005; 2006).

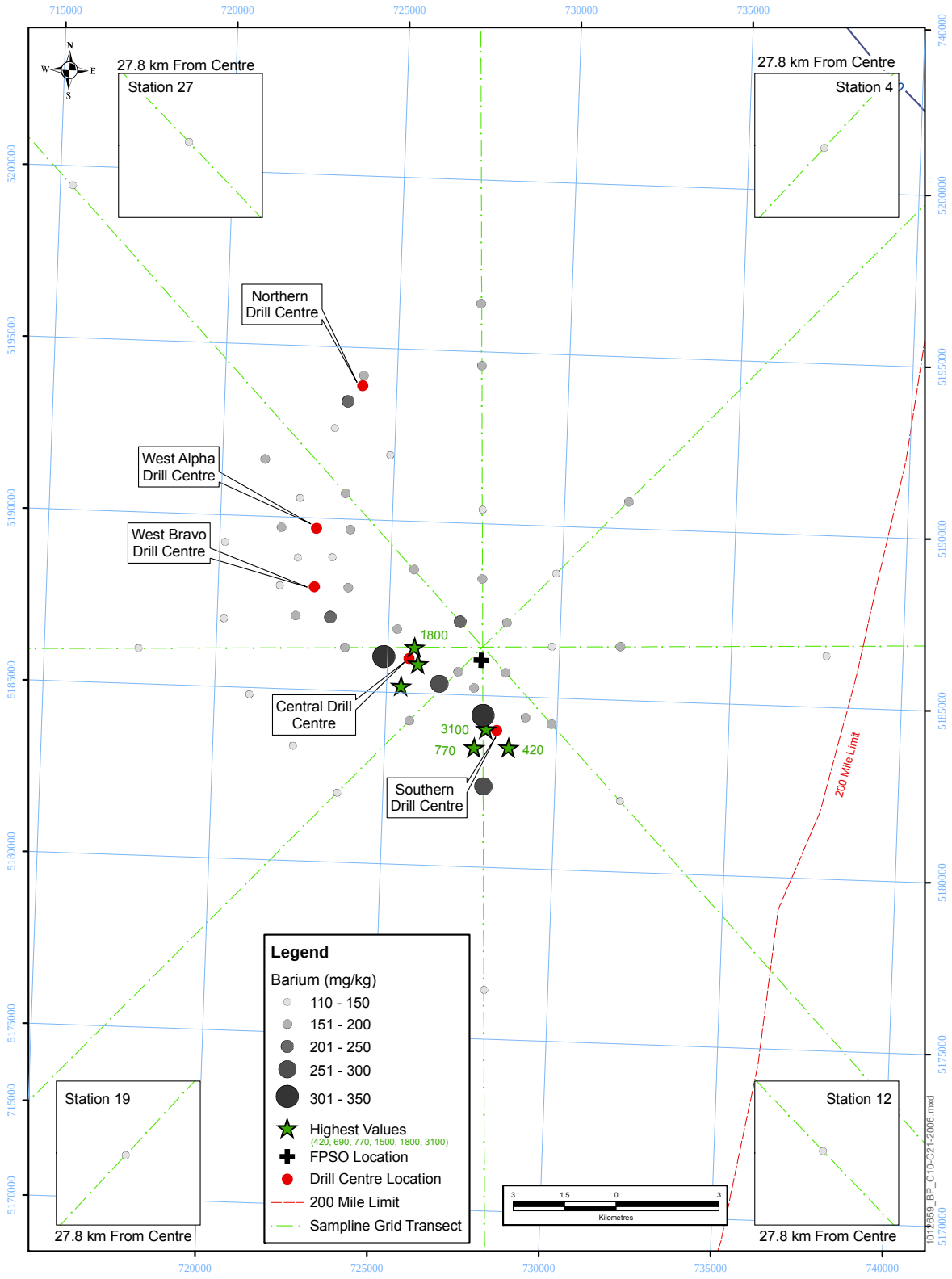


Figure 5-7 Spatial Distribution of Barium (2006)

Note: - Highest values were identified as outliers by SPSS 14 software

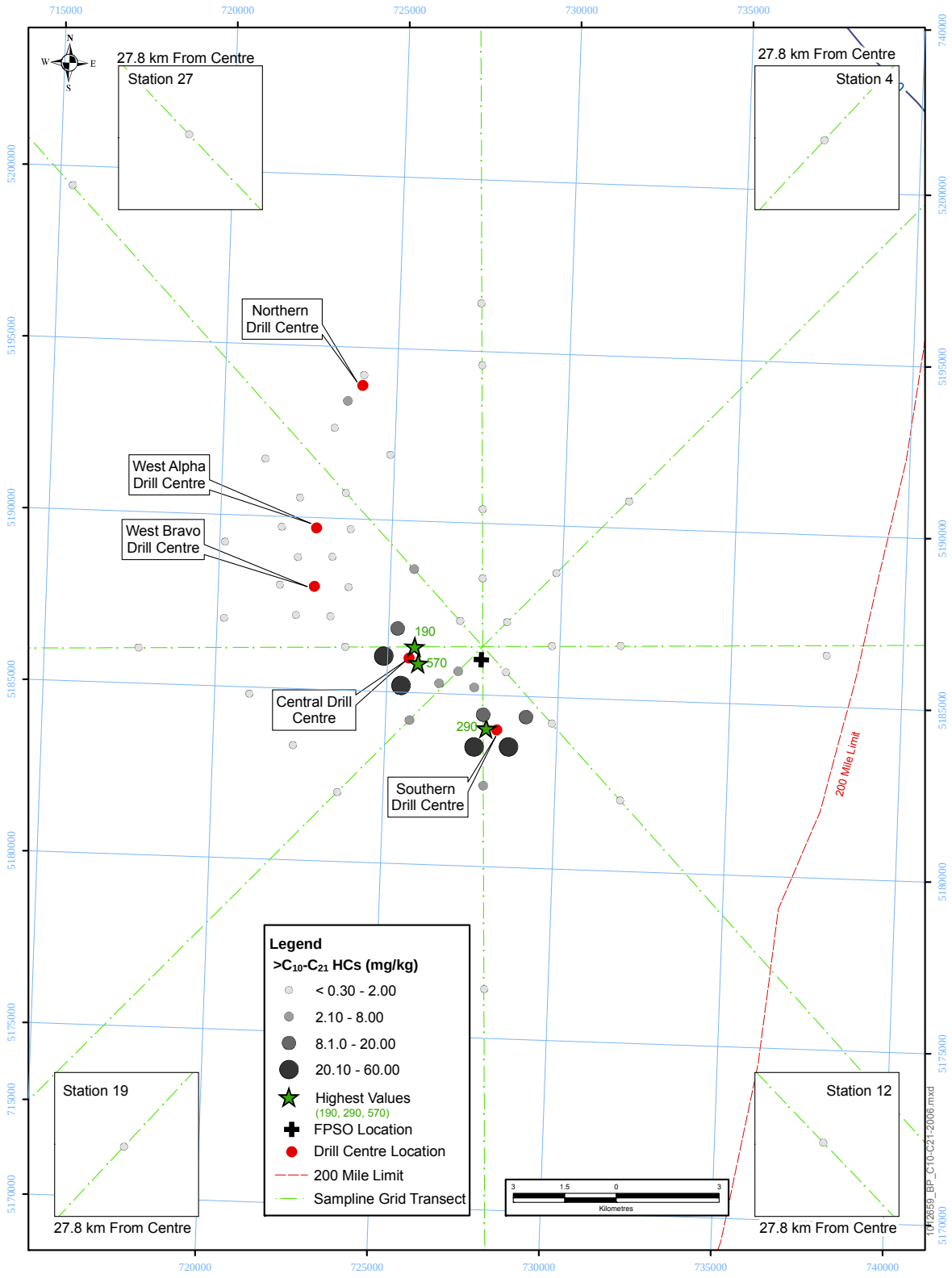


Figure 5-8 Spatial Distribution of >C_{10}-C_{21} HCs (2006)

Note: - Highest values were identified as outliers by SPSS 14 software

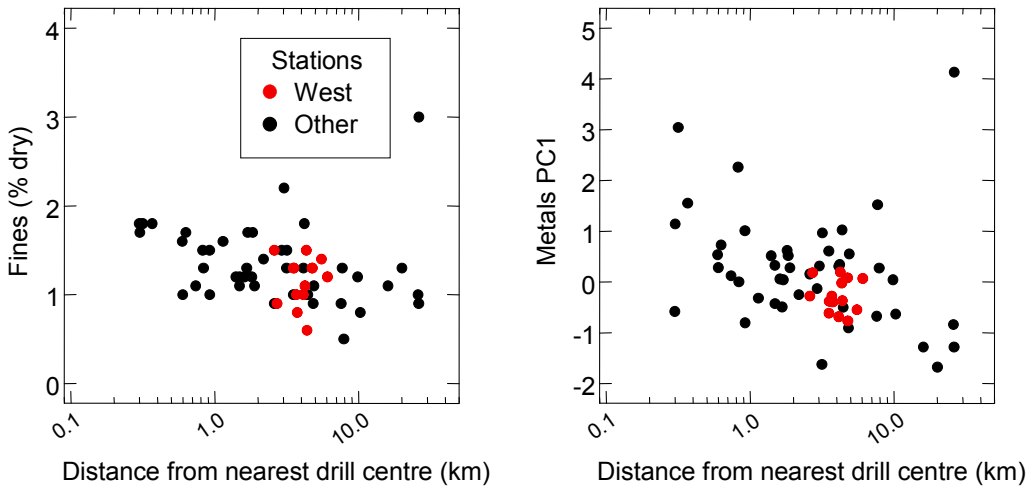


Figure 5-9 Fines Content and Metals PC1 Scores versus Distance from the Nearest Drill Centre (2006)

Gravel content was uncorrelated with depth and distance from the nearest drill centre (Table 5-11). Gravel content is of primary interest as a natural habitat factor, apparently unaffected by drilling activity, which may affect benthic invertebrate communities in predominantly sandy sediments (Section 5.4.3).

TOC content increased with depth and decreased with increasing distance from the nearest drill centres (Table 5-11). Depth effects were significant; distance effects were not signifcant. However, partial r and r_S for the two X variables were similar and weak. The positive correlation between TOC content and depth was largely a function of the low value at the shallowest station (Reference Station 9) and the high value at the deepest station (Reference Station 4) (Figure 5-10). With these two stations deleted, depth correlations were not significant.

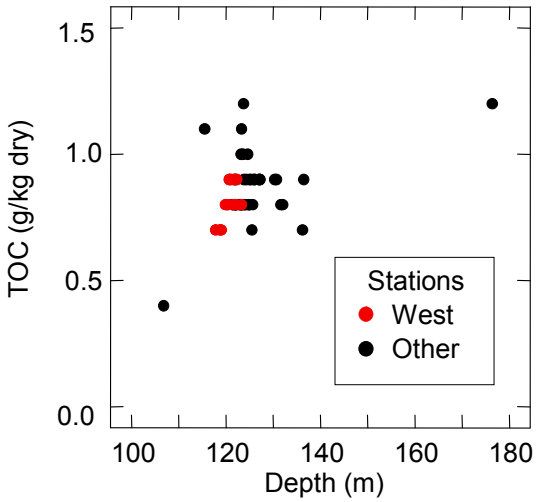


Figure 5-10 TOC Content versus Depth (2006)

Metals

Results of rank-rank depth-distance regressions for concentrations of metals other than barium (i.e., Metals PC1 scores) were similar to those for fines content (Table 5-11; Figure 5-9). Metal concentrations increased, but not significantly, with increasing depth and decreased significantly with increasing distance from the nearest drill centre. As for fines, depth effects have generally been stronger and significant, and distance effects weaker and not significant, in past years. The highest metal concentrations occurred at Reference Station 4. Otherwise, the highest concentrations occurred near the Southern drill centre (Appendix B-3).

Ammonia, Sulphur, Sulphide and Redox

Ammonia levels were largely uncorrelated with depth and distance from the drill centres (Table 5-11). The highest levels (8.9 and 9.6 mg N/kg dry, respectively) occurred at two stations located more than 7 km from any active drill centre and at the periphery of the development area: Station 3 (northeast of the FPSO) and Station W12 (west of the FPSO). Ammonia levels at the other 57 stations were less than 6 mg/kg and less than 4 mg/kg at 52 stations.

Sulphur concentrations and, to a lesser extent sulphide concentrations, decreased significantly with distance from the drill centres and were uncorrelated with depth (Table 5-11; Figure 5-11). Sulphur concentrations were elevated above background at several stations located within 1 km of the drill centres, especially near the Central and Southern drill centres. Sulphide concentrations were elevated only at a few stations nearest (usually within 0.5 km of) the three drill centres (Figure 5-11). Sulphur, and perhaps sulphide, could be considered secondary or weak tracers of drill cuttings discharges. Based on the strength of distance gradients and spatial extent and magnitude of contamination, tracer effectiveness could be listed as follows: >C_{10}-C_{21} HCs > barium > sulphur > sulphide.

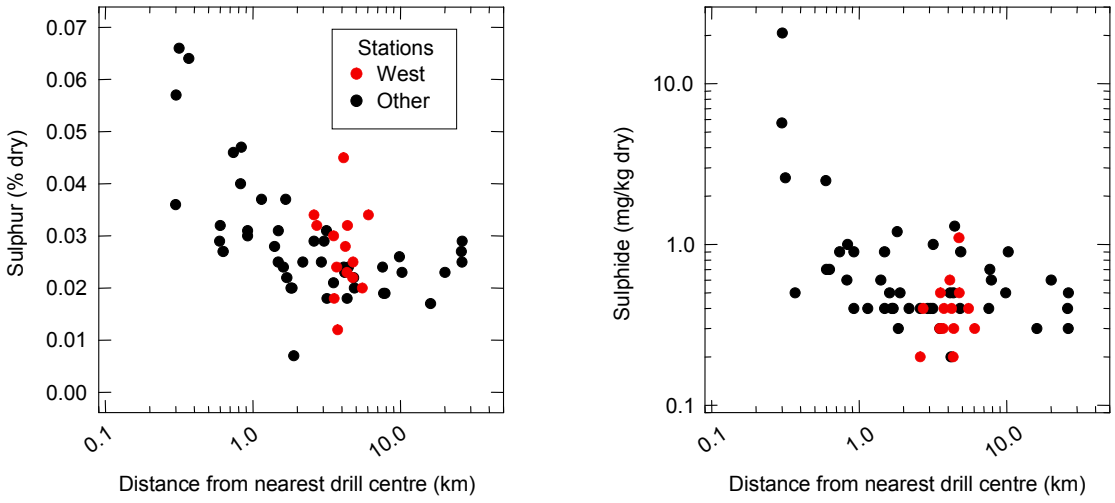


Figure 5-11 Sulphur and Sulphide versus Distance from the Nearest Drill Centre (2006)

In 2006, redox levels were largely uncorrelated with depth or distances from the drill centres (Table 5-11). In 2005, there were much stronger and significant distance relationships for redox, with redox levels low near the Central and Southern drill centres

and increasing with distance (Husky Energy 2006). In 2006, low redox levels (less than 200 mV) were distributed evenly throughout the sampling grid.

5.4.1.3 Comparison Among Years (2000, 2004, 2005 and 2006)

Table 5-13 provides results of RM regression models comparing sediment physical and chemical characteristics among the four sample years (2000, 2004, 2005 and 2006) for the 37 stations sampled in all four years. Table 5-14 provides results of RM regression analyses comparing the three EEM years (2004, 2005 and 2006) for the 42 stations sampled in all three years (stations 4 and 19 with extreme depth values were excluded). In 2000, ammonia and sulphur were not measured and all $>C_{10}$-C_{21} HC concentrations were below RDL. For interpretation of results (also see Appendix B-5 for further details):

- The Among Stations terms test for relationships between *Y* variables and depth or distance common to all years (i.e., relationships between mean *Y* and *X*). The Among Stations Error 1 term tests for *carry-over* effects, or persistent differences among stations unrelated to depth or distance.

- The Within Stations Year terms test for differences among years common to all or most stations. The Within Stations Year $\times$ *X* terms test for changes in slopes of *Y* versus *X* relationships among years (significant effects of *X* on differences in *Y* among years). When changes in *X* effects (i.e., significant Year $\times$ *X* effects) occur, overall or Among Stations *X* effects should be interpreted with caution (i.e., differences are usually more important than averages).

- For the analysis of all four years, Within Stations differences among years were divided into differences or *contrasts* between 2000 versus 2004 to 2006 (baseline versus EEM years), between 2004 versus 2005 and 2006, and between 2005 versus 2006. If drilling effects occurred, slopes of distance relationships should change after drill centres became active (i.e., Year $\times$ *d* terms should be significant for before versus after drilling).

- For the analysis of the three EEM years (2004, 2005, 2006), contrasts tested were 2004 versus 2005 and 2006 and 2005 versus 2006. Results should be similar to tests of the same contrasts for the four-year data set (i.e., adding five stations should not substantially change results). The three-year Among Stations results may reflect a mix of natural and project-related effects common to all three EEM years.

- Both data sets provided strong tests of effects from the Central and Southern drill centres, but weak tests of effects from the Northern drill centre. The set of stations re-sampled over time was biased towards the centre of the White Rose development and locations closer to the Central and Southern drill centres.

- Results are expressed as *F* values, which are estimates of effect sizes. *F* values greater than 1 indicate added variance attributable to the terms tested.

Table 5-13 Results of RM Regression Analysis Comparing Sediment Physical and Chemical Characteristics Among 2000, 2004, 2005 and 2006

Term	df	*F* value for *Y* variable			
		Barium	% fines	TOC	Metals PC1
Among Stations					
Depth	1,32	0.10	**22.56*** **	0.64	0.46
Northern (N) *d*	1,32	1.36	2.52	0.16	0.33
Central (C) *d*	1,32	4.70*	0.47	10.47**	0.04
Southern (S) *d*	1,32	**18.50*** **	7.87**	2.03	3.82
Error 1[1]	32,96	2.18**	1.58*	1.48	0.95
Within Stations					
Overall					
Year	3,96	0.17	3.23*	0.31	0.23
Year × Depth	3,96	0.33	4.63**	0.31	0.28
Year × N *d*	3,96	0.08	5.59**	1.35	1.16
Year × C *d*	3,96	**16.09*** **	5.78**	1.60	0.79
Year × S *d*	3,96	**9.32*** **	1.07	0.86	1.42
2000 versus 2004 to 2006					
Year	1,32	0.02	2.91	0.10	0.22
Year × Depth	1,32	0.22	4.35*	0.09	0.28
Year × N *d*	1,32	0.00	0.08	2.07	0.39
Year × C *d*	1,32	1.03	0.26	0.04	0.27
Year × S *d*	1,32	**13.30*** **	3.46	0.30	1.00
2004 versus 2005, 2006					
Year	1,32	0.15	0.32	0.91	0.42
Year × Depth	1,32	0.28	0.25	0.97	0.58
Year × N *d*	1,32	0.11	0.28	0.29	1.59
Year × C *d*	1,32	**36.82*** **	4.77*	4.07	1.73
Year × S *d*	1,32	12.91**	0.37	2.79	3.32
2005 versus 2006					
Year	1,32	0.36	5.19*	0.11	0.10
Year × Depth	1,32	0.50	7.48*	0.06	0.03
Year × N *d*	1,32	0.15	11.72**	1.16	1.33
Year × C *d*	1,32	7.56**	9.25**	1.87	0.38
Year × S *d*	1,32	0.22	0.28	0.01	0.16

Notes:
- Appendix B-5 explains terms and tests in the RM regression model
- df = degrees of freedom for the numerator (effect) and denominator (error) for *F*
- *d* = distances from various drill centres
- $*p \le 0.05$; $**p \le 0.01$; $***p \le 0.001$ (in bold)
- *n* = 37 stations sampled in all four years
- Distances and all *Y* variables except Metals PC1 were log-transformed
- [1]—Error 1 = carry-over effects or persistent differences among stations unrelated to depth or distance

Table 5-14 Results of RM Regression Analysis Comparing Sediment Physical and Chemical Characteristics Among 2004, 2005 and 2006

Term	df	*F* value for *Y* variable						
		Barium	>C_{10}-C_{21} HCs	% fines	TOC	Metals PC1	Ammonia	Sulphur
Among Stations								
Depth	1,37	0.47	0.45	**16.59*** **	0.00	0.68	2.15	0.46
Northern (N) *d*	1,37	0.60	5.46*	2.69	0.53	0.04	2.70	0.02
Central (C) *d*	1,37	8.70**	5.57*	1.17	1.34	1.14	8.41**	8.91**
Southern (S) *d*	1,37	8.64**	**23.92** **	5.89*	2.97	7.19*	**20.35*** **	0.23
Error 1[1]	37,74	**3.90*** **	**5.62*** **	1.52	2.30**	1.05	0.84	2.23**
Within Stations								

Term	df	*F* value for *Y* variable						
		Barium	>C_{10}-C_{21} HCs	% fines	TOC	Metals PC1	Ammonia	Sulphur
Overall								
Year	2,74	0.49	0.01	0.85	0.94	0.17	2.05	1.75
Year × Depth	2,74	0.68	0.00	1.36	1.09	0.23	2.21	2.47
Year × N *d*	2,74	0.83	5.09**	5.94**	0.01	0.55	0.30	5.74**
Year × C *d*	2,74	**43.07*** **	**71.28*** **	5.24**	2.82	1.61	3.21*	**8.35*** **
Year × S *d*	2,74	**13.78*** **	**16.56*** **	0.48	1.99	2.19	6.68**	3.60*
2004 versus 2005, 2006								
Year	1,37	0.49	0.01	0.01	1.99	0.02	2.44	1.93
Year × Depth	1,37	0.69	0.00	0.00	2.33	0.05	2.13	2.40
Year × N *d*	1,37	1.11	7.42**	0.20	0.02	0.84	0.30	6.13*
Year × C *d*	1,37	**64.68*** **	**108.65*** **	9.71**	5.01*	2.63	0.23	10.56**
Year × S *d*	1,37	**32.56*** **	**24.68*** **	1.50	4.31*	4.73*	2.15	7.05*
2005 versus 2006								
Year	1,37	0.49	0.02	1.25	0.03	0.30	1.29	1.59
Year × Depth	1,37	0.66	0.00	2.00	0.03	0.39	2.37	2.53
Year × N *d*	1,37	0.42	0.84	8.66**	0.00	0.31	0.29	5.38*
Year × C *d*	1,37	10.97**	2.84	3.12	0.94	0.77	9.13**	6.34*
Year × S *d*	1,37	0.75	1.69	0.00	0.01	0.07	**15.66*** **	0.45

Notes:
- Appendix B-5 explains terms and tests in the RM regression model
- df = degrees of freedom for the numerator (effect) and denominator (error) for *F*
- *d* = distances from various drill centres
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- *n* = 42 stations sampled in all three years
- Distances and all *Y* variables except Metals PC1 were log-transformed
- [1]—Error 1 = carry-over effects or persistent differences among stations unrelated to depth or distance

Table 5-15 provides multiple regression slopes for depth and distance *X* variables in each year, which adjust effects of each *X* variable for the effects of other X variables. In most cases, bivariate plots for *Y* variables versus individual *X* variables provided below are adequate to show large changes in depth or distance gradients over time or the absence of any gradients. However, the multiple regression slopes are useful for interpreting more subtle changes in gradients over time, particularly for distances from the Central and Southern drill centres, the two most strongly correlated *X* variables.

Table 5-15 Multiple Regression Slopes for Sediment Physical and Chemical Characteristics versus Depth and Distances from Drill Centres (2000, 2004, 2005 and 2006)

Y variable	*X* variable	Year			
		2000	2004	2005	2006
Barium	Depth	–0.001	0.000	0.001	0.005
	Northern *d*	–0.051	–0.070	–0.060	–0.029
	Central *d*	–0.039	0.182	–0.147	–0.348
	Southern *d*	0.001	–0.396	–0.163	–0.129
>C_{10}-C_{21} HCs	Depth		–0.013	–0.012	–0.012
	Northern *d*		–0.760	–0.329	–0.185
	Central *d*		0.935	–1.025	–1.316
	Southern *d*		–1.705	–0.778	–0.545
% fines	Depth	0.005	0.010	0.004	0.019
	Northern *d*	–0.030	–0.025	0.061	–0.157
	Central *d*	–0.002	0.038	0.040	–0.135
	Southern *d*	–0.013	–0.091	–0.052	–0.082

Y variable	*X* variable	Year			
		2000	2004	2005	2006
TOC	Depth	–0.002	0.001	–0.002	–0.001
	Northern *d*	–0.040	0.015	–0.015	0.018
	Central *d*	0.047	0.071	0.044	0.006
	Southern *d*	–0.006	–0.047	–0.011	–0.008
Metals PC1	Depth	–0.006	0.038	0.027	–0.006
	Northern *d*	0.731	0.411	–0.480	0.731
	Central *d*	0.377	–0.128	–0.559	0.377
	Southern *d*	–1.196	–0.077	–0.349	–1.196
Ammonia	Depth		–0.005	0.018	0.004
	Northern *d*		–0.026	–0.105	–0.059
	Central *d*		0.086	0.280	0.001
	Southern *d*		–0.083	–0.445	–0.065
Sulphur	Depth		0.006	–0.004	0.004
	Northern *d*		–0.065	0.079	–0.025
	Central *d*		0.001	–0.069	–0.192
	Southern *d*		–0.089	0.040	0.006

Notes:
- *d* = distances from various drill centres
- *n* = 37 stations sampled in 2000, 2004, 2005 and 2006 for barium, % fines, TOC and Metals PC1
  n = 42 stations sampled in 2004, 2005 and 2006 for >C_{10}-C_{21} HCs, ammonia and sulphur
- Distances and all *Y* variables except Metals PC1 were log-transformed

Tracers

Results for barium and >C_{10}-C_{21} HCs provided clear evidence of effects of drilling at the Central and Southern drill centres on concentrations of the two tracers. For barium, relationships with distance from the Northern drill centre were weak and did not vary over time (i.e., Among Stations Northern *d* and Within Stations Year × Northern *d* terms were not significant in Tables 5-13 and 5-14) (Figure 5-12). Concentrations greater than 250 mg/kg did not occur within 2 km of the Northern drill centre, even for stations sampled only in 2004 (Husky Energy 2005) and excluded from the RM analysis and Figure 5-12.

In contrast, the relationship between barium and distance from the Central drill centre changed significantly and substantially between 2004 and 2005 after drilling began (Tables 5-13 and 5-14; Figure 5-12). In 2006, the distance gradient for the Central drill centre was stronger than in 2005 (see 2005 versus 2006 Year × Central *d* contrasts in Tables 5-13 and 5-14; Figure 5-12).

Relationships between barium and distance from the Southern drill centre also changed significantly and substantially between 2000 and 2004 after drilling began (Figure 5-12). The distance gradient was weaker in 2005 and 2006 than in 2004. The change in distance relationships between 2004 versus 2005 and 2006 was highly significant ($p \leq 0.001$ for Year × Southern *d* term for 2004 versus 2005, 2006 in Tables 5-13 and 5-14). The change between 2004 and 2005 appears small in Figure 5-12, but multiple regression slopes in 2005 and 2006 were less than in 2004 (Table 5-15).

Figure 5-13 provides barium centroids (left plot), and overall changes in barium concentrations over time (right plot), for the 37 stations sampled in all four years. The sample design and sampling centroid (north and east coordinates = 0,0) were biased towards the Central and Southern drill centres. In 2000, the barium centroid was to the northwest of the sampling centroid, but moved southeast towards the Southern drill

centre in 2004 and then to the east in 2005 and 2006 after drilling began at the Central drill centre.

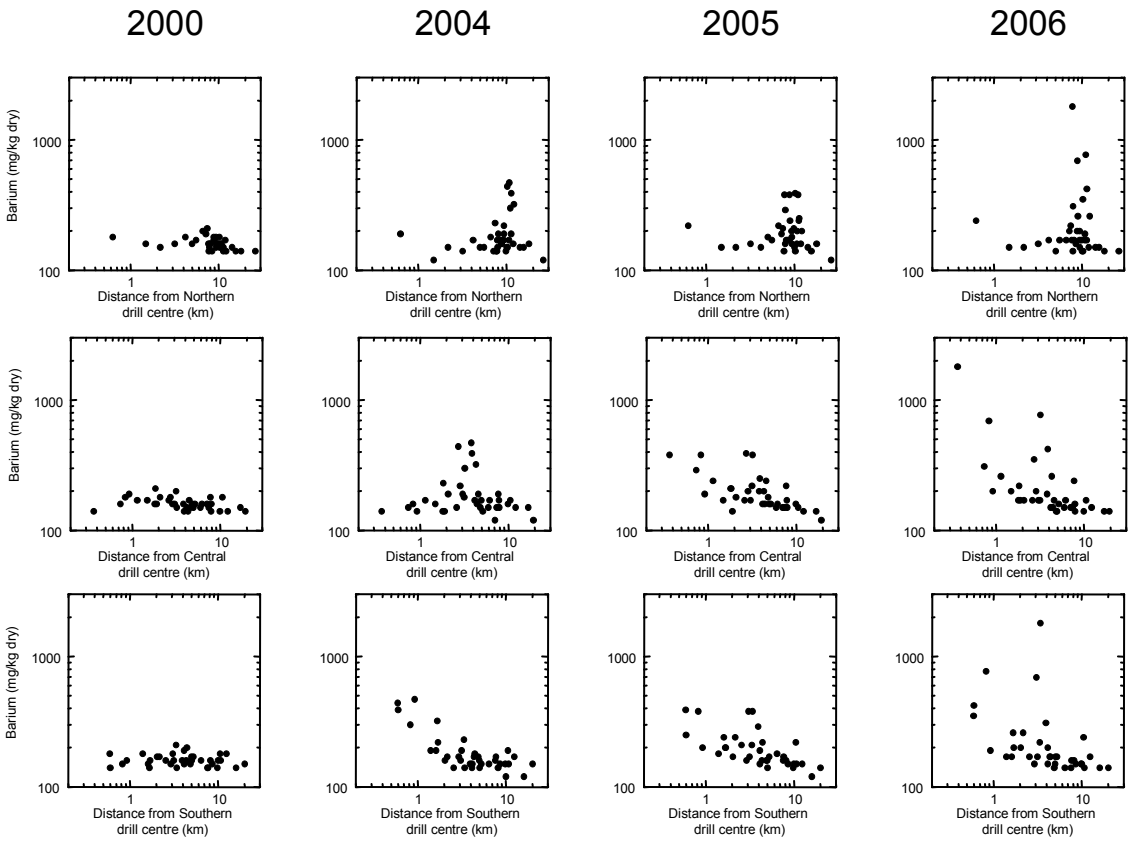


Figure 5-12 Barium Concentrations versus Distances from the Three Drill Centres for 37 Stations Sampled in 2000, 2004, 2005 and 2006

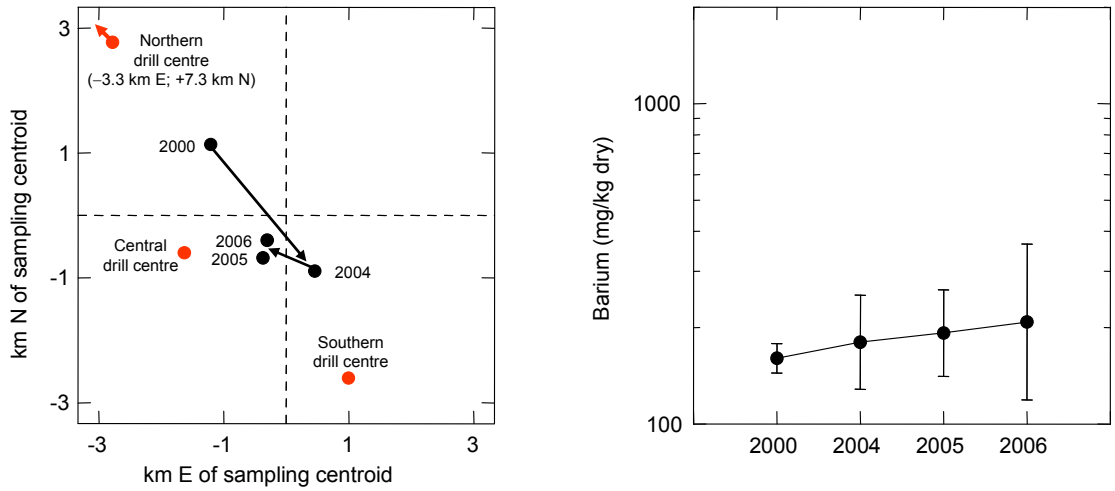


Figure 5-13 Barium Centroids and Changes in Concentrations Over Time for 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used (e.g., logarithmic for barium). The *Y* axes include the full range of individual values

The net result was that barium concentrations over the 37 stations increased over time (Figure 5-13). Most of the increase was attributable to increased concentrations near active drill centres. Barium concentrations at more remote stations, far from the two drill centres, did not increase over time (Figure 5-12). With barium concentrations increasing only near drill centres and remaining relatively unchanged at more remote stations, variances of barium concentrations have also increased over time (Figure 5-13; note also the increasing spread of concentrations over time in Figure 5-12).

With all $>C_{10}$-C_{21} HC concentrations in 2000 less than RDL, baseline depth and distance relationships would be horizontal lines with slope = 0. In 2004 to 2006, $>C_{10}$-C_{21} HC concentrations decreased with distance from the Northern and especially Southern drill centres (Figure 5-14). In 2005 and 2006, $>C_{10}$-C_{21} HC concentrations decreased with distance from the Central drill centre, whereas concentrations increased with distance in 2004.

Distance gradients for all three drill centres changed between 2004 and 2005, but not between 2005 and 2006. Within Stations Year $\times$ distance terms were significant for 2004 versus 2005 and 2006 contrasts, but not for 2005 versus 2006 contrasts (Table 5-14). For the Central drill centre, the change was from an increase in concentration with increasing distance in 2004 to a strong decrease in concentration with increasing distance in 2005 and 2006, after drilling began. Again, it is not obvious from the bivariate plots in Figure 5-14, but distance gradients for the other two drill centres were weaker in 2005 and 2006 than in 2004 (see slopes in Table 5-15). Finally, depth relationships over all three EEM years combined, and any changes in these relationships, were not significant for $>C_{10}$-C_{21} HCs, despite apparent depth effects for all stations sampled in 2006 (Section 5.4.1.2).

Figure 5-15 provides centroids and overall changes over time for $>C_{10}$-C_{21} HCs. In 2000, with all concentrations less than RDL (0.3 mg/kg dry), the $>C_{10}$-C_{21} HC centroid would be at the sampling centroid (0,0). $>C_{10}$-C_{21} HC centroids in 2004 to 2006 were also close to the sampling centroid, with only a slight shift towards the Central drill centre in 2005 and 2006. Centroids for variables unaffected by distance or direction (i.e., varying randomly) will be close to the sampling centroid, but so will centroids for variables affected by all three drill centres because the sampling grid was deliberately biased towards sampling locations close to those sources. The Northern drill centre had some effect on $>C_{10}$-C_{21} HC concentrations. If this were not true, the 2004 centroid would be further southeast and closer to the Southern drill centre, and the 2005 and 2006 centroids further to the southwest and between the Central and Southern drill centres.

In 2004, overall $>C_{10}$-C_{21} HC concentrations increased to approximately 1 mg/kg versus less than 0.3 mg/kg at all stations in 2000 (Figure 5-15; 2000 concentrations would be at or near the bottom of the *Y* axis). In 2005, there was a further increase to approximately 2 mg/kg (i.e., overall concentrations doubled). In 2006, Geometric Mean (GM) concentrations, which are the values plotted in Figure 5-15, were approximately 1.5 mg/kg, or between 2004 and 2005 values.

Increases in GM $>C_{10}$-C_{21} HC concentrations from <0.3 to 1 to 2 mg/kg after 2000 were substantial and attributable to drilling and discharges of cuttings from SBM. However, the use of GM and the log scale in Figure 5-15 conceals an important change between 2004 versus 2005 and 2006, as SBMs continued to be used and HC discharges from cuttings increased. The sum of HC concentrations for the 42 stations sampled in all

three EEM years, which could be considered a correlate of total HC discharge, was approximately five times greater in 2005 and 2006 than in 2004. As Figure 5-14 shows, no concentrations greater than 100 mg/kg occurred in 2004. Concentrations greater than 100 mg/kg and approaching 1,000 mg/kg occurred in 2005 and 2006, but only at stations near the Central and Southern drill centres. In other words, the added HCs discharged after 2004 have been deposited mostly near those two drill centres. GMs for 2005 and 2006 approximate medians or concentrations at most stations, which have remained relatively unchanged from 2004 to 2006.

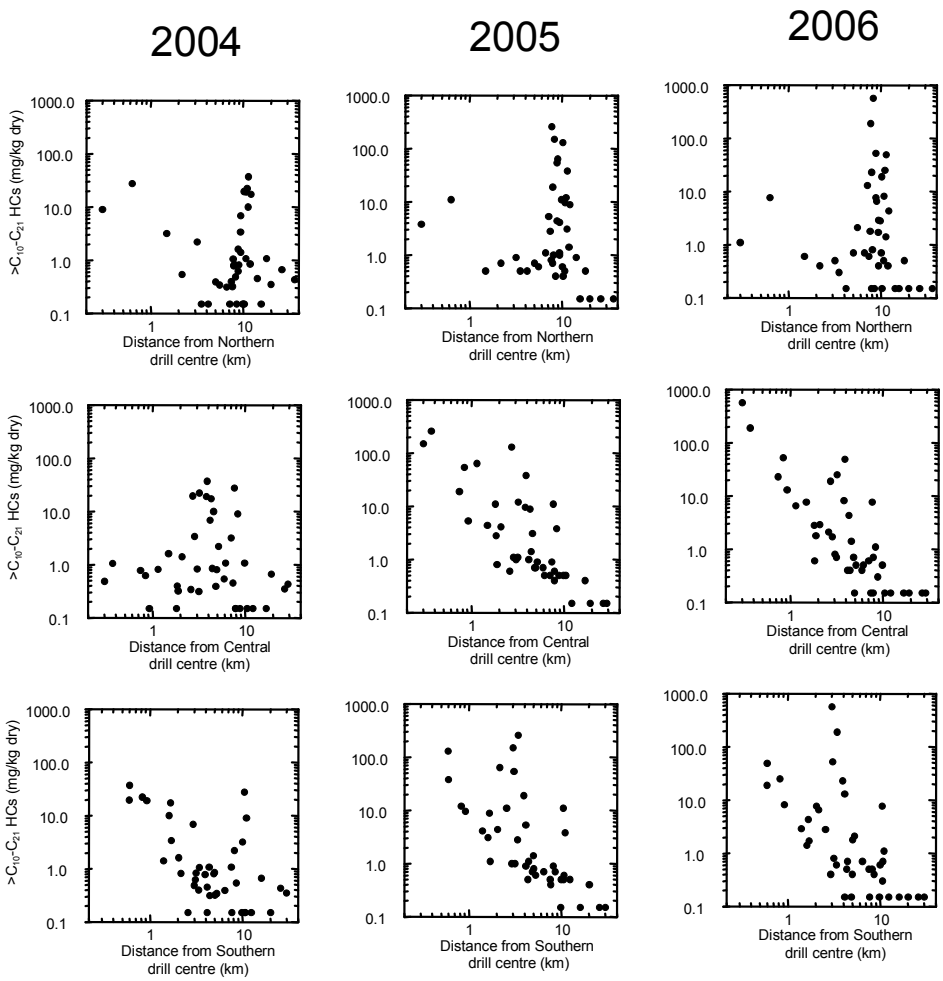


Figure 5-14 $>C_{10}$-C_{21} HC Concentrations versus Distances from the Three Drill Centres for 42 Stations Sampled in 2004, 2005 and 2006

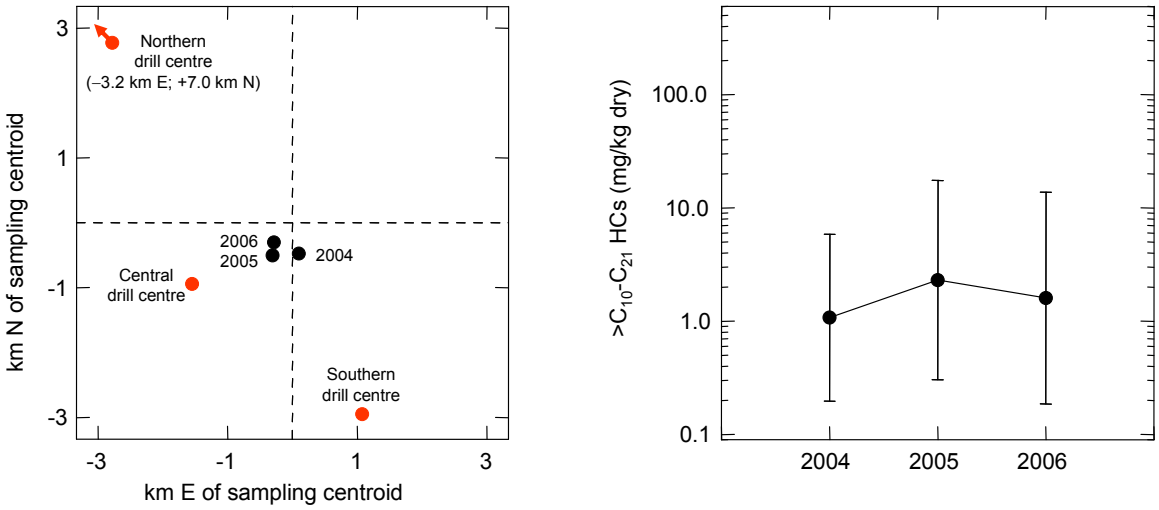


Figure 5-15 $>C_{10}$-C_{21} HC Centroids and Changes in Concentrations Over Time for 42 Stations Sampled in 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

In 2004 and 2005, as in 2006 (Section 5.4.1.2), hockey-stick or threshold distance regression models for both tracers and all stations sampled significantly reduced error variances relative to bivariate log-log regressions (Table 5-16). The distance measure used for 2004 was distance to the nearest of the two active drill centres (Northern and Southern). For both variables, estimated background or blade concentrations were similar among years, suggesting that natural changes at more remote stations were minimal. For barium, estimated background concentrations in 2004 to 2006 were approximately 150 mg/kg dry, similar to baseline (2000) means and medians of approximately 160 mg/kg (Table 5-4). For $>C_{10}$-C_{21} HCs, estimated background levels were near or below RDL of 0.3 mg/kg dry.

Table 5-16 Results of Hockey-stick (Threshold) Regressions on Distance from the Nearest Active Drill Centre for Barium and $>C_{10}$-C_{21} HCs (2004, 2005 and 2006)

Result/Estimate	Barium			$>C_{10}$-C_{21} HCs		
	2004	**2005**	**2006**	**2004**	**2005**	**2006**
Overall *R*	0.776***	0.772***	0.815***	0.824***	0.876***	0.887***
p for adding threshold	<0.001	**0.01**	<0.001	<0.001	**0.02**	<0.001
antilog *a* (blade/background value as mg/kg dry)	**156**	**149**	**156**	**0.26**	**0.20**	**0.34**
b (slope of shaft)	**–0.619**	**–0.387**	**–0.995**	**–1.83**	**–1.74**	**–2.07**
antilog X_T (threshold distance in km)	**2.4**	**3.6**	**1.9**	**6.3**	**8.9**	**5.9**
95% CI	**1.6 to 3.5**	**2.1 to 6.2**	**1.4 to 2.6**	**4.1 to 9.7**	**4.9 to 16**	**4.2 to 8.5**

Notes: - $*p \le 0.05$; $**p \le 0.01$; $***p \le 0.001$ (in bold)
- *X* was distance from the nearest active drill centre (Northern, Southern in 2004; Northern, Central, Southern in 2005 and 2006)
- *n* = 56 stations in 2004, 44 stations in 2005, and 59 stations in 2006
- All variables were log-transformed

In 2004 and 2006, when additional stations at intermediate distances (3 to 10 km) from active drill centres and near proposed new drill centres were sampled, estimated threshold distances for both tracers were less than estimated threshold distances in 2005, when only "core" EEM stations were sampled. This difference should not be considered evidence that the spatial extent of contamination was greater in 2005 than in 2004 and 2006. Instead, sampling additional intermediate distances near threshold distances for 2004 and 2006 increased the power or ability of the hockey-stick regressions to estimate threshold distances (note the lower *p* for adding the threshold, and the narrower CI for 2004 and 2006 versus 2005 in Table 5-16). Note also that increases in tracer concentrations at a few stations near drill centres after 2004 would not increase estimates of threshold distances, which are determined largely by concentrations at intermediate distances. Given the wide CI for estimates of threshold distances in Table 5-16 and the effects of differences in sampling design among years, the most reasonable conclusions are be that:

- post-drilling zones of influence (ZOI or the spatial extent of contamination) were 1 to 3 km for barium and 5 to 10 km for $>C_{10}$-C_{21} HCs;
- these ZOIs have not changed substantially since drilling began; and
- ZOIs have always been greater for $>C_{10}$-C_{21} HCs than for barium, because background levels for $>C_{10}$-C_{21} HCs are much lower (< RDL).

Overall, discharge of drill cuttings had detectable and significant effects on distance gradients for tracers after drilling began at the Northern, Central and Southern drill centres. As drilling progressed, and cuttings increased, tracer concentrations increased mostly at a few stations near drill centres, with minimal or no increases at intermediate and more remote stations. Consequently, the magnitude of contamination at near-field stations increased, but the overall spatial extent of contamination did not substantially increase.

Fines and TOC

Fines content increased with increasing depth in all four sample years, despite the narrow range of depths (116 to 137 m) for the 37 stations sampled in all four years (Tables 5-13 and 5-14; Figure 5-16). For these 37 stations, the depth relationship was stronger in 2004 and 2006 than in 2000 and 2005, accounting for the significant Within Stations Year × Depth terms in Table 5-13. However, there were no significant changes in depth relationships over time for the 42 stations sampled from 2004 to 2006 (Table 5-14).

Fines content has always decreased with increasing distance from the Southern drill centre, accounting for the significant Among Stations Southern *d* effects in Tables 5-13 and 5-14 (see also Figure 5-16). This distance gradient was weaker in 2000 than in 2004 to 2006, although the difference before versus after drilling was not significant ($F = 3.46$ and $p = 0.07$ for the Within Stations 2000 versus 2004 to 2006 Year × Southern *d* contrast in Table 5-13).

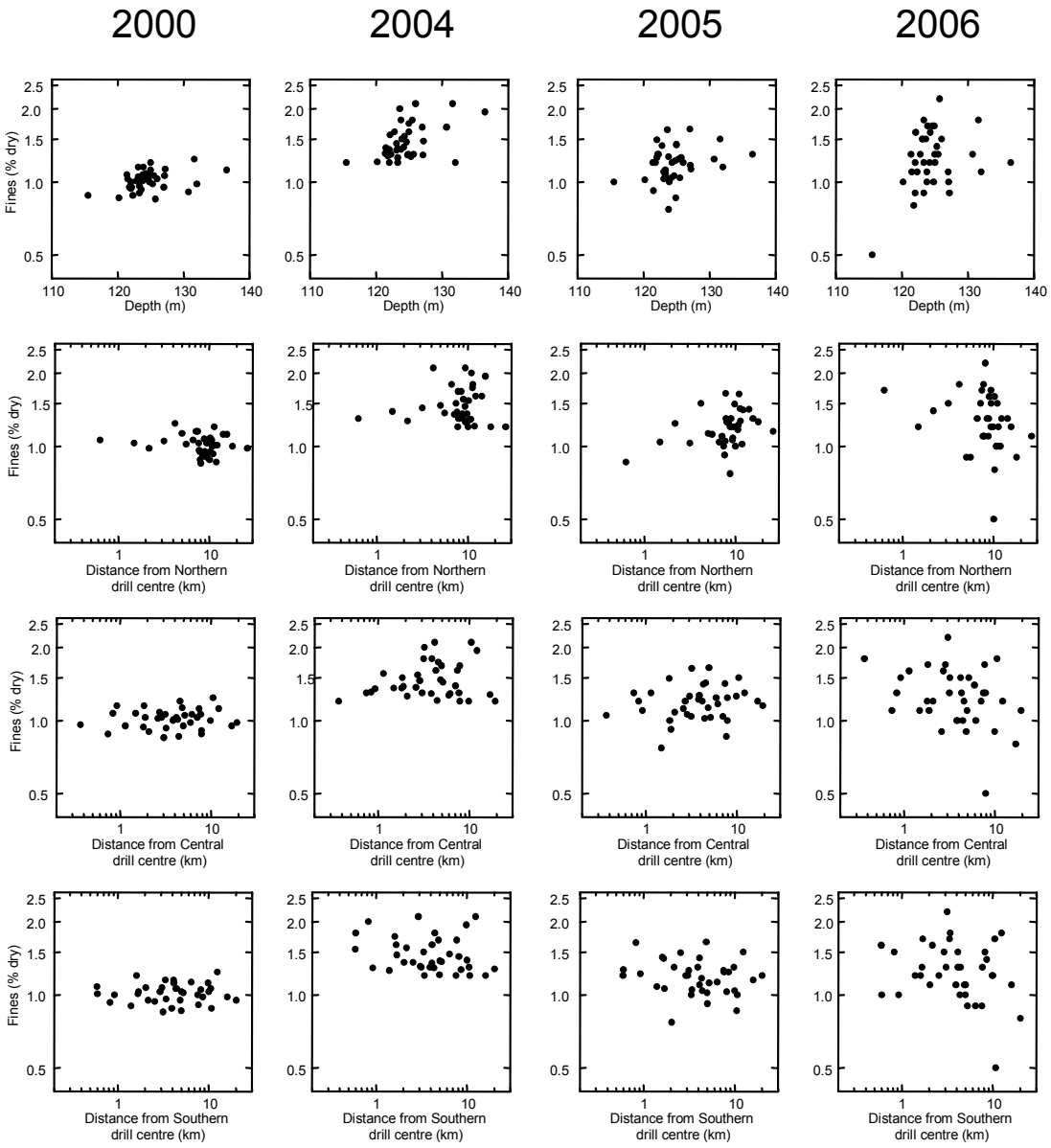


Figure 5-16 Fines Content versus Depth and Distances from the Northern and Southern Drill Centres for 37 Stations Sampled in 2000, 2004, 2005 and 2006

Relationships between fines content and distances from the Northern and Central drill centres varied in strength and even direction over time (Tables 5-13 and 5-14; Figure 5-16). In 2000 and 2004, fines content was largely unrelated to distance from the Northern drill centre (Figure 5-16). In 2005, fines content increased with distance from the Northern drill centre. In 2006, this gradient was reversed, with fines content decreasing with distance. Similarly, fines content did not change (2000) or increased slightly (2004 and 2005) with increasing distance from the Central drill centre from 2000 to 2005, but decreased with distance in 2006.

Fines content has always been greater to the northeast, where depths are greater, as the centroids in Figure 5-17 indicate. Despite the tendency for fines content to be higher

near the Southern drill centre, the centroids are several kilometres from that or any other drill centre. Therefore, depth effects over the narrow range of 116 to 137 m for the 37 stations included in analyses generally overwhelmed any distance effects or gradients. Fines content was highest in 2004 and lowest in 2000. The difference between these two years was presumably natural or methodological, occurring at almost every station (Figure 5-17; Husky Energy 2005).

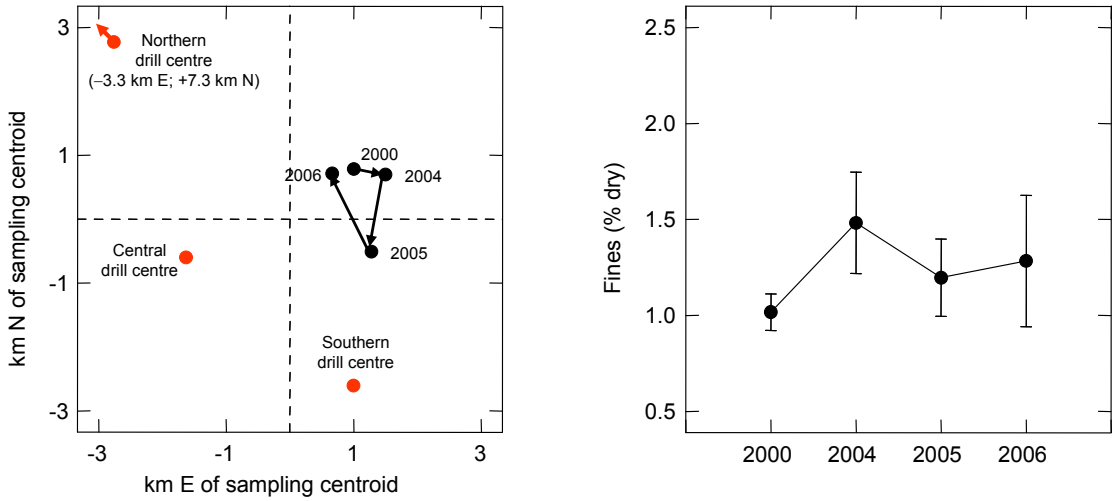


Figure 5-17 Fines Centroids and Changes in Fines Content Over Time for 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

There was a consistent increase in sediment TOC with distance from the Central drill centre over all four sample years (Among Stations Central *d* term in Table 5-13). This distance gradient was stronger in 2004 than in 2005 and 2006 (see Within Stations Year × Central *d* terms and tests for the 2004 versus 2005, 2006 contrast in Tables 5-13 and 5-14). TOC content also decreased with distance from the Southern drill centre in 2004, whereas there was no gradient in other years (Tables 5-13 and 5-14; Figure 5-18).

TOC centroids in all four sample years were north or east of the sampling centroid, relatively far from the Central drill centre (hence the increases with distance from that drill centre in Figure 5-18). Centroid locations in 2000 and 2005 were similar, but the 2004 and 2006 centroids were displaced to the southeast. For TOC, the centroids based on standardized values inflate changes in spatial distribution over time. TOC concentrations have never been outside a narrow range of 0.6 to 1.2 g/kg, with most values between 0.8 to 1.0 g/kg (Table 5-4); Figures 5-18 and 5-19). Distance (and depth) gradients, and variance in the strength of these gradients over time or space, depended on where and when the few values outside the 0.8 to 1.0 g/kg range occurred.

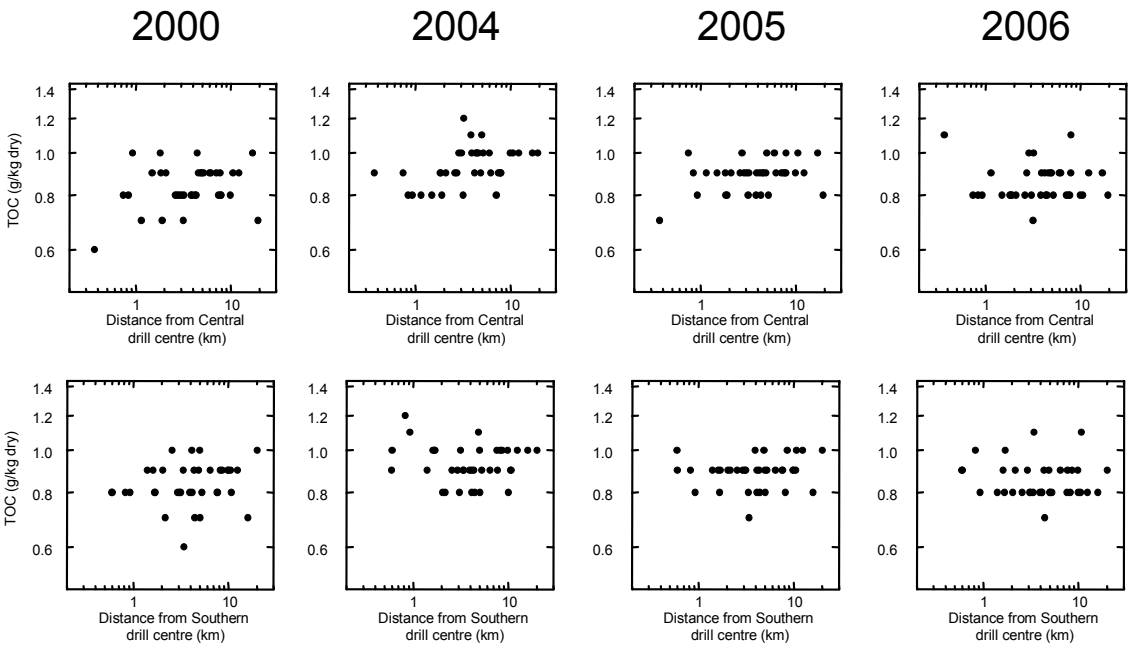


Figure 5-18 TOC versus Distances from the Central and Southern Drill Centres for 37 Stations Sampled in 2000, 2004, 2005 and 2006

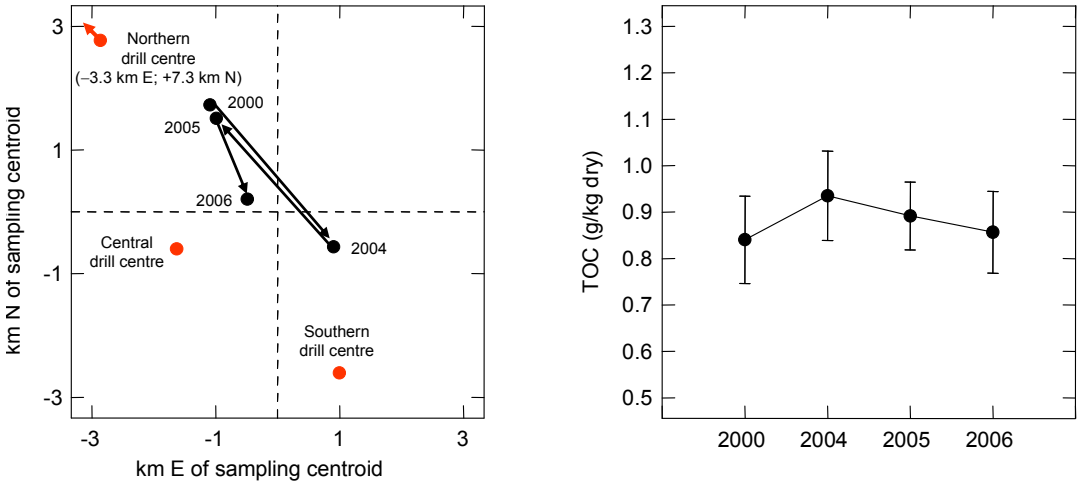


Figure 5-19 TOC Centroids and Changes in TOC Content Over Time for 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

Metals

F values for Metals PC1 in Tables 5-13 and 5-14 were rarely significant. The highest *F* values occurred for Among Stations and Within Stations 2004 versus 2005, 2006 tests of distance from the Southern drill centre. In 2000, 2005 and, arguably 2006, there was effectively no distance gradient (Figure 5-20), although slopes for regressions of Metals

PC1 on Southern *d* were negative for all three years (Table 5-15). In contrast, in 2004, there was a relatively strong gradient, with PC1 scores and total metal concentrations decreasing with increasing distance from the Southern drill centre. The Among Stations Southern *d* and the Within Stations Year × Southern *d* 2004 versus 2005, 2006 contrast was significant at $p \leq 0.05$ for the three EEM years (Table 5-14) but not for all four years (Table 5-13; $0.05 < p < 0.10$).

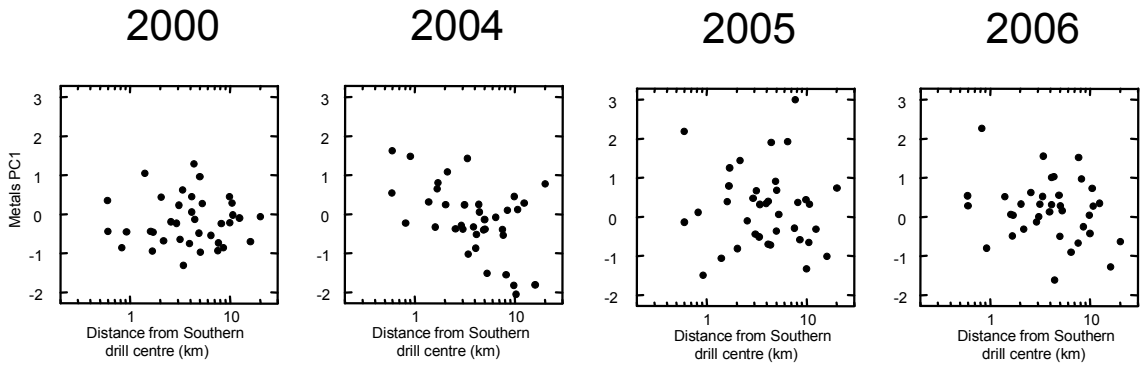


Figure 5-20 Metals PC1 Scores versus Distance from the Southern Drill Centres for 37 Stations Sampled in 2000, 2004, 2005 and 2006

Centroids for Metals PC1 were located near (2004) or slightly north (other years) of the sampling centroid (Figure 5-21). Therefore, even in 2004, the occurrence of some higher concentrations near the Southern drill centre had a negligible effect on the overall spatial distribution of metals concentrations. Metals PC1 scores, a measure of total metals concentrations, slightly increased since 2004 (Figure 5-21), but the increase was not significant ($F << 1$; $p >> 0.5$ for all Year terms in Tables 5-13 and 5-14). Concentrations of the eight frequently detected metals have varied little (less than 10-fold for all eight metals and less than 5-fold for all but lead and manganese) over time and space, whereas barium concentrations have varied by 10- to 30-fold among stations in each post-drilling year (Table 5-4).

Ammonia and Sulphur

Ammonia and sulphur were not measured in 2000, so only the three EEM years could be compared (Table 5-14). In all three years, ammonia concentrations increased with distance from the Central drill centre and decreased with distance from the Southern drill centre (Among Stations terms in Table 5-14; Figure 5-22). These gradients varied significantly in strength among years and were stronger in 2005 than in 2004 or 2006. However, the changes in gradients over time were partly to largely a function of where outliers occurred, and there were one or more outliers in each year (Figure 5-22). Removing individual outliers (i.e., the most extreme values) simply generated new outliers or extremes. Rank transformation of all *Y* and *X* variables removed the significant changes in distance gradients for the Central and Southern drill centres over time, with the gradients over all years (i.e., Among Stations terms) remaining significant. However, the gradient for the Northern drill centre over all years was then significant (and negative), and depth gradients varied significantly over time.

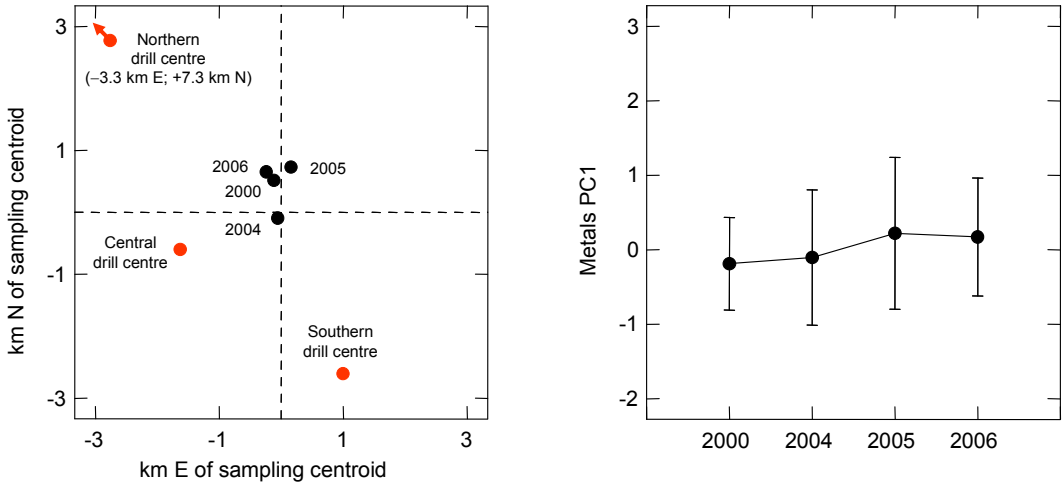


Figure 5-21 Metals PC1 Centroids and Changes in Values Over Time for 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

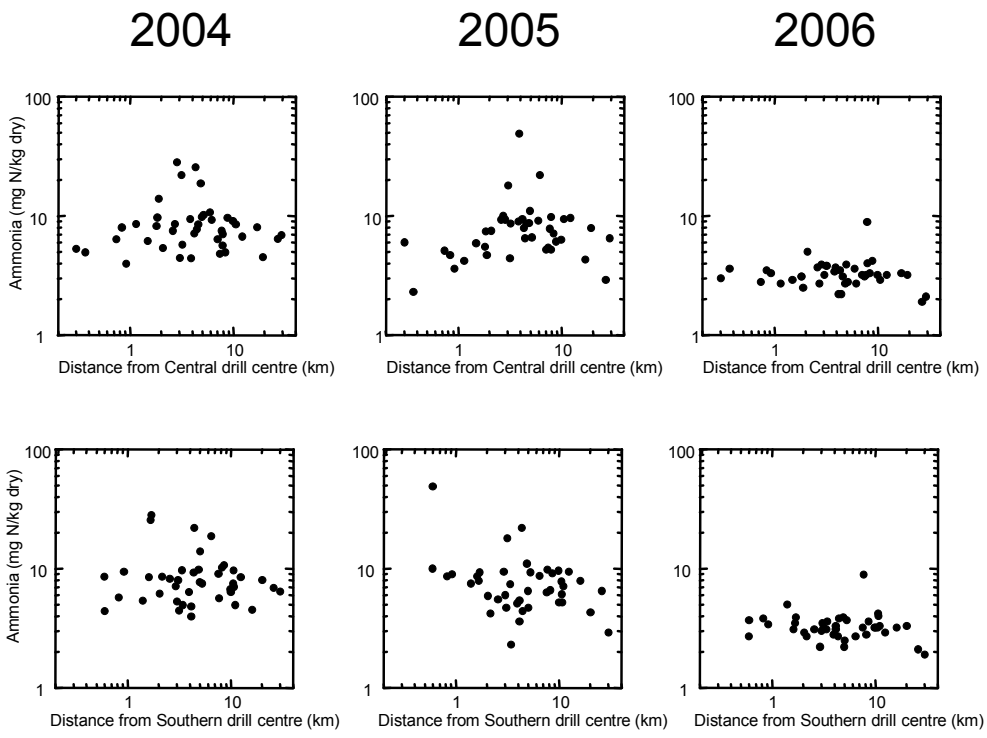


Figure 5-22 Ammonia Concentrations versus Distance from the Central and Southern Drill Centres for 42 Stations Sampled in 2004, 2005 and 2006

The ammonia centroid was at the centre of the sampling grid in 2004 and moved southeast in 2005 then northwest in 2006 (Figure 5-23). Ammonia concentrations were

much lower in 2006 (all less than 10 mg N/kg dry) than in 2004 and 2005 (Figures 5-22 and 5-23).

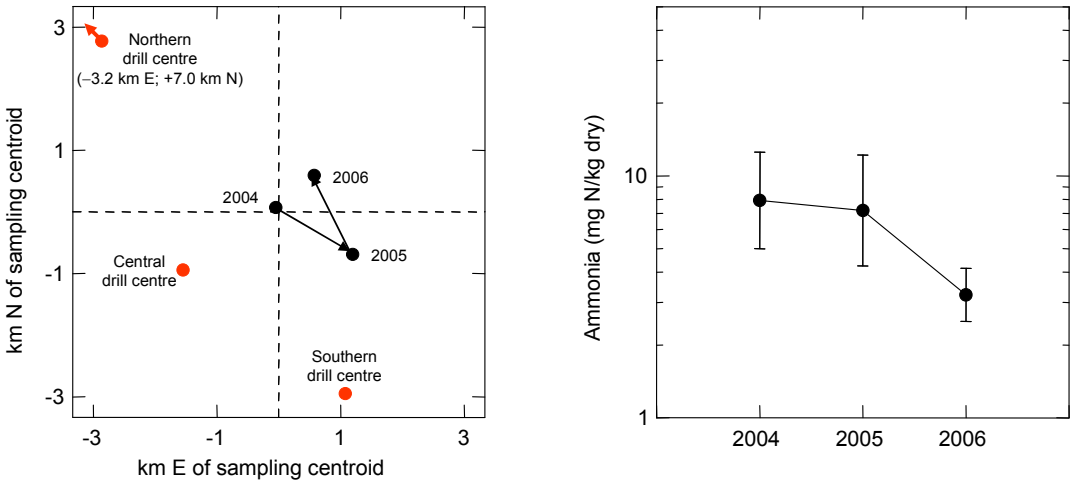


Figure 5-23 Ammonia Centroids and Changes in Concentrations Over Time for 42 Stations Sampled in 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

Overall, ammonia has been statistically problematic because of outliers, and it has been sensitive to the transformations used and data sets analyzed. The analysis of the 42 core EEM stations also excludes some high ammonia levels observed at stations near proposed drill centres but several kilometres from active drill centres sampled in 2004 and 2006 (Section 5.4.1.2; Husky Energy 2005).

Relationships between sulphur concentrations versus distance from the Northern drill centre have differed significantly over time (Table 5-14), with concentrations increasing with distance in 2005 and decreasing with distance in 2004 and 2006 (Figure 5-24). There was no relationship between sulphur and distance from the Central drill centre in 2004, but after drilling began, concentrations decreased with increasing distance, with the gradient stronger in 2006 than in 2005 (Year × Central *d* tests in Table 5-14; Figure 5-24).

Sulphur concentrations also decreased with distance from the Southern drill centre in 2004 but not in 2005 or 2006 (Figure 5-24). With all variables rank transformed, sulphur concentrations decreased with distance from the Southern drill centre in 2006 as well as 2004, but the distance gradient was still significantly stronger in 2004 than in other years.

Post-drilling sulphur distance gradients for the Central and Southern drill centres were probably stronger than the RM analyses indicated. In 2006, values less than the 2005 RDL of 0.02% tended to occur more frequently at more remote stations, so information was lost by setting all concentrations <0.02% to 0.02%.

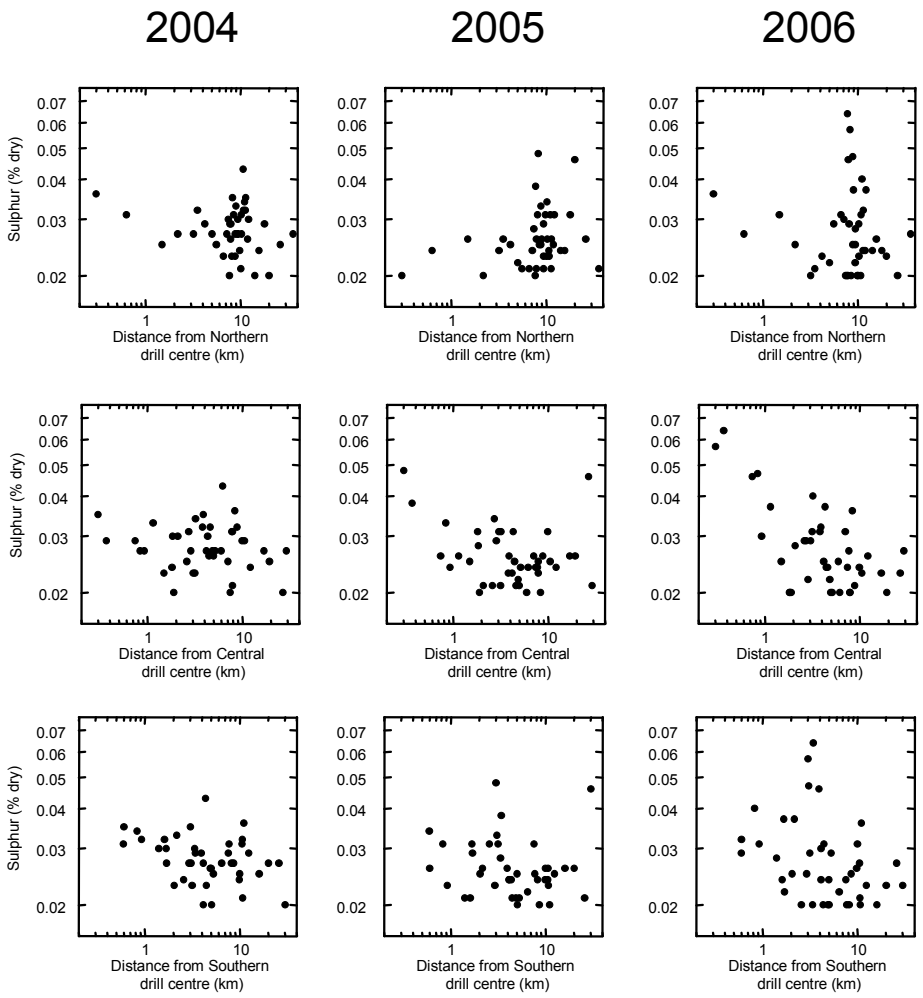


Figure 5-24 Sulphur Concentrations versus Distance from the Three Drill Centres for 42 Stations Sampled in 2004, 2005 and 2006

The sulphur centroid moved substantially north and west between 2004 and 2005 (Figure 5-25) primarily due to the reversal in the distance gradient for the Northern drill centre (Figure 5-24). In 2006, the centroid was south and east of the sampling centroid, reflecting elevated values near the Central and Southern drill centres. Mean sulphur concentrations have been stable over time, since recent high concentrations have occurred at relatively few stations near the Central drill centre.

Overall, sulphur should be regarded as a secondary tracer of drilling activity. Sulphur is an important constituent of barite (barium sulphate) in drilling muds and there was strong evidence of sulphur contamination near the Central drill centre after drilling began there. However, evidence of contamination from the Southern and especially Northern drill centres has been more equivocal, and sulphur has generally been statistically and analytically more problematic than barium, the other constituent of barite.

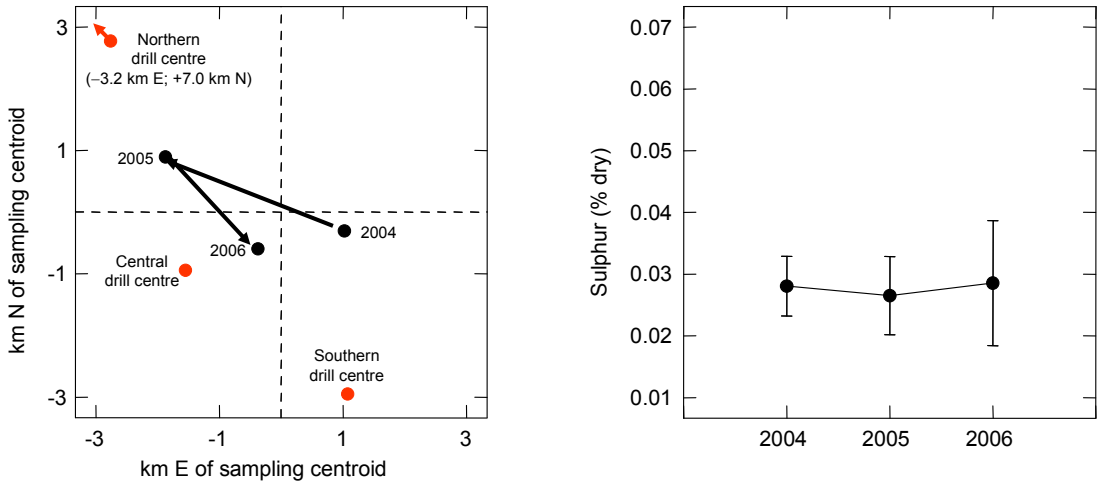


Figure 5-25 Sulphur Centroids and Changes in Concentrations Over Time for 42 Stations Sampled in 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

Carry-over Effects

Results of tests of carry-over effects (Error 1) or persistent differences over time unrelated to depth or distances from drill centres (i.e., *X* variables) from Tables 5-13 and 5-14 are summarized in Table 5-17. Carry-over effects can represent localized persistent and localized natural spatial differences, or persistent and localized differences in project-related contamination not "captured" by regressions on depth and distances (lack-of-fit). Based on the results in Table 5-17, the latter (i.e., lack-of-fit to regressions, especially distance regressions) appears to be the most important source of carry-over effects. Carry-over effects were greater for variables more closely associated with drilling and drilling muds (i.e., barium, $>C_{10}$-C_{21} HCs and sulphur), and for the three post-drilling years. TOC is an exception, with significant persistence of apparently natural spatial differences occurring over a narrow range of values (0.8 to 1.0 g/kg for most stations).

Table 5-17 Carry-over Effects for Sediment Physical and Chemical Characteristics (2000, 2004, 2005, 2006)

Variable	*F* Values for Error 1	
	All Years (2000, 2004 to 2006)	EEM Years (2004 to 2006)
Barium	2.18**	**3.90*** **
$>C_{10}$-C_{21} HCs	Not tested	**5.62*** **
Fines	1.58*	1.52
TOC	1.48	2.30**
Metals PC1	0.95	1.05
Ammonia	Not tested	0.84
Sulphur	Not tested	2.23**

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Carry-over effects are persistent differences among stations unrelated to depth or distance (Among Stations Error 1 in RM models)

5.4.2 Toxicity

In 2006, as in other years (Husky Energy 2001; 2005; 2006), all Microtox IC_{50s} were greater than the highest concentration tested (98,600 mg/L; 197,000 mg/L in 2004 to 2006), indicating that there were no toxic effects on luminescent bacteria. Analysis results for 2006 are provided in Appendix B-6.

In all four sample years, amphipod survival in toxicity tests in most or all sediment samples was greater than 80%, and often greater than 90% (Table 5-18, Appendix B-7). Therefore, most stations would be suitable References as defined by Environment Canada protocols (Environment Canada 1998). In 2005, sediment from station 9 was toxic to amphipods (survival = 28%), and survival in sediment from station N3 (survival = 68%) was lower than in other samples. In 2006, survival in sediment samples from stations 13 and S2 was less than 50% and the sediments were classified as "toxic". Amphipod survival in sediment samples from station 23 was 66% and classified as toxic when compared to Reference Stations. Survival was also low (69%) in sediment from station 16.

Table 5-18 Amphipod Toxicity Trials Summary Data and Interpretation

Distance (km) to Nearest Active Drill Centre	Station	Year	Amphipod Survival (%)	Sample Standard Deviation	Comparison to Laboratory Controls				Comparison to Reference Stations			
					Dunnett's t-stat	Statistically Significant	∃ 30% Reduction in Survival	Interpretation (Toxic / Nontoxic)	Dunnett's t-stat	Statistically Significant	∃ 20% Reduction in Survival	Interpretation (Toxic / Nontoxic)
0.2995	N4	2000	NS									
		2004	89	6.29	2.675	Yes	No	Nontoxic	0.931	No	No	Nontoxic
		2005	93	8.2	–1.49	No	No	Nontoxic	1.463	No	No	Nontoxic
		2006	93	5.7	1.016	No	No	Nontoxic	–0.891	No	No	Nontoxic
0.3012	C5	2000	NS									
		2004	85	4.08	3.969	Yes	No	Nontoxic	1.945	No	No	Nontoxic
		2005	94	5.8	0.84	No	No	Nontoxic	2.716	No	No	Nontoxic
		2006	95	5.77	–0.406	No	No	Nontoxic	–1.279	No	No	Nontoxic
0.3163	S5	2000	NS									
		2004	74	4.79	7.033	Yes	No	Nontoxic	4.645	No	No	Nontoxic
		2005	NS			No	No					
		2006	83	2.89	1.581	No	No	Nontoxic	1.779	No	No	Nontoxic
0.3678	20	2000	97	2.7	0.3	No	No	Nontoxic				
		2004	94	4.79	1.654	No	No	Nontoxic	0.565	No	No	Nontoxic
		2005	92	9.3	1.11	No	No	Nontoxic	2.039	No	No	Nontoxic
		2006	93	8.37	–0.125	No	No	Nontoxic	0.339		No	Nontoxic
0.5943	13	2000	93	5.7	0.23	No	No	Nontoxic				
		2004	88	5	3.349	Yes	No	Nontoxic	1.543	No	No	Nontoxic
		2005	95	5.5	–2.49	No	No	Nontoxic	2.576	No	No	Nontoxic
		2006	**34**	**33.99**	**6.664**	**Yes**	**Yes**	**Toxic**	**9.084**	**Yes**	**Yes**	**Toxic**
0.6001	S1	2000	92	5.7	1.81	No	No	Nontoxic				
		2004	79	4.79	4.85	Yes	No	Nontoxic	3.584	Yes	No	Nontoxic
		2005	83	2.1	0.57	No	No	Nontoxic	0.71	No	No	Nontoxic
		2006	89	7.5	0.862	No	No	Nontoxic	0.124	No	No	Nontoxic
0.6286	N3	2000	90	5	1.92	No	No	Nontoxic				
		2004	90	9.35	2.527	Yes	No	Nontoxic	0.443	No	No	Nontoxic
		2005	68	39.1	0.95	No	No	Nontoxic	2.527	No	No	Nontoxic
		2006	91	9.62	1.524	No	No	Nontoxic	–0.382	No	No	Nontoxic
0.7376	C3	2000	81	8.9	2.57	No	No	Nontoxic				
		2004	95	5.77	1.34	No	No	Nontoxic	0.969	No	No	Nontoxic
		2005	98	2.7	–0.3	No	No	Nontoxic	4.176	Yes	No	Nontoxic

Distance (km) to Nearest Active Drill Centre	Station	Year	Amphipod Survival (%)	Sample Standard Deviation	Comparison to Laboratory Controls				Comparison to Reference Stations			
					Dunnett's t-stat	Statistitically Significant	∃ 30% Reduction in Survival	Interpretation (Toxic / Nontoxic)	Dunnett's t-stat	Statistitically Significant	∃ 20% Reduction in Survival	Interpretation (Toxic / Nontoxic)
0.7376	C3	2006	86	4.79	1.369	No	No	Nontoxic	0.756	No	No	Nontoxic
0.8250	S2	2000	94	4.2	1.21	No	No	Nontoxic				
		2004	89	6.29	3.014	Yes	No	Nontoxic	1.016	No	No	Nontoxic
		2005	89	7.4	–0.72	No	No	Nontoxic	0.649	No	No	Nontoxic
		2006	**29**	**10.25**	**10.219**	**Yes**	**Yes**	**Toxic**	**10.931**	**Yes**	**Yes**	**Toxic**
0.8343	C2	2000	96	4.2	0.67	No	No	Nontoxic				
		2004	86	7.5	3.638	Yes	No	Nontoxic	1.511	No	No	Nontoxic
		2005	93	4.1	1.37	No	No	Nontoxic	2.742	Yes	No	Nontoxic
		2006	83	6.45	2.13	No	No	Nontoxic	1.627	No	No	Nontoxic
0.9204	C4	2000	93	9.8	0.61	No	No	Nontoxic				
		2004	91	4.79	3.344	Yes	No	Nontoxic	0.269	No	No	Nontoxic
		2005	89	7.4	1.87	No	No	Nontoxic	0.961	No	No	Nontoxic
		2006	90	4.08	0.609	No	No	Nontoxic	–0.116	No	No	Nontoxic
0.9220	S4	2000	88	7.6	1.4	No	No	Nontoxic				
		2004	93	6.45	1.712	No	No	Nontoxic	0.213	No	No	Nontoxic
		2005	91	9.7	–1.17	No	No	Nontoxic	1.783	No	No	Nontoxic
		2006	86	10.31	1.016	No	No	Nontoxic	0.536	No	No	Nontoxic
1.1424	C1	2000	87	8.3	1.63	No	No	Nontoxic				
		2004	91	4.79	2.315	No	No	Nontoxic	0.249	No	No	Nontoxic
		2005	97	4.1	0	No	No	Nontoxic	4.343	Yes	No	Nontoxic
		2006	89	6.29	0.862	No	No	Nontoxic	0.163	No	No	Nontoxic
1.4020	S3	2000	91	6.5	0.7	No	No	Nontoxic				
		2004	89	6.29	2.976	Yes	No	Nontoxic	1,016	No	No	Nontoxic
		2005	86	5.4	–0.04	No	No	Nontoxic	0.137	No	No	Nontoxic
		2006	76	5.06	2.522	Yes	No	Nontoxic	2.185	No	No	Nontoxic
1.4864	16	2000	92	7.6	1.44	No	No	Nontoxic				
		2004	84	2.5	3.709	Yes	No	Nontoxic	2.627	No	No	Nontoxic
		2005	93	5.2	1.2	No	No	Nontoxic	2.821	Yes	No	Nontoxic
		2006	69	6.29	2.877	Yes	No	Nontoxic	2.981	Yes	No	Nontoxic
1.4879	N2	2000	91	8.9	2.89	Yes	No	Nontoxic				
		2004	98	5	0.529	No	No	Nontoxic	1.825	No	No	Nontoxic
		2005	94	3.8	0.99	No	No	Nontoxic	3.089	Yes	No	Nontoxic
		2006	93	10.37	1.016	No	No	Nontoxic	–0.891	No	No	Nontoxic
1.6074	9	2000	94	6.5	1.21	No	No	Nontoxic				
		2004	94	4.79	0.953	No	No	Nontoxic	0.487	No	No	Nontoxic
		2005	**28**	**21.9**	**3.37**	**Yes**	**Yes**	**Toxic**	**11.44**	**Yes**	**Yes**	**Toxic**
		2006	91	4.79	0.443	No	No	Nontoxic	–0.753	No	No	Nontoxic
1.6693	14	2000	97	4.5	0.26	No	No	Nontoxic				
		2004	91	8.54	1.997	No	No	Nontoxic	0.087	No	No	Nontoxic
		2005	83	4.2	0.87	No	No	Nontoxic	0.967	No	No	Nontoxic
		2006	84	4.79	1.312	No	No	Nontoxic	0.688	No	No	Nontoxic
1.6979	8	2000	86	8.2	1.87	No	No	Nontoxic				
		2004	89	8.54	1.88	No	No	Nontoxic	0.75	No	No	Nontoxic
		2005	88	6.8	–0.76	No	No	Nontoxic	0.573	No	No	Nontoxic
		2006	88	2.89	1.392	No	No	Nontoxic	0.188	No	No	Nontoxic
1.8082	17	2000	91	8.9	1.68	No	No	Nontoxic				
		2004	91	6.3	2.344	No	No	Nontoxic	0.231	No	No	Nontoxic
		2005	92	5.2	1.79	No	No	Nontoxic	2.068	No	No	Nontoxic
		2006	93	2.89	0.113	No	No	Nontoxic	–0.65	No	No	Nontoxic
1.8379	23	2000	89	11.4	2.3	No	No	Nontoxic				
		2004	90	4.08	2.282	No	No	Nontoxic	0.74	No	No	Nontoxic
		2005	88	2.7	3.09	yes	No	Nontoxic	0.229	No	No	Nontoxic
		2006	**66**	**6.52**	**4.797**	**yes**	**No**	**Nontoxic**	**5.304**	**Yes**	**Yes**	**Toxic**
1.8910	21	2000	93	6.7	0.23	No	No	Nontoxic				
		2004	88	6.45	3.307	Yes	No	Nontoxic	1.388	No	No	Nontoxic
		2005	95	5.5	–0.62	No	No	Nontoxic	2.558	No	No	Nontoxic

Distance (km) to Nearest Active Drill Centre	Station	Year	Amphipod Survival (%)	Sample Standard Deviation	Comparison to Laboratory Controls				Comparison to Reference Stations			
					Dunnett's t-stat	Statistitically Significant	∃ 30% Reduction in Survival	Interpretation (Toxic / Nontoxic)	Dunnett's t-stat	Statistitically Significant	∃ 20% Reduction in Survival	Interpretation (Toxic / Nontoxic)
1.8910	21	2006	88	8.66	0.921	No	No	Nontoxic	0.412	No	No	Nontoxic
2.1801	N1	2000	97	4.5	0.3	No	No	Nontoxic				
		2004	94	7.5	1.956	No	No	Nontoxic	0.658	No	No	Nontoxic
		2005	88	14.4	1.76	No	No	Nontoxic	1.099	No	No	Nontoxic
		2006	93	5.7	1.016	No	No	Nontoxic	–0.891	No	No	Nontoxic
2.5951	24	2000	99	2.2	–0.24	No	No	Nontoxic				
		2004	93	7.5	1.173	No	No	Nontoxic	0.611	No	No	Nontoxic
		2005	95	4	0.68	No	No	Nontoxic	3.562	Yes	No	Nontoxic
		2006	87	10.95	1.066	No	No	Nontoxic	0.596	No	No	Nontoxic
2.5962	W7	2006	85	4.08	1.327	No	No	Nontoxic	1.144	No	No	Nontoxic
2.7131	W6	2006	84	7.5	1.534	No	No	Nontoxic	1.462	No	No	Nontoxic
2.9188	5	2000	96	6.5	0.6	No	No	Nontoxic				
		2004	90	3.54	1.649	No	No	Nontoxic	0.716	No	No	Nontoxic
		2005	98	2.6	–0.65	No	No	Nontoxic	5.156	Yes	No	Nontoxic
		2006	93	2.88	0.127	No	No	Nontoxic	–1.066	No	No	Nontoxic
3.0334	1	2000	97	4.5	0.34	No	No	Nontoxic				
		2004	91	10.3	1.939	Yes	No	Nontoxic	0.014	No	No	Nontoxic
		2005	88	8	2.17	No	No	Nontoxic	0.493	No	No	Nontoxic
		2006	83	9.08	2.684	Yes	No	Nontoxic	1.443	No	No	Nontoxic
3.1564	28	2000	94	4.2	1.02	No	No	Nontoxic				
		2004	89	4.18	2.431	Yes	No	Nontoxic	0.942	No	No	Nontoxic
		2005	93	9.8	0.92	No	No	Nontoxic	3.187	Yes	No	Nontoxic
		2006	87	10.37	1.291	No	No	Nontoxic	0.596	No	No	Nontoxic
3.1801	25	2000	88	11.5	2.4	No	No	Nontoxic				
		2004	96	5.48	1.185	No	No	Nontoxic	1.333	No	No	Nontoxic
		2005	98	2.6		No	No	Nontoxic	4.329	Yes	No	Nontoxic
		2006	90	7.07	1.901	No	No	Nontoxic	–0.119	No	No	Nontoxic
3.5209	30	2000	97	2.7	0.96	No	No	Nontoxic				
		2004	92	12.6	0.837	No	No	Nontoxic	0.419	No	No	Nontoxic
		2005	82	5.2	0.98	No	No	Nontoxic	0.848	No	No	Nontoxic
		2006	95	5	0.543	No	No	Nontoxic	–1.311	No	No	Nontoxic
3.5261	W8	2006	83	6.45	1.742	No	No	Nontoxic	1.485	No	No	Nontoxic
3.5542	W14	2006	89	2.24	2.032	No	No	Nontoxic	0.116	No	No	Nontoxic
3.6966	W2	2006	91	6.29	0.263	No	No	Nontoxic	–0.445	No	No	Nontoxic
3.7499	W5	2006	90	3.54	1.778	No	No	Nontoxic	–0.139	No	No	Nontoxic
4.1243	W1	2006	86	6.29	1.016	No	No	Nontoxic	0.826	No	No	Nontoxic
4.1361	10	2000	95	5	1.01	No	No	Nontoxic				
		2004	89	6.29	3.014	Yes	No	Nontoxic	1.085	No	No	Nontoxic
		2005	82	11.3	–0.48	No	No	Nontoxic	0.829	No	No	Nontoxic
		2006	96	2.5	–0.822	No	No	Nontoxic	–1.223	No	No	Nontoxic
4.1940	31	2000	NS									
		2004	89	7.42	2.811	Yes	No	Nontoxic	0.784	No	No	Nontoxic
		2005	91	5.8	–1.28	No	No	Nontoxic	0.946	No	No	Nontoxic
		2006	97	4.47	0	No	No	Nontoxic	–1.788	No	No	Nontoxic
4.2332	W10	2006	81	6.52	2.927	Yes	No	Nontoxic	1.975	No	No	Nontoxic
4.3297	W9	2006	86	17.02	1.12	No	No	Nontoxic	0.689	No	No	Nontoxic
4.3553	6	2000	97	2.7	0.3	No	No	Nontoxic				
		2004	94	4.18	0.977	No	No	Nontoxic	0.601	No	No	Nontoxic
		2005	94	4.9	0.89	No	No	Nontoxic	3.168	Yes	No	Nontoxic
		2006	88	2.89	1.392	No	No	Nontoxic	0.188	No	No	Nontoxic
4.3757	W3	2006	93	8.66	0.075	No	No	Nontoxic	–0.763	No	No	Nontoxic
4.4355	18	2000	98	4.5	0	No	No	Nontoxic				
		2004	93	2.74	1.822	No	No	Nontoxic	0.254	No	No	Nontoxic
		2005	84	4.9	0.38	No	No	Nontoxic	0.425	No	No	Nontoxic
		2006	98	5	–0.834	No	No	Nontoxic	–1.414	No	No	Nontoxic
4.7496	W4	2006	89	2.5	0.64	No	No	Nontoxic	0.191	No	No	Nontoxic

Distance (km) to Nearest Active Drill Centre	Station	Year	Amphipod Survival (%)	Sample Standard Deviation	Comparison to Laboratory Controls				Comparison to Reference Stations			
					Dunnett's t-stat	Statistitically Significant	∃ 30% Reduction in Survival	Interpretation (Toxic / Nontoxic)	Dunnett's t-stat	Statistitically Significant	∃ 20% Reduction in Survival	Interpretation (Toxic / Nontoxic)
4.7680	W11	2006	85	7.46	1.951	No	No	Nontoxic	1.046	No	No	Nontoxic
4.8313	29	2000	93	10.3	1.28	No	No	Nontoxic				
		2004	89	5.48	4.056	Yes	No	Nontoxic	0.909	No	No	Nontoxic
		2005	94	4.9	0.69	No	No	Nontoxic	2.65	No	No	Nontoxic
		2006	83	11.9	2.13	No	No	Nontoxic	1.523	No	No	Nontoxic
4.8824	2	2000	97	2.7	0.03	No	No	Nontoxic				
		2004	91	6.52	1.939	No	No	Nontoxic	0.28	No	No	Nontoxic
		2005	92	4.1	1.88	No	No	Nontoxic	1.982	No	No	Nontoxic
		2006	80	7.07	3.489	Yes	No	Nontoxic	2.267	No	No	Nontoxic
5.5192	W12	2006	80	8.16	2.99	Yes	No	Nontoxic	2.015	No	No	Nontoxic
6.0694	W13	2006	86	4.79	1.552	No	No	Nontoxic	0.689	No	No	Nontoxic
7.5677	15	2000	96	4.2	0.51	No	No	Nontoxic				
		2004	95	4.08	1.481	No	No	Nontoxic	1.047	No	No	Nontoxic
		2005	83	6.1	0.61	No	No	Nontoxic	0.729	No	No	Nontoxic
		2006	90	4.08	0.487	No	No	Nontoxic	–0.267	No	No	Nontoxic
7.6905	3	2000	94	5.5	1.35	No	No	Nontoxic				
		2004	75	14.1	5.451	Yes	No	Nontoxic	3.742	Yes	No	Nontoxic
		2005	94	4.9	0.9	No	No	Nontoxic	3.156	Yes	No	Nontoxic
		2006	81	9.46	2.973	Yes	No	Nontoxic	1.756	No	No	Nontoxic
7.8851	22	2000	99	2.2	–0.34	No	No	Nontoxic				
		2004	93	5	1.458	No	No	Nontoxic	0.139	No	No	Nontoxic
		2005	98	2.6	–0.47	No	No	Nontoxic	4.329	Yes	No	Nontoxic
		2006	90	11.73	0.533	No	No	Nontoxic	–0.113	No	No	Nontoxic
9.8398	7	2000	95	5	0.91	No	No	Nontoxic				
		2004	95	4.08	0.721	No	No	Nontoxic	0.866	No	No	Nontoxic
		2005	82	8.2	0.95	No	No	Nontoxic	1.051	No	No	Nontoxic
		2006	88	5.7	2.444	No	No	Nontoxic	0.069	No	No	Nontoxic
10.2652	26	2000	95	3.5	0.78	No	No	Nontoxic				
		2004	87	8.37	3.38	Yes	No	Nontoxic	1.255	No	No	Nontoxic
		2005	82	9.8	0.79	No	No	Nontoxic	0.767	No	No	Nontoxic
		2006	94	5.48	0.815	No	No	Nontoxic	–1.073	No	No	Nontoxic
16.0034	11	2000	96	4.2	0.51	No	No	Nontoxic				
		2004	99	2.24	1.776	No	No	Nontoxic	2.947	yes	No	Nontoxic
		2005	90	3.4	–0.94	No	No	Nontoxic	1.174	No	No	Nontoxic
		2006	98	4.47	–0.272	No	No	Nontoxic	–1.633	No	No	Nontoxic
20.0307	27	2000	NS									
		2004	90	7.07	2.345	No	No	Nontoxic				
		2005	90	6.3	–1.2	No	No	Nontoxic				
		2006	97	4.47	0	No	No	Nontoxic				
25.8531	12	2000	NS									
		2004	88	8.37	3.37	Yes	No	Nontoxic				
		2005	87	5.2	–0.23	No	No	Nontoxic				
		2006	83	2.74	3.803	Yes	No	Nontoxic				
26.1679	19	2000	NS									
		2004	99	2.24	0	No	No	Nontoxic				
		2005	83	6.1	0.61	No	No	Nontoxic				
		2006	88	7.58	0.732	No	No	Nontoxic				
26.1886	4	2000	NS									
		2004	94	2.24	2.005	No	No	Nontoxic				
		2005	85	4.5	0.24	No	No	Nontoxic				
		2006	85	10.61	3.259	Yes	No	Nontoxic				

Note - NS = Not Sampled

Over all 59 stations sampled in 2006, amphipod survival increased significantly with distances from the Central and Southern drill centres and was uncorrelated with

sediment physical and chemical characteristics (Table 5-19). The four stations (stations 13, 16, 23 and S2) with low survival were closer to either or both the Central and Southern drill centres than most other stations, with higher barium and >C_{10}-C_{21} HC concentrations (Table 5-20). However, except for the low redox levels at station 23, these four stations did not represent extreme values (i.e., minima or maxima) of any physical or chemical characteristic. There were other more contaminated stations closer to drill centres where survival was high. Survival was also greater than 90% in 2006 at stations 9 and N2, where it was low in 2005.

Table 5-19 Spearman Rank Correlations (r_s) Between Amphipod Survival, Distances from the Drill Centres and Sediment Physical and Chemical Characteristics (2006)

Variable	Correlation (r_s) with amphipod survival
Distance from:	
Northern drill centre	−0.111
Central drill centre	0.336*
Southern drill centre	0.376**
Nearest drill centre	0.075
Barium	−0.234
>C_{10}–C_{21} HCs	−0.191
% fines	−0.081
TOC	0.048
Metals PC1	−0.157
Ammonia	−0.198
Sulphide	−0.180
Sulphur	−0.000
Redox	0.210

Note: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)

Table 5-20 Comparison of Distances from Drill Centres and Sediment Physical and Chemical Characteristics Between All Stations versus the Stations with the Lowest Amphipod Survival (2006)

Variable	Minimum	Maximum	Median	Station 13	Station 16	Station 23	Station S2
Amphipod survival (%)	29	98	87.5	34	68.75	66	29
Distance (km) from:							
Northern drill centre	0.30	36.00	8.26	10.22	8.79	7.43	11.02
Central drill centre	0.30	29.67	4.38	2.72	1.49	1.84	3.21
Southern drill centre	0.32	30.00	5.99	0.59	2.04	3.35	0.83
Nearest drill centre	0.30	26.19	3.18	0.59	1.49	1.84	0.83
Barium (mg/kg)	110	3,300	170	350	200	220	770
>C_{10}–C_{21} HCs (mg/kg)	<0.3	570	0.7	19	7.7	0.6	25
% fines	0.5	3.0	1.3	1.6	1.1	1.7	1.5
TOC (g/kg)	0.4	1.2	0.8	0.9	0.8	0.8	1.0
Metals PC1	−1.68	4.13	0.06	0.54	0.33	0.52	2.26
Ammonia (mg N/kg)	1.9	9.6	3.2	2.7	2.9	3.1	3.8
Sulphur (%)	0.007	0.066	0.025	0.029	0.025	0.020	0.040
Sulphide (mg/kg)	0.2	20.7	0.5	2.5	0.9	0.3	0.6
Redox (mV)	106	308	203	172	129	106	195

5.4.3 Benthic Community Structure

A total of 28,505 invertebrates were collected from 59 stations in 2006, with mean abundances per station lower than in 2000 but higher than in 2004 and 2005 (Table 5-21). The totals exclude nemerteans, nematodes, oligochaetes, ostracods and copepods. Over all four years, 117 "families" were collected. Some families were not taxonomic families, but represented individuals that could not be identified to family (e.g., Bivalvia unidentified), or higher taxonomic levels (e.g., phyla, class or order) that were not identified to lower levels. Raw data for benthic community structure are provided in Appendix B-4.

Table 5-21 Taxonomic Composition of Benthic Invertebrate Community Samples (2000, 2004, 2005 and 2006)

Phylum or subphylum	Class or order	No. families	2006 (EEM) (*n*=59 stations)		2005 (EEM) (*n*=44 stations)		2004 (EEM) (*n*=56 stations)		2000 (baseline) (*n*=46 stations)	
			No.	% of total	No.	% of total	No.	% of total	No.	% of total
Porifera		1	1	0.00	3	0.02	15	0.06	0	0.00
Cnidaria		6	16	0.06	24	0.15	160	0.63	13	0.04
Sipuncula		1	0	0.00	1	0.01	0	0.00	0	0.00
Platyhelminthes	Turbellaria	1	3	0.01	0	0.00	0	0.00	0	0.00
Annelida	Polychaeta	31	22,193	77.86	11,395	72.37	18,907	74.41	26,594	77.12
Mollusca	Total	42	4,057	14.23	2,939	18.67	4,368	17.19	5,932	17.20
	Aplacophora	1	1	0.00	0	0.00	0	0.00	0	0.00
	Bivalvia	21	3,955	13.87	2,870	18.23	4,290	16.88	5,859	16.99
	Gastropoda	20	101	0.35	69	0.44	78	0.31	73	0.21
Crustacea	Total	26	1,795	6.30	1,048	6.66	1,543	6.07	1,427	4.14
	Amphipoda	14	709	2.49	427	2.71	737	2.90	1,184	3.43
	Cirrepedia	1	21	0.07	20	0.13	2	0.01	13	0.04
	Cumacea	5	32	0.11	25	0.16	44	0.17	19	0.06
	Decapoda	1	2	0.01	0	0.00	0	0.00	1	0.00
	Isopoda	4	171	0.60	85	0.54	46	0.18	16	0.05
	Tanaidacea	1	860	3.02	491	3.12	714	2.81	194	0.56
Echinodermata		6	430	1.51	333	2.11	416	1.64	517	1.50
Urochordata	Ascidiacea	3	10	0.04	2	0.01	0	0.00	0	0.00
Total		117	28,505	100	15,745	100	25,409	100	34,483	100
Mean/station			483		358		454		750	

Note - Numbers represent results over all stations

In all four years, polychaetes accounted for more than 70% of the invertebrates collected, and bivalves accounted for 14 to 18% (Table 5-21). Therefore, these two higher-level (major) taxa accounted for 90% or more of the invertebrates collected. Amphipoda, Tanaidacea and Echinodermata were the only other major taxa accounting for more than 1% of total abundance in one or more years. Polychaetes and bivalves accounted for 52 of the 117 families collected. Twenty (20) families of the relatively rare Gastropoda, and 14 families of Amphipoda, were collected.

Table 5-22 lists all families that represented 1% or more of the total number of organisms collected in one or more years. The families are listed in descending order of abundance in 2006. In all four years, polychaetes in the family Spionidae (primarily *Prionospio steenstrupi*), were the most abundant (dominant) family (Table 5-22). Bivalves of the family Tellinidae (primarily *Macoma calcarea*, although juveniles can be difficult to identify to species) and polychaetes of the family Paraonidae (primarily *Aricidea catherinae*) were the second and third most abundant families. With these three

families accounting for 60 to 70% of the organisms collected each year, and dominated by a single species (also true for many sub-dominant families), diversity was limited.

Relative (%) abundances of most sub-dominants listed in Table 5-22 were similar among years. However, there were large differences in abundances among years for some families. Cirratulidae (primarily *Chaetozone setosa*) were abundant in 2000 but not in subsequent years. Dexaminidae (*Guernea nordenskioldi*) were collected in 2000, 2004 and 2006 but not in 2005. Carditidae (*Cyclocardia* spp.) were collected only in 2000. These differences do not appear to be taxonomic/taxonomist artifacts, since both taxonomists have easily identified these taxa when they occurred in the White Rose or Terra Nova monitoring programs. Instead, year-to-year climate (e.g., cumulative degree-days at time of sampling) and other natural differences among years may affect abundances of seasonal and short-lived taxa, despite a relatively fixed calendar sampling time. Differences among years in the set of stations sampled will also affect the numbers of some taxa that were only abundant at one or a few stations.

5.4.3.1 Preliminary Analysis

Non-Metric Multidimensional Scaling

Figure 5-26 provides the two-dimensional NMDS plot based on relative abundances of invertebrate families for the all 205 stations sampled in 2000, 2004, 2005 and 2006. Samples (stations) are colour-coded based on distance from the nearest active drill centre, with the Northern and Southern drill centres active in 2004 (and treated as "active" in 2000) and the Central drill centre also active in 2005 and 2006. The stress coefficient was 0.175, which represents a reasonable fit to the original pair-wise B-C distance matrix for most samples (Clarke 1993). However, the NMDS plots were less effective at reproducing distances among extreme samples (outliers) in time or space, other than to indicate that those samples were different from other samples.

The NMDS plots in Figure 5-26 were rotated to principal axes, maximizing variance over all stations and years along NMDS1. Rotation to principal axes is a useful approach for identifying primary patterns of variance in community composition, and also generates two independent or uncorrelated variables (NMDS1 and NMDS2 scores) for other analyses. However, the plots can be rotated in any direction without altering distances between stations, which may be useful for other purposes (see below).

NMDS1 scores were positively correlated with relative abundances of all Polychaeta combined (% Polychaeta) (r_s = 0.80) and negatively correlated with % Bivalvia (r_s = −0.81). Therefore, NMDS1 (the primary axis of variance in community composition) can be considered a general measure of polychaete dominance or Polychaeta:Bivalvia dominance. Differences in NMDS2 scores reflected secondary variance within Polychaeta (e.g., between Spionidae versus Paraonidae), and among other sub-dominants and lesser taxa. NMDS2 scores were also positively correlated with relative abundances of Cirratulidae (Polychaeta) and Carditidae (Bivalvia), two taxa abundant only in 2000.

The text above provides generalizations useful for interpreting results for the two NMDS axes. However, with more than 100 taxa collected over four years, there are many exceptions to those generalizations and overall differences in community composition should also be considered. These overall differences can be assessed visually using distances among stations in the two-dimensional plots in Figure 5-26.

Table 5-22 Dominant Benthic Invertebrate Families (2000, 2004, 2005 and 2006)

Major taxon	Family	2006				2005				2004				2000			
		Abundance		Occurrence		Abundance		Occurrence		Abundance		Occurrence		Abundance		Occurrence	
		No. organisms	%of total	No. stations	% of total	No. organisms	%of total	No. stations	% of total	No. organisms	%of total	No. stations	% of total	No. organisms	%of total	No. stations	% of total
Polychaeta	Spionidae	10,155	35.6	59	100	5,736	36.4	44	100	9,462	37.2	56	100	12,812	37.15	46	100
Polychaeta	Paraonidae	5,892	20.7	56	95	2,307	14.7	41	93	5,004	19.7	56	100	5,020	14.56	46	100
Bivalvia	Tellinidae	3,413	12.0	59	100	2,456	15.6	44	100	3,784	14.9	56	100	4,616	13.39	46	100
Polychaeta	Phyllodocidae	1,717	6.0	58	98	454	2.9	44	100	745	2.9	56	100	1,153	3.34	46	100
Polychaeta	Orbiinidae	1,639	5.7	48	81	849	5.4	35	80	1,472	5.8	53	95	1,565	4.54	46	100
Tanaidacea		860	3.0	58	98	491	3.1	41	93	714	2.8	54	96	194	0.56	44	96
Polychaeta	Maldanidae	593	2.1	59	100	356	2.3	42	95	431	1.7	55	98	405	1.17	46	100
Polychaeta	Syllidae	499	1.8	46	78	353	2.2	33	75	524	2.1	52	93	312	0.90	44	96
Polychaeta	Capitellidae	397	1.4	57	97	195	1.2	41	93	229	0.9	50	89	232	0.67	45	98
Amphipoda	Dexaminidae	343	1.2	53	90	0	0.0	0	0	259	1.0	51	91	176	0.51	41	89
Echinodermata	Echinarachnidae	303	1.1	58	98	221	1.4	40	91	296	1.2	55	98	348	1.01	46	100
Polychaeta	Cirratulidae	175	0.6	31	53	320	2.0	29	66	257	1.0	32	57	4,412	12.79	46	100
Amphipoda	Phoxocephalidae	170	0.6	40	68	150	1.0	25	57	182	0.7	43	77	269	0.78	43	93
Bivalvia	Hiatellidae	144	0.5	53	90	79	0.5	34	77	136	0.5	48	86	328	0.95	44	96
Amphipoda	Haustoriidae	48	0.2	19	32	54	0.3	20	45	227	0.9	50	89	641	1.86	46	100
Bivalvia	Carditidae	0	0.0	0	0	0	0.0	0	0	0	0.0	0	0	443	1.28	42	91

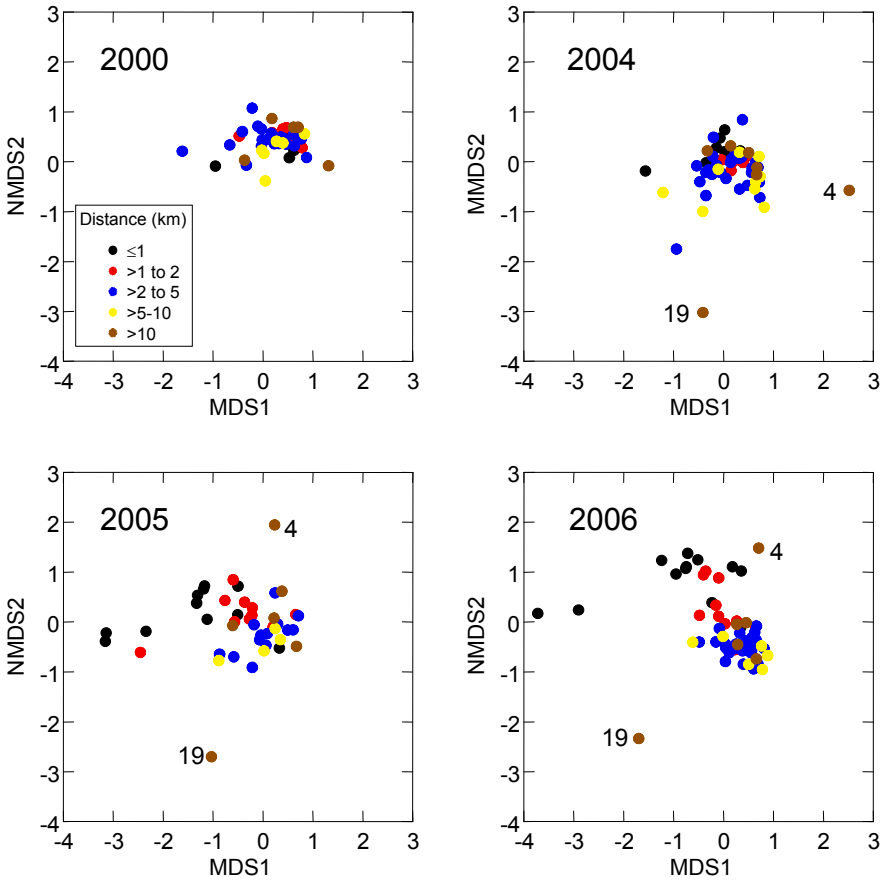


Figure 5-26 NMDS Plots Based on Relative (%) Abundances of Invertebrate Taxa (2000, 2004, 2005 and 2006)

Note: - Distances are distances to the nearest active drill centre (Northern and Southern in 2004; Northern, Central and Southern in 2005 and 2006). For 2000, the Northern and Southern drill centres were considered "active".

Benthic invertebrate communities were similar among stations in 2000, as indicated by the limited variance in NMDS1 and NMDS2 scores, and tight clustering of stations, in Figure 5-26. In 2004, most stations were again tightly clustered, with the few outliers representing a range of distances. In 2005 and 2006, communities at some or most stations within 2 km of drill centres (black and red circles) differed more from communities at more distant stations (i.e., moved away from the central cluster). This separation has occurred along both axes, with NMDS1 scores decreasing and NMDS2 scores increasing at near-field stations (i.e., with near-field stations displaced towards the upper left in NMDS plots in 2005 and 2006).

Communities at Reference Stations 4 and 19, the deepest and shallowest stations, have always differed from communities at other stations. These two stations, which were not sampled in 2000, are the brown outliers in Figure 5-26. Station 19 was the only station at which Cirratulidae were abundant in 2004 to 2006, and NMDS2 scores have consistently been lower there than at other stations. NMDS1 and/or NMDS2 scores for station 4 have generally been higher than at most other stations.

Although stations 4 and 19 were outliers for many analyses, they were useful for indicating the range and type of natural variance in the sampling area. In Figure 5-27, NMDS plots for 2005 and 2006 were rotated clockwise so that stations 4 and 19 defined a horizontal axis of maximum natural variance. Differences between near-field stations within 2 km of drill centres versus more remote or far-field stations were largely vertical or perpendicular to the axis of natural variance. Therefore, the *magnitude* of apparent project effects was within the range of natural differences, but the project effects were of a different *type* (i.e., affected different organisms) than natural effects (probably attributable to the difference in depth and other factors between two stations separated by 60 km).

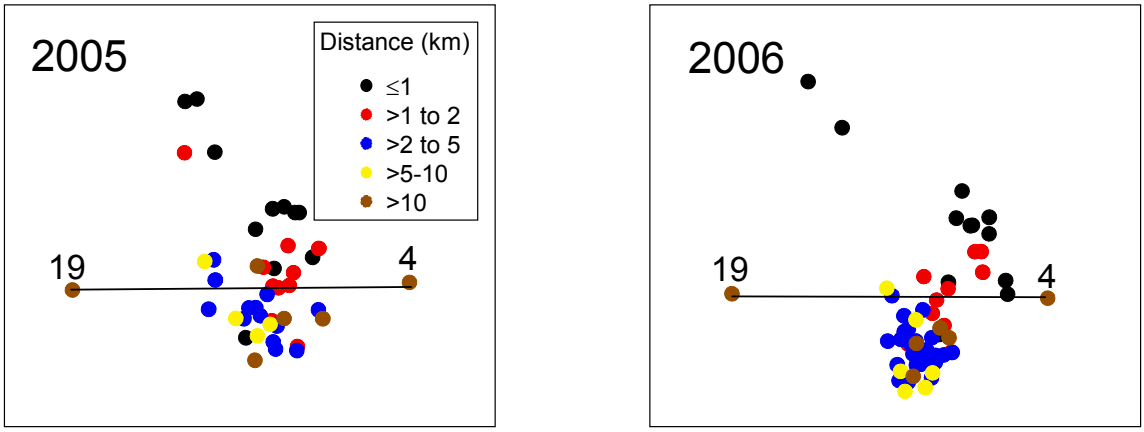


Figure 5-27 NMDS Plots Based on Relative (%) Abundances of Invertebrate Taxa (2005 and 2006), Rotated Clockwise so that Stations 4 and 19 are on a Horizontal Line/Axis

Summary Statistics

Table 5-23 provides summary statistics for invertebrate community summary measures and absolute abundances of selected taxa. Coefficients of Variation (CVs) are not provided for NMDS1 and NMDS2, since scores can be negative or positive and means were close to 0. In 2006, total abundance varied from 210 to 1,047 organisms/station. Standing crop also varied over a 5-fold range, with the same CV (42%). Richness, diversity and evenness were less variable (lower CV) than abundance or biomass. Although more than 20 taxa were collected at most stations, diversity was low (3 to 7 dominant taxa per station). Most stations were dominated by Spionidae, Paraonidae, Tellinidae and a few of the sub-dominants listed in Table 5-22. Consequently, evenness values were also low (i.e., abundances were unevenly distributed among taxa), with the mean and median of 0.18 well below the maximum possible value of 1.

Table 5-23 Summary Statistics for Benthic Invertebrate Community Variables (2006)

Variable	Units	Min	Max	Median	Mean	SD	CV (%)
Summary measures							
Total abundance	No. organisms	210	1,047	454	483	201	42
Standing crop	g wet	58	329	142	156	65	42
Richness (*S*)	No. taxa	18	37	26	26	4	16
Diversity (*D*)	No. dominant taxa	3.2	7.0	4.3	4.6	0.9	20
Evenness (*E*)	*D*/*S*	0.11	0.26	0.18	0.18	0.03	19
NMDS1		–3.72	0.88	0.25	0.01	0.84	
NMDS2		–2.34	1.48	–0.32	–0.10	0.74	
Taxon abundances (No. organisms)							
Paraonidae (Polychaeta)		0	285	95	100	74	74
Spionidae (Polychaeta)		17	495	161	172	87	51
Tellinidae (Bivalvia)		4	158	51	58	32	56
Amphipoda		1	43	10.0	12.0	8.9	74

Notes: - All values were based on pooling two samples per station. Each sample was approximately 0.1 m^2 in surface area
- Richness, diversity, evenness and NMDS scores were based on families

Variances (i.e., CVs) for absolute abundances of individual taxa were greater than for total abundance and other summary measures, and were greater for Paraonidae and Amphipoda than for Spionidae and Tellinidae (Table 5-23). CVs can be high because of natural or project-related variance, but also tend to be higher for less abundant taxa.

5.4.3.2 Correlations Within and Among Groups of Variables (2006)

Correlations Among Invertebrate Community Variables

Table 5-24 provides rank correlations (r_s) among invertebrate community summary measures. These and other correlations among invertebrate community variables presented below were primarily useful for assessing redundancy, since many redundancies were expected for statistical or natural reasons and may not be environmentally meaningful.

Table 5-24 Spearman Rank Correlations (r_s) Among Benthic Invertebrate Community Summary Measures (2006)

	Total abundance	Standing crop	Richness	Diversity	Evenness	NMDS1
Standing crop	0.251					
Richness	**0.700*** **	0.204				
Diversity	0.065	0.270*	0.282*			
Evenness	**–0.460*** **	0.103	–0.425**	**0.703*** **		
NMDS1	0.288*	–0.057	–0.026	–0.298*	–0.216	
NMDS2	–0.164	–0.160	–0.010	–0.234	–0.249	**–0.507*** **

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Richness, diversity, evenness and NMDS scores were based on families

Total abundance was strongly positively correlated with richness (Table 5-24); more taxa will usually be collected when more organisms are collected. Abundance and diversity were uncorrelated, since the most abundant or dominant taxa will usually be collected in most samples (Table 5-22). Richness and diversity were only weakly positively correlated; instead, diversity was more strongly correlated with its other component,

evenness. Despite the reasonably large number of taxa collected per station, diversity was low because abundances were unevenly distributed among those taxa. Evenness (=*D*/*S*) is largely redundant, since it was calculated directly from richness and diversity. Results for evenness could generally be inferred from results for richness and diversity, and these results have generally been "no effects/relationships" (i.e., evenness is insensitive). Standing crop was generally uncorrelated with other summary measures, and typically depends on abundances of larger organisms (e.g., echinoderms). In 2006, the rank correlation between biomass and echinoderm abundance was 0.52; in past years, correlations were 0.39 to 0.48. These correlations were stronger than correlations between standing crop and other biological, physical and chemical variables.

In 2006, total abundance was weakly correlated with NMDS1 and NMDS2 scores (Table 5-24). Conducting NMDS on relative rather than absolute abundances partly to largely removed correlations between the community composition measures and total abundance. Correlations between NMDS scores versus richness, diversity and evenness were negative but weak. In 2006, the rank correlation between NMDS1 and NMDS2 was significantly negative (r_S=–0.507; p<0.001). In contrast, the Pearson r over all 205 stations sampled in four years used for NMDS after rotation to principal axes must be 0, and rank correlations for all 205 stations and within other years were also close to 0.

Table 5-25 provides correlations among absolute abundances of the three dominant families and Amphipoda. All six (6) correlations were positive, indicating the apparently natural tendency of absolute abundances of most taxa to be positively correlated. Correlations among the four taxa in Table 5-25 were also positive for baseline (2000) samples. However, positive correlations could also occur if the four taxa responded similarly to project activity or to natural factors such as depth. The correlations were also low enough (all less than 0.5) that the four variables can be considered at least partly independent (i.e., not highly redundant).

Table 5-25 Spearman Rank Correlations (r_s) Among Abundances of Selected Benthic Invertebrate Taxa (2006)

	Paraonidae	Spionidae	Tellinidae
Spionidae	0.420**		
Tellinidae	0.166	**0.497*** **	
Amphipoda	**0.473*** **	0.424**	0.315*

Note: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)

Total abundance was significantly positively correlated with abundances of the four selected individual taxa (Table 5-26). Positive correlations were expected for the three dominant families (Spionidae, Tellinidae, Paraonidae) since they accounted for 68% of total abundance. Amphipod abundance has also been positively correlated with total abundance in all years, although amphipods account for a minor portion (2 to 3%) of total abundance.

Table 5-26 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Summary Measures and Abundances of Selected Taxa (2006)

	Total abundance	Standing crop	Richness	Diversity	Evenness	NMDS1	NMDS2
Paraonidae	**0.629*** **	0.086	0.282*	0.023	–0.204	**0.754*** **	**–0.667*** **
Spionidae	**0.872*** **	0.132	**0.567*** **	–0.192	**–0.635*** **	0.215	0.214
Tellinidae	**0.580*** **	0.092	**0.444*** **	0.314*	–0.093	–0.332*	0.130
Amphipoda	**0.647*** **	0.226	**0.697*** **	0.302*	–0.213	0.207	–0.309*

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Richness, diversity, evenness and NMDS scores were based on families

Standing crop was uncorrelated with abundances of the four taxa (Table 5-26). The absence of a stronger positive correlation for Tellinidae was surprising, since they were abundant and are relatively large shelled organisms.

Abundances of the four taxa were positively correlated with richness, uncorrelated or weakly positively correlated with diversity and negatively correlated with evenness (Table 5-26). These correlations were qualitatively similar to correlations between total abundance and the three indices (Table 5-24), although there was some variation among the taxa in the strength of the correlations. Specifically, Paraonidae abundances were weakly correlated or uncorrelated with the indices, only Spionidae abundances were significantly negatively correlated with evenness, and abundances of Tellinidae and Amphipoda, but not the two polychaete families, were significantly although weakly positively correlated with diversity.

In 2006, absolute abundances of Paraonidae were strongly positively correlated with NMDS1 scores and strongly negatively correlated with NMDS2 scores (Table 5-26). These correlations were similar to correlations between relative abundances and the two axes (0.754 and −0.598 for NMDS1 and NMDS2, respectively). Absolute and relative abundances of Spionidae were positively correlated with NMDS1 scores although both correlations were weak (0.215 and 0.272, respectively). Absolute and relative abundances of Spionidae were also positively correlated with NMDS2 scores although the correlation was much stronger for relative abundance (0.663 versus 0.214). Absolute and relative abundances of Tellinidae were both negatively correlated with NMDS1 scores, although again the correlation was much stronger for relative abundance (−0.796 versus −0.332). Therefore, the Polychaeta versus Bivalvia contrast and, more specifically, the Paraonidae versus Tellinidae contrast, associated with NMDS1 and the Paraonidae versus Spionidae contrast associated with NMDS2, were much stronger for relative abundances than for absolute abundances. The difference in contrast strength occurred because relative abundances removed much of the positive correlation among absolute abundances of the three dominants. Finally, absolute and relative abundances of Amphipoda were weakly correlated with NMDS scores in 2006 and in past years, which is why these relatively rare but sensitive animals were analyzed separately in 2006 and past years (i.e., analysis of NMDS scores and other summary measures may "miss" effects on amphipods).

Correlations Between Invertebrate Community Variables and Sediment Physical and Chemical Characteristics

In 2006, most correlations between invertebrate community variables and sediment particles size and TOC were weak (Table 5-27), as they have been in the past (Husky Energy 2006). In 2006, NMDS2 scores and Tellinidae abundance increased, and NMDS1 scores decreased, with increasing fines content (Table 5-27). Tellinidae abundance was the only community variable significantly (positively) correlated with TOC content. In past years, Tellinidae abundances (not analyzed in Husky Energy 2006) were also positively correlated with fines and TOC content. Richness was the only community variable significantly (positively) correlated with gravel content. In past years, diversity has also been significantly positively correlated with gravel content (Husky Energy 2006).

Table 5-27 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and Sediment Particle Size and TOC (2006)

Benthic invertebrate community variable	Sediment particle size and organic carbon content		
	% fines	% gravel	TOC
Summary measures			
Total abundance	0.053	0.220	0.095
Standing crop	–0.089	0.026	0.051
Richness	0.049	0.323*	0.108
Diversity	0.144	0.143	0.042
Evenness	0.065	–0.081	–0.127
NMDS1	–0.326*	–0.041	–0.157
NMDS2	0.407**	–0.155	0.205
Taxon abundances			
Paraonidae	–0.252	0.102	–0.075
Spionidae	0.139	0.069	0.084
Tellinidae	0.300*	0.050	0.386**
Amphipoda	0.088	0.225	0.025

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Richness, diversity, evenness and NMDS scores were based on families

Tables 5-28 and 5-29 provide correlations between invertebrate community variables and sediment chemical characteristics. The strongest correlations were between total abundance, NMDS1, NMDS2, Paraonidae abundance and Amphipoda abundance and tracer (barium, $>C_{10}$-C_{21} HC) concentrations. These community variables were also the variables most strongly correlated with distances from the drill centres (see analyses below). For most variables, correlations with sulphur, a secondary tracer, were similar in direction to, but weaker than, correlations with barium and $>C_{10}$-C_{21} HCs. Similarly, correlations with sulphide were weaker versions of correlations with sulphur. There were no significant correlations between community variables and ammonia or redox, which were unrelated to distance from drill centres (Section 5.4.1.2). The significant correlations between NMDS1, NMDS2 and Tellinidae abundance versus Metals PC1 in Table 5-28 were similar to those observed for fines (Table 5-27).

Table 5-28 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and Barium, >C_{10}-C_{21} HCs and Metals PC1 (2006)

Benthic invertebrate community variable	Sediment chemistry variable		
	Barium	>C_{10}-C_{21} HCs	Metals PC1
Summary measures			
Total abundance	–0.222	–0.429**	0.054
Standing crop	–0.167	–0.264*	–0.131
Richness	0.008	–0.106	0.211
Diversity	0.019	–0.131	0.148
Evenness	–0.038	–0.043	–0.060
NMDS1	**–0.564*** **	**–0.474*** **	–0.369**
NMDS2	**0.673*** **	**0.548*** **	0.375**
Taxon abundances			
Paraonidae	**–0.586**	**–0.578*** **	–0.241
Spionidae	–0.047	–0.258*	0.078
Tellinidae	0.152	–0.047	0.333*
Amphipoda	–0.218	**–0.448*** **	0.025

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Richness, diversity, evenness and NMDS scores were based on families

Table 5-29 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and Ammonia, Sulphur, Sulphide and Redox (2006)

Benthic invertebrate community variable	Sediment chemistry variable			
	Ammonia	Sulphur	Sulphide	Redox
Summary measures				
Total abundance	0.120	–0.420**	–0.276*	0.086
Standing crop	–0.141	–0.063	–0.224	0.043
Richness	0.241	–0.247	–0.178	–0.052
Diversity	0.076	–0.054	–0.091	–0.021
Evenness	–0.171	0.128	–0.046	0.018
NMDS1	–0.010	–0.365**	–0.235	0.067
NMDS2	0.039	0.360**	0.370**	0.084
Taxon abundances				
Paraonidae	0.042	**–0.476*** **	–0.337*	0.046
Spionidae	0.068	–0.362**	–0.136	0.175
Tellinidae	0.107	–0.092	–0.007	0.057
Amphipoda	0.149	–0.376**	–0.153	0.025

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Richness, diversity, evenness and NMDS scores were based on families

Correlations Between Invertebrate Community Variables and Amphipod Survival

Over all 59 stations, amphipod survival in toxicity tests was not significantly correlated with any benthic invertebrate community variable except NMDS1. Test amphipod survival increased with increasing NMDS1 scores (r_s = 0.264; $p \approx 0.05$), and NMDS1 scores were also low at the four stations with test survival less than 70% (Table 5-30; 38 of 59 NMDS1 values were greater than 0). At stations 13 and S2, where test survival was lowest and sediments classified as toxic, Paraonidae abundances were low, providing two (2) of the eight (8) abundances less than 10. At these two stations, amphipod abundances were also low and NMDS2 scores higher than at most stations (only nine NMDS2 scores were greater than 1). Paraonidae abundances were also reduced at stations 16 and 23, where test survival was less than 70%. Therefore, there was some agreement between field and laboratory assessments for these four stations and especially stations 13 and S2.

Table 5-30 Comparison of Benthic Invertebrate Community Variable Values for All Stations versus Stations 13, 16, 23 and S2 (2006)

Variable	Minimum	Maximum	Median	Station 13	Station 16	Station 23	Station S2
Amphipod survival (%)	29	98	87.5	34	68.75	66	29
Summary measures							
Total abundance	210	1,047	454	370	383	450	244
Standing crop	58	329	142	148	126	238	142
Richness	18	37	26	23	24	32	26
Diversity	3.2	7.0	4.3	3.4	4.5	6.3	4.2
Evenness	0.11	0.26	0.18	0.15	0.19	0.20	0.16
NMDS1	–3.72	0.88	0.25	–0.52	–0.15	–0.48	–0.76
NMDS2	–2.34	1.48	–0.32	1.25	0.34	0.13	1.07
Taxon abundances							
Paraonidae	0	285	95	7	38	37	1
Spionidae	17	495	161	182	161	157	104
Tellinidae	4	158	51	58	55	52	40
Amphipoda	1	43	10	5	5	16	4

Note: - Richness, diversity, evenness and NMDS scores were based on families

5.4.3.3 Depth and Distance Effects (2006)

Table 5-31 provides results of rank-rank regressions of invertebrate community variables on depth and distance from the nearest active drill centre, with the Northern, Central and Southern drill centres, but not the West drill centres, treated as "active". Overall multiple correlations (*R*) for the regression models with both depth and distance as X variables can range from 0 to 1. Partial correlations (*r*) for each *X* variable can range from −1 to 1, and provide the correlation between each *X* variable and *Y* with the effects of other *X* variables held constant or removed. For bivariate rank-rank regressions on a single *X* variable, *r* will be equal to the Spearman rank correlation (r_s). For all community variables, partial *r* from the multiple regressions were similar to r_s, which will be the case when the two *X* variables are uncorrelated (depth-distance r_s = −0.094) and correlations do not approach 0.9 or −0.9. However, correlations for both depth and distance were significant for several variables (e.g., total abundance), which increased multiple *R* relative to r_s for depth or distance alone but also complicated analyses of distance relationships and thresholds.

Table 5-31 Results of Rank-Rank Regressions of Benthic Invertebrate Community Variables on Depth and Distances from the Drill Centres (2006)

Y Variable	*X*=Depth & distance from nearest drill centre (Min *d*)			*X*=Depth	*X*=Min *d*
	Overall *R*	Partial *r*		r_s	r_s
		Depth	Min *d*		
Summary measures					
Total abundance	**0.549*** **	**0.481*** **	0.382**	0.428**	0.303*
Standing crop	0.372*	0.295*	0.272*	0.263*	0.237
Richness	0.407**	0.394**	0.162	0.379**	0.113
Diversity	0.253	0.252	0.046	0.249	0.021
Evenness	0.057	–0.047	–0.037	–0.043	–0.033
NMDS1	**0.543*** **	–0.215	**0.504*** **	–0.232	**0.510*** **
NMDS2	**0.684*** **	0.340**	**–0.638*** **	0.322*	**–0.631*** **

Y Variable	*X*=Depth & distance from nearest drill centre (Min *d*)			*X*=Depth	*X*=Min *d*
	Overall *R*	Partial *r*		r_s	r_s
Taxon abundances					
Paraonidae	**0.540*** **	0.028	**0.539*** **	–0.027	**0.539*** **
Spionidae	**0.468*** **	**0.460*** **	0.159	**0.446*** **	0.100
Tellinidae	**0.604*** **	**0.602*** **	–0.011	**0.604*** **	–0.066
Amphipoda	**0.476*** **	0.238	**0.450*** **	0.174	0.424**

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Min *d* = distance from the nearest drill centre
- All *Y* and *X* variables were rank-transformed

Richness, diversity, evenness and NMDS scores were based on families

Summary Measures

In 2006, total abundance increased significantly with increasing depth and increasing distance from the nearest drill centre (Table 5-31; Figure 5-28). The depth effects were stronger than the distance effects and remained significant with the deepest and shallowest stations (stations 4 and 19) excluded. Furthermore, there were significant depth-distance interactions in parametric log-log regressions for the full set of 59 stations and for various subsets of data (i.e., deleting stations did not remove the interaction). Therefore, in 2006, distance relationships varied with depth. Depth-distance interactions have not occurred in past years and did not occur for rank-rank regressions for 2006 data.

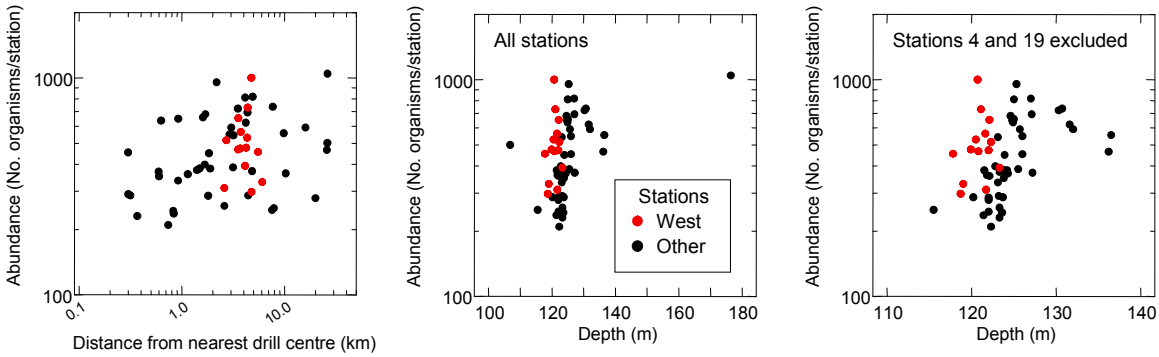


Figure 5-28 Total Abundance versus Distance from the Nearest Drill Centre and Depth (2006)

Depth-distance interactions occurred because depth and distance effects were apparent at extreme but not intermediate values of the two *X* variables. It was inappropriate to parametrically estimate a zone of effects (ZOE) or a general distance model; depth was also a poor predictor (*X*) variable. For example, abundance varied widely among the West stations, which were located close to each other and were of similar depth (117.8 to 123.3 m) (Figure 5-28). Variance among the West stations was uncorrelated with distance from the nearest drill centre (the Central drill centre) (r_s = –0.068 for distances of 2.6 to 6.1 km). Reasonable overall conclusions are that high abundances did not occur near drill centres (i.e., within 1 km; left plot in Figure 5-28), low abundances did not occur at depths greater than 125 m (right plot in Figure 5-28), and the full 5-fold range of abundances occurred at intermediate depths and distances.

Standing crop increased with increasing depth and distance from the nearest drill centre, but correlations with both *X* variables were weak (*r* or r_s less than 0.3; Table 5-31). Richness increased significantly with depth, even with stations 4 and 19 deleted (Figure 5-29). Diversity also increased with depth, although depth correlations were weaker than for richness. In past years, depth effects have been greater for diversity than for richness (Section 5.4.3.4; Husky Energy 2006). Evenness was uncorrelated with depth and distance (Table 5-31).

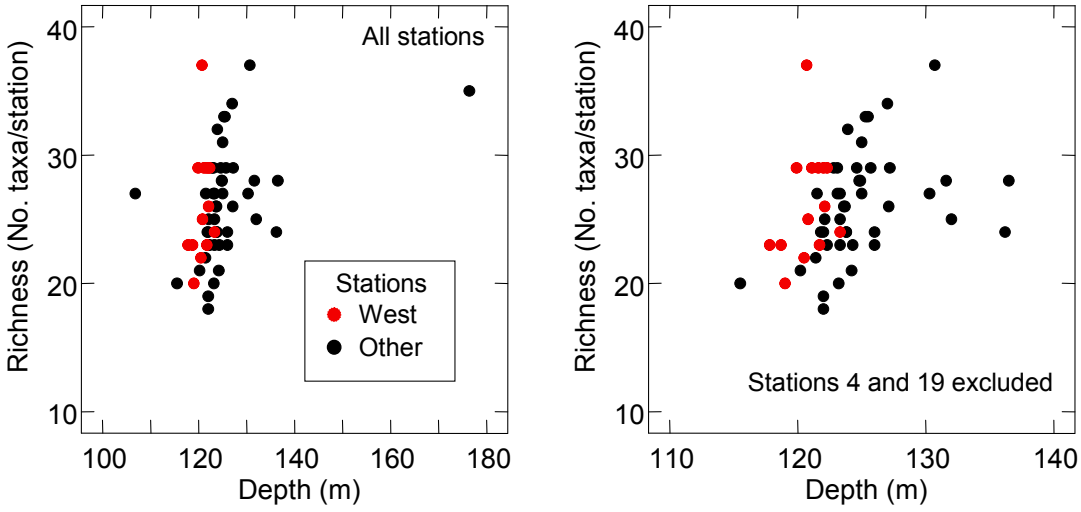


Figure 5-29 Richness versus Depth (2006)

NMDS1 scores increased significantly with increasing distance from the nearest drill centre (Table 5-31). NMDS1 was typical of most invertebrate community variables correlated with distance. Values varied widely among stations within 0.5 km of drill centres where differences among drill centres (i.e., which drill centre is nearest?) were important (Figure 5-30; station 20 is near the Central drill centre). Values also varied widely among remote stations more than 5 to 10 km from drill centres, reflecting natural variance among stations widely separated in space. For these reasons, fitting parametric distance models to NMDS1 and other invertebrate community variables is always an approximate exercise.

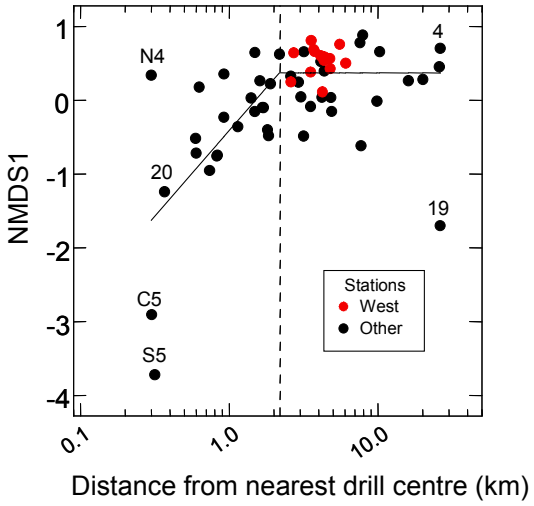


Figure 5-30 NMDS1 Scores versus Distance from the Nearest Drill Centre (2006)

Table 5-32 provides results of parametric distance regressions for NMDS1 versus distance from the nearest drill centre. For all 59 stations, and also with Reference Stations 4 and 19 excluded, a hockey-stick model adding a threshold distance (i.e., ZOE) significantly reduced error variance relative to a bivariate regression. The hockey-stick model with stations 4 and 19 excluded was the regression line used in Figure 5-30 because these two stations were outliers for parametric regressions. The 95% CI of 1.4 to 3.5 km for the threshold distance estimated from that model can be regarded as a conservative estimate (see below) of the ZOE for community effects. More precise estimates of ZOE are generally unwarranted for NMDS1 and other community variables. These estimates vary among data sets (note the effects of excluding 2 of 59 stations in Table 5-32) and among statistical methods (Appendix B-5)), and no simple bivariate or hockey-stick distance model will ever "explain" or predict the wide variances in *Y* variable values at both short and long distances.

Table 5-32 Results for Parametric Distance Models for NMDS1 and Paraonidae Abundance (2006)

Result/Estimate	NMDS1		Paraonidae abundance (All stations)
	All stations	Stations 4 and 19 excluded	
Regression on distance from nearest drill centre			
r	**0.495*** **	**0.613*** **	**0.618*** **
Hockey-stick model			
Overall *R*	**0.672*** **	**0.716*** **	**0.792*** **
p for adding threshold (X_T)	**<0.001**	**<0.001**	**<0.001**
antilog X_T (threshold distance in km)	1.3	2.2	2.8
95% CI	0.8 to 2.2	1.4 to 3.5	1.9 to 4.2

Notes: - $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in bold)
- The *X* variable for the hockey-stick model was distance from the nearest drill centre
- Distance and Paraonidae abundance (+ 1) were log-transformed
NMDS1 scores were based on families

Apparent effects on NMDS1 should not be considered in isolation from effects on NMDS2 and, more generally, effects on overall community composition. In 2006, NMDS2 scores decreased significantly with increasing distance from the nearest drill centre and increased significantly with increasing depth (Table 5-31; Figure 5-31). The depth correlations for rank-transformed data were not significant ($0.05 < p < 0.10$ for partial r and r_s) with stations 4 and 19 (extreme depth and NMDS2 values) excluded. However, for both rank-rank and parametric regressions for all 59 stations or for various subsets of stations, there were significant depth-distance interactions that have not occurred in past years. Therefore, parametric distance models were inappropriate for NMDS2.

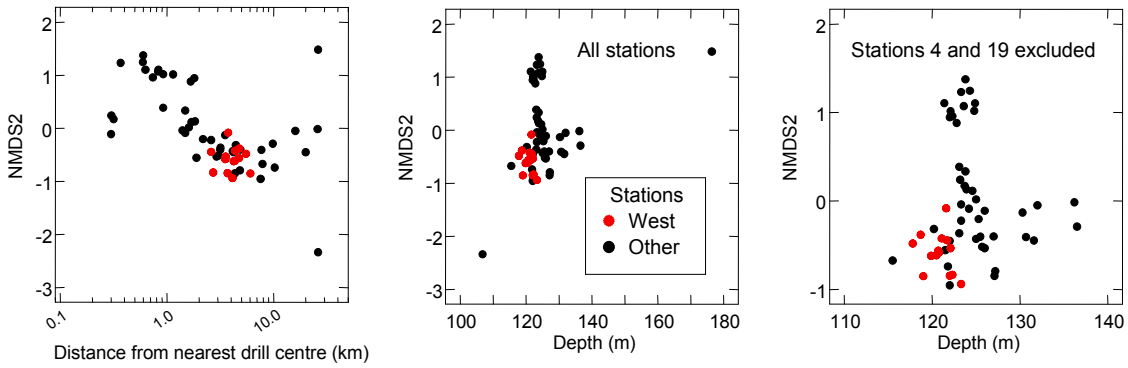


Figure 5-31 NMDS2 Scores versus Distance from the Nearest Drill Centre and Depth (2006)

Some qualitative estimates of ZOE for NMDS2, or both NMDS1 and NMDS2 combined, can still be made for intermediate distances and most stations. At distances of 0.5 to 2 km, there was a reasonably linear decrease in NMDS2 scores with distance (left plot in Figure 5-31). Beyond 5 km, variance increased and the distance relationship arguably reversed. Similarly, if one excludes stations 4 and 19 (Figure 5-26) or rotates axes to maximize natural differences between those two stations (Figure 5-27), there is a relatively clear separation and community difference between stations less than 2 km from drill centres versus more distant stations, but not between stations 2 to 5 km versus greater than 5 km from drill centres. Thus, 2 to 5 km is a reasonable estimate of the ZOE for effects on overall community composition, again, recognizing that any ZOE estimate and distance model largely ignores or cannot predict variance and values at both short and long distances.

Finally, the 14 West stations added in 2006 were at or near various estimated distance thresholds (e.g., as in Figure 5-30). Therefore, apparent effects from existing drill centres were weak at these stations, and additional effects from the West Alpha and West Bravo drill centres should be detectable if future drilling occurs at these centres.

Taxon Abundances

In 2006, Paraonidae abundance increased significantly with increasing distance from the nearest drill centre and was uncorrelated with depth (Table 5-31). In the absence of depth effects, parametric distance models were fit for all 59 stations. A hockey-stick model adding a distance threshold significantly reduced error variance relative to a

bivariate log-log regression (Table 5-32; Figure 5-32). The estimated threshold distance (ZOE) was 2.8 km, with 95% CI of 1.9 to 4.2 km, consistent with quantitative and qualitative estimates of ZOE for overall community composition (see above results for NMDS axes). The West stations were generally outside the estimated ZOE of 2.8 km, with higher Paraonidae abundances than at most other stations (Figure 5-32). Again, these results suggest that effects from existing drill centres were weak.

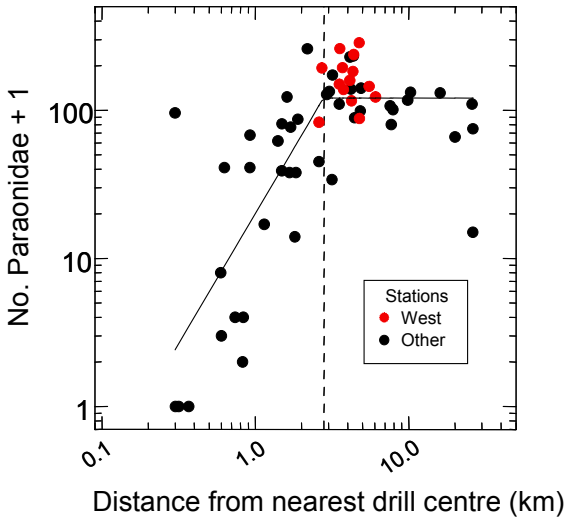


Figure 5-32 Paraonidae Abundance versus Distance from the Nearest Drill Centre (2006)

In 2006, Spionidae and especially Tellinidae abundances increased significantly with increasing depth and were not significantly correlated with distances (Table 5-31). The depth relationships were significant and rank correlations with depth were largely unchanged with Reference Stations 4 and 19 deleted (Figures 5-33 and 5-34). Collectively, results for the three dominant taxa (Spionidae, Paraonidae, Tellinidae) explain why results for total abundance and community composition (i.e., NMDS scores) were not simple to interpret. Two dominant taxa (Spionidae, Tellinidae) were responding primarily to depth whereas the third (Paraonidae) was responding primarily to distance.

In 2006, Amphipoda abundance increased significantly with increasing distance from the nearest drill centre and was not significantly correlated with depth (Table 5-31). With minimal depth effects, a bivariate log-log regression of abundance on distance was the most appropriate parametric model for all 59 stations and is shown in Figure 5-35. The regression equation was:

$$\log_{10} \text{No. Amphipoda} = 0.817\ (\pm\ 0.061) + 0.301\ (\pm\ 0.095) \times \log_{10} \text{Distance (in km)}$$

$$(r = -0.387;\ p = 0.002)$$

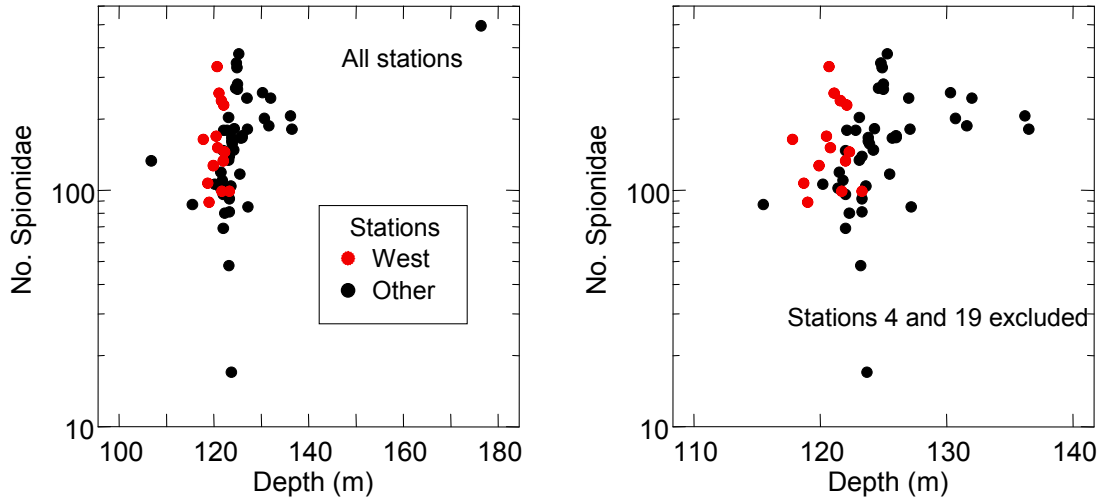


Figure 5-33 Spionidae Abundance versus Depth (2006)

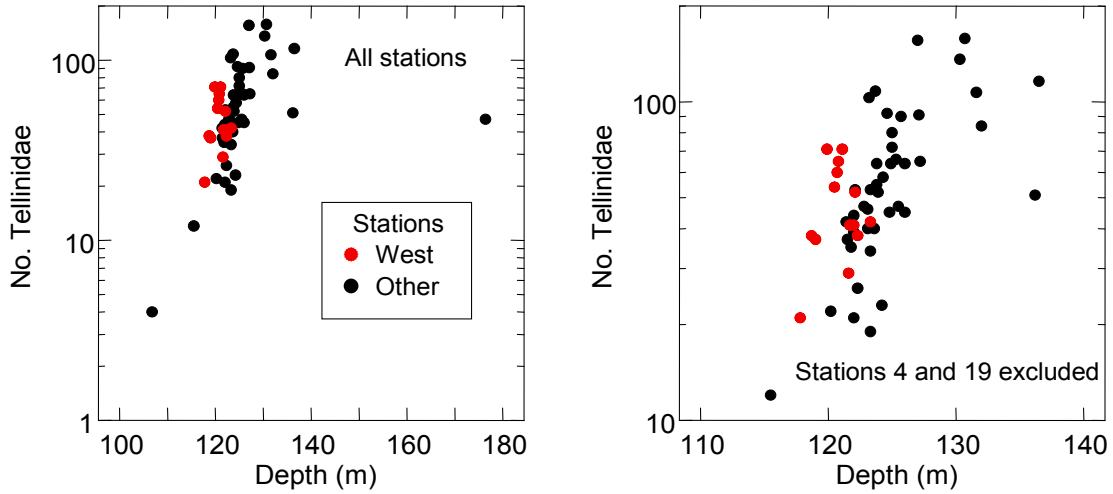


Figure 5-34 Tellinidae Abundance versus Depth (2006)

Values following "±" are standard errors (SE) for the intercept and slope, and approximate 95% CI for these estimates are ± 2 SE. As the wide variance of abundances about the regression line in Figure 5-35 and low correlation (*r*) indicate, the bivariate regression had limited predictive value. However, adding a threshold distance in hockey-stick models did not significantly reduce error variance (p = 0.76). Furthermore, 95% CI for the estimated threshold distance of 10.3 km were 1 to 100 km, encompassing an area much larger than the White Rose sampling grid.

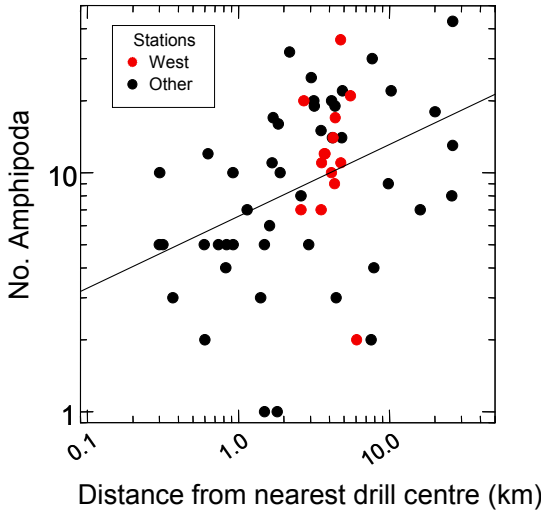


Figure 5-35 Amphipoda Abundance versus Distance from the Nearest Drill Centre (2006)

5.4.3.4 Comparison Among Years (2000, 2004, 2005 and 2006)

Table 5-33 provides results of RM regression models comparing benthic invertebrate community variables among the four sample years (2000, 2004, 2005 and 2006) for the 37 stations sampled in all four years. Results are expressed as *F* values, which are estimates of effect sizes. *F* values greater than 1 indicate added variance attributable to the terms tested. Details of the analysis are provided in Appendix B-5; general guidelines for interpretation are provided in Section 5.4.1.3).

Table 5-33 Results of RM Regression Analysis Comparing Benthic Invertebrate Community Summary Measures Among 2000, 2004, 2005 and 2006

Term	df	*F* value for *Y* variable						
		Abundance	Standing crop	Richness	Diversity	Evenness	NMDS1	NMDS2
Among Stations								
Depth	1,32	8.95**	0.03	10.53**	**14.80*** **	0.79	11.20**	2.30
N d	1,32	0.05	0.07	3.25	0.06	2.87	0.07	4.45*
C d	1,32	0.33	0.04	3.86	9.13**	1.78	2.64	0.20
S d	1,32	1.75	1.35	0.61	2.26	0.78	6.56*	8.14**
Error 1[1]	32,96	1.77*	**2.35*** **	1.59*	1.26	0.55	1.88*	1.87*
Within Stations								
Overall								
Year	3,96	1.11	1.86	1.14	1.24	0.15	1.02	0.97
Year × Depth	3,96	1.25	1.75	1.15	1.14	0.12	0.96	1.43
Year × N d	3,96	2.23	0.56	0.91	3.17*	0.96	0.51	0.98
Year × C d	3,96	4.64**	0.80	0.64	0.81	1.22	4.44*	3.30*
Year × S d	3.96	**15.10*** **	0.43	4.09**	1.62	2.91*	**14.46*** **	4.98**
2000 versus 2004 to 2006								
Year	1,32	0.26	0.25	1.39	0.41	0.03	1.33	0.13
Year × Depth	1,32	0.00	0.36	0.81	0.11	0.07	2.02	0.25
Year × N d	1,32	0.80	0.34	0.97	6.34*	1.79	0.02	2.77
Year × C d	1,32	0.46	0.53	0.01	0.06	0.05	0.01	0.00
Year × S d	1,32	**16.67*** **	0.06	1.98	0.05	0.38	**16.35*** **	8.27**

Term	df	*F* value for *Y* variable						
		Abundance	Standing crop	Richness	Diversity	Evenness	NMDS1	NMDS2
2004 versus 2005, 2006								
Year	1,32	2.44	0.76	0.13	0.09	0.35	1.27	1.12
Year × Depth	1,32	2.15	0.92	0.06	0.12	0.29	0.50	1.49
Year × N d	1,32	1.37	0.03	0.01	0.78	0.79	0.51	0.01
Year × C d	1,32	1.15	1.09	0.04	2.04	2.27	3.26	4.29*
Year × S d	1,32	0.58	0.42	1.01	4.84*	1.43	7.69**	0.74
2005 versus 2006								
Year	1,32	0.65	5.58*	1.78	3.40	0.19	0.46	1.65
Year × Depth	1,32	1.39	4.72*	2.43	3.48	0.10	0.17	2.56
Year × N *d*	1,32	3.87	1.68	1.63	0.70	0.05	1.05	0.41
Year × C *d*	1,32	10.16**	0.69	1.81	0.82	2.13	10.29**	5.34*
Year × S *d*	1,32	**25.33*** **	0.92	8.84**	1.11	6.64*	**17.97*** **	7.14*

Notes:
- Appendix B-5 explains terms and tests in the RM regression model
- df = degrees of freedom for the numerator (effect) and denominator (error) for *F*
- *d* = distances from various drill centres
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- *n* = 37 stations sampled in all four years
- Distances and all *Y* variables except NMDS1 and NMDS2 were log-transformed
- Richness, diversity, evenness and NMDS scores were based on families
- [1]—Error 1=carry-over effects or persistent differences among stations unrelated to depth or distance

Table 5-34 provides multiple regression slopes for depth and distance *X* variables in each year, which adjust effects of each *X* variable for the effects of other X variables. In most cases, bivariate plots and regression lines for *Y* variables versus individual *X* variables provided below are adequate to show large changes in depth or distance gradients over time or the absence of any gradients or changes over time. However, the multiple regression slopes are useful for interpreting more subtle changes in gradients over time, particularly for distances from the Central and Southern drill centres, the two most strongly correlated *X* variables.

Table 5-34 Multiple Regression Slopes for Benthic Invertebrate Community Summary Measures versus Depth and Distances from Drill Centres

Y variable	*X* variable	Year			
		2000	2004	2005	2006
Total abundance	Depth	0.014	0.006	0.011	0.024
	Northern *d*	0.070	0.069	0.081	–0.170
	Central *d*	–0.067	–0.078	–0.167	0.200
	Southern *d*	–0.169	0.098	0.449	–0.122
Standing crop	Depth	–0.003	–0.004	–0.005	0.016
	Northern *d*	0.064	0.016	–0.079	0.072
	Central *d*	0.065	0.076	–0.088	–0.001
	Southern *d*	0.091	0.117	0.093	–0.006
Richness	Depth	0.004	0.006	0.004	0.010
	Northern *d*	–0.070	–0.028	0.002	–0.063
	Central *d*	–0.037	–0.045	–0.068	–0.007
	Southern *d*	–0.023	0.004	0.107	–0.027
Diversity	Depth	0.006	0.009	0.003	0.012
	Northern *d*	–0.109	0.003	0.066	0.019
	Central *d*	–0.072	–0.022	–0.057	–0.103
	Southern *d*	0.023	–0.025	0.037	0.089

Y variable	*X* variable	Year			
		2000	2004	2005	2006
Evenness	Depth	0.003	0.003	–0.001	0.001
	Northern *d*	–0.039	0.030	0.064	0.082
	Central *d*	–0.036	0.023	0.011	–0.096
	Southern *d*	0.046	–0.028	–0.070	0.116
NMDS1	Depth	–0.024	–0.078	–0.052	–0.066
	Northern *d*	0.089	–0.111	0.328	–0.090
	Central *d*	0.305	–0.069	–0.136	1.047
	Southern *d*	–0.498	0.231	1.793	0.254
NMDS2	Depth	–0.028	–0.038	–0.028	0.014
	Northern *d*	–0.014	–0.416	–0.353	–0.553
	Central *d*	–0.056	0.318	0.068	–0.585
	Southern *d*	0.090	–0.409	–0.273	–1.016

Notes:
- *d* = distances from various drill centres
  n = 37 stations sampled in all four years
- Distances and all *Y* variables except NMDS1 and NMDS2 were log-transformed
- Richness, diversity, evenness and NMDS scores were based on families

Total abundance increased with increasing depth in all four sample years (Figure 5-36). The overall or Among Stations depth effects were significant, and there were no significant Within Stations changes in depth slopes over time (Table 5-33). Relationships between total abundance and distance from the Northern drill centre were not significant over all four years and did not differ significantly among years (Table 5-33).

In 2000, 2004 and 2005, total abundance was weakly negatively correlated with distance from the Central drill centre (Table 5-34; Figure 5-36), although drilling started at this drill centre prior to 2005 sampling. In 2006, abundance increased with distance from the Central drill centre, and the difference in gradients between 2005 and 2006 was significant (Within Stations Year $\times$ C *d* contrast in Table 5-33). These results may be evidence of delayed effects from drilling at the Central drill centre.

In 2000, abundance decreased with distance from the Southern drill centre; in 2004 there was no gradient; in 2005, abundance increased with distance from the Southern drill centre (Table 5-34; Figure 5-36). These changes are consistent with a progressive increase in effects (i.e., reductions in abundance near the Southern drill centre) over time. However, in 2006, abundance decreased with distance from the Southern drill centre as in 2000 (Table 5-34; although the gradient is not evident in the bivariate plot in Figure 5-36). The difference in gradients between 2005 and 2006 was highly significant. Note that low abundances (near or below 100 organisms/station) were observed near the Southern drill centre in 2005 but not in 2006 (Figure 5-36). Therefore, any effects on abundance may have been reduced in 2006, despite little or no change in contamination gradients (Section 5.4.1.3).

As a result of increases with distance from the Central and/or Southern drill centres, centroids for total abundance moved north and east (i.e., away from the two drill centres) after 2004 (Figure 5-37; left plot). Centroids for all years have always been to the north and/or east of the sampling centroid, in the direction of greater depths. Total abundance progressively decreased from 2000 to 2005, but returned to 2004 levels in 2006 (Figure 5-37; right plot). Some of these changes may have been natural, but they were also a function of the low abundances near the Southern drill centre in 2005 that were not observed in other years.

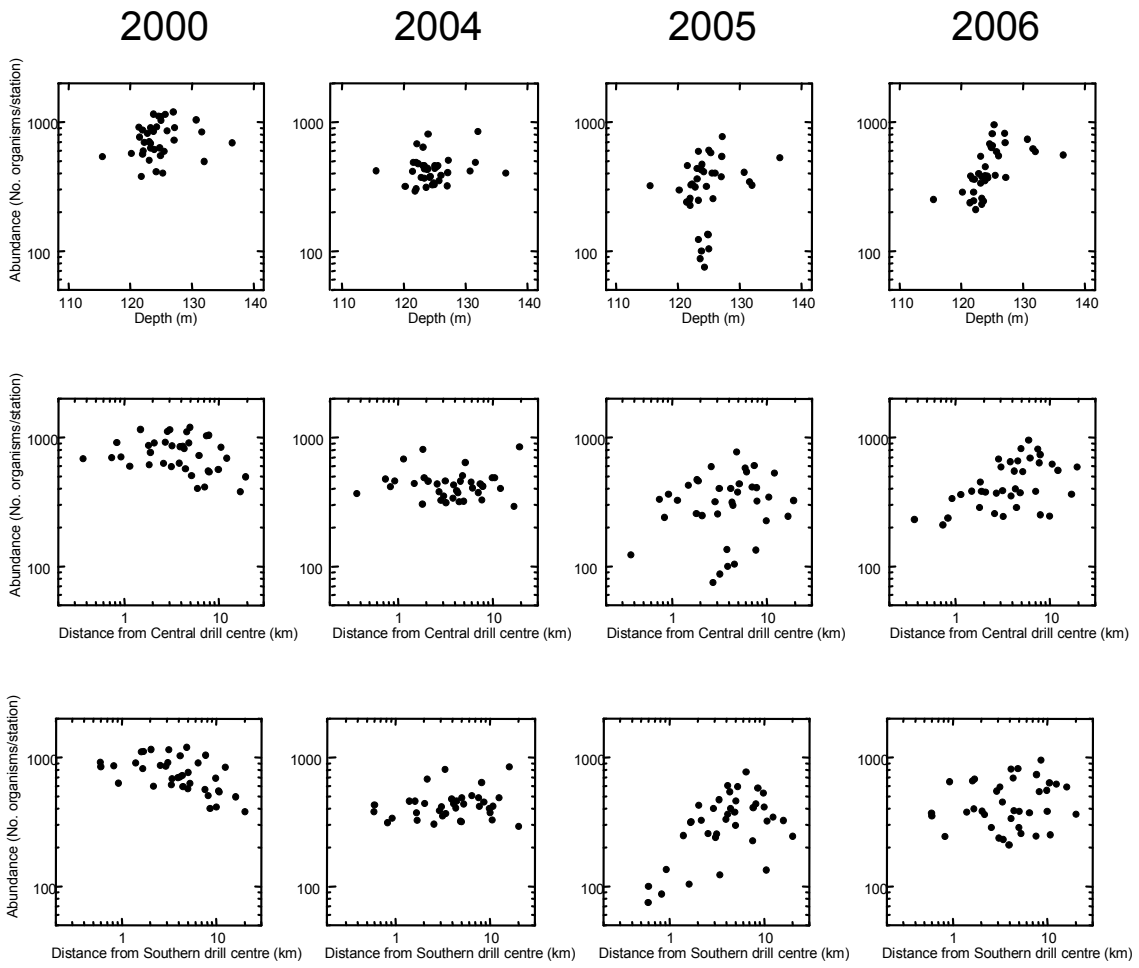


Figure 5-36 Total Abundance versus Depth and Distances from the Central and Southern Drill Centres (2000, 2004, 2005, 2006)

Overall, there were significant and consistent depth effects on total abundance and no consistent distance gradient or changes in gradients for the Northern drill centre. Distance gradients (increases with distance) for the Central and Southern drill centres were not strong until the second EEM year after drilling began. The distance gradient for the Southern drill centre also decreased in strength from 2005 to 2006.

For standing crop, the Within Stations Year and Year × Depth terms for the 2005 versus 2006 contrast were significant (Table 5-33). Prior to 2006, there was no relationship between standing crop and depth, but in 2006 standing crop increased with depth (Table 5-34). As a result, the 2006 centroid was almost 2 km west of centroids for previous years (Figure 5-38). The 2005 versus 2006 Year term was significant only because intercepts change when slopes change; mean standing crop has been relatively constant over time (Figure 5-38).

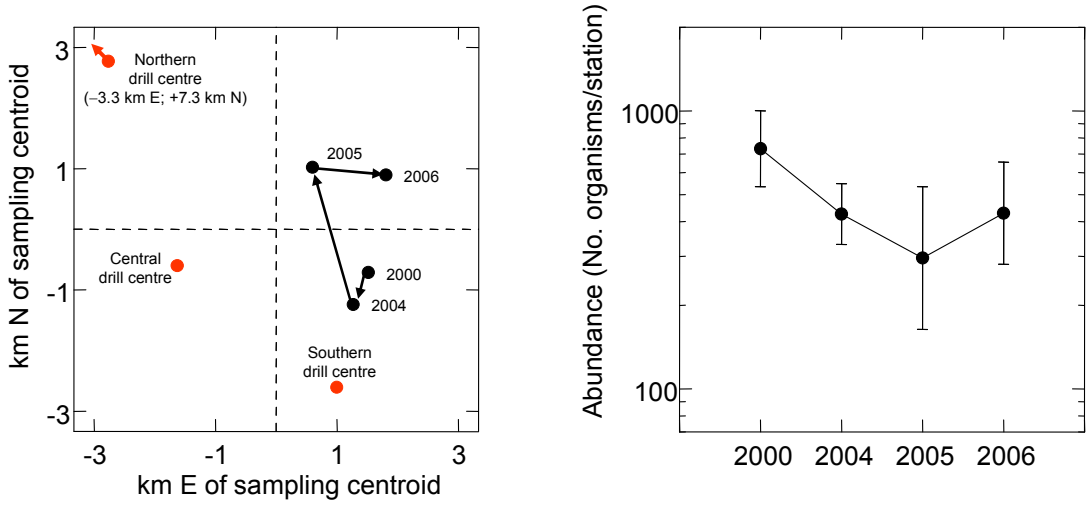


Figure 5-37 Total Abundance Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

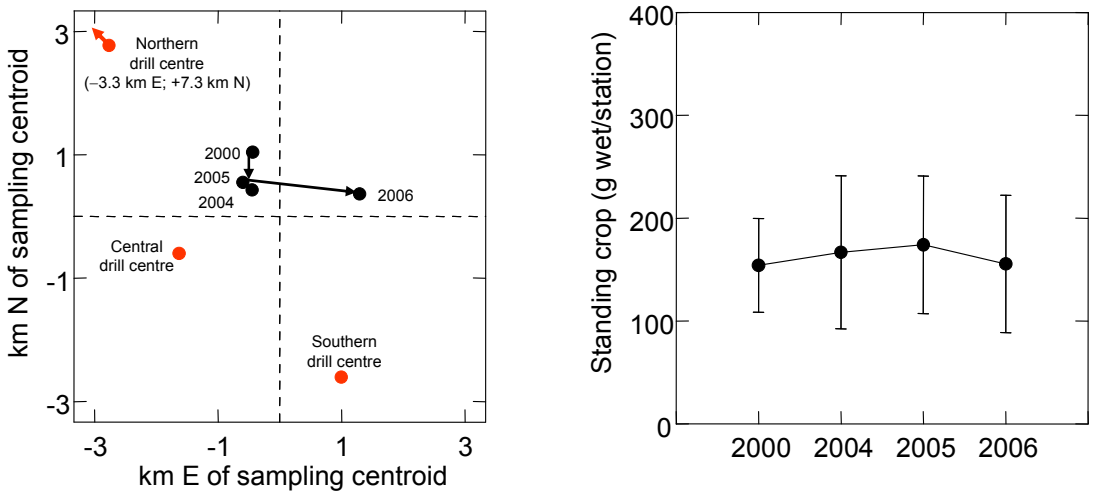


Figure 5-38 Standing Crop Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

RM regression results for richness in Table 5-33 were weaker versions of results for its correlate, total abundance. Richness increased with depth over all years, and within each year (Table 5-34). Distance gradients for the Northern and Central drill centres were not significant over all years and did not change significantly over time. As for total abundance, slopes for richness versus distance from the Southern drill centre increased

from weakly negative in 2000 to positive in 2005, but then reversed to negative in 2006 (Table 5-34).

Richness centroids have always been north and/or east of the sampling centroid because of depth effects (Figure 5-39). Despite a reduction in apparent effects from the Southern drill centre in 2006, the richness centroid actually moved northeast between 2005 and 2006 (i.e., away from the Southern drill centre and towards greater depths) because depth effects were somewhat stronger in 2006 than in previous years (Table 5-34). Richness has not varied significantly among years, and mean values were 25 to 30 taxa/station in all years (Figure 5-39).

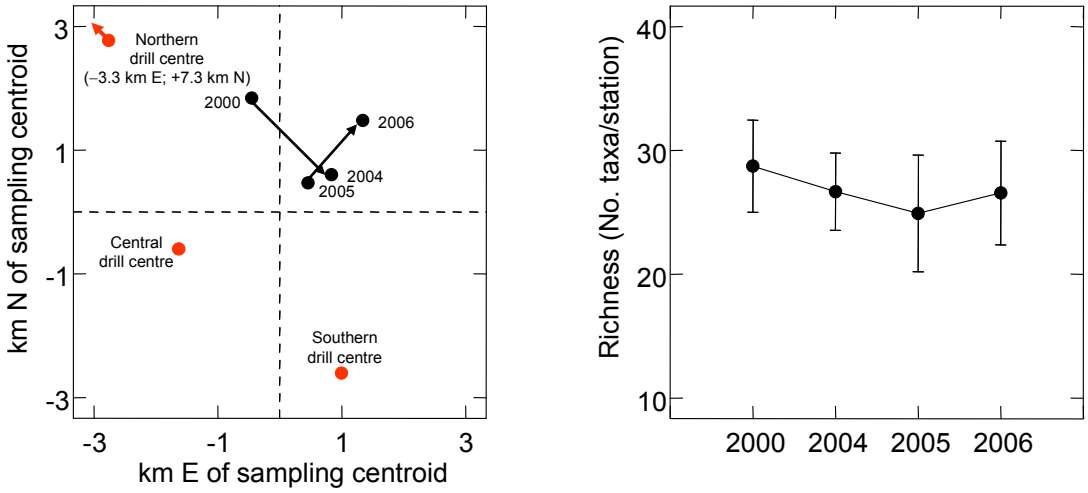


Figure 5-39 Richness Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

Diversity increased significantly with depth (Tables 5-33 and 5-34; Figure 5-40). Diversity was also the only summary measure to provide any evidence of adverse effects from the Northern drill centre. In 2000, diversity decreased with distance from the Northern drill centre, whereas in 2004 to 2006, there was no distance gradient or an increase in diversity with distance (Table 5-34; Figure 5-40). Consequently, the Within Years Overall and 2000 versus 2004 to 2006 contrast Year × N *d* terms in the RM regression model were significant. Diversity also consistently decreased with increasing distance from the Central drill centre over all years (Table 5-33; Figure 5-40). Diversity centroids moved southeast after 2000, after diversity no longer increased with distance from the Northern drill centre (Figure 5-41). Despite this change, mean diversity values over all stations were relatively constant over time (Figure 5-41).

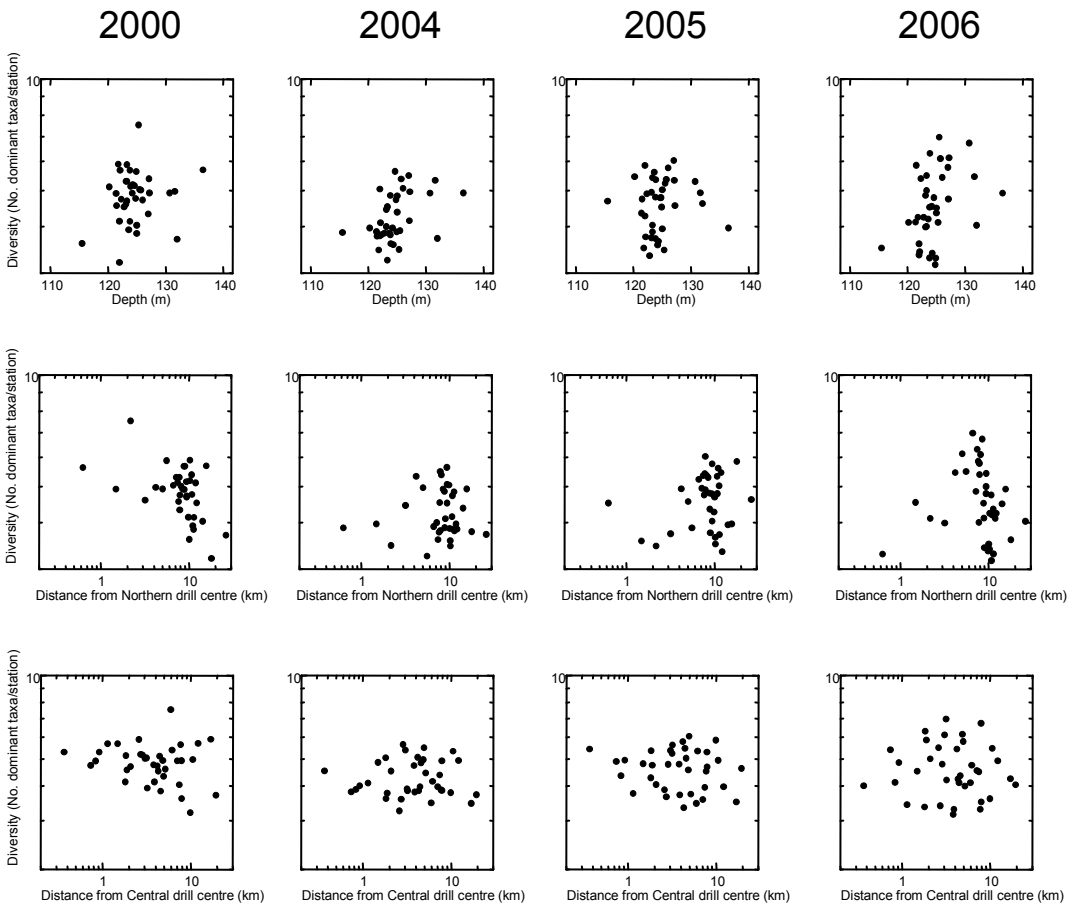


Figure 5-40 Diversity versus Depth and Distances from the Northern and Central Drill Centres (2000, 2004, 2005, 2006)

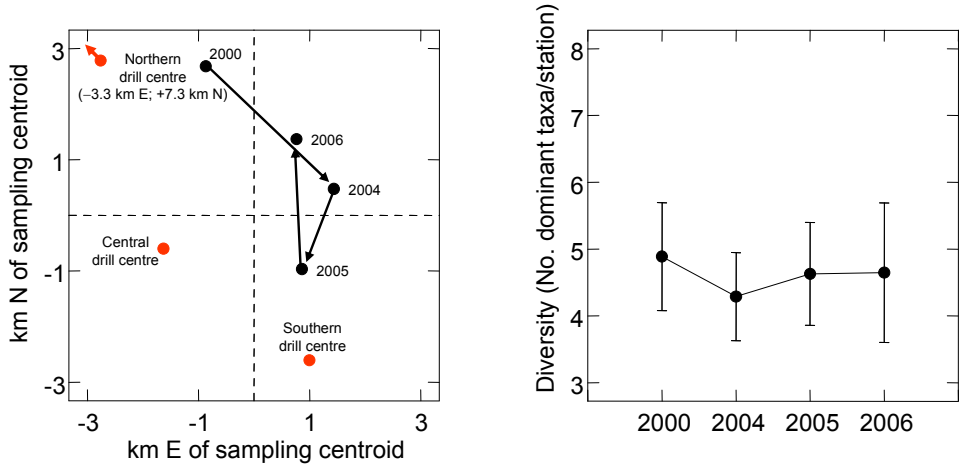


Figure 5-41 Diversity Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

Evenness was largely unrelated to depth or distance (Table 5-33). Values increased with distance from the Southern drill centre in 2000 and in 2006, but decreased with distance in 2004 and 2005 (Table 5-34). These changes account for the significant Within Stations Year × S *d* terms in Table 5-33 and also the differences in centroid locations between 2000 and 2006 versus 2004 and 2005 in Figure 5-42. Evenness values were low (means less than 0.20) in all four years.

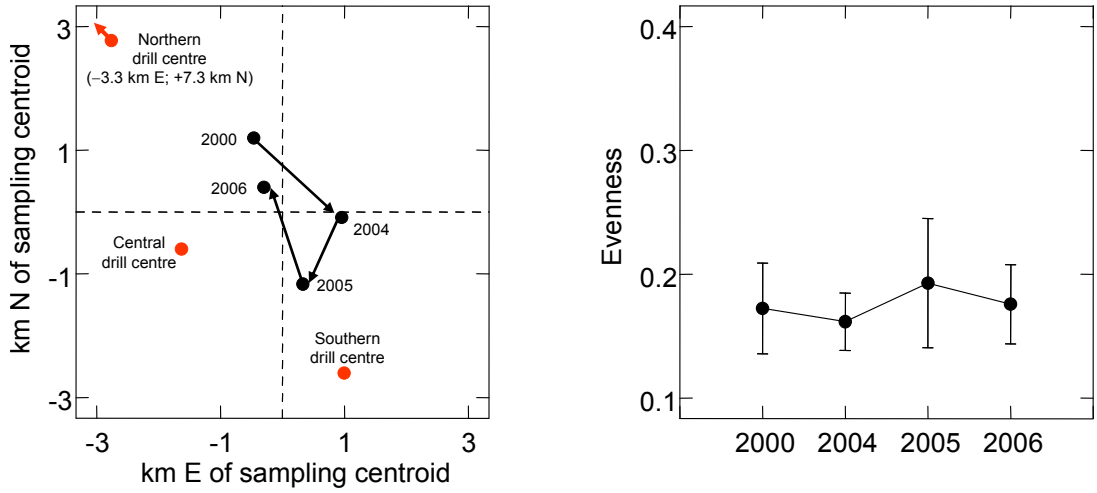


Figure 5-42 Evenness Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

NMDS1 scores and polychaete dominance decreased with depth over all four years and in each year (Tables 5-33 and 5-34; Figure 5-43). The depth effects were primarily a function of increases in abundance of Tellinidae (Bivalvia), the dominant non-polychaete, with depth (see below). There was no significant overall relationship or change in relationships over time for NMDS1 versus distance from the Northern drill centre (Table 5-33). NMDS1 scores increased strongly with distance from the Central drill centre in 2006. In previous years, slopes for Central *d* were weakly positive (2000) or weakly negative (2004 and 2005) (Table 5-34, Figure 5-43). NMDS1 scores decreased with distance from the Southern drill centre in 2000; increased with distance in 2004 and 2006, and increased strongly with distance in 2005 (Table 5-34; Figure 5-43). Therefore, the overall response pattern for NMDS1 was qualitatively similar to that for total abundance: consistent depth effects; no distance effects for the Northern drill centre; potential delayed effects from the Central drill centre in 2006; much stronger effects from the Southern drill centre in 2005 than in 2004 and 2006.

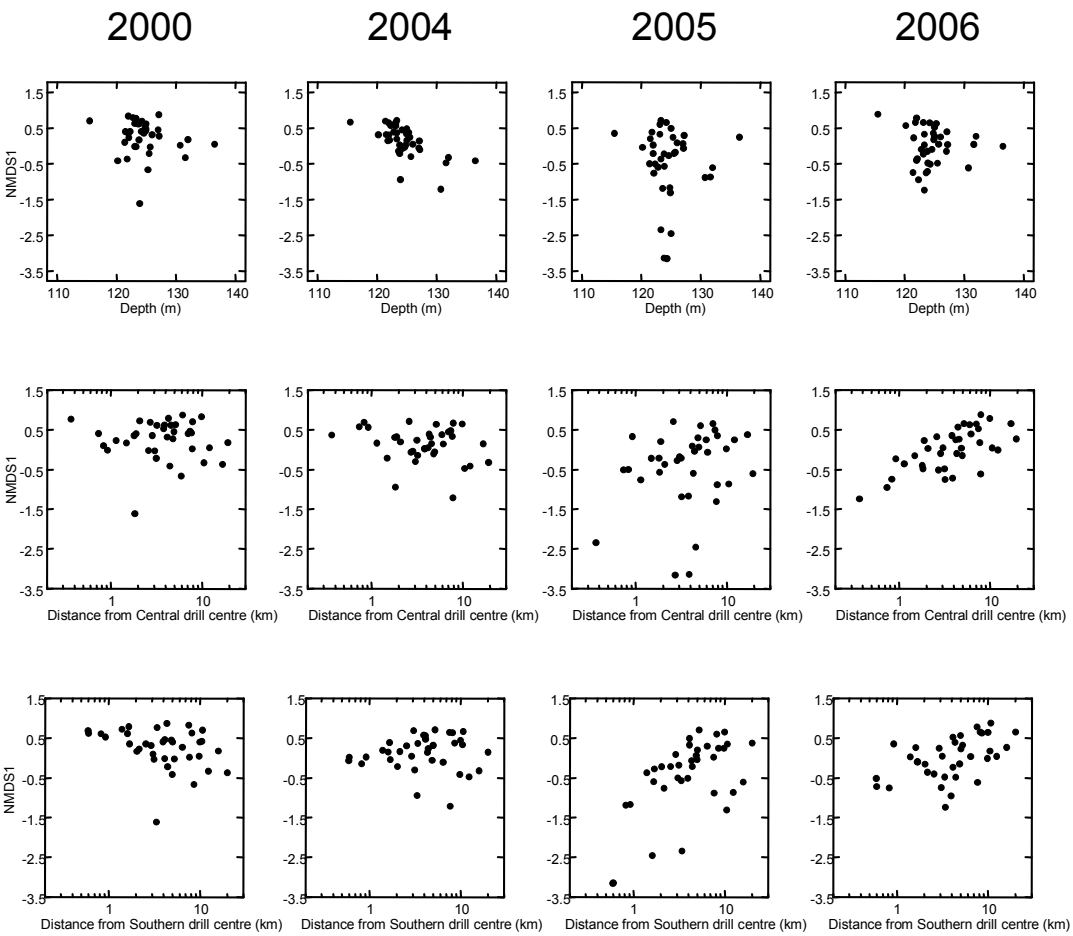


Figure 5-43 NMDS1 versus Depth and Distances from the Central and Southern Drill Centres (2000, 2004, 2005, 2006)

Shifts in spatial distributions and centroids for NMDS1 (Figure 5-44) were also similar to those for total abundance (Figure 5-37), but displaced several kilometres west because NMDS1 decreased rather than increased with depth. Between 2000 and 2004, centroids moved west and away from the Southern drill centre, then moved northeast away from the Central drill centre in 2005 and 2006. NMDS1 scores for the 37 stations included in the RM analyses were lower in 2005 than in other years (Figure 5-44), because of low values near the Southern drill centre (Figure 5-43).

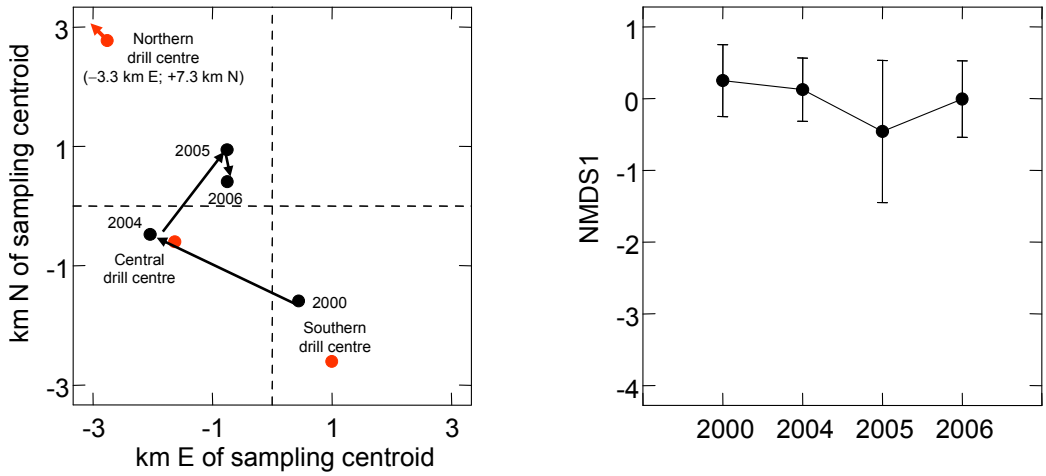


Figure 5-44 NMDS1 Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

NMDS2 scores were not significantly correlated with depth (Table 5-33), an expected result for a summary measure that partly contrasts abundances of Spionidae versus Paraonidae, two dominant taxa largely unaffected by depth (see below). Over all years, NMDS2 scores decreased significantly with distance from the Northern drill centre (Table 5-33). It was somewhat surprising that the Within Stations 2000 versus 2004 to 2006 Year × N *d* term in Table 5-33 was not significant because distance gradients and slopes were steeper for 2004 to 2006 (Table 5-34; Figure 5-45). As for several other variables, gradients with distance from the Central drill centre were not evident until 2006, when NMDS2 scores decreased strongly with distance from this drill centre (Figure 5-45). NMDS2 scores were uncorrelated with distance from the Southern drill centre in 2000, decreased slightly with distance in 2004 and 2005 and decreased strongly with distance in 2006 (Tables 5-33 and 5-34; Figure 5-45). Therefore, results for other variables (e.g., total abundance and NMDS1) may be evidence of a reduction in effects from the Southern drill centre in 2006 relative to 2005 on some or most taxa, but results for NMDS2 may be evidence of an intensification of effects on other taxa.

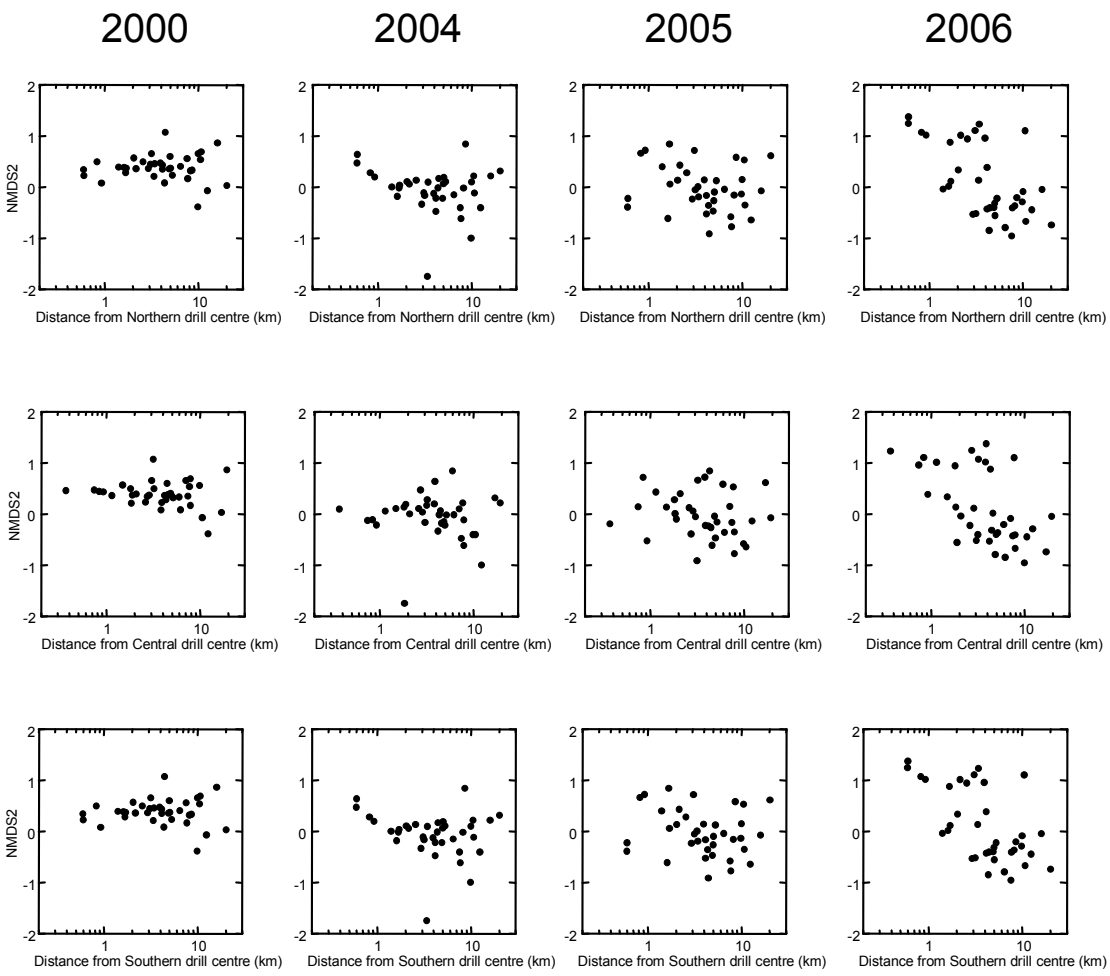


Figure 5-45 NMDS2 versus Distances from the Northern, Central and Southern Drill Centres (2000, 2004, 2005, 2006)

In contrast to most other variables, NMDS2 values decreased rather than increased with distance from each drill centre in one or more years. Consequently, centroid locations were a complex function of the relative strengths of "effects" from each drill centre, with the drill centres acting as "attractors". In 2000, the NMDS2 centroid was midway between the Central and Southern drill centres (Figure 5-46). In 2004 and 2005, centroids were midway between the Northern and Southern drill centres, with regression slopes for distances from these two drill centres approximately equal (Table 5-34). In 2006, centroids moved closer to the Southern drill centre, despite the apparent effects from the Central drill centre (note that regression slopes and apparent effects from the Southern drill centre were greater than for the other two drill centres (Table 5-34)). NMDS2 scores did not change substantially over time; instead, variances increased (Figure 5-46).

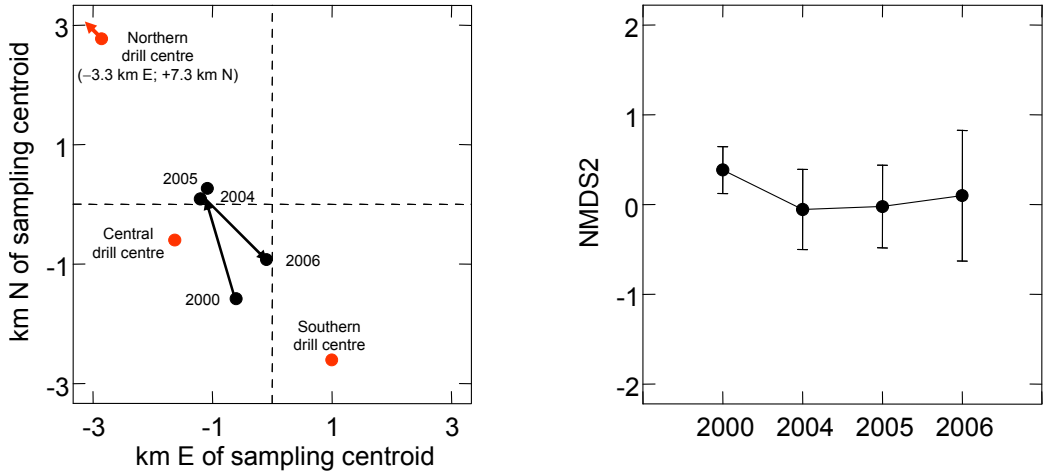


Figure 5-46 NMDS2 Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

Table 5-35 provides parametric regressions of NMDS1 on distance from the nearest active drill centre for 2004 and 2005 for all stations sampled in those years. Excluding stations 4 and 19 improved the fit of the models since one or both stations were outliers but did not substantially alter estimates of threshold distances (ZOE). Estimated ZOE with stations 4 and 19 excluded were less than 1 km in 2004, consistent with results of the RM analyses that indicated minimal or no effects from the Northern and Southern drill centres in that year. The estimated ZOE for 2005 was 2.6 km, similar to the estimated ZOE of 2.2 km in 2006, although with wider confidence intervals (CI; 1.3 to 5.2 km versus 1.4 to 3.5 km). Again, the 95% CI probably provide the best estimates of ZOE, since more precise estimates may differ depending on the methods used. The RM analyses indicated that distance gradients for the Southern drill centre decreased in strength but gradients for the Central drill centre increased in strength from 2005 to 2006, which would account for the similarity in ZOE between the two years.

Table 5-35 Results for Parametric Regressions of NMDS1 on Distance from the Nearest Active Drill Centre (2004, 2005)

Result/Estimate	All stations		Stations 4 and 19 excluded	
	2004	2005	2004	2005
Bivariate regression				
r	0.348**	**0.535*** **	0.301*	**0.593*** **
Hockey-stick model				
Overall R	0.358*	**0.651*** **	0.417**	**0.665*** **
p for adding threshold	0.499	0.003	0.028	0.016
antilog X_T (threshold distance in km)	1.0	2.5	0.6	2.6
95% CI	0.4 to 1.1	1.3 to 4.9	0.4 to 1.1	1.3 to 5.2

Notes: - $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in bold)
- The Northern and Southern drill centres were active in 2004; those two centres and the Central drill centre were active in 2006
Distance was log-transformed
- *n* = 56 stations in 2004; *n* = 44 stations in 2005

Parametric distance models were not calculated for NMDS2, but Figures 5-26 and 5-27 indicate that ZOEs for both NMDS axes and overall community composition would be less than 1 km in 2004, and 2 to 5 km in both 2005 and 2006.

Taxon Abundances

Table 5-36 provides results of RM regression models testing for depth and distance effects on abundances of Paraonidae, Spionidae, Tellinidae and Amphipoda. Table 5-37 provides multiple regression slopes for each *X* variable with the effects of other *X* variables removed.

Table 5-36 Results of RM Regression Analysis Comparing Benthic Invertebrate Taxon Abundances Among 2000, 2004, 2005 and 2006

Term	df	*F* value for *Y* variable			
		Paraonidae	Spionidae	Tellinidae	Amphipoda
Among Stations					
Depth	1,32	0.01	1.12	**46.31*** **	2.56
Northern (N) *d*	1,32	2.13	0.14	2.53	0.43
Central (C) *d*	1,32	1.02	0.03	1.68	0.91
Southern (S) *d*	1,32	7.68**	1.35	0.03	**13.11*** **
Error 1[1]	32,96	**2.72*** **	1.00	**2.90*** **	1.55
Within Stations					
Overall					
Year	3,96	0.36	1.33	2.79*	0.89
Year × Depth	3,96	0.39	1.43	2.91*	0.69
Year × N *d*	3,96	1.16	1.86	2.12	1.48
Year × C *d*	3,96	**8.64*** **	2.90*	3.31*	2.22
Year × S *d*	3,96	**15.65*** **	**14.53*** **	4.18*	**9.64*** **
2000 versus 2004 to 2006					
Year	1,32	0.24	0.01	1.44	2.27
Year × Depth	1,32	0.89	0.02	0.81	0.53
Year × N *d*	1,32	0.20	2.27	0.45	4.52*
Year × C *d*	1,32	0.36	0.03	5.24*	0.01
Year × S *d*	1,32	**25.00*** **	8.35**	0.12	**32.04*** **
2004 versus 2005, 2006					
Year	1,32	0.57	4.34*	0.02	0.26
Year × Depth	1,32	0.20	3.79	0.10	0.13
Year × N *d*	1,32	0.01	0.52	3.15	0.57
Year × C *d*	1,32	2.63	0.11	1.13	8.03**
Year × S *d*	1,32	6.27*	1.24	0.07	0.62
2005 versus 2006					
Year	1,32	0.07	0.36	8.24**	0.63
Year × Depth	1,32	0.00	0.91	9.68**	1.06
Year × N *d*	1,32	5.38*	2.42	3.69	0.67
Year × C *d*	1,32	**36.11*** **	6.41*	2.65	0.08
Year × S *d*	1,32	**21.75*** **	**25.48*** **	**15.71*** **	4.92*

Notes:
- Appendix B-5 explains terms and tests in the RM regression model
- df = degrees of freedom for the numerator (effect) and denominator (error) for *F*
- *d* = distances from various drill centres
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- *n* = 37 stations sampled in all four years
- Distances and all *Y* variables were log-transformed ; log (*Y* + 1) was used for Paraonidae and Amphipoda
- [1]—Error 1 = carry-over effects or persistent differences among stations unrelated to depth or distance

Table 5-37 Multiple Regression Slopes for Benthic Invertebrate Taxon Abundances versus Depth and Distances from Drill Centres

Y variable/Taxon	*X* variable	Year			
		2000	2004	2005	2006
Paraonidae	Depth	0.015	–0.010	0.001	0.000
	Northern *d*	0.155	0.275	0.486	0.000
	Central *d*	0.055	–0.096	–0.262	0.877
	Southern *d*	–0.347	0.223	1.270	0.401
Spionidae	Depth	0.006	–0.009	0.004	0.020
	Northern *d*	0.121	–0.007	0.050	–0.250
	Central *d*	0.007	–0.041	–0.223	0.219
	Southern *d*	–0.183	0.057	0.627	–0.257
Tellinidae	Depth	0.034	0.041	0.030	0.057
	Northern *d*	0.168	0.210	0.137	–0.064
	Central *d*	–0.253	0.036	–0.135	0.019
	Southern *d*	–0.037	0.012	0.174	–0.194
Amphipoda	Depth	0.006	0.012	0.005	0.028
	Northern *d*	–0.291	0.099	0.081	–0.139
	Central *d*	–0.074	–0.376	0.093	0.026
	Southern *d*	–0.233	0.568	0.714	0.183

Notes: - *d* = distances from various drill centres
n = 37 stations sampled in all four years
- Distances and all *Y* variables were log-transformed ; log (*Y* + 1) was used for Paraonidae and Amphipoda

Paraonidae abundance was unrelated to depth (Table 5-36). In 2000, 2004 and 2005, Paraonidae abundance increased with increasing distance from the Northern drill centre but there was no distance gradient in 2006 (Table 5-37). The difference in gradients between 2005 and 2006 was significant; other differences among years were not significant (Table 5-36). There were potential delayed effects from the Central drill centre. Paraonidae abundance was uncorrelated or weakly negatively correlated with distance from the Central drill centre in 2000, 2004 and 2005, but strongly positively correlated with distance in 2006 (Table 5-37). There were also apparent effects from the Southern drill centre, with distance slopes negative in 2000, but positive in 2004 to 2006 (Table 5-37; Figure 5-47). These effects, and distance slopes, were greatest in 2005, with the difference in gradients between 2005 and 2006 significant (Table 5-36).

Centroids for Paraonidae abundance in 2000 were located northeast of the Southern drill centre in 2000 (Figure 5-48). The centroid for 2004 moved closer to the Southern drill centre despite the increases in Paraonidae abundance with distance from that drill centre. In 2005 and 2006, centroids moved north away from the Southern and Central drill centres, reflecting decreased abundance near these drill centres (primarily the Southern drill centre in 2005 and the Central drill centre in 2006). Paraonidae abundance was lower in 2005 than in other years. Variance was also greater in 2005 and 2006, when distance gradients for the Southern and Central drill centres were strongest, than in 2000 and 2004.

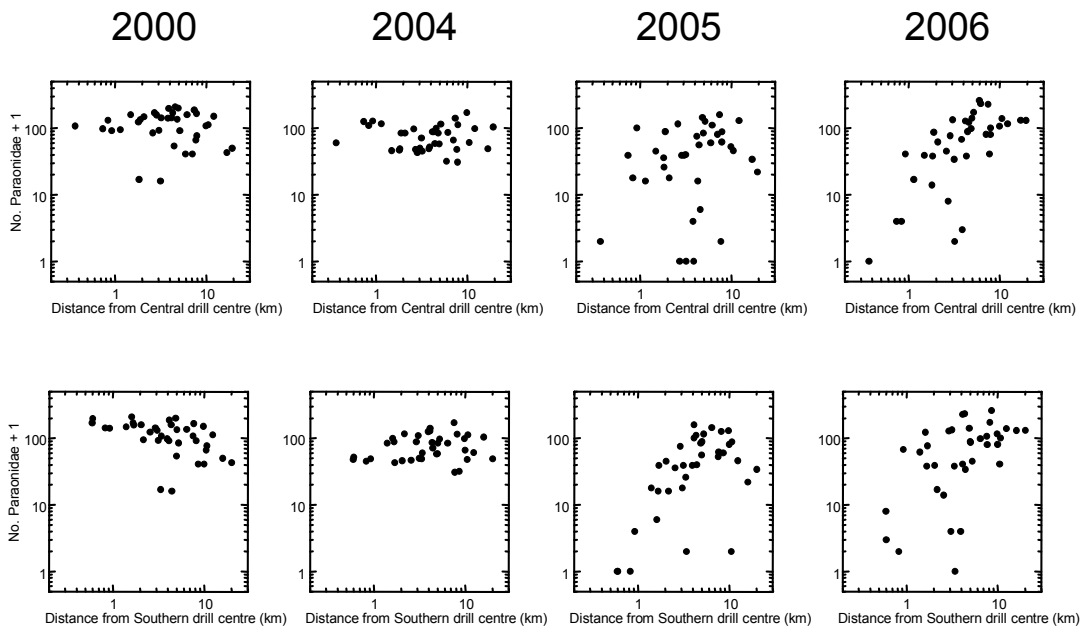


Figure 5-47 Paraonidae Abundance versus Distances from the Central and Southern Drill Centres (2000, 2004, 2005, 2006)

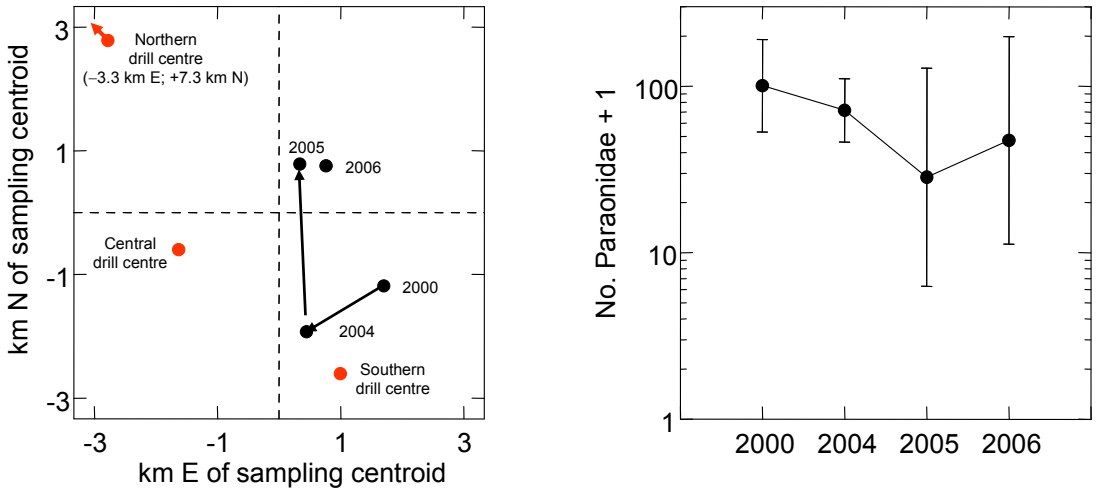


Figure 5-48 Paraonidae Abundance Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

Both the RM analyses and parametric analyses of all stations (Table 5-38) indicated that distance gradients for Paraonidae abundance were stronger in 2005 and 2006 than in 2004. Despite that, estimated ZOE for 2005 and 2006 (2.7 and 2.8 km, respectively) were not much greater than estimated ZOE for 2004 (2.0 km). 95% CI for the 2005 and 2006 estimates were also not much narrower (2 to 4 km versus 1 to 5 km). A reasonable

conclusion would be that, after 2004, the magnitude of effects (i.e., reductions in abundance) near drill centres increased more than the spatial extent of effects, as Figure 5-47 suggests.

Table 5-38 Results for Parametric Regressions of Paraonidae and Amphipoda Abundance on Distance from the Nearest Active Drill Centre (2004, 2005)

Result/Estimate	Paraonidae		Amphipoda	
	2004	2005	2004	2005
Bivariate regression				
r	0.421**	**0.633*** **	**0.517*** **	**0.657*** **
Hockey-stick model				
Overall R	0.470**	**0.756*** **	**0.618*** **	**0.670*** **
p for adding threshold	0.094	**<0.001**	0.003	0.263
antilog X_T (threshold distance in km)	2.0	2.7	2.8	6.8
95% CI	0.8 to 4.9	1.6 to 4.5	1.5 to 5.3	2.4 to 19.3

Notes:
- $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in bold)
- The Northern and Southern drill centres were active in 2004; those two centres and the Central drill centre were active in 2006
  Distance and abundances (+ 1) were log-transformed
- *n* = 56 stations in 2004; *n*=44 stations in 2005

Overall effects of depth and distance from the Northern drill centre, and changes in these effects, were not significant for Spionidae abundance. Increases in Spionidae abundance with distance from the Central drill centre were significantly greater in 2006 than in 2005, potential evidence of delayed effects (Table 5-36; Figure 5-49). Spionidae abundance increased strongly with distance from the Southern drill centre in 2005, but was uncorrelated (2004) or negatively correlated (2000, 2006) with distance from that drill centre in other years. These results may be evidence of effects from the Southern drill centre, but if so, these effects were transient (i.e., restricted to a single year, 2005).

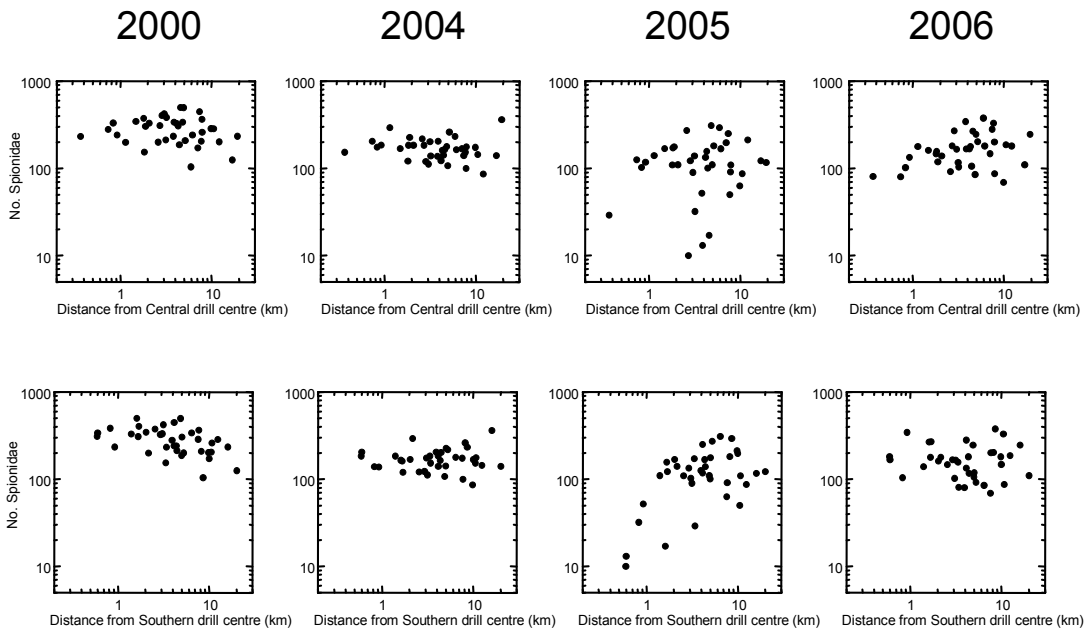


Figure 5-49 Spionidae Abundance versus Distances from the Central and Southern Drill Centres (2000, 2004, 2005, 2006)

Centroids for Spionidae moved away from the Central and Southern drill centres in 2005 and 2006, when distance gradients (increases with distance) for these drill centres were greatest (Figure 5-50). Spionidae abundance was lowest in 2005, when variance was also greatest.

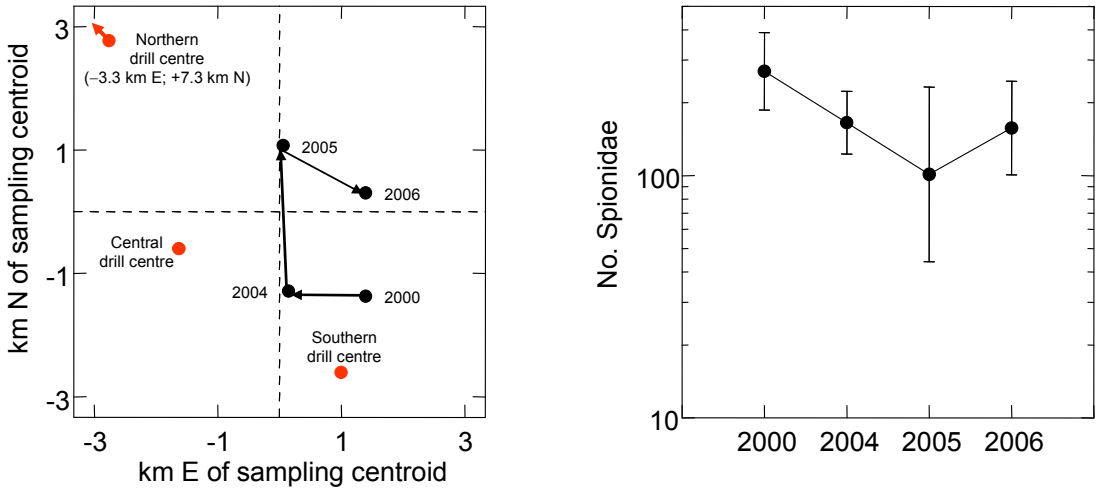


Figure 5-50 Spionidae Abundance Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

Tellinidae abundance increased with depth in all four sample years (Figure 5-51). These depth effects were arguably the strongest effects observed for any benthic invertebrate community variable. The *F* value for the Among Stations Depth term was higher than any other *F* value from the RM regression analyses in Tables 5-33 and 5-36). Depth effects were stronger in 2006 than in previous years, accounting for the significant Within Stations Year × Depth terms in Table 5-36.

There was little evidence for effects on Tellinidae abundance from drilling. Overall distance gradients for the Northern drill centre, and changes in these gradients over time, were not significant (Table 5-36). Distance gradients for the Central drill centre changed significantly over time (Table 5-36). Distance slopes for the Central drill centre were negative in 2000 (pre-drilling) and 2005 (post-drilling) and near 0 in 2004 (pre-drilling) and 2006 (post-drilling), not a pattern suggestive of drilling effects (Table 5-37, Figure 5-51). From 2000 to 2005, distance slopes for the Southern drill centre changed from weakly negative to positive (Table 5-37; 5-51). These results may be evidence of effects (i.e., reduced abundances near) from the Southern drill centre. However, the decrease in Tellinidae abundances with increasing distance from the Southern drill centre was even stronger in 2006 than in 2000, and the change from 2005 to 2006 represented the only significant Year × S *d* contrast in Table 5-36.

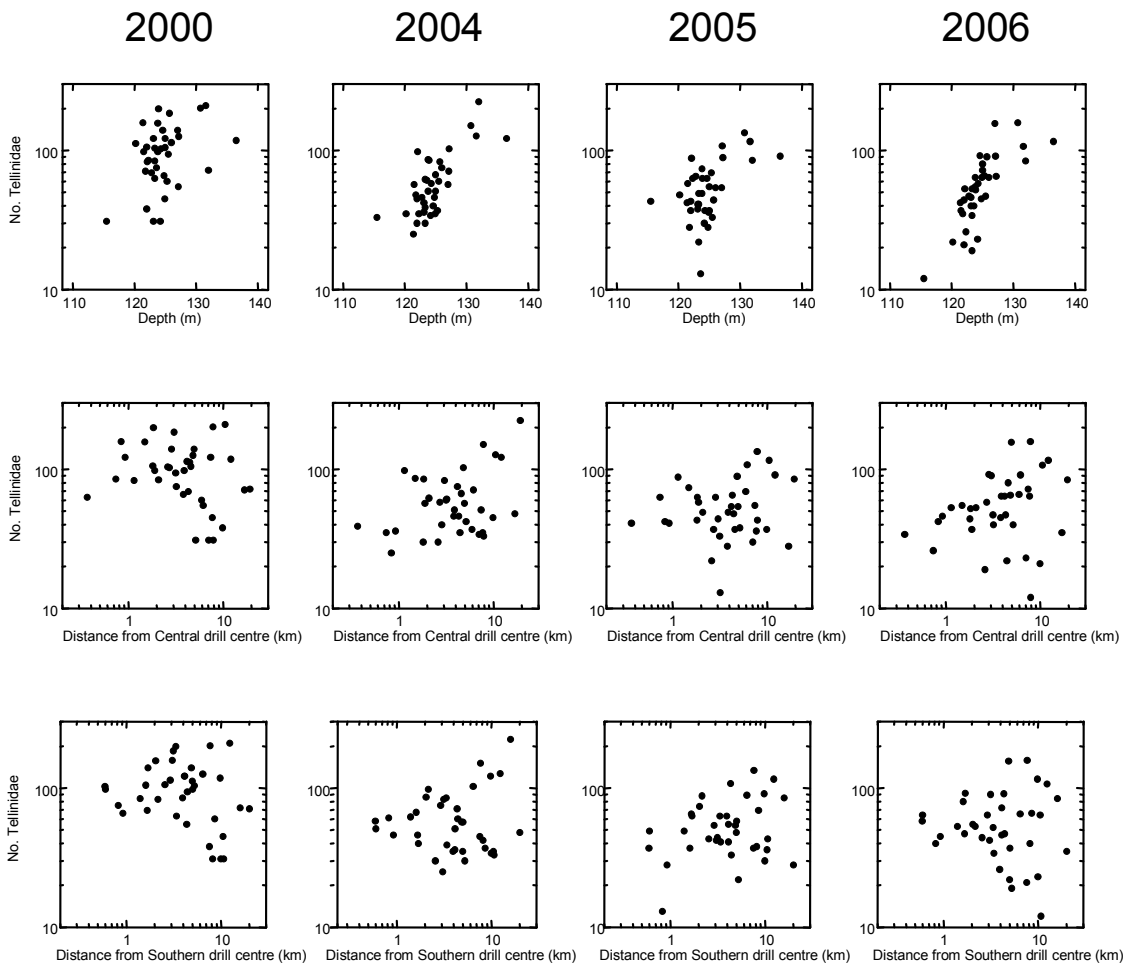


Figure 5-51 Tellinidae Abundance versus Depth and Distances from the Central and Southern Drill Centres (2000, 2004, 2005, 2006)

Centroids for Tellinidae abundance were located to the east of the sampling centroid (Figure 5-52), around what would be the approximate depth centroid for the 37 stations sampled every year. Changes in centroid locations over time were a function of changes in depth effects. Overall Tellinidae abundance was lower in 2004 to 2006 than in 2000, but this was a natural rather than project-related change. The lowest Tellinidae abundances in 2004 to 2006 generally occurred at shallower but intermediate to remote stations (Figure 5-51).

Amphipoda abundance was not significantly correlated with depth over all years (Table 5-36), although regression slopes for depth were weakly positive in all four years (Table 5-37).

Amphipods were the only taxon to provide potential evidence of post-drilling effects from the Northern drill centre in 2004 to 2006. In 2000, Amphipoda abundance decreased with distance from the Northern drill centre, but this natural gradient was reduced in strength or absent in 2004 to 2006, accounting for the significant Within Stations Year × N *d* term for the 2000 versus 2004 to 2006 contrast in Table 5-36. If any effects from the

Northern drill centre occurred, they were minor. Differences between 2000 versus 2004 to 2006 were evident from the slopes in Table 5-37 but not from the bivariate plots in Figure 5-53, and the apparently natural gradient in 2000 was weakened but not reversed in 2004 and 2005 and arguably returned in 2006.

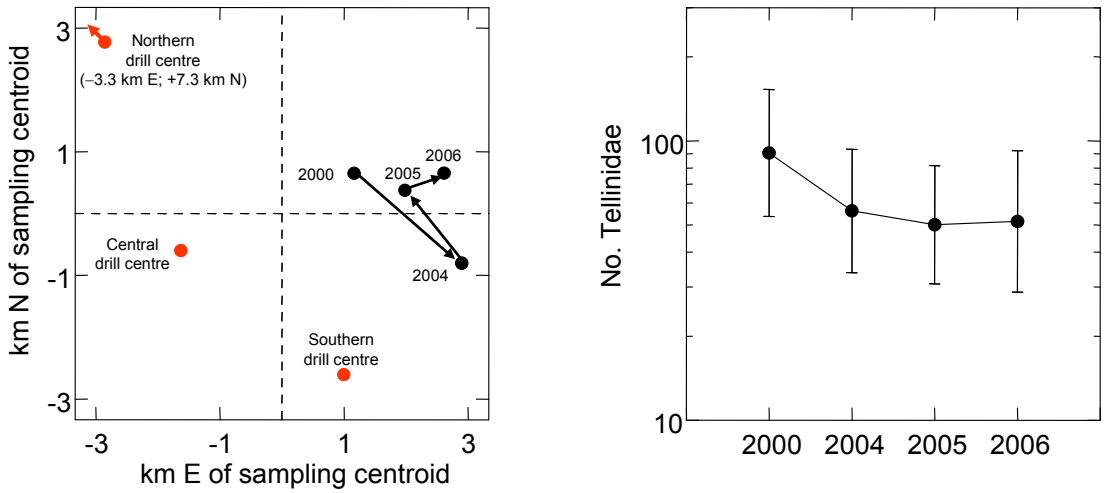


Figure 5-52 Tellinidae Abundance Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

Evidence for immediate and persistent effects on Amphipoda abundance from the Central and especially Southern drill centres was more convincing. In 2000 and 2004, prior to drilling, Amphipoda abundance decreased with distance from the Central drill centre, but in 2005 and 2006, this natural gradient was not evident or partly reversed (Table 5-37, Figure 5-53). In 2000, Amphipoda abundance decreased with distance from the Southern drill centre, but this gradient was reversed from 2004 to 2006 after drilling began (Figure 5-53). Increases in Amphipoda abundance with distance from the Southern drill centre were greater in 2004 and 2005 than in 2006 (compare slopes in Table 5-37).

Changes in Amphipoda abundance centroids over time were a function of both natural and project effects or gradients, which were of opposite direction. Consequently, these changes in centroid were not as dramatic or as easily interpretable as one might expect, given the evidence for project effects. Since 2000, and especially since 2004, centroids for Amphipoda abundance have moved north and away from the Central and Southern drill centres and sampling centroid (Figure 5-54). The shift north from 2005 to 2006 was partly attributable to drilling effects, but was also partly attributable to the partial return to the baseline (2000) gradient of decreasing abundance with increasing distance from the Northern drill centre. Amphipoda abundance decreased after 2000 and after drilling began and was lowest in 2005. The low post-drilling abundances primarily reflected reduced abundances near drill centres. Abundances at more remote stations (typically > 10 amphipods per station) have remained relatively constant over time (Figure 5-53),

although they were somewhat reduced in 2005 when Dexaminidae (*Guernea nordenskoldi*) were not collected at any station.

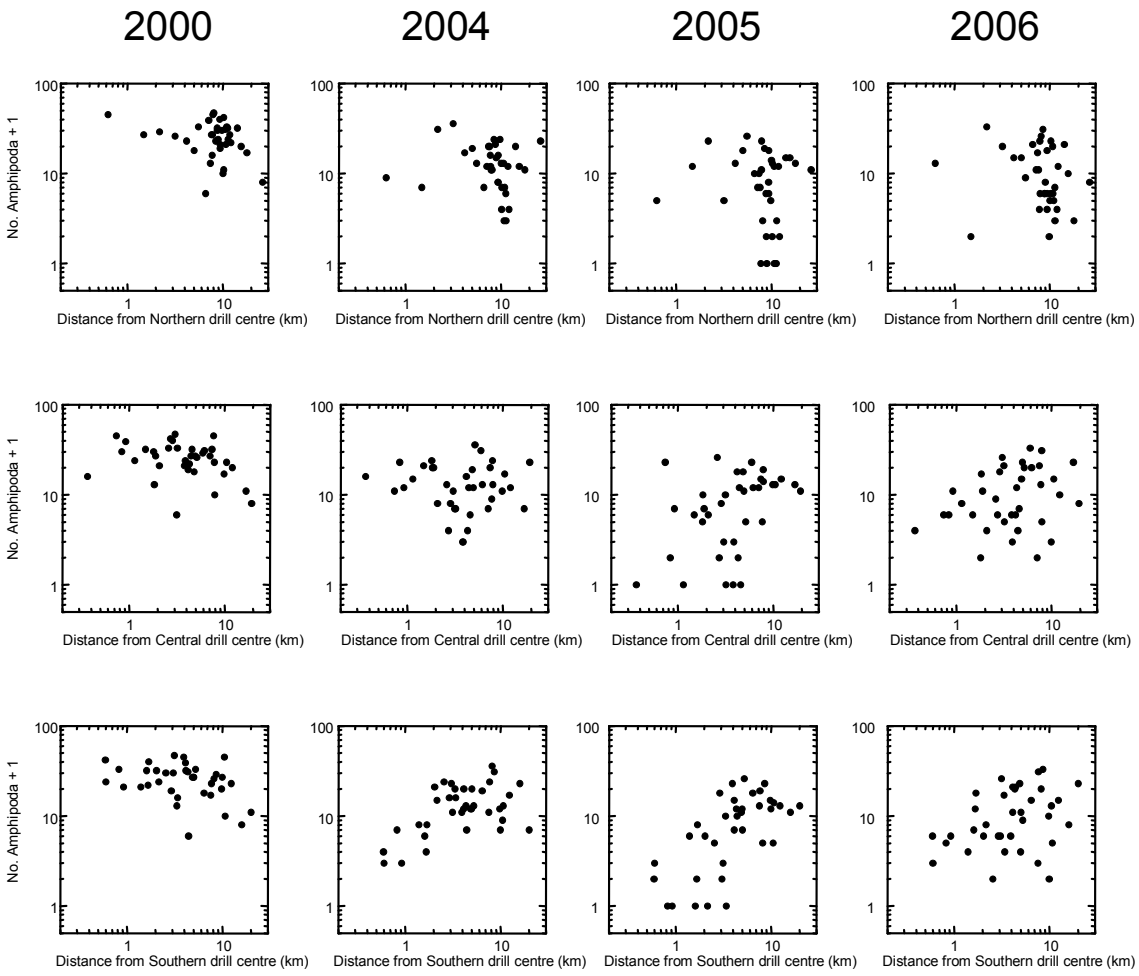


Figure 5-53 Amphipoda Abundance versus Depth and Distances from the Northern, Central and Southern Drill Centres (2000, 2004, 2005, 2006)

In 2004, the estimated ZOE for Amphipoda abundance based on all stations was 2.8 km (95% CI = 1.5 to 5.3 km) (Table 5-38), primarily because of the strong distance gradient for the Southern drill centre. In 2005, after drilling began at the Central drill centre, the ZOE arguably extended to all but the most remote stations. The estimated ZOE was 6.8 km, but adding a distance threshold did not significantly reduce error variance relative to a bivariate log-log regression, and the 95% CI for the estimated ZOE extended to 19 km but not outside the sampling grid. In 2006, adding a distance threshold also did not significantly reduce error variance relative to a bivariate model (Section 5.4.3.3). However, in 2006, distance relationships were weaker than in 2005, overall and especially for the Southern drill centre, and no parametric regression had much predictive or descriptive value.

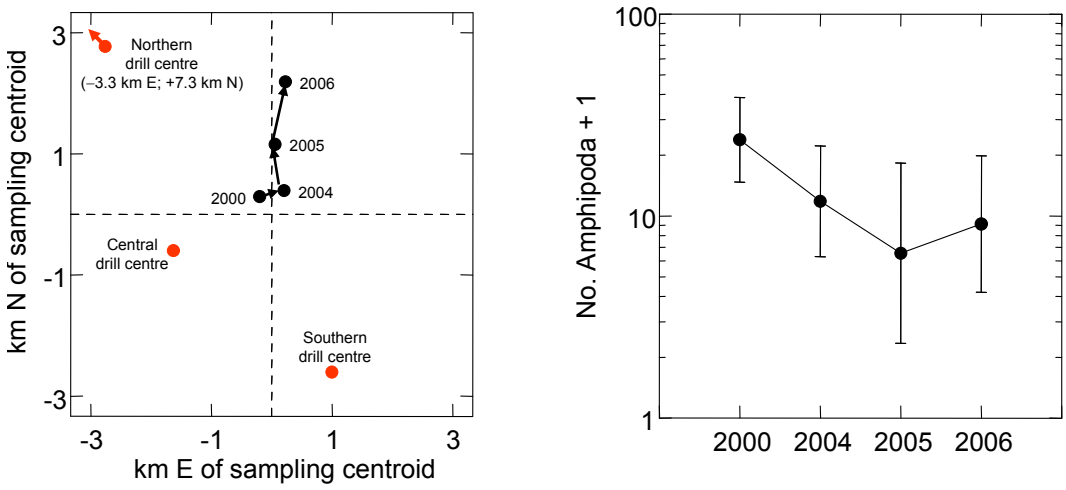


Figure 5-54 Amphipoda Abundance Centroids and Changes Over Time for the 37 Stations Sampled in 2000, 2004, 2005 and 2006

Note: - Means and SD are based on the *Y* scale used. The *Y* axes include the full range of individual values

Carry-over Effects

Results for RM comparisons of benthic invertebrate community variables among the 42 stations sampled in 2004 to 2006 (stations 4 and 19 excluded) are not presented because they were similar to results for comparisons of the 37 stations sampled in all four years. In contrast to results for most sediment physical and chemical characteristics (Section 5.4.1.3), carry-over effects or persistent differences among stations unrelated to depth or distance for invertebrate community variables were not markedly greater for 2004 to 2006 than for all four years (i.e., with 2000 included) (Table 5-39; diversity and arguably evenness are exceptions). Carry-over effects for most community variables were also stronger than carry-over effects for most sediment physical and chemical characteristics. Some carry-over effects from 2004 to 2006 may represent localized project effects not captured by large-scale distance regressions. However, note that carry-over effects from 2004 to 2006 were highly significant for Tellinidae abundances and diversity, two variables largely unaffected by distance from the drill centres. Both variables were strongly correlated with depth, and the carry-over effects may have represented small-scale variance of factors related to depth (e.g., slope or substrate composition).

Table 5-39 Carry-over Effects for Benthic Invertebrate Community Variables (2000, 2004, 2005, 2006)

Variable	*F* Values for Error 1	
	All Years (2000, 2004 to 2006)	EEM Years (2004 to 2006)
Summary measures		
Total abundance	1.77*	1.80*
Standing crop	**2.35*** **	2.20**
Richness	1.59*	1.91**
Diversity	1.26	**2.45*** **
Evenness	0.55	1.48
NMDS1	1.88*	**2.39*** **
NMDS2	1.87*	**2.38*** **

Variable	*F* Values for Error 1	
	All Years (2000, 2004 to 2006)	EEM Years (2004 to 2006)
Taxon abundances		
Paraonidae	**2.72*** **	**3.27*** **
Spionidae	1.00	1.33
Tellinidae	**2.90*** **	**3.24*** **
Amphipoda	1.55	1.47

Notes: - Carry-over effects are persistent differences among stations unrelated to depth or distance (Among Stations Error 1 in RM models)
- Effects significant at $p \leq 0.001$ in bold

5.4.3.5 Correlations Between Benthic Invertebrate Community Variables and >C_{10}-C_{21} HCs

Table 5-40 provides rank correlations (r_s) between benthic invertebrate community variables and >C_{10}-C_{21} HC concentrations for 2004, 2005 and 2006, and results of van Belle tests comparing correlations among years and testing mean correlations over all three years. For most variables, particularly those more strongly correlated with >C_{10}-C_{21} HCs, correlations were weaker in 2004 than in 2005 and 2006. However, the van Belle tests for differences in correlations have limited power for comparisons of only three years. Consequently, differences in correlations among years were significant only for NMDS1 and Paraonidae abundance. In contrast, tests of mean concentrations are powerful because the effective sample size was n = 159 stations.

Table 5-40 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and >C_{10}-C_{21} HCs (2004, 2005 and 2006)

Y variable	r_s			Differences in r_s among years	Mean r_s
	2004 (n= 56 stations)	2005 (n= 44 stations)	2006 (n= 59 stations)		
Summary measures					
Abundance	–0.170	**–0.534*** **	–0.429**	NS	**–0.367*** **
Standing crop	–0.006	–0.075	–0.264*	NS	–0.121
Richness	–0.140	–0.313*	–0.106	NS	–0.175*
Diversity	–0.121	–0.087	–0.131	NS	–0.115
Evenness	–0.025	0.272	–0.043	NS	0.051
NMDS1	0.087	**–0.569*** **	**–0.474*** **	**	NC
NMDS2	0.279*	0.312*	**0.548*** **	NS	**0.388*** **
Taxon abundances					
Paraonidae	–0.066	**–0.647*** **	**–0.578*** **	**	NC
Spionidae	0.004	–0.402**	–0.258*	NS	–0.206**
Tellinidae	–0.047	–0.109	–0.047	NS	–0.064
Amphipoda	–0.440**	**–0.729*** **	**–0.448*** **	NS	**–0.523*** **

Notes: - NS—Not Significant ($p > 0.05$); *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Differences among r_s and mean r_s were tested using the van Belle test (Appendix B-5)
- Mean r_s weight each year by sample size
- NC = Not Calculated; mean r_s were not calculated when correlations differed significantly among years
- Richness, diversity, evenness and NMDS scores were based on families

The mean correlation between total abundance and >C_{10}-C_{21} HC concentrations was significant and negative; correlations within 2005 and 2006 were also significant and negative (Table 5-40). Standing crop, richness, diversity and evenness were weakly correlated or uncorrelated with >C_{10}-C_{21} HCs within years and over all three years. The only significant mean correlation for these four variables occurred for richness;

correlations for standing crop in 2006 and for richness in 2005 were also significant. NMDS1 scores were significantly negatively correlated with >C_{10}-C_{21} HCs in 2005 and 2006, but not in 2000. NMDS2 scores were significantly positively correlated with >C_{10}-C_{21} HCs in each year and over all three years.

Paraonidae and Spionidae abundances were significantly negatively correlated with >C_{10}-C_{21} HCs in 2005 and 2006, but not in 2004 (Table 5-40). The difference in correlations among years was significant for Paraonidae but not Spionidae because 2005 and 2006 correlations were much stronger for Paraonidae. Tellinidae abundance was uncorrelated with >C_{10}-C_{21} HCs within years and over all three years. Amphipoda abundance was significantly negatively correlated with >C_{10}-C_{21} HCs within each year and over all three years.

5.4.3.6 Parametric Concentration-Response Relationships Between Benthic Invertebrate Community Variables and >C_{10}-C_{21} HC Concentrations

Parametric concentration-response regressions were fit for total abundance, NMDS1, NMDS2 and Paraonidae and Amphipoda abundances, the variables most strongly correlated with >C_{10}-C_{21} HCs with rank correlations stronger than $\pm$ 0.5 in at least one year (Table 5-40). LOWESS (Locally Weighted Scatter-plot Smoothers) trend lines (Appendix B-5) were used for plots of community variables versus >C_{10}-C_{21} HCs to suggest the most appropriate parametric relationship, if any.

Total Abundance, NMDS1 and NMDS2

Figure 5-55 plots relationships between total abundance and >C_{10}-C_{21} HC tracer concentrations. Baseline (2000) data were included to illustrate the natural range and variance of *Y* values. The lines in the plots are LOWESS trend lines. Table 5-41 provides results for bivariate and hockey-stick models.

Table 5-41 Results for Parametric Concentration-Response Models for Total Abundance versus >C_{10}-C_{21} HC Concentrations (2004, 2005 and 2006)

Result/Estimate	Year		
	2004	2005	2006
Bivariate *r*	–0.285*	**–0.618*** **	**–0.486*** **
Hockey-stick *R*	0.406**	**0.618****	**0.491*** **
p threshold	0.030	1.000	0.547
X_T (threshold in mg/kg dry)	2.2	None	0.30
95% CI	0.2 to 24		<0.1 to 3.6

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- >C_{10}-C_{21} HC concentrations and total abundance were log-transformed

In 2004, adding a threshold to a bivariate log-log regression of total abundance on >C_{10}-C_{21} HC concentrations significantly reduced error variance (Table 5-41). The estimated threshold was 2.2 mg/kg >C_{10}-C_{21} HCs, approximately the point at which the LOWESS line in Figure 5-55 becomes linear. However, CI for the threshold were wide (0.2 to 24 mg/kg), with the lower limit of 0.2 mg/kg less than RDL of 0.3 mg/kg. In 2005, the relationship between total abundance and >C_{10}-C_{21} HCs was linear throughout the entire range of observed concentrations (i.e., the relationship was a shaft with no blade). A threshold within the range of observed concentrations could not be estimated. In 2006, adding a threshold did not significantly reduce error variance, and the estimated threshold of 0.3 mg/kg was equal to the RDL. Therefore, a linear log-log relationship was

also the most appropriate model for 2006. In 2005, but not in 2004 and 2006, abundances at higher concentrations were well below the range of values observed in 2000, and at lower concentrations in 2004 to 2006.

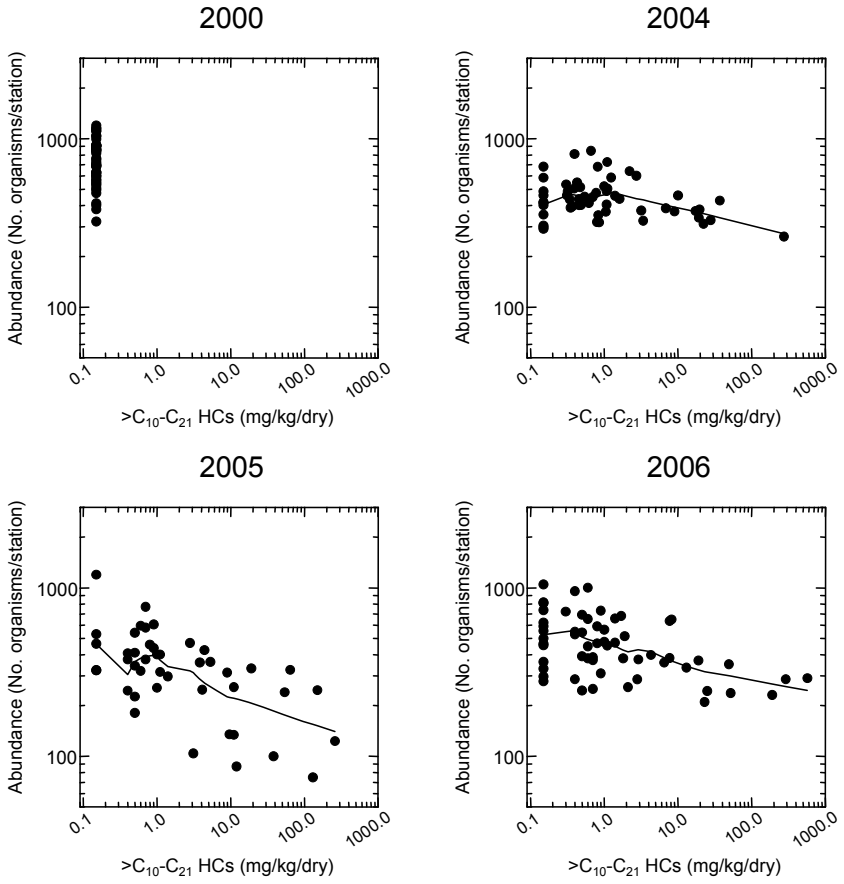


Figure 5-55 Total Abundance versus >C_{10}-C_{21} HC Concentrations (2000, 2004, 2005 and 2006)

Figure 5-56 plots concentration-response relationships for NMDS1. Table 5-42 provides results of parametric regressions for all stations, and with Reference stations 4 and 19 deleted. One or both of these two stations were often outliers in regressions and deleting them improved regression fits and reduced error variances at lower concentrations. Deleting these two stations had little effect on estimates of threshold concentrations except to narrow CI.

In 2004, adding a threshold to concentration-response relationships for NMDS1 significantly reduced error variance relative to bivariate regressions (Table 5-42). Hockey-stick models with or without stations 4 and 19 were similar to the LOWESS line in Figure 5-55. The linear portion (=shaft) connected the point at the extreme right at a concentration of 275 mg/kg with the cluster of points at the next highest concentrations of approximately 30 mg/kg, the estimated threshold concentration in Table 5-42. Therefore, in 2004, the linear portion (=shaft) of the hockey-stick model was effectively a two-point regression. In 2005, the relationship between NMDS1 and >C_{10}-C_{21} HCs was linear through most of the range of observed and detectable concentrations. Adding a

threshold did not significantly reduce error variances, and the lower CL (0.2 mg/kg) for the estimates were less than the RDL of 0.3 mg/kg. In 2006, adding a threshold significantly reduced error variances and estimated threshold concentrations were 6 mg/kg.

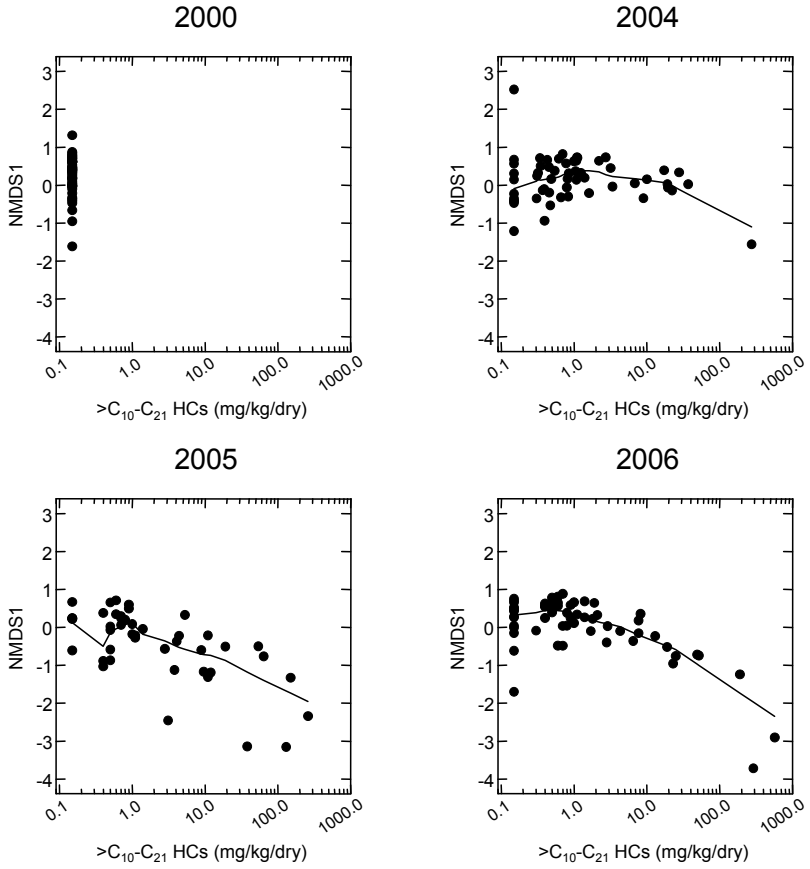


Figure 5-56 NMDS1 versus >C_{10}-C_{21} HC Concentrations (2000, 2004, 2005 and 2006)

Parametric concentration-response regressions were not calculated for NMDS2 because there was either no relationship (2004) or the relationships did not fit a linear or hockey-stick model (2005 and 2006) (Figure 5-57). Stations 4 and 19 were also outliers. For example, in 2005 and 2006, stations 4 and 19 provided the highest and lowest NMDS2 scores. With these two stations deleted, the best-fit model for 2005 was a hockey-stick regression with an upper concentration threshold (i.e., a right-blade model in contrast to the left-blade models used for other variables). In other words, NMDS2 scores apparently increased with increasing concentration at lower concentrations up to some threshold then did not vary with concentration at *higher* concentrations. A right-blade model would also fit the 2006 data, but a sigmoid (S-shaped) curve with upper and lower asymptotes or thresholds would be an even better fit.

Table 5-42 Results for Parametric Concentration-Response Models for NMDS1 versus >C_{10}-C_{21} HC Concentrations (2004, 2005 and 2006)

Result/Estimate	Year		
	2004	2005	2006
All stations			
Bivariate *r*	–0.167	**–0.672*** **	**–0.677*** **
Hockey-stick *R*	0.394*	**0.696*** **	**0.814*** **
p threshold	0.007	0.131	**<0.001**
X_T (threshold in mg/kg dry)	30	0.9	5.9
95% CI	6.3 to 145	0.2 to 4.0	3.1 to 11
Stations 4 and 19 excluded			
Bivariate *r*	–0.127	**–0.689*** **	**–0.746*** **
Hockey-stick *R*	0.465**	**0.711*** **	**0.861*** **
p threshold	0.002	0.361	**<0.001**
X_T (threshold in mg/kg dry)	32	0.8	5.6
95% CI	9.0 to 111	0.2 to 3.5	3.2 to 9.9

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- >C_{10}-C_{21} HC concentrations, total abundance and amphipod abundance (+ 1) were log-transformed
- NMDS1 scores were based on families

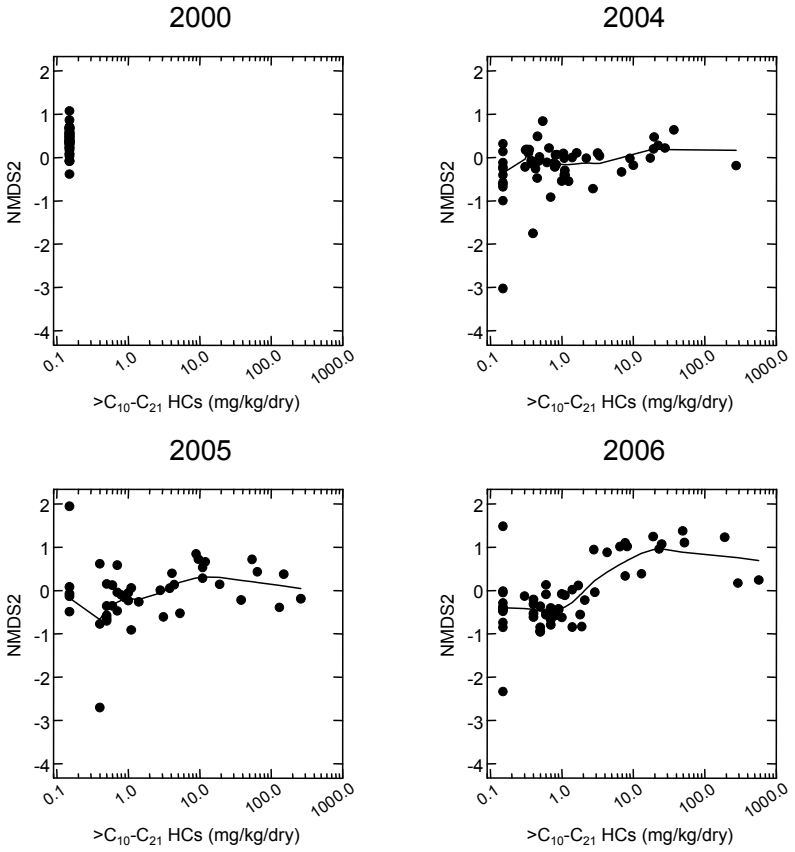


Figure 5-57 NMDS2 versus >C_{10}-C_{21} HC Concentrations (2000, 2004, 2005 and 2006)

Qualitative estimates of concentration-response relationships on overall community composition can be made from examination of NMDS plots. In Figure 5-58, stations

were colour-coded based on logarithmically spaced concentration intervals. In 2004, the greatest community differences generally occurred among lower concentrations, even if stations 4 and 19 are ignored. In 2005 and 2006, there were greater community differences along both axes between higher concentrations (greater than 10 mg/kg; black and red symbols) versus lower concentrations (≤ 1 mg/kg; yellow and brown symbols), again ignoring stations 4 and 19. Furthermore, community differences among intermediate concentrations between 1 to 10 mg/kg (blue symbols in Figure 5-58) were also partly related to differences in concentration. Plots and LOWESS trend lines for both NMDS1 and NMDS2 versus >C_{10}-C_{21} HCs were approximately linear through 1 to 10 mg/kg in 2005 and 2006 (Figures 5-56 and 5-57).

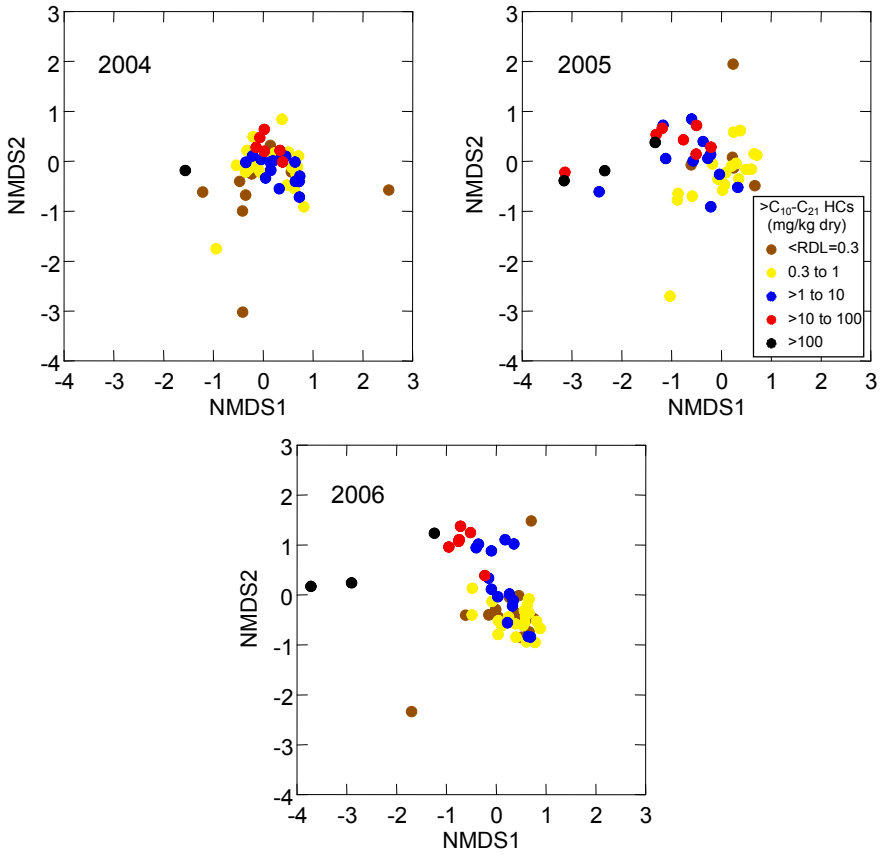


Figure 5-58 NMDS Plots Based on Relative (%) Abundances of Invertebrate Taxa (2004, 2005 and 2006)

Overall, there were minimal "effects" on community composition in 2004, except at the highest >C_{10}-C_{21} HC concentrations. A reasonable threshold concentration for overall community effects in 2005 and 2006 would be at the lower end of the 1 to 10 mg/kg range. The approximately 5-fold difference between estimated threshold concentrations for NMDS1 in 2005 versus 2006 (Table 5-41) should not be interpreted as evidence that potential effects on overall community responses were greater in 2005 than in 2006. Instead, community effects in 2006 occurred along a different community axis (NMDS2), representing a difference in effects "type" versus "magnitude". Statistically, it was also easier to estimate a concentration threshold in 2006 than in 2005 because variance

about the liner relationship at higher concentrations was lower and there were also more concentration values near or below RDL with the addition of 14 stations near the proposed West Alpha and West Bravo drill centres (Figure 5-56).

Taxon Abundances

Figure 5-59 plots concentration-response relationships between Paraonidae abundance and >C_{10}-C_{21} HC concentrations and Table 5-43 provides results of parametric regressions. Adding a threshold concentration significantly reduced error variances in 2004. The estimated threshold concentration was 6 mg/kg, and Paraonidae abundances at all but the highest concentration were within the range observed at lower concentrations (≤ 1 mg/kg) that year and in 2000 (20 to 200 Paraonidae/station).

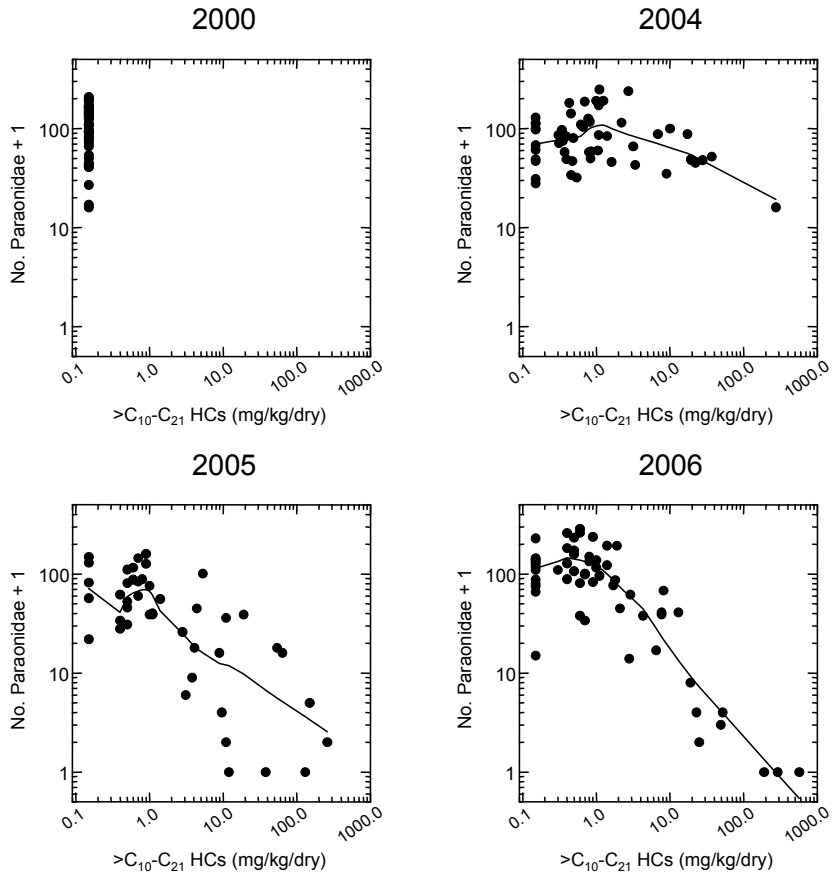


Figure 5-59 Paraonidae Abundance versus >C_{10}-C_{21} HC Concentrations (2000, 2004, 2005 and 2006)

Table 5-43 Results for Parametric Concentration-Response Models for Paraonidae Abundance versus >C_{10}-C_{21} HC Concentrations (2004, 2005 and 2006)

Result/Estimate	Year		
	2004	2005	2006
Bivariate *r*	0.239	**–0.741*** **	**–0.832*** **
Hockey-stick *R*	0.439**	**0.763*** **	**0.907*** **
p threshold	0.003	0.077	**<0.001**
X_T (threshold in mg/kg dry)	6.4	0.7	1.3
95% CI	1.6 to 26	0.2 to 2.5	0.8 to 2.2

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- >C_{10}-C_{21} HC concentrations and Paraonidae abundance (+ 1) were log-transformed

Estimated thresholds for Paraonidae abundances in 2005 and 2006 were lower, approximately 1 mg/kg (Table 5-42). Abundances at higher concentrations were well below ranges for 2000 and at low concentrations in subsequent years, and approached or reached 0 at the highest concentrations. Adding a threshold in 2005 did not significantly reduce error variance ($0.05 < p < 0.10$). However, the concentration-response relationship in 2005 should be considered similar to the relationship in 2006 but with greater variance about any linear relationship at higher concentrations (Figure 5-59). 95% CI were wide for the 2005 estimate and extended below the RDL of 0.3 mg/kg, but included the narrower CI for the 2006 threshold (Table 5-43).

Figure 5-60 plots concentration-response relationships between Amphipoda abundance and >C_{10}-C_{21} HC concentrations, and Table 5-44 provides results of parametric regressions. In 2004, there was a strong relationship (decrease) between Amphipoda abundance and >C_{10}-C_{21} HC concentrations, and adding a threshold significantly reduced error variance. The estimated threshold concentration was 5 mg/kg with 95% CI of 2 to 11 mg/kg. Amphipoda was the only community variable with 2004 values at higher concentrations extended below the range of values observed in 2000 and in subsequent years at concentrations near or below RDL of 0.3 mg/kg. In 2005, there was a stronger linear relationship across the entire range of observed concentrations with no threshold. A hockey-stick model improved R^2 only to the fifth decimal place, and the estimated threshold of 0.16 mg/kg was effectively equal to the value of ½ RDL = 0.15 mg/kg used for values less than RDL. In contrast, adding a threshold to concentration-response relationships in 2006 did not significantly reduce error variance because the overall relationship was much weaker than in 2004 and 2005. Error variance can best be reduced by fitting a right-blade model, with Amphipoda abundance decreasing with concentration up to an *upper* threshold concentration, beyond which no further decreases occur (i.e., as the LOWESS trend line in Figure 5-60 indicates).

Table 5-44 Results for Parametric Concentration-Response Models for Amphipoda Abundance versus >C_{10}-C_{21} HC Concentrations (2004, 2005, 2006)

Result/Estimate	Year		
	2004	2005	2006
Bivariate *r*	**0.661*** **	**0.773*** **	**0.411*** **
Hockey-stick *R*	**0.739*** **	**0.773*** **	**0.411*** **
p threshold	**<0.001**	0.954	1.000
X_T (threshold in mg/kg dry)	4.9	0.2	
95% CI	2.2 to 11	0.03 to 1.0	

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- >C_{10}-C_{21} HC concentrations and Amphipoda abundance (+ 1) were log-transformed

Overall, $>C_{10}$-C_{21} HC concentrations were a better *X* variable or predictor of biological responses than distance from the nearest drill centre. The concentration-response relationships could account for some variance in responses at stations near drill centres where contamination but not distance varied widely (i.e., where "which drill centre is nearest?" was important). For example, Table 5-45 compares *R* values for parametric concentration-response versus distance relationships for hockey-stick models for Paraonidae and Amphipoda abundances. *R* values were substantially greater for concentration-response than for distance relationships when those relationships were strong (i.e., significant at $p < 0.001$).

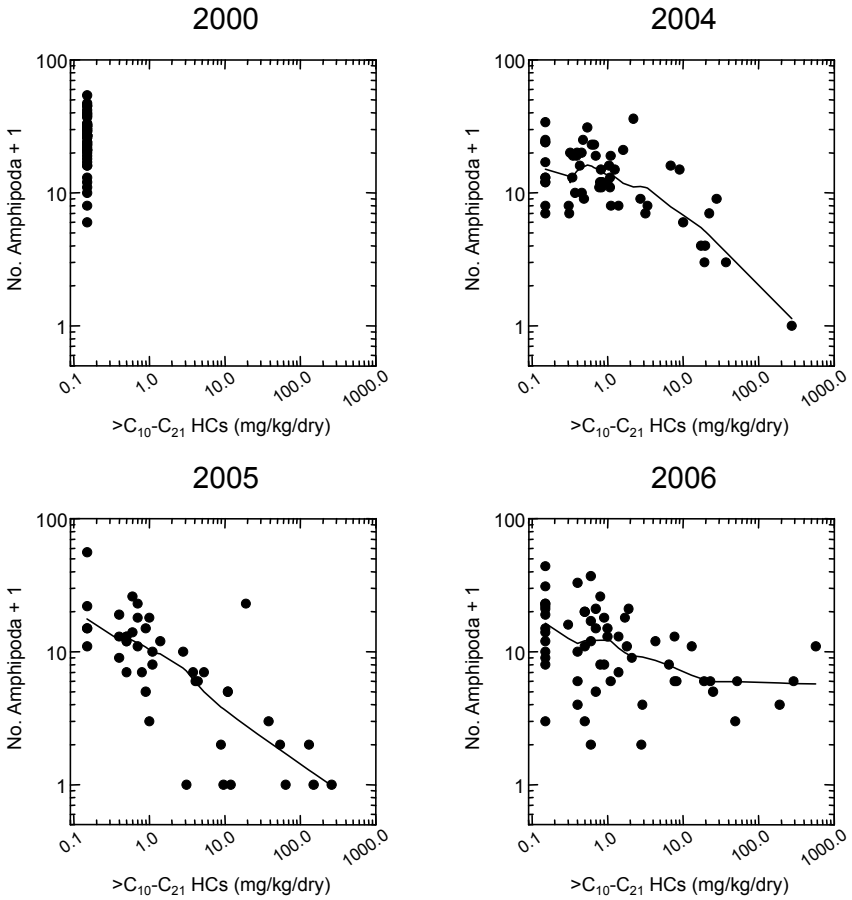


Figure 5-60 Amphipoda Abundance versus $>C_{10}$-C_{21} HC Concentrations (2000, 2004, 2005 and 2006)

Table 5-45 Correlations (*R*) for Hockey-stick Concentration-Response and Distance Models for Paraonidae and Amphipoda Abundance versus >C_{10}-C_{21} HC Concentrations (2004, 2005, 2006)

Response (*Y*) variable	Year	*X* variable	
		Distance	>C_{10}-C_{21} HC concentration
No. Paraonidae	2004	0.470**	0.439**
	2005	**0.665*** **	**0.763*** **
	2006	**0.792*** **	**0.907*** **
No. Amphipoda	2004	**0.618*** **	**0.739*** **
	2005	**0.670*** **	**0.773*** **
	2006	0.405**	0.411**

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold)
- Distance = distance to the nearest active drill centre (Northern and Southern in 2004; Northern, Central and Southern in 2005 and 2006)
- Distances, >C_{10}-C_{21} HC concentrations and Paraonidae/Amphipoda abundance (+ 1) were log-transformed

5.5 Summary of Findings

5.5.1 Physical and Chemical Characteristics

Sediments collected from 59 stations in 2006 were predominantly (97.3%) sand. Fines (1.2%) and TOC content (0.085%) were low.

PAHs and BTEX were not detected at any station in 2006 at an RDL of 0.03 mg/kg. >C_{10}-C_{21} HCs were detected at 45 of 59 stations at an RDL of 0.3 mg/kg. >C_{21}-C_{32} HCs were detected at 58 of 59 stations at an RDL of 0.3 mg/kg. Aluminum, barium, chromium, iron, lead, manganese, strontium, uranium, vanadium, ammonia and sulphur were detected at all 59 stations.

In 2006, fines and TOC content were not significantly correlated. Concentrations of barium and other metals were positively correlated with fines and TOC content. Barium and >C_{10}-C_{21} HC concentrations, used as tracers of drilling muds, were strongly positively correlated. Concentrations of other metals, sulphur and sulphide were positively correlated with concentrations of the two tracers. Sulphide concentrations were positively correlated with concentrations of metals other than barium and negatively correlated with redox levels. Ammonia concentrations were uncorrelated with concentrations of tracers, metals, sulphur, sulphide and redox levels.

In 2006, concentrations of barium and >C_{10}-C_{21} HCs decreased significantly with distances from drill centres. Estimated zones of influence were 1.9 km (95% CI: 1.4 to 2.6 km) for barium and 5.9 km (95% CI: 4.2 to 8.5 km) for >C_{10}-C_{21} HCs. These zones of influence were based on distance from the nearest drill centre (Northern, Central, Southern). Concentrations of the two tracers were generally greater to the southeast of the Central and/or Southern drill centres, in the direction of residual currents.

Relationships between barium concentrations and distance from the Northern drill centre did not change between baseline (2000) and EEM years (2004, 2005, 2006), after drilling began at this centre. In contrast, relationships with distance from the Southern drill centre changed substantially and significantly between baseline and EEM years after drilling started, from “no relationship” to a “strong decrease in concentration with distance”. The distance gradient for the Southern drill centre was stronger in 2004 than

in 2005 and 2006. A similar change in relationships with distance from the Central drill centre occurred between 2004 and 2005, after drilling started. The distance gradient for the Central drill centre was stronger in 2006 than in 2005. Overall barium concentrations progressively increased over time.

In 2000, all $>C_{10}$-C_{21} HC concentrations were less than RDL (0.03 mg/kg). In 2004 to 2006, most concentrations were greater than RDL. $>C_{10}$-C_{21} HC concentrations decreased significantly with distances from the Northern and Southern drill centres in 2004 to 2006, after drilling started at these two centres. Distance gradients for both centres were stronger in 2004 than in 2005 and 2006. A similar decrease with distance from the Central drill centre was not observed until 2005, after drilling started at this centre. The distance gradient for the Central drill centre increased in strength from 2005 to 2006. Overall $>C_{10}$-C_{21} HC concentrations were greater in 2005 and 2006 than in 2004.

In 2006, sulphur concentrations decreased significantly with distance from the nearest drill centre. In 2004, sulphur concentrations increased with distance from the Northern and Southern drill centres, after drilling began at these centres. These gradients were weaker or reversed in 2005 and 2006. Sulphur concentrations decreased with distance from the Central drill centre in 2005 and, to a larger extent, in 2006, after drilling began at that centre.

Fines content consistently and significantly increased with depth and decreased with distance from the Southern drill centre, in all four sample years (2000, 2004, 2005 and 2006). Fines content also decreased with distance from the Central drill centre in 2006, but not in previous years. Distance gradients for the Northern drill centre varied in strength and direction among years, with decreases with distance greatest in 2006.

TOC content increased with distance from the Central drill centre and was unrelated to depth and distances from the Northern and Southern drill centres, in all four sample years.

Concentrations of metals other than barium were uncorrelated with depth and distances from the Northern and Central drill centres in all four years. Concentrations decreased with distance from the Southern drill centre in all four years, with the distance gradient strongest in 2004.

Ammonia concentrations were not measured in 2000, and were unrelated to depth and distance from the Northern drill centre in 2004, 2005 and 2006. In 2005, ammonia concentrations increased with distance from the Central drill centre and decreased with distance from the Southern drill centre; these gradients were weaker or non-existent in 2004 and 2006. In 2006, ammonia concentrations were much lower than in 2004 and 2005.

In 2006, redox levels were uncorrelated with distance from drill centres or concentrations of tracers (barium and $>C_{10}$-C_{21} HCs). In contrast, in 2005, redox levels increased with distance from drill centres and decreased with increasing tracer concentrations.

Carry-over effects, or persistent differences among stations unrelated to distance or depth, were small and generally not significant over all four sample years for sediment physical and chemical variables. Carry-over effects were larger and usually significant,

especially for barium, >C_{10}-C_{21} HCs and sulphur, when only the three EEM years (2004, 2005 and 2006) were compared.

5.5.2 Toxicity

No sediment samples were toxic to bacteria in 2000, 2004, 2005 and 2006 when tested in laboratory toxicity tests.

No sediment samples were toxic to amphipods in 2000 and 2004 when tested in laboratory toxicity tests. In 2005, sediment from one station was toxic to amphipods (survival: 28%), and survival in sediment from another station (68%) was lower than in samples from other stations sampled in 2000, 2004 and 2005 (survival was usually greater than 80%). In 2006, sediments from three stations were classified as toxic (survival: 29, 34% and 66%) and survival from one other stations was low (68.75%). These four stations were closer to either or both the Central and Southern drill centres, and had higher barium and >C_{10}-C_{21} HC concentrations, than most other stations. However, survival was high for other stations closer to drill centres and with higher tracer concentrations.

5.5.3 Benthic Community Structure

In each sample year (2000, 2004, 2005 and 2006), polychaetes accounted for 72 to 78% of the invertebrates collected. Bivalves accounted for 14 to 18% of the total in each year. Amphipoda, Tanaidacea and Echinodermata were the only other “major” (higher-level) taxa accounting for more than 1% of total abundance in one or more years.

The primary patterns of variance in community composition were related to the relative abundances of the two dominant major taxa (i.e., polychaetes versus bivalves). When relative abundances of polychaetes increased, relative abundances of bivalves decreased, and vice versa. Three families, the polychaetes Spionidae and Paraonidae and the bivalve Tellinidae, accounted for 65 to 70% of the invertebrates collected. Secondary patterns of variance over space and time were related to the relative abundance of Spionidae versus Paraonidae and differences in abundances of sub-dominant families.

Total abundance was generally greater where the three dominant families (Spionidae, Paraonidae and Tellinidae) were abundant. Richness was positively correlated with total abundance, with more taxa (families) generally collected where and when more organisms were collected. Diversity was largely unrelated to total abundance.

In 2006, most benthic invertebrate community summary measures, and abundances of the dominant families and Amphipoda, were not significantly correlated with sediment particle size and TOC content. Tellinidae abundance was positively correlated with fines and TOC content, and richness was positively correlated with gravel content. Correlations between invertebrate community variables and drilling mud tracers (barium,>C_{10}-C_{21} HCs) and sulphur were much stronger. Total abundance, polychaete dominance (i.e., polychaetes:bivalves) and abundances of Paraonidae, Spionidae and Amphipoda decreased with increasing tracer and sulphur concentrations.

In 2006, total abundance, polychaete dominance, Paraonidae abundance and Amphipoda abundance significantly increased with increasing distance from the drill

centres. There were also differences in overall community composition among distance categories. A zone of effects was not estimated for total abundance because of the confounding effects of depth (total abundance also increased with increasing depth). The estimated zone of effects for polychaete dominance was 2.2 km. The 95% CI of 1.4 to 3.5 km for that estimate, and not any more precise value, should probably be used as the zone of effects because estimates were sensitive to the stations included and statistical methods used. Changes in overall community composition extended 2 to 5 km from drill centres. The estimated zone of effects for Paronidae abundance was 2.8 km (95% CI: 1.9 to 4.2). A zone of effects could not be estimated for Amphipoda abundance because the distance relationship was weak for that taxon.

Total abundance increased with depth and was uncorrelated with distance from the Northern drill centre, in all four sample years (2000, 2004, 2005 and 2006). Total abundance decreased with distance from the Southern drill centre in 2000. This distance gradient was absent in 2004 and reversed in 2005, which might suggest delayed drilling effects. However, in 2006, the gradient reversed again and was similar to the baseline (2000) gradient. Total abundance also increased with distance from the Central drill centre in 2006 but not in 2005, although drilling began prior to 2005 sampling.

In all four sample years, polychaete dominance decreased with increasing depth and was unrelated to distance from the Northern drill centre. Polychaete dominance decreased with distance from the Southern drill centre in 2000, but increased with distance in 2004 to 2006. The distance gradient was much stronger in 2005 than in 2004 or 2006. However, in 2006, there was a strong distance gradient for other aspects of community composition (e.g., variance within Polychaeta and Bivalvia, and among sub-dominants). Polychaete dominance increased with distance from the Central drill centre in 2006 but not in 2005.

Paraonidae abundance increased with distance from the Northern drill centre in 2000 and 2006 but not in 2004 and 2005. Like total abundance and polychaete dominance, distance gradients (increases with distance) for the Central drill centre were not evident until 2006, and were stronger for the Southern drill centre in 2005 than in 2004 and 2006.

In 2000, Amphipoda abundance decreased with distances from all three drill centres. The baseline distance gradients for the Northern and Southern drill centres were reversed in 2004, after drilling began at these two centres. In 2006, Amphipoda abundance again decreased with distance from the Northern drill centre, and the distance gradient for the Southern drill centre was weaker than in 2004 and 2005. The baseline distance gradient for the Central drill centre was reversed in 2005 and 2006, after drilling began at this centre.

Richness and diversity increased with increasing depth and decreased with distance from the Central drill centre, in all four sample years. Depth and distance effects for abundance of Spionidae, the most abundant taxon, were similar to but weaker than those for total abundance. Abundance of Tellinidae, the dominant bivalve, decreased significantly and substantially with depth in all four years, which would account for some or most of the depth effects on total abundance and polychaete dominance (i.e., polychaete:bivalve).

Carry-over effects for invertebrate community variables were generally stronger than for sediment physical and chemical characteristics when all four sample years were compared. Carry-over effects for the community variables were not markedly stronger when only the three EEM years (2004, 2005 and 2006) were compared.

5.5.4 Concentration-Response Relationships

In 2005 and 2006, total abundance, polychaete dominance and abundances of Paraonidae, Spionidae and Amphipoda decreased significantly with increasing $>C_{10}$-C_{21} HC concentrations. In 2004, only total and amphipod abundance were significantly negatively correlated with $>C_{10}$-C_{21} HC concentrations. $>C_{10}$-C_{21} HC concentrations were effective quantitative predictors, usually more effective than distances from drill centres, of post-drilling total abundance, polychaete dominance, Paraonidae abundance and Amphipoda abundance values.

In 2004, estimated threshold $>C_{10}$-C_{21} HC concentrations for total abundance (i.e., concentrations below which effects did not occur) were 2.2 mg/kg. The 95% CI (0.2 to 24 mg/kg) for that estimate included the RDL of 0.3 mg/kg and most of the observed concentration values. In 2005 and 2006, concentration-response relationships were linear across all or most of the concentration range (i.e., with no threshold concentration, or with a threshold close to the lowest concentrations). The linear relationship was stronger in 2005 than in 2006.

In 2004, the estimated threshold concentration for polychaete dominance was 32 mg/kg (95% CI: 9 to 111 mg/kg), but that estimate was entirely a function of the low polychaete dominance at a single station with the only concentration greater than 100 mg/kg. In 2005, the concentration-response relationship for polychaete dominance was linear across most of the concentration range. In 2006, the estimated threshold concentration was 5.6 mg/kg (95% CI: 3.2 to 9.9 mg/kg). For both years, a reasonable estimate of a threshold concentration for effects on overall community composition would be towards the lower end of the 1 to 10 mg/kg range. It was easier to estimate a threshold in 2006 than in 2005 because of the addition of 14 West stations with low $>C_{10}$-C_{21} HC concentrations.

In 2004, the concentration-response relationship for Paraonidae abundance was weak and the estimated concentration threshold of 6.4 mg/kg had wide 95% CI (1.6 to 26 mg/kg). Estimated thresholds in 2005 and 2006 were 0.7 (95% CI: 0.2 to 2.5) and 1.4 mg/kg (95% CI: 0.8 to 2.2 mg/kg), respectively. Given the overlap between the CI, concentration-response relationship should be considered similar for the two years.

In 2004, the estimated threshold concentration for Amphipoda abundance was 4.9 mg/kg (95% CI: 2.2 to 11 mg/kg). In 2005, the concentration-response relationship was linear across the concentration range. In 2006, the concentration-response relationship was much weaker than in 2004 and 2005, and a threshold could not be estimated.

6.0 Commercial Fish Component

6.1 Field Collection

The *CCG Wilfred Templeman*, its crew and Fisheries and Oceans Canada (DFO) Science personnel were chartered for the 2006 commercial fish survey of American plaice ("plaice") and snow crab ("crab") between July 11 and 20, 2006. Collection dates for the baseline program and EEM programs, and tests performed on collected specimens, are shown in Table 6-1.

Table 6-1 Field Trip Dates

Trip	Collections/Tests	Date
2000 Baseline Program	Study Area Crab for Body Burden Analysis; Study and Reference Area plaice for body burden and taste analysis; Study Area plaice for health analysis.	July 4 to July 10, 2000
2002 Baseline Program	Reference Area crab for body burden analysis; Study and Reference Area crab for taste analysis; Reference Area plaice for health analysis.	June 24 to July 10, 2002
2004 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	July 10 to July 18, 2004
2005 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	July 8 to July 13, 2005
2006 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	July 11 to July 20, 2006

Notes:
- Since the location of Reference Areas sampled from 2004 to 2006 differs from locations sampled in 2000 and 2002, data from Reference Areas collected during baseline can not be compared to EEM Reference Area data
- Study Area data are generally comparable

Details on the collection and processing of 2000, 2002, 2004 and 2005 samples are presented in Husky Energy (2001; 2003; 2005; 2006). Sampling for the 2006 program was conducted under a DFO Stock Assessment license. A total of 99 plaice (out of 894 fish caught) and 181 crab from the White Rose Study Area were retained for analysis in 2006. A total of 120 plaice (out of 615 fish caught) and 127 crab from the four Reference Areas were retained. Plaice that were not retained were released with as little damage as possible. Both plaice and crab were collected using a Campellan 1800 trawl towed at three knots for 15 minutes per transect. Because of limited time available for sampling, the liner was removed from the Campellan trawl in order to minimize by-catch and speed up sample processing time. Location of transects are provided in Figure 1-8 (Section 1) and Appendix C-1.

Preliminary processing of samples was done onboard ship. Plaice and crab that had suffered obvious trawl damage were discarded. Tissue samples, top fillet for plaice and left legs for crab, were frozen at -20°C for subsequent taste analysis. Bottom fillets and liver (left half only) for plaice and right legs for crab were frozen at -20°C for body burden analysis. Blood, gill, liver (right half), heart, spleen, gonad, kidney and otolith samples from plaice were preserved for fish health indicators analysis (see below). Additional measurements on plaice included fish length, weight (whole and gutted), sex and

maturity stage, liver weight, and gonad weight. For crab, measurements included carapace width, shell condition (see Appendix C-1 for shell condition indices), sex and chela height. Only those plaice larger than 250 mm in length and those crab larger than 40 mm in carapace width were retained for analysis. This size cut-off for crab excluded most female crab, which were usually smaller than 40 mm.

Blood from plaice used in fish health analysis was drawn from a dorsal vessel near the tail and dispensed carefully into a tube containing an anticoagulant (EDTA) and gently mixed. Two blood smears were prepared for each fish within one hour of blood withdrawal according to standard haematological methods (Platt 1969). After collection of blood samples, fish were killed by severing the spinal cord. Each fish was assessed visually for any parasites and/or abnormalities on the skin and fins. The entire liver was excised and bisected. A 4 to 5 mm thick slice was cut from the centre portion of the right half of the liver (along the longitudinal axis) and placed in 10% buffered formalin for histological processing and the rest was frozen on dry ice until return to port, when it was placed in a -65°C freezer for Mixed Function Oxygenase (MFO) analysis. The first gill arch on the right of the fish was removed and placed in 10% buffered formalin for histological processing. Tissue samples of heart, spleen and head-kidney were removed and placed in 10% buffered formalin for histological processing, if required. The otoliths was removed for ageing. Throughout the dissection process, any internal parasites and/or abnormal tissues were recorded and preserved in 10% buffered formalin for subsequent identification.

The following sampling QA/QC protocols were followed for collection of samples to ensure sample integrity and prevent onboard contamination. The top deck of the survey vessel was washed with degreaser then flushed with seawater. The fishing deck and chute leading to the processing facilities were flushed continuously during the survey. Sampling personnel wore new latex gloves and all sampling and measuring instruments were washed with mild soap and water then rinsed with distilled water before each transect. Where applicable, processed samples were transferred to a -20°C freezer within one hour of collection.

6.2 Laboratory Analysis

6.2.1 Allocation of Samples

Plaice from 10 trawls in the Study Area and 15 trawls in the Reference Areas were used for body burden analysis, taste tests and fish health. Plaice bottom fillets and half-livers were composited to generate 10 individual body burden samples for fillet and liver for the Study Area and three individual samples for each of the four Reference Areas. Tissue from individual fish was archived for body burden on individuals if warranted by results of taste or health analyses. Top fillets from a subset of fish from each trawl used in body burden analysis were used in taste analysis. In this test, fish fillet selected from the Study Area and the Reference Areas were allocated to the triangle test and the hedonic scaling test (see Section 6.2.3 for details on taste tests) and randomly assigned to panelists. Fish health analyses focused on individual fish rather than composite or randomly assigned samples (Table 6-2).

Table 6-2 Plaice Selected for Body Burden, Taste and Health Analyses (2006)

Transect Number	Group	Total No. Fish Retained	Body Burden Composites (Bottom Fillet, or Liver)	Taste (wt. of Top Fillet)	Health (Number of Fish)
WR-01	Study (North)	10	Composite 1 (6 fish)	291	6
WR-02	Study (North)	10	Composite 2 (6 fish)	612	6
WR-03	Study (North)	10	Composite 3 (6 fish)	566	6
WR-04	Study (North)	10	Composite 4 (6 fish)	619	6
WR-05	Study (North)	10	Composite 5 (6 fish)	1116	6
	Total Study (North)	**50**		**3204**	**30**
WR-08	Study (South)	10	Composite 6 (6 fish)	852	6
WR-09	Study (South)	10	Composite 7 (6 fish)	656	6
WR-10	Study (South)	9	Composite 8 (6 fish)	494	6
WR-11	Study (South)	10	Composite 9 (6 fish)	532	6
WR-12	Study (South)	10	Composite 10 (6 fish)	580	6
	Total Study (South)	**49**		**3114**	**30**
WR-22	Reference 1	10	Composite 11 (10 fish)	878	10
WR-23	Reference 1	10	Composite 12 (10 fish)	1073	10
WR-24	Reference 1	10	Composite 13 (10 fish)	349	10
	Total Reference 1	**30**		**2300**	**30**
WR-29	Reference 2	10	Composite 14 (10 fish)	840	10
WR-30	Reference 2	10	Composite 15 (10 fish)	1082	10
WR-31	Reference 2	10	Composite 16 (10 fish)	410	10
	Total Reference 2	**30**		**2332**	**30**
WR-33/38	Reference 3	10	Composite 17 (10 fish)	847	10
WR-34/36	Reference 3	10	Composite 18 (10 fish)	912	10
WR-35/37	Reference 3	10	Composite 19 (10 fish)	547	10
	Total Reference 3	**30**		**2306**	**30**
WR-39	Reference 4	10	Composite 20 (10 fish)	642	10
WR-40	Reference 4	10	Composite 21 (10 fish)	630	10
WR-41	Reference 4	10	Composite 22 (10 fish)	1010	10
	Total Reference 4	**30**		**2282**	**30**

Notes: - For taste tests, tissue weights were selected so as to generate relatively constant weights between the northern and southern portion of the Study Area, and among all four Reference Areas. This assured that no one sampling location was over-represented in the Study versus Reference Area comparison
- Location of transects are provided in Figure 1-10, Section 1

Crab from 21 trawls in the Study Area and 19 trawls in the Reference Areas were used for body burden and taste analyses. Soft shell crab were excluded from all analyses. Tissue from right legs were composited to generate 10 individual body burden samples for the Study Area and three individual samples for each of the four Reference Areas (Table 6-3). Left leg tissue was used in taste analysis. In this test, leg tissue selected from the Study Area and the Reference Areas were allocated to the triangle test and the hedonic scaling test (see Section 6.2.3 for details on taste tests) and randomly assigned to panelists.

Table 6-3 Crab Selected for Body Burden and Taste Analysis (2006)

Transect Number	Group	Total No. of Crab	Body Burden Composites	Taste Tests
			(Right Legs)	(wt. of Crab, Left Legs)
WR-05	Study (North)	18	Composite 1 (18 crab)	1230
WR-07	Study (North)	8	Composite 2(8 crab)	436
WR-04	Study (North)	7	Composite 3 (7 crab)	496
WR-06/03	Study (North)	13	Composite 4 (13 crab)	912

Transect Number	Group	Total No. of Crab	Body Burden Composites (Right Legs)	Taste Tests (wt. of Crab, Left Legs)
WR-02/01	Study (North)	9	Composite 5 (9 crab)	310
	Total Study (North)	**55**		**3384**
WR-19/10/21	Study (South)	32	Composite 6 (32 crab)	1080
WR-16/18/9	Study (South)	27	Composite 7 (27 crab)	1078
WR-11/12	Study (South)	18	Composite 8 (18 crab)	254
WR-17/14/15	Study (South)	24	Composite 9 (24 crab)	702
WR-20/13/8	Study (South)	20	Composite 10 (20 crab)	526
	Total Study (South)	**121**		**3640**
WR-24/22	Reference 1	9	Composite 11 (9 crab)	670
WR-23/27	Reference 1	7	Composite 12 (7 crab)	470
WR-25/26	Reference 1	8	Composite 13 (8 crab)	620
	Total Reference 1	**24**		**1760**
WR-30	Reference 2	11	Composite 14 (11 crab)	722
WR-32	Reference 2	7	Composite 15 (7 crab)	398
WR-29/31	Reference 2	8	Composite 16 (8 crab)	754
	Total Reference 2	**26**		**1874**
WR-34/35	Reference 3	7	Composite 17 (7 crab)	934
WR-36/33	Reference 3	7	Composite 18 (7 crab)	312
WR-37/38	Reference 3	12	Composite 19 (12 crab)	748
	Total Reference 3	**26**		**1994**
WR-39	Reference 4	6	Composite 20 (6 crab)	204
WR-40	Reference 4	16	Composite 21 (16 crab)	670
WR-41	Reference 4	29	Composite 22 (29 crab)	1022
	Total Reference 4	**51**		**1896**

Note: - For taste tests, tissue weights were selected so as to generate relatively constant weights between the northern and southern portion of the Study Area, and among all four Reference Areas. This assured that no one sampling location was over-represented in the Study versus Reference Area comparison
- Location of transects are provided in Figure 1-10, Section1

6.2.2 Body Burden

Samples were delivered frozen to Maxxam Analytics in Halifax, Nova Scotia, and processed for the analytes listed in Table 6-4. Analytical methods and QA/QC procedures for these tests are provided in Appendix C-2.

Table 6-4 Body Burden Variables (2000 to 2006)

Variables	Method	2000 RDL	2002 RDL	2004 RDL	2005 RDL	2006 RDL	Units
Hydrocarbons							
$>C_{10}$-C_{21}	GC/FID	15	15	15	15	15	mg/kg
$>C_{21}$-C_{32}	GC/FID	15	15	15	15	15	mg/kg
PAHs							
1-Chloronaphthalene	GC/MS	NA	NA	0.05	0.05	0.05	mg/kg
2-Chloronaphthalene	GC/MS	NA	NA	0.05	0.05	0.05	mg/kg
1-Methylnaphthalene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
2-Methylnaphthalene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Acenaphthene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Acenaphthylene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Anthracene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Benz[a]anthracene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[a]pyrene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[b]fluoranthene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg

Variables	Method	2000 RDL	2002 RDL	2004 RDL	2005 RDL	2006 RDL	Units
Benzo[ghi]perylene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[k]fluoranthene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Chrysene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Dibenz[a,h]anthracene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Fluoranthene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Fluorene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Indeno[1,2,3-cd]pyrene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Naphthalene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Perylene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Phenanthrene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Pyrene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Metals							
Aluminum	ICP-MS	2.5	2.5	2.5	2.5	2.5	mg/kg
Antimony	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Arsenic	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Barium	ICP-MS	1.5	1.5	1.5	1.5	1.5	mg/kg
Beryllium	ICP-MS	1.5	1.5	0.5	0.5	0.5	mg/kg
Boron	ICP-MS	1.5	1.5	1.5	1.5	1.5	mg/kg
Cadmium	GFAAS	0.08	0.05	0.05	0.05	0.05	mg/kg
Chromium	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Cobalt	ICP-MS	0.2	0.2	0.2	0.2	0.2	mg/kg
Copper	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Iron	ICP-MS	5	5	15	15	15	mg/kg
Lead	ICP-MS	0.18	0.18	0.18	0.18	0.18	mg/kg
Lithium	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Manganese	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Mercury	CVAA	0.01	0.01	0.01	0.01	0.01	mg/kg
Molybdenum	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Nickel	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Selenium	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Silver	ICP-MS	0.12	0.12	0.12	0.12	0.12	mg/kg
Strontium	ICP-MS	1.5	1.5	1.5	1.5	1.5	mg/kg
Thallium	ICP-MS	0.02	0.02	0.02	0.02	0.02	mg/kg
Tin	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Uranium	ICP-MS	0.02	0.02	0.02	0.02	0.02	mg/kg
Vanadium	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Zinc	ICP-MS	0.5	0.5	0.5	0.5	1.5	mg/kg
Other							
Percent Lipids/Crude Fat	PEI FTC/ AOAC92 2.06	0.1	0.5	0.5	0.5	0.5	%
Moisture	Grav.	0.1	0.1	0.1	0.1	0.1	%

Notes: - The RDL is the lowest concentration that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions. RDLs may vary from year to year because of methods improvement and because instruments are checked for precision and accuracy every year as part of QA/QC procedures
- NA = Not Analyzed

6.2.3 Taste Tests

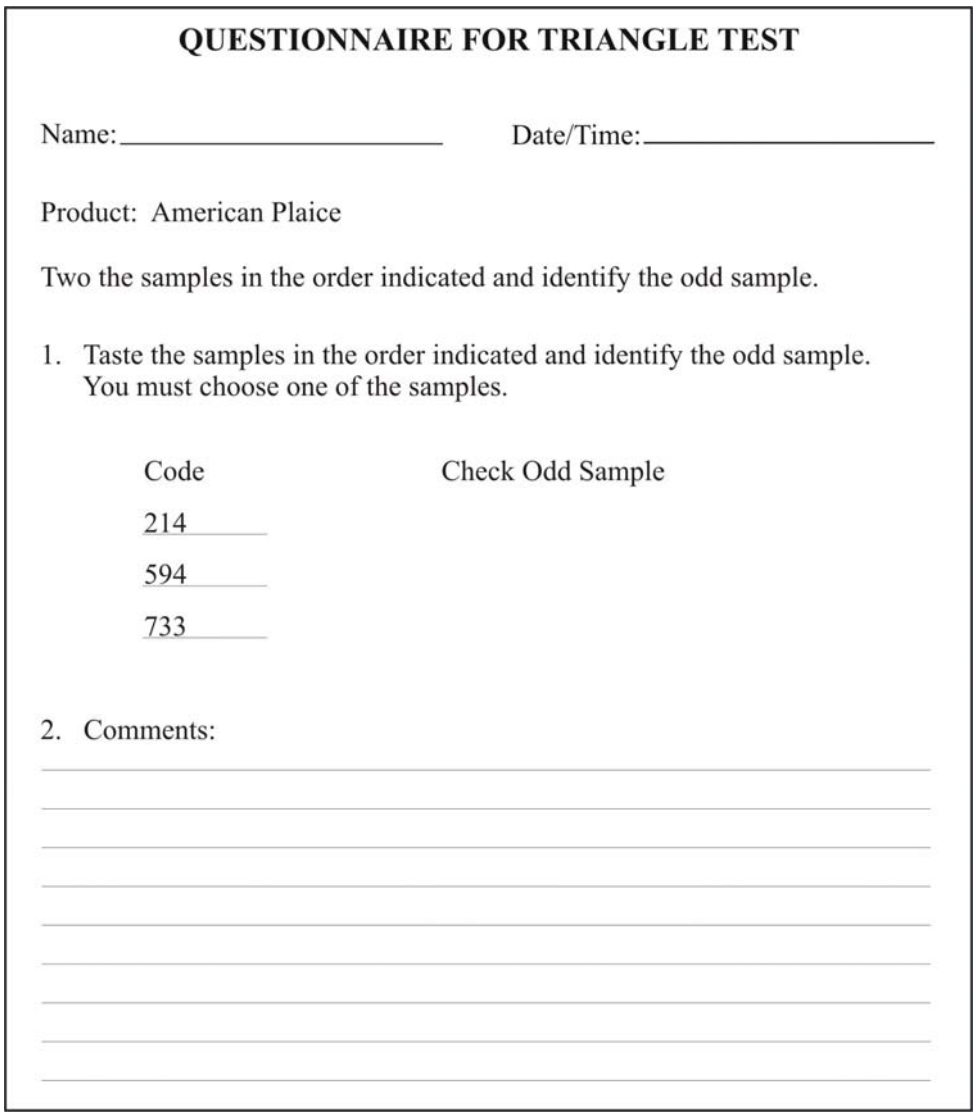
Plaice and crab samples were delivered frozen to the Fisheries and Marine Institute of Memorial University for sensory evaluation, using taste panels and triangle and hedonic scaling taste test procedures. Since no procedures have been established to compare multiple Reference Areas to one Study Area, samples were selected from each of the four Reference Areas to generate one set of Reference Area samples to be compared to Study Area samples.

Frozen plaice samples were thawed for 24 hours at 2°C, removed from plastic bags and homogenized in a food processor. Samples were allocated to either the triangle taste test or the hedonic scaling test. Samples were enclosed in individual aluminum foil packets (Figure 6-1), labelled with a predetermined random three-digit code and cooked in a convection oven at 82°C for 11 minutes. Plaice samples were served in glass cups at approximately 35°C.

Figure 6-1 Plaice Taste Test Preparations

Frozen crab samples were cooked, shucked of meat and stored overnight at 4°C. All meat was homogenized in a food processor and allocated to either the triangle taste test or the hedonic scaling test. Crab was served to taste panelists in glass cups at room temperature.

Each panel included 24 untrained panelists who were provided with score sheets (Figures 6-2 and 6-3) and briefed on the presentation of samples prior to taste tests. Panelists were instructed that samples were being tested for uncharacteristic odour or taste and that grit, cartilage and texture should not be considered in their assessment. Panelists were also instructed not to communicate with each and to leave immediately upon completion of the taste tests.



QUESTIONNAIRE FOR TRIANGLE TEST

Name:_____ Date/Time:_____

Product: American Plaice

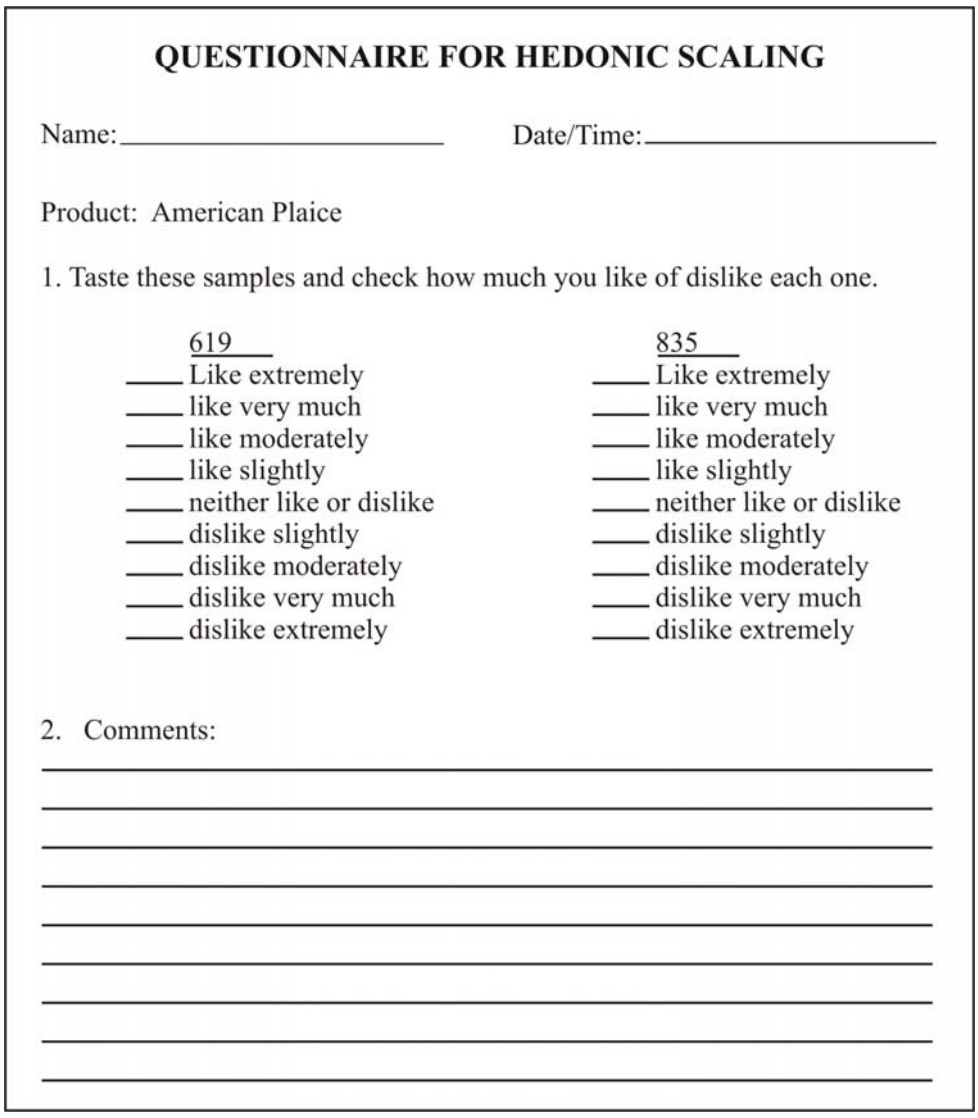
Two the samples in the order indicated and identify the odd sample.

1. Taste the samples in the order indicated and identify the odd sample. You must choose one of the samples.

Code	Check Odd Sample
214	
594	
733	

2. Comments:

Figure 6-2 Questionnaire for Taste Evaluation by Triangle Test



QUESTIONNAIRE FOR HEDONIC SCALING

Name:_____ Date/Time:_____

Product: American Plaice

1. Taste these samples and check how much you like of dislike each one.

619	835
____ Like extremely	____ Like extremely
____ like very much	____ like very much
____ like moderately	____ like moderately
____ like slightly	____ like slightly
____ neither like or dislike	____ neither like or dislike
____ dislike slightly	____ dislike slightly
____ dislike moderately	____ dislike moderately
____ dislike very much	____ dislike very much
____ dislike extremely	____ dislike extremely

2. Comments:

Figure 6-3 Questionnaire for Taste Evaluation by Hedonic Scaling

For the triangle test, panelists were presented with a three-sample set (triangle) of samples and asked to identify the sample that was different from the others. Half of the panelists received sets composed of two samples from Treatment A (Study Area) and one from Treatment B (Reference Areas). The other panelists received sets composed of one sample from Treatment A and two from Treatment B. There were six possible orders in which the samples were presented to panelists, after Botta (1994): ABB, AAB, ABA, BAA, BBA, and BAB.

The rest of the samples were used for hedonic scaling tests. In this test, one sample from the Study Area and one from the Reference Areas were presented to panelists. Panelists were instructed to rate how much they liked or disliked each sample on the form provided to them. A nine-point hedonic scale was used, with ratings ranging from “like extremely” (9) to “dislike extremely” (1) (see Figure 6-3 for full range of ratings).

6.2.4 Fish Health Indicators

6.2.4.1 Haematology

Blood smears were stained with Giemsa stain and examined with a Wild Leitz Aristoplan bright field microscope to identify different types of cells based on their general form and affinity to the dye (Ellis 1976).

Size, shape and degree of haemoglobinization of red blood cells were examined and recorded.

Differential blood cell counts were performed on lymphocytes, neutrophils and thrombocytes and expressed as a percentage of each type of cells on 200 white blood cells counted. Cells were counted under oil immersion (1000x) in fields along a row commencing from the front edge of the smear continuing parallel to the slide edge, until the total number of cells were counted.

6.2.4.2 Mixed Function Oxygenase

MFO induction was assessed in liver samples of plaice as 7-ethoxyresorufin O-deethylase (EROD) activity according to the method of Pohl and Fouts (1980) as modified by Porter et al. (1989).

Sample preparation

Liver samples were thawed on ice within four weeks of storage at -65°C and homogenized in four volumes of 50 mM Tris buffer, pH 7.5, (1 g liver to 4 ml buffer) using at least 10 passes of a glass Ten Broek hand homogenizer. Homogenates were centrifuged at 9,000 g for 15 minutes at 4°C and the post-mitochondrial supernatant (S9 fraction) was frozen in triplicate at -65°C until assayed.

All liver samples were held and processed under the same storage and assay conditions. Assays were carried out within four weeks of storage of S9 fractions.

EROD assay

The reaction mixture, final volume of 1 ml, contained 50 mM Tris buffer, pH 7.5, 2 µM ethoxyresorufin (Sigma) dissolved in dimethyl sulphoxide, 0.15 mM NADPH and 20 µl of S9 protein (diluted five times). After a 15-minute incubation at 27ºC, the reaction was stopped with 2 ml of methanol (HPLC grade) and samples were centrifuged (3,600 g for five minutes) in order to remove the protein precipitate. The fluorescence of resorufin formed in the supernatant was measured at an excitation wavelength of 550 nm and an emission wavelength of 580 nm using a Perkin-Elmer LS-5 fluorescence spectrophotometer. Blanks were performed as above, with methanol added before the incubation. All the samples were run in duplicate. Protein concentration was determined using the Lowry protein method (Lowry et al. 1951), with bovine serum albumin as standard. The rate of enzyme activity in pmol/min/mg protein was obtained from the regression of fluorescence against standard concentrations of resorufin. One low and one high resorufin standard were prepared daily from a stock solution and run with each batch of samples to check the standard curve.

6.2.4.3 Histopathology

Fixed liver and gill samples were processed by standard histological methods (Lynch et al. 1969) using a Tissue-Tek® VIP Processor. A graded ethyl alcohol series of 70%, 80%, 95%, and two changes of 100%, were used for dehydration of the samples. The livers were then cleared in four changes of xylene. Finally, the tissues were impregnated with three changes of molten embedding media, Tissue Prep 2™. The processed tissues were embedded in steel molds using molten embedding media and topped with labeled embedding rings. After cooling, the hardened blocks of embedded tissues were removed from their base molds. The blocks were then trimmed of excess wax. Sections were cut at 6 µm on a Leitz microtome, floated on a 47°C water bath containing gelatin, and then picked up on labelled microscope slides. After air drying, slides were fixed at 60°C for approximately two hours to remove most of the embedding media and allow the tissue to adhere properly to the slide. Sections were stained using Mayers Haematoxylin and Eosin method (Luna 1968). Coverslips were applied using Entellan ® and the slides were left to air dry and harden overnight.

Histological examination of each tissue was conducted by the same investigator. One slide with four to six sections was examined per fish. If an abnormality was found in a section, the other sections were checked for the same abnormality. To minimize interpretive bias, a “blind” system in which the examiner is not aware of the site of capture of specimen was used. This is accomplished by using a “pathology” number on the slide label generated from a random number table matched with the actual specimen number.

Liver

All liver samples were assessed microscopically for the presence of different lesions previously identified as having a putative chemical aetiology in fish (e.g. Myers et al. 1987; Boorman et al. 1997; ICES 2004; Blazer et al. 2006). Among them were:

1.	Nuclear pleomorphism	6.	Hepatocellular carcinoma
2.	Megalocytic hepatosis	7.	Cholangioma
3.	Eosinophilic foci	8.	Cholangiofibrosis
4.	Basophilic foci	9.	Macrophage aggregates
5.	Clear cell foci	10.	Hydropic vacuolation

Any other observations were also recorded. Among them, hepatocellular vacuolation, parasitic infestation of the biliary system, inflammatory response and granuloma.

Lesions (except macrophage aggregates and inflammatory response) were recorded for each fish as not detected (0) or detected (1).

Macrophage aggregation was recorded on a relative scale from 0 to 7 and prevalence was calculated for fish showing a moderate to high aggregation (3 or higher on the scale). Inflammatory response was recorded on a relative scale from 0 to 3 (0-absent, 1-mild, 2-moderate and 3-heavy).

The percentage of fish affected by each type of lesions or prevalence of lesion was then calculated.

Gill

Each gill sample was examined microscopically, first under low power (x20) for a general overview of the entire section and to record any abnormalities or parasites present. Four filaments, or primary lamellae, sectioned at a correct angle (with the central venous sinus visible in at least ⅔ of the filament) were selected and examined under x250 magnification for the presence of gill lesions associated with chemical toxicity (Mallat 1985). This included observations for epithelial lifting (separation of the epithelial layer from the basement membrane), telangiectasis (dilation of blood vessel at the tip of the secondary lamellae), lamellar hyperplasia (thickening of the epithelium due to an increase in the number of epithelial cells), fusion (fusion of two or more adjacent secondary lamellae) or oedema (swelling between or within cells).

A semi-quantitative examination was carried out where the total number of secondary lamellae as well as the lamellae presenting the lesions were counted on each selected filament. With respect to lamellar hyperplasia, results from previous years indicated that slight changes in the thickness of the epithelium of primary and secondary lamellae of plaice are apparently normal in nature. Therefore, the method of analysis was slightly modified as follows to account for conditions that would be more abnormal in nature: (1) basal hyperplasia was recorded when an increase in thickness of the epithelium near the base of the lamellae reached at least 1/3 of the total length of the lamellae, (2) distal hyperplasia was recorded when there were more than two cell layers (instead of one layer in previous years) around the two sides of the secondary lamellae and (3) tip hyperplasia was recorded when there were more than three cell layers (instead of one layer in previous years) at least 2/3 around the secondary lamellar tip. Results of the lamellar counts for each fish were expressed as the percentage of secondary lamellae presenting the lesion in relation to the total number of lamellae counted. The prevalence of the various types of lesions (presence or absence of each lesion for each fish) was also examined. Up to 1,000 lamellae were counted per fish.

The degree of oedema present, if any, was recorded on a 0 to 3 relative scale (0-absent, 1-light, 2-moderate and 3-heavy).

6.3 Data Analysis

For most analyses except taste tests, the Commercial Fish component of the 2006 White Rose EEM program used a multiple-reference design with four Reference Areas and two sub-Areas, North and South, within the Study Area. Three comparisons were of interest:

- Study versus Reference Areas (SR)
- Between the northern and southern portions of the Study Area (BS)
- Among Reference Areas (AR)

The modified nested Analysis of Variance (ANOVA) model in Table 6-5 was used for analysis of continuous variables. The SR and BS contrasts are tested against the variance (MS) among Reference Areas, or MS(AR), which is a measure of natural variance among Areas. The SR contrast compares the mean for the northern and southern portions of the Study Area to the mean for the Reference Areas and provides a test for overall project effects. The BS contrast compares the difference between the northern and southern portion of the Study Area to variances among the Reference

Areas. The Study Area was split into north and south parts to provide even coverage, and not to test for smaller-scale natural or project-related differences within the overall Study Area. However, the BS contrast can provide additional information and, in some cases, splitting the Study Area can increase the power of tests of the SR contrast. The AR contrast is tested against the variance among replicates (composites for most analyses) within Areas (MSE). This test is equivalent to an ANOVA comparing the Reference Areas with composites as replicates within Areas, except that variance among replicates within the northern and southern portions of the Study Area is incorporated into the MSE.

Table 6-5 Modified Nested ANOVA Model for Analysis of Multiple-Reference Design

Source/Term	df	Mean Square (MS)	*F*
Among Areas			
Study versus Reference (SR)	1	MS(SR)	MS(SR)/MS(AR)
Between Study (BS)	1	MS(BS)	MS(BS)/MS(AR)
Among References (AR)	3	MS(AR)	MS(AR)/MSE
Within Areas			
Among composites	*N*–5	MSE	

Notes: - df = degrees of freedom
- *N* = total number of composites

The model in Table 6-5 is referred to as a "modified" nested ANOVA because it is unconventional, with no replicate "Areas" within the northern and southern portions of the Study Area. There are reasonable alternative models and significance tests (see Quinn and Keough (2002) for an extended discussion).

With four replicate Reference Areas for crab and plaice, tests of the SR and BS contrasts will not be powerful. If the added natural variance among Reference Areas is small (i.e., MS(AR) is less than or similar to MSE), power can be increased by testing the SR and BS contrasts against the MSE, which is typically based on 22 composites. Quinn and Keough (2002) discuss the issue of when to pool higher- and lower-order terms, or test against lower-order terms (e.g., MSE), in nested and other complex ANOVA. They recommend testing against lower-order terms when $p \geq 0.25$ for higher-order terms such as MS(AR). Their recommendation was adopted in this report for interpretation of results. However, other authors have recommended using p from 0.05 to ≥ 0.50 to define when higher-order terms are small, so p for tests of the SR and BS contrasts against both MS(AR) and MSE are provided in this report.

6.3.1 Biological Characteristics

Biological Characteristics (morphometric and life history characteristics) of crab and plaice were analyzed primarily to determine if there were differences among composites that could affect results of body burden analyses. The analyses of Biological Characteristics also provided basic biological information on the two species.

6.3.1.1 Crab

Biological Characteristics of crab included carapace width and claw height (i.e., size), and frequency of recent moult based on the shell condition index (see Appendix C-1). Recent moults included crab with shell condition index values of 1 or 2. Non-recent moults included crab with condition index values of 6 (probably one year since moult),

and 3 or 4 (two or more years since moult). Values other than 1 to 4 and 6 were not observed.

The first step was to determine if there was added variance among composites within Areas. Variance among composites is small-scale spatial variance among trawl locations. The nested ANOVA in Table 6-5, with a third level added (variance among individual crab within composites), was used for the analysis. The variance among composites within Areas is tested against the variance among crab within composites. For individual crab, a score of 0 was assigned to recent moults and a score of 1 was assigned to non-recent moults.

For all three biological variables, there was added variance among composites within Areas ($0.05 < p < 0.10$). Therefore, mean carapace width, claw height and frequencies of recent moults were calculated for each composite and the composite values were analyzed in the nested ANOVA in Table 6-5.

Spearman rank correlations (r_s) were calculated among the three biological variables based on individual and composite values. Correlations were calculated over all Areas pooled and then separately for the pooled Reference Areas and the pooled Study Areas.

Analyses of Biological Characteristics were restricted to crab used for body burden analyses in 2006. Formal comparisons among years (2004 to 2006) were not conducted.

6.3.1.2 Plaice

In this section, analyses of plaice Biological Characteristics were restricted to gutted weight (i.e., size). Immature and mature females and males were pooled for the analyses, since they were pooled within composites. The primary objective was to determine if there were size differences that might affect results of body burden analyses. Appendix C-3 provides more extensive analyses of a larger suite of biological variables (length, age, body weight, liver and gonad weight) for plaice.

Analyses were conducted on composite mean weights. Distributions of individual weights within composites were rarely normal. Instead, they were usually bimodal, since immature fish were smaller than mature fish and males were smaller than females. Distributions of individual weights were also truncated at the left (low) end because fish smaller than 25 cm in length were released and not retained for body burden and health analyses. Composite mean weights were compared among Areas using the nested ANOVA in Table 6-5.

6.3.2 Body Burden

6.3.2.1 Crab

Analysis of 2006 Data

Body burden variables analyzed were moisture content, fat (lipid) content and wet weight concentrations of eight frequently detected metals (arsenic, boron, copper, mercury, selenium, silver, strontium and zinc). Variable values less than RDL were set at RDL rather than ½ RDL. For the Sediment Component of this report, values less than RDL were usually set at ½ RDL. However, for body burdens, the two-fold difference between RDL versus ½ RDL was larger than most differences in detectable concentrations within

and among Areas, and using ½ RDL to replace values less than RDL could potentially bias analyses and results.

A summary measure of metal concentrations was derived using Principal Components Analysis (PCA[9]). Metal concentrations were $\log_{10}$ transformed prior to conducting the PCA. The PCA included all samples from 2004, 2005 and 2006, since PC1 scores were compared among years (see below).

Fat content, moisture content, Metals PC1 scores and untransformed concentrations of the eight metals frequently detected in 2006 were analyzed in the nested ANOVA in Table 6-5. Rank correlations were also calculated among body burden variables and between them and the three biological variables (carapace width, claw height and % recent moult).

Comparison Among Years (2004 to 2006)

Body burden results from 2004, 2005 and 2006 were compared in the RM ANOVA in Table 6-6, which can be considered the RM or multi-year version of the nested ANOVA in Table 6-5. The Study Area was treated as a single Area because it was not distinctly split into north and south Areas in 2004 (see Figures 1-8 to 1-10, Section 1). Values analyzed (*Y*) were Area means within each year. The RM ANOVA has limited power with only three years and five Areas, but sample sizes and power will increase as more years are added in future EEM programs.

Table 6-6 Repeated Measures (RM) ANOVA Used for Comparison of Body Burden Variables Among Years (2004 to 2006)

Source/Term	df	Error	Description
Among Areas			Tests differences in mean *Y* over all 3 years
Study versus Reference (SR)	1	Error 1	Tests for differences in mean *Y* between Study versus Reference Areas
Among References (AR) (Error 1)	3	Error 2	Tests for differences in mean *Y* among Reference Areas
Within Areas (Among Years)			Tests for changes in *Y* and SR difference over time
Overall			Tests for any changes in *Y* or SR difference over time
Year	2	Error 2	Tests for any changes in *Y* over time in all Areas
Year × SR	2	Error 2	Tests for any changes in SR difference over time
Error 2	6	Not tested	Residual variance of differences among Reference Areas over time
Contrasts			Test for specific changes over time
Linear (Trend)			Tests for progressive increases or decreases (linear trend) in *Y* and SR difference over time
Year	1	Error 3	Tests for linear trend in Y in all Areas
Year × SR	1	Error 3	Tests for linear trend in SR difference over time
Error 3	3	Not tested	Residual variance of linear trend among Reference Areas

[9] PCA identifies the major axis of covariance (Principal Component or PC1) among the original variables (concentrations of the eight metals). PC1 is also the major axis of variance among samples (i.e., composites). PCA then identifies lesser (minor) axes of variance, each perpendicular to, and uncorrelated with, PC1 and each other. PC2 will account for more variance than PC3, PC3 will account for more variance than PC4, and so on. Positions of samples along any axis or PC can be defined by scores, which are weighted means or sums of the original variables. The scores are scaled so that the mean is 0 and the variance and standard deviation (SD) are 1. The scores can be used as summary variable values for further analyses.

Source/Term	df	Error	Description
Remainder			Tests for other changes in Y and SR difference over time
Year	1	Error 4	Tests for other changes in Y in all Areas
Year × SR	1	Error 4	Tests for other changes in SR difference
Error 4	3	Not tested	Residual variance of other changes among Reference Areas

Note: - df = degrees of freedom

The Among Areas terms in the RM ANOVA compare averages over the three years among Areas. These are tests for persistent differences among Areas over time. The Study versus Reference Areas (SR) difference is tested against the variance (MS) among Reference Areas, as in the nested ANOVA used for analysis of 2006 data (Table 6-5). The Among Reference (AR) term tests for carry-over effects (persistent differences among the Reference Areas over time).

The Within Areas terms in the RM ANOVA test for changes in *Y* variable values over time. The Year terms test for changes in *Y* occurring in all Areas. The Year × SR interaction terms test for changes in the Study versus Reference Areas (SR) difference over time. The Overall Within Areas terms are omnibus tests for *any* changes over time. Contrasts were used to test for more specific changes over time. The Linear contrasts test for progressive increases or decreases over time (i.e., trends); the Remainder contrasts test for other (i.e., non-linear) changes over time. With only three years, significant Overall differences in *Y* or the SR difference will usually be associated with significant Linear "trends" whenever 2004 values or SR differences are greater or less than 2006 values or differences. The Remainder contrasts will only be significant when 2005 values or SR differences are much greater or less than *both* 2004 and 2005 values or differences.

Body burden variables compared between years were moisture content, fat content, Metals PC1 and concentrations of the eight metals analyzed for 2006. Only two (rather than three) composites were analyzed from Reference Area 3 in 2004, and only one composite from Reference Area 4 was analyzed in 2005, because few crab were captured in those Areas. In each of 2004 and 2005, fat content was also not measured on one Reference composite because of insufficient tissue volume.

6.3.2.2 Plaice

Analyses of 2006 Data

Body burden data from composite samples were available for both liver and fillet tissue. Variables analyzed for liver were moisture and fat content, concentrations of eight metals detected in every composite (arsenic, cadmium, copper, iron, manganese, mercury, selenium, zinc), Metals PC1 derived from log-transformed concentrations of the eight metals, and $>C_{10}$-C_{21} and $>C_{21}$-C_{32} HC concentrations.

Variables analyzed for fillets were moisture and fat content, and concentrations of arsenic, mercury and zinc (detected in every composite).

Body burden variables for liver and fillets were compared among Areas in the nested ANOVA in Table 6-5. Liver $>C_{10}$-C_{21} and $>C_{21}$-C_{32} HC concentrations were rank-transformed to remove the effects of outliers.

Nested Analyses of Covariance (ANCOVA), with mean composite gutted weight as the covariate or *X*, were also conducted for selected variables. The ANCOVA compare regressions of *Y* on *X* among Areas and were conducted to determine if differences in *Y* variables among Areas were attributable to differences in size.

Comparison Among Years (2004 to 2006)

Plaice body burden results from 2004, 2005 and 2006 were compared in the RM ANOVA in Table 6-6. Variables analyzed were the same as those analyzed for 2006. Data analyzed were annual Area means. There were 66 composites (22 per year) analyzed over all three years combined, but fat content was not measured in one Reference Area 2 liver composite and three Study Area liver composites in 2005 because of insufficient sample volume.

6.3.3 Taste Tests

Unlike analyses on Biological Characteristics (Section 6.3.1), body burdens (Section 6.3.2) and health (Section 6.3.4), triangle tests and hedonic scaling tests compared Study Area samples to pooled Reference Area samples (see Section 6.2.3).

The triangle test datum is the number of correct sample identifications over the number of panelists. This value was calculated and compared to values in Appendix C-4 (after Larmond 1977) to determine statistical significance. For a panel size of 24, a statistically significant discrimination between Areas (at α = 0.05) would require that 13 panelists correctly identify samples.

Hedonic scaling results were processed in ANOVA and presented graphically in frequency histograms.

Ancillary comments from panelists were tabulated and assessed for both tests.

6.3.4 Fish Health Indicators

A multiple-reference design, with four Reference Areas and two Study Areas (northern and southern, which were pooled for some analyses), was used. When possible, three comparisons, Among Reference Areas, between Study Areas, and between Study Areas versus Reference Areas, were conducted. A more detailed description of the statistical methods is provided in Appendix C-3, Annex B. Briefly:

- Length, gutted weight, age, MFO activity and percentages of blood cell types were compared among Areas in the modified nested ANOVA described in Appendix C-3, Annex B, when sample sizes permitted.
- Log-log regressions of gutted weight versus length, and liver and ovary weight versus gutted weight were compared among Areas in modified nested ANCOVA.
- Sex ratios, ratios of mature:immature females, and prevalences of liver and gill histopathologies were compared among Areas using G tests or Fisher's Exact Tests.

6.4 Results

6.4.1 Biological Characteristics

6.4.1.1 Crab

Shell condition index values for the crab used for body burden analyses in 2006 are provided in Table 6-7. Shell condition was not recorded for one (1) of the 303 crab. Most (217) index values were stage 2 (recent moult). Frequencies of recent moults for the northern and southern portions of the Study Area were within the range of values observed for the Reference Areas.

Table 6-7 Frequencies of Crab Shell Condition Index Values (2006)

Moult year	Index value	Area								Total
		Ref 1	Ref 2	Ref 3	Ref 4	All Refs	North Study	South Study	Both Study	
Recent (0)	1	0	0	0	0	0	3	4	7	7
	2	18	22	17	31	88	35	94	129	217
Total (No.)		18	22	17	31	88	38	98	136	224
(%)		75	85	65	62	70	69	81	77	74
Not recent (–1+)	6	1	4	7	12	24	8	12	20	44
Last year (–1)	3	5	0	2	7	14	9	10	19	33
Previous (–2+)	4	0	0	0	0	0	0	1	1	1
Total (No.)		6	4	9	19	38	17	23	40	78
(%)		25	15	35	38	30	31	19	23	26
Grand total (No.)		24	26	26	50	126	55	121	176	302

Notes: - Moult years: 0 = 2006; –1 = 2005; –2+ = 2004 or earlier
- Values are numbers of crab unless otherwise indicated

Summary statistics for composite means are provided in Table 6-8. Carapace widths of Study Area crab were lower than carapace widths of Reference Area crab (i.e., Study Area crab were smaller). Crab in Reference Area 2 were larger than in other Areas. Area differences in claw height were similar to those for carapace width, since the two size measures were correlated (see below). CVs for the two size measures were greatest in Reference Area 3 and lowest in Reference Area 1.

Table 6-8 Summary Statistics for Biological Characteristics of Crab Based on Composite Means (2006)

Variable	Area	*n*	Min	Max	Median	Mean	SD	CV (%)
Carapace width (mm)	Reference Area 1	3	78	83	81	81	3	3
	Reference Area 2	3	88	101	90	93	7	8
	Reference Area 3	3	74	102	76	84	16	19
	Reference Area 4	3	71	86	76	78	8	10
	Reference means					84		
	North Study Area	5	63	80	76	74	7	9
	South Study Area	5	55	77	70	69	9	13
	Study means					72		
Claw height (mm)	Reference Area 1	3	16.6	18.3	17.3	17.4	0.9	5
	Reference Area 2	3	18.2	23.0	19.0	20.1	2.6	13
	Reference Area 3	3	16.7	24.4	17.5	19.6	4.2	22
	Reference Area 4	3	14.4	18.2	16.6	16.4	1.9	12
	Reference means					18.4		
	North Study Area	5	12.0	17.2	16.9	15.4	2.4	15
	South Study Area	5	9.7	16.8	14.5	13.9	2.6	19

Variable	Area	*n*	Min	Max	Median	Mean	SD	CV (%)
Claw height (mm)	Study means					14.7		
% recent moult	Reference Area 1	3	71	78	75	75	3	
	Reference Area 2	3	63	100	86	83	19	
	Reference Area 3	3	43	92	43	59	28	
	Reference Area 4	3	59	83	60	67	14	
	Reference means					71		
	North Study Area	5	29	83	75	65	22	
	South Study Area	5	74	88	81	81	5	
	Study means					73		

Notes: - CV = Coefficient of Variation (SD as % of mean)
- Reference Area 4 means are not included in overall Reference Area means because they were not included in ANOVA comparisons among Reference Areas and between the Study Area and Reference Areas

Area differences in frequencies of recent moults based on composite means in Table 6-8 differed from those for individual crab in Table 6-7. The values in Table 6-8 weight each composite rather than each individual equally, and there were some large differences in numbers of individuals in composites both within and among Areas. However, the general conclusion that Study Area values were within the Reference range applies to both Tables 6-7 and 6-8.

CVs are not provided for % recent moult because composite means could be expressed as either % recent moult or % non-recent moult (100-% recent moult; SDs remain the same). SDs differed widely among the Reference Areas, and between the northern and southern portions of the Study Area. The differences in variance among Areas may have affected analyses in ANOVA but could not be removed by transformations.

The three biological variables did not differ significantly among Reference Areas or between the two portions of the Study Area (Table 6-9). Frequencies of recent moults also did not differ significantly between the Study versus Reference Areas. Reference Area crab were larger than Study Area crab (Table 6-8). Based on strict adherence to the definition of statistical significance as $p \leq 0.05$, and the "decision rule" to test against the MSE only when $p \geq 0.25$ for the Among References contrast, the size differences between Study and Reference Area crab were significant for claw height but not for carapace width (Table 6-9). However, given the similarity of *p* values for the two strongly correlated size measures in Table 6-9, a more reasonable conclusion would be that Study versus Reference Area size differences were significant.

Table 6-9 Results of Modified Nested ANOVA Comparing Crab Biological Characteristics Among Areas (2006)

Variable	*p* values				
	Among References	Between Study		Study versus Reference	
	Error=MSE	Error= MS(AR)	Error=MSE	Error= MS(AR)	Error=MSE
Carapace width	0.217	*0.484*	0.321	*0.084*	0.005
Claw height	0.289	0.495	*0.379*	0.066	***0.004***
% recent moult	0.405	0.244	*0.162*	0.783	*0.763*

Notes: - MSE = variance among composites within Areas; MS(AR) = variance among Reference Areas
- *Italics* indicate *p* values that should be used for tests of the Between Study and Study versus Reference contrasts, following recommendations in Quinn and Keough (2002; i.e., test against MSE only when $p \geq 0.25$ for Among References contrast)

As expected, the two size variables (carapace width and claw height) were significantly and strongly positively correlated among individual crab and among composite means (Table 6-10). For individual crab, size and % recent moult were significantly negatively correlated, indicating that smaller crab were more likely to have moulted in 2006. Correlations between size and % recent moult for composite means were weaker, especially for the Reference Areas, and not significant. These results indicate that size and frequencies of recent moult were mostly correlated within rather than among composites.

Table 6-10 Spearman Rank Correlations (r_s) Among Crab Biological Variables (2006)

Values	Areas	Carapace width-claw height		Carapace width-% recent moult		Claw height-% recent moult	
		n	***r_s***	***n***	***r_s***	***n***	***r_s***
Individual crab	All	282	**0.964****	302	**–0.563****	281	**–0.566****
	Reference	122	**0.966****	126	**–0.506****	121	**–0.490****
	Study	160	**0.958****	176	**–0.582****	160	**–0.613****
Composite means	All	22	**0.932****	22	–0.292	22	–0.338
	Reference	12	**0.888****	12	–0.133	12	–0.203
	Study	10	**0.903****	10	–0.389	10	–0.462

Note: - * $p \leq 0.05$; ** $p \leq 0.01$; r_s at $p \leq 0.05$ in bold

6.4.1.2 Plaice

Summary statistics for composite mean gutted weights of plaice are provided in Table 6-11. Females accounted for 163 (91%) of the 180 plaice used for body burden and health analyses. Approximately 70% (114) of the females were mature, and mature females were larger than males (all mature) and immature females.

Table 6-11 Summary Statistics for Plaice Gutted Weight, Based on Composite Means (2006)

Area	*n*	Min	Max	Median	Mean	SD	CV (%)
Reference Area 1	3	303	694	571	523	200	38
Reference Area 2	3	472	813	680	655	172	26
Reference Area 3	3	428	673	552	551	123	22
Reference Area 4	3	340	515	356	404	97	24
Reference means					533		
North Study	5	647	836	800	753	96	13
South Study	5	469	775	574	590	119	20
Study means					671		

Composite mean weights did not differ significantly among Reference Areas, between the northern and southern portions of the Study Area or between Study versus Reference Areas (Table 6-12). Mean weights for the northern portion of the Study Area and Reference Area 2 were greater than for other Areas, but as the minima, maxima and SD in Table 6-11 show, there was also considerable variance among composites within Areas. The variance in size within Areas had some apparent effects on body burden variables, considered in more detail in Section 6.4.2.2.

Table 6-12 Results of Modified Nested ANOVA Comparing Plaice Composite Mean Gutted Weights Among Areas (2006)

p values				
Among References	Between Study		Study versus Reference	
Error=MSE	Error= MS(AR)	Error=MSE	Error= MS(AR)	Error=MSE
0.183	*0.246*	0.070	*0.169*	0.027

Notes: - MSE = variance among composites within Areas; MS(AR) = variance among Reference Areas
- *Italics* indicate *p* values that should be used for tests of the Between Study and Study versus Reference contrasts, following recommendations in Quinn and Keough (2002; i.e., test against MSE only when $p \geq 0.25$ for Among References contrast)

A more extensive analysis of size and other biological characteristics conducted as part of the health assessment (Appendix C-3) indicated that Study Area samples included more large mature females relative to small immature females than Reference Area samples. However, the size of mature females differed mostly among Reference Areas rather than between Study versus Reference Areas, and ratios of mature to immature females also differed significantly among the Reference Areas. Consequently, the size differences in Table 6-11 are partly a function of differences in mature to immature ratios among and within Areas and also partly a function of differences in size among the predominant mature females.

6.4.2 Body Burden

6.4.2.1 Crab

Summary statistics for concentrations of detected substances in crab claw composites in 2004 to 2006 are provided in Table 6-13. Raw data for 2006 are provided in Appendix C-2.

Table 6-13 Summary Statistics for Crab Body Burden (2004 to 2006)

Variable	Year	Area	*n*	*n* < RDL	Min	Max	Median	Mean	SD	CV %
Aluminum	2006	Reference Area 2	3	2	<2.5	7.2	<2.5			
Arsenic	2004	Reference Area 1	3	0	6.9	7.8	7.5	7.40	0.46	6
		Reference Area 2	3	0	6.8	10.0	9.6	8.80	1.74	20
		Reference Area 3	2	0	8.5	8.6	8.6	8.55	0.07	1
		Reference Area 4	3	0	11.0	13.0	11.0	11.67	1.15	10
		Reference Means					9.2	9.10		
		Study Area	10	0	4.8	12.0	8.6	8.71	2.44	28
	2005	Reference Area 1	3	0	6.11	9.46	7.84	7.80	1.68	21
		Reference Area 2	3	0	5.22	8.51	7.55	7.09	1.69	22
		Reference Area 3	3	0	7.38	8.38	7.93	7.90	0.50	6
		Reference Area 4	1	0	9.02	9.02	9.02	9.02		
		Reference Means					8.09	7.95		
		Study Area North	5	0	6.46	7.64	6.93	7.04	0.50	7
		Study Area South	5	0	5.59	6.81	6.16	6.26	0.48	8
		Study Means					6.55	6.65		
	2006	Reference Area 1	3	0	5.08	7.05	6.05	6.06	0.99	16
		Reference Area 2	3	0	5.03	8.71	6.04	6.59	1.90	29
		Reference Area 3	3	0	9.37	11.00	9.97	10.11	0.82	8
		Reference Area 4	3	0	8.79	9.74	8.82	9.12	0.54	6
		Reference Means					7.72	7.97		
		Study Area North	5	0	4.69	10.10	7.34	7.55	1.99	26
		Study Area South	5	0	7.13	7.89	7.38	7.49	0.30	4
		Study Means					7.36	7.52		

Variable	Year	Area	*n*	*n* < RDL	Min	Max	Median	Mean	SD	CV %
Boron	2004	Reference Area 1	3	0	1.9	2.5	2.3	2.23	0.31	14
		Reference Area 2	3	1	<1.5	2.8	1.9			
		Reference Area 3	2	0	1.7	2.3	2.0	2.00	0.42	21
		Reference Area 4	3	1	<1.5	2.0	1.9			
		Reference Means					2.0			
		Study Area	10	1	<1.5	3.2	1.9			
	2005	Reference Area 1	3	1	<1.5	2.4	1.7			0
		Reference Area 2	3	0	2.1	4.7	3.3	3.37	1.30	39
		Reference Area 3	3	0	2.3	4.2	3.8	3.43	1.00	26
		Reference Area 4	1	0	3.3	3.3	3.3	3.30	.	
		Reference Means					3.0			
		Study Area North	5	0	2.4	4.1	3.2	3.22	0.64	20
		Study Area South	5	1	<1.5	3.5	2.3			
		Study Means					2.8			
	2006	Reference Area 1	3	0	1.6	3.5	3.2	2.77	1.02	37
		Reference Area 2	3	1	<1.5	2.4	2.4			
		Reference Area 3	3	0	2.5	4.4	3.1	3.33	0.97	29
		Reference Area 4	3	0	2.4	3.5	3.3	3.07	0.59	19
		Reference Means					3.0			
		Study Area North	5	0	2.4	3.2	2.9	2.82	0.36	13
		Study Area South	5	0	2.7	3.4	3.1	3.02	0.28	9
		Study Means					3.0	2.92		
Cadmium	2004	Reference Area 1	3	2	<0.05	0.07	<0.05			
		Reference Area 2	3	2	<0.05	0.05	<0.05			
		Reference Area 3	2	1	<0.05	0.05	<0.05			
		Reference Area 4	3	1	<0.05	0.10	0.05			
		Reference Means					<0.05			
		Study Area	10	3	<0.05	0.10	0.050			
	2005	Reference Area 4	1	1	0.090	0.090	0.090			
		Study Area South	5	3	<0.05	0.054	<0.05			
	2006	Reference Area 1	3	2	<0.05	0.058	<0.05			
		Reference Area 3	3	2	<0.05	0.054	<0.05			
		Reference Area 4	3	2	<0.05	0.084	<0.05			
Copper	2004	Reference Area 1	3	0	2.9	4.0	3.2	3.37	0.57	17
		Reference Area 2	3	0	3.1	5.8	5.3	4.73	1.44	30
		Reference Area 3	2	0	3.2	3.8	3.5	3.50	0.42	12
		Reference Area 4	3	0	4.2	5.1	4.7	4.67	0.45	10
		Reference Means					4.2	4.07		
		Study Area	10	0	2.90	4.80	3.90	3.94	0.63	16
	2005	Reference Area 1	3	0	2.92	2.99	2.96	2.96	0.04	1
		Reference Area 2	3	0	3.45	3.88	3.64	3.66	0.22	6
		Reference Area 3	3	0	3.02	3.56	3.20	3.26	0.27	9
		Reference Area 4	1	0	3.23	3.23	3.23	3.23	.	
		Reference Means					3.26	3.28		
		Study Area North	5	0	2.45	3.01	2.53	2.70	0.28	11
		Study Area South	5	0	2.40	4.12	3.01	3.05	0.70	23
		Study Means					2.77	2.88		
	2006	Reference Area 1	3	0	2.44	3.02	2.65	2.70	0.29	11
		Reference Area 2	3	0	2.32	3.05	2.53	2.63	0.38	14
		Reference Area 3	3	0	2.48	3.13	3.03	2.88	0.35	12
		Reference Area 4	3	0	2.53	2.90	2.61	2.68	0.19	7
		Reference Means					2.71	2.72		
		Study Area North	5	0	2.61	3.94	2.88	3.16	0.59	19
		Study Area South	5	0	2.23	3.19	2.70	2.62	0.40	15
		Study Means					2.79	2.89		
Mercury	2004	Reference Area 1	3	0	0.06	0.10	0.08	0.080	0.020	25
		Reference Area 2	3	0	0.06	0.10	0.07	0.077	0.021	27
		Reference Area 3	2	0	0.09	0.10	0.10	0.095	0.007	7
		Reference Area 4	3	0	0.09	0.11	0.10	0.100	0.010	10
		Reference Means					0.09	0.090		
		Study Area	10	0	0.05	0.15	0.09	0.094	0.028	30
	2005	Reference Area 1	3	0	0.13	0.18	0.18	0.163	0.029	16
		Reference Area 2	3	0	0.05	0.17	0.13	0.117	0.061	47
		Reference Area 3	3	0	0.08	0.16	0.14	0.127	0.042	30

Variable	Year	Area	*n*	*n* < RDL	Min	Max	Median	Mean	SD	CV %
Mercury	2005	Reference Area 4	1	0	0.20	0.20	0.20	0.200	.	
		Reference Means					0.16	0.152		
		Study Area North	5	0	0.10	0.12	0.10	0.104	0.009	9
		Study Area South	5	0	0.05	0.11	0.07	0.080	0.024	35
		Study Means					0.09	0.092		
	2006	Reference Area 1	3	0	0.06	0.12	0.09	0.090	0.030	33
		Reference Area 2	3	0	0.05	0.15	0.08	0.093	0.051	55
		Reference Area 3	3	0	0.09	0.17	0.09	0.117	0.046	40
		Reference Area 4	3	0	0.11	0.12	0.11	0.113	0.006	5
		Reference Means					0.09	0.103		
		Study Area North	5	0	0.07	0.10	0.09	0.086	0.011	13
		Study Area South	5	0	0.07	0.11	0.10	0.092	0.016	18
		Study Means					0.10	0.089		
Selenium	2004	Reference Area 1	3	0	0.7	0.8	0.7	0.73	0.06	8
		Reference Area 2	3	0	0.5	0.8	0.8	0.70	0.17	25
		Reference Area 3	2	0	0.7	0.7	0.7	0.70	0.00	0
		Reference Area 4	3	0	0.7	0.8	0.8	0.77	0.06	8
		Reference Means					0.8	0.73		
		Study Area	10	0	0.50	0.80	0.60	0.66	0.11	16
	2005	Reference Area 1	3	0	0.56	0.67	0.60	0.61	0.06	9
		Reference Area 2	3	0	0.53	0.65	0.55	0.58	0.06	12
		Reference Area 3	3	1	<0.5	0.62	0.61			
		Reference Area 4	1	0	0.54	0.54	0.54	0.54	.	
		Reference Means					0.58			
		Study Area North	5	0	0.58	0.69	0.65	0.64	0.05	7
		Study Area South	5	1	<0.5	0.59	0.53			
		Study Means					0.59			
	2006	Reference Area 1	3	0	0.59	0.67	0.66	0.64	0.04	7
		Reference Area 2	3	0	0.55	0.76	0.59	0.63	0.11	18
		Reference Area 3	3	0	0.75	0.84	0.78	0.79	0.05	6
		Reference Area 4	3	0	0.61	0.69	0.68	0.66	0.04	7
		Reference Means					0.68	0.68		
		Study Area North	5	0	0.62	0.83	0.73	0.74	0.08	11
		Study Area South	5	0	0.60	0.76	0.66	0.67	0.06	9
		Study Means					0.70	0.71		
Silver	2004	Reference Area 1	3	0	0.14	0.26	0.18	0.193	0.061	32
		Reference Area 2	3	0	0.15	0.25	0.20	0.200	0.050	25
		Reference Area 3	2	0	0.16	0.16	0.16	0.160	0.000	0
		Reference Area 4	3	0	0.21	0.27	0.23	0.237	0.031	13
	2004	Reference Means					0.19	0.200		
		Study Area	10	0	0.15	0.25	0.20	0.205	0.032	15
	2005	Reference Area 1	3	1	<0.12	0.15	0.14			
		Reference Area 2	3	1	<0.12	0.14	0.13			
		Reference Area 3	3	1	<0.12	0.25	0.24			
		Reference Area 4	1	0	0.22	0.22	0.22	0.220	.	
		Reference Means					0.18			
		Study Area North	5	0	0.13	0.19	0.15	0.158	0.023	15
		Study Area South	5	0	0.13	0.25	0.21	0.202	0.044	21
		Study Means					0.18	0.180		
	2006	Reference Area 1	3	1	<0.12	0.15	0.14			
		Reference Area 3	3	1	<0.12	0.19	0.13			
		Reference Area 4	3	0	0.13	0.27	0.19	0.197	0.070	36
		Study Area North	5	2	<0.12	0.20	0.13			
		Study Area South	5	2	<0.12	0.18	0.13			
		Study Means					0.13			
Strontium	2004	Reference Area 1	3	0	5.2	10.0	9.3	8.17	2.59	32
		Reference Area 2	3	0	8.9	13.0	10.0	10.63	2.12	20
		Reference Area 3	2	0	6.2	15.0	10.6	10.60	6.22	59
		Reference Area 4	3	0	5.1	18.0	6.0	9.70	7.20	74
		Reference Means					9.0	9.78		
		Study Area	10	0	4.4	18.0	9.0	10.03	4.64	46
	2005	Reference Area 1	3	0	6.1	8.6	6.9	7.20	1.28	19
		Reference Area 2	3	0	6.8	26.8	10.9	14.83	10.56	97
		Reference Area 3	3	0	14.7	20.1	16.0	16.93	2.82	18

Variable	Year	Area	*n*	*n* < RDL	Min	Max	Median	Mean	SD	CV %
Strontium	2005	Reference Area 4	1	0	8.4	8.4	8.4	8.40	.	
		Reference Means					10.6	11.84		
		Study Area North	5	0	5.6	14.2	6.1	8.02	3.60	59
		Study Area South	5	0	9.7	21.0	12.8	14.16	5.01	39
		Study Means					9.5	11.09		
	2006	Reference Area 1	3	0	17.8	32.6	22.0	24.13	7.63	32
		Reference Area 2	3	0	16.8	44.2	22.6	27.87	14.44	52
		Reference Area 3	3	0	13.1	19.6	18.6	17.10	3.50	20
		Reference Area 4	3	0	14.3	33.6	32.1	26.67	10.74	40
		Reference Means					23.8	23.94		
		Study Area North	5	0	9.2	30.3	16.8	16.84	8.29	49
		Study Area South	5	0	16.2	32.7	21.1	23.38	6.94	30
		Study Means					19.0	20.11		
Zinc	2004	Reference Area 1	3	0	31	32	31	31.33	0.58	2
		Reference Area 2	3	0	23	30	23	25.33	4.04	16
		Reference Area 3	2	0	27	30	29	28.50	2.12	7
		Reference Area 4	3	0	31	35	33	33.00	2.00	6
		Reference Means					29	29.54		
		Study Area	10	0	17.0	33.0	30.5	28.20	4.78	17
	2005	Reference Area 1	3	0	25.6	32.4	29.3	29.10	3.40	12
		Reference Area 2	3	0	17.5	28.9	23.0	23.13	5.70	25
		Reference Area 3	3	0	24.7	30.9	27.1	27.57	3.13	12
		Reference Area 4	1	0	27.3	27.3	27.3	27.30	.	
		Reference Means					26.7	26.78		
		Study Area North	5	0	25.0	30.6	27.3	27.74	2.09	8
		Study Area South	5	0	21.2	26.2	24.6	24.10	1.89	8
		Study Means					26.0	25.92		
	2006	Reference Area 1	3	0	20.9	27.9	26.3	25.03	3.67	15
		Reference Area 2	3	0	20.1	32.1	27.6	26.60	6.06	23
		Reference Area 3	3	0	32.1	33.9	33.0	33.00	0.90	3
		Reference Area 4	3	0	26.2	32.2	31.7	30.03	3.33	11
		Reference Means					30.0	28.67		
		Study Area North	5	0	24.2	31.5	28.7	28.32	2.91	10
		Study Area South	5	0	24.2	30.8	29.3	28.54	2.55	9
		Study Means					29.0	28.43		
Crude Fat %	2004	Reference Area 1	2	1	<0.5	0.7	0.6			
		Reference Area 2	3	0	0.5	1.9	1.1	1.17	0.70	60
		Reference Area 3	2	0	0.6	1.3	1.0	0.95	0.49	52
		Reference Area 4	3	0	0.6	0.7	0.6	0.63	0.06	9
		Reference Means					0.8			
		Study Area	10	2	<0.5	1.4	0.7			
	2005	Reference Area 1	3	0	0.5	0.6	0.6	0.57	0.06	10
		Reference Area 2	2	0	0.5	1.0	0.8	0.75	0.35	47
		Reference Area 3	2	0	0.5	0.7	0.6	0.60	0.14	23
		Reference Area 4	1	0	0.5	0.5	0.5	0.50	.	
		Reference Means					0.6	0.60		
		Study Area North	5	2	<0.5	0.6	0.5			
		Study Area South	5	0	0.5	2.2	0.6	0.92	0.72	120
		Study Means					0.6			
	2006	Reference Area 1	3	0	0.5	0.7	0.6	0.60	0.10	17
		Reference Area 2	3	0	0.5	0.8	0.6	0.63	0.15	24
		Reference Area 3	3	0	0.5	0.9	0.6	0.67	0.21	31
		Reference Area 4	3	0	0.6	0.8	0.7	0.70	0.10	14
		Reference Means					0.6	0.65		
		Study Area North	5	0	0.5	0.6	0.5	0.54	0.05	10
		Study Area South	5	1	<0.5	0.7	0.6			
		Study Means					0.6			
Moisture %	2004	Reference Area 1	3	0	78	81	79	79.33	1.53	2
		Reference Area 2	3	0	80	85	81	82.00	2.65	3
		Reference Area 3	2	0	79	82	81	80.50	2.12	3
		Reference Area 4	3	0	78	80	78	78.67	1.15	1
		Reference Means					80	80.13		
		Study Area	10	0	80	85	81	81.70	1.77	2
	2005	Reference Area 1	3	0	78	82	80	80.00	2.00	3

Variable	Year	Area	*n*	*n* < RDL	Min	Max	Median	Mean	SD	CV %
Moisture %	2005	Reference Area 2	3	0	78	83	81	80.67	2.52	3
		Reference Area 3	3	0	79	80	80	79.67	0.58	1
		Reference Area 4	1	0	80	80	80	80.00	.	
		Reference Means					80	80.08		
		Study Area North	5	0	80	81	80	80.20	0.45	1
		Study Area South	5	0	79	82	80	80.40	1.14	1
		Study Means					80	80.30		
	2006	Reference Area 1	3	0	80	84	81	81.67	2.08	3
		Reference Area 2	3	0	80	85	83	82.67	2.52	3
		Reference Area 3	3	0	79	81	81	80.33	1.15	1
		Reference Area 4	3	0	80	81	81	80.67	0.58	1
		Reference Means					82	81.33		
		Study Area North	5	0	80	84	81	81.60	1.52	2
		Study Area South	5	0	80	82	81	80.80	0.84	1
		Study Means					81	81.20		

Note - All units in mg/kg (wet weight) except where indicated
- Means and SDs are reported to one more significant digit than what is given for RDL (see Table 6-4)

Analysis of 2006 Data

The first step in analysis of 2006 crab body burden data was to conduct PCA on log-transformed concentrations of eight frequently detected metals (arsenic, boron, copper, mercury, selenium, silver, strontium, zinc). The PCA included 2004 and 2005 as well as 2006 data, since Metals PC1 scores were compared among the three years (see below). PC1 was positively correlated with concentrations of all metals, except boron and strontium, and accounted for 38% of total variance (Table 6-14). Boron was uncorrelated with PC1 and strontium was negatively correlated with PC1. PC2 was positively correlated with concentrations of mercury and boron, and negatively correlated with concentrations of copper and silver. PC3 was positively correlated with concentrations of boron and silver, and negatively correlated with concentrations of selenium.

Table 6-14 Correlations (Parametric or Pearson *r*) Between Metal Concentrations in Crab Claw Composites and Principal Components Derived from Those Concentrations (2004 to 2006)

Metal	Correlation (*r*) with:		
	PC1	PC2	PC3
Zinc	**0.839**	0.367	–0.211
Arsenic	**0.831**	0.062	–0.098
Selenium	**0.607**	0.138	**–0.642**
Mercury	**0.591**	0.468	0.486
Copper	0.448	**–0.748**	0.041
Silver	0.422	**–0.593**	0.417
Boron	0.087	**0.598**	0.479
Strontium	**–0.604**	0.308	–0.207
% variance	36	22	14

Notes: - Metals are listed in descending order of their correlations with PC1
- $|r| \geq 0.5$ in bold
- Metal concentrations were $\log_{10}$ transformed prior to deriving PC
- *n* = 63 composites (21 from 2004; 20 from 2005; 22 from 2006)

Metals PC1 scores were used as a summary measure of total metal concentrations (excluding strontium and boron) for subsequent analyses. The positive correlations with PC1 for most metals indicated that higher concentrations of these metals tended to co-occur. The negative correlation between PC1 (and most metals) and strontium may

indicate that strontium competes with other metals for binding sites in the claw and possibly other tissues or, more generally, that strontium "behaves differently" than other metals.

Metals PC2 and PC3 scores were not analyzed further. These secondary axes of variance among metals are not robust and are difficult to interpret, with many concentrations close to RDL and often reported and precise to only one or two significant digits. Furthermore, departures from spatial or temporal variance common to most metals (i.e., PC1 scores) patterns were usually evident from analyses of individual metal concentrations.

The next step was to compare body burden variables for 2006 among Areas using modified nested ANOVA; results are provided in Table 6-15. Moisture and fat content did not differ significantly among Reference Areas, between the northern and southern portions of the Study Area, or between the Study versus Reference Areas. Metals PC1 scores (i.e., concentrations of most metals) differed significantly among Reference Areas, but not between the northern and southern portions of the Study Area, nor between Study versus Reference Areas. PC1 scores and concentrations of most metals were highest in Reference Area 4 and lowest in Reference Areas 2 and 3 (Figure 6-4). Study Area Metals PC1 scores were within the Reference Area range.

Table 6-15 Results of Modified Nested ANOVA Comparing Crab Body Burden Variables Among Areas (2006)

Variable	*p* values				
	Among References	Between Study		Study versus Reference	
	Error=MSE	Error= MS(AR)	Error=MSE	Error= MS(AR)	Error=MSE
% moisture	0.264	0.538	*0.416*	0.875	*0.840*
% fat	0.743	0.188	*0.290*	0.116	*0.176*
Metals PC1	**0.019**	*0.796*	0.561	*0.966*	0.924
Arsenic	**0.004**	*0.978*	0.939	*0.776*	0.432
Boron	0.122	*0.754*	0.613	*0.810*	0.699
Copper	0.897	0.019	*0.058*	0.133	*0.376*
Mercury	0.575	0.715	*0.744*	0.251	*0.257*
Selenium	**0.047**	*0.461*	0.145	*0.653*	0.380
Silver	0.105	*0.879*	0.800	*0.792*	0.663
Strontium	0.469	0.304	*0.260*	0.362	*0.327*
Zinc	**0.047**	*0.959*	0.920	*0.934*	0.873

Notes:
- MSE = variance among composites within Areas; MS(AR) = variance among Reference Areas
- *Italics* indicate *p* values that should be used for tests of the Between Study and Study versus Reference contrasts, following recommendations in Quinn and Keough (2002; i.e., test against MSE only when $p \geq 0.25$ for Among References contrast)

Results for individual metals in Table 6-15 should be interpreted with some caution since there were zero or near-zero variances within some Areas and also some outliers relative to those low variances. Results are most robust for individual metals occurring at concentrations more than 5 to 10 times RDL. Concentrations of arsenic, selenium and zinc differed significantly among Reference Areas. There were no significant differences in concentrations of individual metals between the northern and southern portions of the Study Area or between the Study versus Reference Areas. Study Area concentrations of most metals, as well as Metals PC1 scores, were within the Reference Area range (Table 6-13).

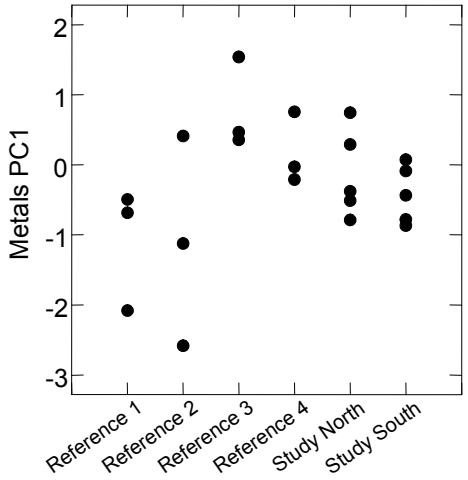


Figure 6-4 Distributions of Metals PC1 Scores for Crab Claw Composites (2006)

Note: - Some points may represent more than one composite

Moisture and fat content, and Metals PC1 (and also concentrations of individual metals), were not significantly correlated with biological variables (size and frequency of recent moults) (Table 6-16). Moisture and fat content were significantly negatively correlated. A negative correlation was expected since fat is one component, although minor, of the dry weight content of claw tissue. Metals PC1 scores were based on wet weight concentrations and were also negatively correlated with moisture content. This negative correlation would also be expected, assuming a constant mass of metal per unit *dry* tissue weight. For wet weight concentrations, higher tissue moisture content would then represent greater "dilution".

Table 6-16 Spearman Rank Correlations (r_s) Among Crab Body Burden Variables, and Between Those Variables and Biological Characteristics (2006)

	% moisture	% fat	Metals PC1
Carapace width	0.124	–0.347	0.130
Claw height	–0.099	–0.237	0.250
% recent moult	0.108	0.245	–0.255
% moisture		**–0.428***	**–0.590****
% fat			0.110

Notes: - n = 22 composites
- *$p \leq 0.05$; **$p \leq 0.01$; r_s at $p \leq 0.05$ in bold

Comparison Among Years (2004 to 2006)

Results of RM ANOVA comparing crab body burden variables among Areas and years (2004 to 2006) are provided in Table 6-17. Composites from various portions of the Study Area were pooled for calculation of the annual means analyzed, since the Study Area was not always separated into northern and southern portions. The tests had limited power, so $p \leq 0.10$ rather than the traditional $p \leq 0.05$ are shown in bold. Few terms or tests were significant even at $p \leq 0.10$.

Table 6-17 Results of Repeated Measures ANOVA Comparing Crab Body Burden Variables Among Areas and Between Years (2004 to 2006)

Variable	Between Areas		Within Areas					
			Overall		Linear Contrast (Trend)		Remainder	
	Study versus Reference (SR)	Among References	Year	Year × SR	Year	Year × SR	Year	Year × SR
% moisture	0.611	**0.068**	0.260	0.377	0.625	0.281	0.146	0.622
% fat	0.925	0.200	0.336	0.638	0.331	0.958	0.387	0.103
Metals PC1	0.703	**0.098**	0.192	0.794	0.209	0.785	0.325	0.493
Arsenic	0.656	**0.076**	0.267	0.858	0.347	0.980	0.214	0.548
Boron	0.981	0.596	0.205	0.921	0.106	0.991	0.443	0.753
Copper	0.743	0.308	**0.027**	0.718	**0.078**	0.770	0.079	0.194
Mercury	0.330	0.191	0.206	0.197	0.158	**0.035**	0.247	0.253
Selenium	0.756	0.710	**0.064**	0.545	0.972	0.432	**0.030**	0.612
Silver	0.943	**0.062**	**0.093**	0.920	**0.040**	0.676	0.917	0.874
Strontium	0.548	0.979	**0.022**	0.824	**0.024**	0.528	0.265	0.885
Zinc	0.774	0.190	0.481	0.967	0.911	0.848	0.156	0.981

Notes: - See Table 6-6 for further explanation of the RM ANOVA

The Between Areas Study versus Reference (SR) contrast was not significant at $p \leq 0.10$ for any of the body burden variables in Table 6-17; 10 of 11 p values were > 0.50. Thus, there were no consistent large differences in body burden variable values from 2004 to 2006 between the Study and Reference Areas (= SR differences). SR differences for most variables have always been small, with Study Area values usually within the Reference Area range (see below).

Tests of the Between Areas Among References contrast were significant at $p \leq 0.10$ but not $p \leq 0.05$ for moisture content, Metals PC1, arsenic and silver (Table 6-17). These results indicate that there have been some consistent differences over time for the Reference Areas. Moisture content has generally been higher and metals concentrations have generally been lower in Reference Area 1 (and to a lesser extent Reference Area 2) than in Reference Areas 3 and 4 (Figure 6-5). Study Area values were within the Reference Area range, indicating that the limited spatial variance among Areas has generally occurred among Reference Areas rather than between the Study versus Reference Areas.

The Within Areas Year × SR terms or contrasts in Table 6-17 test for changes in differences between Study versus Reference Areas over time. The Linear Year × SR contrast was significant for mercury. Study Area concentrations have been constant over time (means = 0.89 to 0.94 mg/kg wet) (Figure 6-6). However, Reference Area concentrations and, consequently, the SR difference (with S < R), have increased since 2004. Year × SR tests were not significant at $p \leq 0.10$ for any other variable.

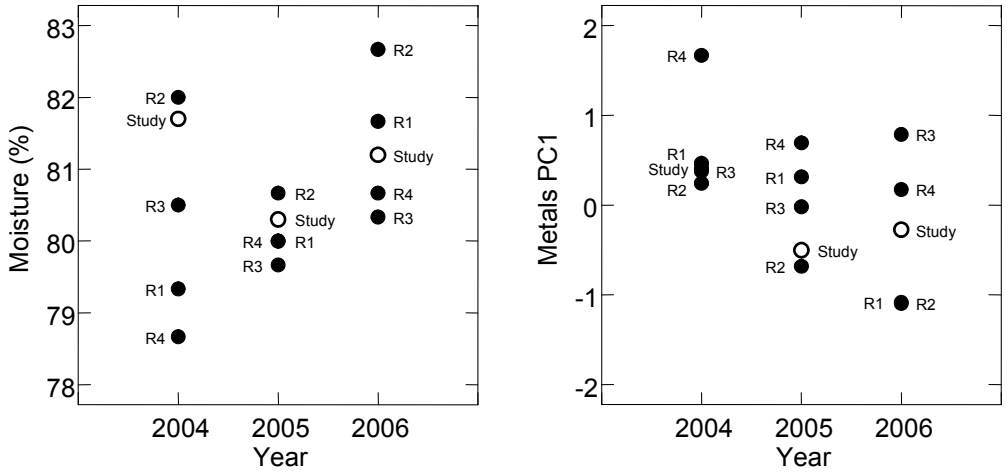


Figure 6-5 Moisture Content and Metals PC1 Scores for Crab Claw Composites (2004 to 2006)

Note: - Values are Area means

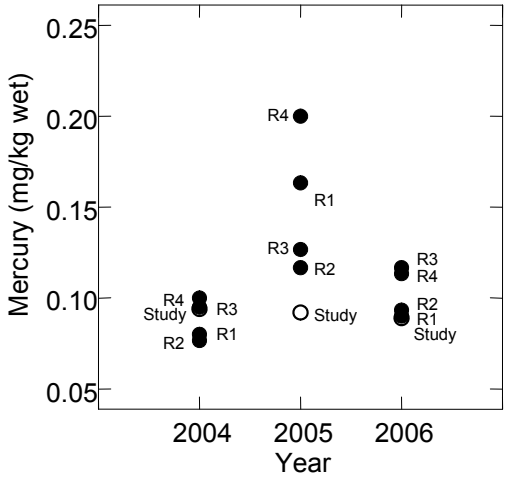


Figure 6-6 Mercury Concentrations in Crab Claw Composites (2004 to 2006)

Note: - Values are Area means

The Within Areas Year terms or contrasts in Table 6-17 test for consistent temporal changes occurring in all Areas. One or more Year terms were significant at $p \leq 0.10$ for copper, selenium, silver and strontium. Copper and silver concentrations have decreased and strontium concentrations have increased progressively over time (low *p* for Linear Year contrast in Table 6-17) (Figure 6-7). Selenium concentrations were lower in 2005 than in 2004 and 2006 (low *p* for Remainder Year contrast in Table 6-17). It was surprising that any changes over either time or space were detectable for selenium and silver, since many concentrations have been near or occasionally below RDL (Figure 6-7; Table 6-13).

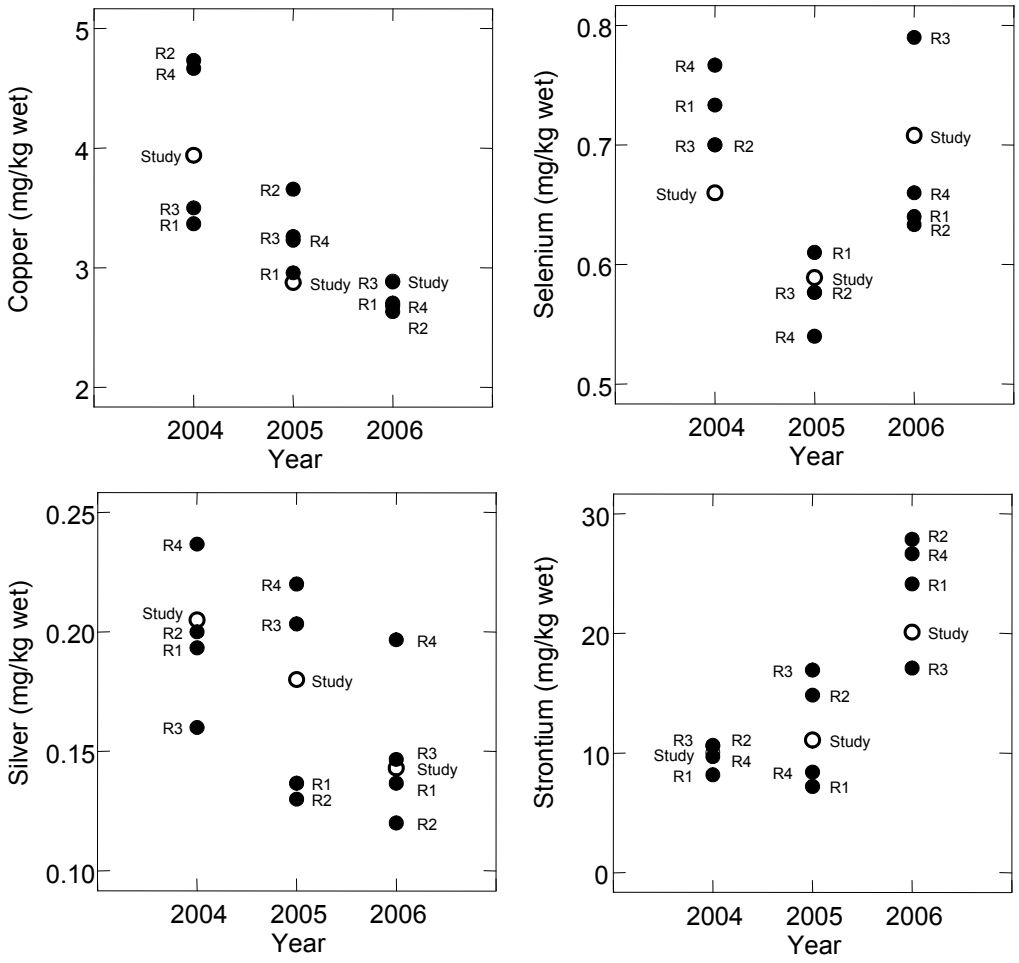


Figure 6-7 Copper, Selenium, Silver and Strontium Concentrations in Crab Claw Composites (2004 to 2006)

Note: - Values are Area means

6.4.2.2 Plaice

Liver

Summary statistics for detected substances in plaice liver in 2004, 2005 and 2006 are provided in Table 6-18. Raw data for 2006 are provided in Appendix C-2. HCs detected in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} range in all years showed no resemblance to drill fluid. Most of the HC peaks observed on chromatograms for liver (Appendix C-2; also see Husky Energy 2005 and 2006 for chromatograms for 2004 and 2005 samples, respectively) were consistent with those expected for extracted fatty acids and derivative compounds (Maxxam Analytics, pers. comm.). The liver sample from tow WR-3 collected in the northern portion of the Study in 2006 had the highest HC concentration (530 mg/kg) and these HCs did not resemble fatty acids. Compounds in this sample were identified by Dr. Joe Kiceniuk as a distallate in the fluel oil range and a light lube oil, resulting most probably from on-board vessel contamination. Neither of these products had any resemblance to PureDrill. The full comments from Dr. Kiceniuk are provided in Appendix C-3 immediately following the WR-3 liver chromatogram.

Table 6-18 Summary Statistics for Plaice Liver Body Burden (2004 to 2006)

Variable	Year	Area	*n*	*n* <RDL	Min	Max	Median	Mean	SD	CV%
$>C_{10}$-C_{21}	2004	Reference Area 1	3	0	31	87	70	62.7	28.7	46
		Reference Area 2	3	0	44	56	49	49.7	6.0	12
		Reference Area 3	3	0	76	85	78	79.7	4.7	6
		Reference Area 4	3	0	110	150	140	133.3	20.8	16
		Reference Means					84	81.3		
		Study Area	9	0	47	110	65	74.3	24.7	33
	2005	Reference Area 1	3	0	33	120	81	78.0	43.6	56
		Reference Area 2	3	0	44	73	44	53.7	16.7	31
		Reference Area 3	3	0	56	68	63	62.3	6.0	10
		Reference Area 4	3	0	99	130	100	109.7	17.6	16
		Reference Means					72	75.9		
		Study Area North	5	0	42	110	61	67.0	25.7	38
		Study Area South	5	0	35	74	53	55.0	14.2	26
		Study Means					57	61.0		
	2006	Reference Area 1	3	0	55	92	68	71.7	18.8	26
		Reference Area 2	3	0	22	45	41	36.0	12.3	34
		Reference Area 3	3	0	21	34	21	25.3	7.5	30
		Reference Area 4	3	0	27	51	33	37.0	12.5	34
		Reference Means					41	42.5		
		Study Area North	5	0	16	560	59	148.8	231.2	155
		Study Area South	5	0	33	65	42	47.2	13.3	28
		Study Means					51	98.0		
$>C_{21}$-C_{32}	2004	Reference Area 1	3	0	62	130	79	90.3	35.4	39
		Reference Area 2	3	0	64	110	71	81.7	24.8	30
		Reference Area 3	3	0	57	100	65	74.0	22.9	31
		Reference Area 4	3	0	56	96	91	81.0	21.8	27
		Reference Means					77	81.8		
		Study Area	9	0	40	120	55	62.1	23.3	37
	2005	Reference Area 1	3	0	43	57	46	48.8	7.4	15
		Reference Area 2	3	0	45	73	63	60.3	14.2	24
		Reference Area 3	3	0	47	75	56	59.3	14.3	24
		Reference Area 4	3	0	60	110	67	79.0	27.1	34
		Reference Means					58	61.8		
		Study Area North	5	0	42	81	70	65.6	16.1	25
		Study Area South	5	0	50	93	71	69.2	16.5	24
		Study Means					71	67.4		
	2006	Reference Area 1	3	0	59	84	73	72.0	12.5	17
		Reference Area 2	3	0	51	94	68	71.0	21.7	31
		Reference Area 3	3	0	51	62	52	55.0	6.1	11
		Reference Area 4	3	0	69	97	93	86.3	15.1	18
		Reference Means					72	71.1		
		Study Area North	5	0	26	660	68	178.0	270.2	152
		Study Area South	5	0	70	92	87	84.4	9.2	11
		Study Means					78	131.2		
Arsenic	2004	Reference Area 1	3	0	2.8	4.3	2.9	3.33	0.84	25
		Reference Area 2	3	0	1.8	5.2	4.0	3.67	1.72	47
		Reference Area 3	3	0	3.1	3.4	3.1	3.20	0.17	5
		Reference Area 4	3	0	4.1	5.4	4.3	4.60	0.70	15
		Reference Means					3.6	3.70		
		Study Area	10	0	1.8	5.8	3.4	3.42	1.08	32
	2005	Reference Area 1	3	0	3.11	4.49	3.4	3.67	0.73	20
		Reference Area 2	3	0	2.98	3.26	3.25	3.16	0.16	5
		Reference Area 3	3	0	3.90	4.92	4.39	4.40	0.51	12
	2005	Reference Area 4	3	0	1.74	3.21	2.58	2.51	0.74	29
		Reference Means					3.41	3.44		
		Study Area North	5	0	2.60	3.79	2.83	3.12	0.54	17
		Study Area South	5	0	2.54	8.27	3.43	4.17	2.36	57
		Study Means					3.13	3.65		
	2006	Reference Area 1	3	0	2.92	3.96	3.22	3.37	0.54	16
		Reference Area 2	3	0	1.85	3.08	2.28	2.40	0.62	26
		Reference Area 3	3	0	1.89	3.92	2.98	2.93	1.02	35
		Reference Area 4	3	0	1.91	3.32	3.00	2.74	0.74	27
		Reference Means					2.87	2.86		

Variable	Year	Area	*n*	*n* <RDL	Min	Max	Median	Mean	SD	CV%
Arsenic	2006	Study Area North	5	0	2.65	4.62	3.18	3.40	0.83	24
		Study Area South	5	0	2.48	7.07	2.95	3.80	1.91	50
		Study Means					3.07	3.60		
Cadmium	2004	Reference Area 1	3	0	0.38	0.69	0.41	0.493	0.171	35
		Reference Area 2	3	0	0.46	0.65	0.48	0.530	0.104	20
		Reference Area 3	3	0	0.38	0.41	0.41	0.400	0.017	4
		Reference Area 4	3	0	0.49	0.65	0.53	0.557	0.083	15
		Reference Means					0.46	0.495		
		Study Area	10	0	0.33	0.54	0.435	0.435	0.072	17
	2005	Reference Area 1	3	0	0.362	0.766	0.538	0.555	0.203	36
		Reference Area 2	3	0	0.401	0.575	0.55	0.509	0.094	18
		Reference Area 3	3	0	0.573	0.805	0.601	0.660	0.127	19
		Reference Area 4	3	0	0.283	0.518	0.336	0.379	0.123	33
		Reference Means					0.506	0.526		
		Study Area North	5	0	0.291	0.532	0.461	0.420	0.099	24
		Study Area South	5	0	0.377	0.723	0.414	0.464	0.146	32
		Study Means					0.438	0.442		
	2006	Reference Area 1	3	0	0.248	0.518	0.486	0.417	0.148	35
		Reference Area 2	3	0	0.479	0.732	0.532	0.581	0.133	23
		Reference Area 3	3	0	0.259	0.491	0.491	0.414	0.134	32
		Reference Area 4	3	0	0.266	0.339	0.327	0.311	0.039	13
		Reference Means					0.459	0.431		
		Study Area North	5	0	0.354	0.468	0.392	0.395	0.046	12
		Study Area South	5	0	0.3	0.546	0.406	0.417	0.093	22
		Study Means					0.399	0.406		
Copper	2004	Reference Area 1	3	0	3.1	4.9	4.2	4.07	0.91	22
		Reference Area 2	3	0	2.8	4.6	4.5	3.97	1.01	26
		Reference Area 3	3	0	3.3	4.7	4.0	4.00	0.70	18
		Reference Area 4	3	0	3.0	6.6	5.1	4.90	1.81	37
		Reference Means					4.5	4.23		
		Study Area	10	0	1.8	6.0	3.4	3.62	1.42	39
	2005	Reference Area 1	3	0	2.88	5.74	5.25	4.62	1.53	33
		Reference Area 2	3	0	2.60	6.92	3.75	4.42	2.24	51
		Reference Area 3	3	0	4.57	5.46	4.88	4.97	0.45	9
		Reference Area 4	3	0	3.83	4.28	3.95	4.02	0.23	6
		Reference Means					4.46	4.51		
		Study Area North	5	0	1.69	4.58	2.29	2.95	1.33	45
		Study Area South	5	0	3.15	7.22	4.74	4.80	1.59	33
		Study Means					3.52	3.87		
	2006	Reference Area 1	3	0	3.27	5.5	3.94	4.24	1.14	27
		Reference Area 2	3	0	2.97	5.42	3.77	4.05	1.25	31
		Reference Area 3	3	0	2.60	2.99	2.74	2.78	0.20	7
		Reference Area 4	3	0	4.02	4.52	4.49	4.34	0.28	6
		Reference Means					3.74	3.85		
		Study Area North	5	0	2.95	4.95	3.87	3.89	0.80	21
		Study Area South	5	0	2.34	5.81	4.19	3.98	1.28	32
		Study Means					4.03	3.93		
Iron	2004	Reference Area 1	3	0	22	66	44	44.0	22.00	50
		Reference Area 2	3	0	36	58	52	48.7	11.37	23
		Reference Area 3	3	0	30	36	33	33.0	3.00	9
		Reference Area 4	3	0	32	45	42	39.7	6.81	17
		Reference Means					43	41.3		
	2004	Study Area	10	0	29	52	42	40.5	7.8	19
	2005	Reference Area 1	3	0	40	57	45	47.3	8.7	18
		Reference Area 2	3	0	37	52	41	43.3	7.8	18
		Reference Area 3	3	0	52	70	64	62.0	9.2	15
		Reference Area 4	3	0	32	67	33	44.0	19.9	45
		Reference Means					46	49.2		
		Study Area North	5	0	29	111	36	54.6	34.2	63
		Study Area South	5	0	32	55	42	44.2	9.0	20
		Study Means					39	49.4		
	2006	Reference Area 1	3	0	30	53	38	40.3	11.7	29
		Reference Area 2	3	0	30	52	38	40.0	11.1	28
		Reference Area 3	3	0	42	77	42	53.7	20.2	38
		Reference Area 4	3	0	26	63	31	40.0	20.1	50

Variable	Year	Area	*n*	*n* <RDL	Min	Max	Median	Mean	SD	CV%
Iron	2006	Reference Means					37	43.5		
		Study Area North	5	0	25	51	41	38.8	10.1	26
		Study Area South	5	0	27	61	30	35.2	14.5	41
		Study Means					36	37.0		
Manganese	2004	Reference Area 1	3	0	0.7	0.8	0.8	0.77	0.06	8
		Reference Area 2	3	0	0.8	0.9	0.8	0.83	0.06	7
		Reference Area 3	3	0	0.8	1.0	0.8	0.87	0.12	13
		Reference Area 4	3	0	0.7	1.0	0.9	0.87	0.15	18
		Reference Means					0.8	0.83		
		Study Area	10	0	0.7	1.0	0.8	0.83	0.09	11
	2005	Reference Area 1	3	0	0.85	0.92	0.92	0.90	0.04	5
		Reference Area 2	3	0	0.99	1.59	1.07	1.22	0.33	27
		Reference Area 3	3	0	0.76	0.86	0.81	0.81	0.05	6
		Reference Area 4	3	0	0.72	0.94	0.81	0.82	0.11	13
		Reference Means					0.90	0.94		
		Study Area North	5	0	0.71	0.96	0.86	0.86	0.11	12
		Study Area South	5	0	0.67	0.91	0.89	0.84	0.10	12
		Study Means					0.88	0.85		
	2006	Reference Area 1	3	0	0.90	1.08	0.94	0.97	0.09	10
		Reference Area 2	3	0	0.80	0.94	0.92	0.89	0.08	9
		Reference Area 3	3	0	0.65	0.73	0.68	0.69	0.04	6
		Reference Area 4	3	0	0.64	0.83	0.79	0.75	0.10	13
		Reference Means					0.83	0.83		
		Study Area North	5	0	0.85	0.98	0.86	0.90	0.06	7
		Study Area South	5	0	0.79	1.09	0.97	0.93	0.13	14
		Study Means					0.92	0.91		
Mercury	2004	Reference Area 1	3	0	0.02	0.04	0.03	0.030	0.010	33
		Reference Area 2	3	0	0.03	0.04	0.04	0.037	0.006	16
		Reference Area 3	3	0	0.02	0.04	0.03	0.030	0.010	33
		Reference Area 4	3	0	0.03	0.04	0.03	0.033	0.058	17
		Reference Means					0.03	0.033		
		Study Area	10	0	0.02	0.04	0.03	0.031	0.005	16
	2005	Reference Area 1	3	0	0.04	0.05	0.04	0.043	0.006	13
		Reference Area 2	3	0	0.02	0.06	0.05	0.043	0.021	48
		Reference Area 3	3	0	0.05	0.06	0.05	0.053	0.006	11
		Reference Area 4	3	0	0.03	0.03	0.03	0.030	0.000	0
		Reference Means					0.04	0.043		
		Study Area North	5	0	0.02	0.04	0.02	0.028	0.011	39
		Study Area South	5	0	0.02	0.04	0.03	0.030	0.007	24
		Study Means					0.03	0.029		
	2006	Reference Area 1	3	0	0.02	0.02	0.02	0.020	0.000	0
		Reference Area 2	3	0	0.01	0.02	0.02	0.017	0.006	35
		Reference Area 3	3	0	0.02	0.02	0.02	0.020	0.000	0
		Reference Area 4	3	0	0.01	0.02	0.01	0.013	0.006	43
		Reference Means					0.02	0.018		
		Study Area North	5	0	0.02	0.02	0.02	0.020	0.000	0
		Study Area South	5	0	0.01	0.03	0.02	0.020	0.007	35
		Study Means					0.02	0.020		
Selenium	2004	Reference Area 1	3	0	1.7	2.1	1.9	1.90	0.20	11
		Reference Area 2	3	0	2.1	2.5	2.4	2.33	0.21	9
		Reference Area 3	3	0	1.9	2.2	2.0	2.03	0.15	8
		Reference Area 4	3	0	1.3	1.8	1.7	1.60	0.26	17
	2004	Reference Means					2.00	1.97		
		Study Area	10	0	1.7	2.3	1.95	1.98	0.18	9
	2005	Reference Area 1	3	0	1.88	2.36	2.09	2.11	0.24	11
	2005	Reference Area 2	3	0	2.05	2.34	2.3	2.23	0.16	7
		Reference Area 3	3	0	2.51	2.61	2.53	2.55	0.05	2
		Reference Area 4	3	0	1.44	1.86	1.73	1.68	0.22	13
		Reference Means					2.16	2.14		
		Study Area North	5	0	1.74	2.43	2.28	2.17	0.28	13
		Study Area South	5	0	1.79	2.57	2.31	2.20	0.31	14
		Study Means					2.30	2.19		
	2006	Reference Area 1	3	0	2.44	2.78	2.48	2.57	0.19	7
		Reference Area 2	3	0	2.6	2.89	2.72	2.74	0.15	5
		Reference Area 3	3	0	2.64	2.85	2.8	2.76	0.11	4

Variable	Year	Area	*n*	*n* <RDL	Min	Max	Median	Mean	SD	CV%
Selenium	2006	Reference Area 4	3	0	1.65	2.12	1.87	1.88	0.24	13
		Reference Means					2.47	2.49		
		Study Area North	5	0	2.51	2.9	2.63	2.66	0.15	6
		Study Area South	5	0	2.47	2.8	2.68	2.67	0.13	5
		Study Means					2.66	2.66		
Silver	2004	Reference Area 3	3	2	<0.12	0.13	<0.12			
		Reference Area 4	3	2	<0.12	0.18	<0.12			
	2005	Reference Area 3	3	1	<0.12	0.30	0.14			
		Study Area North	5	4	<0.12	0.25	<0.12			
		Study Area South	5	4	<0.12	0.12	<0.12			
		Study Means					<0.12			
	2006	Reference Area 3	3	2	<0.12	0.23	<0.12			
Strontium	2004	Reference Area 4	3	2	<1.5	1.6	<1.5			
	2006	Study Area South	5	4	<1.5	1.9	<1.5			
Uranium	2005	Reference Area 2	3	2	<0.02	0.022	<0.02			
Zinc	2004	Reference Area 1	3	0	23	25	23	23.67	1.15	5
		Reference Area 2	3	0	23	24	24	23.67	0.58	2
		Reference Area 3	3	0	22	26	22	23.33	2.31	10
		Reference Area 4	3	0	22	29	28	26.33	3.79	14
		Reference Means					24	24.25		
		Study Area	10	0	19.0	24.0	22.5	22.20	1.75	8
	2005	Reference Area 1	3	0	23.2	30.3	27.0	26.83	3.55	13
		Reference Area 2	3	0	25.5	27.8	27.5	26.93	1.25	5
		Reference Area 3	3	0	24.9	28.1	26.9	26.63	1.62	6
		Reference Area 4	3	0	22.6	27.1	22.9	24.20	2.52	10
		Reference Means					26.1	26.15		
		Study Area North	5	0	20.0	27.2	21.6	23.18	3.36	15
		Study Area South	5	0	21.7	28.7	25.1	25.26	2.70	11
		Study Means					23.4	24.22		
	2006	Reference Area 1	3	0	23.0	25.0	24.9	24.30	1.13	5
		Reference Area 2	3	0	26.2	28.1	26.5	26.93	1.02	4
		Reference Area 3	3	0	21.3	24.8	23.4	23.17	1.76	8
		Reference Area 4	3	0	23.6	23.9	23.8	23.77	0.15	1
		Reference Means					24.7	24.54		
		Study Area North	5	0	23.2	27.8	24.9	25.30	2.12	8
		Study Area South	5	0	24.6	30.4	28.6	27.60	2.81	10
		Study Means					26.8	26.45		
Crude Fat %	2004	Reference Area 1	3	0	14	23	15	17.33	4.93	28
		Reference Area 2	3	0	11	13	12	12.00	1.00	8
		Reference Area 3	3	0	11	17	14	14.00	3.00	21
		Reference Area 4	3	0	15	18	16	16.33	1.53	9
		Reference Means					14	14.92		
		Study Area	10	0	10	20	13	13.30	2.87	22
	2005	Reference Area 1	3	0	11	14	13	12.67	1.53	12
		Reference Area 2	2	0	14	15	15	14.50	0.71	5
		Reference Area 3	3	0	12	17	13	14.00	2.65	19
		Reference Area 4	3	0	17	25	24	22.00	4.36	20
		Reference Means					16	15.79		
		Study Area North	2	0	10	18	14	14.00	5.66	40
		Study Area South	5	0	13	21	18	17.20	3.19	19
		Study Means					16	15.60		
	2006	Reference Area 1	3	0	15	18	16	16.33	1.53	9
		Reference Area 2	3	0	12	21	16	16.33	4.51	28
		Reference Area 3	3	0	10	16	16	14.00	3.46	25
		Reference Area 4	3	0	17	31	19	22.33	7.57	34
		Reference Means					17	17.25		
		Study Area North	5	0	13	19	15	15.20	2.28	15
		Study Area South	5	0	15	22	19	18.20	2.77	15
		Study Means					17	16.70		
Moisture %	2004	Reference Area 1	3	0	63	70	68	67.00	3.61	5
		Reference Area 2	3	0	70	71	70	70.33	0.58	1
		Reference Area 3	3	0	66	71	68	68.33	2.52	4
		Reference Area 4	3	0	66	69	67	67.33	1.53	2
		Reference Means					68	68.25		
		Study Area	10	0	66	73	70	69.90	2.02	3

Variable	Year	Area	*n*	*n* <RDL	Min	Max	Median	Mean	SD	CV%
Moisture %	2005	Reference Area 1	3	0	67	70	69	68.67	1.53	2
		Reference Area 2	3	0	61	68	66	65.00	3.61	6
		Reference Area 3	3	0	67	70	69	68.67	1.53	2
		Reference Area 4	3	0	59	65	61	61.67	3.06	5
		Reference Means					66	66.00		
		Study Area North	5	0	64	70	69	67.40	2.70	4
		Study Area South	5	0	61	69	64	64.40	2.97	5
		Study Means					67	65.90		
	2006	Reference Area 1	3	0	67	69	68	68.00	1.00	1
		Reference Area 2	3	0	64	72	68	68.00	4.00	6
		Reference Area 3	3	0	68	73	68	69.67	2.89	4
		Reference Area 4	3	0	56	68	66	63.33	6.43	10
		Reference Means					68	67.25		
		Study Area North	5	0	65	70	69	68.00	2.00	3
		Study Area South	5	0	62	69	65	65.80	2.77	4
		Study Means					67	66.90		

Note - All units in mg/kg (wet weight) except where indicated
- Means and SDs are provided to one more significant digit than what is given for RDL (see Table 6-4)

Analysis of 2006 Data

The first step in analysis of plaice liver body burdens was to conduct a PCA on log-transformed concentrations of eight metals (arsenic, cadmium, copper, iron, manganese, mercury, selenium, zinc). The PCA included 2004 and 2005, as well as 2006, samples since PC scores were compared between years (see below). Concentrations of all metals were positively correlated with PC1 (Table 6-19), which served as a summary measure of total metal concentrations for subsequent analyses. Iron, manganese and selenium concentrations were not strongly correlated with PC1 and were more strongly correlated with PC2, PC3 or both secondary axes of variance. Results for these three metals were sometimes different from those for the metals that were more strongly correlated with Metals PC1, as noted below.

The next step was to compare liver body burden variables for 2006 among Areas using modified nested ANOVA. Moisture and fat content did not differ significantly among Reference Areas, between the northern and southern portions of the Study Area, or between the Study versus Reference Areas (Table 6-20).

Table 6-19 Correlations (Parametric or Pearson *r*) Between Metal Concentrations in Plaice Liver Composites and Principal Components (PC) Derived from Those Concentrations (2004 to 2006)

Metal	Correlation (*r*) with:		
	PC1	PC2	PC3
Cadmium	**0.754**	–0.301	0.220
Copper	**0.727**	0.229	–0.339
Arsenic	**0.698**	–0.160	0.057
Zinc	**0.616**	**0.625**	0.057
Mercury	**0.594**	–0.355	–0.382
Iron	0.312	**–0.528**	**0.571**
Selenium	0.239	0.436	**0.746**
Manganese	0.085	**0.686**	–0.100
% variance	31	20	15

Notes: - Metals are listed in descending order of their correlations with PC1
- $|r| \geq 0.5$ in bold
- Metal concentrations were $\log_{10}$ transformed prior to deriving PC
- *n* = 66 composites (22 from each year)

Table 6-20 Results of Modified Nested ANOVA Comparing Plaice Liver Body Burden Variables Among Areas (2006)

Variable	*p* values				
	Among References	Between Study		Study versus Reference	
	Error=MSE	Error= MS(AR)	Error=MSE	Error= MS(AR)	Error=MSE
% moisture	0.157	*0.515*	0.315	*0.874*	0.811
% fat	0.089	*0.498*	0.234	*0.848*	0.742
Metals PC1	0.352	0.746	*0.706*	0.350	*0.250*
Arsenic	0.787	0.430	*0.596*	0.090	*0.161*
Cadmium	**0.034**	*0.865*	0.727	*0.784*	0.573
Copper	0.210	*0.919*	0.888	*0.892*	0.851
Iron	0.594	0.661	*0.701*	0.287	*0.313*
Manganese	**0.006**	*0.876*	0.684	*0.421*	0.038
Mercury	0.261	1.000	*1.000*	0.391	*0.219*
Selenium	**0.000**	*0.987*	0.937	*0.608*	0.020
Zinc	0.130	*0.295*	0.080	*0.219*	0.036
$>C_{10}$-C_{21} HCs (rank)	0.067	*0.942*	0.894	*0.578*	0.304
$>C_{21}$-C_{32} HCs (rank)	0.148	*0.435*	0.217	*0.638*	0.466

Notes: - MSE = variance among composites within Areas; MS(AR) = variance among Reference Areas
- *Italics* indicate *p* values that should be used for tests of the Between Study and Study versus Reference contrasts, following recommendations in Quinn and Keough (2002; i.e., test against MSE only when $p \geq 0.25$ for Among References contrast)

Metals PC1 scores did not differ significantly among Reference Areas, between the northern and southern portions of the Study Area, or between the Study versus Reference Areas (Table 6-20; Figure 6-8). Concentrations of individual metals also did not differ significantly between the two portions of the Study Area, or between the Study versus Reference Areas. Cadmium, manganese and selenium concentrations differed significantly among the Reference Areas. Cadmium concentrations were highest in Reference Area 2 and lowest in Reference Area 4 (Figure 6-8). Manganese concentrations were lower in Reference Area 3 than in other Reference Areas. Selenium concentrations were much lower in Reference Area 4 than in other Reference Areas.

Rank-transformed $>C_{10}$-C_{21} HC and $>C_{21}$-C_{32} HC concentrations did not differ significantly among Reference Areas, between the northern and southern portions of the Study Area, or between the Study Area versus Reference Areas (Table 6-20; Figure 6-9). Rank transformation substantially reduced the influence of the high HC concentrations in one northern Study Area composite. Consequently, results for HC in Table 6-20 should be regarded as evidence that concentrations of fatty acids and their derivatives did not differ significantly among Areas.

Table 6-21 provides Spearman rank correlations among body burden variables and between those variables and composite mean gutted weight (i.e., size). Fat and moisture content were almost perfectly negatively correlated, which confounded interpretation of correlations between these two variables and other variables. The strong negative correlation was expected and was also observed for 2004 and 2005 samples (Husky Energy 2005, 2006). The liver is an important site for fat storage and the fat content in liver samples accounted for approximately 50% of the dry weight content (i.e., liver tissue is mostly water plus fat). Mean composite gutted weight (i.e., size) was positively correlated with moisture content and negatively correlated with fat content, although only the correlation with fat content was significant. Gutted weights were wet weights, but the moisture content of the liver would make a negligible contribution to those body wet

weights. One might also expect fat content in liver and other tissues to be higher in older and larger females.

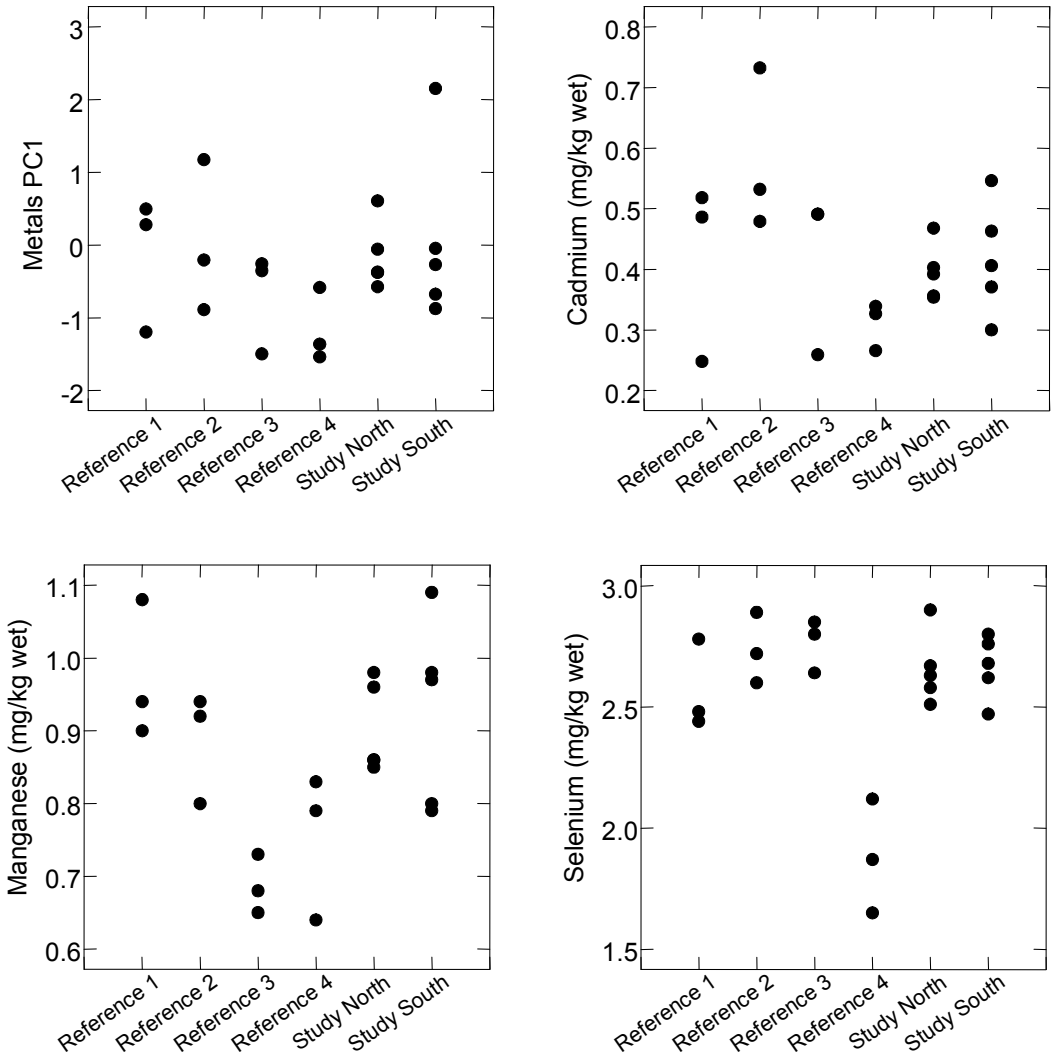


Figure 6-8 Distributions of Metals PC1 Scores, Cadmium, Manganese and Selenium Concentrations in Plaice Liver Composites (2006)

Note: - Some points may represent more than one composite

Metals PC1 scores and selenium concentrations were significantly positively correlated with gutted weight (Table 6-21), which is potential evidence of biomagnification or changes in physiology and metal uptake/elimination rates associated with size differences. Relationships between Metals PC1 and selenium versus size were primarily a within-Area phenomenon. Using gutted weight as a covariate in nested ANCOVA comparing Areas did not alter the results from ANOVA in Table 6-20. Metals PC1 scores did not differ significantly among Areas and selenium concentrations differed significantly only among Reference Areas.

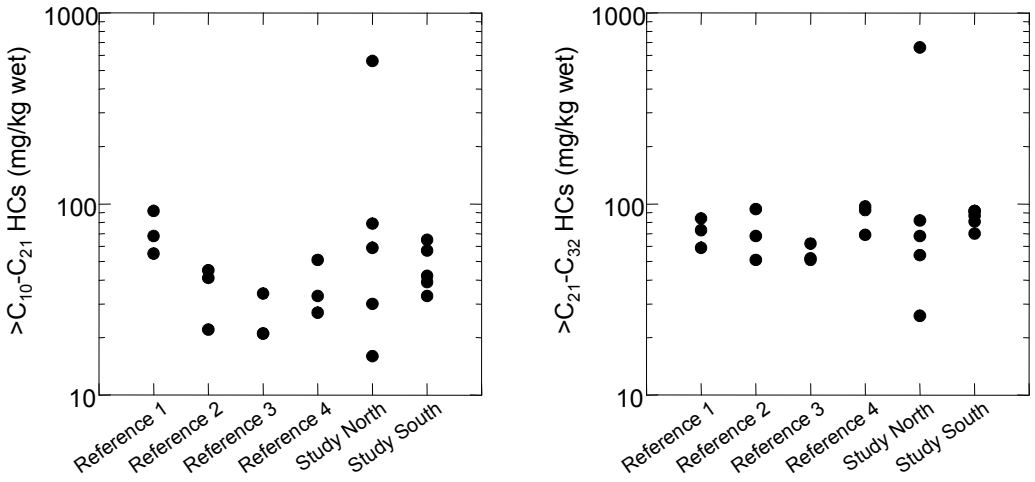


Figure 6-9 Distributions of >C_{10}-C_{21} and >C_{21}-C_{32} HC Concentrations in Plaice Liver Composites (2006)

Note: - Some points may represent more than one composite

Table 6-21 Spearman Rank Correlations (r_s) Among Plaice Liver Burden Variables, and Between Those Variables and Composite Mean Gutted Weights (2006)

	% moisture	% fat	Metals PC1	Iron	Manga-nese	Sele-nium	>C_{10}-C_{21} HCs	>C_{21}-C_{32} HCs
Gutted weight	0.343	**–0.472***	**0.642****	0.228	0.205	**0.450***	0.216	–0.367
% moisture		**–0.950****	0.237	**0.493***	–0.034	0.196	–0.123	**–0.486***
% fat			–0.322	**–0.483***	–0.035	–0.279	0.172	**0.557****
Metals PC1				0.363	0.330	**0.570****	0.263	–0.136
Iron					–0.202	0.262	–0.087	–0.307
Manganese						–0.031	0.323	0.160
Selenium							–0.109	–0.217
>C_{10}-C_{21} HCs								0.378

Notes: - n = 22 composites
- *$p \leq 0.05$; ** $p \leq 0.01$; r_s at $p \leq 0.05$ in bold

Metals PC1 scores and concentrations of iron and selenium were positively correlated with moisture content, although only the correlation for iron was significant (Table 6-21). Nevertheless, one might expect negative rather than positive concentrations between wet weight concentrations and moisture content, as observed in crab claws (Section 6.4.2.1). Correlations between metal concentrations and fat content were similar in strength to correlations with moisture content, but of opposite sign (i.e., generally negative). Concentrations of most metals should be uncorrelated with fat content, except that a positive correlation may be expected for organic forms of mercury and selenium that may preferentially accumulate in fat/lipids.

Iron and manganese concentrations in 2006 samples were weakly correlated with Metals PC1 scores (Table 6-21), which was also true for the larger 2004 to 2006 data set (Table 6-19). Selenium concentrations were significantly positively correlated with Metals PC1 in 2006 (Table 6-21) and also in 2005 (r_s = 0.613; p < 0.01). The weak correlation between selenium concentrations and Metals PC1 for the three-year data set (Table 6-19) was a function of the weak correlation in 2004 (r_s = 0.087; p >> 0.05) and

some changes in selenium concentrations over time that did not occur for other metals (see Comparison Among Years). Iron, manganese and selenium concentrations were not significantly correlated with each other (Table 6-21), indicating that there was no common pattern to any differences in their "behaviour" versus other metals.

Fat, as measured in liver samples, largely consists of fatty acids and their derivatives (Lehninger et al. 1993) and those compounds also account for a substantial portion of the HCs in most plaice liver samples. Consequently, in 2006, concentrations of $>C_{10}$-C_{21} and $>C_{21}$-C_{32} HCs were positively correlated with fat content (Table 6-21). The correlation between $>C_{10}$-C_{21} HCs and fat content was weak and not significant. Most fatty acids and especially their derivatives are large molecules with higher carbon (C) numbers. In 2004 and 2005, HC chromatogram profiles were not indicative of PureDrill and, as in 2006, HC concentrations were positively correlated with fat content, with the correlations significant for $>C_{21}$-C_{32} HCs but not $>C_{10}$-C_{21} HCs (Husky Energy 2005; 2006).

Concentrations of HCs were not significantly correlated with gutted weight or metal concentrations (Table 6-21). Concentrations of HCs were negatively correlated with moisture content, probably a function of the strong negative correlation between fat and moisture content, plus perhaps some tendency for wet weight concentrations to be lower in samples with higher moisture content. In 2006 (Table 6-21), as in 2004 and 2005 (Husky Energy 2005; 2006), concentrations of $>C_{10}$-C_{21} and $>C_{21}$-C_{32} HCs in plaice liver were not significantly correlated.

Comparison Among Years (2004 to 2006)

Results of RM ANOVA comparing plaice liver body burden variables among Areas and years (2004 to 2006) are provided in Table 6-22. Composites from all portions of the Study Area were pooled for calculation of the annual means analyzed because the Study Area was not always separated into northern and southern portions. The tests had limited power, so $p \leq 0.10$ rather than the traditional $p \leq 0.05$ are shown in bold. Few terms or tests were significant even at $p \leq 0.10$.

Table 6-22 Results of Repeated Measures (RM) ANOVA Comparing Plaice Liver Body Burden Variables Among Areas and Between Years (2004 to 2006)

Variable	Between Areas		Within Areas					
			Overall		Linear Contrast (Trend)		Remainder	
	Study versus Reference (SR)	Among References	Year	Year × SR	Year	Year × SR	Year	Year × SR
% moisture	0.875	**0.096**	0.210	0.792	0.262	0.540	0.238	0.812
% fat	0.874	**0.055**	0.355	0.855	0.225	0.795	0.775	0.654
Metals PC1	0.422	0.714	0.629	0.584	0.739	0.344	0.476	0.623
Arsenic	0.384	0.886	0.821	0.699	0.547	0.376	0.815	0.989
Cadmium	0.400	0.590	0.738	0.941	0.573	0.827	0.640	0.815
Copper	0.209	0.765	0.802	0.713	0.930	0.410	0.613	0.734
Iron	0.588	0.657	0.352	0.854	0.932	0.720	0.161	0.706
Manganese	0.992	0.360	0.840	0.701	0.723	0.667	0.684	0.530
Mercury	0.365	0.375	**0.026**	0.287	**0.030**	0.495	0.119	0.267
Selenium	0.850	**0.003**	**0.007**	0.785	**0.015**	0.546	0.378	0.838
Zinc	0.393	0.733	0.237	0.288	0.190	0.237	0.491	0.442
$>C_{10}$-C_{21} HCs	0.658	0.182	0.870	0.198	0.789	0.315	0.250	**0.015**
$>C_{21}$-C_{32} HCs	0.183	0.196	**0.006**	**0.005**	**0.019**	**0.008**	**0.057**	0.388

Notes: - See Table 6-6 for further explanation of the RM ANOVA

The Between Areas Study versus Reference Areas (SR) contrast was not significant at $p < 0.10$ for any body burden variable (Table 6-22). Thus, there were no consistent large differences between the Study versus Reference Areas over time, mostly because those differences have generally been small in all years.

The Between Areas Among References contrast was significant at $p \leq 0.10$ for fat and moisture content and selenium concentrations (Table 6-22), indicating that there were consistent differences Among Reference Areas for these three variables. Moisture content has generally been greater in Reference Area 3 and lower in Reference Area 4 than in the other Reference Areas (Figure 6-10). These differences and, more generally, the rank order of Area means were reversed for fat content, which was strongly negatively correlated with moisture content in all years. Selenium concentrations were lower in Reference Area 4 than in the other three Reference Areas in all three years. In all years, Study Area means for the three variables were within the Reference Area range.

Within Areas Year $\times$ SR terms or contrasts, which test for changes in the SR difference over time, were significant at $p \leq 0.10$ only for $>C_{10}$-C_{21} and $>C_{21}$-C_{32} HCs (Table 6-22). Averaging 10 sample values within the Study Area for 2006 substantially reduced the influence of the one northern Study Area sample with high HC concentrations. However, mean Study Area HC concentrations in 2006 were still higher in the Study Area than in any Reference Area, whereas Study Area HC concentrations in 2004 and 2005 were similar to or lower than Reference concentrations (Figure 6-11). If the one high HC outlier were deleted, the 2006 Study Area mean would be within the Reference range, as Figure 6-9 suggests.

Within Areas Year terms or contrasts, which test for changes over time occurring in all or most Areas, were significant at $p \leq 0.10$ for mercury, selenium and $>C_{21}$-C_{32} HCs. (Table 6-22). Mercury concentrations decreased over time (Figure 6-10). The decreases primarily occurred between 2005 and 2006, and concentrations actually increased between 2004 and 2005 in Reference Areas 1, 2 and 3. Selenium concentrations have increased over time in all or most Areas, and provide a more convincing example of a progressive or linear trend (Figure 6-10). Year effects or changes over time for $>C_{21}$-C_{32} HCs should be ignored, since there were highly significant Year $\times$ SR interactions. Note that Reference Area mean $>C_{21}$-C_{32} HCs concentrations have been relatively constant over time (Figure 6-11), which would also be the case for Study Area mean concentrations with the 2006 outlier deleted.

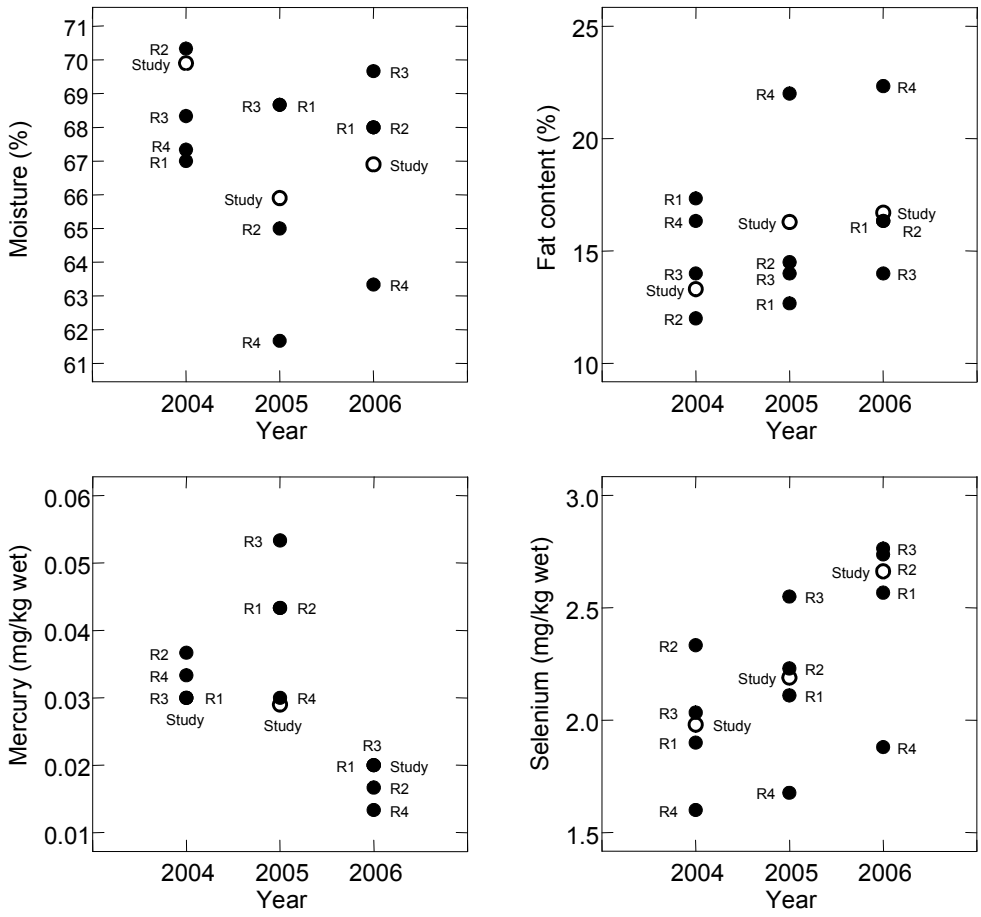


Figure 6-10 Moisture and Fat Content, and Mercury and Selenium Concentrations, in Plaice Liver Composites (2004 to 2006)

Note: - Values are Area means

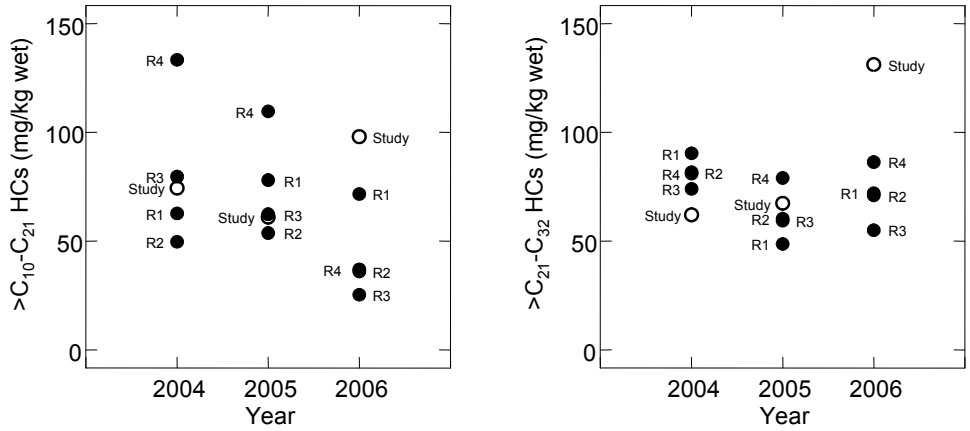


Figure 6-11 $>C_{10}$-C_{21} and $>C_{21}$-C_{32} HC Concentrations in Plaice Liver Composites (2004 to 2006)

Note: - Values are Area means

Fillets

Summary statistics for concentrations of detected substances are provided in Table 6-23. Raw data are provided in Appendix C-2. One 2005 fillet sample from Reference Area 4 had detectable HCs in the >C_{10}-C_{21} range, and one 2006 sample from the same Area had detectable HCs in the >C_{10}-C_{21} and >C_{21}-C_{32} ranges, but the chromatograms for these samples did not indicate the presence of drill muds (Maxxam Analytics, pers. comm.).

Table 6-23 Summary Statistics for Plaice Fillet Body Burden (2004 to 2006)

Variable	Year	Area	*n*	*n* < RDL	Min	Max	Median	Mean	SD	CV%
>C_{10}-C_{21}	2005	Reference Area 4	3	2	<15	16	<15			
>C_{10}-C_{21}	2006	Reference Area 4	3	1	<15	40	22			
>C_{21}-C_{32}	2006	Reference Area 4	3	1	<15	72	61			
Arsenic	2004	Reference Area 1	3	0	1.9	2.9	2.6	2.47	0.51	21
		Reference Area 2	3	0	2.1	2.6	2.2	2.30	0.26	11
		Reference Area 3	3	0	2.6	3.5	3.3	3.13	0.47	15
		Reference Area 4	3	0	3.4	4.0	3.5	3.63	0.32	9
		Reference Means					2.9	2.88		
		Study Area	10	0	2	4.2	2.8	2.79	0.68	24
	2005	Reference Area 1	3	0	2.20	4.36	2.48	3.01	1.17	39
		Reference Area 2	3	0	2.34	3.33	2.53	2.73	0.53	19
		Reference Area 3	3	0	2.99	4.27	3.88	3.71	0.66	18
		Reference Area 4	3	0	2.55	3.59	3.53	3.22	0.58	18
		Reference Means					3.11	3.17		
		Study Area North	5	0	2.25	3.09	2.97	2.84	0.34	12
		Study Area South	5	0	2.46	2.83	2.51	2.61	0.17	6
		Study Means					2.74	2.72		
	2006	Reference Area 1	3	0	3.13	4.13	3.39	3.55	0.52	15
		Reference Area 2	3	0	2.32	3.79	3.04	3.05	0.74	24
		Reference Area 3	3	0	2.82	3.23	3.14	3.06	0.22	7
		Reference Area 4	3	0	2.57	3.51	2.79	2.96	0.49	17
		Reference Means					3.09	3.16		
		Study Area North	5	0	2.64	5.04	3.22	3.66	1.01	28
		Study Area South	5	0	2.31	3.70	3.25	3.13	0.54	17
		Study Means					3.24	3.40		
Iron	2004	Study Area	10	9	<15	38	<15			
Mercury	2004	Reference Area 1	3	0	0.07	0.12	0.09	0.093	0.025	27
		Reference Area 2	3	0	0.07	0.10	0.09	0.087	0.015	18
		Reference Area 3	3	0	0.06	0.09	0.06	0.070	0.017	25
		Reference Area 4	3	0	0.05	0.08	0.08	0.070	0.017	25
		Reference Means					0.08	0.080		
		Study Area	10	0	0.04	0.10	0.09	0.083	0.021	25
	2005	Reference Area 1	3	0	0.06	0.08	0.07	0.070	0.010	14
		Reference Area 2	3	0	0.03	0.11	0.07	0.070	0.040	57
		Reference Area 3	3	0	0.07	0.14	0.11	0.107	0.035	33
		Reference Area 4	3	0	0.06	0.07	0.06	0.063	0.006	9
		Reference Means					0.08	0.078		
		Study Area North	5	0	0.04	0.10	0.08	0.072	0.023	32
		Study Area South	5	0	0.07	0.15	0.08	0.092	0.033	36
		Study Means					0.08	0.082		
	2006	Reference Area 1	3	0	0.06	0.09	0.09	0.080	0.017	22
		Reference Area 2	3	0	0.06	0.12	0.09	0.090	0.030	33
		Reference Area 3	3	0	0.07	0.09	0.08	0.080	0.010	13
		Reference Area 4	3	0	0.05	0.07	0.06	0.060	0.010	17
		Reference Means					0.08	0.078		
		Study Area North	5	0	0.07	0.11	0.08	0.088	0.016	19

Variable	Year	Area	*n*	*n* < RDL	Min	Max	Median	Mean	SD	CV%
Mercury	2006	Study Area South	5	0	0.05	0.10	0.09	0.078	0.022	28
		Study Means					0.09	0.083		
Selenium	2004	Study Area	10	9	<0.5	0.50	<0.5			
	2005	Reference Area 3	3	2	<0.5	0.51	<0.5			
Strontium	2004	Reference Area 3	3	2	<1.5	1.5	<1.5			
Zinc	2004	Reference Area 1	3	0	4.2	4.6	4.4	4.40	0.20	5
		Reference Area 2	3	0	4.3	4.8	4.3	4.47	0.29	6
		Reference Area 3	3	0	4.0	4.3	4.2	4.17	0.15	4
		Reference Area 4	3	0	3.8	4.0	3.9	3.90	0.10	3
		Reference Means					4.2	4.23		
		Study Area	10	0	3.4	4.8	4.2	4.20	0.36	9
	2005	Reference Area 1	3	0	3.8	4.6	4.2	4.20	0.40	10
		Reference Area 2	3	0	3.4	4.2	4.0	3.87	0.42	11
		Reference Area 3	3	0	4.6	4.7	4.7	4.67	0.06	1
		Reference Area 4	3	0	3.7	4.1	4.0	3.93	0.21	5
		Reference Means					4.2	4.17		
		Study Area North	5	0	3.8	4.6	4.2	4.16	0.36	9
		Study Area South	5	0	3.7	4.8	4.6	4.38	0.44	10
		Study Means					4.4	4.27		
	2006	Reference Area 1	3	0	4.1	4.3	4.2	4.20	0.10	2
		Reference Area 2	3	0	3.8	4.2	3.9	3.97	0.21	5
	2006	Reference Area 3	3	0	4.0	4.5	4.2	4.23	0.25	6
		Reference Area 4	3	0	3.8	4.2	4.0	4.00	0.20	5
		Reference Means					4.1	4.10		
		Study Area North	5	0	4.1	4.9	4.5	4.48	0.33	7
		Study Area South	5	0	3.9	4.6	4.0	4.10	0.29	7
		Study Means					4.3	4.29		
Crude Fat %	2004	Reference Area 1	3	0	1.1	1.9	1.7	1.57	0.42	27
		Reference Area 2	3	0	1.1	1.4	1.2	1.23	0.15	12
		Reference Area 3	3	0	2.2	3.6	2.5	2.77	0.74	27
		Reference Area 4	3	0	1.1	3.1	2.2	2.13	1.00	47
		Reference Means					1.9	1.93		
		Study Area	10	0	1.0	3.3	2.0	1.99	0.67	34
	2005	Reference Area 1	3	0	1.3	1.8	1.70	1.60	0.26	17
		Reference Area 2	3	0	0.9	1.5	0.90	1.10	0.35	31
		Reference Area 3	3	0	1.5	2.6	2.00	2.03	0.55	27
		Reference Area 4	3	0	1.4	1.8	1.50	1.57	0.21	13
		Reference Means					1.53	1.58		
		Study Area North	5	0	0.8	1.7	1.50	1.32	0.40	30
		Study Area South	5	0	0.6	2.3	1.90	1.56	0.69	44
		Study Means					1.70	1.44		
	2006	Reference Area 1	3	0	0.9	1.8	1.5	1.40	0.46	33
		Reference Area 2	3	0	1.2	2.1	1.3	1.53	0.49	32
		Reference Area 3	3	0	1.2	1.6	1.2	1.33	0.23	17
		Reference Area 4	3	0	1.0	1.6	1.4	1.33	0.31	23
		Reference Means					1.4	1.40		
		Study Area North	5	0	1.1	1.8	1.3	1.42	0.31	22
		Study Area South	5	0	1.1	1.5	1.2	1.26	0.18	14
		Study Means					1.3	1.34		
Moisture %	2004	Reference Area 1	3	0	77	80	78	78.33	1.53	2
		Reference Area 2	3	0	77	79	78	78.00	1.00	1
		Reference Area 3	3	0	77	81	79	79.00	2.00	3
		Reference Area 4	3	0	80	81	81	80.67	0.58	1
		Reference Means					79	79.00		
		Study Area	10	0	78	81	79	78.90	1.10	1
	2005	Reference Area 1	3	0	77	82	81	80.00	2.65	3
		Reference Area 2	3	0	80	83	83	82.00	1.73	2
		Reference Area 3	3	0	81	82	81	81.33	0.58	1

Variable	Year	Area	*n*	*n* < RDL	Min	Max	Median	Mean	SD	CV%
Moisture %	2005	Reference Area 4	3	0	79	81	81	80.33	1.15	1
		Reference Means					82	80.92		
		Study Area North	5	0	80	83	80	80.80	1.30	2
		Study Area South	5	0	78	82	80	79.80	1.79	2
		Study Means					80	80.30		
	2006	Reference Area 1	3	0	81	82	81	81.33	0.58	1
		Reference Area 2	3	0	80	82	80	80.67	1.15	1
		Reference Area 3	3	0	81	83	82	82.00	1.00	1
		Reference Area 4	3	0	78	80	80	79.33	1.15	1
		Reference Means					81	80.83		
		Study Area North	5	0	80	81	81	80.60	0.55	1
		Study Area South	5	0	78	82	81	80.80	1.64	2
		Study Means					81	80.70		

Note - All units in mg/kg (wet weight) except where indicated
- Means and SDs are provided to one more significant digit that what is given as RDL (see Table 6-4)

Analyses of 2006 Data

Moisture and fat content and metal concentrations in plaice fillets did not differ significantly among Reference Areas, or between the Study versus Reference Areas (Table 6-24). Except for zinc, there were also no significant differences between the northern and southern portions of the Study Area. Mean zinc concentrations were higher in the northern portion of the Study Area than in the southern portion. However, the difference was small (4.5 versus 4.1 mg/kg wet) for concentrations measured to only one decimal place, and significant only because of the narrow range of concentrations within Areas (Table 6-23). The only other spatial differences to approach significance were differences in moisture content among Reference Areas (p = 0.056). Again, these differences among Areas were small (range of Reference Area means = 79 to 83%) and p values were low only because of the limited variance within Areas.

Table 6-24 Results of Modified Nested ANOVA Comparing Plaice Fillet Body Burden Variables Among Areas (2006)

Variable	*p* values				
	Among References	Between Study		Study versus Reference	
	Error=MSE	Error= MS(AR)	Error=MSE	Error= MS(AR)	Error=MSE
% moisture	0.056	*0.883*	0.781	*0.885*	0.784
% fat	0.862	0.219	*0.452*	0.454	*0.675*
Arsenic	0.714	0.166	*0.234*	0.313	*0.424*
Mercury	0.303	0.521	*0.417*	0.592	*0.508*
Zinc	0.508	0.084	***0.036***	0.156	*0.110*

Notes: - MSE = variance among composites within Areas; MS(AR) = variance among Reference Areas
- *Italics* indicate p values that should be used for tests of the Between Study and Study versus Reference contrasts, following recommendations in Quinn and Keough (2002; i.e., test against MSE only when $p \geq 0.25$ for Among References contrast)

Fat and moisture content were not significantly correlated with each other or with mean composite gutted weight (i.e., size) and metal concentrations (Table 6-25). The absence of a negative correlation between moisture and fat content in fillets was surprising. Fat content in fillets was low, with fat representing a relatively small portion of the dry weight content. However, moisture and fat content were negatively correlated in crab claws (Section 6.4.2.1), although fat content was lower in claws than in plaice fillets. Note also

that correlations between moisture and wet weight metal concentrations were positive, although not significant, rather than negative.

Table 6-25 Spearman Rank Correlations (r_s) Among Plaice Fillet Body Burden Variables, and Between Those Variables and Composite Mean Gutted Weights (2006)

	% moisture	% fat	Arsenic	Mercury	Zinc
Gutted weight	0.278	0.202	**0.589****	**0.742****	**0.474***
% moisture		–0.090	0.292	0.365	0.291
% fat			0.212	0.179	0.046
Arsenic				**0.583****	0.384
Mercury					**0.477***

Notes: - n = 22 composites
- *$p \leq 0.05$; **$p \leq 0.01$; r_s at $p \leq 0.05$ in bold

Arsenic, mercury and zinc concentrations in fillets were positively correlated with each other, although the arsenic-zinc correlation was not significant (Table 6-25). Positive correlations have occurred in past years between zinc and mercury, but not between these two metals and arsenic (Husky Energy 2005; 2006).

Metal concentrations increased significantly with increasing size (i.e., composite mean gutted weights) (Table 6-25). As was the case for crab claws and plaice liver, positive correlations between metal concentrations and size may be evidence of biomagnification or changes in physiology and uptake/elimination rates with size. The relationships between metal concentrations and size were surprisingly strong, given that metal concentrations varied less than three-fold among composites. However, when mean weight was used as a covariate in ANCOVA, the basic conclusion from ANOVA in Table 6-24 was unaltered: metal concentrations in fillets generally did not differ significantly among Areas. In fact, with weight as a covariate, the significant difference in zinc concentrations between the northern and southern portions of the Study Area from the ANOVA was removed (p = 0.141 for ANCOVA versus p = 0.036 for ANOVA).

Comparison Among Years

Terms in RM ANOVA comparing plaice fillet body burden variables among Areas and between years (2004, 2005, 2006) were not significant at $p \leq 0.10$ (or even at $p \leq 0.20$; Table 6-26). Any differences over space or time were small, and probably artifacts of low variances within Areas and limited analytical precision at low variable values in all three years.

Table 6-26 Results of Repeated Measures (RM) ANOVA Comparing Plaice Fillet Body Burden Variables Among Areas and Between Years (2004 to 2006)

Variable	Between Areas		Within Areas					
			Overall		Linear Contrast (Trend)		Remainder	
	Study versus Reference (SR)	Among References	Year	Year × SR	Year	Year × SR	Year	Year × SR
% moisture	0.551	0.841	0.206	0.958	0.222	0.990	0.326	0.723
% fat	0.910	0.219	0.219	0.948	0.258	0.892	0.207	0.532
Arsenic	0.772	0.371	0.466	0.633	0.398	0.733	0.580	0.234
Mercury	0.709	0.366	0.988	0.994	0.852	0.852	0.936	0.993
Zinc	0.699	0.265	0.991	0.845	0.898	0.526	0.952	0.952

Note: - See Table 6-6 for further explanation of the RM ANOVA

6.4.3 Taste Tests

No significant difference in taste was noted between crab from the Study and Reference Areas in both the triangle and hedonic scaling tests. Panelists for the triangle test were successful in discriminating only 7 out of 24 samples. These results were not significant at α = 0.05 (Appendix C-4). ANOVA statistics for hedonic scaling are provided in Table 6-27. The results were not significant (p = 0.10; α = 0.05), and from the frequency histogram (Figure 6-12), samples from both the Study and Reference Areas were assessed similarly for preference. From ancillary comments (Tables 6-28 and 6-29, and Appendix C-4), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 6-27 Analysis of Variance for Taste Preference Evaluation of Crab by Hedonic Scaling (2006)

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.33	1	5.33	2.90	0.10
Within Groups	84.58	46	1.84		
Total	89.917	47			

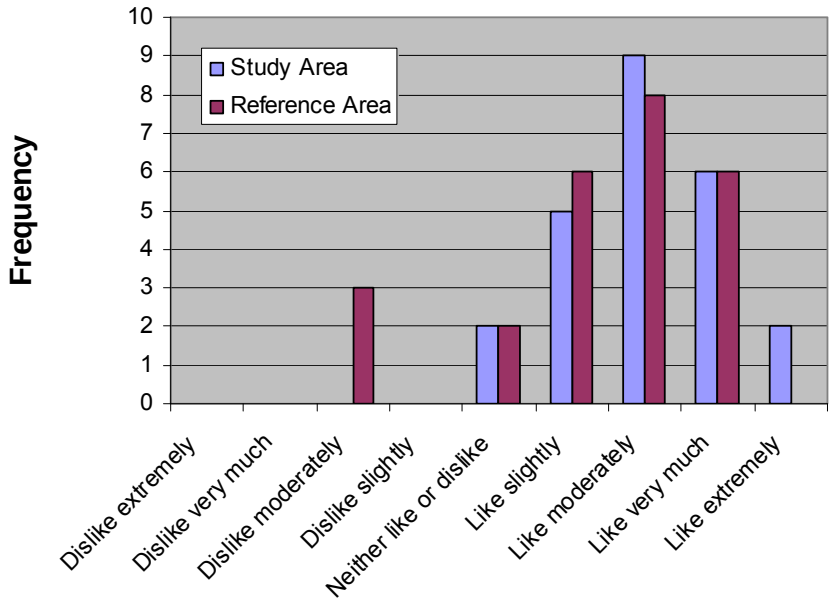


Figure 6-12 Crab Frequency Histogram for Hedonic Scaling Taste Evaluation (2006)

Table 6-28 Summary of Comments from the Triangle Taste Test for Crab (2006)

Reference Area (RA) Correctly Identified as Odd Sample	Study Area (SA) Correctly Identified as Odd Sample
233 (RA) was slightly saltier.	I prefer 518 (SA) over the two other samples. Seemed sweeter.
233 (RA) seems more salty.	518 (SA) was more bland than the two other samples. There was less of a crab taste.
Taste and smell the same.	
Reference Area Incorrectly Identified as Odd Sample	**Study Area Incorrectly Identified as Odd Sample**
I found it very difficult to pick out the odd sample. They tasted and smelled very similar to me.	Very similar, OK flavour, 104 (SA) was slightly different, it had a strange after taste.
Based on odour, I can not detect any difference. Based on flavour, 272 (SA) and 356 (RA) seem slightly sweeter; 805 (RA) a little bland but the difference in the samples overall is very minor.	124 (SA) smell is more faint. However, taste is similar.
272 (SA) and 356 (RA) sweeter. 805 (RA) tasted more bland than the others. All tasted OK.	Could not detect any difference in odour. 124 (SA) slightly sweeter, stronger taste - good taste.
Slight difference in both odour and flavour.	No difference in odour. Sample 215 (SA) appear to be slightly less desirable flavour.
Quite a bit more bland (805, RA) than the other two and less moist.	They all stink. Pretty good flavour.
518 (SA) and 900 (RA) had stronger odours and flavours than sample 683 (RA). Neither of the samples were very desirable.	No significant difference. 215 (SA) may have had a stronger after taste.
518 (SA) and 900 (RA) were very similar with 683 (RA) the most different. The taste of 683 was off. Of 518 and 900, 518 was a little better. There was no appreciable odour from either of the samples.	Taste, odour fine for all samples. 215 (SA) seemed a little more bland.
	215 (SA) had a bland taste, poor flavour.

Table 6-29 Summary of Comments from Hedonic Scaling Taste Tests for Crab (2006)

Preferred Reference Area (RA)	Preferred Study Area (SA)
Very similar in taste and odour.	More odour on sample 151 (RA).
	Very similar in taste and odour.
Sample 151 (RA) has a more preferred flavour. No significant difference in odour.	508 (SA) was a lot sweeter and tasted better. 151 (RA) tasted a little bitter.
	151 (RA) bland.
No big difference in flavour. Mild odour. Thanks.	Found slight off odour on 363 (RA). Flavour was also slightly different. 306 (SA) more pleasing however.
	No big difference in flavour. Mild odour. Thanks.
363 (RA) sweet taste. 306 (SA) bland taste.	306 (SA) was very good, good taste and smell. 363 (RA) was not very good, had an off taste and an off smell.
	Sample 306 (SA) natural flavour, neutral/slight odour. Sample 363 (RA) neutral odour, off taste.
Odour strong from sample 306 (SA). Sample 363 tasted sweeter.	Odour strong from sample 306 (SA). Sample 363 tasted sweeter.
	566 (RA) odour is unpleasant, gritty.
138 (SA) smell faint/weak and taste not as sweet as 566 (RA).	138 (SA) was sweeter, both had similar odour.
	138 (SA) had a stronger odour/flavour, it was also more salty tasting, more shells also.
566 (RA) good characteristic taste for crab. 138 (SA) a little more bland but still very good.	Both are comparable. 138 (SA) seemed to be less salty. 566 (RA) seemed a little too salty.
	836 (RA) appeared a little more bitter. 720 (SA) - more sweet. Nothing significant.

Preferred Reference Area (RA)	Preferred Study Area (SA)
Very little difference.	Very little difference.
836 (RA) is slightly better in terms of it being less 'stale' but neither product is pleasant to taste. 720 (SA) has an 'extra' flavour - almost like herring. (not the good crab I'm used to).	836 (RA) is slightly better in terms of it being less 'stale' but neither product is pleasant to taste. 720 (SA) has an 'extra' flavour - almost like herring. (not the good crab I'm used to).
836 (RA) seemed more tasty. The odour and flavour was very similar between the two.	No difference in odour. Not a big difference in terms of flavour or taste. 720 (SA) tasted a little more fresh, not significantly, however.

Note: - Comments included in both columns when ranks between Study and Reference Area samples were equal

For plaice, panelists for the triangle test were successful in discriminating 10 out of 24 samples. These results are not significant at α = 0.05 (Appendix C-4). ANOVA statistics for hedonic scaling are provided in Table 6-30. The results were not significant (p = 0.15; α = 0.05), and from the frequency histogram (Figure 6-13), samples from both the Study and Reference Areas were assessed similarly for preference. From ancillary comments (Tables 6-31 and 6-32, and Appendix C-4), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 6-30 Analysis of Variance for Taste Preference Evaluation of Plaice by Hedonic Scaling (2006)

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.08	1	4.08	2.14	0.15
Within Groups	87.83	46	1.91		
Total	91.92	47			

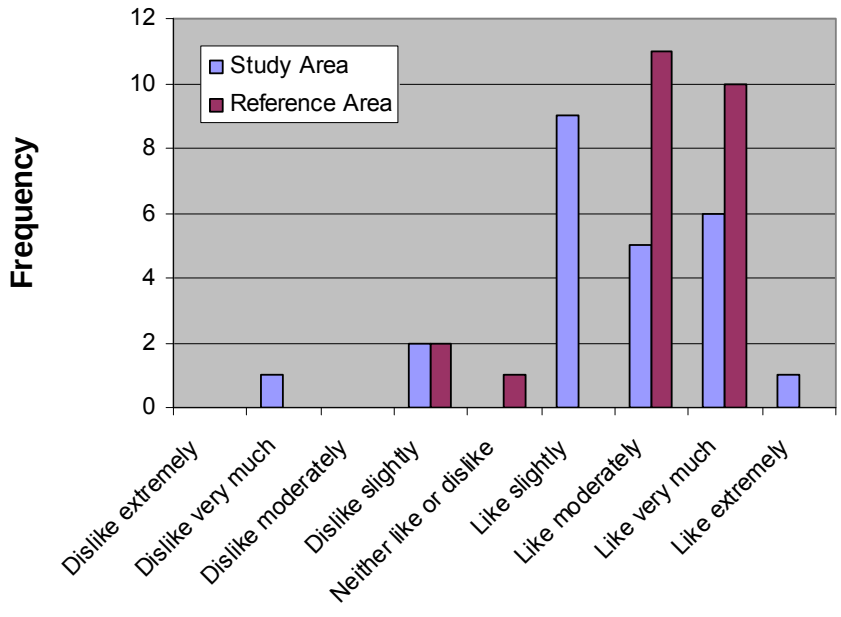


Figure 6-13 Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2006)

Table 6-31 Summary of Comments from the Triangle Taste Test for Plaice (2006)

Reference Area (RA) Correctly Identified as Odd Sample	Study Area (SA) Correctly Identified as Odd Sample
356 (RA) smelled a little stronger and also tasted stronger.	Very similar, hard to tell differences. More or less had to guess which one was odd. Good flavour and smell from all three.
All tasted very similar. No odour or taste issues overall.	
356 (RA) was a lot better tasting, whereas the other two samples had the same flavour.	
All tasted very similar. I found 929 (RA) to be a little plain. The others seemed more tasty and odour was fine on all three.	I'm not really sure which is different, maybe 785 (SA). Thanks.
929(RA) tastes more 'fishy' and smells more of 'old' or stale fish.	
929(RA) more flavour - nice taste. The other two more bland - fair taste. Odour much the same on all three.	
Reference Area Incorrectly Identified as Odd Sample	**Study Area Incorrectly Identified as Odd Sample**
456 (RA) has an off-taste compared to the other two and had a bad odour.	Crackers a little stale.
Both the other samples I found bland. 456 (RA) was more flavourfull - oil taste.	Slightly off-flavour in sample 319 (SA), also had more fish odour.
456 (RA) was not as salty as the other two.	Off smell on 850 (SA). All three similar. Off taste on 850 (SA)
Really not a big difference. I think the two alike (490, RA; 814, SA) taste better.	929 (RA) and 850 (SA) had drier taste, while 609 (SA) was more moist and had a stronger odour.
Very dry.	
No real noticeable difference.	Very similar. Slight difference in 850 (SA)?
Not much difference at all. 957 (RA) appeared a little more land.	

Table 6-32 Summary of Comments from the Hedonic Scaling Taste Test for Plaice (2006)

Prefer Reference Area (RA)	Prefer Study Area (SA)
Prefer 131 (RA) very much over 704 (SA). 704 has a stronger taste which to me is not that good. 131 is very good. 704 also didn't smell that great.	No detectable odour from samples. Both samples are comparable to each other.
Both smelled 'normal'. 131 (RA) tasted fresher. I didn't notice any difference in texture.	
Fishier smell on 704 (SA).	Both tasted really nice.
More flavour on 135 (SA). Something is added. 883 (RA) tasted normal.	
Good flavour but was a little bland. Would be good with some salt.	704 (SA) not too salty, tasted very well, odour was appealing. 131 (RA) a little watery, not too salty, taste was good and odour was not offensive.
883 (RA) tasted good and smelled OK. 135 (SA) smelled artificial but taste was ok.	
The 883 (RA) sample had a better flavour.	Bland hospital food.
275 (SA) not salty enough. Odour was fine. 581 (RA) tastes nicer than 275.	
581 (RA) tasted slightly better than 275 (SA). However, I did not detect a discernable difference in terms of odour between the two samples.	Good flavour but was a little bland. Would be good with some salt.
581 (RA) had a better taste but the odour was not more fishy than the 275 (SA) sample.	
581 (RA) distinct flavour. 275 (SA) somewhat milder flavour.	Can not differentiate any flavour differences between the two samples.
Can not differentiate any flavour differences between the two samples.	
Very little difference.	Sample 800 (RA) had a slightly better taste and sweeter odour.
Sample 800 (RA) had a slightly better taste and sweeter odour.	
Sample 800 (RA) is more preferred. Sample 700 (SA) had more fish odours.	800 (RA) was blander than 700. 700 had a slightly fishier taste.
Sample 700 (SA) had a metalic odour and poor taste.	
Both samples very bland; liked 800 (RA) better. 800 smelled better. I would also add salt and pepper, for sure!	800 (RA) - did not like the aftertaste. Odour fine on both samples.

Note: - Comments included in both columns when ranks between Study and Reference Area samples were equal

6.4.4 Fish Health Indicators

6.4.4.1 Gross Pathology

Six fish, one from Reference Area 1, one from Reference Area 2, two from Reference Area 4 and two from the southern portion of the Study Area, displayed pale gills (Appendix C-3, Annex H, Photo 1). Two fish, one from Reference Area 3 and one from Reference Area 4, exhibited minor to mild fin rot.

6.4.4.2 Haematology

Blood smears were examined for various types of cells. The red blood cells of all fish appeared to be normal in size and shape. Coloration was also similar indicating a similar degree of haemoglobinization.

A differential cell count of lymphocytes, neutrophils and thrombocytes was carried out on a total of 171 fish. Blood smears of nine fish were not suitable for cell counting due to thin smearing or clotting problems. For the other blood smears, 200 cells were counted per fish and the results were expressed as mean percentage ± SD of each cell type (Table 6-33). The complete data set on the different cells examined is provided in Appendix C-3, Annex D, and a representative photograph of a blood smear (Photo 2) is included in Appendix C-3, Annex H.

Table 6-33 Frequencies of Blood Cell Types in Plaice (2006)

Area	No. fish	% lymphocytes	% thrombocytes	% neutrophils
Reference 1	29	86.9 ± 4.3	12.5 ± 4.2	0.62 ± 0.83
Reference 2	30	88.4 ± 3.0	11.1 ± 2.7	0.53 ± 0.83
Reference 3	29	89.9 ± 3.0	9.3 ± 2.8	0.71 ± 0.79
Reference 4	28	90.6 ± 2.6	9.2 ± 2.6	0.20 ± 0.37
All References	116	89.0	10.5	0.51
North Study	25	70.1 ± 12.2	29.2 ± 12.4	0.74 ± 0.63
South Study	30	82.2 ± 6.5	17.5 ± 6.4	0.35 ± 0.40
Both Study	55	76.2	23.3	0.55

Notes:
- All data are means ± SD
- All References = means of the four Reference Area means; Both Study = means of the two Study Area means

Probit-transformed percentages of lymphocytes and thrombocytes were compared among Areas using modified nested ANOVA. For all tests, *p* values for the two variables were similar (Table 6-34) because the two percentages summed to almost 100% for all fish (i.e., the two variables were almost perfectly negatively correlated). Percentages of the two cell types differed significantly among Reference Areas (Table 6-34). Percentages of lymphocytes were lower and percentages of thrombocytes were higher in Reference Areas 1 and 2 than in Reference Areas 3 and 4 (Table 6-33). The differences among Reference Areas, although significant, were small, representing an average of less than 10 cells in samples of 200 cells.

Table 6-34 Results of Nested ANOVA Comparing Percentages of Blood Cell Types in Plaice (2006)

Group	*p* values				
	Among References	Between Study		Study versus Reference	
	Error=MSE	Error= MS(AR)	Error=MSE	Error= MS(AR)	Error=MSE
% lymphocytes	**0.005**	*0.052*	<0.001	***0.007***	<0.001
% thrombocytes	**0.008**	*0.052*	<0.001	***0.006***	<0.001

Notes:
- See Appendix C-3, Annex B for details on application and interpretation of modified nested ANOVA
- MSE = variance among fish within Areas; MS(AR) = variance among Reference Areas
- *Italics* indicate *p* values that should be used for tests of the Between Study and Study versus Reference contrasts, following recommendations in Quinn and Keough (2002; i.e., test against MSE only when $p \geq 0.25$ for Among References contrast)
- Cell type percentages were probit-transformed

Differences between Study versus Reference Areas were significant, despite the limited power of tests using the variance among Reference Areas (MS(AR)) as the error term (Table 6-34). Percentages of lymphocytes were much lower and percentages of thrombocytes were much higher in the two portions of the Study Area than in any Reference Area (Table 6-33). Lymphocyte:thrombocyte ratios were approximately 3-4:1 in the Study Area versus 9:1 in the Reference Areas. Percentages of lymphocytes were also lower and percentages of thrombocytes higher in the northern portion of the Study Area compared to the southern portion (Table 6-33), although the difference was not quite significant (p = 0.052; Table 6-34). Percentages of the two cell types also varied more within the Study Areas than within Reference Areas (see SD in Table 6-33), even after probit transformation.

6.4.4.3 Mixed Function Oxygenase Activity

Since basal levels of MFO enzymes can vary seasonally between males and females of the same species (e.g. Walton et al. 1983; Mathieu et al. 1991), results were analyzed separately for each sex. They were also analyzed separately for immature and mature females, since maturity stage can probably result in some loss of sensitivity for resolving contaminant mediated differences in female fish during spawning (e.g. Whyte et al. 2000).

MFO enzyme activities, measured as EROD, in mature females, immature females, and mature males from the six Areas are summarized in Figure 6-14. MFO activities were greater in mature males (overall median = 40 pmol/min/mg protein) and immature females (median = 40 pmol/min/mg) than in mature females (median = 20 pmol/min/mg protein). The complete data set is provided in Appendix C-3, Annex E.

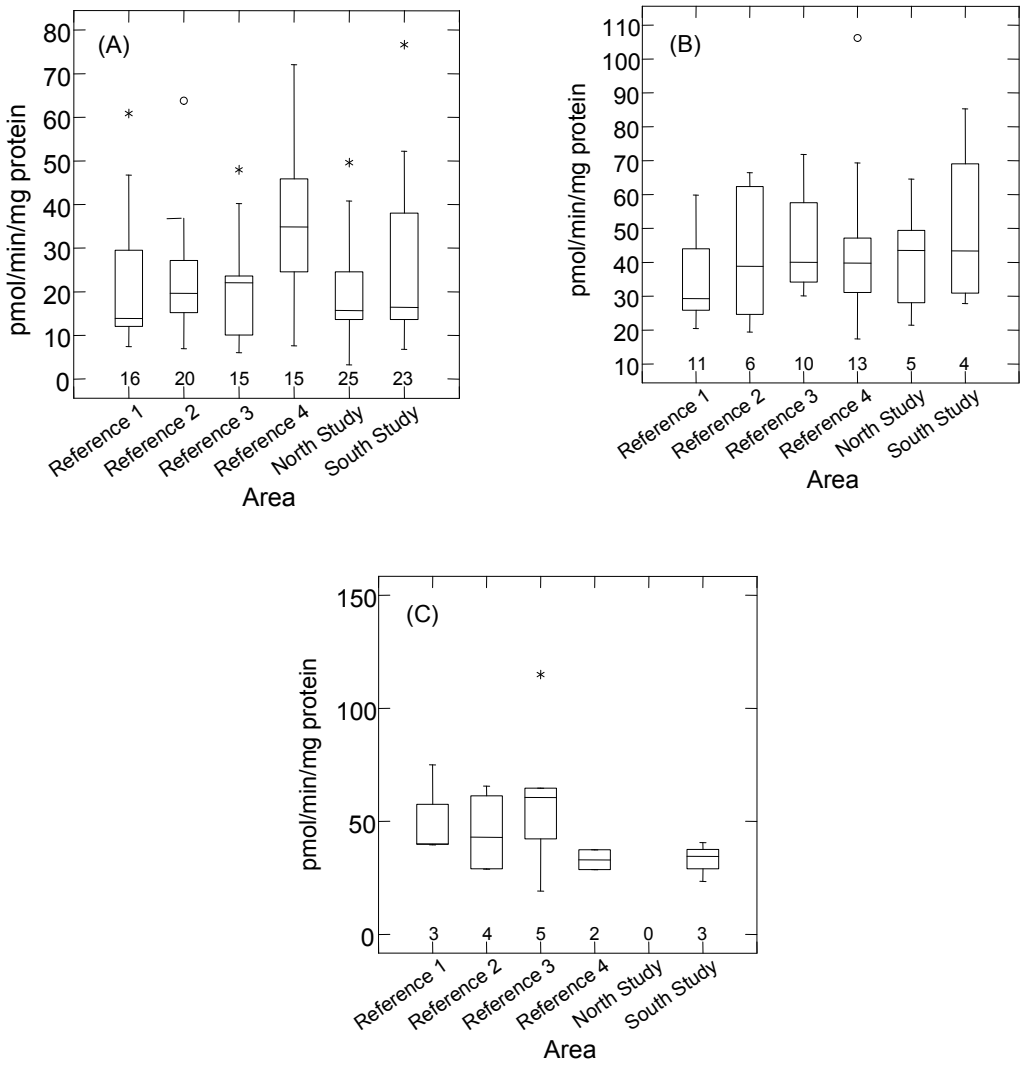


Figure 6-14 MFO Activity in (A) Mature Females, (B) Immature Females and (C) Males (all maturity stages pooled)

Notes:
- Horizontal line in middle of box = median
- Box = 25th to 75th percentile
- Vertical lines = whiskers; include all values within 1.5 Hspread (75th minus 25th percentiles)
- The box + whiskers will often include all the points, especially when n is small
- * Asterisks are outside values, > 1.5 Hpsreads from the 25th or 75th percentiles
- º Circles are far outside values, > 3 Hspreads from the 25th or 75th percentiles
- The number under each box is the sample size

MFO activities in mature females differed significantly among Reference Areas, but not between Study Areas or between Study versus Reference Areas (Table 6-35). MFO activities were greater in mature females from Reference Area 4 than in mature females from other Areas (Figure 6-14(A)). MFO activities in immature females did not differ significantly among Areas (Table 6-35) and varied widely within Areas (Figure 6-14(B)). MFO activities in males were not compared statistically among Areas because of small sample sizes. Activities were lower in the three males from the southern portion of the Study Area and two males from Reference Area 3 than in males from other Areas (Figure 6-14(C)).

Table 6-35 Results of Nested ANOVA Comparing MFO Activities in Female Plaice (2006)

Group	*p* values				
	Among References	Between Study		Study versus Reference	
	Error=MSE	Error= MS(AR)	Error=MSE	Error= MS(AR)	Error=MSE
Mature females	**0.022**	*0.704*	0.448	*0.581*	0.262
Immature females	0.520	Not tested		0.671	*0.643*

Notes:
- See Appendix C-3, Annex B for details on application and interpretation of modified nested ANOVA
- MSE = variance among fish within Areas; MS(AR) = variance among Reference Areas
- Italics indicate p values that should be used for tests of the Between Study and Study versus Reference contrasts, following recommendations in Quinn and Keough (2002; i.e., test against MSE only when $p \geq 0.25$ for Among References contrast)
- MFO activities were rank-transformed

6.4.4.4 Histopathology

Liver Histopathology

Results of the detailed histopathological studies carried out on liver tissues of plaice from the Reference and Study Areas are summarized in Table 6-36. The complete data set is provided in Appendix C-3, Annex F, and representative photographs are included in Appendix C-3, Annex H, with Photo 3 representing a normal liver structure.

Table 6-36 Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions (2006)

Variable		Area							
		Reference 1	Reference 2	Reference 3	Reference 4	All References	North Study	South Study	Both Study
No. fish		30	30	30	30	120	30	30	60
Nuclear pleomorphism	No.	0	0	0	0	0	0	0	0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Megalocytic hepatosis	No.	0	0	0	0	0	0	0	0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Basophilic foci	No.	0	0	0	0	0	0	0	0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Clear cell foci	No.	0	0	0	0	0	0	0	0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Variable		Area							
		Reference 1	Reference 2	Reference 3	Reference 4	All References	North Study	South Study	Both Study
Eosinophilic foci	No.	0	0	0	0	0	0	0	0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Macrophage aggregation [a]	No.	0	0	0	0	0	0	0	0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hepatocellular carcinoma	No.	0	0	0	0	0	0	0	0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cholangioma	No.	0	0	0	0	0	0	0	0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cholangio-fibrosis	No.	0	0	0	0	0	0	0	0
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inflammatory response	No.	0	0	2	0	2	0	0	0
	%	0.0	0.0	6.7	0.0	1.7	0.0	0.0	0.0
Hepatocellular vacuolation	No.	2	1	2	3	8	4	3	7
	%	6.7	3.3	6.7	10.0	6.7	13.3	10.0	11.7
Biliary parasites	No.	5	6	6	8	25	12	4	16
	%	16.7	20.0	20.0	26.7	20.8	40.0	13.3	26.7
Granuloma	No.	0	0	0	1	1	0	1	1
	%	0.0	0.0	0.0	3.3	0.8	0.0	3.3	1.6

Note: - [a] Moderate to high aggregation (> 3 on a 0-7 relative scale)

Sixty (60) fish from the Study Area and 120 fish from the four Reference Areas were examined and no cases of nuclear pleomorphism, megalocytic hepatosis, foci of cellular alteration (including basophilic foci, clear cell foci and eosinophilic foci), carcinoma, cholangioma, cholangiofibrosis or hydropic vacuolation were observed.

The frequencies of macrophage aggregates in livers of fish from the various Areas were low (0-2 rating on a relative scale of 0-7) and no cases of moderate to high aggregation (4 or higher on the relative scale) were observed.

Two fish from Reference Area 3 exhibited a mild to moderate inflammatory response (Appendix C-3, Annex H, Photo 4).

Eight fish (7%) from the Reference Areas and seven fish (12%) from the Study Area displayed a patchy distribution of hepatocellular vacuolation. The difference in incidences between the Study versus Reference Areas was not significant (p = 0.264; Fisher's Exact Test). This type of vacuolation is likely a reflection of gonadal maturaty stage.

An infestation of the biliary system with a myxosporean parasite (Appendix C-3, Annex H, Photo 5), possibly *Myxidium sp*., was observed in 21% of fish from the Reference Areas and in 27% of fish from the Study Area. Incidences of parasitic infestation did not differ significantly among the Reference Areas (p = 0.200; G Test), but was significantly greater in the northern portion of the Study Area (40%) than in the southern portion (13%) (p = 0.039; Fisher's Exact Test). The incidences in the Study Area were the highest (north) and lowest (south) observed in any Area.

Also, one fish from the northern portion of the Study Area exhibited multifocal granuloma, whereas one fish from Reference Area 4 exhibited a single granuloma (Appendix C-3, Annex H, Photo 6).

The observations on parasitism are of general interest but the absence or very low incidence of liver lesions that have been associated with chemical toxicity are more relevant from an EEM perspective.

Gill Histopathology

One fish from the southern portion of the Study Area, one fish from Reference Area 1, as well as two fish from Reference Area 4, displayed extensive proliferation of ovoid and pale staining cells, or X-cells, in the interlamellar spaces of secondary lamellae (Appendix C-3, Annex H, Photo 7) and tissue structure was altered to such an extent that it was not possible to count the secondary lamellae in these samples. Although all samples were processed in the same manner, four samples from Reference Area 1, two samples from Reference Area 2, four samples from Reference Area 3 and seven samples from Reference Area 4 could not be read accurately.

Detailed histopathological studies were therefore carried out on gill tissues of 100 fish from the four Reference Areas and 59 fish from the Study Area. Sections were examined for the presence of various gill lesions, which included epithelial lifting, telangiectasis, tip, distal and basal hyperplasia, as well as fusion. Results for each fish were expressed as the percentage of secondary lamellae affected by the lesion in relation to the total number of lamellae counted on four filaments. The percentages of lamellae affected by the various lesions were very low, all were less than 3%, except for one fish from Reference Area 1, with 3.8 % of lamellae exhibiting distal hyperplasia (Appendix C-3, Annex G). Means and SD of lamellae presenting each type of lesion are provided in Table 6-37.

Table 6-37 Occurrence of Lesions and Oedema Condition in the Gill Tissues of Plaice (2006)

Variable	Area							
	Reference 1	Reference 2	Reference 3	Reference 4	All References	North Study	South Study	Both Study
Number of fish	26	27	26	21	100	30	29	59
Distal hyperplasia [a]	0.17 ± 0.75	0.11 ± 0.38	0.00	0.11 ± 0.21	0.10 ± 0.44	0.03 ± 0.07	0.08 ± 0.20	0.05 ± 0.15
Epithelial lifting [a]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tip hyperplasia [a]	0.06 ± 0.19	0.08 ± 0.25	0.05 ± 0.28	0.00	0.05 ± 0.21	0.11 ± 0.32	0.04 ± 0.18	0.04 ± 0.18
Telangiectasis [a]	0.07 ± 0.38	0.01 ± 0.07	0.03 ± 0.13	0.04 ± 0.18	0.04 ± 0.22	0.00	0.00	0.00
Basal hyperplasia 1 [a c]	0.13 ± 0.28	0.08 ± 0.23	0.04 ± 0.15	0.08 ± 0.25	0.08 ± 0.23	0.12 ± 0.24	0.08 ± 0.37	0.10 ± 0.31
Basal hyperplasia 2 [a d]	.01 ± 0.08	0.02 ± 0.16	0.05 ± 0.19	0.03 ± 0.11	0.03 ± 0.13	0.05 ± 0.16	0.06 ± 0.19	0.05 ± 0.17

Variable	Area							
	Reference 1	Reference 2	Reference 3	Reference 4	All References	North Study	South Study	Both Study
Fusion [a]	0.00	0.00	0.12 ± 0.54	0.02 ± 0.08	0.04 ± 0.28	0.11 ± 0.33	0.21± 0.65	0.16 ± 0.51
Oedema condition [b]	0.462 ± 0.811	0.556 ± 0.892	1.000 ± 0.980	1.000 ± 0.894	0.740 ± 0.917	0.733 ± 1.015	1.000 ± 1.069	0.864 ± 1.042

Notes:
- All data are means ± SD
- [a] Mean percentage of lamellae presenting the lesion
- [b] Mean of rating on a relative 0-3 scale
- [c] Basal hyperplasia 1: increase in thickness of the epithelium reaching 1/3 to 2/3 of total lamellar length
- [d] Basal hyperplasia 2: increase in thickness of the epithelium reaching more than 2/3 of total lamellar length
- All References = means of the four Reference Area means; Both Study = means of the two Study Area means

Degree of oedema, which was recorded on a 0 to 3 relative scale, was quite low in all Areas and no significant differences were observed among Areas after univariate nested ANOVA analysis of rank-transformed data.

Since the lesions were rare or absent, being found in only a small number of fish (less than 30 fish), it was not meaningful to carry out statistical comparisons on the percentages of lamellae affected by the lesions. The only statistical comparisons which could be made were on percentages of fish exhibiting the lesions between the Study Area versus the pooled Reference Areas, using Fisher's Exact Test (Table 6-38).

Table 6-38 Number of Plaice with Specific Types of Gill Lesions and Percentages of Fish Exhibiting the Lesions (2006)

Variable		Area							
		Reference 1	Reference 2	Reference 3	Reference 4	All References	North Study	South Study	Both Study
No. fish		26	27	26	21	100	30	29	59
Distal hyperplasia	No.	3	5	0	5	13	4	6	10
	%	11.5	18.5	0.0	23.8	13.0	13.3	20.7	16.9
Tip hyperplasia	No.	3	3	1	0	7	8	3	11
	%	11.5	11.1	3.8	0.0	7.0	26.7	10.3	18.6
Basal hyperplasia 1 [a]	No.	6	3	2	2	13	8	2	10
	%	23.1	11.1	7.7	9.5	13.0	26.7	6.9	16.9
Basal hyperplasia 2 [b]	No.	1	1	2	2	6	3	3	6
	%	3.8	3.7	7.7	9.5	6.0	10.0	10.3	10.2
Fusion	No.	0	0	2	1	3	4	4	8
	%	0.0	0.0	7.7	4.8	3.0	13.3	13.8	13.6
Telangiectasis	No.	1	1	1	1	4	0	0	0
	%	3.8	3.7	3.8	4.8	4.0	0.0	0.0	0.0

Notes:
- Hyperplasia and fusion were considered "present" if those conditions occurred on any of the lamellae examined for each fish
- [a] Basal hyperplasia 1: increase in thickness of the epithelium reaching 1/3 to 2/3 of total lamellar length
- [b] Basal hyperplasia 2: increase in thickness of the epithelium reaching more than 2/3 of total lamellar length

Hyperplasia (Appendix C-3, Annex H, Photo 7), fusion (Appendix C-3, Annex H, Photo 8) and telangiectasis (Appendix C-3, Annex H, Photo 9) were considered "present" if those conditions occurred on any of the lamellae examined for each fish.

Telangiectasis occurred in less than 10 fish and was not analyzed statistically.

Incidences of distal and both types of basal hyperplasia were generally 10 to 20% within Areas (Table 6-37), with no significant differences between Study versus Reference Areas (p = 0.36-0.49; Fisher's Exact Test). Incidences of tip hyperplasia were significantly greater for the Study Area than for the Reference Areas (p = 0.04; Fisher's Exact Test), because of the higher incidence in the northern portion of the Study Area. Incidences of fusion were also significantly greater in the Study Area than in the Reference Areas (p = 0.020; Fisher's Exact Test).

6.5 Summary of Findings

6.5.1 Biological Characteristics

6.5.1.1 Crab

Crab size and frequencies of recent moult for the 303 crab used in body burden analyses in 2006 did not differ significantly among Reference Areas, or between the northern and southern portion of the Study Area. Crab from the Study Area were significantly smaller than Reference Area crab. Frequencies of recent moult did not differ significantly between the Study and Reference Areas, and were approximately 70% over all Areas pooled. Smaller crab were more likely to be recent moults.

6.5.1.2 Plaice

Plaice liver and body burden composites usually consisted of a mix of larger mature females and smaller males and immature females. Therefore, size varied considerably and was not normally distributed within composites. Composite mean gutted weights did not differ significantly among Reference Areas, between the northern and southern portions of the Study Area, or between the Study and Reference Areas.

6.5.2 Body Burden

6.5.2.1 Crab

HCs were not detected in crab claw samples in 2004, 2005 and 2006.

Concentrations of arsenic, copper, mercury, selenium, silver and zinc in crab claws were positively correlated over all 2004, 2005 and 2006 samples (i.e., higher concentrations of these metals co-occurred). Boron concentrations were uncorrelated, and strontium concentrations were negatively correlated, with concentrations of the six correlated metals. Other metals were rarely or never detected.

Moisture and fat content did not differ significantly among Areas in 2006. Concentrations of most metals differed mostly among Reference Areas. Concentrations in the northern and southern portions of the Study Area were similar and within the range observed in the Reference Areas.

In 2006, moisture and fat content of crab claws were negatively correlated. Moisture content was also negatively correlated with metal concentrations (wet weight). Size and frequencies of recent moult were uncorrelated with body burden variables.

In multi-year comparisons, there were no consistent and significant differences in moisture and fat content and metal concentrations between the Study and Reference Areas over the three EEM years (2004 to 2006). There were some consistent differences among Reference Areas for moisture content and concentrations of some metals.

There were also no significant changes in Study versus Reference Area differences over time, except for mercury. Study Area mercury concentrations have been relatively constant over time. Reference Area concentrations have increased since 2004 and were greater than Study Area concentrations in 2005 and 2006.

Copper and silver concentrations decreased, and strontium concentrations increased, from 2004 to 2006 in all or most Areas. Selenium concentrations were higher in 2005 than in 2004 and 2006.

6.5.2.2 Plaice

Liver

$>C_{10}$-C_{21} and $>C_{21}$-C_{32} HCs were detected in every plaice liver composite in 2006; as they were in every liver composite in 2005, and all but one composite in 2004. These HCs did not resemble drill muds. Most peaks observed on chromatograms were consistent with those expected for extracted fatty acid compounds. One liver sample was most likely contaminated on-board the sampling vessel by a distillate in the fuel range and a light lube oil. The chromatogram for this sample also did not resemble PureDrill.

Arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc were detected in every liver composite sample from 2004 to 2006. Other metals were rarely or never detected in liver samples.

Based on multivariate analyses of all liver samples from 2004 to 2006, manganese concentrations were largely uncorrelated with concentrations of other frequently detected metals. Iron and selenium concentrations were only weakly positively correlated with concentrations of arsenic, cadmium, copper, mercury and zinc. Therefore, high concentrations of most metals tended to co-occur; but manganese and, to some extent, iron and selenium, may “behave differently” from the other five frequently detected metals.

In 2006, moisture content, fat content, metal concentrations and HC concentrations either did not differ significantly among Areas, or differed mostly among Reference Areas. Overall, Study Area metal and HC concentrations were generally within or below the Reference Area range, except for one sample from the northern portion of the Study Area that had much higher HC concentrations than in any other sample, including the other nine Study Area samples.

Liver moisture and fat content were strongly negatively correlated in 2006, as in 2004 and 2005. In 2006, as in past years, plaice body size (i.e., composite mean gutted

weights) was significantly positively correlated with concentrations of most metals. The positive correlation was mostly a function of covariance of size and metal concentrations within rather than among Areas.

In all three EEM years (2004 to 2006), $>C_{10}$-C_{21} and especially $>C_{21}$-C_{32} HC concentrations were positively correlated with fat content. The HCs detected appear to be fatty acids and their derivatives, which are an important component of fat and will be included in both HC and fat content measurements.

There were no consistent significant differences in liver body burden variables between the Study and Reference Areas over all three EEM years (2004 to 2006). Except for HCs, differences between Study and Reference Areas have always been small and relatively constant over time. Because of the one (of 10) Study Area sample with high HC concentrations in 2006, mean HC concentrations in the Study Area were higher than in the Reference Areas in 2006, but not in 2004 and 2005.

There were consistent differences among Reference Areas over time for moisture and fat content and selenium concentrations. Selenium concentrations have also increased, and mercury concentrations have decreased, in all or most Areas since 2004.

Fillets

HCs and most metals were rarely or never detected in plaice fillet samples in 2004, 2005 and 2006. Arsenic, mercury and zinc were detected in every fillet sample in all three years.

In 2006, moisture and fat content and concentrations of arsenic, mercury and zinc did not differ significantly among Areas.

As was the case for plaice liver, concentrations of metals for fillets increased with increasing body size in 2006 samples. Concentrations of arsenic, mercury and zinc were also positively correlated with each other, indicating that higher concentrations of the three metals tended to co-occur.

In comparisons of all three EEM years (2004 to 2006), there were no significant changes or differences over time or space for fat and moisture content, and metal concentrations, in fillets.

6.5.3 Taste Tests

There was no difference in taste between Study and Reference Area crab and plaice.

6.5.4 Fish Health Indicators

Four plaice from the Reference Areas and two plaice from the Study Area displayed pale gills. Two fish from the Reference Areas exhibited minor to mild fin rot.

Red blood cells of fish from the Reference and Study Areas appeared normal in size, shape and colour. For white blood cells, there were small differences (less than 5%) in the percentage of lymphocytes and thrombocytes between Reference Areas 1 and 2 and Reference Areas 3 and 4, with lower lymphocyte percentages in Reference Areas 1 and 2. A more marked difference was noted between the Reference Areas and the

Study Area, with lower lymphocyte percentages in the Study Area. The difference was greater for the northern portion of the Study Area (approximately 20%) versus the Southern portion (approximately 8%).

There were no differences in MFO activities between the Study Area and the Reference Areas for mature females, immature females and males.

For liver histopathology, no cases of nuclear pleomorphism, megalocytic hepatosis, foci of cellular alteration (including eosinophilic, basophilic and clear cell foci), carcinoma, cholangioma, cholangiofibrosis or hydropic vacuolation were observed. The frequencies of macrophage aggregates in livers of fish from various Areas were low and no cases of moderate to high aggregation were observed. Two fish from the Reference Areas exhibited a mild to moderate inflammatory response. Eight fish from the Reference Areas and seven fish from the Study Area displayed a patchy distribution of hepatocellular vacuolation. An infestation of the biliary system with a myxosporean parasite was observed in 21% of fish from the Reference Areas and 27% of fish from the Study Area, with no statistical differences between Study and Reference. Incidences of parasitism were highest in the northern portion of the Study Area. One fish from the northern potion of the Study Area exhibited multifocal granuloma and one fish from the Reference Areas exhibited single granuloma.

For gill histopathology, one fish from the Study Area and three fish from the Reference Areas displayed extensive proliferation of X-cells in the interlamellar spaces of secondary lamellae. Degree of oedema was quite low in all Areas. Incidences of distal and both types of basal hyperplasia were generally 10 to 20% within Areas, with no differences between the Study and Reference Areas. Incidences of tip hyperplasia were slightly greater in the Study Area than in the Reference Areas, with higher levels overall in the northern portion of the Study Area. Incidences of fusion were also slightly greater in the Study Area. Overall, the percentages of lamellae affected by the various lesions were very low (less than 4%) and found in only a small number of fish.

7.0 Discussion

7.1 Sediment Component

Evidence of contamination and effects from drilling and discharge of drill cuttings in the White Rose EEM program can come from:

- changes in relationships between sediment variables and distances from the drill centres after drilling began; and
- correlations between biological variables (responses) and drilling mud tracers (barium and $>C_{10}$-C_{21} HCs).

In general, the second approach and, specifically, concentration-response relationships between biological variables and $>C_{10}$-C_{21} HC concentrations provided the strongest evidence of project effects. However, analysis of distance relationships is necessary to first determine if contamination occurs; and the spatial extent of both contamination and effects is of interest to Husky Energy and its partners, regulators and the public.

7.1.1 Physical and Chemical Characteristics

Sediments at White Rose were uniformly sandy (usually more than 90% sand), with low fines and gravel content. Fines content in 2000, 2004, 2005 and 2006 was usually 1 to 2% and rarely exceeded 3%. These fines levels are similar to fines levels at Terra Nova (Petro-Canada 2005). Gravel content in White Rose sediments was lower than gravel content at Terra Nova.

The TOC content in White Rose sediments was also low, usually less than 0.1%. TOC values of 1% are considered typical of uncontaminated marine sediments (CCME 2006), although this value may be more applicable to nearshore rather than offshore sediments. Organic carbon is normally associated with finer particles in sediments, but this relationship has been weak for White Rose sediments because of the restricted range of fines and TOC content.

There was clear evidence of contamination from drilling and discharge of drill cuttings on $>C_{10}$-C_{21} HC concentrations and, to a lesser extent, on barium concentrations. Both substances are major constituents of drilling muds and elevated concentrations would be expected where these muds are used and cuttings discharged. Field monitoring results for both tracers indicated that contamination has generally been greater and/or spatially more extensive near the Central and Southern drill centres than near the Northern drill centre. These results were expected, since drilling activity has been greater at the Central and Southern drill centres.

In 2000, prior to drilling, $>C_{10}$-C_{21} HC concentrations at all 46 stations sampled were less than RDL (0.3 mg/kg). In 2004 to 2006, after drilling began, $>C_{10}$-C_{21} HC concentrations at stations located 10 or more km from active drill centres were also near or below RDL but many concentrations within 10 km of active drill centres were greater than RDL. Therefore, concentrations above RDL can be considered evidence of contamination from drilling and, specifically, the use of SBMs. Drilling started at the Northern and Southern drill centre in 2003 and started at the Central drill centre in 2004, after the 2004

EEM field season. Results from the 2004 EEM program showed that $>C_{10}$-C_{21} HC concentrations decreased significantly with increasing distances from the Northern and Southern drill centres. In 2004, $>C_{10}$-C_{21} HC concentrations did not decrease with increasing distance from the Central drill centre, but did in 2005 and 2006. Distance gradients were steep in all years, with concentrations decreasing by 100- to 1,000-fold over 10 km. Overall concentrations in 2005 and 2006 were greater than in 2004. The estimated zone of influence for $>C_{10}$-C_{21} HCs in 2006 was 6 km from the nearest drill centre.

Barium, as barium sulphate (barite), is a major constituent of WBMs and SBMs. Barium occurs naturally in White Rose sediments at concentrations ranging from approximately 120 to 210 mg/kg. Therefore, low-level contamination from drilling can be difficult to detect. Despite this limitation, barium concentrations decreased significantly with distances from the Southern and Central drill centres after drilling began at these two centres. There was no evidence of contamination from the Northern drill centre after drilling began at this centre. Overall barium concentrations from stations sampled in all sample years have progressively increased over time. The estimated zone of influence for barium in 2006 was 2 km from the nearest drill centre.

In 2006, $>C_{10}$-C_{21} HC and barium concentrations were greater to the southeast within 1 km of the Central and Southern drill centres, in the direction of the residual current.

Overall, $>C_{10}$-C_{21} HCs were a better indicator of drilling activity for White Rose than barium. However, this conclusion is specific to the White Rose, Terra Nova and other recent offshore oil developments where the drilling fluid used has a fingerprint detected in the fuel range ($>C_{10}$-C_{21} HCs).

Elevated concentrations of HCs and barium have been observed near drill centres and platforms in other offshore oil developments (Table 7-1). Levels of HCs and barium at White Rose were within the range noted elsewhere.

Table 7-1 Hydrocarbon and Barium Concentration at White Rose and at Other Development Sites

Well Location	Year of Study	Distance from Source (m)	Total Petroleum Hydrocarbon (mg/kg)	Barium (mg/kg)
White Rose	2006	300 to 750 750 to 2,500 2,500 to 5,000	1.5 to 576.0 0.7 to 53.4 <3	200 to 3,100 150 to 770 140 to 250
	2005	300 to 750 750 to 2,500 2,500 to 5,000	<3 to 261.7 <3 to 54.6 <3	210 to 810 140 to 380 150 to 220
	2004	300 to 750 750 to 2,500 2,500 to 5,000	8.99 to 275.9 <3 to 22.20 <3 to 6.85	190 to 1400 120 to 470 140 to 230
	2000	300 to 750 750 to 2,500 2,500 to 5,000	<3 <3 <3	140 to 180 140 to 210 150 to 210
Terra Nova	2004	140 to 750 750 to 2,500 2,500 to 5,000	7.78 to 6,580 2.9 to 72.2 <3 to 4.3	140 to 2,100 100 to 340 63 to 190
	2002	140 to 750 750 to 2,500 2,500 to 5,000	<3 to 931 <3 to 49 <3 to 4.8	110 to 2,200 84 to 330 83 to 200

Well Location	Year of Study	Distance from Source (m)	Total Petroleum Hydrocarbon (mg/kg)	Barium (mg/kg)
Terra Nova	2001	750 to 2,500 2,500 to 5,000	<3 to 29.5 <3 to 8.13	100 to 190 87 to 180
	2000	750 to 2,500 2,500-5,000	0.59 to 14.4 <3 to 5.59	92 to 210 80 to 230
	1997	750 to 2,500 2,500-5,000	<32.5 <32.5	87 to 190 79 to 280
Gulf of Mexico (NPO-895) (Candler et al. 1995)	1993	50 200 2,000	134,428 80 to 11,460 24	47,437 542 to 5,641
Gulf of Mexico (MAI-686) (Kennicutt et al. 1996)	1993	200 500 3,000	40 43 49	1,625 1,134 1,072
Gulf of Mexico (MU-A85) (Kennicutt et al. 1996)	1993	200 500 3,000	42.3 31.7 27.1	3,706 1,817 1,094
Gulf of Mexico (HI-A389) (Kennicutt et al. 1996)	1993	200 500 3,000	65 33 32	13,756 3,993 1,293
North Sea (Beatrice) (Addy et al. 1984)	1982	250 750 3,000	8 to 759 5 to 105 3 to 73	
Dutch Continental Shelf (K14-13) (Daan and Mulder 1996)		200	54 to 161	
Norway (Valhall) (Hartley 1996)	1985	250 500 3,000		19,000 to 96,000 3,700 to 9,300 280 to 430
North Sea (Brent) (Massie et al. 1985)	1981	800 3,200	41 to 61 33 to 43	
North Sea (Forties) (Massie et al. 1985)	1980	800 3,200	9 to 78 16 to 55	
Gulf of Mexico (Matagorda 622) (Chapman et al. 1991; Brooks et al. 1990)	1987	25 150 750 3,000	757 ±1,818	6,233 12,333 980
Santa Maria Basin (Hidalgo) (Phillips et al. 1998)	1991	125 500 1,000		1,250 975 1,050
Norway (Ekofisk) (Ellis and Schneider 1997)	1996	750 2,000 5,000		3,650 2,214 667
Norway (Gyda 2/1-9) (Bakke et al. 1995)	1994	100 to 200	236	
Norway (Tordis) (Gjøs et al. 1991)	1990	500	8,920	
Norway (U/a 2/7-29) (Vik et al. 1996)		200	1,000 to 2,368	
North Sea (UK) (UKOOA 2001)	1975 to 1995	0 to 500 >500 to 2,000 >2,000 to 5,000	124 to 11,983 3 to 164 3 to 76	84 to 2,040 7 to 1595 8 to 729

Notes:
- Absolute barium levels should not be compared across projects because of potential differences in measurement techniques (Hartley 1996) and differences in background levels
- Distance for 2000, 2005 and 2006 is distance to nearest of the Northern, Central and Southern Drill Centres. Distance for 2004 is distance to the nearest of the Northern and Southern Drill Centres

Sulphur, as barium sulphate, is a constituent of WBMs and SBMs, but there are also many natural sources of sulphur. In 2006 and past years, there was some evidence of decreases in sulphur concentrations with distance from the drill centres. In all post-

drilling years, sulphur concentrations were significantly positively correlated with barium and >C_{10}-C_{21} HC concentrations. Sulphur concentrations at most stations have varied within a narrow range (0.02 to 0.04%, or 200 to 400 mg/kg). Consequently, distance gradients have been weak and detectable contamination has been generally restricted to stations within 1 km of drill centres.

In 2006, sulphide levels were elevated at a few (4) stations near (usually within 0.5 km) drill centres. In 2004 and 2005, most sulphide concentrations were below RDL (2 mg/kg in 2004 and 0.2 mg/kg in 2005). In 2005, redox levels increased with distance from drill centres and decreased with increasing tracer concentration. This was not noted in 2006.

Fines content increased with increasing depth in all four sample years (2000, 2004, 2005 and 2006). Finer particles are expected to move down-slope. In 2006, fines content decreased with increasing distance from drill centres, particularly the Central drill centre. In the past, there have been no strong distance gradients and/or no changes in baseline gradients for fines that would indicate that drill cuttings discharges elevated fines content.

TOC content decreased with distance from the Central drill centre in all four sample years and was unrelated to depth or distances from the other two drill centres. >C_{10}-C_{21} HC contamination would only affect TOC levels at high concentrations. Most >C_{10}-C_{21} HC concentrations in 2004, 2005 and 2006 were less than 10 mg/kg.

Concentrations of metals other than barium appeared to be unaffected by drilling. Ammonia concentrations were also unaffected by drilling.

7.1.2 Biological Effects

Biological effects from drilling have been assessed in laboratory sediment toxicity tests and from field surveys of *in-situ* benthic invertebrate communities. The invertebrate community surveys have provided much stronger evidence of effects than the laboratory toxicity tests, probably because the field surveys assess longer-term effects on a wide range of taxa.

7.1.2.1 Project Effects

Laboratory Toxicity Tests

None of the 205 sediment samples collected in 2000, 2004, 2005 and 2006 were toxic to bacteria in laboratory tests.

For the amphipod tests, one of 44 samples tested in 2005 was classified as toxic and survival was low (less than 70%) in one other sample. In 2006, two out of 59 samples were classified as toxic when compared to laboratory controls, one additional sample was classified as toxic when compared to Reference Station sediment and survival was low (69%) in one other sample. Otherwise, amphipod survival has always been greater than 70% and usually greater than 80%.

The four stations with low survival in the amphipod test in 2006 were closer to drill centres than most stations, and there was some indication that *in-situ* invertebrate communities were affected at two stations with the lowest amphipod survival. However, there were other stations near drill centres with elevated tracer levels where survival in

amphipod toxicity tests was high. Survival was also high in 2006 for the stations with low survival in 2005. Survival in toxicity tests was not significantly correlated with >C_{10}-C_{21} HC concentrations in any post-drilling year and correlations with various distance measures have been weak and usually not significant. In general, effects in laboratory toxicity tests have been sporadic and unpredictable.

In-Situ (Field) Benthic Invertebrate Communities

In all four sample years (2000, 2004, 2005 and 2006), benthic invertebrate communities in White Rose sediments were dominated by polychaetes, which accounted for approximately 75% of the total number of organisms collected. Bivalves accounted for approximately 15% of the total number of organisms collected. The most abundant taxon (family) was Spionidae (Polychaeta), with Paraonidae (Polychaeta) and Tellinidae (Bivalvia) the next most abundant families. These three dominant families accounted for 65 to 70% of the invertebrates collected.

In 2006 and in previous years, there were no detectable project effects on many benthic invertebrate community summary measures including standing crop, richness, diversity and evenness. However, total abundance, overall community composition (both NMDS axes, see Section 5), polychaete dominance, Paraonidae (Polychaeta) abundance and Amphipoda abundance were affected by project activity. The variables affected and the strength of effects varied among post-drilling years and among drill centres and there have been few consistent response patterns. However, it is reasonable to conclude that at least some taxa were affected in every post-drilling year.

Estimated zones of effects for polychaete dominance, overall community composition, and Paraonidae abundance in 2006 were approximately 1 to 5 km. In 2005, effects on Amphipoda appeared to extend to even greater distances. However, these effects were considerably weaker in 2006 and Amphipoda were a relatively small component of the invertebrate community. Zones of effects for total abundance were not estimated in 2006 because distance relationships were confounded with depth effects and other variables provided better estimates of the spatial extent of effects.

Estimates of the magnitude of effects will vary depending on what variables are compared (pre/post drilling, distance effects within year, effects related to HC concentrations). Appendix B-5 provides more details on estimated effect-size. Very general conclusions are provided in the text that follows.

From 2004 to 2006, total abundance was approximately 20% lower at stations within 2.5 km from active drill centres and reductions in abundance were noted at HC concentrations ranging from 1 to 10 mg/kg. Based on comparison to either remote stations or low HC concentrations, reductions in the relative abundance of polychaetes near drill centres or at higher HC concentrations were never greater than 25%. This was expected since this variable, like total abundance, aggregated information on taxa that responded to project activity (Paraonidae) with information on those that did not. In effect, reductions in Paraonidae abundance within 2.5 km of drill centres were approximately 50% of abundances noted at greater distances in 2004 and reductions in 2005 and 2006 were approximately 70%. In both years, Paraonidae abundance decreased to near 0 at >C_{10}-C_{21} HC concentrations greater than 10 mg/kg; 50% reductions were noted at concentrations between 1 to 10 mg/kg (relative to numbers at 1 mg/kg >C_{10}-C_{21} HC). Finally, post-drilling concentration-response relationships for Amphipoda abundance were strongest in 2005 and stronger in 2004 than in 2006.

Median abundances within 2.5 km of drill centres from 2004 to 2006 were 55 to 70% lower than at stations greater than 5 km from drill centres. When looking at individual years, reductions at 2.5 to 5 km were 20 to 30% in 2004 and 2005 and not evident in 2006. Amphipoda abundances were reduced by 60 to 90% at $>C_{10}$-C_{21} HC concentrations greater than 10 mg/kg. Reductions at 1 to 10 mg/kg were approximately 50% in 2005 and 2006, and not apparent in 2004.

In 2005, the spatial extent of the benthic invertebrate responses and, specifically, the extent of the amphipod response at White Rose exceeded what had been observed at other developments. This was not the case in 2006 and the extent of the observed responses for 2006 approached results observed elsewhere. As noted in previous EEM reports (Husky Energy 2004; 2005), benthic invertebrate responses in the North Sea and the Gulf of Mexico have tended to extend to a little less than the zone of chemical contamination. This zone extended to approximately 6 km at White Rose in 2006 (Section 7.1.1).

The response of some taxa at White Rose appears to have occurred at lower HC concentrations (1 to 10 mg/kg) than elsewhere. Candler et al. (1995) reports that HC concentrations in excess of 100 mg/kg are required before benthic communities are affected. Kingston (1992) notes that a decrease in diversity can be expected when HCs in sediments reach 50 to 60 mg/kg. Kingston (1992) does also note, however, that certain sensitive species could be affected at concentrations of less than 10 mg/kg.

In summary, the White Rose EEM program was powerful enough to detect project-related changes for specific taxa. However, the program did not detect similar project-related changes on a number of general indices of community composition (but see Section 7.1.2.3 for change in these indices unrelated to the project).

Potential Causal Mechanisms

Elevated barium concentrations are unlikely to be the direct cause of any observed effects on benthic invertebrates. Effects occurred within the background range of barium concentrations (120 to 210 mg/kg). Barium, as barite in fine particulates, is primarily a physical irritant rather than a chemical toxicant, adversely affecting cilia and gills (Barlow and Kingston 2001; Armsworthy et al. 2005). Gray et al. (1990) suggested that effects from HCs in oil-based drilling muds were greater than any effects of barium in the North Sea. These authors also noted that metal impurities in WBMs may have effects where barium concentrations are high, but concentrations of metals in White Rose sediments were below sediment quality guidelines (Section 7.1.3) and unrelated to invertebrate community variables.

Laboratory toxicity tests with amphipods indicate that effects do not occur at $>C_{10}$-C_{21} HC concentrations less than 1,900 mg/kg (Payne et al. 2001), well above any concentrations measured in White Rose sediments. As noted above, only four White Rose samples were toxic to amphipods in laboratory tests in 2005 and 2006, and none were toxic in 2004. *In-situ,* estimated thresholds for effects on polychaetes and Amphipoda in 2005 and 2006 were generally towards the lower end of the 1 to 10 mg/kg range, or approximately three orders of magnitude below the laboratory effects threshold. Given the differences between field measurements and laboratory measurements, reduced field abundances are probably not due to direct acute toxicity. Rather, community effects could be due to indirect effects, chronic toxicity involving longer term exposure, or some correlate of HC concentrations.

7.1.2.2 Biological Effects Unrelated to the Project

Husky Energy (2006) provides a multi-year review of relationships between invertebrate community variables and sediment physical and chemical characteristics. Fines and TOC content in White Rose sediments had little or no effect on benthic invertebrate community variables except for Tellinidae abundance, probably because fines and TOC content were low and did not vary widely. Relationships between Tellinidae abundance and sediment fines and TOC content were probably natural and not project-related, since they occurred in every year and there was no evidence that distance from drill centres or HC contamination had any effects on Tellinidae.

In the past, richness and diversity increased and polychaete dominance decreased with increasing gravel content. Except for richness, these correlations were not significant in 2006. At Terra Nova, gravel appears to be one of the primary variables affecting invertebrate communities (Petro-Canada 2005). The emphasis on particle size effects in other studies has typically been on fines (e.g., "smothering" from discharge of fine drill cuttings) but gravel may be the more important particle size variable in the predominantly sandy sediments on the Grand Banks.

Total abundance, richness, diversity and Tellinidae abundance increased and polychaete dominance decreased with depth in all sample years. Except for Tellinidae abundance, these depth effects were relatively small. The ability of the program to detect these small effects implies that project effects on richness and diversity would have been detected if they occurred.

7.1.3 CCME Guidelines

The Canadian Council of Ministers of the Environment (CCME) provides marine sediment quality guidelines for PAHs and several metals (CCME 2006). Interim Sediment Quality Guidelines (ISQG) are Threshold Effects Levels (TEL) below which biological effects are rarely observed. Probable Effects Levels (PEL) are levels above which effects are often observed. The CCME guidelines are based on literature reviews of concentration-effects relationships from laboratory and field studies (i.e., co-occurrence or correlation of chemical contamination and biological effects).

Table 7-3 compares maximum levels of PAHs and metals in White Rose sediments to CCME ISQG and PEL. No PAHs were detected at RDLs of 0.05 mg/kg, and these RDLs were less than PEL. However, RDLs were higher than ISQG for acenaphthene, acenaphthylene, anthracene, dibenz(*a,h*)anthracene, fluorene, 2-methylnaphthalene and naphthalene. Maximum concentrations and RDLs for the seven metals with guidelines were well below ISQG. At these low levels, most metals would be essential elements rather than toxicants.

Table 7-2 Comparison of Measured Concentrations of PAHs and Metals to Canadian Sediment Quality Guidelines

Variable	ISQG (mg/kg)	PEL (mg/kg)	Maximum value			
			2000 (*n*=46 stations)	2004 (*n*=56 stations)	2005 (*n*=44 stations)	2006 (*n*=59 stations)
Acenaphthene	0.00671	0.0889	<0.05	<0.05	<0.05	<0.05
Acenaphthylene	0.00587	0.128	<0.05	<0.05	<0.05	<0.05
Anthracene	0.0469	0.245	<0.05	<0.05	<0.05	<0.05
Benz(*a*)anthracene	0.0748	0.693	<0.05	<0.05	<0.05	<0.05
Benzo(*a*)pyrene	0.088	0.763	<0.05	<0.05	<0.05	<0.05
Chrysene	0.108	0.846	<0.05	<0.05	<0.05	<0.05
Dibenz(*a,h*)anthracene	0.00622	0.135	<0.05	<0.05	<0.05	<0.05
Fluoranthene	0.113	1.494	<0.05	<0.05	<0.05	<0.05
Fluorene	0.0212	0.144	<0.05	<0.05	<0.05	<0.05
2-Methylnaphthalene	0.0202	0.201	<0.05	<0.05	<0.05	<0.05
Naphthalene	0.0346	0.391	<0.05	<0.05	<0.05	<0.05
Phenanthrene	0.0867	0.544	<0.05	<0.05	<0.05	<0.05
Pyrene	0.153	1.398	<0.05	<0.05	<0.05	<0.05
Arsenic	7.24	41.6	2	<2	<2	<2
Cadmium	0.7	4.2	<0.05	0.08	0.07	0.06
Chromium	52.3	160	4	7	5.5	5.8
Copper	18.7	108	4	3	2.9	3.6
Lead	30.2	112	5.1	4	5.9	9.5
Mercury	0.13	0.7	<0.01	<0.01	<0.01	<0.01
Zinc	124	271	14	9	10	9.4

Notes: - Source – CCME (2006); www.ccme.ca/ccme
- CCME guidelines are not available for other variables measured at White Rose

7.2 Commercial Fish Component

7.2.1 Biological Characteristics

Analysis of crab Biological Characteristics (size and frequencies of recent moult) in 2006 indicated that Study Area crab used in body burden samples were approximately 15% smaller than Reference Area crab. In 2004 and 2005, Study and Reference Area crab were similar in size. Overall, however, crab sampled in 2006 were approximately 15% larger than crab sampled in 2005, but 20% smaller than crab sampled in 2004. Frequencies of recent moult did not differ among Areas in 2006, but did in 2004 and 2005. In all three years, there was considerable small-scale variance in size and frequency of recent moults among trawls or composites within Areas. Differences in Biological Characteristics of crab among Areas and years appeared to have little effect on differences in body burdens (Section 7.2.2).

In 2004, 2005 and 2006, composite plaice samples used for body burden analyses have consisted of a mix of large mature females, some smaller immature females and few males. Body size varied mostly within composites rather than among Areas. In 2006, there were no significant differences in body size (mean gutted weight) per composite among Areas.

7.2.2 Body Burden

Metal concentrations in crab claws, plaice livers and plaice fillets from the Study Area were generally similar to or lower than Reference Area concentrations in 2004, 2005 and

2006. However, there have been some significant differences among the four Reference Areas.

HCs have not been detected in crab claw. HCs have only been detected in one plaice fillet, from Reference Area 4, in 2005; the chromatogram for this sample did not indicate the presence of drill fluids. HC have consistently been detected in every liver sample, except one 2004 sample with unusually high RDL. These HCs did not resemble drill fluid and peaks observed on chromatograms were consistent with those expected for extracted fatty acids and their derivatives (e.g., glycerols). In 2006, the chromatogram for one liver sample indicated that the sample was most likely contaminated on-board the sampling vessel by a distillate in the fuel range and a light lubricating oil. The chromatogram for this sample also did not indicate the presence of drill fluid.

7.2.3 Taste Tests

No taste difference was noted between Reference and Study Area crab and plaice in the triangle and hedonic scaling taste tests. For both species, there were no consistent comments from panelists identifying abnormal or foreign odour or taste. Combined, test results do not indicate the presence of taint in either crab or plaice at White Rose in 2006.

7.2.4 Fish Health Indicators

7.2.4.1 Gross Pathology

Gross pathology, including external and internal abnormalities, was assessed visually in all fish. One fish from Reference Area 3 and one from Reference Area 4 exhibited fin rot, while one fish from Reference Area 1, one fish from Reference Area 2, two fish from Reference Area 4 and two fish from the southern portion of the Study Area displayed pale gill filaments.

7.2.4.2 Haematology

Haematology, including the analysis of red and white blood cells, has potential to help assess the overall health of fish as well as to indicate immunological effects which may be important in disease susceptibility.

There were no apparent qualitative differences in morphology or staining characteristics of red blood cells in samples of plaice from the different sampling Areas.

White blood cell counts were significantly different among Areas. There were less lymphocytes and more thrombocytes in fish from Reference Areas 1 and 2 than in fish from Reference Areas 3 and 4. Overall, there were also less lymphocytes and more thrombocytes in fish from the Study Area than in fish from the Reference Areas. Differences in percentages of cell numbers were quite small among the Reference Areas but larger between the Reference Areas and the Study Area, and particularly the northern portion of the Study Area. The differences between the Reference Areas versus the Study Area may be due to natural variation (Svobodová and Vykusová 1991; De Pedro et al. 2005 and references therein), but changes in the number of white blood cells may also reflect a level of contaminant exposure. For instance, reduced lymphocyte counts have recently been observed in laboratory studies with fish in association with

wastewaters from oil-sand refining operations (Farrell et al. 2004) and production waters (Payne et al. 2005).

7.2.4.3 Mixed Function Oxygenase

Since maturity stage might result in some loss of sensitivity for resolving contaminant mediated differences in females during spawning (e.g., Mathieu et al. 1991; Whyte et al. 2000), MFO enzyme activities were analyzed separately in immature and mature female plaice from the different Areas. MFO activities did not differ in mature females between the northern and southern portions of the Study Area or between the Study Area and the Reference Areas. However, differences were observed among Reference Areas, with mature females from Reference Area 4 having a greater activity than females from the other Reference Areas. Fish from Reference Area 4 were slightly smaller and younger and, since size and age can influence MFO activity in fish with younger and smaller animals exhibiting higher levels (Pluta 1993; Peters and Livingstone 1995), it was not surprising to find a slightly higher MFO levels in female plaice from Reference Area 4. MFO enzyme activities in immature females did not differ among Reference Areas, between the northern and southern portions of the Study Area or between the Study Area and the combined Reference Areas.

MFO activities in males were not compared statistically among Areas because of the small sample sizes.

7.2.4.4 Histopathology

With respect to liver histopathology, no hepatic lesions associated with chemical toxicity in field and laboratory studies (e.g. Myers and Fournie 2002) were detected. This included observations for nuclear pleomorphism, megalocytic hepatosis, eosinophilic, basophilic and clear cell foci, high aggregation of macrophages, carcinoma, cholangioma, cholangiofibrosis and hydropic vacuolation.

However, a few hepatic differences were noted. A mild to moderate inflammatory response was observed in two fish from Reference Area 3 and granuloma were observed in one fish from the southern portion of the Study Area and one fish from the Reference Area 4. As noted in previous years, a “patchy distribution” of hepatocellular vacuolation, not associated with degenerative changes, was observed in a few fish from each Area and is likely linked to gonadal maturation (Timashova 1981; Bodammer and Murchelano 1990; Couillard et al. 1997). Also, liver tissues of some fish contained myxosporean parasites but no differences between the two portions of the Study Area and the pooled Reference Areas were found. The infestation did not appear to result in any other pathological changes in hepatic tissues.

Observations on mild inflammatory responses, granuloma, hepatocellular vacuolation and parasitism are of value in relation to providing general information on their presence in the area. However, it is important to note from an EEM perspective that liver lesions more commonly associated with chemical toxicity were absent in the general area.

With respect to studies on gill microstructures, the percentages of secondary lamellae affected by various lesions were very low (less than 4%) and found in only a small number of fish (less than 30 fish). However, when results were expressed as percentages of fish exhibiting a type of lesion (whatever the severity), slight but

statistically significant differences in tip hyperplasia and fusion of secondary lamellae were observed between the Study Area and the combined Reference Areas, with the highest percentages in the Study Area. This observation is of interest but slight differences could be attributed to natural variation. Microstructural changes which could be more pathological in nature such as severe lamellar hyperplasia and epithelial lifting or extensive gill oedema, telangiectasis and fusion (e.g. Mallat 1985) were absent or found at very low frequencies in all Areas.

The presence of gill achromasia and X-cell lesions in one plaice from the southern portion of the Study Area, one plaice from Reference Area 1 and two plaice from Reference Area 4 is also of interest. This type of lesion has been reported in various bottom-dwelling fish species, particularly flatfishes and cod living in temperate to cold sea-water (Dethlefsen et al. 1996; Mellergaard and Lang 1999; McVicar et al. 1987). Desser and Khan (1982) also observed X-cells in the gills of eelpouts from several areas off coastal Newfoundland and Labrador. There had been some debate on whether X-cells are host cells such as protozoa (Alpers et al. 1977) or cells which have undergone transformation due to pollution or viral infection (Lange and Johannessen 1977; Peters et al., 1978). However, it has been confirmed recently that X-cells in fish are parasitic protozoans (Miwa et al. 2004).

As was the case for the liver histopathological indices, the absence or very low incidence of gill lesions associated with chemical toxicity is interest from an EEM perspective.

Overall, fish health analyses indicate that the present health of American plaice is similar between the Reference Areas and the Study Area.

7.3 Summary of Effects and Monitoring Hypotheses

As discussed in Section 1.7, monitoring hypotheses were developed in Husky Energy (2004) as part of EEM program design to test effects predictions and determine physical and chemical zones of influence.

These hypotheses (reiterated in Table 7-3) were set up to guide interpretation of results. As noted in Section 1.7, the “null” hypotheses (H0) always state that no pattern will be observed.

Table 7-3 Monitoring Hypotheses

Sediment Component
H0: There will be no change in SQT variables with distance or direction from project discharge sources over time.
Commercial Fish Component
H0(1): Project discharges will not result in taint of snow crab and American plaice resources sampled within the White Rose Study Area, as measured using taste panels.
H0(2): Project discharges will not result in adverse effects to fish health within the White Rose Study Area, as measured using histopathology, haematology and MFO induction.

Note: - No hypothesis is developed for plaice and snow crab body burden, as these tests are considered to be supporting tests, providing information to aid in the interpretation of results of other monitoring variables (taste tests and health).

Given results observed in the 2006 EEM program, the null hypothesis is rejected for the Sediment Component of the program, but null hypotheses are not rejected for the Commercial Fish Component. Rejection of the null hypothesis for the Sediment Component was expected since drill cuttings modelling and EIS predictions do indicate that there should be change in SQT variables with distance or direction from discharge sources. The following re-iterates and summarizes project effects.

As indicated above, there was clear evidence that concentrations of $>C_{10}$-C_{21} HCs and barium were elevated by drilling activity near drill centres. There was more equivocal evidence that sulphur concentrations and, potentially, sulphide and fines levels were elevated by drilling. Elevated concentrations of $>C_{10}$-C_{21} HCs and barium at White Rose are comparable to levels observed at other developments.

Sediment contamination did not extend beyond the 9 km zone of influence predicted by drill cuttings modelling (Hodgins and Hodgins 2000; Section 1.5). $>C_{10}$-C_{21} HC contamination extended to 6 km from source. Barium contamination extended to 2 km from source. Any contamination from sulphur would be limited to within 1 km from source and increased sulphide levels were noted only in the immediate vicinity (0.5 km) of drill centres. Increases in fines near drill centres were more apparent in 2006 than in previous years. Future monitoring programs will determine if effects observed in 2006 can be attributed to the project.

Weak directional effects were noted for both $>C_{10}$-C_{21} HCs and barium in 2006, with dispersion primarily to the southeast within 1 km from the Southern and Central drill centres. This is consistent with current records at White Rose for 2003 and 2004 (Husky Energy 2004) and with Hodgins and Hodgins (2000), who note that currents at White Rose are generally dominated by wind and tide, with a weak mean flow to the south.

Three of the 59 samples tested in 2006 were toxic to amphipods in laboratory tests and survival was reduced to 69% in another sample.

In 2006, there was evidence of project effects on *in-situ* benthic invertebrate abundance (total abundance), polychaete dominance, overall community composition, abundances of Paranonidae and abundances of Amphipoda. Across years, the variables affected and the strength of effects varied overall and among drill centres and there were few consistent response patterns.

The zone of effects on benthic invertebrates extended to 1 to 5 km from source, beyond the 500-m zone of effects predicted in the White Rose EIS. Nevertheless, the spatial extent of the benthic invertebrate response in 2006 appears to be generally consistent with the recent literature on effects of contamination from offshore oil developments.

Sediment contamination and effects on benthos were not coupled with effects on commercial fish. No project-related tissue contamination was noted for crab and plaice. Neither resource was tainted and plaice health was similar between White Rose and more distant Reference Areas.

7.4 Summary of Other Relevant Findings

Total abundance, richness and diversity increased, and polychaete dominance decreased, with increasing depth. These depth effects occurred over a relatively narrow depth range (115 to 140 m for all but two stations).

In 2006 and in past years, Tellinidae abundance (not previously analyzed) was positively correlated with sediment fines and TOC content.

In 2006, Study Area crab were approximately 15% smaller than Reference Area crab. Overall (Study and Reference Areas combined), crab sampled in 2006 were larger than those sampled in 2005 by approximately 15%. However, crab sampled in both 2005 and 2006 were smaller (approximately 20%) than crab sampled in 2004.

Carry-over effects, or persistent differences among stations unrelated to distance and depth, from 2000 to 2006 were generally stronger for invertebrate community variables than for physical and chemical characteristics. Carry-over effects for barium, HCs and sulphur from 2004 to 2006 were significant, which may be evidence of persistent small-scale contamination unrelated to distance.

7.5 Considerations and Recommendations for Future EEM Programs

Based on results obtained to date, it is recommended that the next EEM sampling program take place in 2008.

Elevation of fines near drill centres should be examined again in future years to determine if the patterns observed in 2006 continue or intensify. Fines have not been elevated by drilling in 2004 and 2005; but may have been elevated by drilling in 2006.

Significant Depth X Distance interactions rarely occurred prior to 2006, which is why results of tests of those interactions have not been presented and discussed. In future, if these interactions are as common and strong as in 2006, they should be considered in more detail.

All stations do not need to be re-sampled over time, although RM analyses should be used for long-term, multi-year effects assessment. Some alternatives for analyzing all stations sampled were introduced in this report and others could be explored. The best approach would probably be to continue sampling a core set of stations every year and add other stations (e.g., near existing or new drill centres) to address issues inadequately addressed by RM analyses of the core stations.

The White Rose EEM program has reached the stage where the program design, methods and data analyses have generally been validated and; when necessary, modified. Results in future years that simply confirm past results need not be reported or discussed in detail and could be placed in Appendices. For example, in 2004 to 2006, it was necessary to assess changes in barium and HC levels near each drill centre separately to confirm that contamination and effects could be detected once drilling began. Having demonstrated that, it is not necessary to discuss or analyze changes in contamination and effects from each centre in detail in the future. The centres are not managed or regulated separately and changes in contamination and effects were

generally consistent with what one would expect from drilling intensity and drill cuttings discharges.

Where applicable, figures should show results from the three drill centres as separate symbols to indicate if patterns observed are primarily due to the influence of one or a few drill centres.

7.6 Actions Taken on Previous Recommendations

Actions taken for the 2006 EEM program based on recommendations provided in 2005 are listed in Table 7-4. Recommendations combine recommendations from the EEM program reporting team, the WRAG and regulatory reviews. Text has been paraphrased to shorten comments and responses. Recommendations and comments that were specific to previous reports are not included below. Discussion items also are not included below. However, regulator comments and Husky Energy responses on the 2004 EEM program are provided in Appendix A, along with WRAG comments on the 2006 program.

Table 7-4 Actions Taken on Previous Recommendations

Recommendation	Action
Consideration should be give to using glass cups for taste tests, rather than plastic cups.	Incorporated into the 2006 program.
Effects on benthic invertebrates should be examined in future years to determine if patterns observed to date persist or intensify. More focused studies should be conducted on abundances of individual dominant polychaete and bivalve families (e.g., Spionidae, Paraonidae, Tellinidae) and possibly echinoderms.	Incorporated into the 2006 program.
Zones of influence/effects for sediment quality variables should be formally defined using hockey-stick (threshold) relationships, where appropriate. Where threshold relationships do not apply, zone of influence/effects should not be defined.	Incorporated into the 2006 program.
It might be useful to mention the EIS predicted scales. It might also be appropriate to mention the scales of effects from other developments.	Scales of effects noted in the EIS have been incorporated in the 2006 report. Comparison to other developments is provided but only general comparisons can be made given the level of detail provided in the literature.
$>C_{10}$-C_{21} HCs should be treated as the primary and most useful drilling mud tracer, and concentration-response relationships between $>C_{10}$-C_{21} HCs and invertebrate community variables should continue to be examined.	Incorporated into the 2006 program.
Barium should continue to be measured and a zone of influence for barium defined. However, barium is not a useful concentration measure (*X* variable). Normalizing barium concentrations to aluminum concentrations has minimal value for effects assessment, and should be dropped as a routine part of the White Rose EEM program.	Incorporated into the 2006 program.
Multi-year comparisons of correlations between sediment physical and chemical variables other than $>C_{10}$-C_{21} HCs, and invertebrate community, should be dropped unless those correlations within one or more sample years become stronger than in the past.	Incorporated into the 2006 program.
Depth should continue to be included in analyses of distance effects, and it may be useful to adjust for depth effects when estimating the zone of effects for invertebrate community variables.	Incorporated into the 2006 program.

Recommendation	Action
For the Commercial Fish Component, the Study Area should continue to be split into north and south “sub-areas”, with approximately equal numbers of crab and plaice collected from each sub-area. There were some differences between the two sub-areas, and even if there are no differences, the two sub-areas can always be pooled.	Incorporated into the 2006 program.
Moisture content, fat content and average size of crab or plaice in composites should be used as covariates in analyses of body burden, when appropriate.	Incorporated into the 2006 program.
For station location figures, it could be useful to have some designation to show stations that were dropped in each year.	This was considered but the resulting figures would be too cluttered.
The number of significant digits in summary tables of chemical concentrations should be reduced.	Incorporated in the 2006 program.
It could be worth showing the three drill centres as separate symbols in plots, where applicable, to show whether the patterns observed are driven by one or a subset of drill centres.	This will be included in subsequent reports. Exclusion of this was an oversight in this year’s report.
Include confidence limits to estimates of threshold distances.	Incorporated in the 2006 program.
It could be useful to included a vertical line in hockey stick plots to indicate the point of inflection.	Incorporated in the 2006 program.
NMDS plots should include some identification of stations.	In the 2006 report, different coloured symbols were used to identify various distance classes among stations.
Units of measurement should be provided for all variables in the summary statistics tables.	Incorporated in the 2006 program.
The amphipod toxicity results section is too brief and does not address effects with distance; nor are comparisons to reference stations provided.	The toxicity summary table now includes distance to the nearest drill centre for each station. Comparison of results to reference station sediment results are provided and correlations between amphipod survival and various indicators of drilling activity are provided.
More detailed headers should be provided on those tables that are split between pages.	Incorporated into the 2006 program.
Replace “achieved” with “detected” in “EQL is the lowest concentration that can be reliably achieved”	The use of “achieved” is appropriate and is the definition provided by the analytical consultant: Maxxam Analytics.
Units should be provided in tables summarizing benthic community statistics.	Incorporated into the 2006 program.
The timing of the EEM program should be coordinated to avoid bitter crab disease.	Soft-shelled crab (more likely to suffer from bitter crab disease) are now excluded from analyses. Changing the timing of the sampling program would introduce other seasonal variability.

Recommendation	Action
Could it be that benthic invertebrates in the field are subject to higher but discontinuous exposure levels.	This was considered, but the presence of significant carry-over effects for barium and hydrocarbons over multiple EEM years suggest that exposure within years does not vary greatly beyond what would be expected from additional drilling and drill cuttings deposition.

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