Husky Energy REPORT

REPORT TITLE

White Rose

Environmental Effects Monitoring Program

2008

Volume 1

SUBMITTED TO

Canada-Newfoundland and Labrador Offshore Petroleum Board

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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 was designed to evaluate the environmental effects of Husky Energy's offshore oil drilling and production activities for the White Rose Development. Program design drew on the predictions and information in the White Rose development plan Environmental Impact Statement (EIS) and its supporting modeling studies on drill cuttings and produced water dispersion. A baseline study to document pre-development conditions was conducted in 2000 and 2002. This study, combined with stakeholder and regulatory agency consultations, initiated the detailed design phase of the program. Further input on EEM program design was obtained from an expert advisory group called the White Rose Advisory Group (WRAG). The WRAG has reviewed results and provided interpretation and feedback for each program to date - 2004, 2005, 2006 and 2008.

The purpose of the EEM program is to assess environmental effects predictions made in the EIS and determine the area demonstrably affected by Husky Energy activities in the White Rose Field. In accordance with the design protocol, the program is updated to accommodate expansions and the establishment of new drill centres within the White Rose Field.

Seabed sediments and commercial fish species from the White Rose Field (Study Area) are sampled in each program year to assess environmental effects. The sediment samples are collected for physical, chemical and toxicity testing and an evaluation of benthic (seafloor invertebrate) communities. The selected commercial fish species, American plaice (a common flatfish species) and snow crab (an important commercial shellfish species), are sampled to test for contaminants (body burden), taint and, for plaice, various health indices. A series of measurements (length, weight, maturity, etc.) are also made on each species. Figure 1 illustrates the components of the EEM program.

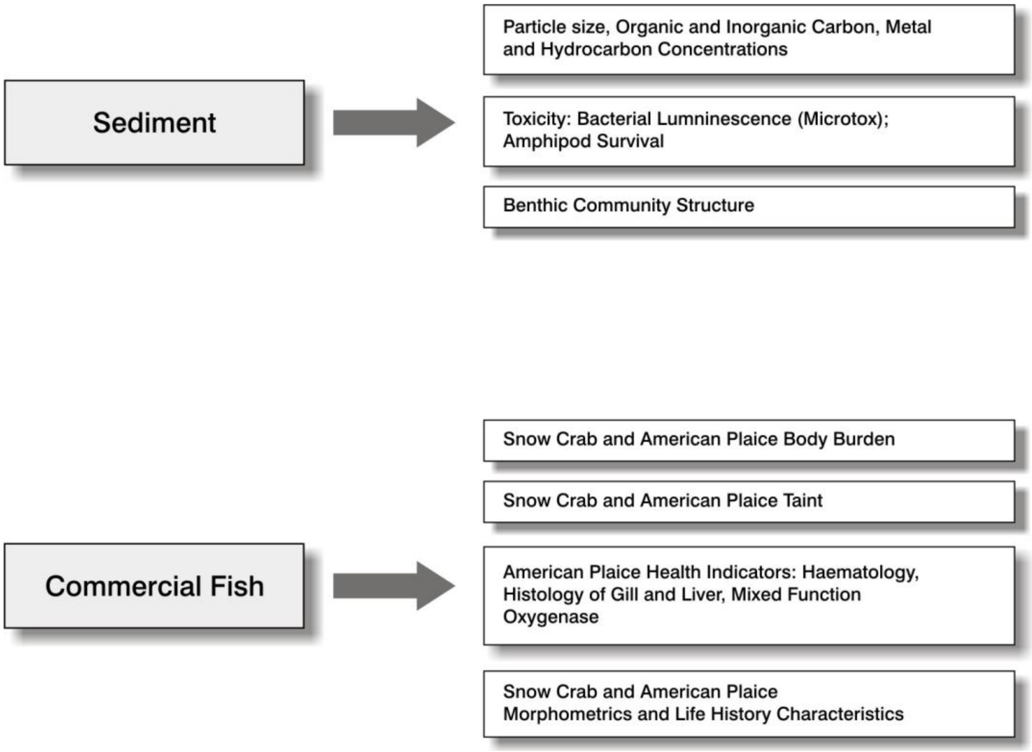

Figure 1 EEM Program Components

This report provides the results from the fourth year of sampling under the program conducted in the late spring (commercial fish survey) and early fall (sediment survey) of 2008. The findings are interpreted in the context of results of previous sampling years and the baseline data collected pre-development.

In 2008, seafloor sediments were sampled at 30 locations along transect lines radiating from the centre of the development and 17 locations surrounding the Northern, Central, Southern and the planned North Amethyst drill centres. This allowed an assessment of environmental conditions over an area of 1,200 km^2 (approximately 40 by 38 km) around the White Rose Field. Physical and chemical analyses were conducted on the sediment samples and toxicity tests were performed to determine if the sediments sampled were toxic to bacteria (Microtox) and a marine amphipod (a small crustacean). In addition, seafloor invertebrate infaunal species (i.e., species living in the sediment) were identified and enumerated for community analysis.

Hydrocarbons and barium, both constituents of drill muds, were used as indicator chemicals to estimate the zone of influence for project activities[1]. Concentrations of hydrocarbons and barium were elevated near drill centres and concentrations decreased with distance from drill centres, as expected. Sulphur and, to some extent, sulphide concentrations were also elevated within 0.5 to 1 km of drill centres. The zone of influence of project contaminants estimated from hydrocarbon concentrations extended to 10 km from source. This result is consistent with drill cuttings dispersion modeling that predicted a zone of influence of approximately 9 km. The zone of influence estimated from barium concentrations extended to 2 km from source. Overall, hydrocarbons were a better indicator of drilling activity than was barium. The concentrations of both chemicals in White Rose sediments were within the range of concentrations observed at other offshore oil and gas developments.

There continues to be no detectable project effects on benthic invertebrate community richness[2]. However, there was evidence of project effects on total abundance, standing crop[3], polychaete (a marine worm) abundance and the abundance of amphipods. Values for each of these variables were lower at higher hydrocarbon concentration and values decreased with proximity to drill centres. In 2008, effects on the polychaete Paraonidae extended to approximately 4 km from source and effects on standing crop extended to approximately 1.5 km from source. These distances extend further than the 500-m predicted in the EIS for effects on benthic invertebrate. Nevertheless, the spatial extent of effects on Paraonidae and standing crop in 2008 was generally consistent with recent literature on the effects on benthic communities from other offshore oil developments. The spatial extent of effects on total abundance, amphipod abundance and the abundance of the polychaete Spionidae could not be estimated in 2008 because relationships (decreases in numbers with proximity to drill centres) were weak.

During the summer of 2008, samples of American plaice and snow crab were collected at the White Rose Study Area and at two Reference Areas, located approximately 28 km to the southwest and northwest of White Rose. As noted above, samples were analyzed for chemical body burden and taint. In addition, analyses were also performed on American plaice for a variety of fish health indices, as outlined in Figure 1. Physical measurements taken on American plaice and snow crab (length, weight, maturity, etc.) were used as supporting information for analyses of body burden, taint and health.

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[1] In the report that follows, it is not assumed that these two chemicals cause effects. Based on available literature, it is possible that hydrocarbons and barium directly or indirectly cause effects, but it is also possible that less easily detected correlates of these two indicator chemicals cause effects.

[2] Number of taxonomic groups per station.

[3] Wet weight of all organisms collected per station.

In 2008, metal and hydrocarbon concentrations in American plaice and snow crab tissue continued to show that body burden in these species is unaffected by project activities. Furthermore, the results of taste tests, carried out at the Marine Institute, demonstrated that the two species were not tainted. Indicators of fish health used to evaluate potential effects on America plaice showed that the general health and condition of this species was similar in the Study and Reference Areas.

The results for both American plaice and snow crab are consistent with work in previous program years and with the predictions of the EIS.

Conclusion: Overall, project effects at White Rose in 2008 remained limited. The spatial distribution of drilling discharges, as determined by sediment concentrations of hydrocarbons and barium, approximated the predictions made in the EIS. Effects on benthic invertebrates were noted and the spatial distribution of effects on the abundance of the polychaete Paraonidae and standing crop exceeded EIS predictions. However, these effects are consistent with recent literature on effects on benthic invertebrates from other offshore oil developments. American plaice and snow crab metals and hydrocarbon body burdens were not affected by project activity. Edible tissue from American plaice and snow crab was not tainted and American plaice health was comparable between the White Rose Study Area and the Reference Areas.

Acknowledgements

The White Rose EEM program (2008) was led by Jacques Whitford (St. John’s, Newfoundland and Labrador) under contract to Husky Energy and under the direction of Francine Wight and Dave Taylor (Husky Energy).

Jacques Whitford led data collection, with participants including Matthew Hynes, Barry Wicks, Chris Brown, John Pennell, Doug Rimmer and James Loughlin. 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. Laboratory analyses for fish health indicators were supervised by Dr. Anne Mathieu of Oceans Ltd. (St. John’s, Newfoundland and Labrador). Sediment quality and body burden data were analyzed by Dr. Michael Paine of Paine, Ledge and Associates (North Vancouver, British Columbia). Fish health data were analyzed Dr. Elisabeth DeBlois (Elisabeth DeBlois Inc., St. John’s, Newfoundland and Labrador) and supervised by Dr. Michael Paine. The overall technical advisor for the program was Dr. Elisabeth DeBlois. The reporting team included Dr. Elisabeth DeBlois, Beverley Best and Carolyn Pelley. Project management was executed by Ellen Tracy (Jacques Whitford). Ellen Tracy, Elizabeth Way (Jacques Whitford), the White Rose Advisory Group, Francine Wight (Husky Energy) and Dave Taylor (Dave Taylor Inc.) reviewed the document before final printing.

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1.0 Introduction

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 centre (Figure 1-2). The North Amethyst satellite tie-back (see Figure 1-3) is a new project that will begin production in late 2009 or early 2010. Development drilling in the North Amethyst drill centre is scheduled start in early 2009.

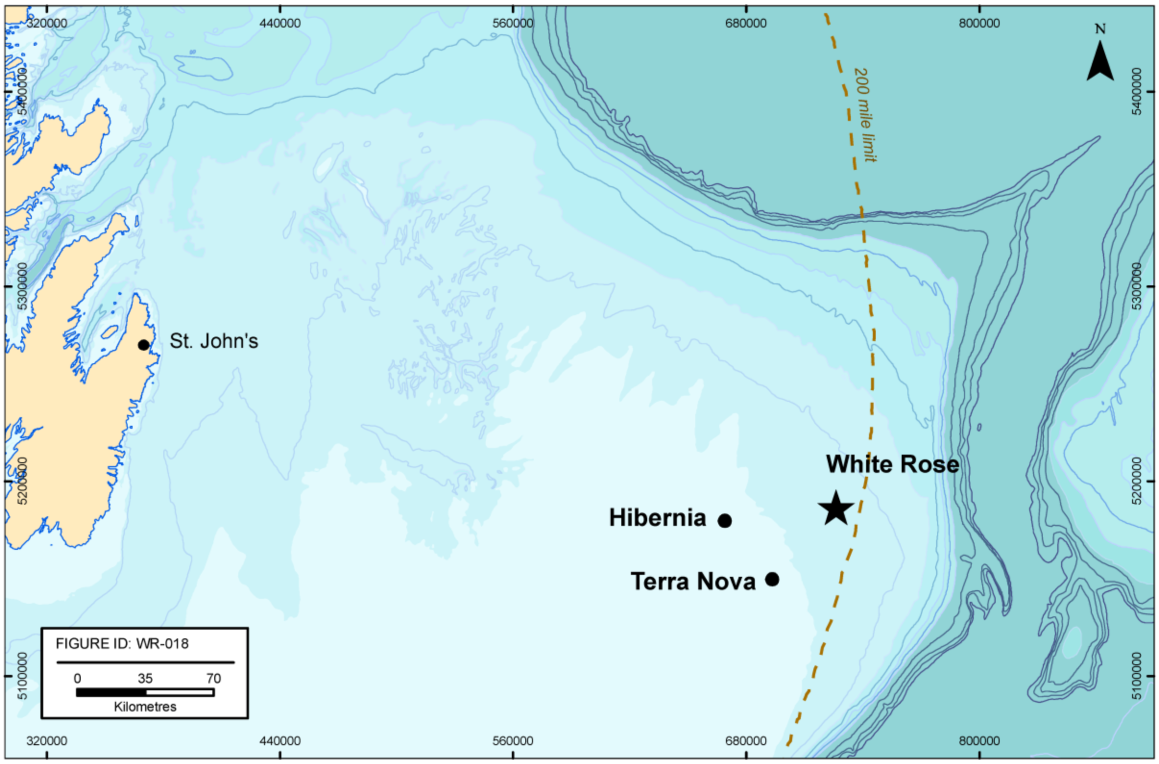

Figure 1-1 Location of the White Rose Oilfield

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 **Current Field Layout at White Rose**

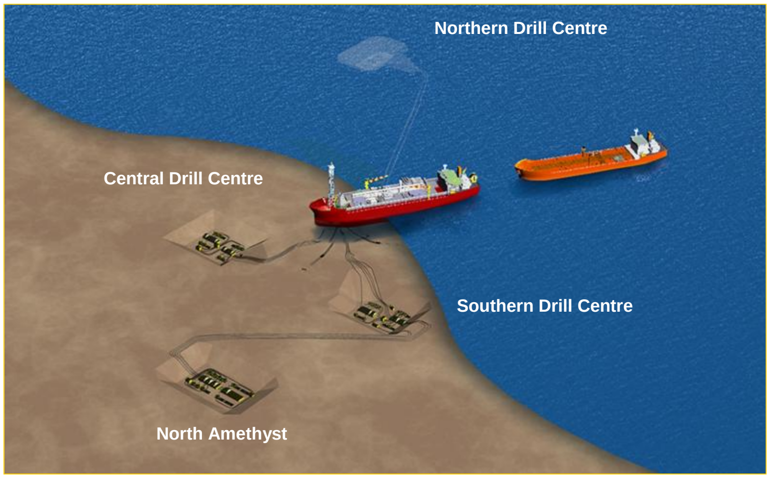

Figure 1-3 **Field Layout after Development of the North Amethyst Drill Centre**

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. A revised version of the EEM program design document to accommodate the planned development of the North Amethyst drill centre was submitted to the C-NLOPB in July 2008.

The original program was designed with the input of 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 2008, Dr. Roger Green, Dr. Douglas Holday and Dr. Roger Green provided feedback on the report. Fishing interests on the WRAG were represented by Jamie Coady of the Fish, Food and Allied Workers Union (FFAW). WRAG comments on the 2008 EEM program and comments from the regulatory community 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:

- estimate 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; and
- provide a scientifically-defensible synthesis, analysis and interpretation of data.

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 expected to have the greatest effect on physical and chemical characteristics of water, through release of produced water. The zone of influence[4] for these two waste streams, predicted from a modeling study for White Rose (Hodgins and Hodgins 2000) was not expected to extend beyond approximately 9 km and 3 km from source for drill cuttings and produced water, respectively. Effects of other waste streams (see Section 4 for details) on physical and

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

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[5] 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.

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 program (Section 1.4) are to estimate 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 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 2008 EEM program for White Rose are shown in Figure 1-4. Further details on the selection of monitoring variables are provided in the White Rose EEM Program Design document (Husky Energy 2004, 2008).

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[5] 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.

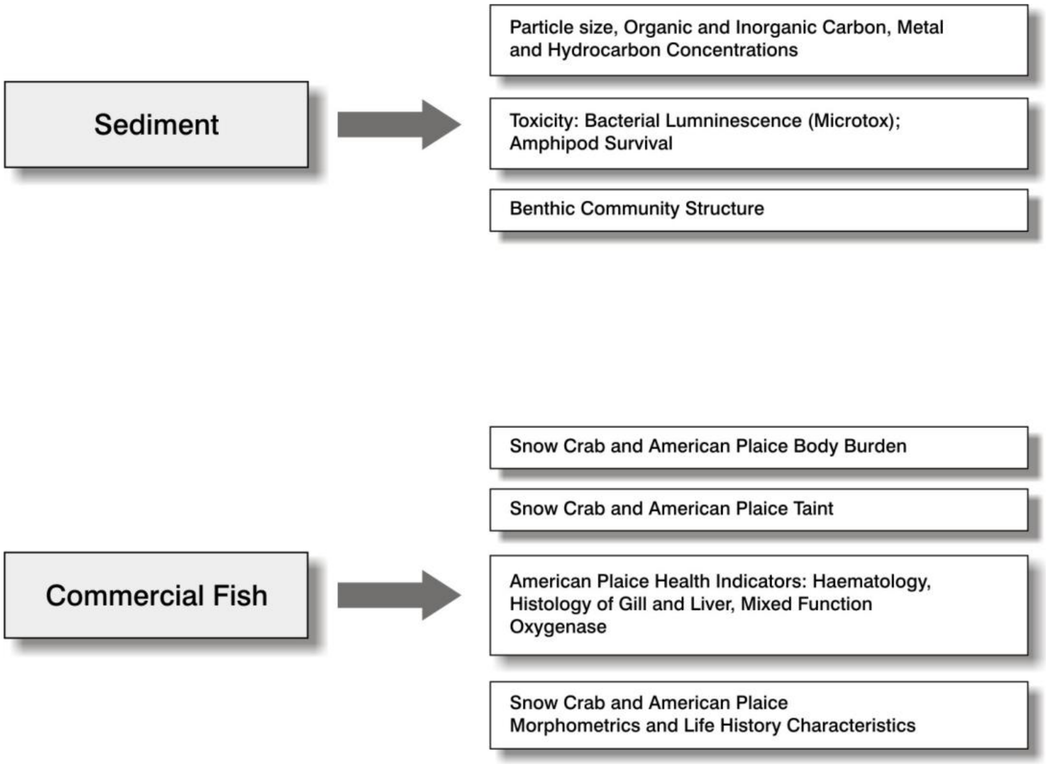

Figure 1-4 EEM Program Components

1.7 Monitoring Hypotheses

Monitoring, or null (H_0), 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 (H_0) 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:
  - H_0: There will be no change in SQT variables with distance or direction from project discharge sources over time.
- Commercial Fish:
  - $H_0(1)$: 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.

- $H_0(2)$: 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).

1.8 Sampling Design

In the Baseline Characterization (“baseline”) and the EEM programs, sediment was sampled at discrete stations in the immediate vicinity of drill centres and along transects extending to a maximum of 28 km along north-south, east-west, northwest-southeast and northeast-southwest axes (see Figures 1-5 to 1-9). Commercial fish were sampled in the vicinity of the drill centres (Study Area) and at more distant Reference Areas (with no intermediate distances) (see Figures 1-10 to 1-13). The sediment sampling design is commonly referred to as a gradient design while the commercial fish design is a control-impact design. Additional information on the baseline program and the EEM program can be found in the White Rose EEM design document (Husky Energy 2004). In 2008, Husky Energy revised the EEM design document (Husky Energy 2008) to accommodate planned development at the North Amethyst drill centre.

In keeping with EEM program objectives (Section 1.4) and EIS predictions of cuttings distribution (Section 1.5), analysis of the sediment portion of the EEM program relies first on estimating a zone of influence relative to drill centres for drill cuttings. Two indicators of drilling activity, barium and $>C_{10}$-C_{21} hydrocarbons (HCs) are used. Barium is a major constituent of water-based and synthetic-based drill muds and $>C_{10}$-C_{21} HCs are a major constituent of synthetic-based drill muds (see Section 4 for details). The spatial extent of biological effects on sediment variables (effects on benthic invertebrates and/or laboratory toxicity tests) is then defined in relation to drill centres and in relation to indicators of drilling activity.

1.8.1 Modifications to Sediment Component

There are some differences between sediment stations sampled for baseline (2000) and for EEM programs (2004, 2005, 2006 and 2008). A total of 48 sediment stations were sampled during baseline (Figure 1-5), 56 stations were sampled for the 2004 EEM program (Figure 1-6), 44 stations were sampled for the 2005 EEM program (Figure 1-7), 59 stations were sampled in 2006 (Figure 1-8) and 47 stations were sampled in 2008. In all, 36 stations were common to all sampling programs. As part of EEM program design (Husky Energy 2004, 2008), seven 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 the central, northern and southern 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).

Original station additions for the EEM program 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 to provide additional baseline data should drilling occur at these drill centres (see Figure 1-6). Since there are no immediate plans to drill at these centres, these stations were not sampled in subsequent programs. 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 1-8). In 2008, stations C5 and 17 could not be sampled because of drilling activity and four new stations were added to the EEM program around the North Amethyst drill centre (Figure 1-9) (drilling is scheduled to begin at North Amethyst in early 2009). These four stations along with stations 14 and 18 were also sampled in 2007 to provide additional pre-drilling baseline information for that drill centre. Table 1-1 provides a summary of changes between the 2000 baseline program and the 2008 EEM program as well as station name changes that were proposed in the EEM design document to simplify reporting of results.

1.8.2 Modifications to the Commercial Fish Component

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 1-10 to 1-13 provide trawl locations for the 2004, 2005, 2006 and 2008 EEM programs. The fisheries exclusion zone in 2004 was larger to accommodate possible drilling at the NN and SS drill centres. In 2008, heavy commercial fishing activity for crab in Reference Areas 3 and 4 precluded sampling.

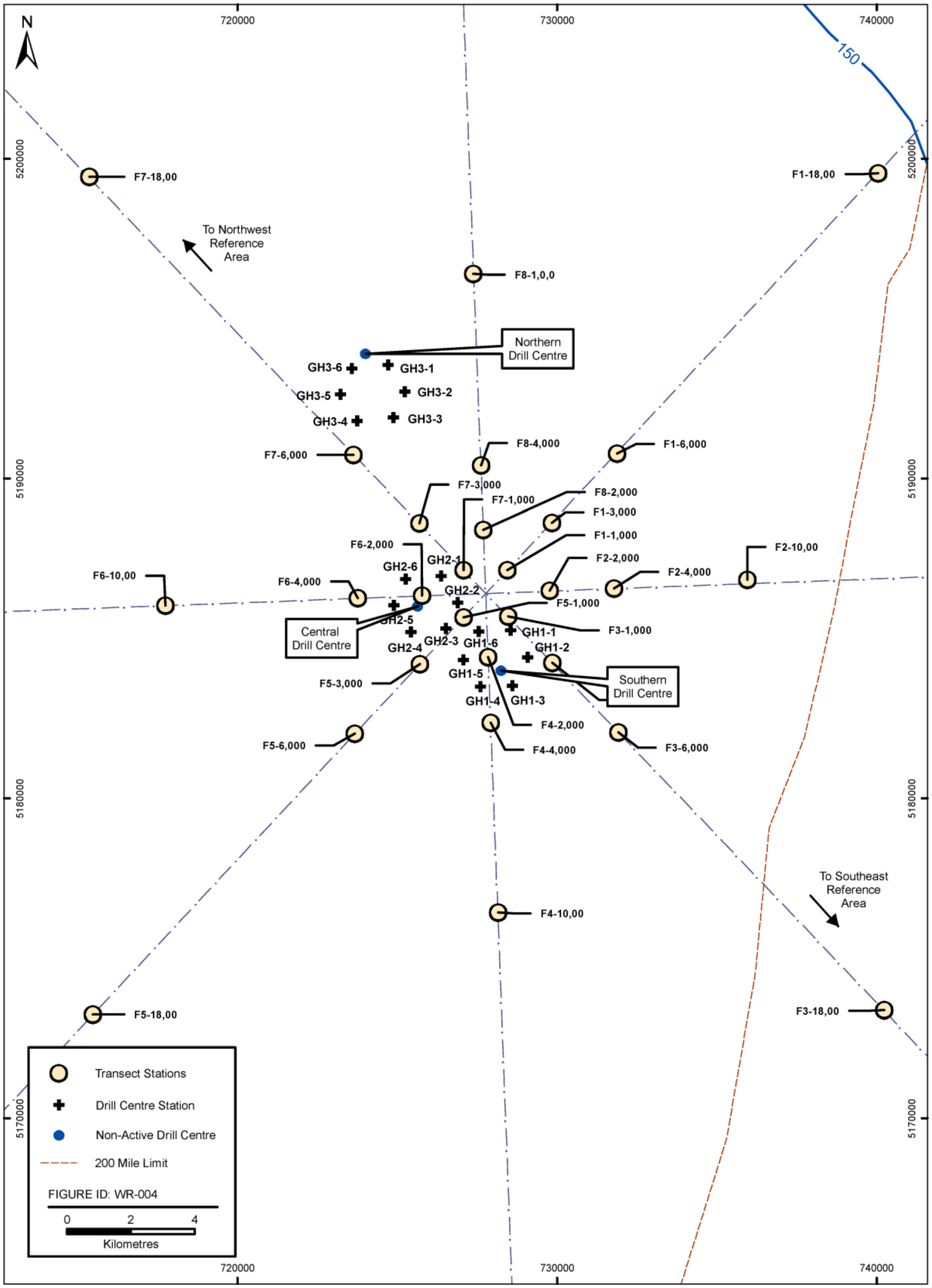

Figure 1-5 2000 Baseline Program Sediment Stations

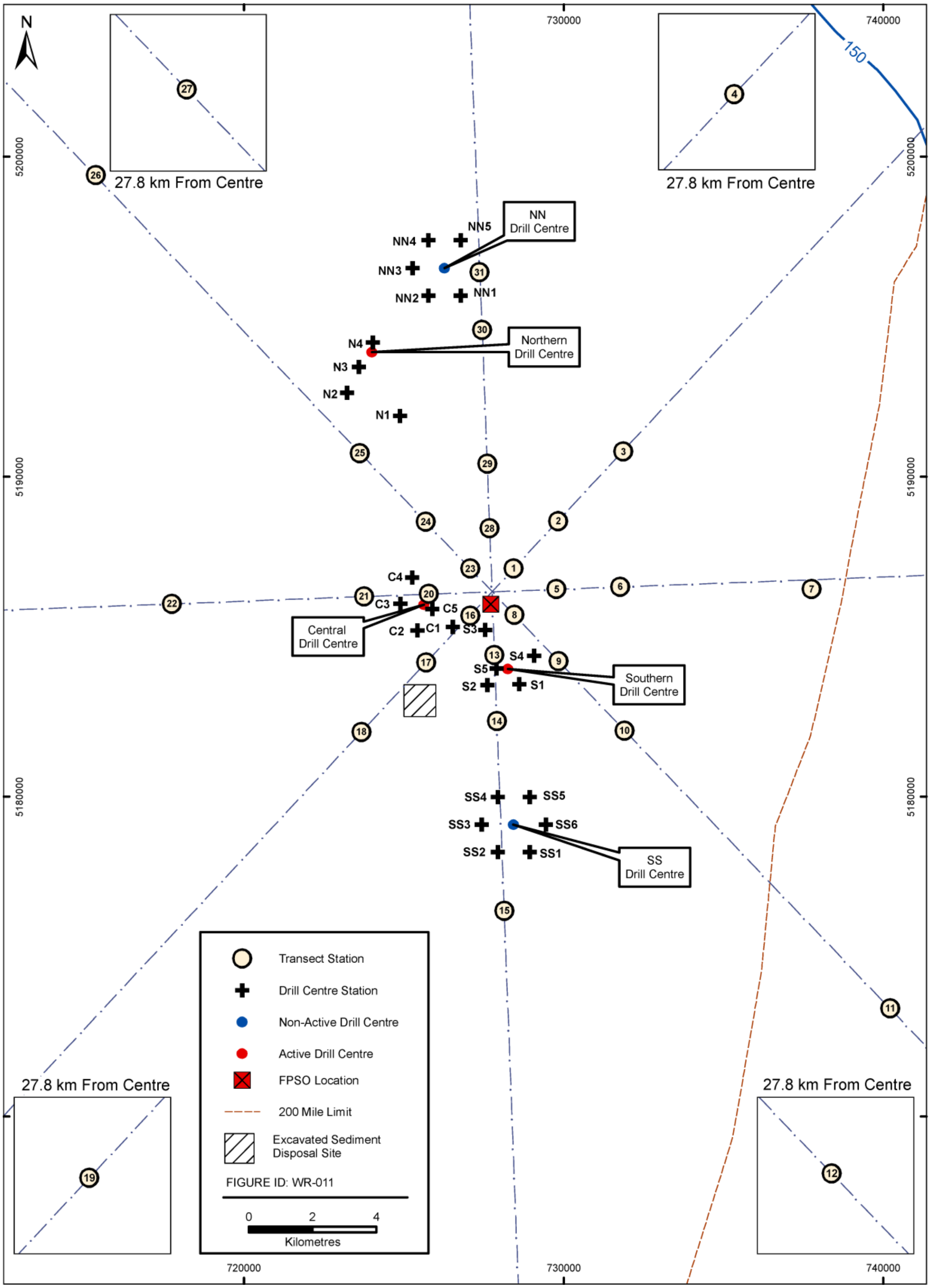

Figure 1-6 2004 EEM Program Sediment Stations

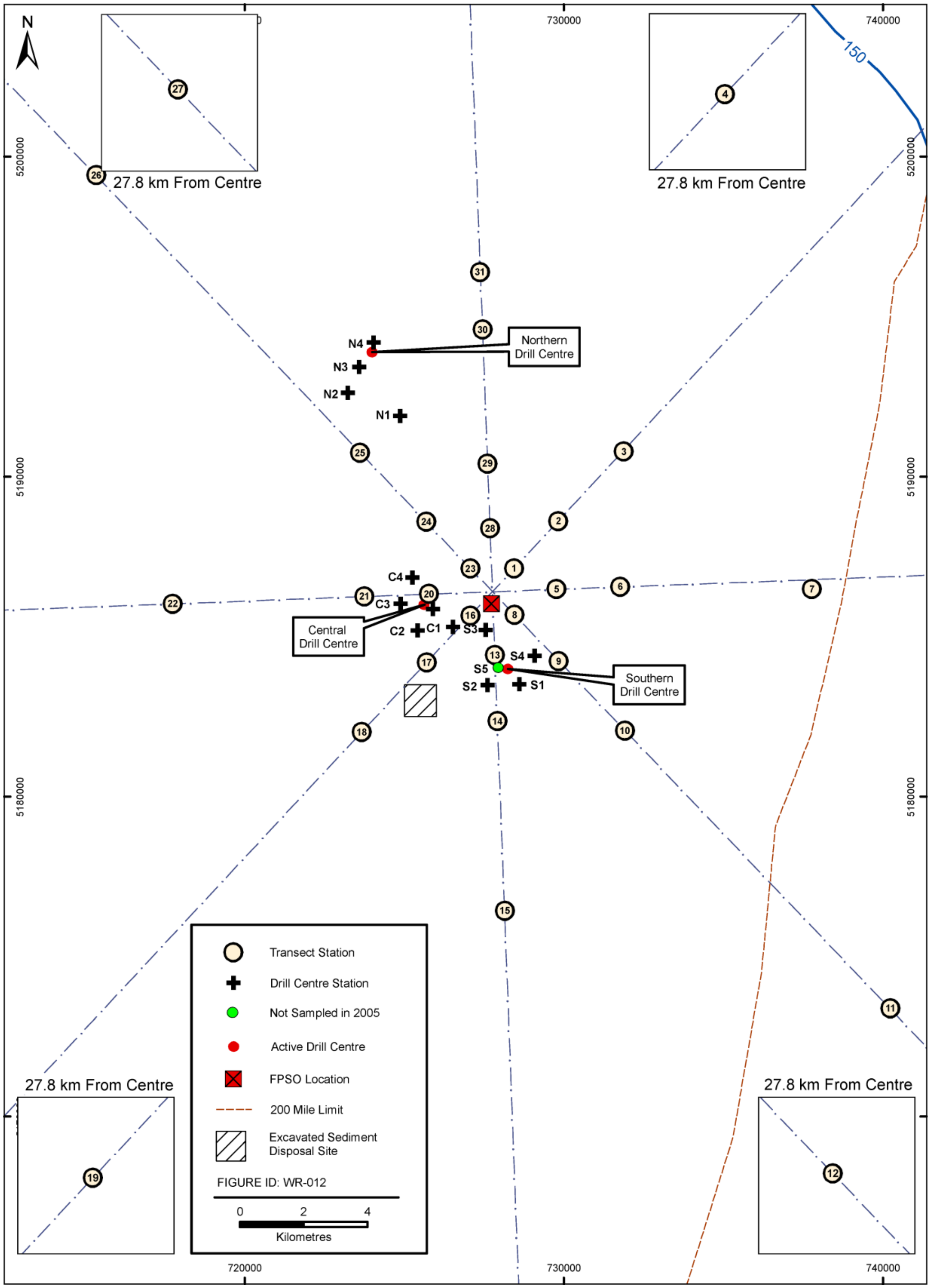

Figure 1-7 2005 EEM Program Sediment Stations

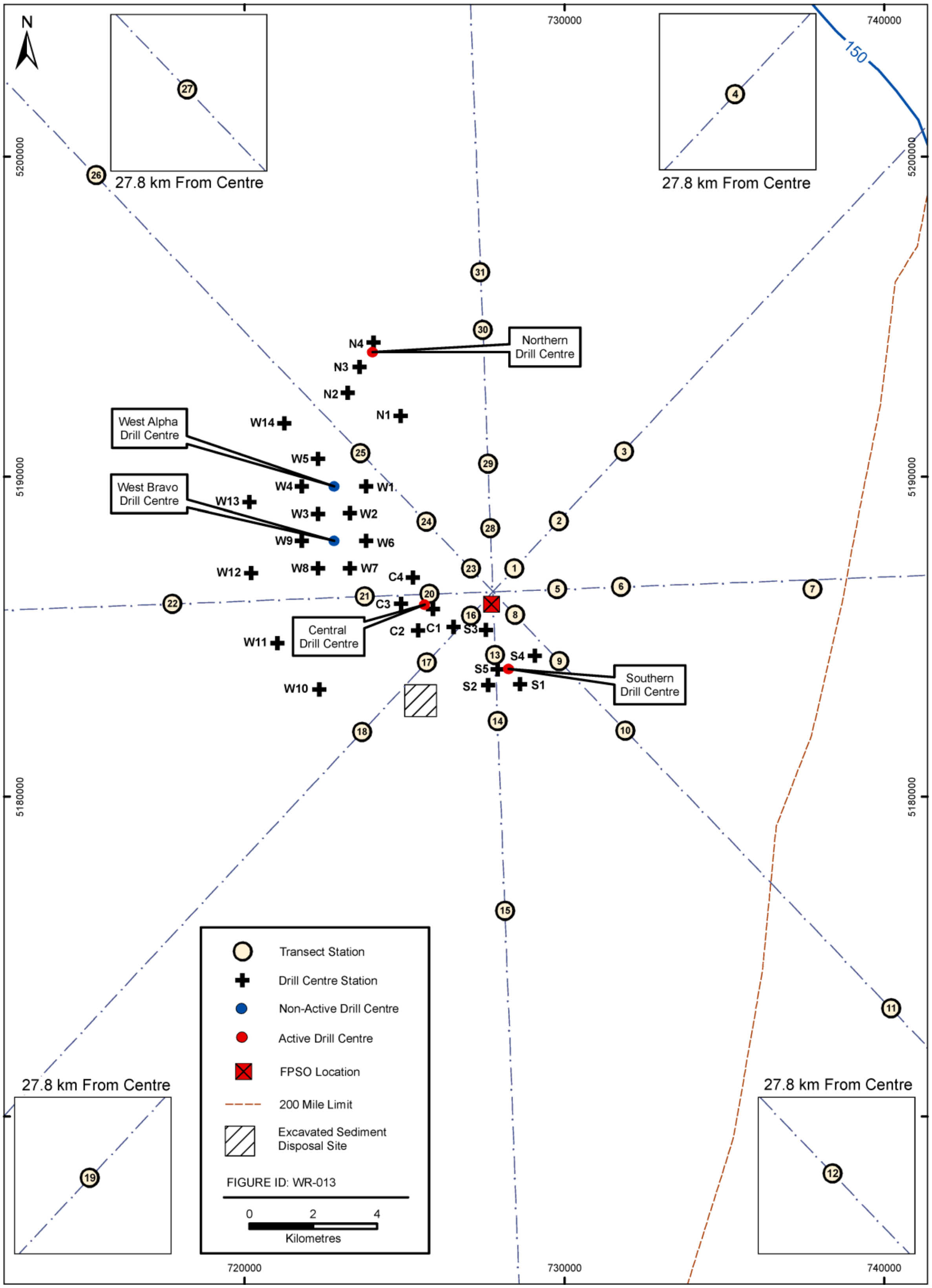

Figure 1-8 **2006 EEM Program Sediment Stations**

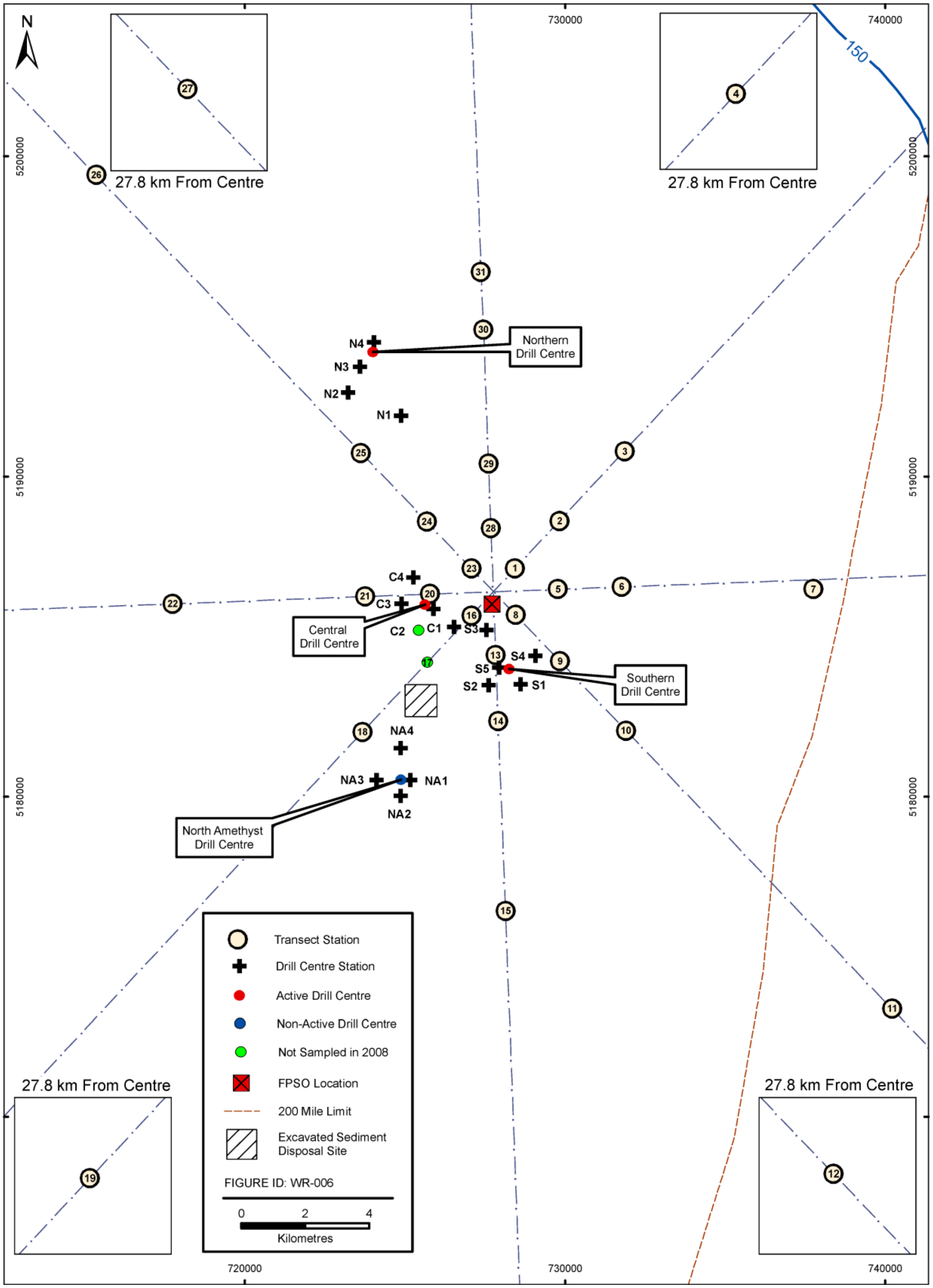

Figure 1-9 2008 EEM Program Sediment Stations

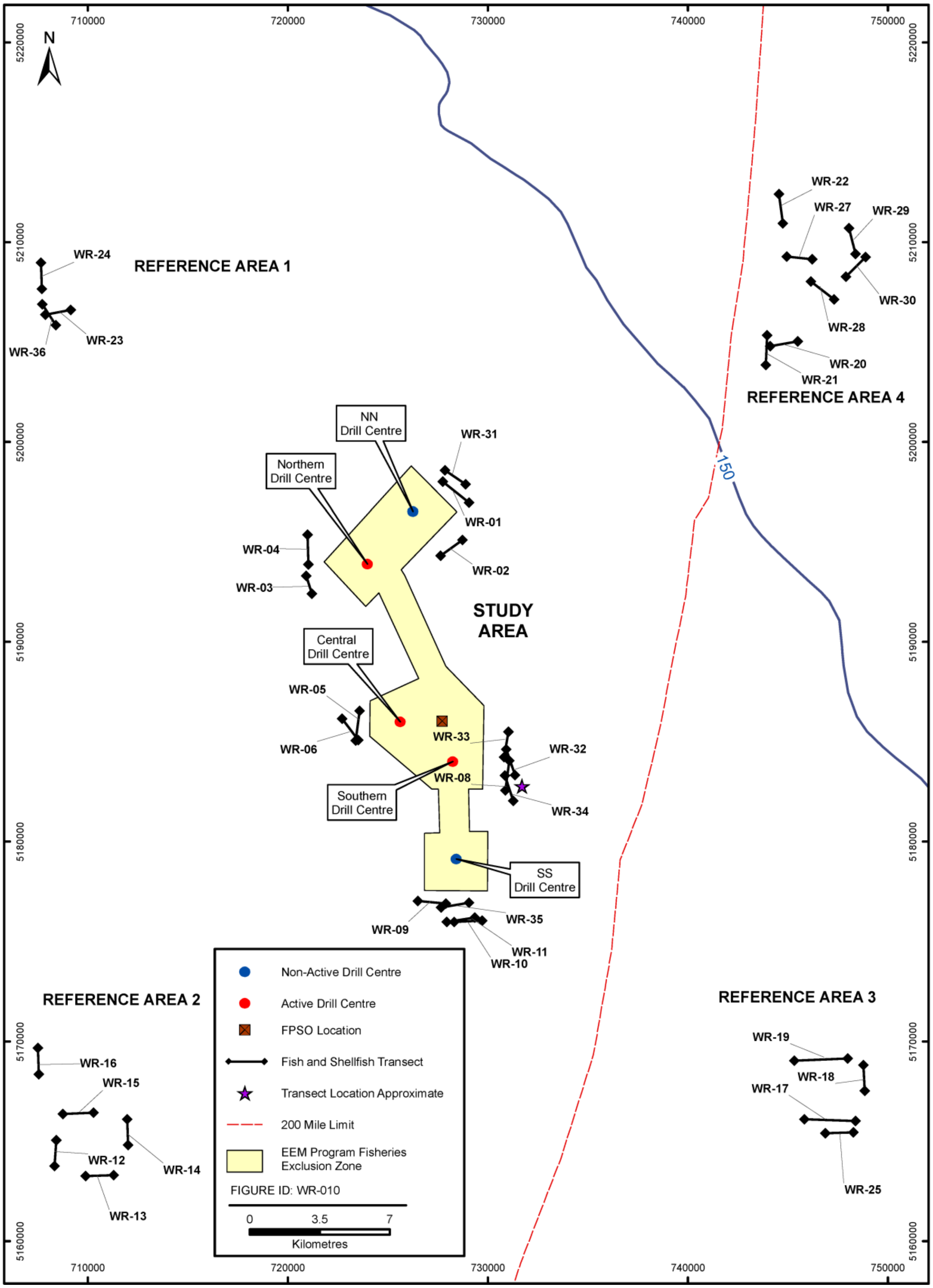

Figure 1-10 2004 EEM Program Transect Locations

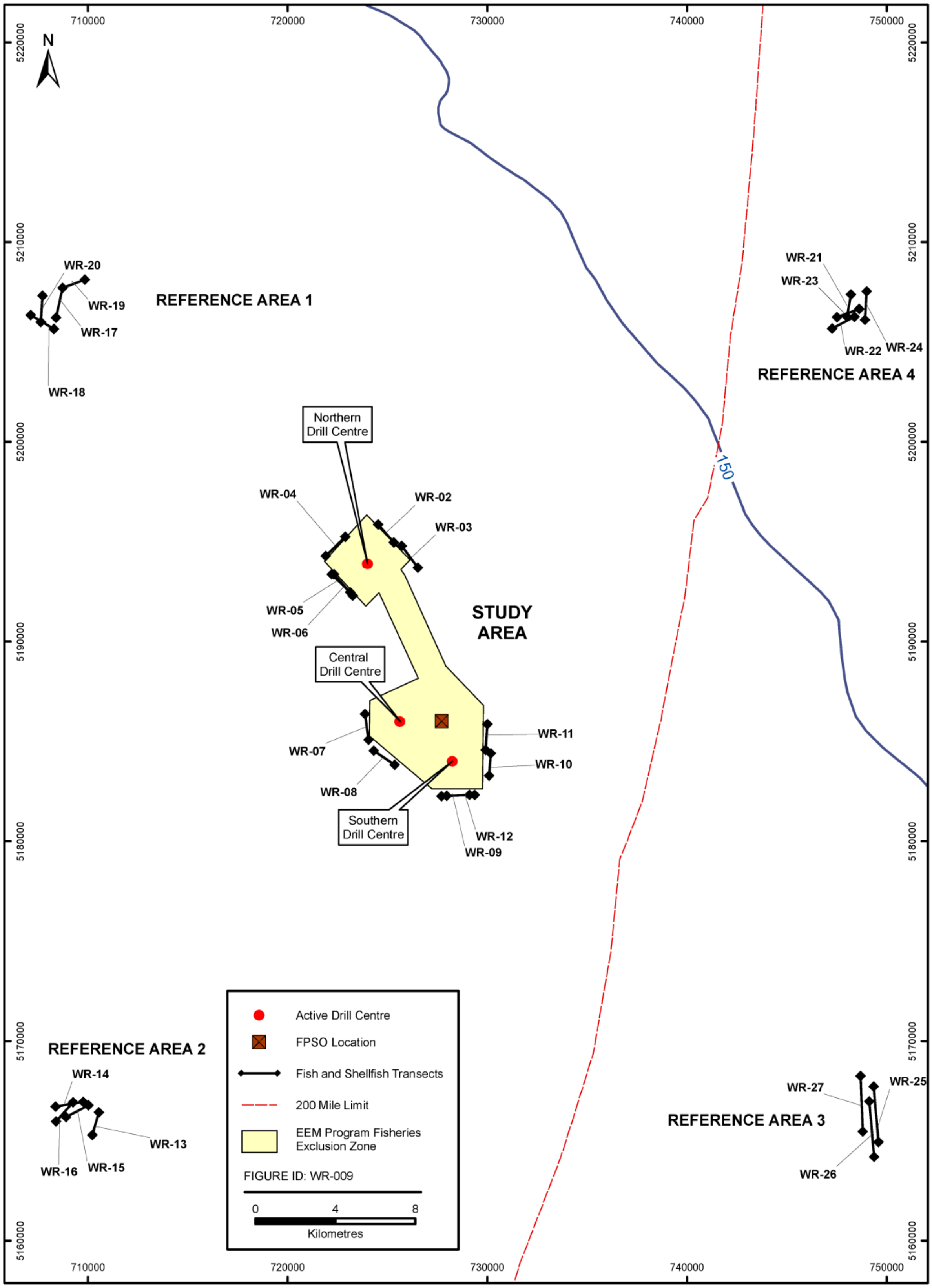

Figure 1-11 2005 EEM Program Transect Locations

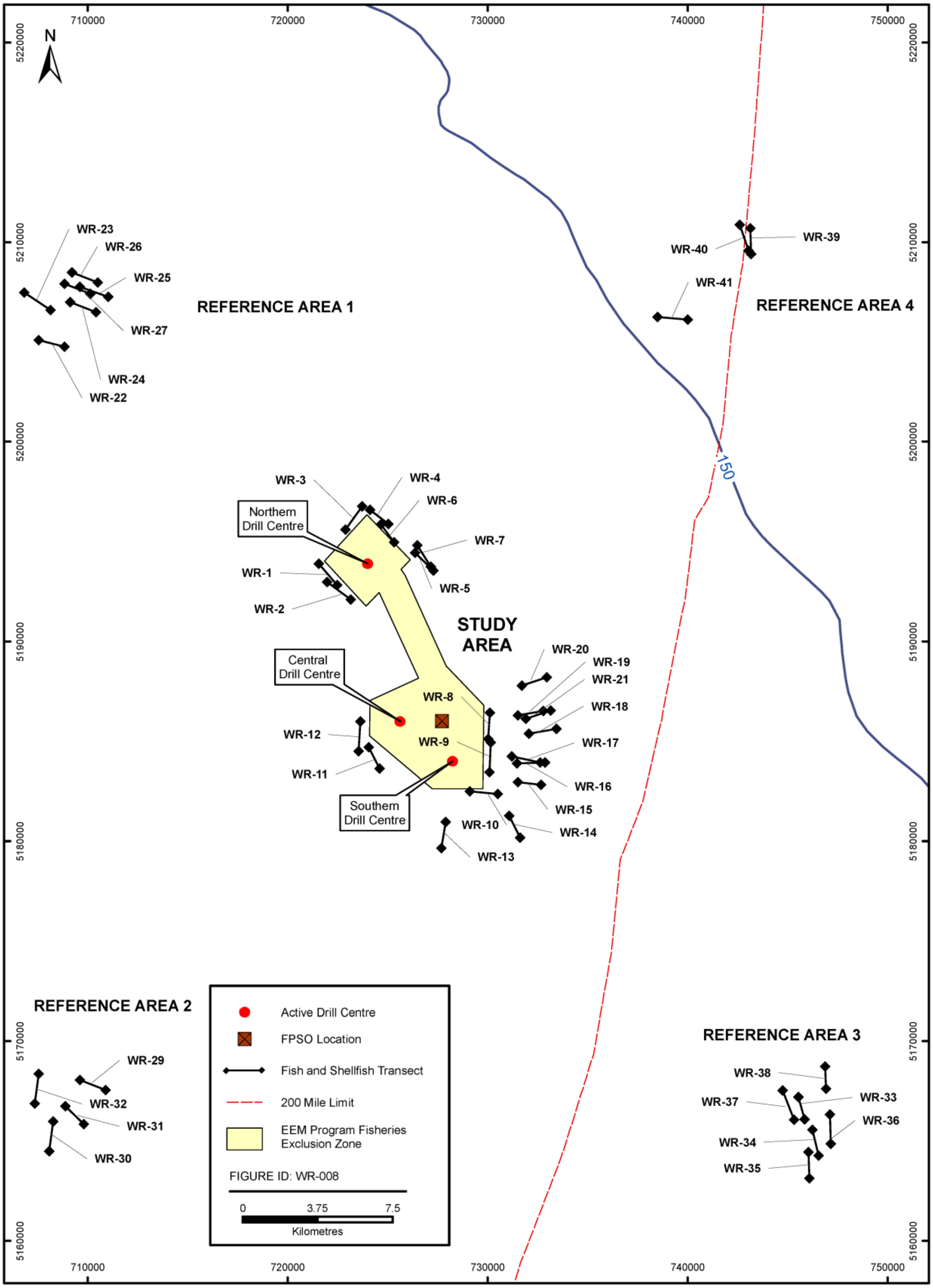

Figure 1-12 2006 EEM Program Transect Locations

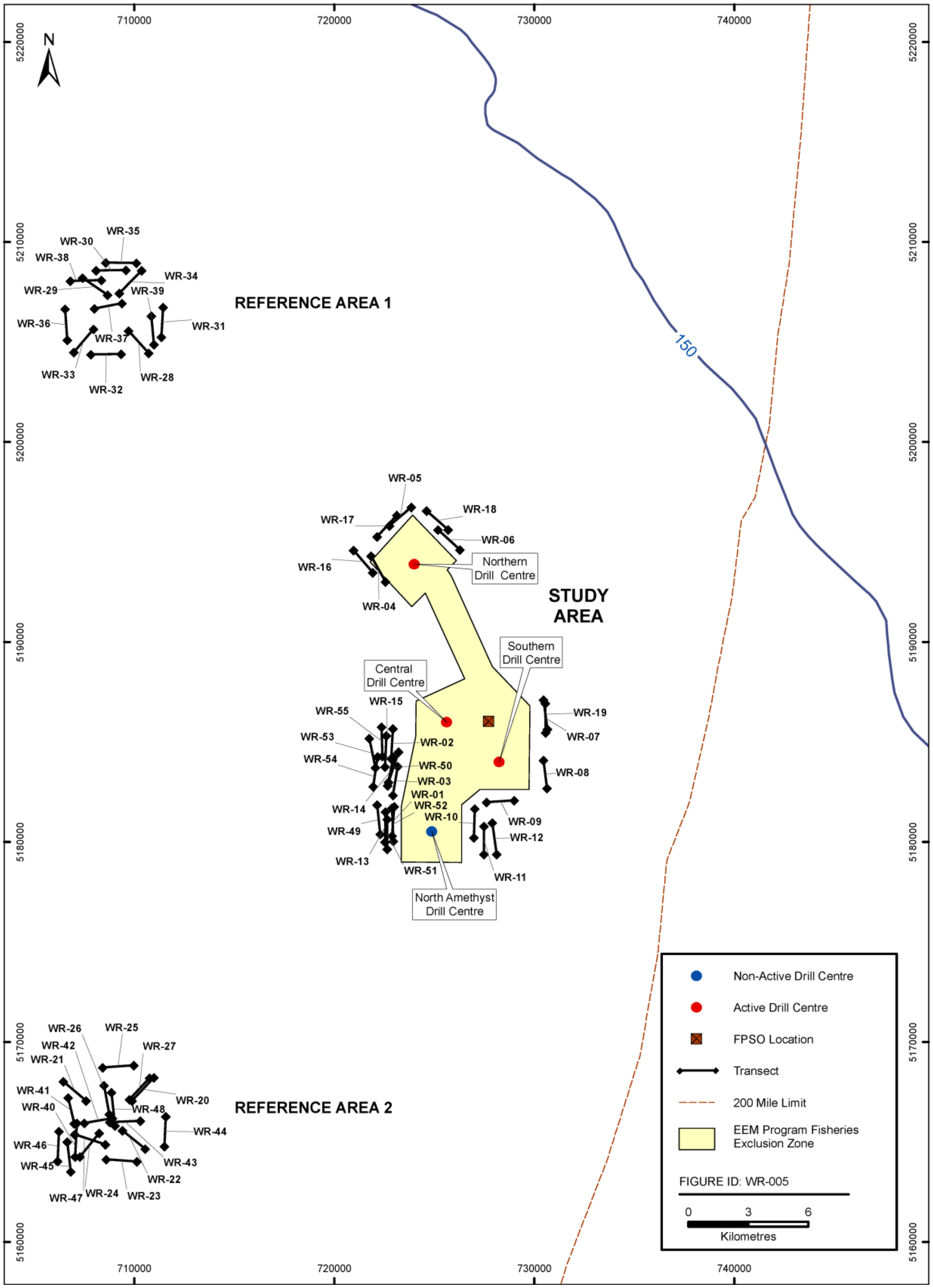

Figure 1-13 2008 EEM Program Transect Locations

Table 1-1 Table of Concordance Between Baseline (2000) and 2008 EEM Stations

EEM Program Station Name	Corresponding Station Name during the 2000 Baseline Program
1	F1-1,000
2	F1-3,000
3	F1-6,000
4	Not Sampled in 2000
5	F2-2,000
6	F2-4,000
7	F2-10,000
8	F3-1,000
9	F3-3,000
10	F3-6,000
11	F3-18,000
12	Not Sampled in 2000
13	F4-2,000
14	F4-4,000
15	F4-10,000
16	F5-1,000
17**	F5-3,000
18	F5-6,000
19	Not Sampled in 2000
20	F6-2,000
21	F6-4,000
22	F6-10,000
23	F7-1,000
24	F7-3,000
25	F7-6,000
26	F7-18,000
27	Not Sampled in 2000
28	F8-2,000
29	F8-4,000
30	F8-10,000
31	Not Sampled in 2000
C1	GH2-3
C2	GH2-4
C3	GH2-5
C4	GH2-6
C5**	Not Sampled in 2000
N1	GH3-3
N2	GH3-5
N3	GH3-6
N4	Not Sampled in 2000
S1	GH1-3
S2	GH1-4
S3	GH1-6
S4	GH1-2
S5*	Not Sampled in 2000
NA1	Not Sampled in 2000
NA2	Not Sampled in 2000
NA3	Not Sampled in 2000
NA4	Not Sampled in 2000

Notes:
- For 2000 baseline stations, only those stations retained for the EEM program (37 in total) are listed.
- Additional baseline stations sampled in 2004 and 2006 are not listed in the above Table, but see text and Figures for details.
- * Not sampled in 2005 because of drilling activity.
- ** Not sampled in 2008 because of drilling activity.

2.0 Scope

This document, *White Rose Environmental Effects Monitoring Program 2008 (Volume 1)*, provides summary results, analysis and interpretation for the White Rose 2008 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 previous EEM programs are compared to 2008 results. Since analysis of 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).

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 2008 (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 this document. 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.

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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
BAT	Best Available Technology
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
CR	Completely Random
CV	Coefficient of Variation
DFO	Fisheries and Oceans Canada
EEM	Environmental Effects Monitoring
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EQL	Estimated Quantification Limit
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
MDL	Method Detection Limit
MFO	Mixed Function Oxygenase
NEB	National Energy Board
NMDS	Non-Metric Multidimensional Scaling
OWTG	Offshore Waste Treatment Guidelines
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
SQT	Sediment Quality Triad
SR	Study versus Reference Areas
TEL	Threshold Effects Levels
TOC	Total Organic Carbon
UCM	Unresolved Complex Mixture

Acronym	Definition
VEC	Valued Ecosystem Component
WBM	Water-Based Mud
WRAG	White Rose Advisory Group

4.0 Project Activities

4.1 Introduction

This section reports on both drilling and production activities in the White Rose Field and 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 for the original White Rose Field 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 late 2009 or early 2010, White Rose is scheduled to start producing from the North Amethyst drill centre.

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 HCs to the *SeaRose* FPSO were completed.

Development drilling from the drill rig *GSF Grand Banks* continued in 2006 through 2008, as did normal supply and standby vessel operations. Delineation and exploration drilling operations from the drill rig *Henry Goodrich* took place between August and December 2008.

4.3 Drilling and Completions Operations

As mentioned, drilling activities continued in 2006 through 2008. 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 barite and bentonite 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 marine environment. Since its introduction in November of 2005, the viscosified NaCl brine has been used in the first two hole sections, or the WBM 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 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 marine environment by 48%. The result of the toxicity studies has indicated the LC_{50}[6] is approximately the same for both systems; however, the environmental load has been reduced by almost 50 percent.

Table 4-1 Volume of Traditional Barite and Bentonite 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)

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

4.3.1 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.

Table 4-2 Cuttings and WBM Discharges from 2003 to September 2008

Year	Drill Centre	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	1,282
	Southern	🟨	🟨											638	932
2007	Northern								🟩					N/A	N/A
	Central	🟦	🟦	🟦	🟦	🟦								655	867
	Southern													N/A	N/A
	Well K 03*											🟧	🟧	619	718
2008	Northern										🟩	🟩	🟩	653	726
	Central	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			651	985
	Southern			🟨	🟨	🟨	🟨	🟨	🟨					557	753
Total Discharge at Northern Drill Centre														1,335	1,182
Total Discharge at Central Drill Centre														5,458	5,281
Total Discharge at Southern Drill Centre														3,760	4,817
Total Field Discharge														11,172	11,998

Note: - *Well K 03 is a Delineation Well.

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 2008

Year	Drill Centre	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
2007	Northern								🟩					409	719.9	71
	Central	🟦	🟦	🟦	🟦	🟦								1,291	2,382	241
	Southern													N/A	N/A	N/A
	Well K 03*											🟧	🟧	437	775	65
2008	Northern										🟩	🟩	🟩	771	1,765.6	202
	Central	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			483	979	88
	Southern			🟨	🟨	🟨	🟨	🟨	🟨					668	1,518	151
Total Discharge at Northern Drill Centre														1,530	2,958.6	308
Total Discharge at Central Drill Centre														4,586	10,103	1,287
Total Discharge at Southern Drill Centre														4,046	9,224	1,233
Total Field Discharge														10,599	23,060.6	2,893

Note: - *Well K 03 is a Delineation Well.

On completion, a well bore needs to be cleaned of residual cuttings. This is done by flushing with "completion fluids" consisting primarily of 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 2008

Year	Drill Centre	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
2007	Northern								🟩	🟩				150
	Central				🟦	🟦	🟦							573
	Southern													N/A
	Well K 03*													N/A
2008	Northern													N/A
	Central									🟦	🟦			186
	Southern								🟨	🟨				250
Total Discharge at Northern Drill Centre														150
Total Discharge at Central Drill Centre														2,676.06
Total Discharge at Southern Drill Centre														3,717
Total Field Discharge														6,543.06

Note: - *Well K 03 is a Delineation Well.

4.3.2 Other Discharges from Drilling Operations

Between October 2006 and September 2008, a total of 253.1 m^3 of bilge water from drilling operations has been discharged. All bilge water is treated in an oily water separator prior to release to reduce HC content to 15 ppm or less (in accordance with Offshore Waste Treatment Guidelines (OWTG: NEB et al. 2002)). In total, 3.8 kg of dispersed HCs were released to the marine environment from bilge water. Similarly, all deck drainage is collected and treated to reduce HC content to 15 ppm or less. There has been approximately 5423.3 m^3 of deck drainage reported during this period, which represents a transfer of 81.4 kg of dispersed HCs to the marine environment.

Water and ethylene glycols are routinely discharged during function testing of a seabed blowout preventer and subsea flowline valves. In total, over the reporting period, approximately 167 m^3 of water and glycols have been discharged from these sources, of which approximately 53.6 m^3, or 32% of the total volume, has been the active ingredients.

4.4 FPSO Production Operations

The primary points of HC discharge to seawater for the *SeaRose* FPSO are from the bilge, the slops tanks and produced water. Bilge and slops water discharge is permitted under the OWTG, following a separation process, to reduce the oil in water content to less than 15 pmm. Bilge water on the *SeaRose* FPSO is typically directed towards the slops tanks to discharge. Slops tanks are reservoirs for collecting both rainwater (washed over the production facility from open and closed drains) and the redirected bilge water. Contents of the slops tanks undergo oil/water separation and testing prior to discharge to a level of less than 15 ppm HC as per the OWTG. Between October 2006 and September 2008, a total of 7,036 m^3 of water was released from the slops tanks, representing 44.57 kg (6.3 ppm) of dispersed HCs to the marine environment.

Produced water is a by-product of oil production and is a combination of water entrained within the reservoir (formation) and seawater injected into the reservoir to maintain pressure. Produced water is removed from crude oil through a series of separation processes in the Production Train. Produced water has two regulatory limits for oil in water, as per the OWTG: a 24-hour arithmetic mean is to be less than 60 ppm, whereas a volume weighted 30-day rolling average is to be less than 30 ppm. Produced water for White Rose was first realized on March 9, 2007, and between that date and September 2008, 996,6 m^3 of produced water was released, representing 25,363 kg (25.4 ppm) of dispersed HCs to the marine environment.

Seawater is pumped aboard the *SeaRose* FPSO and is circulated around equipment as cooling water to reduce operating temperatures. Approximately 9,840 m^3 is discharged daily from the cooling water system. To prevent biofouling within the cooling water system, the seawater is treated with chlorine and is managed such that the residual chlorine level at discharge is 0.5 ppm or less, approximately the same as drinking water. Between October 2006 and September 2008, the monthly average concentration of chlorine prior to release was 0.25 ppm.

4.5 Supply Vessel Operations

All offshore facilities and operations 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 2008 EEM Program was conducted from September 17 to September 21, 2008, using the offshore supply vessel *Gabarus*. 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 1-5 to 1-9 (Section 1). More details on the baseline survey can be found Section 1 and in Husky Energy (2001). More details on the year 1, 2 and 3 EEM programs can be found in Husky Energy (2005; 2006; 2007). Geographic coordinates and distances to drill centres for EEM stations sampled in 2008 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
EEM Program Year 4	September 17 to September 21, 2008

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[7]. These samples were preserved with approximately 1 L of 10% buffered formalin. Benthic invertebrate counts from these two samples were later pooled for analysis.

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[7] 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.

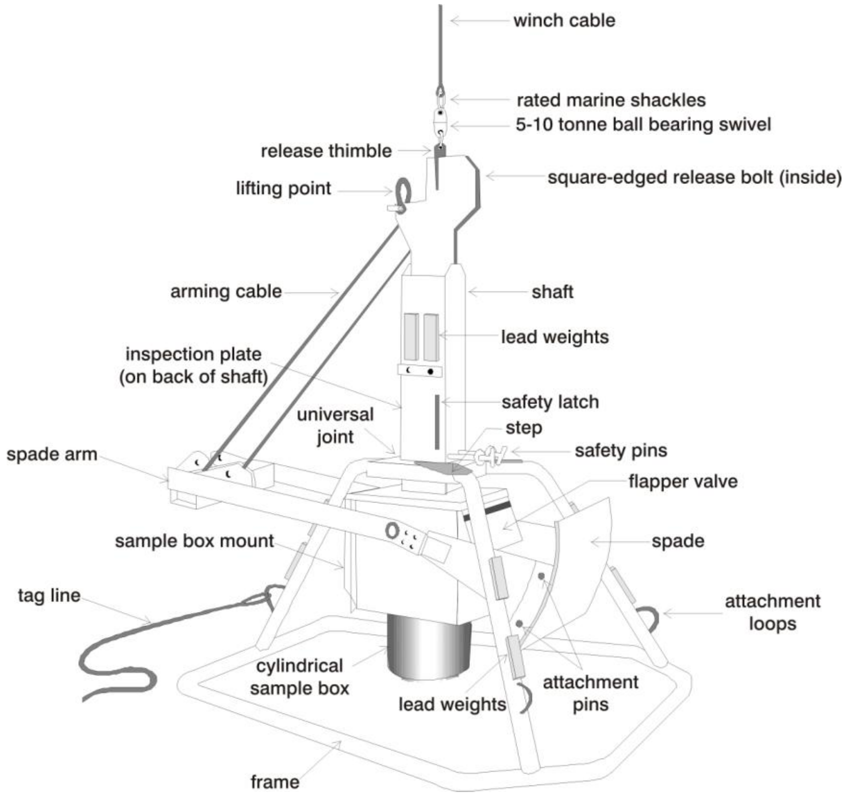
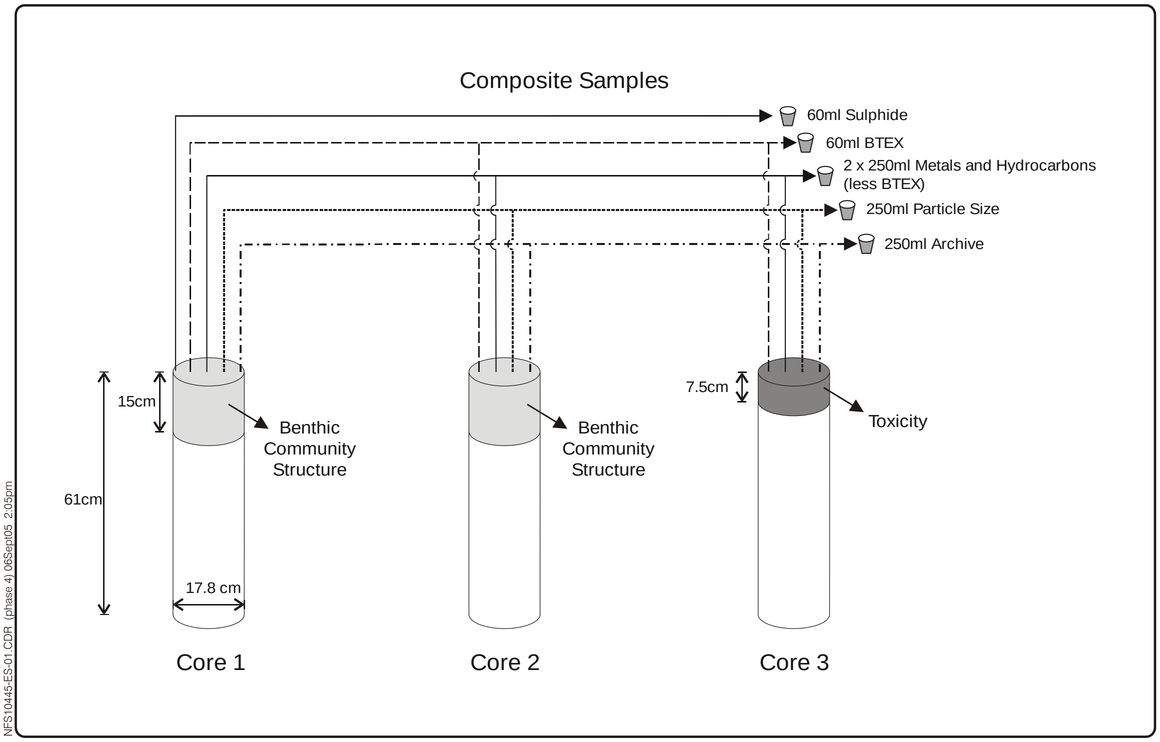


Figure 5-1 Sediment Corer Diagram

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 18, 20 and NA4. 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 5, 11, 29, C4 and S3. Both field blanks and field duplicates were assigned randomly to stations.

The following Quality Assurance/Quality Control (QA/QC) protocols were implemented 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, 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, 2006 and 2008)

Variables	Method	RDL					Units
		2000	2004	2005	2006	2008	
HCs							
Benzene	Calculated	0.025	0.025	0.025	0.03	0.03	mg/kg
Toluene	Calculated	0.025	0.025	0.025	0.03	0.03	mg/kg
Ethylbenzene	Calculated	0.025	0.025	0.025	0.03	0.03	mg/kg
Xylenes	Calculated	0.05	0.05	0.05	0.05	0.05	mg/kg
C_6-C_{10}	Calculated	2.5	2.5	2.5	4	3	mg/kg
>C_{10}-C_{21}	GC/FID	0.25	0.25	0.3	0.3	0.3	mg/kg
>C_{21}-C_{32}	GC/FID	0.25	0.25	0.3	0.3	0.3	mg/kg
PAHs							
1-Chloronaphthalene	GC/FID	NA	0.05	0.05	0.05	0.05	mg/kg
2-Chloronaphthalene	GC/FID	NA	0.05	0.05	0.05	0.05	mg/kg
1-Methylnaphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
2-Methylnaphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Acenaphthene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Acenaphthylene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Benz[*a*]anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*a*]pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*b*]fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*ghi*]perylene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*k*]fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Chrysene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Dibenz[*a,h*]anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Fluorene	GC/FID	0.05	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	0.05	mg/kg
Naphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Perylene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Phenanthrene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	mg/kg
Carbon							
Carbon	LECO	0.1	0.2	0.2	0.2	0.2	g/kg
Organic Carbon	LECO	0.1	0.2	0.2	0.2	0.2	g/kg
Inorganic Carbon	By Diff	0.2	0.3	0.2	0.2	0.2	g/kg
Metals							
Aluminum	ICP-MS	10	10	10	10	10	mg/kg
Antimony	ICP-MS	2	2	2	2	2	mg/kg
Arsenic	ICP-MS	2	2	2	2	2	mg/kg
Barium	ICP-MS	5	5	5	5	5	mg/kg
Beryllium	ICP-MS	5	2	2	2	2	mg/kg
Cadmium	GFAAS	0.05	0.05	0.05	0.05	0.05	mg/kg
Chromium	ICP-MS	2	2	2	2	2	mg/kg
Cobalt	ICP-MS	1	1	1	1	1	mg/kg
Copper	ICP-MS	2	2	2	2	2	mg/kg

Variables	Method	RDL					Units
		2000	2004	2005	2006	2008	
Iron	ICP-MS	20	50	50	50	50	mg/kg
Lead	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Lithium	ICP-MS	5	2	2	2	2	mg/kg
Manganese	ICP-MS	2	2	2	2	2	mg/kg
Mercury	CVAA	0.01	0.01	0.01	0.01	0.01	mg/kg
Molybdenum	ICP-MS	2	2	2	2	2	mg/kg
Nickel	ICP-MS	2	2	2	2	2	mg/kg
Selenium	ICP-MS	2	2	2	2	2	mg/kg
Strontium	ICP-MS	5	5	5	5	5	mg/kg
Thallium	ICP-MS	0.1	0.1	0.1	0.1	0.1	mg/kg
Tin	ICP-MS	2	2	2	2	2	mg/kg
Uranium	ICP-MS	0.1	0.1	0.1	0.1	0.1	mg/kg
Vanadium	ICP-MS	2	2	2	2	2	mg/kg
Zinc	ICP-MS	2	5	2	5	5	mg/kg
Other							
Ammonia (as N)	COBAS	NA	0.25	0.3	0.3	0.3	mg/kg
Sulphide	SM4500	NA	2	0.2	0.2	0.2	mg/kg
Sulphur	LECO	NA	0.02	0.02	0.002	0.01	%(w)
Moisture	Grav.	0.1	0.1	0.1	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[8].
- NA = Not Analyzed.

Within the HCs, benzene, toluene, ethylbenzene and xylenes (BTEX) are aromatic 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 assess concentrations of HCs in 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

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[8] 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. The matrix is any material, chemical, physical property of the real world sample that can affect the analytical determination.

retention time of C_{11} 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.

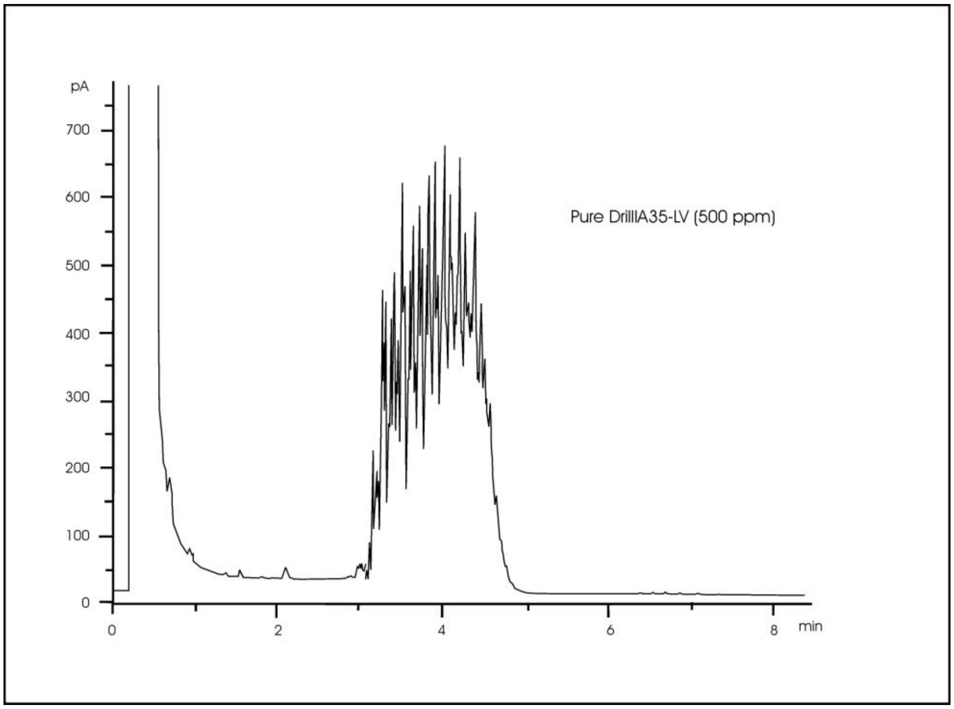

Figure 5-4 **Gas Chromatogram Trace for PureDrill IA35-LV**

5.2.2 Toxicity

Jacques Whitford's Science 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 used 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 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, 2006 and 2008 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 Environment 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 Canada 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}[9] 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.

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[9] An IC_{50} (50% inhibitory concentration) is the concentration of a substance that produces 50% of the maximum possible inhibitory response to that substance.

For any test sediment from a particular station that is comprised of less than 20% fines and that has an IC_{50} 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 2008 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 5.3.4).

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 the 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, 2005 and 2006 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 2008 samples (see Husky Energy 2001 for details).

5.3 Data Analysis

Major changes in analyses relative to analyses conducted in past years were:

1. station 31, within 0.4 km of delineation well K-03 (drilled in 2007), was excluded from all distance analyses;
2. distance from the North Amethyst drill centre (inactive in 2008 and prior years) was added to Repeated Measures (RM) regression analyses comparing years;
3. Simpson's diversity (*D*) and evenness (*E*) were dropped from analyses of benthic invertebrate communities; and
4. analyses of abundances of several sub-dominant Polychaete taxa were added (these analyses were considered exploratory and are provided in Appendix B-5).

These changes are described in more detail in the text that follows.

5.3.1 General Approach

Analyses of sediment quality data included:

1. analyses of correlations among variables for 2008 and between these variables and depth and distances from drill centres;
2. comparison of depth and distance relationships among years (2000, 2004, 2005, 2006 and 2008); and
3. multi-year assessment of relationships between benthic invertebrate community variables and concentrations of $>C_{10}$-C_{21} HCs.

The distance relationships tested "attenuation with distance" hypotheses. $>C_{10}$-C_{21} HCs (constituents of SBMs and indicators of drilling activity) were the best chemistry predictor (*X*) of biological responses (e.g., effects on *in-situ* benthic invertebrates or laboratory toxicity test results).

Given the large and complex multivariate sediment quality data set, there were reasonable alternatives available at almost every step in analyses. The general strategy was to try different approaches (e.g., parametric versus non-parametric analyses; use of chemical concentrations versus distance as *X* in regression) as opposed to minor variations of the same approach. 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:

1. results significant at $p \leq 0.01$ and especially $p \leq 0.001$ (highlighted in bold in Tables);
2. strong correlations (i.e., |r| or |rs| > 0.5 and especially > 0.7); and
3. notable differences over space and time, especially those representing potential project effects.

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. However, 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 relevance. These results were always reported for interested readers.

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 indicators of drilling activity; after versus before drilling began).

All log transformations were $\log_{10}$ rather than natural log ($\log_e$) transformations. More details on data transformations are provided in Appendix B-5. All analyses were conducted using SYSTAT 11 software.

5.3.1.1 Analysis of 2008 Data

For analysis of 2008 data, the first step was to calculate summary statistics and multivariate summary measures required for further analyses. Bivariate 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*). Min *d* was a useful summary distance measure, particularly for plotting distance relationships in two dimensions.

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 and 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 (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 estimating zones of influence based on chemical variables or the spatial extent of effects for biological variables (threshold distances (X_T)), or in some cases, indicating that zones of influence or the spatial extent of effects could not or should not be estimated.

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 (i.e., did hokey-stick models provide a better fit)?" (see Appendix B-5 for the test used).

station 31, within 0.4 km of a delineation well (K-03) drilled in 2007 and with high levels of barium and HCs, was included in all correlation analyses of relationships among sediment physical, chemical and biological variables but excluded from all analyses of distance relationships.

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 of the four drill centres (X variables) among years. Distances from the North Amethyst drill centres (inactive in 2008) were included to provide an assessment of baseline conditions at that drill centre. The RM approach can only be used to analyze stations re-sampled every year. For most variables, emphasis was on the 35 stations sampled in all five years (excluding station 31), which allowed a comparison to baseline (2000). However, ammonia, sulphide and sulphur were not measured in 2000, so analyses of those variables were conducted on the 39 stations sampled in 2004, 2005, 2006 and 2008. Reference stations 4 and 19, sampled in 2004, 2005 and 2006, were excluded from these four-year RM analyses because depths at these stations were extreme and would have a large influence on any analysis of depth effects. Similarly, station 31, which was sampled every year, was also excluded from RM analyses because the high HC and barium values noted in 2008 as a result of delineation drilling at K-03 would have affected distance relationships. For the RM analyses, distances were log-transformed, some Y variables were log-transformed, and depth was not transformed.

Multiple regression slopes were calculated for each year for stations included in RM analyses and were used to summarize general depth and distance trends. The multiple regression slopes for each X variable are adjusted for the effects of other X variables. When Y and X are log-transformed, the slopes are power functions. For example, a slope of 1 indicates that Y increased linearly with X and a slope of 0.5 indicates that Y increased with the square root (0.5^{th} power) of X. Overall distributions, medians (50^{th} percentiles), and 20^{th} and 80^{th} percentiles were used to assess net changes over time. The 20^{th} and 80^{th} percentiles were calculated using non-parametric methods (Gilbert 1987) since overall distributions were rarely normal (see Section 5.4 for data distributions). Appendix B-5 discusses multiple regression slopes and non-parametric percentiles in more detail.

For selected *Y* variables, threshold distances (X_T) were compared among 2004, 2005, 2006 and 2008 to qualitatively assess if estimated zones of influence or the spatial extent of effects changed. These analyses included all stations sampled within each year, except that 2008 data from station 31 were excluded. The distance measure used was distance from the nearest active drill centre (Northern and Southern drill centres in 2004; Northern, Central and Southern drill centres in 2005, 2006 and 2008).

Non-parametric r_s between *Y* variables and distance from the nearest active drill centre were also calculated within each year, and provided as a general summary. The Northern and Southern drill centres were assumed to be “active” for calculation of distance correlations for 2000, since those two drill centres were the first to be active in the next sample year (2004).

As mentioned in Section 1.8, six stations near the North Amethyst drill centre were sampled in 2007, and again in 2008. Limited RM and other analyses were conducted on 2007 data, with methods and results provided in Appendix B-5.

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 variables:

1. sediment particle size and total organic carbon (TOC) content;
2. known constituents of drill muds and indicators of drilling activity ($>C_{10}$-C_{21} HCs and barium);
3. metals other than barium; and
4. other variables (ammonia, sulphide, sulphur, redox and $>C_{21}$-C_{32} HCs).

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. WBMs and 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.

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. Barium, as barium sulphate (barite), is a constituent of both WBMs and SBMs, but barium also occurs naturally in marine sediments. Baseline barium levels at White Rose ranged from 120 to 210 mg/kg.

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 are 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.

$>C_{21}$-C_{32} HCs are not a 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.

5.3.2.2 Statistical Analysis

For analysis of 2008 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 hockey-stick models were also tested for $>C_{10}$-C_{21} HCs and barium concentrations, which were strongly affected by distance from the drill centres.

Barium, fines, 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 35 stations, excluding station 31, sampled in all five years (2000, 2004, 2005, 2006, 2008). $>C_{10}$-C_{21} HCs (not detected in 2000), and ammonia and sulphur (not measured in 2000), were also analyzed in RM regression models based on the 39 stations sampled in the four EEM years (stations 4, 19 and 31 excluded). All Y variables except Metals PC1 were log-transformed. Estimates of the zones of influence (threshold distances: X_T) based on concentrations of $>C_{10}$-C_{21} HCs and barium were also compared among the four EEM years (2004 to 2006; 2008).

Principal Components Analysis (PCA[10]) was used to derive a summary measure of concentrations of metals other than barium for analyses of 2008 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 years.

In 2000 and 2004, RDLs for $>C_{10}$-C_{21} HCs were reported as 0.25 mg/kg. In 2005, 2006 and 2008, 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

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[10] 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 standard deviation (SD) = 1. Metal concentrations were log-transformed prior to conducting the PCA. The sediment metals PCA was based on data from all sample years, including 2007 data from six stations near the North Amethyst drill centre, because comparisons were made among years. The sediment metal and other PCAs in this report were based on correlation rather than covariance matrices.

change. For parametric statistical analyses, all concentrations less than the RDL of 0.3 mg/kg were set at ½ that RDL (0.15 mg/kg).

In 2004 and 2005, there were five sulphur values less than the RDL of 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%). All values less than 0.02% in 2006 were set at 0.02% for comparisons among years in parametric tests.

5.3.3 Toxicity

In 2008 and in previous years, no analyses of results for bacterial toxicity tests were conducted because all samples were non-toxic, with IC_{50}s greater than the highest concentration tested (98,600 mg/kg in 2000; 197,000 mg/kg in subsequent years).

For 2008, rank correlations between amphipod survival in toxicity tests versus distance from the nearest active drill centre and sediment physical and chemical characteristics were calculated. A qualitative comparison of amphipod survival among years was also conducted for all stations with less than 70% survival in at least one year. Samples with 70% or greater survival cannot be considered toxic based on comparison to control sediments, even if survival is 100% in those control sediments, because the reduction in survival will not be greater than 30%. Samples with 70% survival or greater have also never been classified as toxic based on comparison to Reference sediments.

5.3.4 Benthic Community Structure

5.3.4.1 Groups of Variables

In 2008, three summary benthic community variables were analyzed in detail:

1. total abundance (number of organisms collected per station);
2. standing crop (wet weight of organisms collected per station); and
3. taxonomic richness (number of taxa collected per station).

Abundances of the following four taxa were also analyzed in detail: Paraonidae (Polychaeta), Spionidae (Polychaeta), Tellinidae (Bivalvia) and Amphipoda. Paraonidae, Spionidae and Tellinidae were the three most abundant taxa. Although Amphipoda were relatively rare, they were included in analyses of individual taxa because they are generally considered sensitive and were also reduced in abundance near drill centres and at high $>C_{10}$-C_{21} HC concentrations in past years (Husky Energy 2007).

Prior to 2008, overall community composition measures (axis scores) based on Non-metric Multidimensional Scaling (NMDS) were also analyzed in detail (Husky Energy 2007). Effects on overall community composition are important, and NMDS is a useful non-parametric multivariate analogue of PCA generally preferred for benthic invertebrate community analysis (Clarke 1993). NMDS was conducted on benthic invertebrate community data for 2008 and past years based on relative (%) abundances of all taxa, and results are provided in Appendix B-5 and also summarized in Section 5.5.3. NMDS was excluded from more detailed analyses because:

1. scores for individual NMDS axes can be difficult to interpret and/or are not easily adapted to the univariate analyses used for other summary measures and individual taxon abundances;

2. previous NMDS analyses generally demonstrated that apparent project-related effects on community composition were largely related to abundances of the dominant taxa, especially Paraonidae (Husky Energy 2007); and

3. the two-dimensional qualitative graphical approach for analysis of NMDS used in Husky Energy (2007) and Appendix B-5 is probably the most effective approach for identifying project-related effects on overall community composition.

Simpson's diversity (*D*) and evenness (*E*) were analyzed in past White Rose EEM reports (Husky Energy 2005, 2006, 2007) but were not analyzed in 2008. These past analyses indicated that diversity, and especially evenness, were insensitive to project effects. There are also statistical problems associated with analyzing diversity and evenness, which are derived from richness and abundance (Green 1979).

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[11].

5.3.4.2 Statistical 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 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, 2006, 2007 and 2008. 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 used, especially for juveniles, and differences in the treatment of uncertain identifications. Appendix B-4 provides abundances of lower-level taxa (usually species) for the 2007 and 2008 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*) is the number of taxa (families) per station. NMDS was based on relative (%) abundances of taxa (families) (see Appendix B-5 for details).

Summary statistics for invertebrate community variables were calculated over all 47 stations sampled in 2008. Rank correlations (r_s) among the variables were also calculated. Rank correlations between invertebrate community variables versus

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

sediment physical and chemical characteristics and amphipod survival in laboratory toxicity tests were also calculated for 2008 samples.

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 (2000, 2004, 2005, 2006 and 2008). Threshold distances for selected variables were compared among EEM years (2004, 2005, 2006 and 2008). A comparison to those few stations sampled around the North Amethyst drill centre in 2007 is provided in Appendix B-5.

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

5.3.4.3 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 four EEM program years (2004, 2005, 2006 and 2008). 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 chemical X variable may also be a simpler and better predictor of community Y variable values than one or more distance X variables.

The first step was to calculate and compare rank correlations between invertebrate community variables (Y) and $>C_{10}$-C_{21} HCs (X) among the four 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. For parametric analyses, $>C_{10}$-C_{21} HC concentrations and all community variables were log transformed.

5.4 Results

5.4.1 Physical and Chemical Characteristics

Appendix B-3 provides summary statistics for sediment physical and chemical characteristics occurring at or above RDL in 2000, 2004, 2005, 2006 and 2008. 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, 2006 and 2008, 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 were aluminum, barium, chromium, iron, lead, manganese, strontium, uranium, vanadium and zinc.

5.4.1.1 Analysis of 2008 Data

Correlations Within and Among Groups of Variables (2008)

Sediments sampled in 2008 and previous years were predominantly (usually more than 90%) sand. 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 was usually the major non-sand component by weight in 2008 sediment samples, and varied among stations from less than 0.1 to 4.6%. Fines content varied from 0.7 to 2.4%. Gravel and fines content were strongly and significantly negatively correlated with sand content, and weakly and not significantly positively correlated with each other (Table 5-4). Based on these correlations, sand was considered redundant and eliminated from further analyses.

Table 5-4 Spearman Rank Correlations (r_s) Among Particle Size Categories and TOC (2008)

	% Fines	% Sand	% Gravel
% Sand	**–0.560*****		
% Gravel	0.201	**–0.888*****	
TOC	0.385**	–0.102	–0.103

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold).
- $n = 47$ stations.

TOC levels in sediments collected in 2008 were low (0.6 to 2.1 g/kg, or 0.06 to 0.21%) and did not vary widely among stations. TOC levels were weakly but significantly positively correlated with fines content (Table 5-4). Organic matter (i.e., TOC) should be associated with finer particles but the expected positive correlation between the two variables has rarely been strong over the narrow range of TOC and fines values at White Rose.

Concentrations of the two primary drill mud constituents, >C_{10}-C_{21} HCs and barium, were strongly and significantly positively correlated (Table 5-5). This correlation was expected since both WBMs and SBMs were used at all drill centres and barium is a constituent of both types of muds. >C_{21}-C_{32} HC concentrations were positively correlated with concentrations of both >C_{10}-C_{21} HCs and barium. >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 concentrations of >C_{21}-C_{32} HCs were low (less than 0.3 to 15 mg/kg dry weight).

Table 5-5 Spearman Rank Correlations (r_s) Among HC and Barium Concentrations (2008)

	>C_{10}-C_{21} HCs	Barium
Barium	**0.816*****	
>C_{21}-C_{32} HCs	**0.750*****	**0.532*****

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold).
- $n = 47$ stations.

Concentrations of the eight other frequently detected metals in sediments collected in 2000, 2004, 2005, 2006, 2007 and 2008 were positively correlated with each other and with the first Principal Component (Metals PC1) derived from these concentrations (Table 5-6). Metals PC1 accounted for more than 60% 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 further analyzed.

Table 5-6 Correlations (*r*) Between Concentrations of Frequently Detected Metals and PCs Derived from these Concentrations (2000, 2004, 2005, 2006, 2007 and 2008)

Metal	**Correlation (*r*) with:**		
	PC1	**PC2**	**PC3**
Iron	**0.920**	0.267	0.076
Manganese	**0.865**	0.343	0.058
Aluminum	**0.827**	–0.036	0.072
Strontium	**0.801**	**–0.540**	0.039
Vanadium	**0.792**	0.219	0.153
Chromium	**0.779**	0.168	0.188
Uranium	**0.672**	0.092	**–0.729**
Lead	**0.604**	**–0.739**	0.020
% variance	62.1	13.9	7.6

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* = 258 stations: 47 in 2008; 6 in 2007; 59 in 2006; 44 in 2005, 56 in 2004; 46 in 2000.

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 5-7). However, the presumably natural correlation between barium concentrations and concentrations of other metals was weaker than the project-related correlation between barium and >C_{10}-C_{21} HC concentrations (compare correlations in Tables 5-5 and 5-7). Metals PC1 scores were less strongly correlated with >C_{10}-C_{21} HCs than with barium.

Table 5-7 Spearman Rank Correlations (r_s) Among Chemistry Variables (2008)

	>C_{10}-C_{21} HCs	**Barium**	**Metals PC1**	**Ammonia**	**Sulphur**	**Sulphide**
Metals PC1	0.255	**0.493*** **				
Ammonia	–0.086	–0.204	–0.014			
Sulphur	0.389**	0.429**	0.191	–0.025		
Sulphide	0.393**	0.301*	0.085	–0.052	0.386**	
Redox	–0.014	0.047	0.156	0.154	–0.107	–0.154

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold).
  n = 47 stations.

Ammonia levels were uncorrelated with concentrations of >C_{10}-C_{21} HCs, barium, metals, sulphur, sulphide and redox (Table 5-7). Sulphur levels increased with increasing concentration of >C_{10}-C_{21} and barium, suggesting that drilling and drill cutting discharges elevated sulphur concentrations. Sulphide concentrations were also significantly positively correlated with concentrations of >C_{10}-C_{21} and barium. In 2008, redox levels were uncorrelated with concentrations of all chemistry variables.

In 2008, concentrations of >C_{10}-C_{21} HCs, barium and other metals were significantly positively correlated with sediment fines content (Table 5-8). Concentrations of metals (i.e., Metals PC1), ammonia and sulphur were significantly positively correlated with sediment TOC content. Except for redox, values of the sediment chemistry variables would be expected to be higher in finer more organic sediments, and all correlations in

Table 5-8 were positive (i.e., in the expected direction). However, the correlations were relatively weak (all $r_s < 0.5$, and none significant at $p \leq 0.001$) because fines and TOC levels were low and varied little among stations.

Table 5-8 Spearman Rank Correlations (r_s) Between Chemistry Variables, Fines and TOC (2008)

Chemistry Variable	**Correlation (rs) with:**	
	% Fines	**TOC**
>C_{10}-C_{21} HCs	0.320*	0.266
Barium	0.355*	0.288
Metals PC1	0.442**	0.463**
Ammonia	0.098	0.369*
Sulphur	0.166	0.305*
Sulphide	0.149	0.217
Redox	0.069	0.085

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold).
n = 47 stations.

Depth and Distance Effects (2008)

Table 5-9 provides results of rank-rank regressions of sediment physical and chemical characteristics on depth and distance from the nearest active drill centre. Station 31, within 0.4 km of a delineation well (K-03) but approximately 4 km from the nearest (Northern) drill centre, was excluded. 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 the other *X* variable held constant. For bivariate rank-rank regressions on a single *X* variable, *r* is equal to the Spearman rank correlation (r_s).

Table 5-9 Results of Rank-Rank Regressions of Physical and Chemical Characteristics on Depth and Distance from the Nearest Active Drill Centre (Min *d*) (2008)

***Y* Variable**	***X*=Depth & Distance from Nearest Drill Centre (Min *d*)**			***X*=Depth**	***X*=Min *d***
	Overall *R*	**Partial *r***		**$r=r_s$**	**$r=r_s$**
		Depth	**Min *d***		
>C_{10}–C_{21} HCs	**0.910*****	**–0.501*****	**–0.902*****	–0.280	**–0.878*****
Barium	**0.839*****	–0.023	**–0.839*****	–0.050	**–0.839*****
% fines	0.169	0.011	–0.169	0.004	–0.169
% gravel	0.221	0.054	0.213	0.062	0.215
TOC	0.206	–0.196	–0.058	–0.198	–0.065
Metals PC1	0.211	–0.128	–0.165	–0.133	–0.170
Ammonia	0.365*	–0.289	0.254	–0.270	0.232
Sulphur	0.380*	–0.053	–0.375*	–0.066	–0.377*
Sulphide	0.359	–0.171	–0.318*	–0.177	–0.321*
Redox	0.032	–0.017	0.027	–0.016	0.027

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold).
- Min *d* = distance from the nearest active drill centre.
- n = 46 stations; station 31 excluded.
- All *Y* and *X* variables were rank-transformed.

>C_{10}-C_{21} HCs and Barium (2008)

In 2008, >C_{10}-C_{21} HC and barium concentrations decreased significantly with distance from the nearest active drill centre (negative r or r_s in Table 5-9). Partial r for distance in the multiple regressions were similar to r (=r_s for rank-rank regression) for bivariate regressions on distance. Depth effects, unadjusted for distance effects, were not significant. However, depth effects adjusted for distance effects (partial r) were significant for >C_{10}-C_{21} HCs, with concentrations decreasing with increasing depth. Any depth effects on >C_{10}-C_{21} HCs in 2008 were small relative to the strong distance effects, and depth effects were not evident in the multi-year comparisons (Section 5.4.1.2).

Adding a threshold distance (X_T) significantly reduced error variances relative to bivariate log-log regressions for >C_{10}-C_{21} and barium concentrations on distance to the nearest active drill centre (Table 5-10). The hockey-stick regressions (solid lines) and estimated threshold distances (vertical dashed lines) are provided in Figure 5-6; individual station values are colour-coded based on the closest drill centre (including the inactive North Amethyst drill centre). >C_{10}-C_{21} HC concentrations reached estimated background (blade) levels of 0.15 mg/kg dry weight (effectively, concentrations less than the RDL of 0.3 mg/kg) at 10.4 km from the nearest active drill centre. Barium concentrations reached estimated background levels (168 mg/kg dry weight) at 2.4 km from the nearest active drill centre. The estimated background concentration of 168 mg/kg was approximately the mid-point of baseline (2000) values of 120 to 210 mg/kg.

Table 5-10 Parametric Distance Models for >C_{10}-C_{21} HCs and Barium (2008)

Result/Estimate	**>C_{10}-C_{21} HCs**	**Barium**
Bivariate Regression		
R	**–0.840*****	**0.692*****
Hockey-stick (Threshold) Model		
Overall *R*	**0.856*****	**0.762*****
p for adding threshold (X_T)	0.046	0.002
antilog *a* (blade or background concentration; mg/kg dry weight)	0.15	168
95% CI	0.06 to 0.39	144 to 196
b (slope of shaft)	–1.67	–0.72
95% CI	–2.02 to –1.31	–1.01 to –0.44
antilog X_T (km)	10.4	2.4
95% CI	5.2 to 20.9	1.5 to 3.8

Notes:
- $^*p \le 0.05$; $^{**}p \le 0.01$; $^{***}p \le 0.001$ (in bold).
- Bivariate regressions = regressions of Y on distance to the nearest active drill centre (X).
- X variables for the hockey-stick model were distance from the nearest active drill centre plus the threshold distance (X_T).
- All Y and X variables were log-transformed.
- Station 31 was excluded.

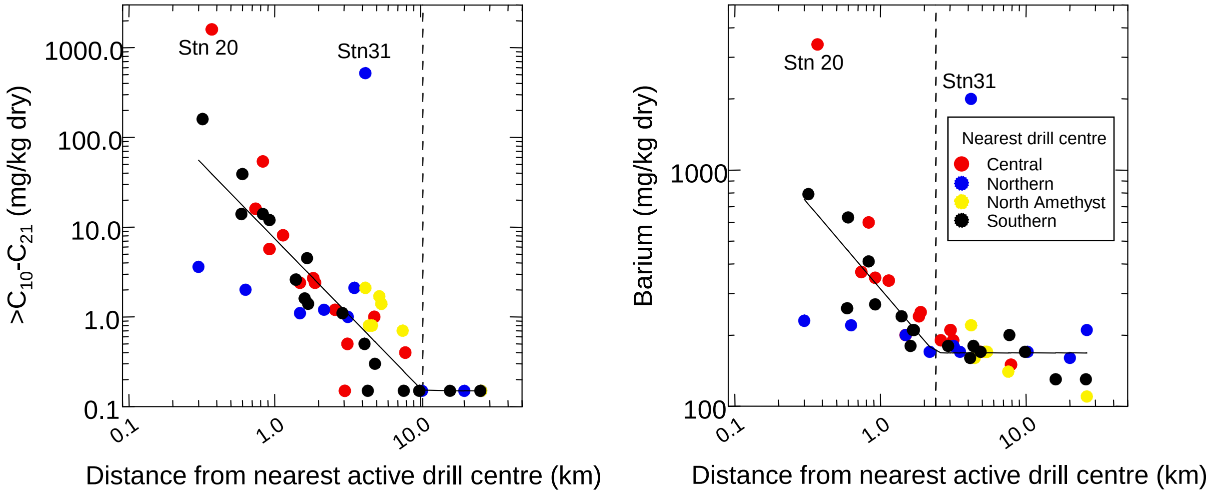

Figure 5-6 $>C_{10}$-C_{21} HC and Barium Concentrations versus Distance from the Nearest Active Drill Centre (2008)

Estimates of threshold distances or zones of influence based on concentrations of $>C_{10}$-C_{21} HCs and barium should be regarded as approximate (i.e., within the 95% confidence intervals (CIs) in Table 5-10). The lower ends of the CI (lower 95% Confidence Limits or CL) provide useful estimates of the minimum extent of zones of influence. In 2008, the zone of influence based on $>C_{10}$-C_{21} HC and barium concentrations would be at least 5 km and 1.5 km, respectively. Estimated zones of influence are also more robust and precise when they occur in the mid-range of distances (i.e., 1 to 5 km from drill centres) (see Appendix B-5 for further discussion). In 2008, 95% CI for the estimated zone of influence base on barium concentrations (2.4 km) were 1.5 to 3.8 km, a less than 3-fold range and within the mid-range of distances sampled (Figure 5-6). Approximately half the stations were outside the estimated zone of influence. In contrast, 95% CI for the estimated zone of influence based on $>C_{10}$-C_{21} HC concentrations (10.4 km) were 5.2 to 20.9 km (a 4-fold range), the upper end of that range approached the maximum distances sampled, and only five (of 46) stations were outside the estimated zone of influence.

Figure 5-6 also indicates that the hockey-stick (and any other) models did not provide a good fit at distances less than 1 km and especially less than 0.5 km. At those distances, variances among stations were wide, differences among drill centres and localized differences around each drill centre were important. In 2008, $>C_{10}$-C_{21} and barium concentrations were lower at stations within 1 km of the Northern drill centre than at stations closer to the Central and Southern drill centres. $>C_{10}$-C_{21} and barium concentrations were also much higher at station 20 (0.37 km from the Central drill centre) than at other stations within 1 km of active drill centres (Figures 5-7 and 5-8), and much higher than any distance model would predict.

$>C_{10}$-C_{21} and barium concentrations at station 31, within 0.4 km of delineation well K-03, were higher than at every other station except station 20 and much higher than at nearby stations within 4 km of the Northern drill centre (Figures 5-6, 5-7 and 5-8). High $>C_{10}$-C_{21} and barium concentrations at this station can be attributed to the recent delineation drilling at K-03.

In 2008, >C_{10}-C_{21} HC concentrations at stations closest to the proposed North Amethyst drill centre (yellow symbols in Figure 5-6; also see Figure 5-7) and within 10 km of the Central and Southern drill centres (the two nearest active drill centres) were higher than expected based on distances from those two active drill centres. There may be a net directional effect of dispersion of >C_{10}-C_{21} HCs; the prevailing current is towards the south and the North Amethyst drill centre is south of the Central and Southern drill centres. The important point is that baseline >C_{10}-C_{21} HC concentrations near the North Amethyst drill centre were within the estimated zone of influence based on >C_{10}-C_{21} HC concentrations for the Central and Southern drill centres and were above an RDL of 0.3 mg/kg, which needs to be considered in any future assessment (Appendix B-5). In contrast, barium concentrations at stations closest to the proposed North Amethyst drill centre were within the baseline (2000) range of 120 to 210 mg/kg and those stations were outside the estimated zone of influence based on barium concentration for currently active drill centres.

Other Variables (2008)

In 2008, sulphur and sulphide were the only chemistry variables other than >C_{10}-C_{21} HCs and barium that decreased significantly with distance from the nearest active drill centre (Table 5-9). The highest sulphur and sulphide concentrations occurred at a few stations within 1 km of drill centres (Figure 5-9). Sulphur and sulphide levels were highest at station 20, and also higher at station 31, than at most other stations.

In past years, fines content has increased significantly with depth and has occasionally been greater within 1 km of drill centres than at more remote stations (Husky Energy 2005, 2006, 2007; see also Section 5.4.1.2). In 2008, neither depth nor distance effects were significant for fines content (Table 5-9). The highest fines content (2.4% dry weight) occurred at the deepest station (NE Reference station 4, 176 m depth and 26 km from the nearest drill centre) (Figure 5-9). Fines content was also higher at station 20 and station 31 than at other stations.

Ammonia concentrations decreased with depth and increased with distance from the nearest drill centre (Table 5-9), although the depth effects mask any distance effects in Figure 5-9. The highest ammonia concentration (21 mg N/kg dry weight) occurred at NE Reference station 4. Ammonia concentrations were also high (17 mg N/kg) at station 20, but lower at station 31 (1.6 mg N/kg) than at all but one other station.

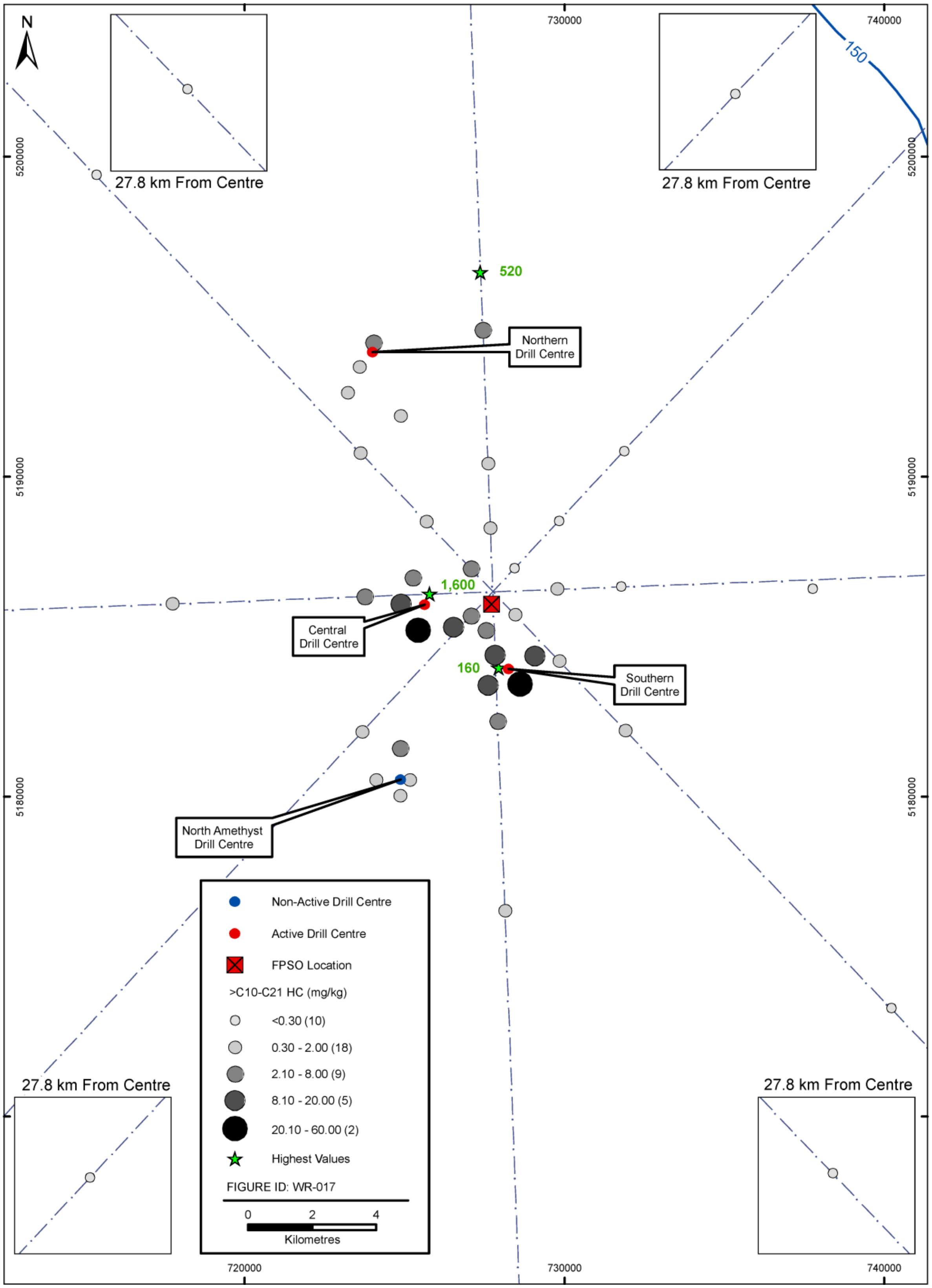

Figure 5-7 Spatial Distribution of >C_{10}-C_{21} HCs (2008)

Note: Highest values ($\log_{10}$ transformed) were identified as outliers by SPSS 11.5 software.

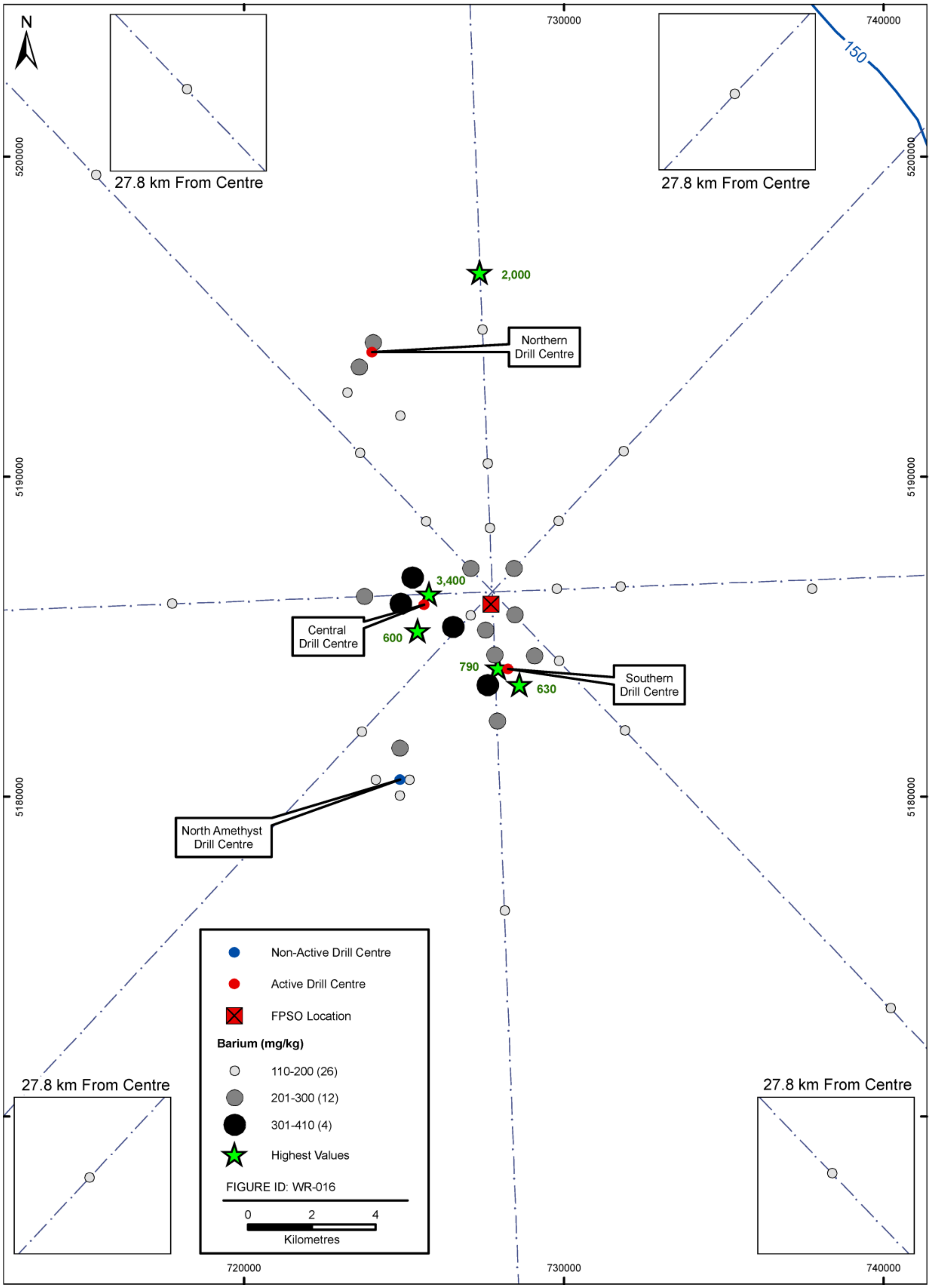

Figure 5-8 Spatial Distribution of Barium (2008)

Note: Highest values ($\log_{10}$ transformed) were identified as outliers by SPSS 11.5 software.

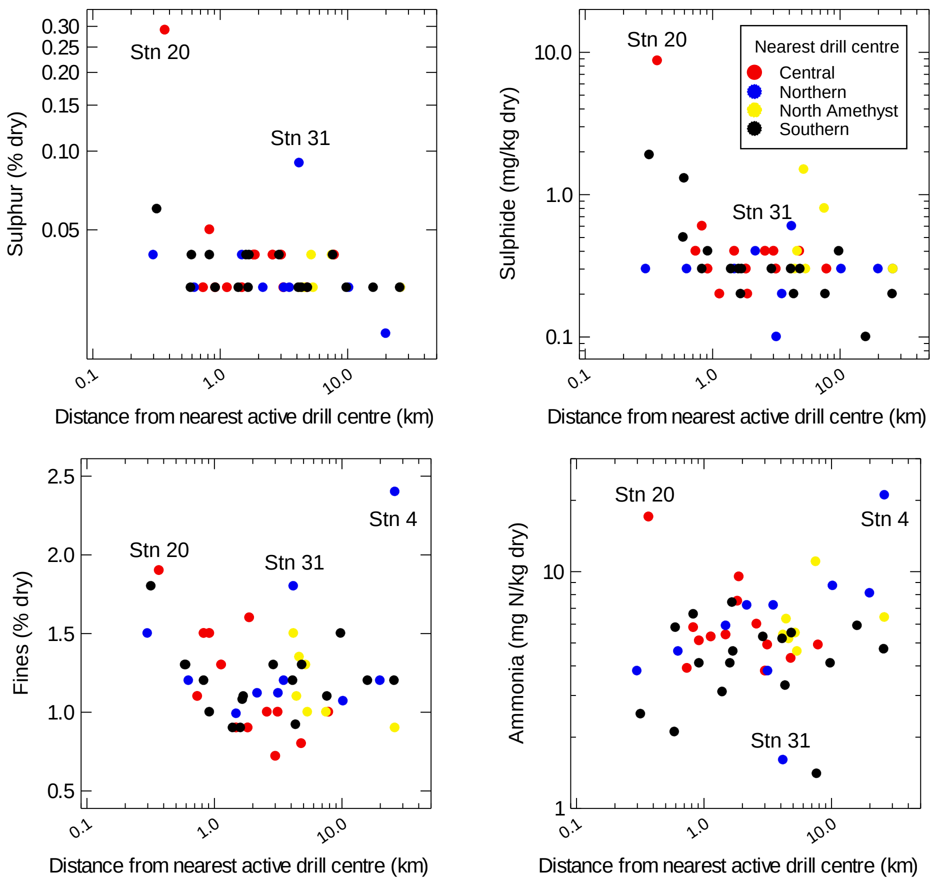

Figure 5-9 Sulphur and Sulphide Concentrations, Fines Content and Ammonia Concentrations versus Distance from the Nearest Drill Centre (2008)

5.4.1.2 Comparison Among Years (2000, 2004, 2005, 2006 and 2008)

Table 5-11 provides results of RM regression models comparing sediment physical and chemical characteristics among years. Baseline (2000) data were included for analyses of barium, fines, TOC and Metals PC1. Baseline data were not included for analyses of >C_{10}-C_{21} HCs, ammonia and sulphur because these were either not measured (ammonia and sulphur) or detected (HCs) in 2000. *X* variables analyzed were depth and distances (*d*) to the four drill centres. Results in Table 5-11 are given as *F* values, which can be considered measures of effect sizes. *F* values greater than 1 indicate added variance attributable to the term tested (see Appendix B-5 for further details). To assist interpretation:

1. The Among Stations terms test for depth or distance effects common to all years. Some Among Stations distance effects may be natural, especially for variables with baseline (2000) data included. The Among Stations Error 1 term tests for carry-over effects, or persistent differences among stations unrelated to depth or distance.

2. The Within Stations terms test for differences among years common to all or most stations (Year term) and changes in depth or distance relationships over time (Year × *X* terms). Table 5-11 provides the overall Within Years tests (i.e., tests for *any* differences among years), which can be broken down into more specific differences

or *contrasts* among subsets of years. Table 5-12 lists the contrast terms significant at $p \leq 0.05$. Appendix B-5 provides more complete results.

3. When Within Stations Year × X terms are significant, Among Stations results for the same X terms should be ignored unless F values are much higher. Significant Year × X terms indicate that relationships changed over time (i.e., that there was no relationship common to all years).

4. The RM regression models provided relatively powerful tests of effects from the Central and Southern drill centres. Most stations were located either closer to those two drill centres than to the other two drill centres or far from any drill centre. Drilling activity and drill cuttings discharges at those two centres have also extended over several years. Tests of effects from the Northern and especially North Amethyst drill centres were relatively weak. There were fewer stations close to those drill centres than to the other two centres. Drilling activity at the Northern drill centre has been less than at the Central or Southern drill centre and drilling has yet to occur at the North Amethyst drill centre.

Table 5-11 Results of RM Regression Analysis Comparing Sediment Physical and Chemical Characteristics Among Years

Term	**>C_{10}-C_{21} HCs**	**Barium**	**% Fines**	**TOC**	**Metals PC1**	**Ammonia**	**Sulphur**
Years Compared	**2004-06, 2008**	**2000, 2004-06, 2008**	**2000, 2004-06, 2008**	**2000, 2004-06, 2008**	**2000, 2004-06, 2008**	**2004-06, 2008**	**2004-06, 2008**
No. stations	39	35	35	35	35	39	39
Among Stations							
Depth	0.77	0.03	10.66**	2.73	0.03	0.16	0.09
Northern (N) *d*	4.33*	0.13	0.60	1.08	0.79	0.58	0.01
Central (C) *d*	5.68*	12.56**	2.21	0.08	4.71*	3.24	8.37**
Southern (S) *d*	**14.05*** **	8.04**	2.11	1.02	0.47	1.81	0.09
North Amethyst (NA) *d*	0.47	0.48	0.08	2.20	0.99	0.81	0.15
Error 1[1]	**8.48*** **	**3.39*** **	1.59*	1.38	1.37	0.79	2.23**
Within Stations							
Year	0.31	0.06	2.10	0.84	0.32	2.07	0.99
Year × Depth	0.34	0.08	2.75*	1.18	0.33	2.13	1.40
Year × N *d*	4.05**	0.26	3.93**	2.97*	0.97	1.33	2.32
Year × C *d*	**41.11*** **	**18.59*** **	4.19**	**9.87*** **	**4.98*** **	3.75*	**7.04*** **
Year × S *d*	5.74**	4.38*	1.80	0.47	2.81*	**6.60*** **	1.45
Year × NA *d*	0.77	0.36	0.28	2.61*	0.33	0.19	0.22

Notes:
- Appendix B-5 explains terms and tests in the RM regression model.
- *d* = distances from various drill centres.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold).
- 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 5-12 Significant ($p \le 0.05$) Within Stations Contrasts for RM Regression Analyses of Sediment Physical and Chemical Variables

Years Compared	$>C_{10}$-C_{21} HCs	Barium	% fines	TOC	Metals PC1	Ammonia	Sulphur
2000 vs 2004-06, 2008	Not tested	C _d_ (*) S _d_ (*)	None	N _d_ (*)	None	Not tested	Not tested
2004 vs 2005-06, 2008	N _d_ (**) **C _d_ (***)** S _d_ (**)	**C _d_ (***)** S _d_ (**)	C _d_ (*)	Depth (*) **C _d_ (***)** NA _d_ (*)	C _d_ (*) S _d_ (*)	None	N _d_ (*) C _d_ (**)
2005 vs 2006, 2008	None	**C _d_ (***)**	N _d_ (*) C _d_ (**)	C _d_ (**)	None	Depth C _d_ (**) **S _d_ (***)**	C _d_ (**)
2006 vs 2008	None	C _d_ (**)	N _d_ (*)	C _d_ (**)	C _d_ (*) S _d_ (*)	S _d_ (*)	None

Notes:
- Appendix B-5 explains Within Stations contrasts in RM regression.
- _d_ = distances from various drill centres.
- Significant _X_ (depth or _d)_ terms indicate that _Y-X_ relationships differed significantly among the years compared (i.e., these are Year × _X_ terms and tests).
- $*p \le 0.05$; $**p \le 0.01$; $***p \le 0.001$ (in bold).

Three general conclusions can be made from the RM regression results in Tables 5-11 and 5-12. First, Among and Within Stations terms and tests for distance from the inactive North Amethyst drill centre (NA _d_) were not significant for any variable except TOC. Therefore, there was little or no evidence for any overall natural distance gradients or changes in gradients over time for the North Amethyst drill centre, once adjustments were made for depth effects and effects from other active drill centres. In other words, results indicated that the North Amethyst drill centre was inactive. Appendix B-5 provides a comparison of 2007 versus 2008 chemical and physical characteristics for stations nearest the North Amethyst drill centre, which indicated that those characteristics have not changed recently.

Second, the overall Within Stations Year × Central _d_ terms and one or more associated contrasts were significant for every variable. Therefore, distance gradients for the Central drill centre changed over time, although those changes were not necessarily project effects (see Sections on _>C_{10}-C_{21} HC and Barium_ and _Other Variables_, below).

Third, the overall Within Stations Year term and associated contrasts were not significant for any variable. Therefore, there were no significant and presumably natural changes over time common to all or most stations. Instead, changes were restricted to a few stations, usually near drill centres. In statistical terms, it was usually the 80th (or more extreme) percentiles that changed over time rather than medians or lower (e.g., 20th) percentiles (see Sections on _>C_{10}-C_{21} HC and Barium_ and _Other Variables_, below).

Results for specific variables are considered in detail below. The focus was on significant overall depth and distance gradients, and on significant changes in those gradients over time. Plots of multiple regression slopes for each year versus time were used to summarize general trends in depth and distance effects. The multiple regression slopes for depth and each distance variable adjust for the effects of other _X_ variables (see Appendix B-5 for further details). Overall changes in variable values over time were summarized in plots of distributions of individual station values, medians, 20th percentiles and 80th percentiles versus year. Spearman rank correlations (r_s) with distance from the nearest active drill centre versus year were also provided as a general summary of net distance effects (or their absence).

<C_{10}-C_{21} HC and Barium

>C_{10}-C_{21} HCs were not detected in baseline (2000) (at a RDL of 0.3 mg/kg dry weight), so the occurrence of concentrations greater than RDL in EEM years can be considered evidence of project effects. >C_{10}-C_{21} HC concentrations also decreased with distance from the Northern, Central and Southern drill centres after drilling began at those drill centres.

>C_{10}-C_{21} HC distance gradients for the Northern, Central and Southern drill centres changed significantly and substantially between 2004 and 2005. The Within Stations distance terms (Year × *d*) were significant at $p \leq 0.01$ for all three drill centres (Table 5-11), but only the 2004 versus 2005-06 and 2008 contrasts were significant (i.e., no contrasts comparing years after 2004 were significant; Table 5-12). In 2004, >C_{10}-C_{21} HC concentrations decreased substantially with distance from the Northern and especially Southern drill centres (see multiple regression slopes in Figure 5-10; slopes for 2000 can be assumed to be 0). Those gradients and slopes decreased in strength in subsequent years, with most of the changes occurring between 2004 and 2005. In contrast, >C_{10}-C_{21} HC concentrations increased with distance from the Central drill centre in 2004, prior to drilling (positive slope in Figure 5-10), then decreased with distance in subsequent years, after drilling began. More details on interpretation of Figure 5-10 and similar figures are provided in Appendix B-5.

Median (50th percentile) >C_{10}-C_{21} HC concentrations for the 39 stations considered in the multi-year comparison were approximately 1 mg/kg dry weight in all years (Figure 5-11). 80th percentiles were approximately 10 mg/kg in all EEM years. 20th percentiles were greater than or equal to RDL of 0.3 mg/kg in 2004 and 2005 when less than 20% of concentrations were less than RDL (treated as 0.15 mg/kg for analysis and plotting in Figure 5-11). In 2006 and 2008, approximately 20% (8 of 39) concentrations were less than RDL and 20th percentiles were 0.15 mg/kg. These results suggest that large-scale or net >C_{10}-C_{21} HC contamination has not changed substantially over time.

RM regression results for barium were qualitatively similar to, but generally weaker than, results for >C_{10}-C_{21} HCs. Barium, as a constituent of both WBMs and SBMs, was a reasonable indicator of drilling activity and drill cuttings discharges and concentrations have generally decreased with increasing distance from active drill centres. However, detectable and variable background barium concentrations (approximately 100 to 200 mg/kg dry weight, based on baseline and Reference values) limited the distances at which project related changes could be separated from natural variance.

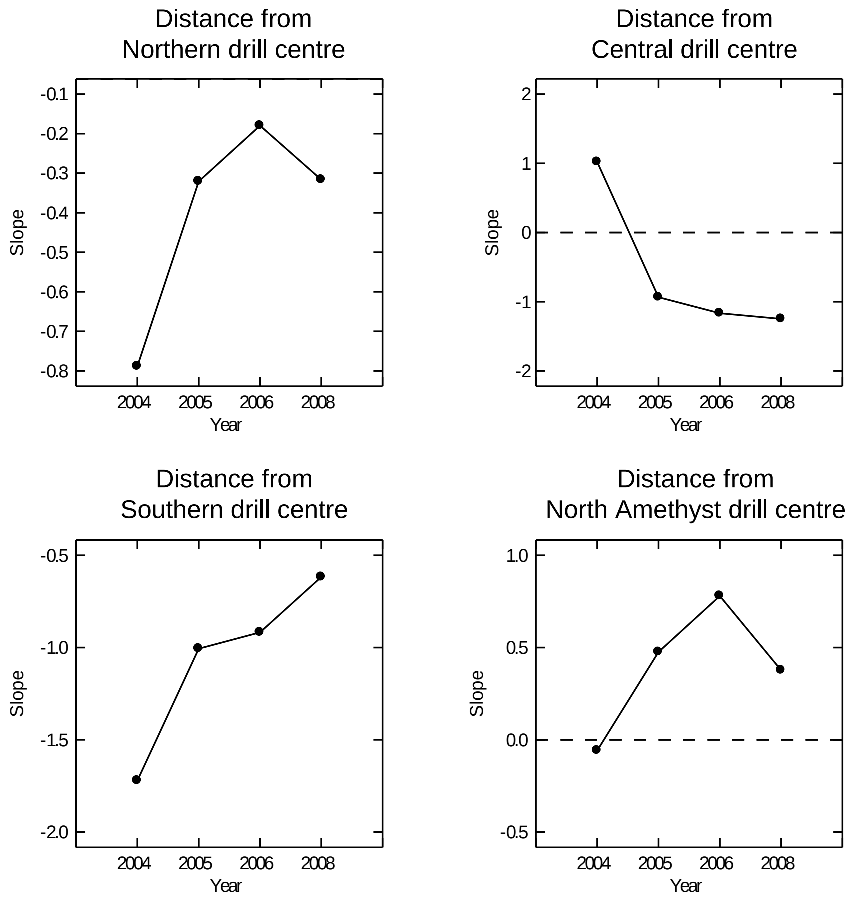

Figure 5-10 **Multiple Regression Slopes for >C_{10}-C_{21} HC Concentrations versus Distances from the Four Drill Centres for the 39 Stations Sampled in 2004, 2005, 2006 and 2008**

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

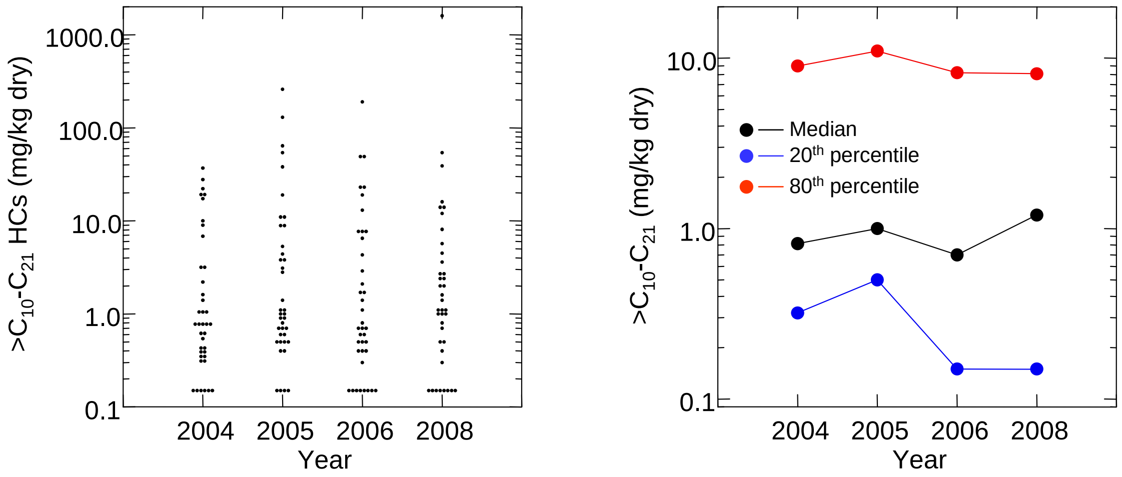

Figure 5-11 **>C_{10}-C_{21} HC Concentrations for the 39 Stations Sampled in 2004, 2005, 2006 and 2008**

Note: The X axes on these figures are not linear.

There was no evidence of project effects from the Northern drill centre on barium concentrations for the 35 stations included in RM regression analyses. The Among Stations term and the overall Within Stations term and associated contrasts were not significant for distance from the Northern drill centre (Tables 5-11 and 5-12). Distance gradients and specifically decreases in concentrations with distance in EEM years have generally been weak or non-existent. Barium concentrations decreased slightly and presumably naturally with distance in 2000, and that distance gradient did not get stronger in 2004 (after drilling began) or in subsequent years (see regression slopes in Figure 5-12). Barium concentrations greater than 250 mg/kg have never occurred within 2 km of the Northern drill centre, even at stations excluded from the RM regressions (Figure 5-6 provides 2008 data and Husky Energy 2007 provides data for previous years).

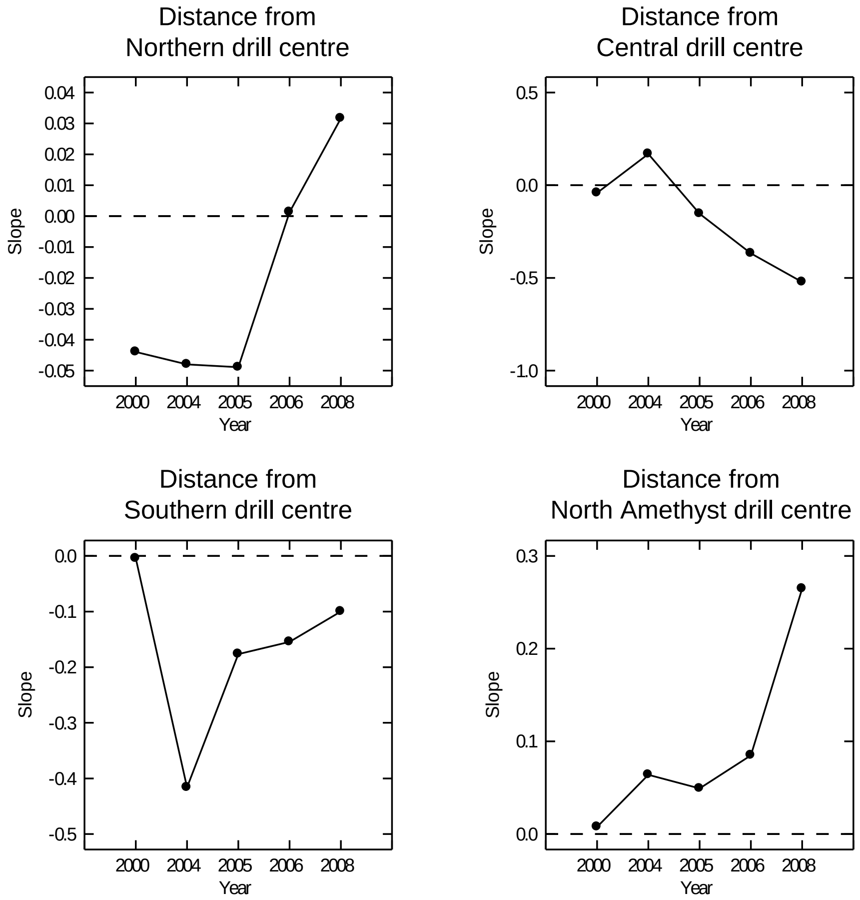

Figure 5-12 **Multiple Regression Slopes for Barium Concentrations versus Distances from the Four Drill Centres for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008**

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

In contrast, there was clear evidence of changes in barium distance gradients for the Central and Southern drill centres after drilling began at those drill centres. The overall Within Stations terms and several associated contrasts were significant for distances from those two drill centres (Tables 5-11 and 5-12). In 2000 and 2004, prior to the start of drilling at the Central drill centre, barium concentrations were unrelated or weakly positively correlated with distance from the drill centre (Figure 5-12). After drilling began, distance slopes for 2005, 2006 and 2008 were negative (i.e., barium concentrations decreased with distance) with slopes and gradients increasing in strength over time. The changes in barium distance gradients for the Central drill centre after 2005 were significant, as indicated by the significant 2005 versus 2006, 2008 and 2006 versus 2008 contrasts in Table 5-12.

In 2000 (baseline), there was no barium distance gradient for the Southern drill centre (slope = 0 in Figure 5-12). After drilling began, barium concentrations decreased with distance from the Southern drill centre (negative slopes for 2005. 2006 and 2008). The largest changes in multiple regression slopes and distance gradients occurred between 2000 and 2004 after drilling began and distance gradients were first evident, and between 2004 and 2005 when regression slopes and gradients decreased in strength (see Year × Southern *d* contrasts in Table 5-12).

Most barium concentrations in 2004 and later EEM years at the 35 stations included in RM regression analyses were within the baseline (2000) range of approximately 100 to 200 mg/kg dry weight (Figure 5-13). Median (50th percentile) and 20th percentile concentrations were also similar from 2000 to 2006 and increased slightly in 2008. However, 80th percentiles progressively increased over time. Therefore, changes in barium concentrations over time represented localized and/or small-scale changes in extremes occurring at a few stations (usually near drill centres) rather than larger-scale changes occurring at most stations at intermediate distances (i.e., 2 to 10 km) from drill centres.

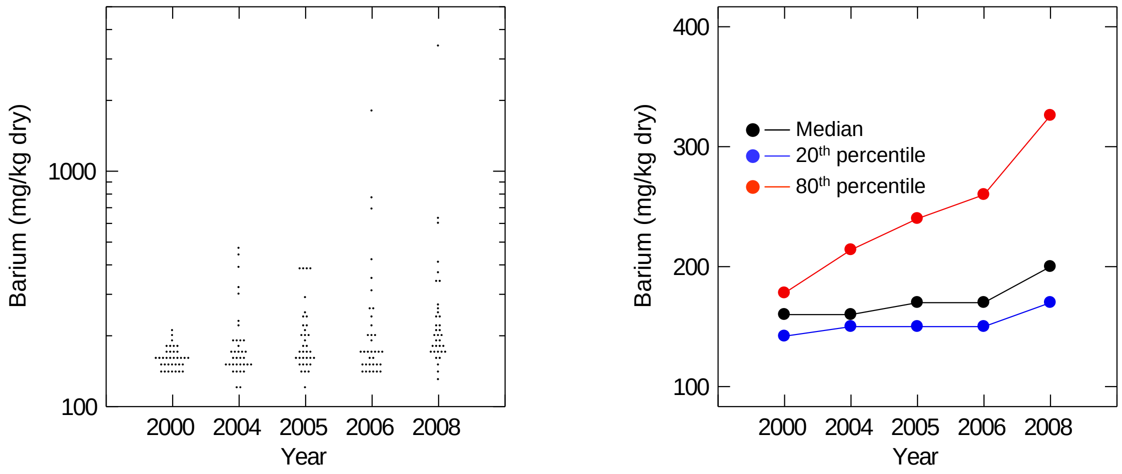

Figure 5-13 Barium Concentrations for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Note: The X axes on these figures are not linear.

Table 5-13 provides estimates of threshold distances or zones of influence based on >C_{10}-C_{21} HCs and barium concentrations for all stations sampled in each year after drilling began. The distance measure (*X*) used was distance from the nearest active drill centres, with active drill centres changing over time as noted. All hockey-stick or threshold distance models were significant at $p \leq 0.001$, as were simpler bivariate log-log regressions. In other words, there were always highly significant distance relationships for >C_{10}-C_{21} HCs and barium. The important issues were whether a zone of influence could or should be estimated, and if so, whether estimated zones of influence (i.e., the spatial extent of contamination) changed over time.

Table 5-13 Results of Hockey-stick (Threshold) Regressions on Distance from the Nearest Active Drill Centre for >C_{10}-C_{21} HCs and Barium (2004, 2005, 2006 and 2008)

Result/ Estimate	>C_{10}-C_{21} HCs				Barium			
	2004	**2005**	**2006**	**2008**	**2004**	**2005**	**2006**	**2008**
Overall *R*	**0.824*****	**0.876*****	**0.887*****	**0.856*****	**0.776*****	**0.772*****	**0.815*****	**0.615*****
p for adding threshold	**<0.001**	0.02	**<0.001**	0.05	**<0.001**	0.01	**<0.001**	<0.01
Background value (mg/kg dry weight)	0.26	0.20	0.34	0.15	156	149	156	168
Slope of shaft	–1.83	–1.74	–2.07	–1.67	–0.62	–0.39	–1.00	–0.72
Threshold distance (km)	6.3	8.9	5.9	10.4	2.4	3.6	1.9	2.4
95% CI	4.1 to 9.7	4.9 to 16	4.2 to 8.5	5.2 to 20.9	1.6 to 3.5	2.1 to 6.2	1.4 to 2.6	1.5 to 3.8

Notes:
- $^{*}p \leq 0.05$; $^{**}p \leq 0.01$; $^{***}p \leq 0.001$ (in bold).
- *X* was distance from the nearest active drill centre (Northern, Southern in 2004; Northern, Central, Southern in 2005, 2006 and 2008).
- *n* = 56 stations in 2004, 44 stations in 2005, 59 stations in 2006 and 46 stations in 2008.
- All variables were log-transformed.

Adding threshold distances has always significantly reduced error variances for the >C_{10}-C_{21} HCs and barium (Table 5-13). However, 95% CI have generally been wide and overlapped considerably among years, especially for >C_{10}-C_{21} HCs. Therefore, estimated zones of influence should be considered similar among years. Over the four sample years, estimated zones of influence based on >C_{10}-C_{21} HC and barium concentrations were approximately 6 to 10 km and 2 to 4 km, respectively. The lower limits of the 95% CI (lower 95% Confidence Limits or CL) have been relatively consistent over time and can be used as minimum estimates of zones of influence. Therefore, the estimated zone of influence based on >C_{10}-C_{21} HC and barium concentrations would be at least 4 to 5 km and 1.5 to 2 km, respectively.

In every EEM year, the estimated zones of influence based on >C_{10}-C_{21} HC concentrations exceeded estimated zones of influence based on barium concentrations (Table 5-13). In other words, detectable >C_{10}-C_{21} HC contamination was always spatially more extensive than detectable barium contamination. Estimated zones of influence and 95% CI based on barium concentrations were within the mid-range of distances sampled (1 to 5 km). In contrast, the lower CI for zones of influence based on >C_{10}-C_{21} HCs were towards the upper end of that range and upper CI approached or exceeded 10 km.

Figure 5-14 provides non-parametric Spearman rank correlations (r_s) between >C_{10}-C_{21} HC and barium concentrations and distance from the nearest active drill centre for each sample year, based on all stations sampled (except station 31 in 2008). Distance correlations for >C_{10}-C_{21} HCs in 2000, prior to drilling, were assumed to be 0 since all concentrations at the 46 stations sampled were less than the RDL of 0.3 mg/kg dry weight. For barium in 2000, the Northern and Southern drill centres were considered "active" so results are most comparable to 2004 when those drill centres were first active. Table 5-13 provides sample sizes for each year. For those sample sizes:

1. $|r_s| > 0.3$ are significant at $p < 0.05$;
2. $|r_s| > 0.4$ are significant at $p < 0.01$; and
3. $|r_s| > 0.5$ are significant at $p < 0.001$.

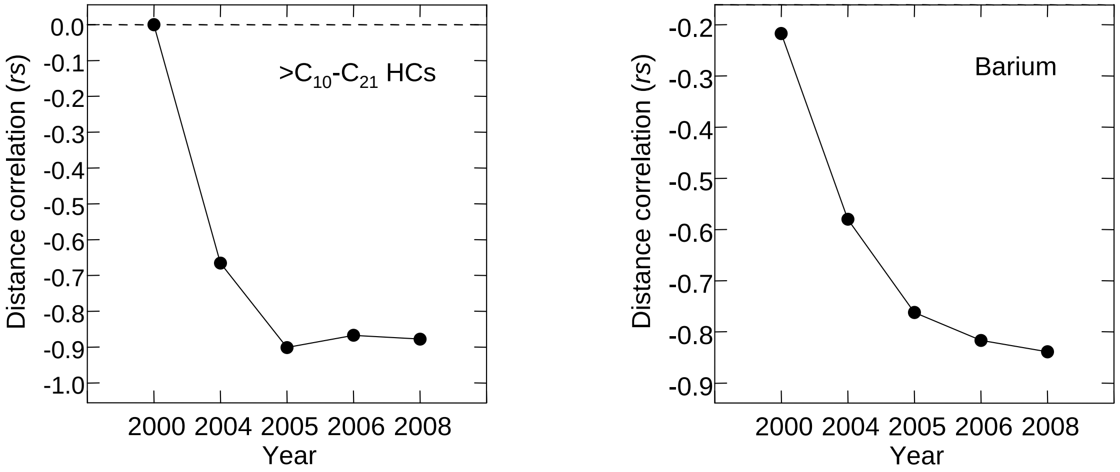

Figure 5-14 Spearman Rank Correlations (r_s) Between >C_{10}-C_{21} HC and Barium Concentrations versus Distance from the Nearest Active Drill Centre for all Stations Sampled in 2000, 2004, 2005, 2006 and 2008 (excluding station 31 in 2008)

Note: The X axes on these figures are not linear.

The non-parametric distance correlations for >C_{10}-C_{21} HC and barium concentrations in Figure 5-14 qualitatively confirm findings from parametric RM regression (Tables 5-11 and 5-12) and hockey-stick model analyses (Table 5-13). The non-parametric distance correlations in EEM years were always significant at $p \leq 0.001$ and comparable in strength to distance correlations for parametric models (i.e., highly significant distance effects in EEM years have always occurred for >C_{10}-C_{21} HC and barium concentrations). Non-parametric distance gradients and correlations for both constituents increased in strength between 2000 and 2004, or before versus after drilling at the Northern and Southern drill centres occurred. There was a further increase in the strength of overall distance gradients and correlations between 2004 and 2005, before versus after drilling began at the Central drill centre, which was less evident from RM regression analyses based on distances from each drill centre and from parametric threshold hockey-stick models based on distances from the nearest active drill centre. There was also a negative but not significant correlation ($r_s = -0.2$) between barium concentrations and distance in 2000.

Fines and TOC

Fines content increased with increasing depth in all five sample years, despite the narrow range of depths (116 to 137 m) for the 35 stations included in RM regression analyses. The Among Stations Depth term in Table 5-11 was significant with an *F* value larger than for any other term tested; multiple regression depth slopes were positive in every year (Figure 5-15). The overall Within Stations Year × Depth term was significant in Table 5-11 because depth effects were stronger in 2006 than in other years.

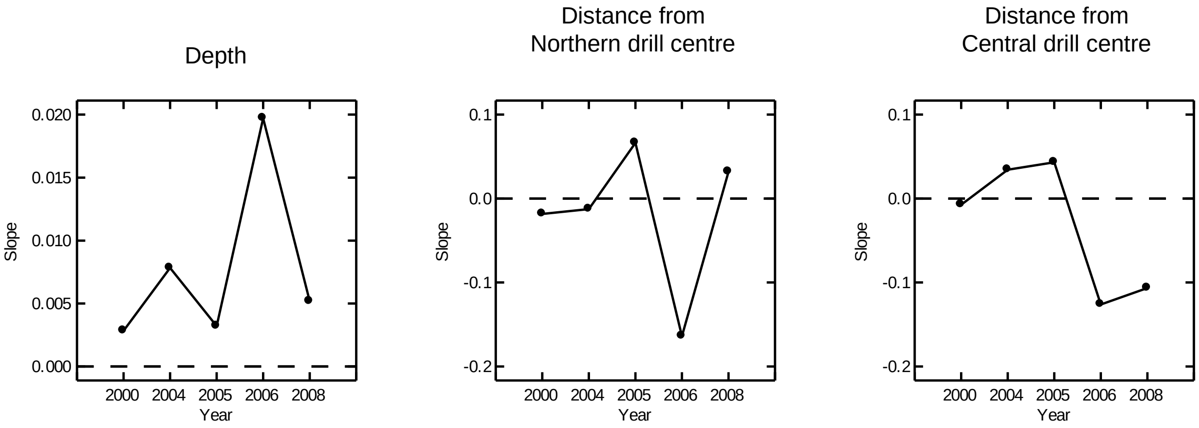

Figure 5-15 Multiple Regression Slopes for Fines Content versus Depth and Distances from the Northern and Central Drill Centres for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

Distance gradients for fines content changed significantly over time for the Northern and Central drill centres (overall Within Stations term and associated contrasts in Tables 5-11 and 5-12). However, those changes did not coincide with the onset of drilling at the two centres. Fines content decreased with distance from the Northern drill centre in 2006, but was otherwise uncorrelated with distances from that centre (Figure 5-15). In 2006 and 2008, but not in 2000, 2005 and 2006, fines content decreased with distance from the Central drill centre.

20th percentile and median fines content for the 35 stations included in RM regression analyses increased from 2000 to 2004 and then subsequently returned to baseline (2000) levels (Figure 5-16). The high fines content observed in 2004 was presumably a natural or analytical "effect" common to all or most stations in the White Rose study area (Husky Energy 2005) and also in the nearby Terra Nova study area (Petro-Canada 2005). Otherwise, overall variance has increased since baseline (2000) and 80th percentiles have also varied more over time than medians or 20th percentiles, which may be evidence that drill cuttings discharge have increased fines content beyond background at a few stations near drill centres in some years (see below for further discussion).

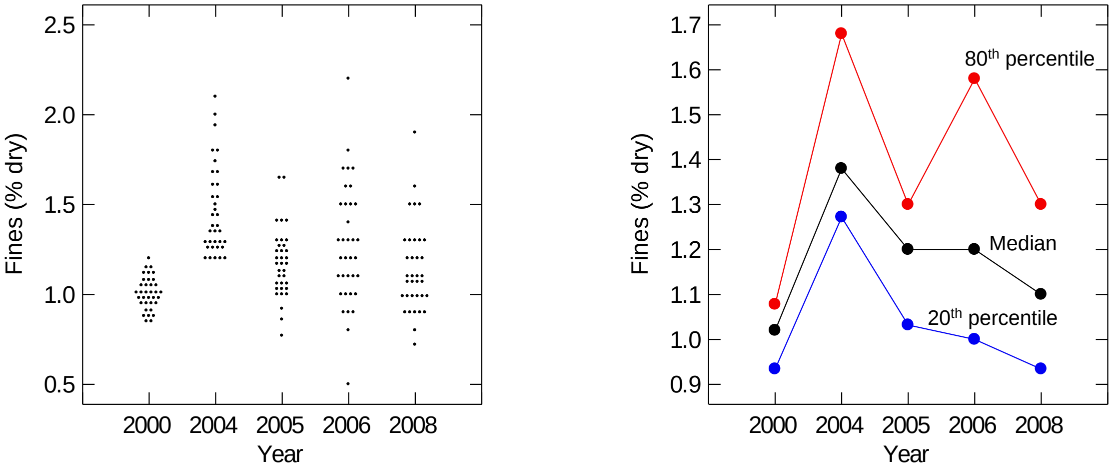

Figure 5-16 Fines Content for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Note: The X axes on these figures are not linear.

Sediment TOC content has generally decreased with depth, especially in recent years (Figure 5-17). However, Among Stations and Within Stations depth effects were not significant (Tables 5-11 and 5-12). Multiple regression slopes for distance from the Northern and North Amethyst drill centres increased over time from negative to positive, and slopes for distance from the Central drill centre decreased over time from positive to negative. Those changes are statistically significant but involve relatively small changes in weak distance gradients.

Overall, TOC values (reported as g/kg dry weight to one decimal place) have been uniformly low, with medians always 0.8 or 0.9 g/kg, 20th percentiles approximately 0.8 g/kg, and 80th percentiles either 0.9 or 1.0 g/kg (Figure 5-18). The one notable exception was the TOC content of 2.1% at station 20 (0.37 km from the Central drill centre) in 2008, the only value greater than 1.2% in the 252 sediment samples collected in 2000, 2004, 2005, 2006 and 2008.

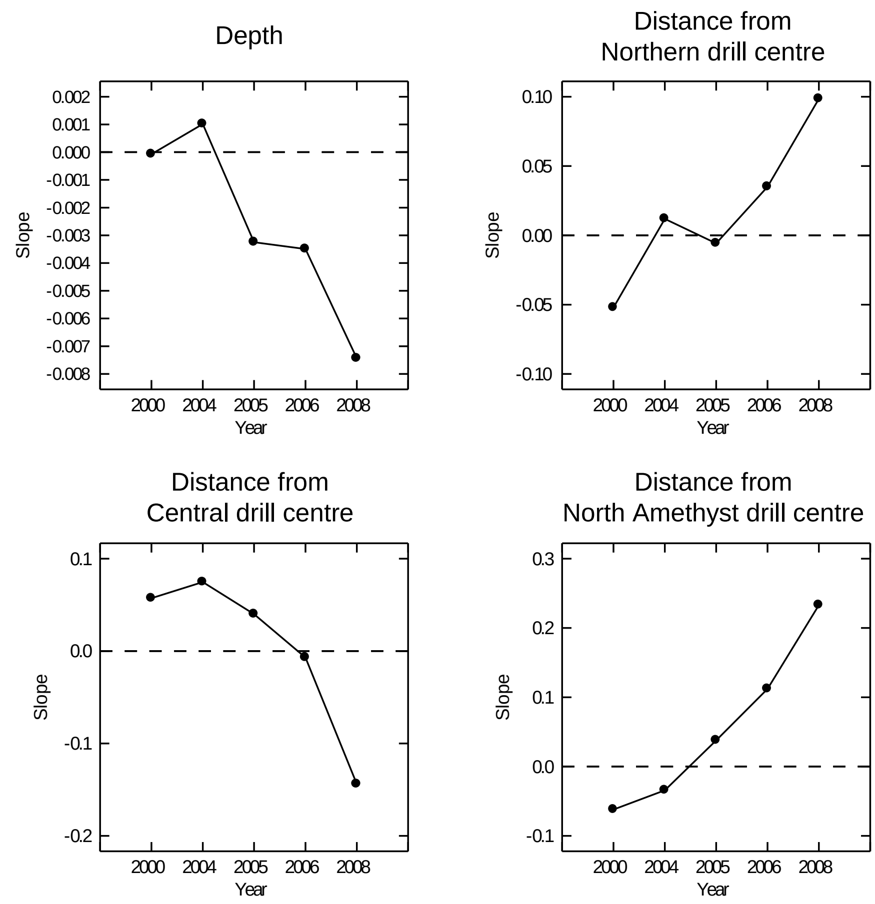

Figure 5-17 Multiple Regression Slopes for TOC Content versus Depth and Distances from the Northern, Central and North Amethyst Drill Centres for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

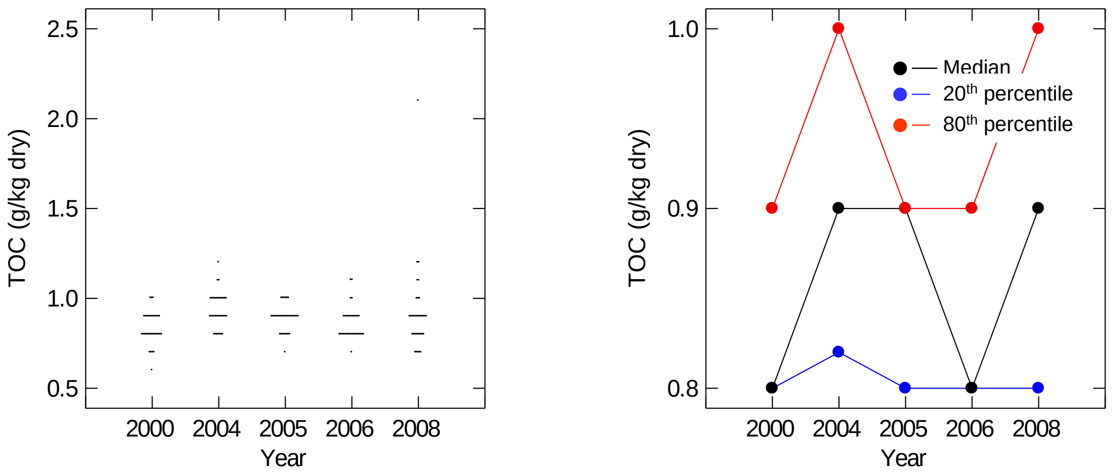

Figure 5-18 TOC Content for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Note: The X axes on these figures are not linear.

Spearman rank correlations (r_s) between fines content and distance from the nearest active drill centre have generally been weakly negative and rarely significant (Figure 5-19). The negative correlations in EEM years, especially 2006 (Husky Energy 2007), may be evidence that drill cuttings discharge may have occasionally increased fines content beyond background at a few stations near drill centres. However, the distance correlations ignore depth effects, which were significant for the stations included in RM regression analyses. There have been only eight fines content values greater than 2% in 206 samples collected in the four EEM years. Four of those values came from Reference station 4 (depth = 176 m; not sampled in 2000 and not included in RM regression analyses), where the highest value occurred in every year except 2004.

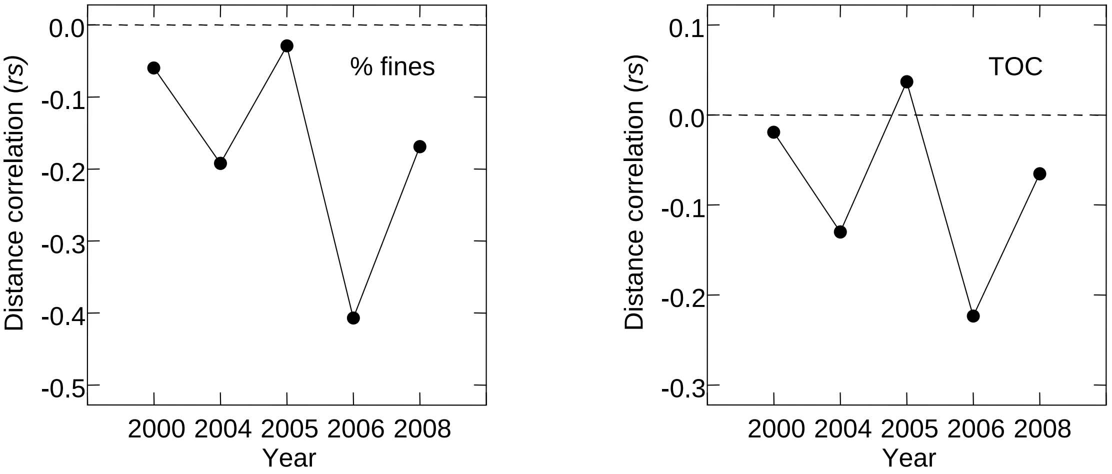

Figure 5-19 Spearman Rank Correlations (r_s) Between Fines and TOC Content versus Distance from the Nearest Active Drill Centre for all Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Note: The X axes on these figures are not linear.

Rank correlations between TOC and distance have never been strong or significant (Figure 5-19). Most TOC values observed to date have been between 0.8 and 1.0 g/kg, a narrow range of low values.

Other Variables

Relationships between concentrations of metals other than barium (i.e., Metals PC1 scores) and distances from the Central and Southern drill centres changed significantly over time and more specifically, among EEM years (Tables 5-11 and 5-12). Multiple regression slopes for distance from the Central drill centre have decreased over time, from near 0 to negative, with the largest changes occurring between 2006 and 2008 (Figure 5-20). Regression slopes for distance from the Southern drill centre were approximately 0 in 2000, decreased in 2004, then progressively increased and reversed direction over the next three sample years (2005, 2006 and 2008). Over all 35 stations included in RM regression analyses, 20th percentiles, medians and 80th percentiles have progressively increased over time (Figure 5-21).

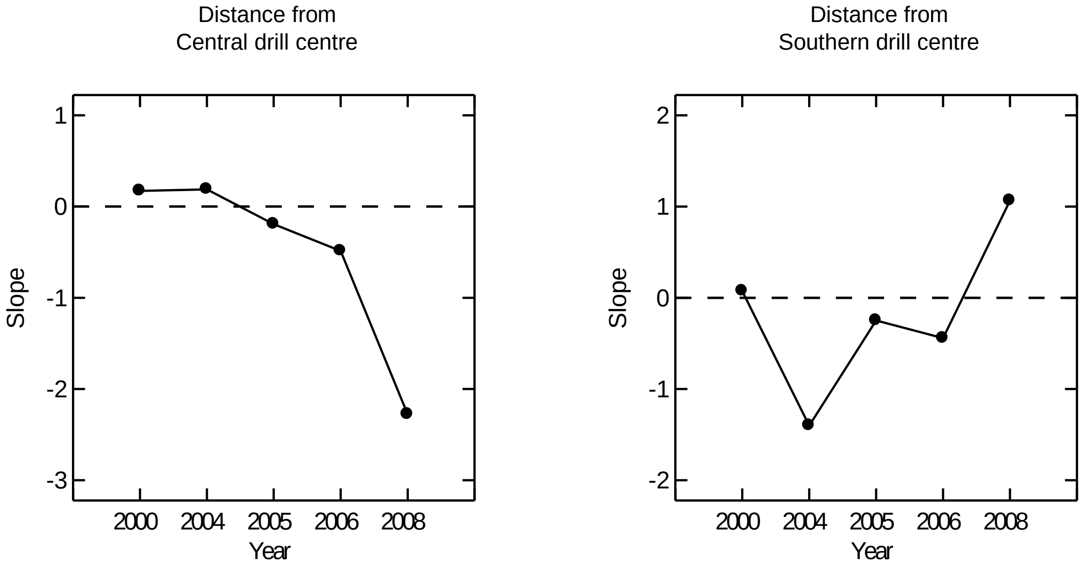

Figure 5-20 **Multiple Regression Slopes for Metals PC1 Scores versus Distances from the Central and Southern Drill Centres for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008**

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

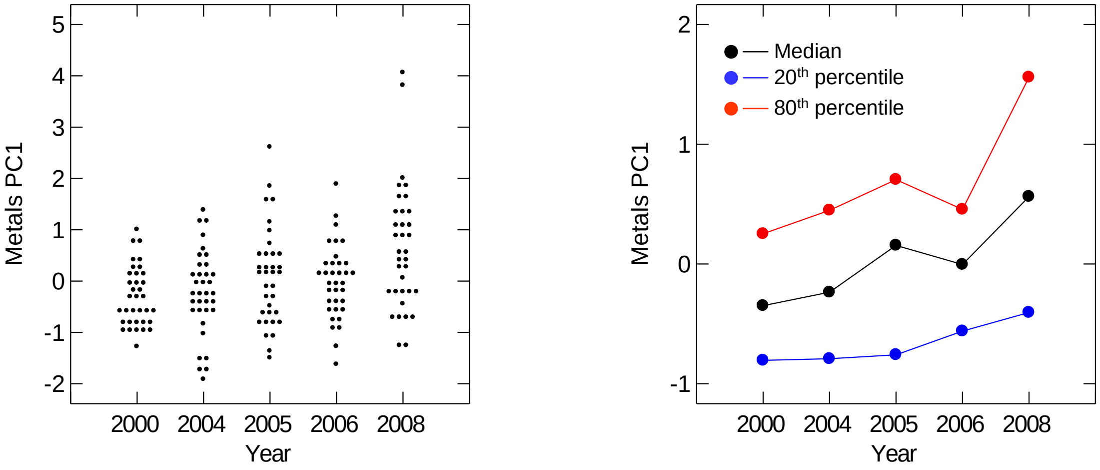

Figure 5-21 **Metals PC1 Scores for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008**

Note: The X axes on these figures are not linear.

In all four EEM years, relationships between ammonia concentrations (not measured in 2000) versus depth and distances from the Central and Southern drill centres have changed over time (Tables 5-11 and 5-12). However, those changes have basically reflected apparently random fluctuations about depth and distance regression slopes of 0 (Figure 5-22). Ammonia concentrations over all 39 stations included in RM regression analyses were lowest and least variable in 2006 (Figure 5-23).

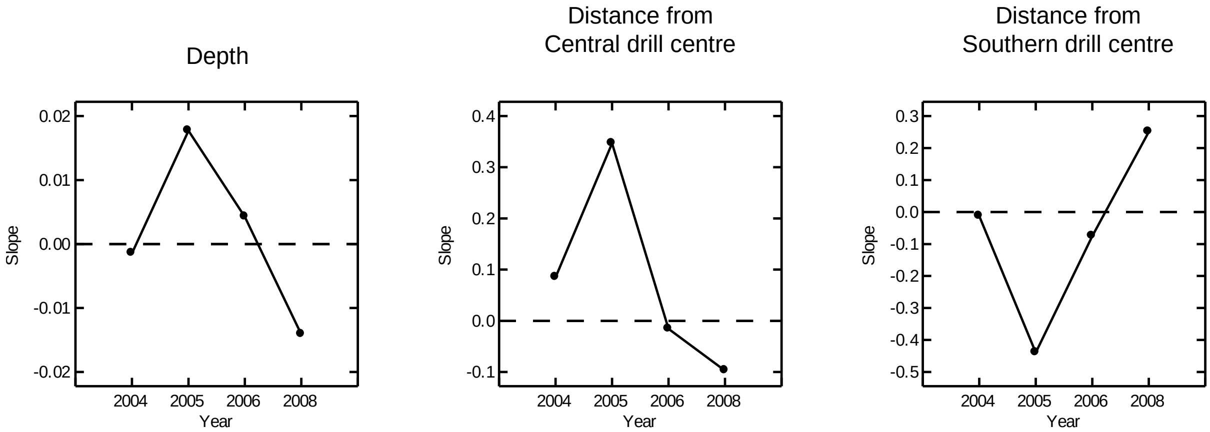

Figure 5-22 **Multiple Regression Slopes for Ammonia Concentrations versus Depth and Distances from the Central and Southern Drill Centres for the 39 Stations Sampled in 2004, 2005, 2006 and 2008**

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

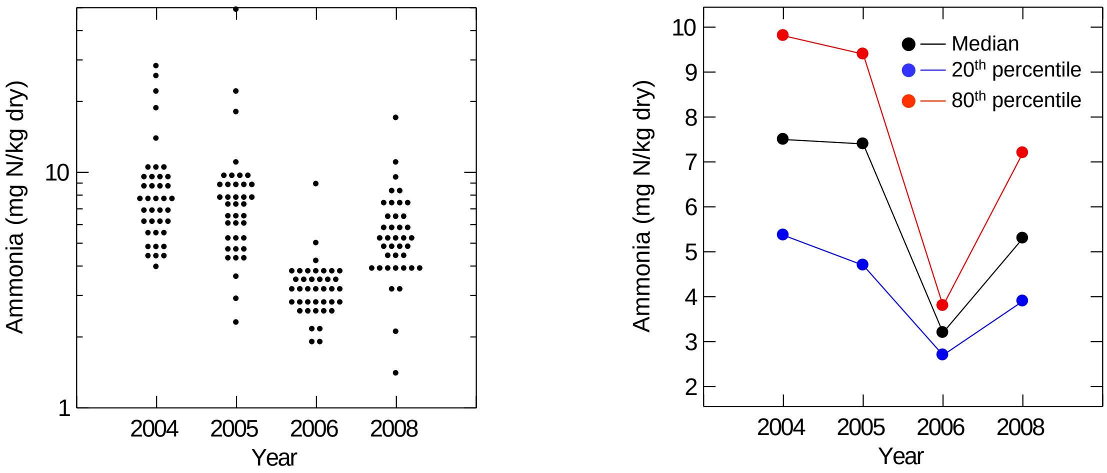

Figure 5-23 **Ammonia Concentrations for the 39 Stations Sampled in 2004, 2005, 2006 and 2008**

Note: The X axes on these figures are not linear.

In the four EEM years, relationships between sulphur concentrations (not measured in 2000) and distances from the Northern and Central drill centres changed significantly over time (Tables 5-11 and 5-12). In 2004, after drilling began, sulphur concentrations decreased with distance from the Northern drill centre (Figure 5-24). If there were any effects in 2004 from the Northern drill centre, they were not evident in subsequent years (i.e., distance gradients were reversed in 2005, and then non-existent in 2006 and 2008). In 2004, prior to drilling, there was no relationship between sulphur concentrations and distance from the Central drill centre. From 2005 to 2008, after drilling began, distance gradients (decreases with distance) progressively increased in strength. Distance gradients for the Southern drill centre have gradually shifted from weakly negative (decreases with distance) in 2004 to weakly positive (increases with distance) in 2008 (Figure 5-24), although those changes were not significant (Tables 5-11 and 5-12).

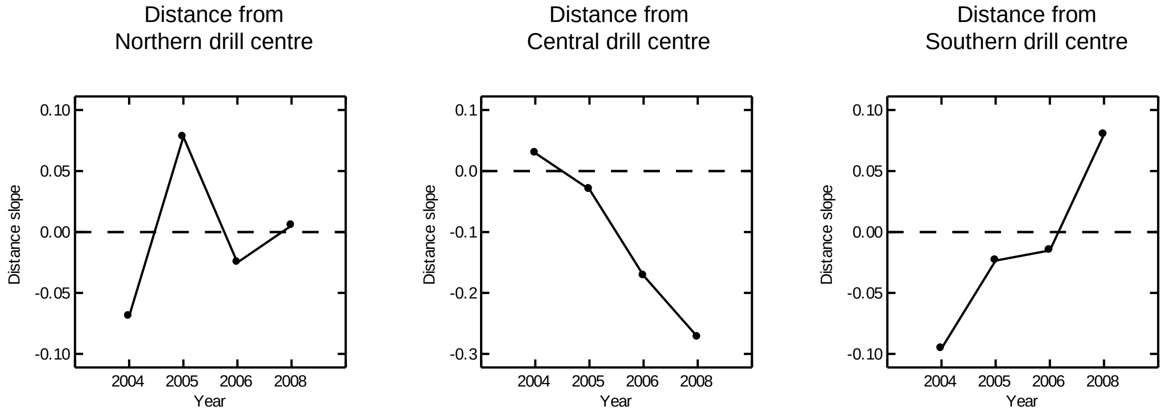

Figure 5-24 **Multiple Regression Slopes for Sulphur Concentrations versus Distances from the Northern, Central and Southern Drill Centres for the 39 Stations Sampled in 2004, 2005, 2006 and 2008**

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

Sulphur concentrations were problematic for parametric statistical analyses because there were several concentrations below the detection limit (RDL) of 0.02% (all set to 0.02%), concentrations were reported to three decimal places in 2004 to 2006 but only two decimal places in 2008, and most concentrations were confined to a narrow range near RDL (≤0.02 to 0.04%) (Figure 5-25). For the 39 stations included in RM regression analyses, 20th percentiles, medians and 80th percentiles all increased in 2008 relative to previous EEM years. It was unclear how much of that increase was real as opposed to a function of the reduction in the number of decimal places reported.

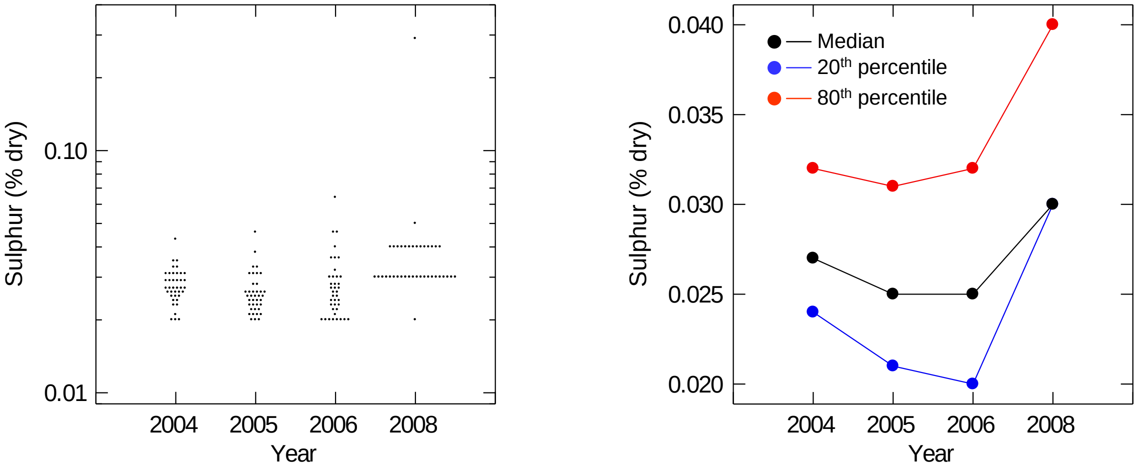

Figure 5-25 **Sulphur Concentrations for the 39 Stations Sampled in 2004, 2005, 2006 and 2008**

Note: The X axes on these figures are not linear.

Rank correlations between Metals PC1 scores and distance from the nearest active drill centres have fluctuated about the weakly negative correlation observed in baseline (2000; the baseline correlation could be weaker or stronger depending on which drill centres are arbitrarily considered “active”) (Figure 5-26). There was a net increase in Metals PC1 scores over time but it was unclear from both the parametric RM regression analyses and the non-parametric distance correlations how much, if any, of that increase could be attributed to drilling activity. Both the RM regression analyses and non-parametric distance correlations (Figure 5-26) indicated that ammonia concentrations varied randomly with depth, distance and time. In contrast, distance correlations for sulphur have always been negative (Figure 5-26), mostly because the few high concentrations observed have occurred near drill centres (e.g., as in 2008; Figure 5-9). Sulphur is also a variable more suitable for non-parametric analyses based on a single summary distance measure than for parametric RM or other analyses that attempt to separate the effects of different drill centres and identify larger-scale spatial gradients.

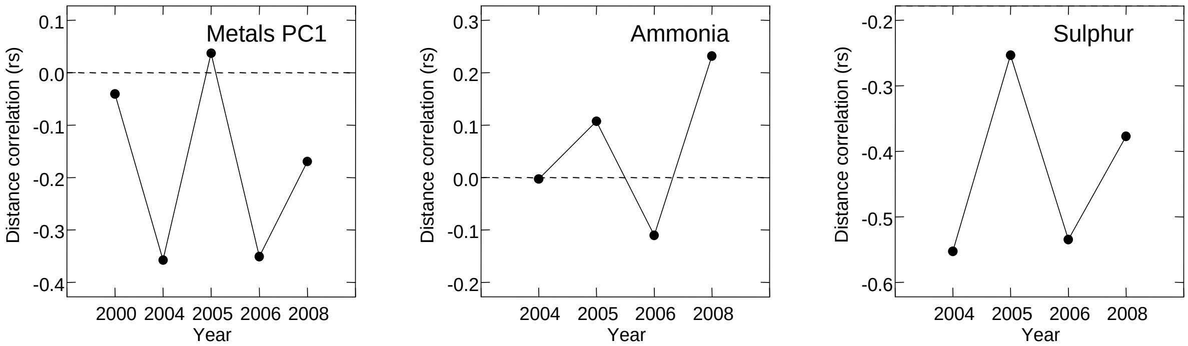

Figure 5-26 Spearman Rank Correlations (r_s) Between Metals PC1 Scores, Ammonia and Sulphur Concentrations versus Distance from the Nearest Active Drill Centre for all Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Notes: The X axes on these figures are not linear; Ammonia and sulphur were not measured in 2000.

Carry-over Effects

In RM regression, the Among Stations Error 1 term (Table 5-11) tests for carry-over effects or persistent differences over time among stations unrelated to depth or distance. Those carry-over effects could reflect localized natural or project-related differences among stations (i.e., “lack-of-fit” to depth and distance regressions). For the White Rose development, localized but persistent project effects on sediment chemical and physical variables should be considered the most important source of carry-over effects. The strength and significance of carry-over effects in RM regression was greater for variables more closely related to project activity; *F* values for Error 1 in Table 5-11 were largest, in descending order, for >C_{10}-C_{21} HCs, barium, sulphur, fines, TOC, Metals PC1 and ammonia. Distance regressions provide reasonable predictions of large-scale project effects, but cannot predict the specific locations of extremes (usually maxima) near drill centres. For example, >C_{10}-C_{21} HCs and barium levels have always been higher at station 20, 0.37 km from the Central drill centre, than distance regressions predict since drilling began (Figure 5-6 provides 2008 data).

5.4.2 Toxicity

In 2008, as in other years (Husky Energy 2001, 2005, 2006 and 2007), all Microtox IC_{50}s were greater than the highest concentration tested (98,600 mg/L in 2000; 197,000 mg/L in subsequent years), indicating that there were no toxic effects on luminescent bacteria. Results for 2007 and 2008 are provided in Appendix B-6.

Amphipod survival in toxicity tests in most White Rose sediment samples has been greater than 80%, and often greater than 90% (Appendix B-7). In 2000 and 2004, survival was greater than 70% in all 102 samples tested, and no sediments were considered toxic based on comparison to negative controls or Reference stations. In 2005, survival was less than 70% in sediments from stations 9 and N3, and sediment from station 9 was toxic to amphipods on comparison to both negative controls and Reference stations (survival = 28%). In 2006, survival was less than 70% in sediments from stations 13, S2, 16 and 23. Survival in sediments from stations 13 and S2 was less than 50% and those sediments were classified as toxic on comparison to both negative controls and Reference stations. Amphipod survival in the sediment sample from station 23 was 66%, and the sediments were classified as toxic when compared to Reference stations. In 2008, survival was less than 70% in sediments from 11 of 47 stations, and less than 50% in sediments from stations S2, NA1, N4, S5 and S3. Sediments from those five stations and station N3 (51% survival) were classified as toxic based on comparison to both laboratory controls and Reference stations. The same six stations plus stations 30 (56% survival) and C2 (57% survival) were classified as toxic based on comparison to negative control sediments.

In 2008, amphipod survival in toxicity tests was significantly positively correlated (i.e., increased) with distance from the nearest active drill centre. Survival was also significantly negatively correlated (i.e., decreased) with $>C_{10}$-C_{21} HC and barium concentrations (Table 5-14). All 11 survival values less than 70% occurred at stations within 5 km of the nearest active drill centre, and all but one survival value less than 70% occurred at $>C_{10}$-C_{21} HC concentrations greater than 1 mg/kg dry weight (Figure 5-27). However, there were also many survival values greater than 70% within 5 km of drill centres and at $>C_{10}$-C_{21} HC concentrations greater than 1 mg/kg. Station 31, near delineation well K-03, was excluded from the distance correlation to be consistent with distance analyses of other variables but was not an outlier. Survival was greater than 80% at both station 31 and station 20, the two stations with the highest $>C_{10}$-C_{21} HC concentrations, and survival was lowest (25%) at station NA1 with $>C_{10}$-C_{21} HC concentrations of 0.8 mg/kg. Therefore, although there may have been overall relationships between survival versus distance and $>C_{10}$-C_{21} HC and barium concentrations, those relationships would be poor predictors of survival at specific stations.

Table 5-14 Spearman Rank Correlations (r_s) Between Amphipod Survival versus Distance from the Nearest Active Drill Centre and Sediment Physical and Chemical Characteristics (2008)

Variable	Correlation (r_s) with Amphipod Survival
Distance from nearest active drill centre	0.349*
$>C_{10}$–C_{21} HCs	–0.453**
Barium	–0.304*
% fines	–0.138
% gravel	–0.107
TOC	–0.075
Metals PC1	–0.080
Ammonia	0.073
Sulphide	–0.042
Sulphur	–0.208
Redox	0.073

Notes:
- $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in bold).
- n = 47 stations for physical and chemical variables; n=46 stations for distance (station 31 excluded).

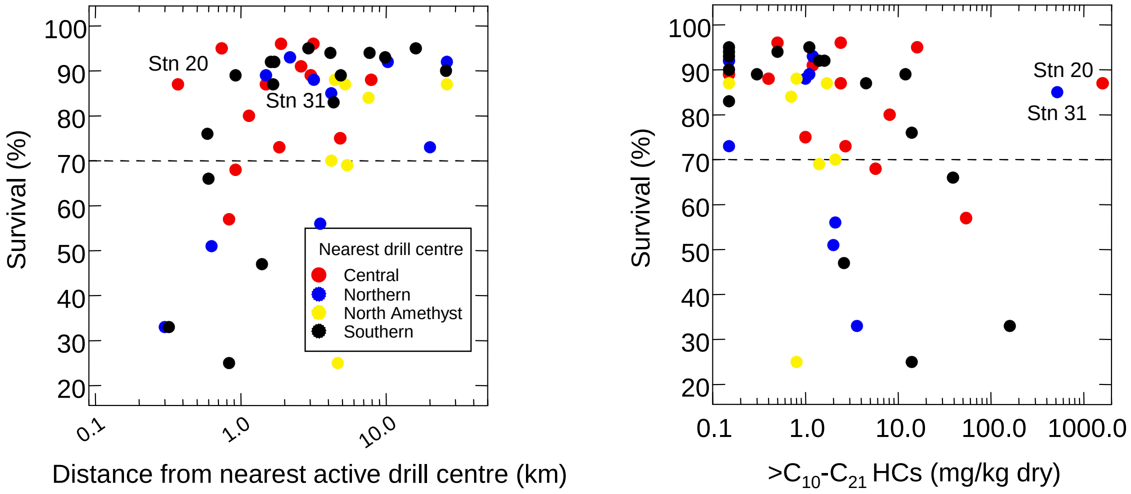

Figure 5-27 Percent Amphipod Survival versus Distance from the Nearest Drill Centre and $>C_{10}$-C_{21} HC Concentrations (2008)

Table 5-15 provides amphipod survival for Reference stations and for all stations with survival less than 70% in any one year. In 2008, survival in sediments from the NW Reference station 27 was 73%. Otherwise, Reference survival has always been greater than 80%. Although the frequency of low survival has progressively increased over time, and all but one station (NA3) with low survival has been within 5 km of the nearest active drill centre, the occurrence of low survival values was otherwise unpredictable in time as well as space. First, amphipod survival has always been greater than 70% for 22 other routinely sampled EEM stations within 5 km of active drill centres. Second, low survival does not appear to recur at the same station. Station S2 was the only station classified as toxic in more than one year (2006 and 2008). Station S2 and station N3 (2005 and 2008) were the only stations with less than 70% survival in more than one year. In contrast, the low survival observed for station 9 in 2005, and for stations 13 and 16 in 2006, did not recur in subsequent years.

Table 5-15 Amphipod Survival for Reference Stations and all Stations with Survival Less Than 70% in any Year (2000, 2004, 2005, 2006 and 2008)

Station	Min *d*	Amphipod Survival (%)				
		2000	2004	2005	2006	2008
Reference Stations						
27	20.03	NS	90	90	97	73
12	25.85	NS	88	87	83	90
19	26.17	NS	99	83	88	87
4	26.19	NS	94	85	85	92
Other Stations						
N4	0.30	NS	89	93	93	**33**
S5	0.32	NS	74	NS	83	**33**
13	0.59	93	88	95	**34**	76
S1	0.60	92	79	83	89	**66**
N3	0.63	90	90	**68**	91	**51**
C2	0.83	96	86	93	83	**57**
S2	0.83	94	89	89	**29**	**25**
C4	0.92	93	91	89	90	**68**
S3	1.40	91	89	86	76	**47**
16	1.49	92	84	93	**69**	87
9	1.61	94	94	**28**	91	92
23	1.84	89	90	88	**66**	73
30	3.52	97	92	82	95	**56**
NA4	4.20	NS	NS	NS	NS	70
NA1	4.65	NS	NS	NS	NS	**25**
NA2	5.22	NS	NS	NS	NS	87
NA3	5.40	NS	NS	NS	NS	**69**

Notes:
- Bold underline indicates sediments classified as toxic; bold indicates sediments with less than 70% survival.
- NS – Not sampled.

5.4.3 Benthic Community Structure

A total of 30,764 invertebrates were collected from 47 stations in 2008, with mean abundances per station lower than in 2000 but higher than in 2004, 2005 and 2006 (Table 5-16). The totals exclude nemerteans, nematodes, oligochaetes, ostracods and copepods. Over all samples years (2000, 2004, 2005, 2006 and 2008), 130 "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. There were also two families (one Amphipoda; one Isopoda) that were only collected from the six stations sampled around the North Amethyst drill centre in 2007. Raw data for benthic community structure in 2007 and 2008 are provided in Appendix B-4.

Table 5-16 Taxonomic Composition of Benthic Invertebrate Community Samples (2000, 2004, 2005, 2006 and 2008)

Phylum or Subphylum	Class or Order	No. Families	2008 (EEM)		2004 to 2006 (EEM)		2000 (baseline)	
			(*n*=47 stations)		(*n*=159 stations)		(*n*=46 stations)	
			No.	% of total	No.	% of total	No.	% of total
Porifera		1	3	0.01	19	0.03	0	0.00
Cnidaria		6	44	0.14	200	0.29	13	0.04
Sipuncula		1	0	0.00	1	0.00	0	0.00
Platyhelminthes	Turbellaria	1	0	0.00	3	0.00	0	0.00
Annelida	Polychaeta	33	24,863	80.82	52,495	75.36	26,594	77.12
Mollusca	Total	44	3,878	12.61	11,364	16.31	5,932	17.20
	Aplacophora	1	0	0.00	1	0.00	0	0.00
	Bivalvia	22	3,794	12.33	11,115	15.96	5,859	16.99
	Gastropoda	21	84	0.27	248	0.36	73	0.21
Crustacea	Total	28	1,553	5.05	4,386	6.30	1,427	4.14
	Amphipoda	16	724	2.35	1,873	2.69	1,184	3.43
	Cirrepedia	1	86	0.28	43	0.06	13	0.04
	Cumacea	5	31	0.10	101	0.14	19	0.06
	Decapoda	1	9	0.03	2	0.00	1	0.00
	Isopoda	4	58	0.19	302	0.43	16	0.05
	Tanaidacea	1	645	2.10	2,065	2.96	194	0.56
Chelicerata	Pycnogonida	1	1	0.00	0	0.00	0	0.00
Brachiopoda	Inarticulata	1	1	0.00	0	0.00	0	0.00
Echinodermata		8	370	1.20	1,179	1.69	517	1.50
Hemichordata		1	50	0.16	0	0.00	0	0.00
Urochordata	Ascidiacea	3	1	0.00	12	0.02	0	0.00
Total		128	30,764	100	69,659	100	34,483	100
Mean/station			655		438		750	

Note: - Numbers represent results over all stations.

In all sample years, polychaetes accounted for 70 to 80% of the invertebrates collected and bivalves accounted for approximately 15% (Table 5-16). 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 55 of the 128 families collected in baseline and EEM years (with 2007 excluded). Twenty-one (21) families of the relatively rare Gastropoda and 16 families of Amphipoda were collected.

Table 5-17 lists all families that represented 1% or more of the total number of organisms collected in 2000, 2004, 2005 and 2008. The families are listed in descending order of abundance in 2008. Polychaetes in the family Spionidae (primarily *Prionospio steenstrupi* and several *Spio* species) were the most abundant (dominant) family. 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 one or a few species, diversity was limited.

Relative (%) abundances of most sub-dominant groups listed in Table 5-17 were similar among years. However, there were large changes in abundances among years for some families. For example, Cirratulidae (primarily *Chaetozone setosa*) and Carditidae (*Cyclocardia* spp.) were relatively abundant in 2000 but they were much less abundant (Cirratulidae) or never collected (Carditidae) in subsequent EEM years. Dexaminidae

(*Guernea nordenskioldi*) were relatively abundant in 2000 and 2004, and then again in 2006 and 2008, but were not collected in 2005 (Husky Energy 2007; pooling 2004 to 2006 samples in Table 5-17 conceals the absence of Dexaminidae in 2005 samples). These changes over time 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.

Table 5-17 Dominant Benthic Invertebrate Families (2000, 2004, 2005, 2006 and 2008)

Major Taxon	Family	2008				2004, 2005 and 2006				2000			
		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
Polychaeta	Spionidae	14,614	47.5	47	100	25,353	36.4	159	100	12,812	37.2	46	100
Bivalvia	Tellinidae	3,302	10.7	47	100	9,653	13.9	159	100	4,616	13.4	46	100
Polychaeta	Paraonidae	3,119	10.1	44	94	13,203	19.0	153	96	5,020	14.6	46	100
Polychaeta	Phyllodocidae	1,929	6.3	47	100	2,916	4.2	158	99	1,153	3.3	46	100
Polychaeta	Orbiinidae	1,423	4.6	41	87	3,960	5.7	136	86	1,565	4.5	46	100
Polychaeta	Maldanidae	660	2.1	45	96	1,380	2.0	156	98	405	1.2	46	100
Tanaidacea		645	2.1	43	91	2,065	3.0	153	96	194	0.6	44	96
Polychaeta	Sabellidae	485	1.6	44	94	351	0.5	102	64	27	0.1	17	37
Polychaeta	Syllidae	443	1.4	42	89	1,376	2.0	131	82	312	0.9	44	96
Polychaeta	Sigalionidae	406	1.3	41	87	366	0.5	125	79	184	0.5	40	87
Amphipoda	Dexaminidae	392	1.3	43	91	602	0.9	104	65	176	0.5	41	89
Polychaeta	Capitellidae	298	1.0	41	87	821	1.2	148	93	232	0.7	45	98
Echinodermata	Echinarachnidae	221	0.7	44	94	820	1.2	153	96	348	1.0	46	100
Polychaeta	Cirratulidae	216	0.7	27	57	752	1.1	92	58	4,412	12.8	46	100
Amphipoda	Haustoriidae	12	0.0	5	11	329	0.5	89	56	641	1.9	46	100
Bivalvia	Carditidae	0	0.0	0	0	0	0.0	0	0	443	1.3	42	91

Appendix B-5 provides a more detailed analysis of overall community composition, based on NMDS. Differences in community composition over space and time depended largely on the three dominant taxa (Spionidae, Paraonidae, Tellinidae), which are analyzed separately below.

5.4.3.1 Analysis of 2008 Data

Summary Statistics

Table 5-18 provides summary statistics for invertebrate community summary measures and absolute abundances of selected taxa. Total abundance was expressed both as numbers of organisms per station and as numbers per unit area (m^2). Standing crop was expressed as both wet weight per station and wet weight per unit area. Richness cannot be expressed on a per unit area basis since richness is not a linear function of the area sampled. Caution should also be applied about directly comparing numbers and weights per unit area from this study with values obtained in studies performed in other areas, since sampling efficiency, particularly for individual taxa, will vary with the type of sampler used and the substrate sampled. For those reasons, numbers and weight per station rather than per unit area are used elsewhere.

Table 5-18 Summary Statistics for Benthic Invertebrate Community Variables (2008)

Variable	Units	Min	Max	Median	Mean	SD	CV (%)
Summary Measures							
Total Abundance	No./station	167	1,507	602	655	247	38
	No./m^2	835	7,535	3,010	3,273	1,236	38
Standing Crop	g wet/station	28	331	123	139	74	53
	g. wet/m^2	139	1,656	613	694	370	53
Richness (S)	No. taxa/station	17	41	29	29	4	15
Taxon Abundances (No./Station)							
Paraonidae (Polychaeta)		0	325	43	66	64	97
Spionidae (Polychaeta)		3	727	264	311	147	47
Tellinidae (Bivalvia)		6	162	67	70	32	46
Amphipoda		1	53	13	15	11	69

Notes:
- All values were based on pooling two samples per station. Each sample was approximately 0.1 m^2 in surface area.
- Richness was based on families.
- *n* = 47 stations.

In 2008, total abundance and standing crop varied over 10-fold ranges, with coefficients of variations (CVs) of approximately 40 to 50%. Richness was less variable (less than a 3-fold range and a lower CV). More than 20 taxa were collected at most stations, but most stations were dominated by Spionidae, Paraonidae, Tellinidae and a few of the sub-dominant groups listed in Table 5-17. 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. CVs can be high because of natural or project-related variance, but also tend to be higher for less abundant taxa.

Correlations Among Invertebrate Community Variables (2008)

Table 5-19 provides rank correlations (r_s) among invertebrate community summary measures. Total abundance and standing crop were weakly and not significantly positively correlated, since standing crop depends largely on abundances of larger but rarer organisms such as echinoderms. In 2008, the rank correlation (r_s) between standing crop and echinoderm abundance was 0.56, comparable to r_s of 0.39 to 0.52 in past years. Standing crop was also uncorrelated with richness, which was largely a function of the abundance and occurrence of diverse groups of smaller organisms (e.g., polychaetes, bivalves and amphipods). Richness is usually positively correlated with total abundance since more taxa will usually be collected when more organisms are collected. However, the correlation between richness and abundance in 2008 (Table 5-19) was not significant and was much weaker than in past years when r_s between the two variables ranged from 0.35 to 0.78.

Table 5-19 Spearman Rank Correlations (r_s) Among Benthic Invertebrate Community Summary Measures (2008)

	Total Abundance	Standing Crop
Standing crop	0.237	
Richness	0.168	–0.032

Notes: - *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in bold).
- Richness was based on families.
- $n = 47$ stations.

Table 5-20 provides correlations among absolute abundances of the three dominant families and Amphipoda. All six 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 5-20 were also positive for baseline (2000) samples. However, positive correlations could also occur if the four taxa responded similarly to project activity. In 2008, correlations between abundances of Tellinidae and abundances of the other three taxa were weak and not significant, whereas correlations between Paraonidae and Spionidae abundances were strong and highly significant ($p << 0.001$).

Table 5-20 Spearman Rank Correlations (r_s) Among Abundances of Selected Benthic Invertebrate Taxa (2008)

	Paraonidae	Spionidae	Tellinidae
Spionidae	**0.723*** **		
Tellinidae	0.260	0.108	
Amphipoda	0.328*	0.493***	0.058

Notes: - *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in bold).
- $n = 47$ stations.

In 2008, total abundance was strongly positively correlated with abundances of all four taxa (Table 5-21). Positive correlations were expected for the three dominant families (Spionidae, Tellinidae, Paraonidae) since they accounted for approximately 70% of total abundance in 2008 (Table 5-17). Amphipod abundance has also been positively correlated with total abundance in all years, although amphipods accounted for a minor portion (2% in 2008) of total abundance (Table 5-16). Based on the strong correlations among total abundance and Paraonidae and Spionidae abundances, the three variables may be redundant, an issue partly addressed by the NMDS conducted on relative (%) abundances (Appendix B-5).

Table 5-21 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Summary Measures and Abundances of Selected Taxa (2008)

	Total Abundance	Standing Crop	Richness
Paraonidae	**0.752*** **	0.458**	0.043
Spionidae	**0.933*** **	0.256	0.161
Tellinidae	0.326*	–0.019	0.094
Amphipoda	**0.528*** **	0.007	0.425**

Notes: - *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in bold).
- Richness was based on families.
- $n = 47$ stations.

In 2008, standing crop was significantly positively correlated with Paraonidae abundances (Table 5-21). However, as noted above, standing crop depends more on abundances of larger organisms such as echinoderms than on abundances of smaller organisms such as polychaetes. In 2008 (and in most past years), richness was more strongly correlated with abundances of Amphipoda than with abundances of the other three taxa. Amphipoda abundances reflect the contributions of several different taxa (families), whereas Paraonidae, Spionidae and Tellinidae represent single taxa.

Correlations Between Invertebrate Community Variables and Sediment Physical and Chemical Characteristics (2008)

In 2008, most correlations between invertebrate community variables and sediment particle size and TOC were weak (Table 5-22), as they have been in the past (Husky Energy 2006, 2007). Only one (of 21) correlations was significant at $p \leq 0.05$. Standing crop appeared to be the variable responding most strongly to particle size and TOC, decreasing with increasing fines and TOC content and increased with increasing gravel content.

Table 5-22 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and Sediment Particle Size and TOC (2008)

Benthic Invertebrate Community Variable	Sediment Particle Size and Organic Carbon Content		
	% fines	% gravel	TOC
Summary Measures			
Total abundance	–0.106	–0.019	0.038
Standing crop	–0.379*	0.285	–0.272
Richness	–0.080	0.236	0.027
Taxon Abundances			
Paraonidae	–0.233	0.192	–0.009
Spionidae	–0.088	–0.026	0.043
Tellinidae	–0.038	0.100	–0.129
Amphipoda	–0.204	–0.101	0.107

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold).
- Richness was based on families.
- n = 47 stations.

In 2008, richness was the only community variable that was not significantly correlated with either >C_{10}-C_{21} HCs or barium concentrations (Table 5-23). Total abundances, standing crop, and abundances of Paraonidae, Spionidae, Tellinidae and Amphipoda all decreased with increasing concentrations of >C_{10}-C_{21} and barium, with the strongest correlations observed for Paraonidae. Correlations between those variables and barium were generally stronger than correlations with >C_{10}-C_{21} HCs. Correlations between invertebrate community variables and concentrations of metals other than barium (Metals PC1), ammonia, sulphur and sulphide and redox, were generally weaker and rarely significant (Table 5-23 and 5-24).

Table 5-23 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and >C_{10}-C_{21} HCs, Barium, and Metals PC1 (2008)

Benthic Invertebrate Community Variable	Sediment Chemistry Variable		
	>C_{10}-C_{21} HCs	Barium	Metals PC1
Summary Measures			
Total abundance	–0.430**	**–0.520*** **	–0.107
Standing crop	–0.273	–0.437**	–0.287
Richness	–0.009	0.052	–0.155
Taxon Abundances			
Paraonidae	**–0.544*** **	**–0.746*** **	–0.266
Spionidae	–0.319*	–0.472**	–0.139
Tellinidae	–0.330*	–0.244	–0.036
Amphipoda	–0.394**	–0.397**	–0.236

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold).
- Richness was based on families.
- n = 47 stations.

Table 5-24 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and Ammonia, Sulphur, Sulphide and Redox (2008)

Benthic Invertebrate Community Variable	Sediment Chemistry Variable			
	Ammonia	Sulphur	Sulphide	Redox
Summary Measures				
Total abundance	0.146	-0.218	-0.066	-0.148
Standing crop	0.055	–0.297*	–0.286	–0.037
Richness	–0.032	–0.108	0.058	–0.229
Taxon Abundances				
Paraonidae	0.165	–0.291*	–0.246	–0.116
Spionidae	0.260	–0.276	–0.086	–0.006
Tellinidae	–0.385**	–0.001	–0.145	–0.166
Amphipoda	0.275	–0.141	–0.064	–0.044

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold).
- Richness was based on families.
- n = 47 stations.

Correlations Between Invertebrate Community Variables and Amphipod Survival (2008)

In 2008, amphipod survival in laboratory toxicity tests was not significantly correlated with any benthic invertebrate community variable (Table 5-25).

Table 5-25 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and Amphipod Survival in Laboratory Toxicity Tests (2008)

Benthic Invertebrate Community Variable	R_s with Survival
Summary Measures	
Total abundance	–0.057
Standing crop	–0.118
Richness	–0.045
Taxon Abundances	
Paraonidae	0.145
Spionidae	–0.115
Tellinidae	0.058
Amphipoda	0.026

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in bold).
- Richness was based on families.
- n = 47 stations.

Depth and Distance Effects (2008)

Table 5-26 provides results of rank-rank regressions of invertebrate community variables on depth and distance from the nearest active drill centre. Station 31, within 0.4 km of a delineation well (K-03) but approximately 4 km from the nearest (Northern) drill centre, was excluded. 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 the other *X* variable held constant. For bivariate rank-rank regressions on a single *X* variable, *r* is equal to the Spearman rank correlation (r_s).

Table 5-26 Results of Rank-Rank Regressions of Benthic Invertebrate Community Variables on Depth and Distances from the Drill Centres (2008)

***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	0.411*	0.088	0.401**	0.098	0.403**
Standing crop	0.362*	–0.121	0.350*	–0.098	0.344*
Richness	0.194	0.165	–0.112	0.160	–0.103
Taxon Abundance					
Paraonidae	**0.655*** **	–0.119	**0.654*** **	–0.061	**0.649*** **
Spionidae	0.347	–0.035	0.347*	–0.017	0.346*
Tellinidae	**0.527*** **	**0.501*** **	0.192	**0.500*** **	0.189
Amphipoda	0.371*	0.029	0.369*	0.044	0.370*

Notes:
- *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in bold).
- Min *d* = distance from the nearest drill centre.
- All *Y* and *X* variables were rank-transformed.
- Richness was based on families.
- *n* = 46 stations; station 31 excluded.

Summary Measures

In 2008, depth effects were not significant for total abundance, standing crop or richness (Table 5-26). Total abundance and standing crop increased significantly with distance from the nearest active drill centre; richness was uncorrelated with distance.

Parametric threshold hockey-stick models were fit and tested for total abundance and standing crop to estimate the spatial extent of effects on these variables. For total abundance, adding a threshold distance did not significantly reduce error variance relative to a bivariate log-log regression (Table 5-27). The estimated spatial extent of effects (X_T) was 4.7 km, but with wide 95% CI (1.1 to 15.2 km; most of the distance range sampled). Total abundance was typical of most invertebrate community variables (Figure 5-28). Variable values were reduced at some stations within 1 km of drill centres (i.e., near the Central drill centre for total abundance) and within 5 km there may be an overall distance relationship (i.e., increase with distance). However, beyond 5 km, variances (presumably natural) were wide and unrelated to distances. In these cases, distance correlations will usually be weak (bivariate *r* or $r_s \le 0.5$), and no parametric relationship will provide precise estimates of the spatial extent of effects. In 2008, standing crop was an exception. Adding a threshold significantly reduced error variance relative to a bivariate regression (Table 5-27), and the estimated threshold of 1.5 km (95% CI of 0.7 to 3.4 km) provided a reasonable estimate of the distance beyond which there was no distance relationship (Figure 5-28).

Table 5-27 Results for Parametric Distance Models for Total Abundance, Standing Crop and Paraonidae Abundance (2008)

Result/Estimate	Total Abundance	Standing Crop	Paraonidae Abundance
Bivariate Regression on Distance from the Nearest Active Drill Centre			
r	0.448**	0.422**	**0.642*** **
Hockey-stick Model			
Overall *R*	0.482*	0.502**	**0.751*** **
p for adding threshold	0.195	0.046	**<0.001**
antilog X_T (threshold distance in km)	4.1	1.5	3.8
95% CI	1.1 to 15.2	0.7 to 3.4	2.1 to 6.9

Notes:
- *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in bold).
- The *X* variable for the hockey-stick model was distance from the nearest active drill centre.
- Distance (*X*) and *Y* variables were log transformed, with log (*Y* + 1) used for Paraonidae abundance.
- *n* = 46 stations (station 31 excluded).

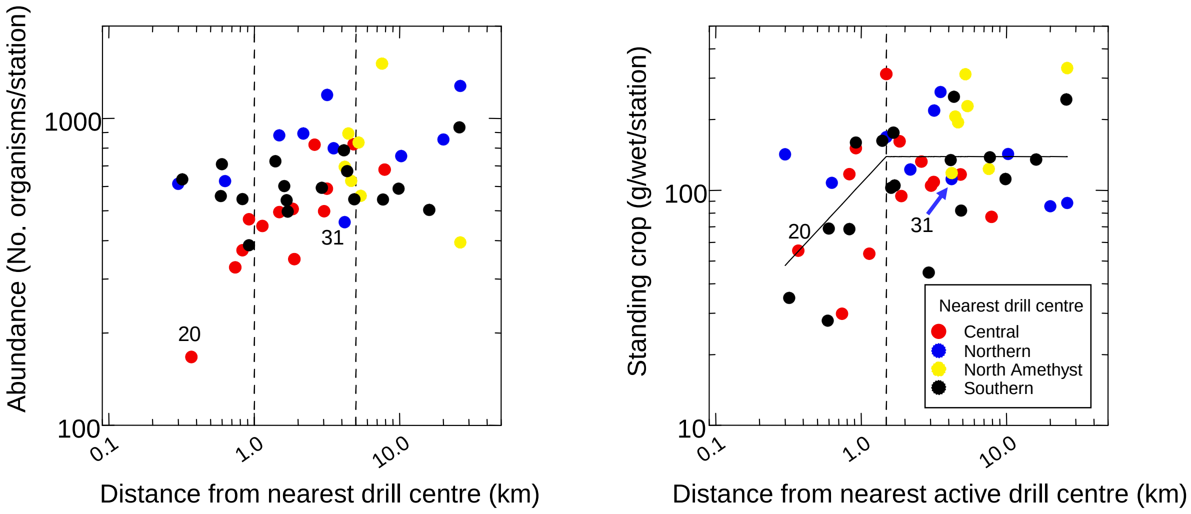

Figure 5-28 Total Abundance and Standing Crop versus Distance from the Nearest Active Drill Centre (2008)

Figure 5-28 and other depth and distance plots identify stations 20 and 31, the two stations with the highest >C_{10}-C_{21} HC and barium concentrations. Station 20 was a negative outlier for some invertebrate community variables (e.g., total abundance) but community variable values for station 31 were usually similar to values for other stations approximately 4 km from an active drill centre. In other words, drilling at delineation well K-03 (0.4 km from station 31) had no apparent effects on benthic invertebrate communities.

Taxon Abundances

In 2008, Paraonidae, Spionidae and Amphipoda abundances increased significantly with increasing distance from the nearest active drill centre (Table 5-26). Depth effects were not significant for those three taxa. Distance correlations were strongest for Paraonidae abundances and adding a threshold distance significantly reduced error variance relative to a bivariate regression (Table 5-27). The estimated threshold distance (i.e., the spatial extent of effects) was 3.8 km with 95% CI of 2.1 to 6.9 km, and increases in Paraonidae abundance with increasing distance within this area were greater than 10-fold (Figure 5-29).

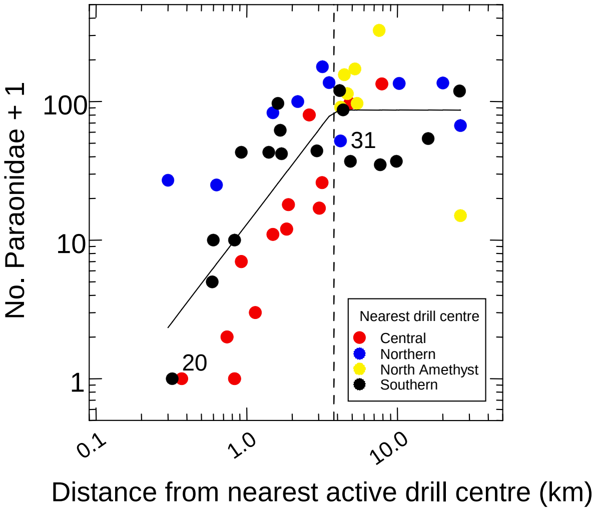

Figure 5-29 Paraonidae Abundance versus Distance from the Nearest Active Drill Centre (2008)

In 2008, only three Spionidae were collected at station 20 (0.4 km from the Central drill centre); 100 or more were collected at all other stations (Figure 5-30). The abundance at station 20 was the lowest observed since sampling began in 2000. For the other stations, there was a weak but significant distance correlation ($r_s \approx 0.3$ and $p < 0.05$, with or without station 31 included). In contrast, Amphipoda abundances increased more continuously with distance (Figure 5-30). Rank-rank distance correlations were significant (Table 5-26), but the overall relationship was too weak to fit a threshold hockey-stick model ($p = 1$ for adding the threshold; a parametric bivariate regression is probably also inappropriate).

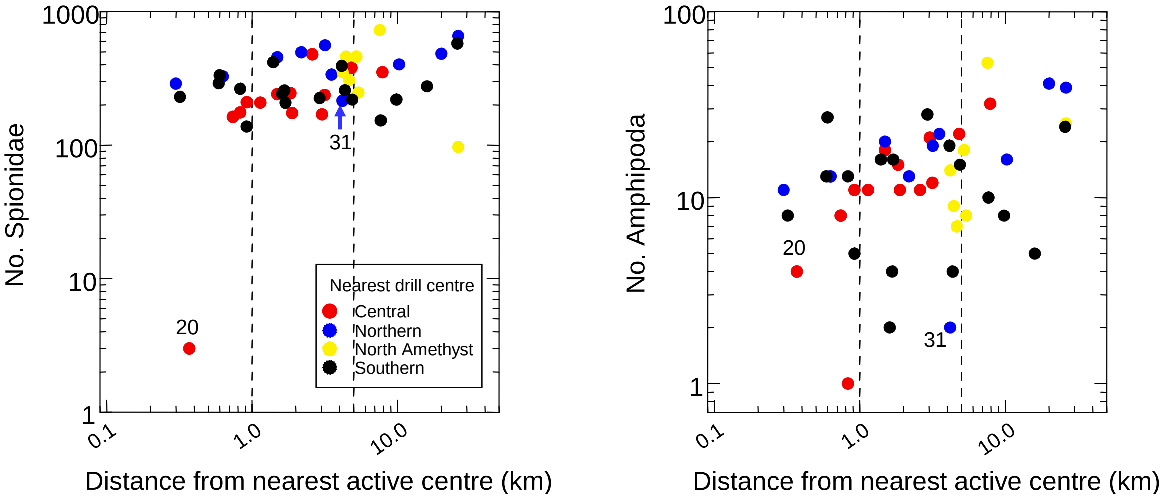

Figure 5-30 Spionidae and Amphipoda Abundances versus Distance from the Nearest Active Drill Centre (2008)

In 2008, Tellinidae abundance was strongly positively correlated (i.e., increased) with depth and was uncorrelated with distance (Table 5-26). The depth correlation (r or r_s = 0.5) was stronger than distance correlations for any other invertebrate community variable except Paraonidae abundance. The depth correlation increased (to 0.56, with or without station 31 included) with the two depth extremes (Reference stations 4 and 19) excluded (Figure 5-30; station 4 is arguably a negative outlier for the depth relationship at intermediate depths). The only evidence for any project effects was the reduced abundance of Tellinidae at station 20 relative to abundances at other stations in the mid-depth range.

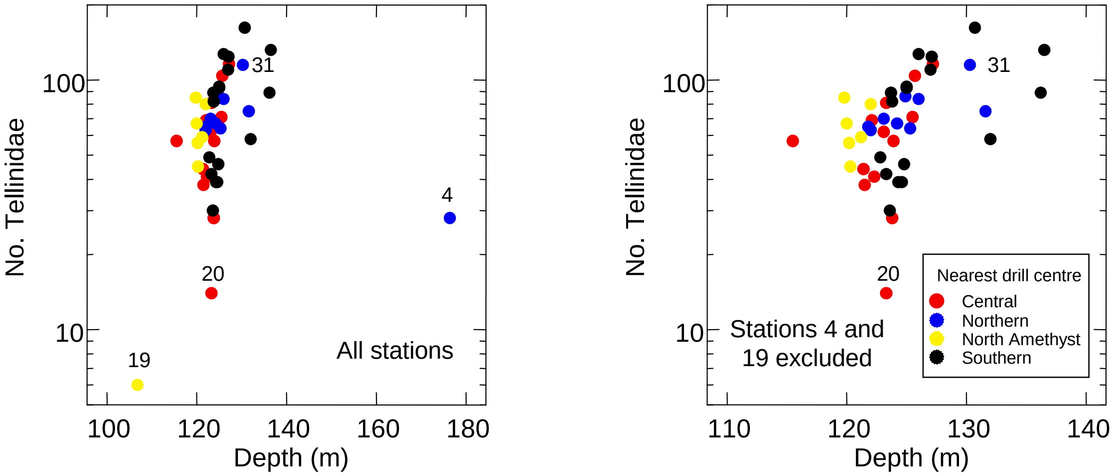

Figure 5-31 Tellinidae Abundance versus Depth (2008)

5.4.3.2 Comparison Among Years (2000, 2004, 2005, 2006 and 2008)

Table 5-28 provides results of RM regression models comparing benthic invertebrate community variables among years. Section 5.3.1.2 provides details on interpretation (see also Appendix B-5 for further details). Results in Table 5-28 are given as *F* values, which can be considered measures of effect sizes. *F* values greater than 1 indicate added variance attributable to the term tested. Table 5-29 provides significant Within Stations contrast terms. Appendix B-5 also provides a multi-year assessment of effects on overall community composition, a comparison between 2007 versus 2008 for stations nearest the North Amethyst drill centre, and estimates of effect sizes based on results provided from RM regression (e.g., multiple regression slopes) and other approaches.

Table 5-28 Results of RM Regression Analysis Comparing Benthic Invertebrate Community Variables Among Years

Term	Summary Measures			Taxon Abundances			
	Total Abundance	Standing Crop	Richness	Paraonidae	Spionidae	Tellinidae	Amphipoda
Among Stations							
Depth	3.12	0.01	2.93	0.00	0.01	**22.79*****	0.35
Northern (N) d	0.12	0.02	2.05	0.46	0.99	1.41	0.64
Central (C) d	1.35	0.28	0.53	8.13**	5.49*	0.07	0.00
Southern (S) d	1.03	0.89	0.16	5.32*	0.22	0.03	5.18*
North Amethyst (NA) d	0.21	0.18	0.05	0.78	0.32	0.01	0.00
Error 1^1	2.12**	1.89**	1.92**	**4.00*****	1.67*	**3.22*****	1.99**
Within Stations							
Year	3.04*	1.12	2.28	1.27	2.62*	2.19	2.14
Year × Depth	2.16	1.04	1.81	1.02	1.95	1.67	1.79
Year × N d	1.96	0.64	0.27	1.15	1.56	2.43	1.01
Year × C d	**9.54*****	1.07	3.34*	**18.62*****	**11.4*****	**5.65*****	2.79*
Year × S d	**9.98*****	0.74	5.72*	**10.22*****	**8.30*****	3.25*	**6.47*****
Year × NA d	1.03	1.49	1.21	0.54	0.79	0.86	1.12

Notes:
- Appendix B-5 explains terms and tests in the RM regression model.
- d = distances from various drill centres.
- $^*p \le 0.05$; $^{**}p \le 0.01$; $^{***}p \le 0.001$ (in bold).
- 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 5-29 Significant ($p \le 0.05$) Within Stations Contrasts for RM Regression Analyses of Benthic Invertebrate Community Variables (2000, 2004, 2005, 2006 and 2008)

Years	Summary Measures			Taxon Abundances			
	Total Abundance	Standing Crop	Richness	Paraonidae	Spionidae	Tellinidae	Amphipoda
2000 vs 2004-06, 2008	S d (**)	None	None	C d (*) **S d (***)**	None	None	S d (**)
2004 vs 2005-06, 2008	N d (*) C d (**)	None	None	C d (**)	C d (**)	C d (**)	C d (*) S d (**)
2005 vs 2006, 2008	C d (***) S d (***)	None	C d (*) S d (***)	N d (*) C d (***) S d (***)	C d (***) S d (***)	N d (*)	S d (***)
2006 vs 2008	Year (**) Depth (*)	None	Year Depth	C d (**)	Year C d (**)	Year Depth C d (*) S d (*)	Year

Notes:
- Appendix B-5 explains Within Stations contrasts in RM regression.
- d = distances from various drill centres.
- Significant X (depth or d) terms indicate that Y-X relationships differed significantly among the years compared (i.e., these are Year × X terms and tests).
- $^*p \le 0.05$; $^{**}p \le 0.01$; $^{***}p \le 0.001$ (in bold).

Results for individual variables are discussed below, but two general observations can be made. First, neither the overall Among Stations and Within Stations terms in Table 5-28 nor contrasts in Table 5-29 for distance from the North Amethyst drill centre (NA *d*) was significant. Therefore, there was no evidence of any distance gradients or changes in distance gradients that could confound future analyses of effects from the North Amethyst drill centre when drilling occurs there.

Second, 2005 was an unusual year for most variables. The largest and most significant changes occurred between 2005 and 2006 (see 2005 versus 2006, 2008 contrasts in Table 5-29) and, to a lesser extent, between 2004 and 2005. Values for most variables were lower in 2005 than in other years.

Summary Measures

Changes in depth and distance gradients over time for total abundance were a complex and often difficult to interpret combination of changes in those gradients for the three dominant taxa: Paraonidae, Spionidae and Tellinidae.

Total abundance increased with depth in every year except 2008 (Figure 5-32). Overall depth effects were not significant (see Among Stations depth term in Table 5-28) because the change in (reversal of) depth gradients from 2006 to 2008 was substantial and significant (see 2006 versus 2008 contrast in Table 5-29).

There has been no clear evidence of effects of the Northern drill centre on total abundance. Distance gradients for that drill centre in 2000 and 2004 were similar and positive (increases in abundance with distance) (see multiple regression slopes in Figure 5-32). After 2004, the distance gradient decreased in strength (2005) and then reversed. The difference in gradients between 2004 versus subsequent years was significant (Table 5-29), but represented relatively small changes in weak distance gradients.

In contrast, there was clear evidence of changes in distance gradients for the Southern and Central drill centres, although those changes did not always closely follow the onset of drilling. For example, the largest changes in distance gradients for the Central drill centre did not occur in 2005 after drilling began at that drill centre[12], but rather in 2006 (see 2005 versus 2006, 2008 contrasts in Table 5-29). Distance slopes for the Central drill centre were weakly negative (decreases with distance) in 2000, 2004 and 2005, then reversed and were strongly positive (increases with distance) by 2008 (Figure 5-32). Those changes may indicate that effects were delayed and/or intensified one or more years after drilling began, or may simply represent a combination of natural variance in distance gradients and variance of project effects over time and among dominant taxa.

Overall, there was evidence for some effects from the Southern drill centre. The “average” distance slope after drilling began (2004) would be positive versus the weakly negative slope in 2000 prior to drilling, and the Within Stations 2000 versus 2004-2006, 2008 contrast was significant at $p \leq 0.01$ (Table 5-29). However, if there were any effects, they have varied widely among EEM years.

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[12] Drilling began at the Central drill centre in October 2004.

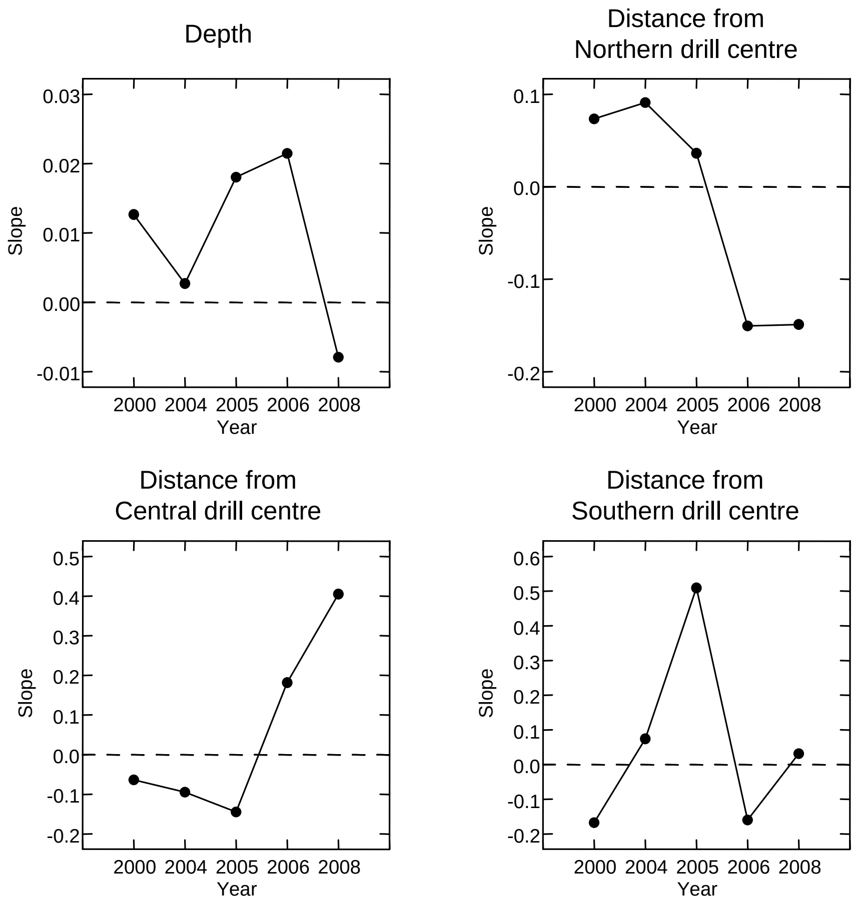

Figure 5-32 Multiple Regression Slopes for Total Abundance versus Depth and Distances from the Northern, Central and Southern Drill Centres for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

Figure 5-33 provides annual distributions of variable values (left plot) and medians and 20th and 80th percentiles (right plot) for the 35 stations considered in RM regression analyses. For total abundance (and also standing crop and taxon abundances), a log scale was appropriate for individual values since extremes were often well below (or occasionally well above) most other values. However, an arithmetic scale was used for medians and percentiles because distributions approached normal for central values (i.e., between the 20th and 80th percentiles, which exclude the lowest and highest values). As noted above, temporal changes in total abundance reflected a pattern common to most variables, progressively decreasing from 2000 to 2004 to 2005, then increasing from 2005 to 2006 to 2008.

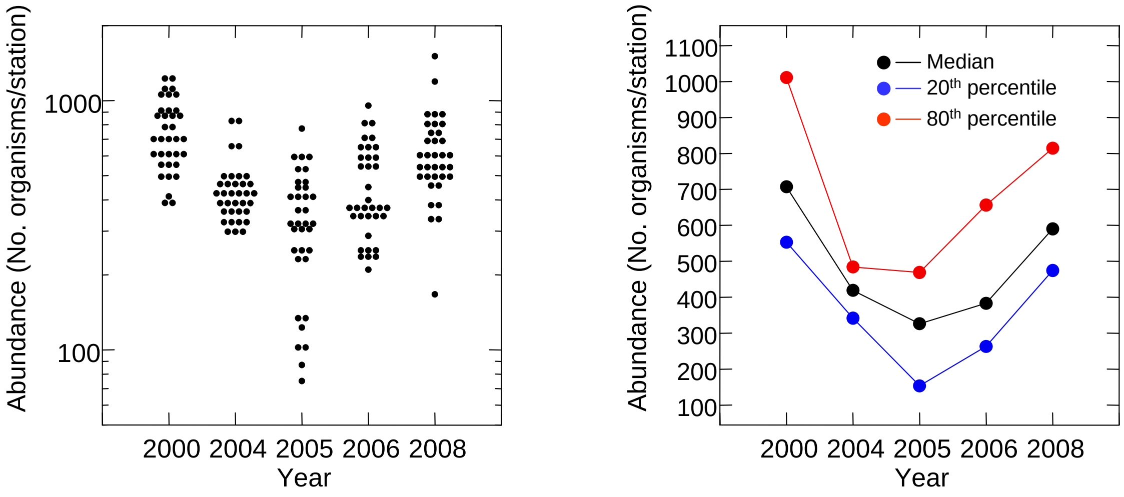

Figure 5-33 Total Abundance for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Note: The X axes on these figures are not linear.

In the multi-year comparison, there were no significant overall depth or distance gradients, nor any significant changes in those gradients, for standing crop (Tables 5-28 and 5-29). Standing crop values have remained reasonably constant over time (Figure 5-34).

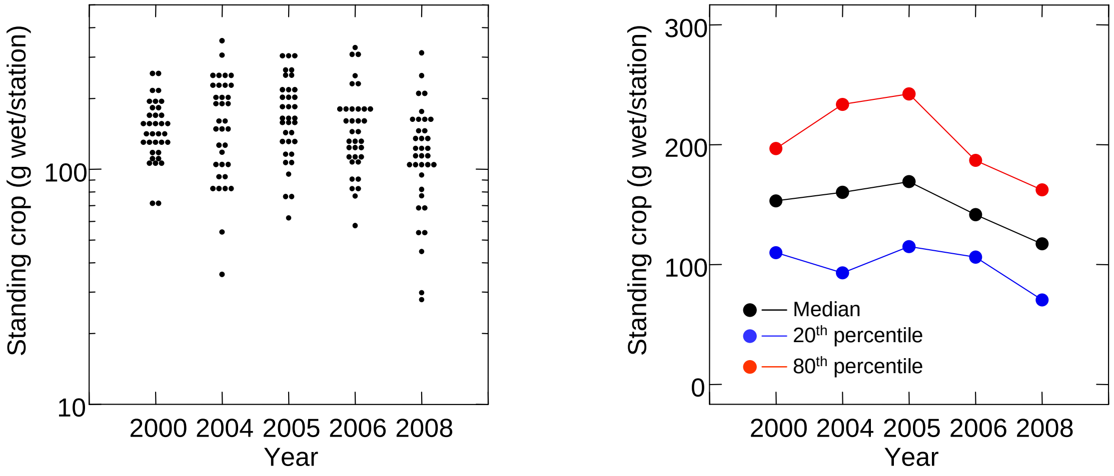

Figure 5-34 Standing Crop for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Note: The X axes on these figures are not linear.

Results for richness were a weak version of results for its correlate, total abundance (Tables 5-28 and 5-29). Richness increased with depth in 2000, with the depth gradient progressively increasing in strength to 2006 (Figure 5-35). There were significant changes in distance gradients for the Central and Southern drill centres over time, but those changes were similar to, but usually less significant than, changes in gradients for total abundance. Richness decreased from 2004 to 2005, then increased in 2006 and 2008 to baseline (2000) levels (Figure 5-36).

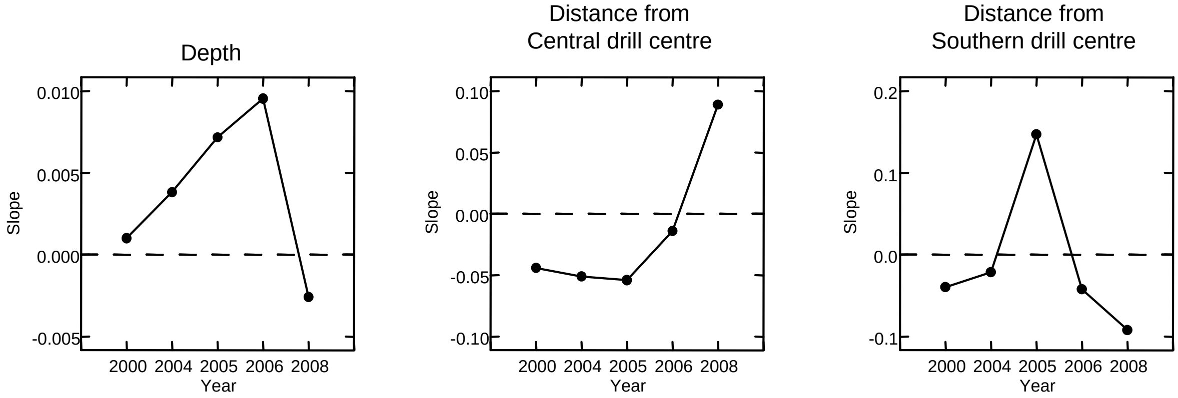

Figure 5-35 **Multiple Regression Slopes for Richness versus Depth and Distances from the Central and Southern Drill Centres for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008**

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

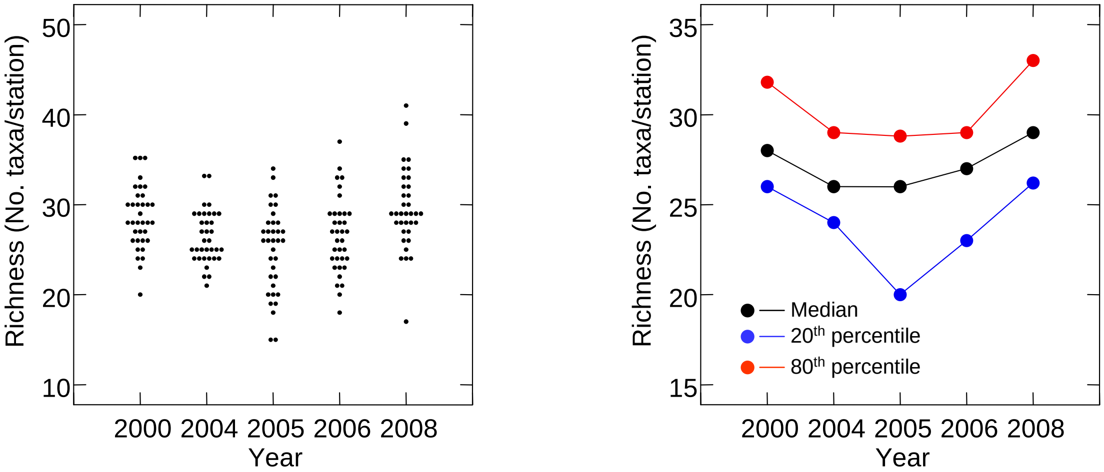

Figure 5-36 **Richness for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008**

Note: The X axes on these figures are not linear.

Figure 5-37 provides non-parametric Spearman rank correlations (r_s) between invertebrate community summary measures and distance from the nearest active drill centre for each sample year. Active drill centres were the Northern and Southern drill centres in 2004 (also assumed to be "active" for calculating correlations for 2000), and the Northern, Southern and Central drill centres in subsequent years. Sample sizes are provided in the plot for total abundance. For those sample sizes:

1. $|r_s| > 0.3$ are significant at $p < 0.05$;

2. $|r_s| > 0.4$ are significant at $p < 0.01$; and

3. $|r_s| > 0.5$ are significant at $p < 0.001$.

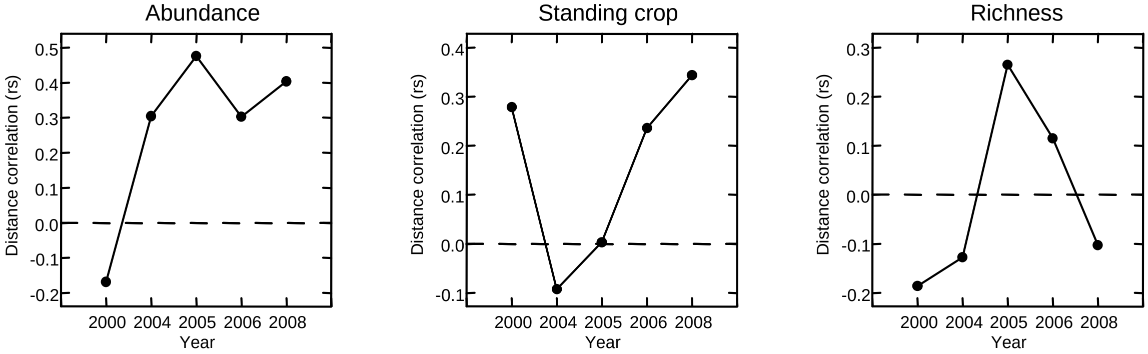

Figure 5-37 Spearman Rank Correlations (r_s) Between Invertebrate Community Summary Measures versus Distance from the Nearest Active Drill Centre for all Stations Sampled in 2000, 2004, 2005, 2006 and 2008 (excluding Station 31 in 2008)

Note: The X axes on these figures are not linear.

The simple distance correlations for summary measures in Figure 5-37 qualitatively supported results of the more detailed RM regression analyses. Overall distance correlations for total abundance were weakly negative (decreases with distance) in 2000, then reversed and were relatively constant (r_s = 0.3 to 0.5) after drilling began (Figure 5-37). Therefore, although there may have been evidence from the RM regression analyses of changes in effects from the Central and Southern drill centres over time (see above), net effects have been relatively constant since drilling began. Although distance correlations for total abundance have been significant at $p \leq 0.05$ in every EEM year, they have never been strong enough to adequately estimate threshold distance (Section 5.4.3.1; Husky Energy 2006, 2007).

Distance correlations for standing crop have been approximately 0 to weakly positive (Figure 5-37), with the strongest positive correlations occurring during baseline (2000) and 2008. It was possible to estimate the extent of decreases in standing crop with proximity to drill centres in 2008, but that estimate (1.5 km) simply indicated that the strongest distance correlation during EEM years was largely a function of low standing crop at some stations within 1 to 2 km of drill centres.

Taxon Abundances

There were no significant depth gradients, or any significant changes in depth gradients over time, for Paraonidae abundance (Tables 5-28 and 5-29). Distance gradients (increases with distance) for the Northern drill centre increased from 2000 to 2005, and then reversed (Figure 5-38). However, those were relatively small changes in weak distance gradients.

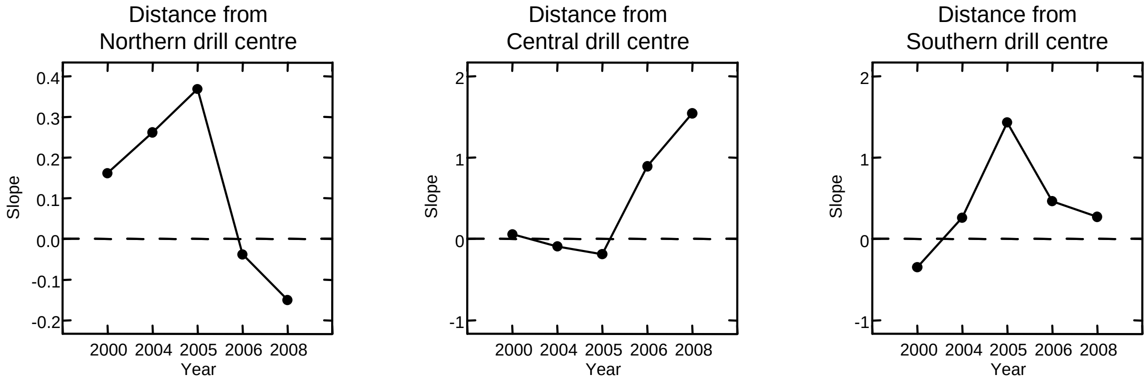

Figure 5-38 **Multiple Regression Slopes for Paraonidae Abundance versus Depth and Distances from the Northern, Central and Southern Drill Centres for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008**

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

Distance effects for the Central and Southern drill centres for Paraonidae abundance were similar to but stronger than effects on total abundance (compare *F* values for C and S *d* terms in Table 5-28 and the significance of C and S *d* contrasts in Table 5-29 between the two variables, and also time profiles in Figure 5-38 versus Figure 5-32). As for total abundance, distance gradients (i.e., slopes in Figure 5-38) for the Central drill centre did not change substantially in the 2005 EEM program after drilling began but then increased substantially and significantly in strength in the 2006 and 2008 programs. Distance slopes for the Southern drill centre reversed from negative in 2000 to positive in 2004 after drilling began, increased in strength in 2005, then decreased in strength (but remained positive) in 2006 and 2008.

Effects from the Central and Southern drill centres substantially reduced Paraonidae abundances for the 35 stations considered in RM regression analyses (Figure 5-39). In each year since 2005, there have been 23 abundances less than the baseline (2000) minimum of 15 Paraonidae/station. One of those low values occurred within 0.63 km of the Northern drill centre; the other 22 occurred within 2 km of the Central or Southern drill centres. Six of those low values were 0 (i.e., no Paraonidae were collected). Median abundances decreased from more than 100/station in 2000 to 40 to 80/station after drilling began in 2004.

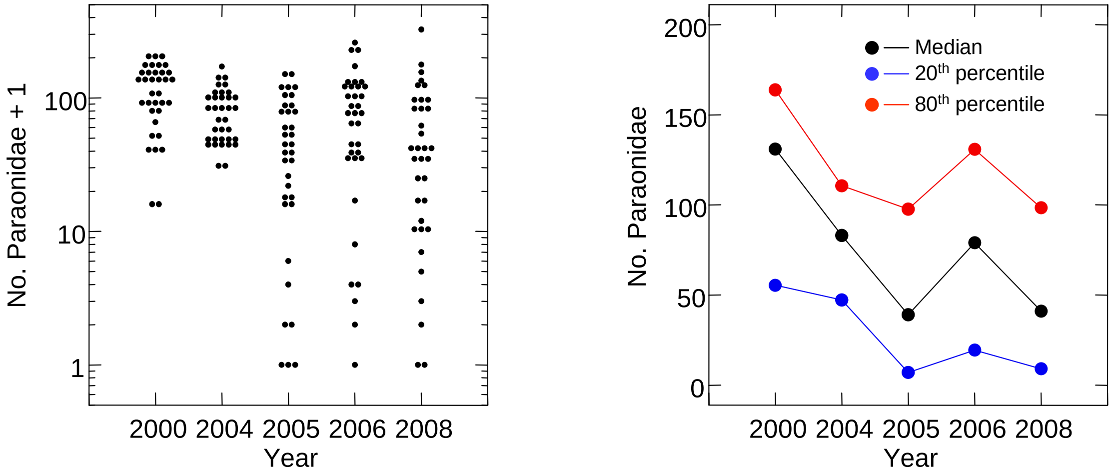

Figure 5-39 Paraonidae Abundance for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Note: The X axes on these figures are not linear.

Distance gradients for Paraonidae abundance since 2005 were strong enough to provide reasonably robust estimates of threshold distance (Table 5-30). The estimated spatial extent of effects was approximately 2 km in 2004, approximately 3 km in 2005 and 2006, and approximately 4 km in 2008 (Table 5-30). Therefore, there appeared to be a progressive increase in the spatial extent of effects over time. However, estimates for 2004 were based on a relatively weak distance relationship and had wide 95% CIs, and 2008 could have been an "unusual" year. A safer conclusion based on lower 95% CIs listed in Table 5-30 would be that the spatial extent of effects are at least 1 to 3.5 km.

Table 5-30 Results for Parametric Regressions of Paraonidae Abundance on Distance from the Nearest Active Drill Centre (2004, 2005, 2006 and 2008)

Result/Estimate	**2004**	**2005**	**2006**	**2008**
No. stations	56	44	59	46
Bivariate *r*	0.421**	**0.633*** **	**0.618*** **	**0.642*** **
Hockey-stick model *R*	0.470**	**0.756*** **	**0.792*** **	**0.751*** **
p for adding threshold	0.094	**<0.001**	**<0.001**	**<0.001**
antilog X_T (threshold distance in km)	2.0	2.7	2.8	3.8
95% CI	0.8 to 4.9	1.6 to 4.5	1.9 to 4.2	3.4 to 6.9

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 and 2008.
  Distance and abundances (+ 1) were log-transformed.
- Station 31 excluded from 2008 estimates.

RM regression results for Spionidae abundance were similar to those for total abundance (Tables 5-28 and 5-29), as expected for the most abundant taxon. Depth effects on Spionidae were not significant and were weaker than depth effects on total abundance, which were primarily influenced by the strong depth effects on Tellinidae (see below). Otherwise, time profiles for distance gradients for the Central and Southern for Spionidae abundance (Figure 5-40) were similar to those for total abundance (Figure 5-32).

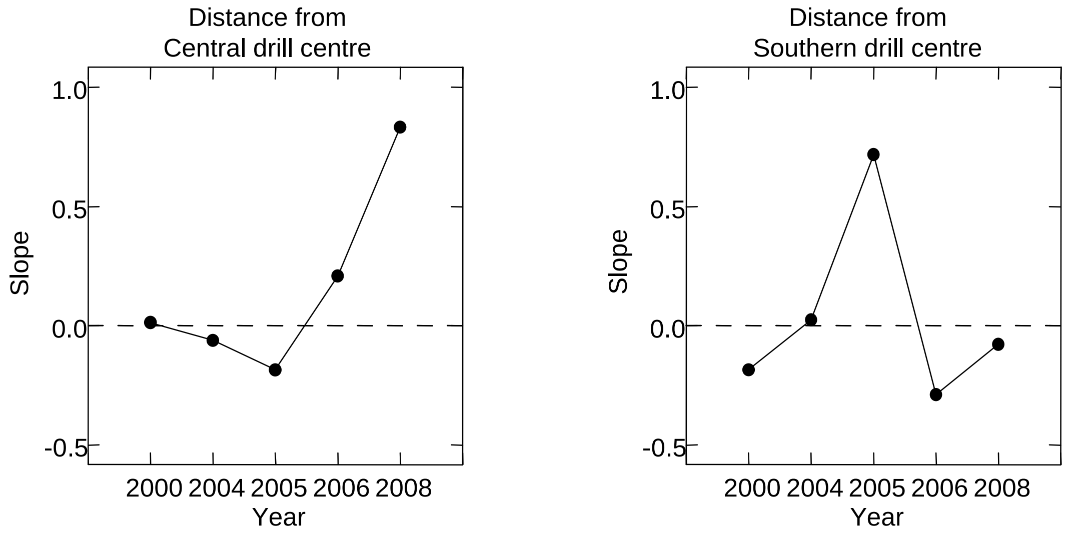

Figure 5-40 **Multiple Regression Slopes for Spionidae Abundance versus Distances from the Central and Southern Drill Centres for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008**

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

Spionidae abundance decreased from 2000 to 2005 and then increased, returning to baseline (2000) values by 2008 (Figure 5-41). Extreme low values (all within 2 km of drill centres) occurred only in 2005 and at station 20 (0.37 km from the Central drill centre) in 2008.

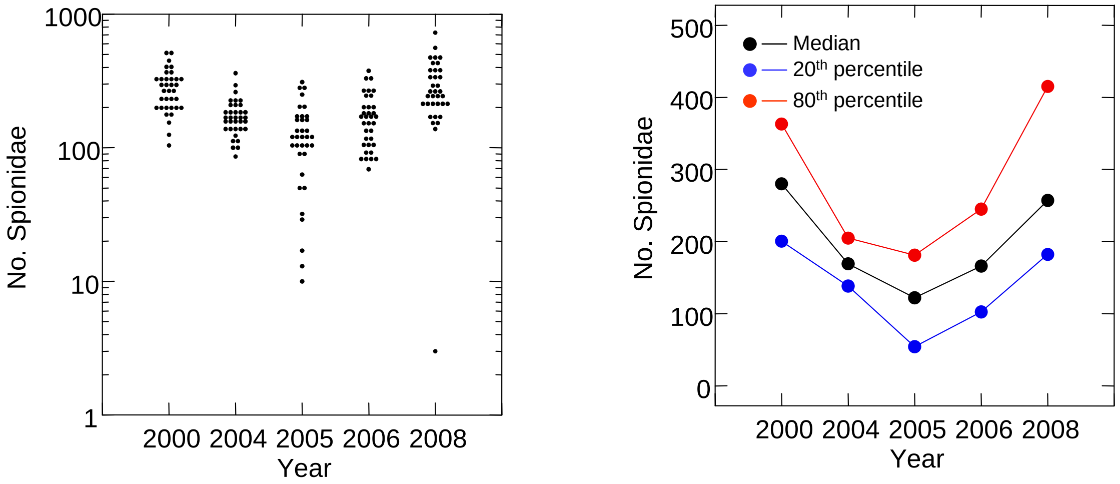

Figure 5-41 **Spionidae Abundance for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008**

Note: The X axes on these figures are not linear.

Tellinidae abundance increased with increasing depth in every year (Figure 5-42), and overall depth effects were stronger than any distance effects for Tellinidae abundance or any other variable (i.e., *F* for the Among Stations depth term for Tellinidae abundance is the largest *F* value in Table 5-28). Depth effects on Tellinidae were greatest in 2006 and least in 2008 and these depth effects were largely responsible for depth effects on total abundance shown in Figure 5-32.

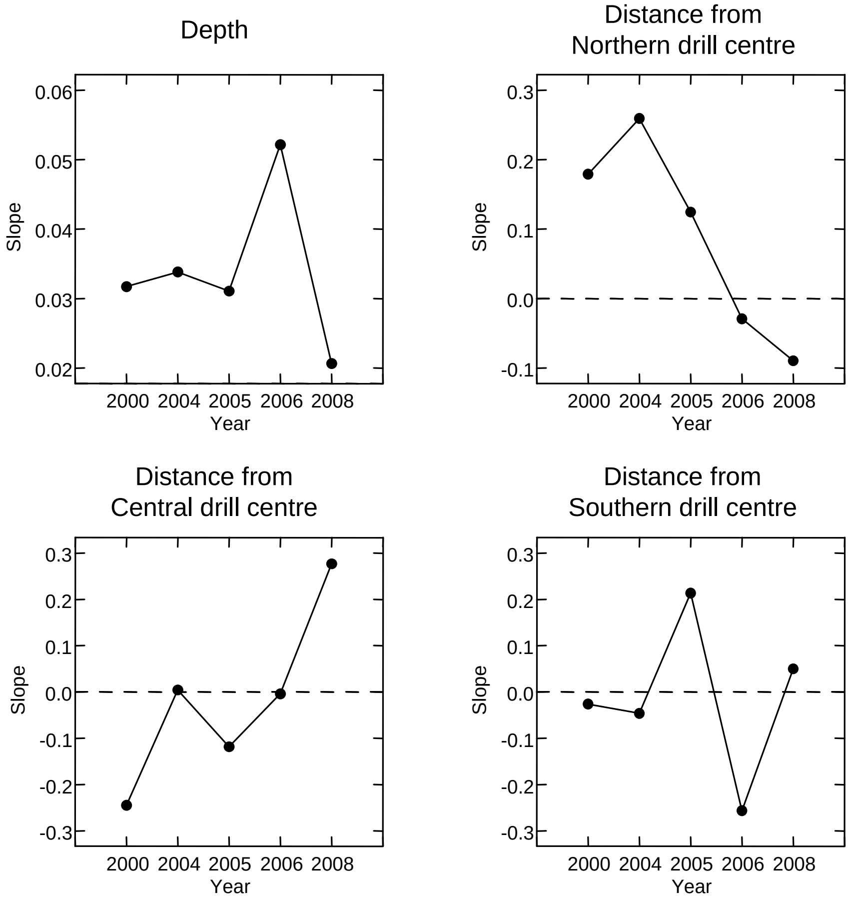

Figure 5-42 Multiple Regression Slopes for Tellinidae Abundance versus Depth and Distances from the Northern, Central and Southern Drill Centres for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

There were some changes in distance gradients for Tellinidae abundance, as indicated by the significant Within Stations distance terms and contrasts in Tables 5-28 and 5-29. Those changes in gradients could represent project effects, since they were largely associated with the Central and Southern drill centres and distance slopes for the Central drill centre have increased from negative to positive over time (Figure 5-42).

Tellinidae abundance decreased from a median of approximately 100 Tellinidae/station in 2000 to a median of approximately 50 Tellinidae/station in 2004 (Figure 5-43). Medians have increased since 2004, but have not returned to baseline values.

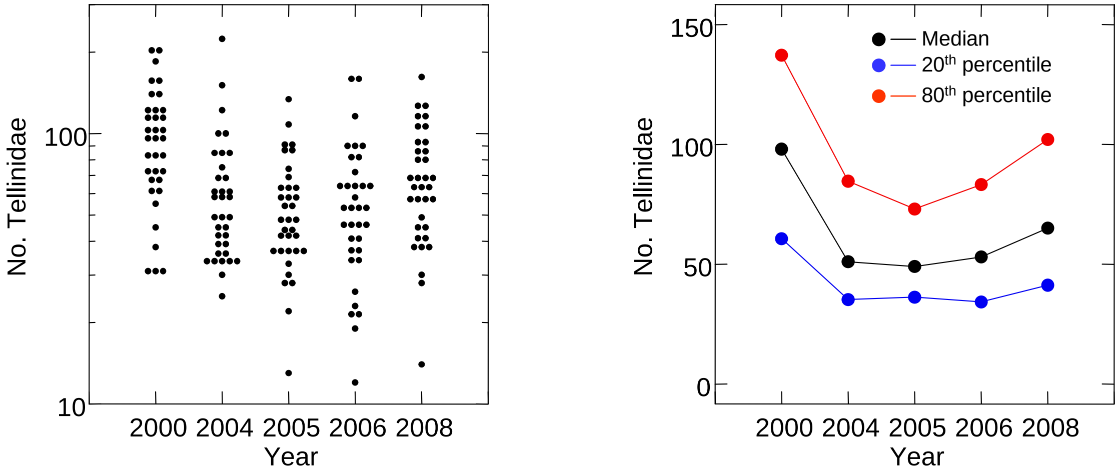

Figure 5-43 Tellinidae Abundance for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Note: The X axes on these figures are not linear.

Overall depth gradients, and changes in depth gradients over time, were not significant for Amphipoda abundance (Tables 5-28 and 5-29). There were also no significant natural or project-related effects of distance from the Northern drill centre.

Changes in distance gradients for Amphipoda abundance were evident for the Central and Southern drill centres in the EEM years following onset of drilling at those two drill centres. However, distance gradients and any project effects varied widely among subsequent EEM years (Figure 5-44). Amphipoda abundance was unrelated to distance from the Central drill centre in 2000 and decreased with distance from that drill centre in 2004. In 2005, after drilling began, Amphipoda abundance increased with distance, a gradient that was even steeper in 2008. However, in 2006, Amphipoda abundance was unrelated to distance from the Central drill centre, as in 2000. Similarly, Amphipoda was unrelated to distance from the Southern drill centre in 2000, increased with distance in 2004 (the first sample year after drilling began) and again in 2005, and was unrelated to distance in 2006 and 2008.

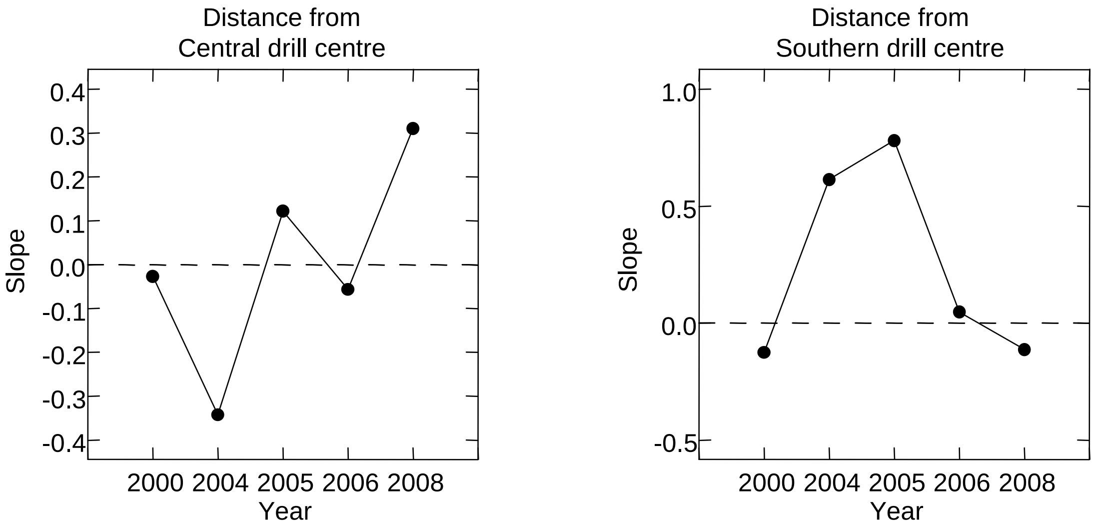

Figure 5-44 Multiple Regression Slopes for Amphipoda Abundance versus Distances from the Central and Southern Drill Centres for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

Median Amphipoda abundances decreased from more than 20 Amphipoda/station in 2000 to approximately 10 Amphipoda/station in subsequent EEM years (Figure 5-44). In EEM years, there were 29 Amphipoda abundances less than the baseline (2000) minimum of 5 Amphipoda/station. Twenty-three (23) of these low abundances occurred within 2 km of active drill centres.

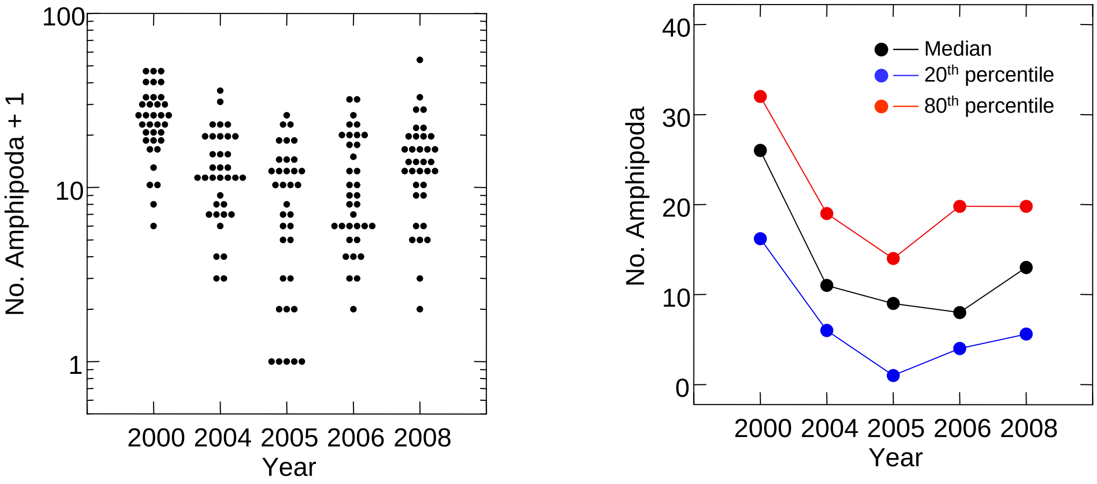

Figure 5-45 Amphipoda Abundance for 35 Stations Sampled in 2000, 2004, 2005, 2006 and 2008

Note: The X axes on these figures are not linear.

Figure 5-46 provides correlations (r_s) between taxon abundances and distance from the nearest active drill centre, based on all stations sampled in each year. Distance gradients for Paraonidae increased in strength in 2004 from approximately 0 to 0.5 or greater. Distance correlations for Amphipoda abundance were significantly negative (decreases with distance) in 2000 and reversed and were significantly positive in EEM years. Thus, although distance gradients for Amphipoda abundance for the Central and Southern drill centres varied widely and significantly among EEM years (Figure 5-43), overall distance gradients were relatively consistent over those same years (r_s approximately 0.5). For Spionidae abundance, there was an apparent increase from a weak negative distance correlation in 2000 to positive but weak and variable correlations in EEM years, which would be consistent with the occasional occurrence of near-field effects within 1 or 2 km of drill centres. In contrast, distance correlations for Tellinidae abundance have never been significant, and correlations for baseline (2000) and EEM years have fluctuated around 0.

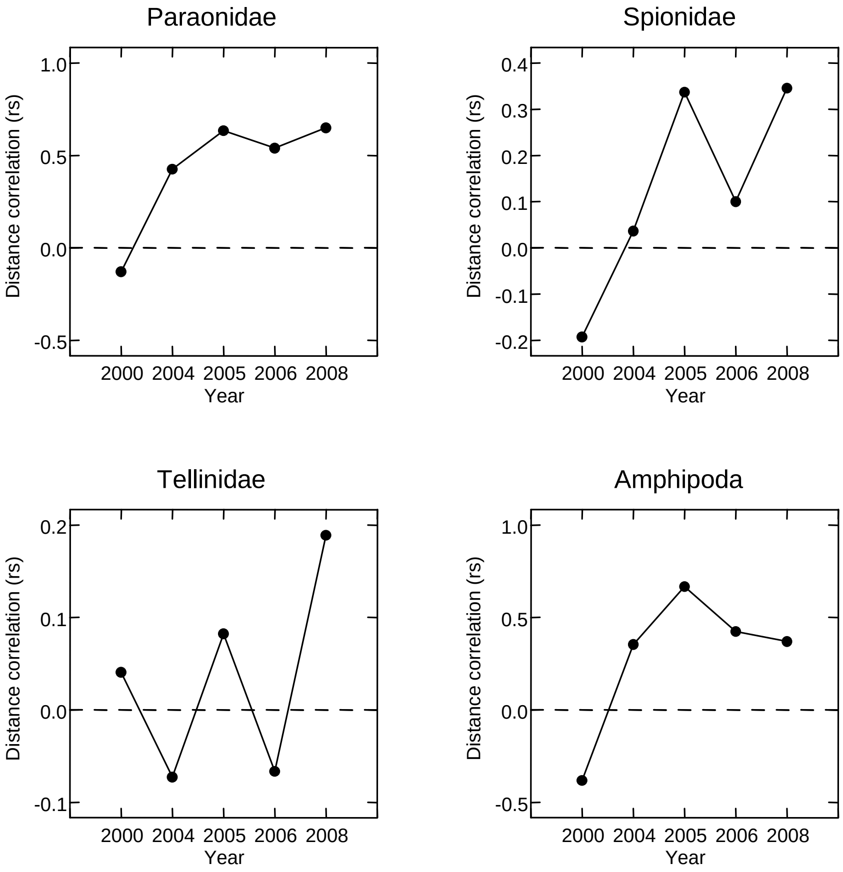

Figure 5-46 Spearman Rank Correlations (r_s) Between Invertebrate Taxon Abundances versus Distance from the Nearest Active Drill Centre for all Stations Sampled in 2000, 2004, 2005, 2006 and 2008 (excluding station 31 in 2008)

Notes: The X axes on these figures are not linear; these figures are meant to indicate general trends rather than to compare annual differences.

Results of the more complex RM regression analyses and the simpler non-parametric distance analyses of taxon abundances qualitatively agreed with results of NMDS analyses of overall community composition provided in Appendix B-5. In 2000, communities were similar at all stations. Some differences in community composition occurred in 2004, but those differences were unassociated with distance from the Northern and Southern drill centres (active prior to 2004). In 2005, 2006 and 2008, there were clear differences in community composition between stations within versus beyond 2 km of active drill centres, with distance effects greatest for stations within 1 km. The distance effects were largely dependent on reductions in the relative and absolute abundances of Paraonidae, but there may also have been corresponding increases in the relative and absolute abundances of several sub-dominant polychaete taxa (e.g., Phyllodocidae and Sabellidae). Spionidae and especially Tellinidae appeared largely unaffected by distance to drill centres and, instead, defined an axis of predominantly natural variance (see Appendix B-5 for details).

Carry-over Effects

Carry-over effects, or persistent differences among stations unrelated to depth or distance effects, were significant at $p < 0.01$ (see Among Stations Error 1 terms in Table 5-28). Some of the carry-over effects may have represented “lack-of-fit” to the specific models used, since they were greatest for Paraonidae and Tellinidae abundances, the two variables with the strongest distance or depth effects. However, carry-over effects for standing crop and richness were similar in strength and significance to carry-over effects for Amphipoda abundance, which was affected by distance.

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

Table 5-31 provides rank correlations (r_s) between benthic invertebrate community variables and >C_{10}-C_{21} HC concentrations for all EEM years, and results of van Belle tests comparing correlations among years and testing mean correlations over all four years. For most variables, particularly those more strongly correlated with >C_{10}-C_{21} HCs, correlations were weaker in 2004 than in subsequent years. However, the van Belle tests for differences in correlations have limited power for comparisons of only four years. Consequently, differences in correlations among years were significant only for Paraonidae abundance. In contrast, tests of mean concentrations were powerful because the effective sample size was $n = 206$ stations.

Table 5-31 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Variables and >C_{10}-C_{21} HCs (2004, 2005, 2006 and 2008)

***Y* Variable**	**r_s within Years**				**Differences in r_s Among Years**	**Mean r_s**
	2004 (*n*=56 stations)	**2005 (*n*=44 stations)**	**2006 (*n*=59 stations)**	**2008 (*n*=47 stations)**		
Abundance	–0.170	**–0.534*****	–0.429**	–0.430**	NS	**–0.381*****
Standing crop	–0.006	–0.075	–0.264*	–0.273	NS	–0.156*
Richness	–0.140	–0.313*	–0.106	–0.009	NS	–0.137*
Paraonidae	–0.066	**–0.647*****	**–0.578*****	**–0.544*****	*	**–0.446*****
Spionidae	0.004	–0.402**	–0.258*	–0.319*	NS	**–0.232*****
Tellinidae	–0.047	–0.109	–0.047	–0.330*	NS	–0.125
Amphipoda	–0.440**	**–0.729*****	**–0.448*****	–0.394**	NS	**–0.493*****

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.
- Richness was based on families.

With one exception (Spionidae abundance in 2004), within-year correlations between invertebrate community variables and >C_{10}-C_{21} HCs in EEM years were negative (i.e., variable values decreased with increasing >C_{10}-C_{21} HC concentrations) (Table 5-31). All mean correlations were negative and, except for Tellinidae abundance, significant at $p \leq 0.05$. However, no mean correlation was stronger than $r_s = -0.5$, and within-year correlations stronger than $r_s = -0.5$ occurred only for total abundance and Paraonidae and Amphipoda abundances. Therefore, parametric analyses were restricted to those three variables.

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

Figure 5-47 plots the relationship between total abundance and >C_{10}-C_{21} HC concentrations for the 47 stations sampled in 2008. Adding a threshold concentration significantly reduced error variance relative to a bivariate log-log concentration-response relationship (Table 5-32). The estimated threshold concentration was 1.0 mg/kg dry weight, with 95% CI of 0.2 to 5.6 mg/kg. The estimated threshold was above the RDL of 0.3 mg/kg, but the 95% CIs extended below the RDL.

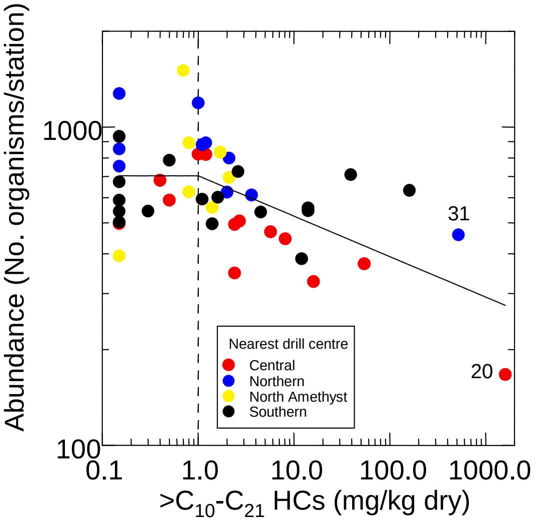

Figure 5-47 Total Abundance versus >C_{10}-C_{21} HC Concentrations (2008)

Estimated threshold concentrations for effects on total abundance in other years ranged from 0.3 (2006) to 2.2 (2004). A threshold could not be estimated in 2005.

Table 5-32 Results for Parametric Concentration-Response Models for Total Abundance versus $>C_{10}$-C_{21} HC Concentrations (2004, 2005, 2006 and 2008)

Result/Estimate	**2004**	**2005**	**2006**	**2008**
No. stations	56	44	59	47
Bivariate *r*	–0.285*	**–0.618*****	**–0.486*****	**–0.518*****
Hockey-stick model *R*	0.406**	**0.618*****	**0.491*****	**0.583*****
p for adding threshold	0.030	1.000	0.547	0.035
antilog X_T (threshold in mg/kg dry weight)	2.2	None	0.3	1.0
95% CI	0.2 to 24		<0.1 to 3.6	0.2 to 5.6

Notes:
- *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in bold).
- The Northern and Southern drill centres were active in 2004; those two centres and the Central drill centre were active in 2006 and 2008.
- Distance and abundances were log-transformed.

In 2008, adding a threshold to the strong relationship between Paraonidae abundance and $>C_{10}$-C_{21} HC concentrations significantly reduced error variance relative to a bivariate regression (Table 5-33). The estimated threshold effects concentration was 0.9 mg/kg dry weight, but the 95% CI of 0.2 to 3.1 mg/kg included the RDL of 0.3 mg/kg. Station 31, within 0.4 km of a delineation well and with high $>C_{10}$-C_{21} HC concentrations, was an outlier, with approximately 50 Paraonidae/station (similar to background values) (Figure 5-48). Deleting station 31 does not substantially alter the estimated threshold concentration (1.0 mg/kg versus 0.9 mg/kg for all stations).

Estimated effect threshold concentrations for Paraonidae abundance in 2005 and 2006 were approximately 1 mg/kg, similar to the 2008 estimate (Table 5-33). In 2004, when the concentration-response relationship was weaker, adding a threshold reduced error variance relative to bivariate regression mostly because any concentration-relationship relationship was restricted to a few stations with $>C_{10}$-C_{21} HC well above the RDL of 0.3 mg/kg.

Table 5-33 Results for Parametric Concentration-Response Models for Paraonidae Abundance versus $>C_{10}$-C_{21} HC Concentrations (2004, 2005, 2006 and 2008)

Result/Estimate	**2004**	**2005**	**2006**	**2008**
No. stations	56	44	59	47
Bivariate *r*	–0.239	**–0.741*****	**–0.832*****	**–0.643*****
Hockey-stick model *R*	0.439**	**0.763*****	**0.907*****	**0.704*****
p for adding threshold	0.003	0.077	**<0.001**	0.010
antilog X_T (threshold in mg/kg dry weight)	6.4	0.7	1.3	0.9
95% CI	1.6 to 26	0.2 to 2.5	0.8 to 2.2	0.2 to 3.1

Notes:
- *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in bold).
- The Northern and Southern drill centres were active in 2004; those two centres and the Central drill centre were active in 2006 and 2008.
- Distance and abundances were log-transformed.

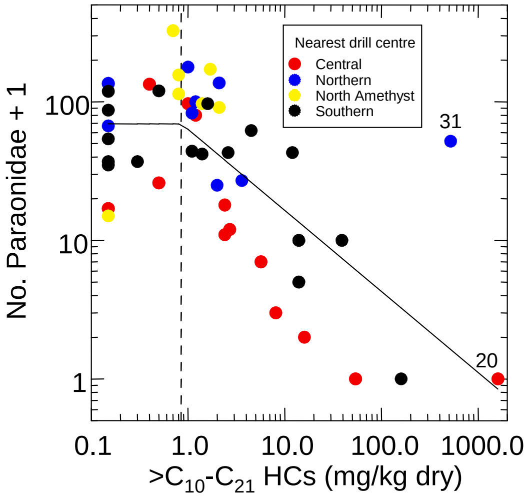

Figure 5-48 Paraonidae Abundance versus >C_{10}-C_{21} HC Concentrations (2008)

In 2008, Amphipoda abundance decreased significantly with >C_{10}-C_{21} HC concentrations (Table 5-34). However, adding a threshold did not significantly reduce error variance, and it was surprising that the overall relationship was significant (Figure 5-49). In 2006, results were similar; the relationship was too weak to define a threshold. In 2005, there was a strong relationship that extended over the entire range of concentrations sampled and to concentrations at or below RDL. In 2004, adding a threshold (4.9 mg/kg) significantly reduced error variance for a strong bivariate relationship and the 95% CI of 2.2 to 11 mg/kg excluded the RDL of 0.3 mg/kg.

Table 5-34 Results for Parametric Concentration-Response Models for Amphipoda Abundance versus >C_{10}-C_{21} HC Concentrations (2004, 2005, 2006 and 2008)

Result/Estimate	**2004**	**2005**	**2006**	**2008**
No. stations	56	44	59	47
Bivariate *r*	**–0.661*****	**–0.773*****	**–0.411*****	**–0.470*****
Hockey-stick model *R*	**0.739*****	**0.773*****	**0.411*****	**0.494*****
p for adding threshold	**<0.001**	0.954	1.000	0.243
antilog X_T (threshold in mg/kg dry weight)	4.9	0.2		0.7
95% CI	2.2 to 11	<0.1 to 1.0		<0.1 to 7.2

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 and 2008.
- Distance and abundances were log-transformed.

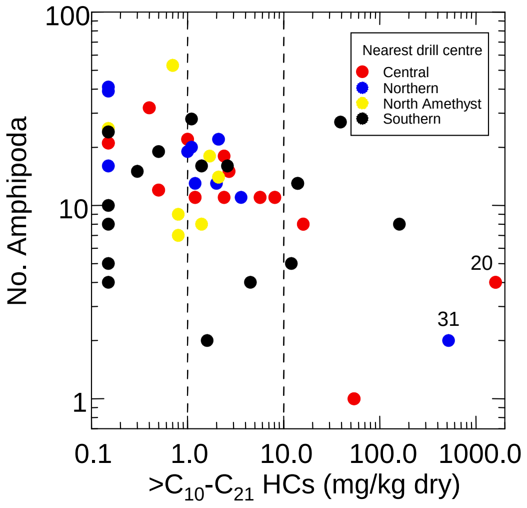

Figure 5-49 Amphipoda Abundance versus >C_{10}-C_{21} HC Concentrations (2008)

In summary, threshold concentrations could be estimated for total abundance and Paraonidae abundance in 2008, and were approximately 1 mg/kg (Tables 5-32 and 5-33). However, 95% CIs for estimated effects concentrations included the RDL of 0.3 mg/kg. More generally, threshold effects concentrations for 2005 to 2008, whenever they could or should be defined, were approximately 1 mg/kg. Effects on overall community composition were also evident at concentrations of 1 to 10 mg/kg after 2004 (Appendix B-5). In 2008, abundances of the polychaete taxa Phyllodocidae, Sabellidae and Sigalionidae increased significantly with increasing >C_{10}-C_{21} HC concentrations. Those concentration-response were generally weaker or not evident prior to 2008 and especially prior to 2006 (Appendix B-5).

5.5 Summary of Findings

5.5.1 Physical and Chemical Characteristics

Sediments collected from 47 stations in 2008 were predominantly (97.8%) sand. Fines (1.2%) and TOC content (1.0%) were low.

PAHs and BTEX were not detected at any station in 2008. >C_{10}-C_{21} HCs were detected at 37 of 47 stations at an RDL of 0.3 mg/kg. >C_{21}-C_{32} HCs were detected at 41 of 47 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 47 stations.

In 2008, fines and TOC content were positively correlated. Concentrations of barium and other metals were positively correlated with fines and TOC content; concentrations of >C_{10}-C_{21} HCs were positively correlated with TOC. >C_{10}-C_{21} HC and barium concentrations, both constituents of drilling muds, were strongly positively correlated. Concentrations of sulphur and sulphide were positively correlated with concentrations of the >C_{10}-C_{21} HCs and barium. Concentrations of other metals were positively correlated with concentrations of barium.

In 2008, concentrations of >C_{10}-C_{21} HCs and barium decreased significantly with distances from drill centres. Estimated zones of influence based on >C_{10}-C_{21} HC and barium concentrations were 10.4 km (95% CI: 5.2 to 20.9 km) and 2.4 km (95% CI: 1.5 to 3.8 km), respectively. These zones of influence were based on distance from the nearest active drill centre (Northern, Central, Southern). >C_{10}-C_{21} HCs and barium concentrations were also high at station 31, 4 km from the Northern drill centre but within 0.4 km of a recently drilled delineation well (K-03).

In 2008, sulphur and sulphide concentrations decreased significantly with distance from the nearest active drill centre. Concentrations well above RDL were observed only at stations within 1 km of the Central and Southern drill centres (and also at station 31 for sulphur). Fines, gravel and TOC content, concentrations of metals other than barium, and redox were not significantly correlated with distance (or depth). Ammonia concentrations increased with distance, but that relationship was not significant. The only concentrations greater than 10 mg N/kg occurred at one station within 0.5 km of the Central drill centre and at a Reference station almost 30 km from any drill centre.

>C_{10}-C_{21} HCs were not detected at an RDL of 0.3 mg/kg at 47 stations sampled in baseline (2000). Most >C_{10}-C_{21} HC concentrations were greater than RDL in 2004, 2005, 2006 and 2008 after drilling began. >C_{10}-C_{21} HC concentrations decreased significantly with distances from the Northern and Southern drill centres in 2004, after drilling started at these two centres. Distance gradients for both drill centres were stronger in 2004 than in subsequent years despite continued drilling at these two drill centres. 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 in 2006 was stronger than in 2005 and 2008.

Median >C_{10}-C_{21} HC concentrations for 35 stations sampled every year were 1 mg/kg in 2004, and did not change substantially over time. 80th percentiles were approximately 10 mg/kg (i.e., 20% of concentrations were greater than 10 mg/kg). Correlations between >C_{10}-C_{21} HC concentrations and distance from the nearest active drill centre based on all stations sampled in EEM years were significantly negative (decreases with distance) in 2004, increased in strength in 2005, and have remained strong in 2006 and 2008. Estimated zones of influence based on >C_{10}-C_{21} HCs concentrations and distance to the nearest active drill centre have ranged from 6.3 km to 10.4 km in EEM years, and should be considered approximately equal given the wide CIs for those estimates. Lower bounds for the CI have been 4 to 5 km, which can be used as an estimate of the minimum extent of zones of influence (i.e., estimated zones of influence were at least 4 to 5 km).

Barium was detected at concentrations of 120 to 210 mg/kg at the 46 stations sampled during baseline (2000). In 2000, barium concentrations decreased with distance from the Northern drill centre and that gradient did not change in 2004 and 2005. The weak baseline gradient was not apparent in 2006 and 2008, when barium concentrations did not decrease (2006) or increased slightly (2008) with distance. In contrast, relationships with distance from the Southern drill centre changed substantially and significantly between baseline and EEM years, from no-relationship in 2000 to a strong decrease in concentration with distance in 2004. The distance gradient for the Southern drill centre was stronger in 2004 than in 2005, 2006 and 2008. 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 has progressively increased in strength since 2005.

Median barium concentrations have increased slightly since 2000, but remain within the baseline range. In contrast, 80th percentiles have increased substantially from less than 200 mg/kg to greater than 300 mg/kg in 2008. Therefore, project-related increases in barium concentrations to above-background levels have largely been restricted to stations near the Central and Southern drill centres. Correlations between barium and distance from the nearest active drill centre were weakly negative in 2000 (Northern and Southern drill centres assumed active), were strongly negative in 2004 after drilling began, and have increased in strength in more recent years. Estimated zones of influence based on barium concentrations and distance to the nearest active drill centre have ranged from 1.9 to 3.6 km in EEM program years with no apparent increase or decrease over time. Lower bounds for 95% CIs have been 1.5 to 2 km, which can be used as an estimate of the minimum extent of zone of influence.

Sulphur concentrations were not measured in 2000. Concentrations decreased with distance from the nearest active drill centre in 2004, 2005, 2006 and 2008, although those correlations varied widely in strength and significance. Distance gradients for the Central drill centre have progressively increased in strength from no-gradient in 2004 (before drilling) to a strong decrease in concentration with distance in 2008. In contrast, distance gradients for the Southern drill centre progressively changed from a decrease with distance in 2004 to an increase with distance in 2008. Median and 80th percentile sulphur concentrations were higher in 2008 than in previous years. In general, project effects appear restricted to stations within 1 km of the Central and Southern drill centres; concentrations at stations beyond 1 km from drill centres were usually near or below RDL (the RDL was 0.02% in most years).

Fines and TOC content, concentrations of metals other than barium and ammonia concentrations were largely unaffected by project activity and distance from the drill centres. Extreme values for these variables have occasionally been observed at a few stations within 0.5 to 1 km of drill centres but correlations between these variables and distance from the nearest active drill have usually been weaker than distance correlations for sulphur and were rarely significant.

Depth was the primary factor affecting fines content, with fines content increasing with increasing depth in all years, including 2000. TOC content is reported to one decimal place, and most values have been within the narrow range of 0.8 to 1.0 g/kg. Concentrations of metals other than barium have increased over time but with no apparent relationship with drilling activity and distance from drill centres. Ammonia concentrations (not measured in 2000) were lower in 2006 than in other years.

Carry-over effects, or persistent differences among stations unrelated to distance or depth, were small and significant at $p \leq 0.01$ only for the three variables affected by project activities: $>C_{10}$-C_{21} HCs, barium and sulphur. Therefore, carry-over effects appeared to be localized (small-scale) spatial differences and project effects not captured by large-scale distance regressions (i.e., lack of fit).

Distance from the currently inactive North Amethyst drill centre was included in comparisons among years to provide baseline data for any future assessment when drilling occurs at that drill centre. There was no evidence of any distance gradients for the North Amethyst drill centre. Sediment physical and chemical characteristics for stations near the North Amethyst drill centre were a predictable function of proximity to the nearby Central and Southern drill centres (and also depth for some variables).

Limited comparisons of selected variables between 2007 and 2008 for the six stations near the North Amethyst drill centre sampled in both years also indicated that sediment physical and chemical characteristics were similar in both years.

5.5.2 Toxicity

No sediment samples were toxic to bacteria in 2000, 2004, 2005, 2006 and 2008 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 and survival in sediment from another station (survival: 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 two stations were classified as toxic when compared to both negative controls and Reference sediments and one additional station was classified as toxic when compared to Reference sediments. Survival from one other station was low (69%). 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.

In 2008, amphipod survival was less than 70% in sediments from 11 stations. Six of those sediments were classified as toxic when compared to both negative controls and Reference sediments and two additional sediments were classified as toxic when compared to Control sediments only. All survival values less than 70% occurred within 5 km of drill centres and survival was significantly negatively correlated with indicators of drilling activity ($>C_{10}$-C_{21} HCs and barium concentrations) and distance from the nearest active drill centre. However, survival was high (greater than 80%) for many other stations near drill centres and with high concentrations of $>C_{10}$-C_{21} HCs and barium. Survival was also greater than 70% in 2008 for some stations classified as toxic in past years.

5.5.3 Benthic Community Structure

Polychaetes accounted for 72 to 81% of the invertebrates collected in each sample year (2000, 2004, 2005, 2006 and 2008). Bivalves accounted for 12 to 18% of the total in each year. Amphipoda, Tanaidacea and Echinodermata were the only other higher-level taxa accounting for more than 1% of total abundance in one or more years. Three families, the polychaetes Spionidae and Paraonidae and the bivalve Tellinidae, accounted for 65 to 70% of the invertebrates collected.

5.5.3.1 Correlations Among Variables

Total abundance was greater where the three dominant families (Spionidae, Paraonidae and Tellinidae) were abundant. Although Amphipoda were a minor component of the invertebrate community, amphipod abundances in 2008 and past years were usually positively correlated with total abundance and abundances of the three dominant taxa. In 2008, richness was uncorrelated with total abundance. In past years, the two variables were positively correlated, with more taxa (families) generally collected where and when more organisms were collected. Over all EEM years, standing crop (wet weight of organisms) was weakly correlated or uncorrelated with total abundance, taxon abundances and richness. Instead, standing crop depended largely on the abundance of echinoderms and other larger but less abundant organisms.

In 2008, benthic invertebrate community summary measures (total abundance, standing crop and richness) and abundances of the three dominant families and Amphipoda were generally not significantly or strongly correlated with sediment particle size and TOC content. Except for richness, correlations between invertebrate community variables and $>C_{10}$-C_{21} HCs and barium were stronger than correlations with particle size and TOC, although correlations were sometimes not significant. Total abundance, standing crop and abundances of the three dominant taxa and Amphipoda decreased significantly with increasing $>C_{10}$-C_{21} concentrations and all variables except Tellinidae abundance decreased significantly with barium concentrations.

5.5.3.2 2008 Results

In 2008, total abundance, standing crop and abundances of Paraonidae, Spionidae and Amphipoda increased with increasing distance from the nearest active drill centre. The spatial extent of effects for total abundance, Spionidae and Amphipoda abundance could not reliably be estimated because distance relationships were relatively weak. The spatial extent of effects on standing crop was 1.5 km (95% CI: 0.7 to 3.4 km). The spatial extent of effects on Paraonidae abundance, the variable exhibiting the strongest distance relationship, was 3.8 km (95% CI: 2.1 to 6.9 km). Tellinidae abundance was uncorrelated with distance but increased significantly with increasing depth even over a narrow depth range of 115 to 135 m. Depth relationships for Tellinidae abundance were stronger than distance relationships for any other variable except Paraonidae abundance.

5.5.3.3 Comparison Among Years

Effects of Individual Drill Centres

There was little or no evidence for effects of the Northern drill centre on total abundance after drilling began in 2004. Total abundance increased with distance from the Northern drill centre in 2000, 2004 and 2005, then decreased with distance in 2006 and 2008. Distance gradients for the Northern drill centre were weak relative to distance gradients for the Central and Southern drill centres. In 2000 and 2004, total abundance decreased with distance from the (inactive) Central drill centre and did not change between 2004 and 2005 after drilling began. However, those distance gradients were reversed in 2006 and 2008, with total abundance increasing with distance from the Central drill centre. In 2000, total abundance decreased with distance from the Southern drill centre but increased with distance in 2004 after drilling began. The largest changes in distance gradients at the Southern drill centre occurred between 2004 and 2005, when the positive distance gradient (increase with distance) intensified, and between 2005 and 2006, when the distance gradient was similar to the baseline (2000) gradient. As noted above, the distance gradient in 2008 was positive.

Paraonidae abundance increased with distance from the Northern drill centre in 2000 and that distance gradient was stronger in 2004 and 2005 after drilling began. However, the gradient reversed (decrease with distance) in 2006 and 2008. In contrast, distance gradients for the Central and Southern drill centres changed substantially and significantly over time after drilling began at those two drill centres. The greatest changes at the Central and Southern drill centres were noted during the second rather than the first EEM program after drilling began (i.e., effects were delayed). In 2000 and 2004, but also in 2005 after drilling began, Paraonidae abundance was unrelated to distance from the Central drill centre. However, in 2006 and 2008, Paraonidae abundance increased significantly and substantially with distance from the Central drill centre. In 2000, Paraonidae abundance decreased with distance from the Southern drill centre, but the gradient reversed in 2004. In 2005, there was a much steeper distance gradient from the Southern drill centre with Paraonidae abundances increasing with distance. Gradients were much weaker in 2006 and 2008, but still positive (increase with distance) and comparable to the 2004 gradient.

Any project effects on Spionidae, the most abundant taxon, were similar to but weaker than effects on total abundance. Spionidae abundance was uncorrelated with distance from the Central drill centre in 2000, decreased slightly with distance in 2004 and 2005, and then increased with distance in 2006 and 2008. Spionidae abundance decreased with distance from the Southern drill centre in 2000, was uncorrelated with distance in 2004, and increased with distance in 2005. Distance gradients in 2006 and 2008 were similar to baseline gradients: slight decreases with distance.

Amphipoda abundance responded (i.e., decreased) after drilling began at the Central and Southern drill centres. Before drilling began, Amphipoda abundance was uncorrelated with distance from the Central drill centre and decreased with distance in 2004. Amphipoda abundance increased with distance from the Central drill centre in 2005 (after drilling began) and especially in 2008. Amphipoda abundance was uncorrelated with distance from the Southern drill centre in 2000, increased with distance in 2004 (after drilling began) and 2005, and was uncorrelated with distance in 2006 and 2008.

Median Abundances and Effects of Distance to the Nearest Drill Centre

Median total abundance for the 35 stations sampled in every year decreased from 700 organisms/station in 2000 to 400 organisms/stations in 2004 after drilling began at the Northern and Southern drill centres, and further decreased to 300 organisms/station in 2005 after drilling began at the Central drill centre. Medians increased in 2006 and then again in 2008 to 600 organisms/station (i.e., near baseline values). Correlations between total abundance and distance from the nearest active drill centre based on all stations sampled were weakly negative in 2000 (Northern and Southern drill centres assumed "active") and significantly positive and reasonably constant over time after drilling began. Although significant, distance relationships for total abundance have generally been too weak to provide reliable estimates of the spatial extent of effects.

When all years were considered, standing crop was generally unrelated to depth and project activity (i.e., distance from drill centres) and the gradient noted in 2008 was similar to the gradient noted during baseline (2000). There may have been some project effects on richness in 2005, but median values have since returned to baseline levels.

Median Paraonidae abundance decreased progressively over time from 2000 to 2005, increased in 2006, then decreased again in 2008. Medians in 2008 were less than 50 Paraonidae/station or less than half of 2000 medians of greater than 100 Paraonidae/station. Correlations between Paraonidae and distance from the nearest active drill centre increased from weakly negative (decrease with distance) in 2000 to strongly positive (increase with distance) in 2004, with some increase in strength after 2004. The estimated spatial extent of effects for Paraonidae abundance has increased from 2 km in 2004 to approximately 4 km in 2008.

Median Spionidae abundances decreased from 2000 to 2005, but are now similar to baseline (2000) values. Correlations with distance to the nearest active drill centre for Spionidae were weakly negative (decrease with distance) in 2000, and weakly positive (increases with distance) in 2004 and later years after drilling began.

Median abundances of Amphipods decreased after 2000 and had not returned to baseline levels by 2008. Correlations between Amphipoda abundance and distance from the nearest active drill centre were significantly negative (decrease with distance) in 2000 (Northern and Southern drill centres assumed to be active) and were significantly positive (increase with distance) in 2004 and subsequent years.

Tellinidae abundance has always increased with increasing depth, an effect as strong as or stronger than distance effects for other variables. There may have been some reductions in Tellinidae abundance in 2005, 2006 and 2008 in the immediate vicinity of drill centres but Tellinidae abundance has never been significantly negatively correlated with distance from the nearest active drill centre. Median Tellinidae abundance decreased from 2000 to 2004 and have only increased slightly since then.

Carry-over Effects

Carry-over effects for invertebrate community variables were significant at $p \leq 0.01$ for all variables analyzed. Carry-over effects were strongest for Paraonidae and Tellinidae abundances, which suggests localized small-scale spatial differences not captured by distance (Paraonidae) or depth (Tellinidae) regressions (lack of fit).

NMDS

Multivariate NMDS analyses of overall community composition indicated that differences in community composition depended largely on abundances of the dominant taxa: Paraonidae, Spionidae and Tellinidae. After drilling began in 2004, communities within 2 km of drill centres have gradually diverged from communities at more remote stations. The changes have largely involved reductions in abundances of Paraonidae and a few other less abundant taxa near drill centres, but relative (%) and absolute abundances of the subdominant polychaete taxa Phyllodocidae, Sabellidae and Sigalionidae have also increased near drill centres.

Concentration-Response Relationships

In EEM years (i.e., since 2004), total abundance, standing crop, richness and abundances of Paraonidae, Spionidae and Amphipoda have decreased with increasing $>C_{10}$-C_{21} HC concentrations. Except for Amphipoda, the decreases and concentration-response correlations were weaker in 2004 than in subsequent years. Concentration-response relationships were strongest for total abundance, Paraonidae and Amphipoda abundances.

When threshold $>C_{10}$-C_{21} HC concentrations associated with the presence of effects could reasonably be defined for total abundance, they were approximately 1 mg/kg after 2004. Threshold concentrations effects on Paraonidae abundance were also approximately 1 mg/kg after 2004. Threshold concentrations were difficult to define for Amphipoda abundance after 2004, but appeared to be near or below 1 mg/kg. Since 2005, overall community composition has differed between stations with concentrations greater than 10 mg/kg, and some stations with concentrations between 1 and 10 mg/kg, versus stations with lower concentrations. In 2008, abundances of the polychaete taxa

Phyllodocidae, Sabellidae and Sigalionidae increased significantly with increasing HC concentrations.

6.0 Commercial Fish Component

6.1 Field Collection

American plaice (“plaice”) and snow crab (“crab”) were collected onboard the *CCG Teleost* between May 26 and June 2, 2008. 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
2008 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	May 26 to June 2, 2008

Notes:
- Since the location of Reference Areas sampled from 2004 to 2008 differs from locations sampled in 2000 and 2002, data from Reference Areas collected during baseline cannot be compared to EEM Reference Area data.
- Study Area data are generally comparable.

Details on the collection and processing of 2000, 2002, 2004, 2005 and 2006 samples are presented in Husky Energy (2001, 2003, 2005, 2006 and 2007). Sampling for the 2008 program was conducted under a Fisheries and Oceans Canada (DFO) Stock Assessment license. A total of 59 plaice and 96 crab from the White Rose Study Area were retained for analysis in 2008. A total of 54 plaice and 86 crab from two Reference Areas (Reference Areas 1 and 2) were retained. Reference Areas 3 and 4 (e.g., Figure 1-12, Section 1) could not be sampled in 2008 because of intense fishing activity for crab. 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 6-1 and Appendix C-1.

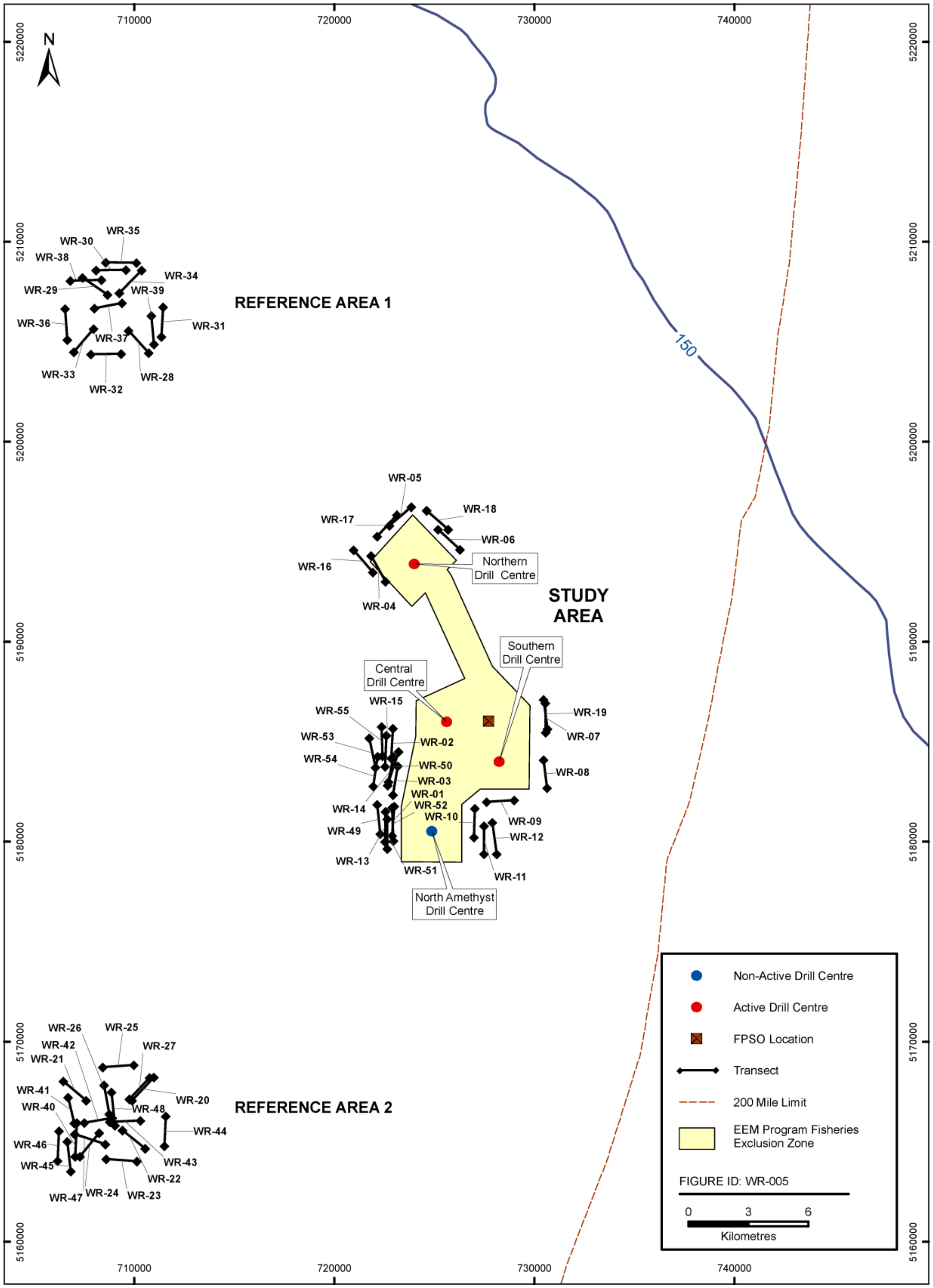

Figure 6-1 2008 EEM Program Transect Locations

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 60 mm in carapace width were retained for analysis. This size cut-off for crab excluded female crab, which were smaller than 60 mm.

The following procedures were followed for collection of fish health indicator samples. Each fish was assessed visually for any parasites and/or abnormalities on the skin and fins or on internal organs (liver, gonads, digestive tract, musculature and spleen) under the general framework of Autopsy-Based Condition Assessment described by Goede and Barton (1990). Approximately 0.5 to 1.0 ml of blood was drawn from a dorsal vessel near the tail, dispensed carefully into a labeled tube containing an anticoagulant (EDTA) and gently mixed. Two blood smears were prepared for each fish within one hour of blood collection according to standard haematological methods (Platt 1969). 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. The remainder of the right half was frozen on dry ice until return to port when it was placed in a -65ºC freezer for MFO analysis. The first gill arch on the right side of the fish was removed and placed in 10% buffered formalin for histological processing. Tissue samples of heart, spleen, gonad and head-kidney were removed and placed in 10% buffered formalin for histological processing, if required. A pair of 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 implemented for each transect 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 -20ºC freezer within one hour of collection.

6.2 Laboratory Analysis

6.2.1 Allocation of Samples

Plaice from 21 trawls in the Study Area and 25 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 nine individual body burden samples for fillet and liver for the Study Area, three composites for Reference Area 1 and five composites for Reference Area 2. When sufficient tissue was available, tissue from individual fish was archived for body burden on individuals if warranted by results of 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 (2008)

Transect No.	Area	No. of Fish Retained	Body Burden Composites (Bottom Fillet, or Liver)	Taste (wt. (g) of Top Fillets)	Health (No. of Fish)
WR-02/WR-52	SW Study Area	5	Composite 10 (5 fish)	274	5
WR-13	SW Study Area	10	Composite 11 (10 fish)	250	10
WR-14	SW Study Area	5	Composite 12 (5 fish)	265	5
WR-15/WR-50	SW Study Area	5	Composite 13 (5 fish)	269	5
WR-01/WR-03/WR-49	SW Study Area	5	Composite 14 (5 fish)	313	5
WR-54/WR-55	SW Study Area	12	Composite 15 (12 fish)	288	12
WR-12/WR-11/WR-08	SE Study Area	5	Composite 16 (5 fish)	250	5
WR-07/WR-09/WR-10	SE Study Area	4	Composite 17 (4 fish)	265	4
WR-04/WR-06/WR-16/WR-17	N Study Area	8	Composite 18 (8 fish)	330	8
Total		**59**	**9**	**2,504**	
WR-28/WR-29/WR-30	Reference Area 1	4	Composite 1 (4 fish)	307	4
WR-31/WR-32/WR/33	Reference Area 1	4	Composite 2 (4 fish)	258	4
WR-35/WR-37/WR-38	Reference Area 1	4	Composite 3 (4 fish)	306	4
WR-20/WR-22/WR-21/WR-24	Reference Area 2	10	Composite 4/5 (5 fish)	366	10
WR-23/WR-26/WR47	Reference Area 2	5	Composite 6 (5 fish)	338	5
WR-40/WR-25/WR-46	Reference Area 2	12	Composite 7 (12 fish)	275	12
WR-41/WR-43/WR-45/WR-48	Reference Area 2	10	Composite 8 (10 fish)	273	10
WR-42/WR-44	Reference Area 2	5	Composite 9 (5 fish)	250	5
Total		**54**	**8**	**2,373**	

Notes:
- Body burden composites 4 and 5 were combined at Maxxam Analytics because of insufficient liver weight. The composite was renamed composite 4/5 in order to match Maxxam data output.
- For taste tests, tissue weights were selected so as to generate relatively constant weights over all composites within either the Study or Reference Areas. This assured that no one transect was over-represented in the Study and Reference Area comparison.

Crab from 17 trawls in the Study Area and 21 trawls in the Reference Areas were used for body burden and taste analyses. No soft shell crabs were noted in samples. Tissue from right legs was composited to generate 10 individual body burden samples for the Study Area, six samples for Reference Area 1 and six samples for Reference Area 2 (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 (2008)

Transect No.	Area	No. of Crab	Body Burden Composites (Right Legs)	Taste Tests (wt. (g) of Crab, Left Legs)
WR-01/WR-02/WR-03/WR-53	SW Study Area	12	Composite 13 (12 crab)	738
WR-16/WR-18	N Study Area	13	Composite 14 (13 crab)	680
WR-15	SW Study Area	10	Composite 15 (10 crab)	665
WR-14/WR-54	SW Study Area	8	Composite 16 (6 crab)	665
WR-55	SW Study Area	6	Composite 17 (6 crab)	546
WR-7/WR-9	SE Study Area	9	Composite 18 (9 crab)	652
WR-8/WR-10	SE Study Area	9	Composite 19 (9 crab)	645
WR-5	N Study Area	10	Composite 20 (10 crab)	710
WR-6	N Study Area	9	Composite 21 (9 crab)	598
WR-17	N Study Area	10	Composite 22 (10 crab)	680
Total		**96**	**10**	**6,579**
WR-30	Reference Area 1	6	Composite 1 (6 crab)	581
WR-31	Reference Area 1	9	Composite 2 (9 crab)	612
WR-39	Reference Area 1	6	Composite 3 (6 crab)	615
WR-28/WR-33/WR-37	Reference Area 1	11	Composite 4 (11 crab)	550
WR-29/WR-32	Reference Area 1	7	Composite 5 (7 crab)	573
WR-34/WR-35	Reference Area 1	7	Composite 6 (6 crab)	624
WR-20/WR-24	Reference Area 2	6	Composite 7 (6 crab)	597
WR-22	Reference Area 2	6	Composite 8 (6 crab)	449
WR-23/WR-42	Reference Area 2	8	Composite 9 (8 crab)	693
WR-25/WR-27	Reference Area 2	6	Composite 10 (6 crab)	544

Transect No.	Area	No. of Crab	Body Burden Composites (Right Legs)	Taste Tests (wt. (g) of Crab, Left Legs)
WR-40/WR-41	Reference Area 2	6	Composite 11 (6 crab)	577
WR-48/WR-44	Reference Area 2	8	Composite 12 (8 crab)	592
Total		**86**	**12**	**7,007**

Notes: - For taste tests, tissue weights were selected so as to generate relatively constant weights between composites in either the Study or Reference Areas. This assured that no one transect was over-represented in the Study and Reference Area comparison.

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. In 2008, moisture content was measured on archived tissues three to six weeks after analysis of remaining variables. This is further discussed in Section 6.4.

Table 6-4 Body Burden Variables (2000, 2002, 2004, 2005, 2006 and 2008)

Variables	Method	2000 RDL	2002 RDL	2004 & 2005 RDL	2006 RDL	2008 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
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

Variables	Method	2000 RDL	2002 RDL	2004 & 2005 RDL	2006 RDL	2008 RDL	Units
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	1.5	1.5	mg/kg
Other							
Percent Lipids/Crude Fat	PEI FTC/ AOAC922.06	0.1	0.5	0.5	0.5	0.5	%
Moisture	Grav.	0.1	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[13].
- 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 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 6-2), 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.

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[13] 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. The matrix is any material, chemical, physical property of the real world sample that can affect the analytical determination.

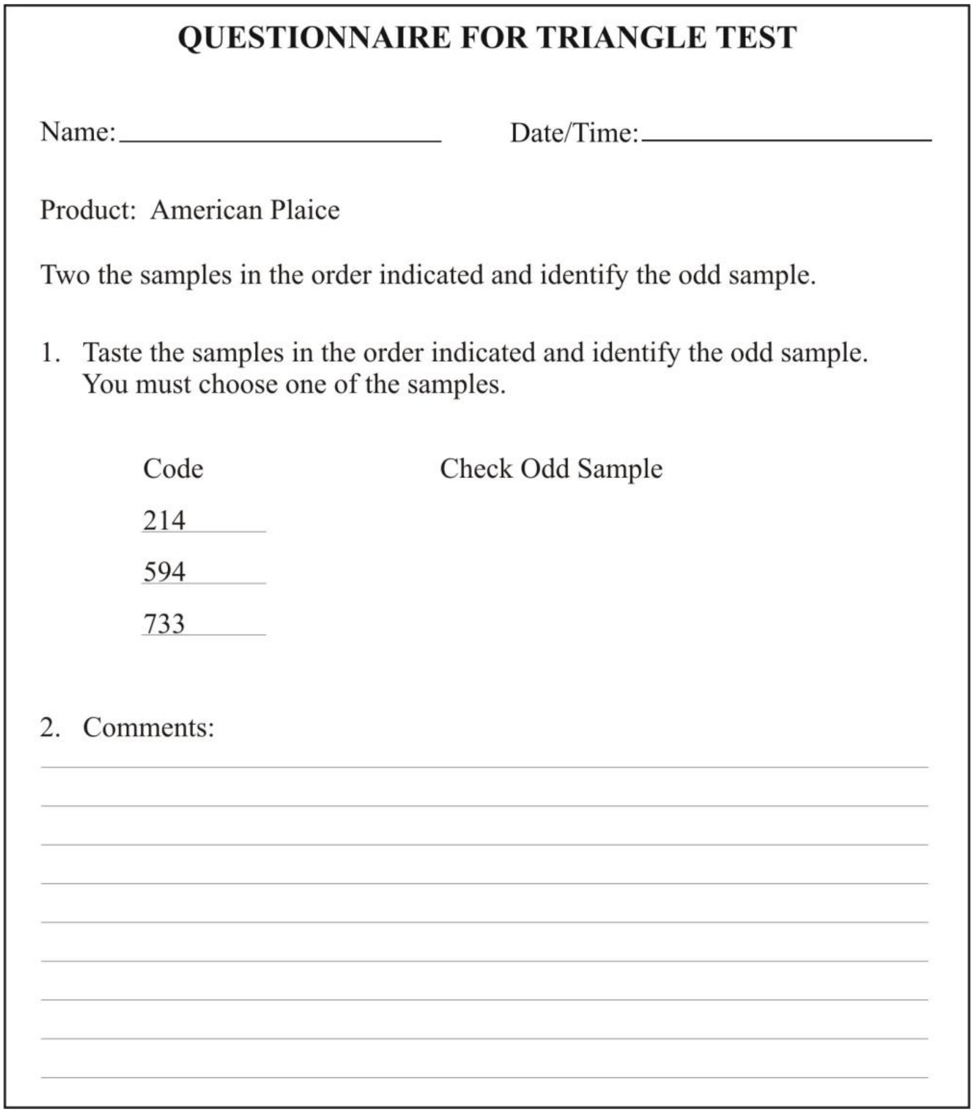
Figure 6-2 Plaice Taste Test Preparations

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 6-3 and 6-4) 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 other and to leave immediately upon completion of the taste tests.

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 6-4 for full range of ratings).



QUESTIONNAIRE FOR TRIANGLE TEST

Name: ____________________ Date/Time: ____________________

Product: American Plaice

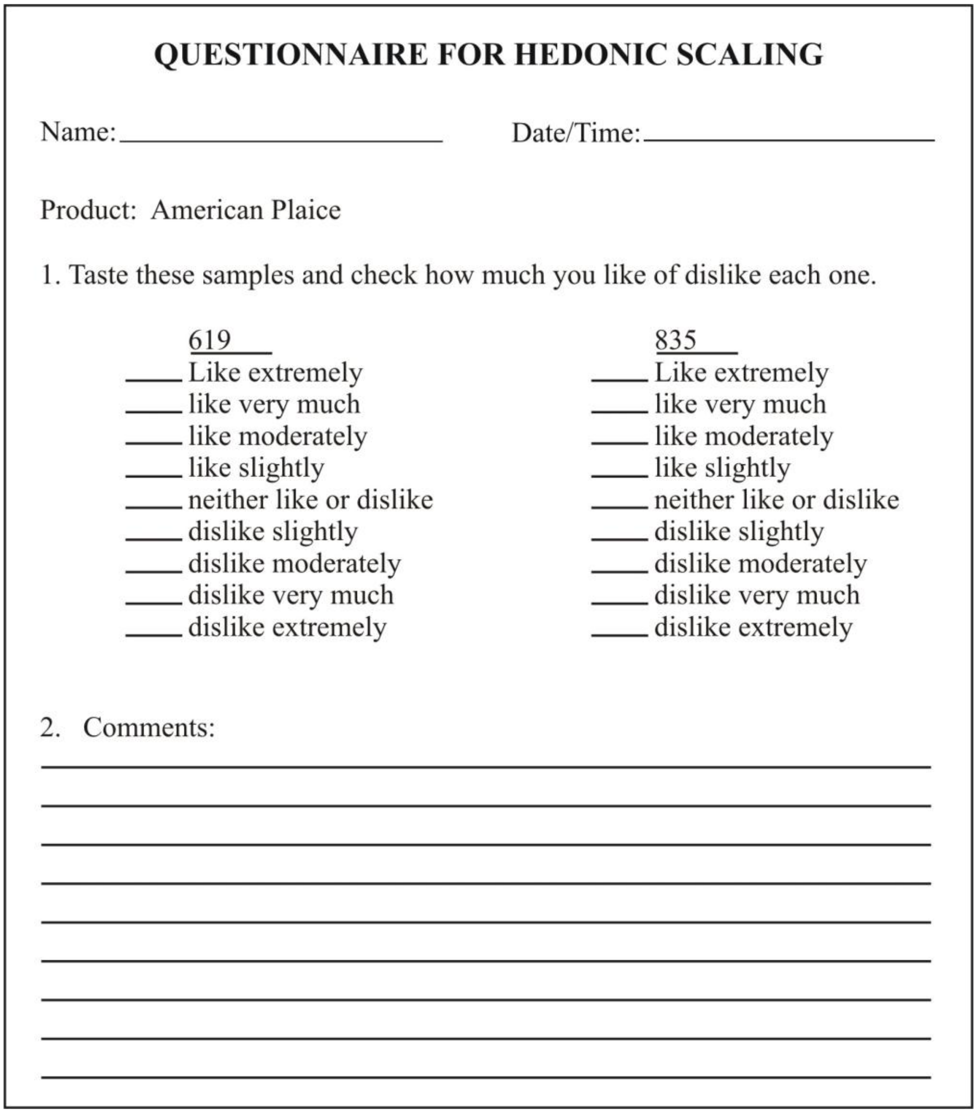
Two the samples in the order indicated and identify the odd sample.

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 6-3 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 6-4 Questionnaire for Taste Evaluation by Hedonic Scaling

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 x400 magnification in fields along a row starting from the front edge of the smear and 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. Two external positive controls (pools of liver homogenates from uninduced cunners and cunners induced with petroleum) were run with each batch of samples to ensure consistency of measurements.

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 tissues 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 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
2. Megalocytic hepatosis
3. Eosinophilic foci
4. Basophilic foci
5. Clear cell foci
6. Hepatocellular carcinoma
7. Cholangioma
8. Cholangiofibrosis
9. Macrophage aggregates
10. Hydropic vacuolation
11. Fibrillar inclusions

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

Lesions (except macrophage aggregates) 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 proliferation of macrophage aggregates (considered here as 4 or higher on the scale).

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 magnification (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 2/3 of the filament and secondary lamellae of equal length on both sides) 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 as follows: (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 all around the two sides of the secondary lamellae and (3) tip hyperplasia was recorded when there were more than three cell layers 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 approximately 1,100 lamellae were counted per fish.

No count was carried out for oedema, but the severity of the condition (here, the swelling within cells) was recorded on a 0 to 3 relative scale (0-rare, 1-light, 2-moderate and 3-heavy).

6.3 Data Analysis

Changes in data analyses in 2008 relative to previous years are described in detail below and in Appendix C-3 and were necessary because crab and plaice could only be collected from two of the four Reference Areas.

For most analyses except taste tests, the Commercial Fish component of the White Rose EEM program uses a multiple-reference design with the Study Area compared to four Reference Areas. Two comparisons or contrasts are of primary interest:

1. Study versus Reference Areas (SR); and
2. Among Reference Areas (AR).

The SR contrast provides a test of potential project effects. The AR contrast provides an estimate of natural (non-project) variance among Areas. In past EEM years (2004, 2005 and 2006), all four Reference Areas were sampled, and a modified nested ANOVA was used for analysis of commercial fish Biological Characteristics, body burdens and fish health indicators (see Husky Energy 2007 for details). The modified nested ANOVA were appropriate for the multiple-reference design, since the SR contrast (difference between Areas) can be tested against the natural variance among Areas rather than the variance among replicates (composites or individual crab or plaice) within Areas.

In 2008, only two Reference Areas (Reference Areas 1 and 2) were sampled because commercial fishing for crab prevented sampling at Reference Areas 3 and 4. Theoretically, a modified nested ANOVA could have been used for data analysis, but with only two Reference Areas, natural variance among Reference Areas would be poorly estimated and tests of the SR contrast against variance among Reference Areas would not be robust or powerful.

Therefore, one-way ANOVA comparing three Areas (the Study Area, Reference Area 1 and Reference Area 2) were used for analysis of 2008 commercial fish biological characteristics and body burdens. The one-way ANOVA tested the AR (Between Reference Areas or BR with only two Reference Areas) and SR contrasts against the variance among replicates within Areas. Therefore, results for the SR contrast for 2008 should be interpreted with caution when differences between Reference Areas are large (i.e., $p < 0.25$ and especially $p \leq 0.05$ for the BR contrast).

One-way ANOVA testing BR and SR contrasts were also used for fish health indices when sufficient fish numbers were available in each Reference Area. Details on these analyses are provided in Section 6.3.4 and Appendix C-3.

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. Additional analyses were carried out on plaice morphometric characteristics and condition within the context of fish health analyses. These are described in Appendix C-3 and briefly discussed in Section 6.4.4.

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 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 2, 3, 4 and 6 were not observed.

Mean carapace width, claw height and frequencies of recent moults were calculated for each composite and the composite values were compared among Areas in ANOVA. Composite means, rather than individual crab, were analyzed because there was significant ($p \leq 0.05$) added variance among composites within Areas for claw height and % recent moult. The composite means also “match” values of body burden variables measured on composites.

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 combined Reference Areas and the Study Area.

Analyses of Biological Characteristics were restricted to crab used for body burden analyses in 2008. Formal comparisons among years were not conducted.

6.3.1.2 Plaice

Analyses of plaice Biological Characteristics were restricted to composite mean gutted weights (i.e., size). Appendix C-3 provides more extensive analyses of a larger suite of biological variables (length, age, body weight, liver, gonad weight and fish condition) analyzed within the context of fish health indicator.

Composite mean weights were compared among Areas in ANOVA. The primary objective was to determine if there were size differences that might affect results of body burden analyses.

It should be noted that immature (few) and mature females, and mature males, were pooled within body burden composites, as they would be in commercial catches or in the diet of any predator. Mature females were generally larger than mature males and immature females. As a result, size generally varied more within composites than among composites within Areas or among Areas.

6.3.2 Body Burden

6.3.2.1 Crab

Analysis of 2008 Data

Body burden variables analyzed were fat (lipid) content and wet weight concentrations of seven frequently detected metals (arsenic, boron, copper, mercury, selenium, strontium and zinc). Fat content, boron and selenium values less than RDL were set at RDL rather than ½ RDL. For the Sediment Component of this report, values less than RDL were set at ½ RDL. However, for fat content, boron and selenium concentrations in crab claws, the two-fold difference between RDL versus ½ RDL was larger than most differences in detectable values within and among Areas and using ½ RDL to replace values less than RDL could have potentially bias analyses and results.

A summary measure of metal concentrations was derived using Principal Components Analysis (PCA[14]). Metal concentrations were $\log_{10}$ transformed prior to conducting the PCA. The PCA included all samples from 2004, 2005, 2006 and 2008 since PC1 scores were compared among years (see below).

Fat content, Metals PC1 scores and untransformed concentrations of the seven frequently detected metals were compared among Areas in ANOVA. 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, 2005, 2006 and 2008)

Body burden results from 2004, 2005, 2006 and 2008 were compared between the Study and Reference Areas, and among Years, in a two-way ANOVA (Table 6-5). Values analyzed (*Y*) were Area means within each year, so the SR contrast was tested against the natural variance among rather than within Reference Areas, as intended in multiple-reference designs.

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[14] PCA identifies the major axis of covariance (Principal Component or PC1) among the original variables (concentrations of the seven 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 SD are 1. The scores can be used as summary variable values for further analyses.

Table 6-5 Completely Random (CR) ANOVA Used for Comparison of Body Burden Variables Among Years (2004, 2005, 2006 and 2008)

Source/Term	df	Description
Study versus Reference (SR)	1	Tests for consistent differences in *Y* between Study versus Reference Areas
Year (Overall)	3	Tests for consistent differences in *Y* among years in both Study and Reference Areas
Trend	1	Tests for progressive increases or decreases in *Y* over time in both Reference and Study Areas (”common” trend)
SR × Year	3	Tests for differences in SR difference among years (differences in changes over time between Study versus Reference Areas)
SR × Trend	1	Tests for progressive increases or decreases in SR difference over time (differences in trends between Study versus Reference Areas)
Among References (AR) (=Error)	10	Natural variance of *Y* among Reference Areas within years

Note: - df = degrees of freedom.

With the same four Reference Areas sampled in each year from 2004 to 2006 (re-sampling), a Repeated Measures (RM) ANOVA has been used to compare body burden variables among those years (Husky Energy 2007). With Reference Areas 3 and 4 not sampled in 2008, an RM ANOVA would have been restricted to Reference Areas 1 and 2, excluding 6 of the 14 Reference values. In contrast, the Completely Random (CR) ANOVA in Table 6-5 included all 14 Reference values. The CR ANOVA assumes that a different set of randomly selected Reference Areas is sampled each year (re-randomization), ignoring any differences among the four Reference Areas that persist over time (carry-over effects). From 2004 to 2006, carry-over effects were significant at $p \leq 0.10$ for some crab (and plaice) body burden variables (Husky Energy 2007). Those carry-over effects would be incorporated into the error variance (AR) in the CR model, reducing power. However, the reduction in power would be small relative to the increase in power and robustness for the CR ANOVA with 14 Reference Area values versus an RM ANOVA with 8 Reference Area values.

The SR term in the CR ANOVA in Table 6-5 tests for consistent differences between the Study Area and Reference Areas over time, which could potentially represent long-term project effects. The overall Year term tests for any temporal change in *Y* occurring in both Study and Reference Areas. The Year Trend contrast tests for a specific type of temporal change (progressive increase or decrease in *Y* over time). Common trends and other temporal changes occurring in both Study and Reference Areas are presumably unrelated to project activities and would instead represent natural large-scale changes in the field, or changes in field sampling or laboratory analytical methods.

The SR × Year interaction term tests for any differences in the Study versus Reference contrast over time, which could potentially represent changes in the magnitude of project effects over time. The SR × Trend contrast probably provides a better test of project effects, assuming that if effects existed, they would increase over time as drilling intensified. Note that differences in spatial changes over time are also differences in temporal changes over space (i.e., a spatial-temporal interaction is also a temporal-spatial interaction).

Body burden variables compared among years were fat content, Metals PC1 and concentrations of the seven frequently detected metals analyzed for 2008. Study Area means were based on *n* = 10 composites in each of the four years. From 2004 to 2006, there were usually *n* = 3 composites within each of the four Reference Areas. Only two composites from Reference Area 3 were analyzed in 2004 and only one composite from Reference Area 4 was analyzed in 2005 because of limited catches. In each of 2004 and 2005, fat content was also not measured on one Reference Area composite because of insufficient tissue volume. In 2008, all body burden variables were measured in *n* = 6 composites from each of Reference Areas 1 and 2.

6.3.2.2 Plaice

Analyses of 2008 Data

Body burden data from composite samples were available for both liver and fillet tissue. Variables analyzed for liver were fat content, concentrations of eight metals detected in every composite (arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc) in 2004 to 2006 and in 2008, 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 fat content and concentrations of arsenic, mercury and zinc (detected in every composite in 2004 to 2006 and in 2008).

Untransformed body burden variable values for liver and fillets were compared among Areas in one-way ANOVA.

Comparison Among Years (2004, 2005, 2006 and 2008)

Plaice body burden results from 2004, 2005, 2006 and 2008 were compared in the CR ANOVA in Table 6-5. Variables analyzed were the same as those analyzed for 2008. Data analyzed were annual Area means. Ten Study Area composites and three composites per Reference Area were analyzed in each year from 2004 to 2006. Fat content in liver was not measured in one Reference Area 2 composite and three Study Area composites in 2005 because of insufficient sample volume. In 2008, nine Study Area composites, three Reference Area 1 composites and five Reference Area 2 composites were analyzed. Fat content in liver was not measured in one composite from each of the two Reference Areas in 2008 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 $\alpha = 0.05$) 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 a single Study Area, has been used at White Rose since 2004. However, as noted above, poor fish catches in Reference Areas 1 and 2 in 2008 and intense commercial fishing activity for crab in Reference Areas 3 and 4, which precluded sampling, resulted in low fish numbers and a reduced number of sampled areas.

When sample sizes permitted, one-way AN(C)OVA comparing Reference Area 1, Reference Area 2 and the Study Area were conducted (i.e., the two Reference Areas were separated). Two comparisons (contrasts), between Reference Areas (BR contrast) and between the Study Area and the mean of the two Reference Areas (SR contrast), were tested. When numbers did not permit, comparisons were limited to a comparison of the Study Area and the combined Reference Areas (i.e., with the two Reference Areas treated as a single "Area"). A more detailed description of the statistical methods used for Fish Health Indicators 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 ANOVA.

- Log-log regressions of gutted weight versus length, and liver and gonad weight versus gutted weight were compared among Areas in Analysis of Covariance (ANCOVA).

- Sex ratios, ratios of pre-spawning:spent mature females, and prevalences of liver and gill histopathologies were compared between the Study and combined Reference Areas using Fisher's Exact Test.

6.4 Results

6.4.1 Biological Characteristics

6.4.1.1 Crab

Shell condition index values for the crab collected in late May to early June 2008 and used for body burden analyses are provided in Table 6-6. Shell condition was recorded for all 182 crab used for body burden analysis. Approximately 30% of the crab collected in 2008 were recent moults. In contrast, 40 to 70% of crab collected in 2004, 2005 and 2006, when sampling occurred later in the year (July), were recent moults. Frequencies of recent moults for the Study Area in 2008 were between values observed for the two Reference Areas. Non-recent moults were split approximately equally between crab moulting in 2007 (index value = 6) and crab moulting in 2006 or earlier (index values = 3 or 4).

Table 6-6 Frequencies of Crab Shell Condition Index Values (2008)

Moult Year	Index Value	Area				Total
		Ref 1	Ref 2	Both Refs	Study	
Recent (0)	2	11	14	25	26	51
(%)		24	35	29	27	28
Not recent (–1+)	6 (–1)	20	15	35	34	69
	3,4 (–2+)	15	11	26	36	62
Total No.		35	26	61	70	131
(%)		76	65	71	73	72
Grand total		46	40	86	96	182

Notes:
- Moult years: 0 = 2008; –1 = 2007; –2+ = 2006 or earlier.
- Values are numbers of crab unless otherwise indicated.

Summary statistics for composite means are provided in Table 6-7. Mean carapace width of Study Area crab was intermediate between the two Reference Area means. Mean claw height for Study Area crab was slightly greater than Reference Area means. Reference Area 2 crab were smaller than crab in the other two Areas. CVs for carapace width and claw height (i.e., size) for Reference Area 1 were greater than CVs for the other two Areas because mean carapace width and claw height in one Reference Area 1 composite was lower than in any other composite. No attempt was made to correct for this apparent outlier (e.g., by deleting it or using rank transformation) in subsequent analysis. Any correction would simply increase the difference between Reference Areas and would not alter the fact that Study Area size was greater than Reference Area 2 size.

Table 6-7 Summary Statistics for Biological Characteristics of Crab Based on Composite Means (2008)

Variable	Area	*n*	Min	Max	Median	Mean	SD	CV (%)
Carapace width (mm)	Reference Area 1	6	77	104	98	95	9	10
	Reference Area 2	6	82	95	90	89	4	5
	Reference mean					92		
	Study Area	10	82	103	92	92	6	6
Claw height (mm)	Reference Area 1	6	12.8	24.2	22.1	20.5	4.4	21
	Reference Area 2	6	18.1	21.6	19.1	19.4	1.2	6
	Reference mean					19.9		
	Study Area	10	17.7	25.5	20.8	20.9	1.9	9
% recent moult	Reference Area 1	6	0	71	17	23	27	
	Reference Area 2	6	0	63	33	33	22	
	Reference mean					28		
	Study Area	10	0	58	32	27	17	

Note:
- CV = Coefficient of Variation (SD as % of mean).

CVs are not provided for % recent moult in Table 6-7 because composite values could be expressed as either % recent moult or % non-recent moult (100-% recent moult; SDs remain the same). Study Area mean % recent moult was between the two Reference Area means. Area values and differences in % recent moult in Table 6-7 are similar to those in Table 6-6, although frequencies in Table 6-7 weight each composite equally regardless of sample size within composites whereas frequencies in Table 6-6 weight each crab equally (effectively, weight each composite by sample size). The agreement between the two approaches or weighting methods in 2008 was better than in previous years because differences in sample sizes within composites in 2008 (2-fold) were less than in past years (≥ 3-fold).

The three biological variables did not differ significantly between Reference Areas and especially between the Study and Reference Areas (Table 6-8). These results were typical for most crab body burden variables (Section 6.4.2.1) and also for most plaice biological and body burden variables (Sections 6.4.1.2 and 6.4.2.2). Study Area means were usually between the two Reference Area means or, when they were outside the "Reference Range", they were similar to one of the two Reference means. In other words, the greatest differences were generally between the two Reference Areas, although those differences were rarely significant.

Table 6-8 Results of ANOVA Comparing Crab Biological Characteristics Among Areas (2008)

Variable	Between References	Study versus References
Carapace width	0.156	0.989
Claw height	0.474	0.407
% recent moult	0.458	0.925

Note: - $p \leq 0.05$ in bold.

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 6-9). Size and % recent moult were weakly negatively correlated, suggesting that smaller crab were more recent moults, but none of those correlations was significant at $p \leq 0.05$. In 2004, 2005 and 2006, when the frequency of recent moults was greater, the same negative correlations were observed, but were generally stronger and often significant, particularly for individual crab (Husky Energy 2005, 2006, 2007). Basically, in 2008, non-recent moults included smaller crab that presumably would have moulted within a month or two after sampling. In 2004, 2005 and 2006, some or most of the smaller crab had already moulted when samples were collected. The shell condition index can provide a reasonable estimate of when the last moult occurred, but cannot estimate when the next moult will occur.

Table 6-9 Spearman Rank Correlations (r_s) Among Crab Biological Variables (2008)

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	173	**0.930****	182	–0.089	173	–0.089
	Reference	79	**0.942****	86	–0.128	79	–0.106
	Study	94	**0.936****	96	–0.062	94	–0.069
Composite means	All	22	**0.864****	22	–0.129	22	–0.334
	Reference	12	**0.853****	12	–0.139	12	–0.313
	Study	10	**0.855****	10	–0.190	10	–0.239

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 6-10. Females accounted for 40% of the plaice collected and included in composites. Most females were mature and collected prior to or during spawning. Immature females and males (all mature) were generally smaller than mature females. Therefore, mean composite gutted weights increased with increasing F:M ratios ($r_s = 0.642$; $p < 0.01$), and any size differences or effects discussed below and in Section 6.4.2.2 may represent effects of sex ratios rather than size.

Table 6-10 Summary Statistics for Plaice Composite Mean Gutted Weight (2008)

Area	*n*	Min	Max	Median	Mean	SD	CV (%)
Reference Area 1	3	434	501	460	465	34	7
Reference Area 2	5	285	502	356	372	92	25
Reference mean					418		
Study Area	9	296	608	397	412	87	21

Notes: - CV = Coefficient of Variation (SD as % of mean).

Composite mean weights did not differ significantly between Reference Areas or between the Study and the Reference Areas (Table 6-11). Sex (F:M) ratios in Reference Area 1 and Study Area catches and composites were approximately 1:1 (i.e., equal split of sexes). In contrast, males dominated Reference Area 2 catches and composites (F:M approximately 1:3) and mean and median sizes were lower in Reference Area 2 (Table 6-10). However, differences in composite mean weights between Reference Areas were not significant (Table 6-11) because 18 of the 30 males collected in Reference Area 2 were included in only two of the five composites from that Area, whereas the 12 females collected were distributed more evenly among the composites. In other words, any "bias" towards males was largely restricted to two composites within one Area.

Table 6-11 Results of ANOVA Comparing Plaice Composite Mean Gutted Weight Among Areas (2008)

Variable	Between References	Study versus References
Gutted weight	0.116	0.889

Notes: - $p \leq 0.05$ in bold.
- Weights were $\log_{10}$ transformed.

Additional analyses on biological characteristics of plaice related to fish health indicator assessment are provided in Appendix C-3 (Annex B) and selected results are briefly discussed in Section 6.4.4.1.

6.4.2 Body Burden

6.4.2.1 Crab

Summary statistics for concentrations of detected substances in crab claw composites in 2004, 2005, 2006 and 2008 are provided in Appendix C-2, as are raw data for 2008. Summary statistics for moisture content measured on archived samples in 2008 three to six weeks after other body variables were measured were much lower (60 versus 80%) than in previous years, when moisture and other variables were measured at the same time. The moisture results indicate that prolonged storage will decrease moisture content, an important methodological issue when wet weight body burden concentrations are reported and analyzed.

Analysis of 2008 Data

The first step in analysis of 2008 crab body burden data was to conduct PCA on log-transformed concentrations of seven frequently detected metals (arsenic, boron, copper, mercury, selenium, strontium and zinc). The PCA included 2004, 2005, 2006 and 2008 data, since Metals PC1 scores were compared among the four years (see below). PC1 was positively correlated with concentrations of all metals, except boron and strontium, and accounted for 38% of total variance (Table 6-12). 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. PC3 was positively correlated with concentrations of boron and selenium, and weakly negatively correlated with concentrations of copper and mercury.

Table 6-12 Correlations (Parametric or Pearson *r*) Between Metal Concentrations in Crab Claw Composites and Principal Components Derived from Those Concentrations (2004, 2005, 2006 and 2008)

Metal	**Correlation (*r*) with:**		
	PC1	**PC2**	**PC3**
Zinc	**0.866**	0.259	0.116
Arsenic	**0.831**	–0.140	0.110
Selenium	**0.676**	–0.182	**0.598**
Mercury	**0.521**	**0.634**	–0.342
Copper	0.403	–0.667	–0.342
Boron	0.012	**0.802**	0.177
Strontium	**–0.554**	0.102	**0.646**
% variance	38	23	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.
- $n = 85$ composites (21 from 2004; 20 from 2005; 22 from 2006; 22 from 2008).

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. Boron may also “behave differently” because it is more soluble and occurs at higher concentrations in sea water than other metals (Adey and Loveland 1991).

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 (e.g., boron and selenium).

The next step was to compare body burden variables for 2008 among Areas in ANOVA (Table 6-13). Fat content did not differ significantly between Reference Areas or between the Study and the Reference Areas. Median fat contents in all three Areas (0.60 to 0.65%) were barely above the RDL of 0.5% (Appendix C-2). Metals PC1 scores, a summary measure of total metals, were slightly but not significantly higher in Study Area composites than in Reference Area composites (Figure 6-5).

Table 6-13 Results of ANOVA Comparing Crab Body Burden Variables Among Areas (2008)

Variable	Between References	Study versus Reference
% fat	0.142	0.314
Metals PC1	0.108	0.176
Arsenic	0.825	0.816
Boron	0.210	**0.010**
Copper	**0.050**	0.498
Mercury	**0.009**	0.461
Selenium	0.574	0.740
Strontium	0.562	0.935
Zinc	0.084	0.086

Notes: - *p* ≤ 0.05 in bold.

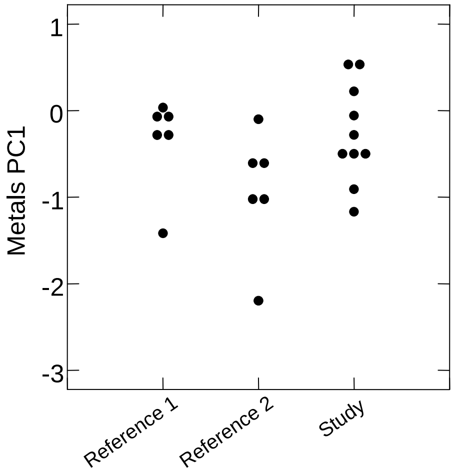

Figure 6-5 Distributions of Metals PC1 Scores for Crab Claw Composites (2008)

Note: - Some points may represent more than one composite.

Results for individual metals in Table 6-13 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 (arsenic, mercury, strontium and zinc). Boron concentrations differed significantly between the Study and the Reference Areas, with the Study Area mean concentration approximately 20% greater than the mean of the two Reference Area means (Appendix C-2). Copper and mercury concentrations differed significantly between Reference Areas by more than 20%, with Study Area concentrations intermediate (Appendix C-2 and 6-13).

Fat content was not significantly correlated with composite mean Biological Characteristic values (Table 6-14). Metals PC1 scores increased significantly with increasing size (carapace width and claw height), which was primarily a within-Area relationship common to all three Areas. With carapace width or claw height included as a covariate (*X* variable) in ANCOVA comparing Metals PC1 among Areas, size (covariate) effects were significant at $0.01 < p < 0.10$, but neither the BR nor SR contrast was significant at $p \leq 0.10$ (i.e., ANCOVA contrast results were similar to ANOVA contrast results in Table 6-13).

Table 6-14 Spearman Rank Correlations (r_s) Among Crab Body Burden Variables, and Between Those Variables and Biological Characteristics (2008)

	% fat	**Metals PC1**
Carapace width	0.156	**0.591****
Claw height	–0.022	**0.510***
% recent moult	0.009	–0.050
% fat		0.322

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, 2005, 2006 and 2008)

Results of CR ANOVA comparing crab body burden variables among Areas and years (2004, 2005, 2006 and 2008) are provided in Table 6-15. The tests had limited power, so $p \leq 0.10$ rather than the traditional $p \leq 0.05$ are shown in bold. Few tests were significant even at $p \leq 0.10$.

Table 6-15 Results of Completely Random (CR) ANOVA Comparing Crab Body Burden Variables Among Areas and Among Years (2004, 2005, 2006 and 2008)

Variable	**Study versus Reference (SR)**	**Year**		**Year x SR**	
		Overall	**Trend**	**Overall**	**Trend x SR**
% fat	0.827	0.508	0.210	0.850	0.955
Metals PC1	0.734	0.351	0.125	0.852	0.471
Arsenic	0.567	0.387	0.153	0.954	0.780
Boron	0.688	0.155	**0.060**	0.863	0.571
Copper	0.642	**0.008**	**0.001**	0.889	0.824
Mercury	0.301	0.399	0.782	0.335	0.713
Selenium	0.906	**0.034**	0.466	0.615	0.344
Strontium	0.668	**0.012**	**0.033**	0.893	0.900
Zinc	0.973	0.695	0.658	0.908	0.505

Notes:
- $p \leq 0.10$ in bold.
- See Table 6-5 for further explanation of the CR 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 6-15; 7 of 8 *p* values for the contrast were > 0.50. Therefore, there were no consistent large differences in body burden variable values from 2004 to 2008 between the Study and Reference Areas (SR differences). The Year × SR and Trend × SR interaction terms were also not significant at $p \leq 0.10$ for any variable, and most *p* values for those terms were > 0.50. Therefore, SR differences did not change significantly over time. SR differences for fat content and metal concentrations have generally been small, with Study Area values usually within the Reference Area range (Figure 6-6 and Figure 6-7).

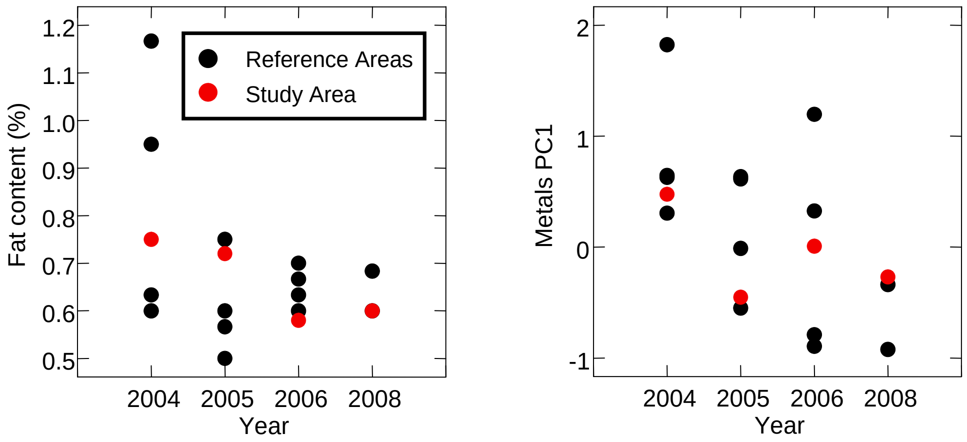

Figure 6-6 Fat Content and Metals PC1 Scores for Crab Claw Composites (2004, 2005, 2006 and 2008)

Notes: The X axes on these figures are not linear; values are Area means; some points may represent more than one mean.

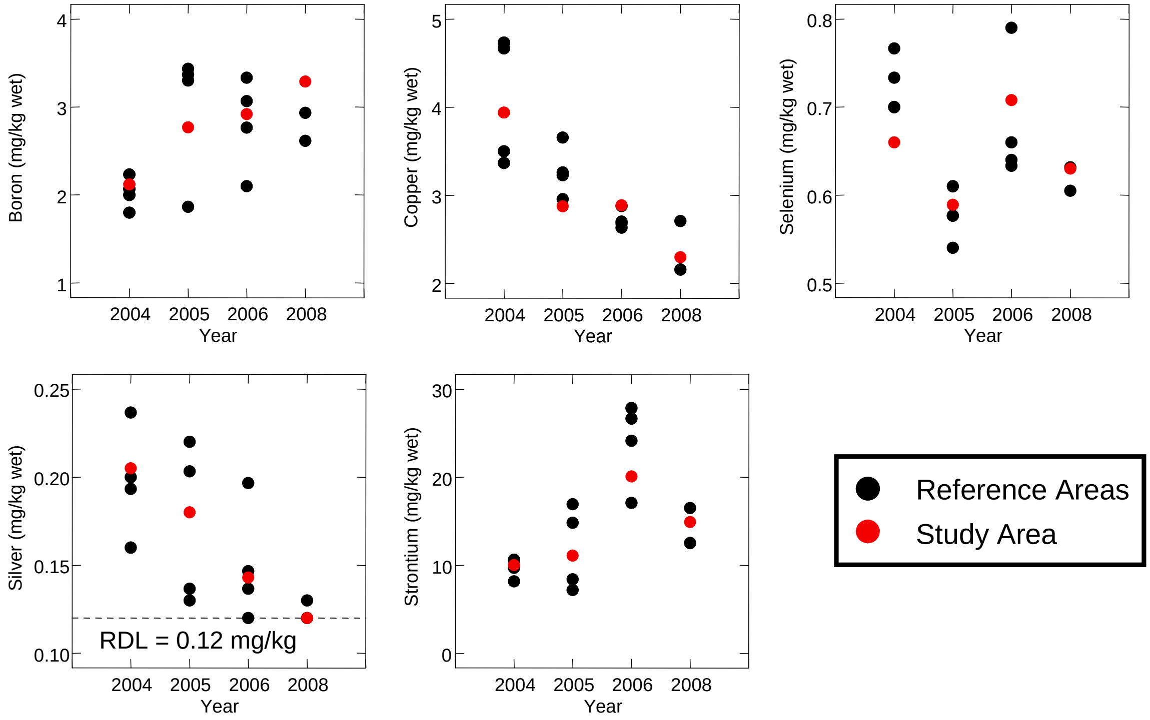

Figure 6-7 Boron, Copper, Selenium, Silver and Strontium Concentrations in Crab Claw Composites (2004, 2005, 2006 and 2008)

Notes: The X axes on these figures are not linear; values are Area means; some points may represent more than one mean.

Large-scale temporal changes and trends common to both Study and Reference Areas (Year terms) were not significant at $p \leq 0.10$ for fat content or Metals PC1, but were significant for several individual metals (Table 6-15). Boron and strontium concentrations increased over time (= trends), although the "trend" for strontium was largely driven by the high concentrations in 2006 (Figure 6-7). Copper and silver concentrations decreased over time (Figure 6-7). Silver was not included in the analysis because the frequency of concentrations below the RDL of 0.12 mg/kg wet increased from 0 (of 22 composite values) in 2004 to 19 (of 22 values) in 2008 (Appendix C-2; Figure 6-7). Selenium concentrations varied significantly over time, but with no trend (i.e., no progressive increase or decrease) (Table 6-15; Figure 6-7).

6.4.2.2 Plaice

Liver

Summary statistics for detected substances in plaice liver in 2004, 2005, 2006 and 2008 and raw data for 2008 are provided in Appendix C-2. Moisture content in 2008 was measured on only four Study Area liver composites because of insufficient tissue volume and tissues analyzed for moisture were archived for three to six weeks longer than tissues analyzed for other constituents. Moisture content in the 2008 samples (approximately 60%) was lower than moisture content in samples from 2004 to 2006 (approximately 70%), again indicating that drying occurs with longer storage. 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, 2006 and 2007 for chromatograms for 2004, 2005 and 2006 samples, respectively) were consistent with those expected for natural compounds (Maxxam Analytics, pers. comm., Joe Kiceniuk, pers. comm.) and similar compounds have consistently been observed at the nearby Terra Nova site. In 2008, two samples from Terra Nova were analyzed further to more precisely determine the nature of the compounds. Results are provided in Appendix C-2 (Results Section). The largest peak on chromatograms was attributable to squalene, a natural product, and a search of available literature indicated that many of the remaining compounds were naturally occurring products (Appendix C-2).

Analysis of 2008 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 and zinc). The PCA included samples from 2004, 2005, 2006 and 2008 since PC scores were compared between years (see below). Concentrations of all metals except manganese were positively correlated with PC1 (Table 6-16), which accounted for 53% of the total variance and served as a summary measure of total metal concentrations for subsequent analyses. Manganese concentrations were strongly negatively correlated with PC2, and selenium concentrations were strongly negatively correlated with PC3. These two secondary PCs were not further analyzed, since results would be similar to results provided for their correlates, manganese and selenium.

Table 6-16 Correlations (Parametric or Pearson *r*) Between Metal Concentrations in Plaice Liver Composites and Principal Components (PC) Derived from Those Concentrations (2004, 2005, 2006 and 2008)

Metal	Correlation (*r*) with:		
	PC1	PC2	PC3
Arsenic	**0.913**	0.037	0.059
Cadmium	**0.864**	0.059	0.053
Zinc	**0.849**	–0.238	0.102
Copper	**0.803**	0.025	0.318
Iron	**0.720**	0.145	–0.401
Mercury	**0.654**	0.193	0.359
Selenium	**0.585**	–0.372	**–0.623**
Manganese	–0.092	**–0.911**	0.255
% variance	53	14	11

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.
- $n = 83$ composites (22 from each of 2004, 2005 and 2006; 17 from 2008).

The next step was to compare liver body burden variables for 2008 among Areas in ANOVA. Fat content did not differ significantly between Reference Areas or between the Study and the Reference Areas (Table 6-17). Metals PC1 scores and concentrations of the eight individual metals did not differ significantly between Reference Areas or between the Study and the Reference Areas. Study Area Metals PC1 scores were intermediate (i.e., within the Reference Range) (Figure 6-8). Concentrations of individual metals were usually intermediate or below Reference values (Appendix C-2).

Table 6-17 Results of ANOVA Comparing Plaice Liver Body Burden Variables Among Areas (2008)

Variable	Between References	Study versus Reference
% fat	0.586	0.392
Metals PC1	0.075	0.495
Arsenic	0.604	0.111
Cadmium	0.098	0.942
Copper	0.924	0.534
Iron	0.084	0.269
Manganese	0.928	0.604
Mercury	0.109	0.114
Selenium	0.143	0.803
Zinc	0.667	0.629
>C_{10}-C_{21} HCs	0.241	0.697
>C_{21}-C_{32} HCs	**0.037**	0.595

Notes:
- $p \leq 0.05$ in bold.

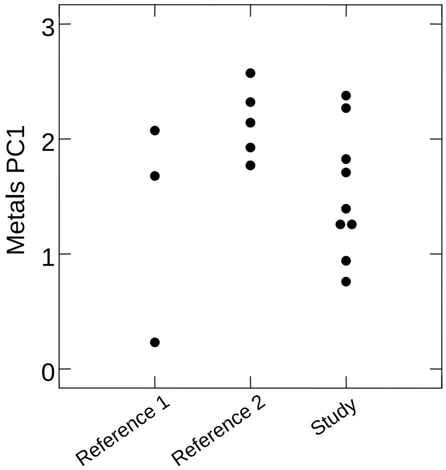

Figure 6-8 Distributions of Metals PC1 Scores in Plaice Liver Composites (2008)

The concentration of compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} HC range did not differ significantly between the Study and the Reference Areas (Table 6-17), and Study Area concentrations were intermediate (Figure 6-9). The concentration of compounds in the >C_{21}-C_{32} HC range were higher in Reference Area 2 composites than in Reference Area 1 composites and the difference between the two Reference Areas was significant despite the small sample sizes.

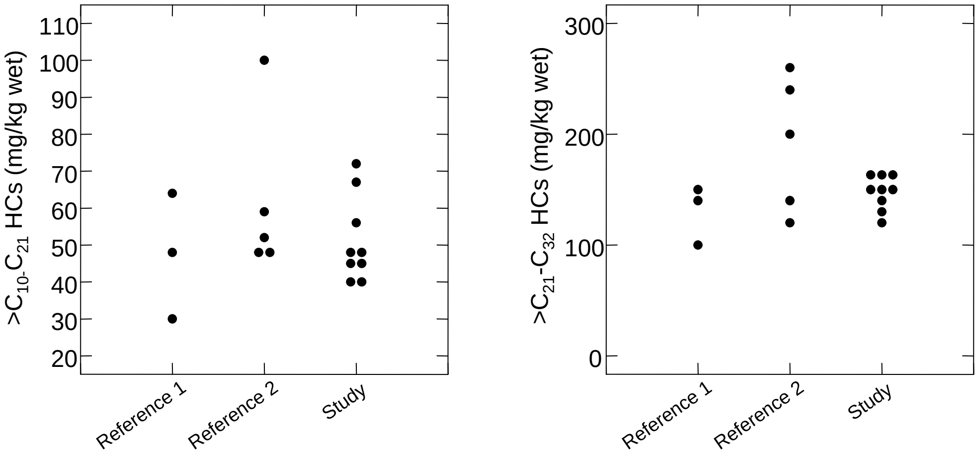

Figure 6-9 Distributions of Concentrations of Compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} HC Range in Plaice Liver Composites (2008)

Fat content, Metals PC1 scores, manganese concentrations and concentrations of compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} HC range were negatively correlated with mean composite gutted weight (i.e., size), but none of the correlations was significant at $p \leq 0.05$ (or even at $p \leq 0.10$) (Table 6-18). The only significant correlation among the body burden variables was the negative correlation between fat content and Metals PC1. Metal concentrations would not be expected to be correlated with fat content, except that a positive correlation might be expected for organic forms of mercury and selenium. Correlations between Metals PC1 scores and concentrations of compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} range were weak. Stronger correlations were not expected given that the concentration of Study Area metals and compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} range were not elevated above Reference levels and all compounds were probably natural in origin. >C_{10}-C_{21} HC and >C_{21}-C_{32} HC concentrations were positively correlated, although the correlation was only marginally significant ($0.05 < p < 0.10$).

Table 6-18 Spearman Rank Correlations (r_s) Among Plaice Liver Burden Variables, and Between Those Variables and Biological Variables (2008)

	% fat	Metals PC1	Manganese	>C_{10}-C_{21} HCs	>C_{21}-C_{32} HCs
Gutted weight	–0.326	0.201	–0.018	–0.087	–0.372
% fat		**–0.581***	–0.061	–0.243	0.208
Metals PC1			0.284	0.211	–0.122
Manganese				0.177	–0.284
>C_{10}-C_{21} HCs					0.472

Notes:
- n = 17 composites except for % fat (n = 15 composites).
- *$p \leq 0.05$; ** $p \leq 0.01$; r_s at $p \leq 0.05$ in bold.

Comparison Among Years (2004, 2005, 2006 and 2008)

Results of CR ANOVA comparing plaice liver body burden variables among Areas and years are provided in Table 6-19. The tests had limited power, so $p \leq 0.10$ rather than the traditional $p \leq 0.05$ are shown in bold. The Study versus Reference (SR) contrast was not significant at $p \leq 0.10$ for any variable; all p values for the contrast were > 0.20. The overall Year × SR interaction was not significant for any variable except for compounds in the >C_{21}-C_{32} HC range. The Trend × SR interaction was significant only for copper and zinc. As for crab, differences in plaice liver body burden variables between the Study and Reference Areas were generally small with Study Area values usually intermediate, and SR differences did not change over time (e.g., Metals PC1 scores and manganese concentrations in Figure 6-10).

Table 6-19 Results of Completely Random (CR) ANOVA Comparing Plaice Liver Body Burden Variables Among Areas and Years (2004, 2005, 2006 and 2008)

Variable	Study versus Reference (SR)	Year		Year x SR	
		Overall	Trend	Overall	Trend x SR
% fat	0.967	0.744	0.464	0.923	0.584
Metals PC1	0.471	**<0.001**	**<0.001**	0.868	0.748
Arsenic (log_{10})	0.563	**<0.001**	**<0.001**	0.155	0.260
Cadmium (log_{10})	0.602	**0.023**	**0.026**	0.956	0.631
Copper	0.860	**<0.001**	**<0.001**	0.272	**0.072**
Iron (log_{10})	0.424	**0.015**	**0.012**	0.851	0.434
Manganese	0.896	0.892	0.870	0.847	0.910
Mercury (log_{10})	0.206	**0.002**	0.323	0.405	0.782
Selenium	0.866	**0.079**	**0.014**	0.981	0.936
Zinc	0.804	**<0.001**	**<0.001**	0.245	**0.097**
>C_{10}-C_{21} HCs (log_{10})	0.464	0.724	0.276	0.300	0.623
>C_{21}-C_{32} HCs (log_{10})	0.339	**<0.001**	**<0.001**	**0.053**	0.224

Notes:
- $p \leq 0.10$ in bold.
- See Table 6-5 for further explanation of the CR ANOVA.

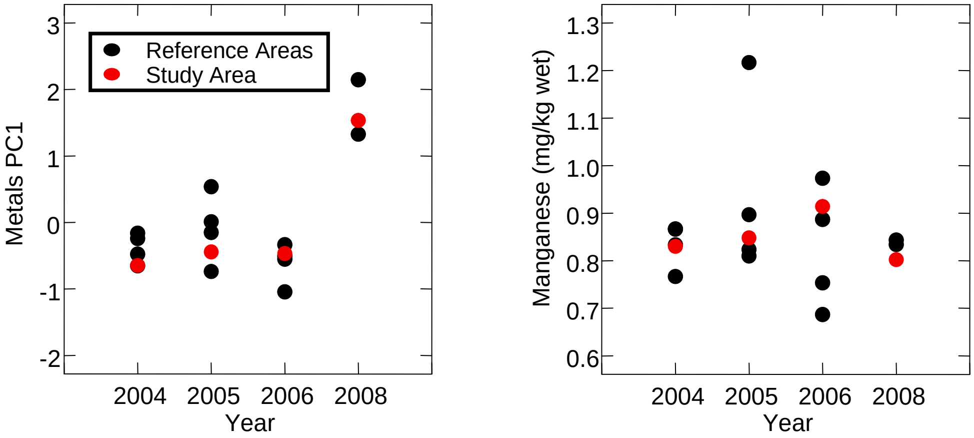

Figure 6-10 **Metals PC1 Scores and Manganese Concentrations in Plaice Liver Composites (2004, 2005, 2006 and 2008)**

Notes: The X axes on these figures are not linear; values are Area means; some points may represent more than one mean.

Metals PC1 scores and concentrations of most metals in both Study Area and Reference Area plaice liver composites increased, often substantially, in 2008 relative to past (2004 to 2006) concentrations (Figure 6-10), which accounted for most of the significant overall Year terms in Table 6-19. Manganese, which was uncorrelated with Metals PC1 (and other metals) and varied little over time and space, was an exception. Common “Trends” were often significant for metals, although progressive increases were rare, because 2008 was the last year in a short (four-year) time series. The Trend term would be less significant or not significant if the high concentrations in 2008 had instead occurred in an intermediate year (2005 or 2006).

Figure 6-11 plots time series for selected metals. Arsenic concentrations increased approximately 10-fold in 2008 relative to past years (note the log scale for the *Y* axis in Figure 6-11). Increases in 2008 for several other metals (e.g., copper and mercury) were also substantial (two- to five-fold). The Trend × SR interaction term was significant at $p \leq 0.10$ for copper and zinc primarily because increases in concentrations of both metals in 2008 were greater in the Study Area than in the Reference Areas. However, for those two metals, there was also a more progressive shift from Study Area values less than Reference Area values in 2004 to Study Area values greater than Reference Area values in 2008, potential evidence of project effects that should be monitored in the future. Mercury concentrations decreased from 2004 to 2006, but that trend was reversed in 2008. Except in 2006, Study Area mercury concentrations were less than Reference Area concentrations. Selenium provided one of the few examples of a more progressive increase in concentration over time, despite the narrow range of concentrations within and among years. The selenium trend was significant for 2004 to 2006 (Husky Energy 2007), and increases in selenium concentrations from 2006 to 2008 were similar to year-to-year increases from 2004 to 2006. Study Area selenium concentrations were intermediate in all four sample years.

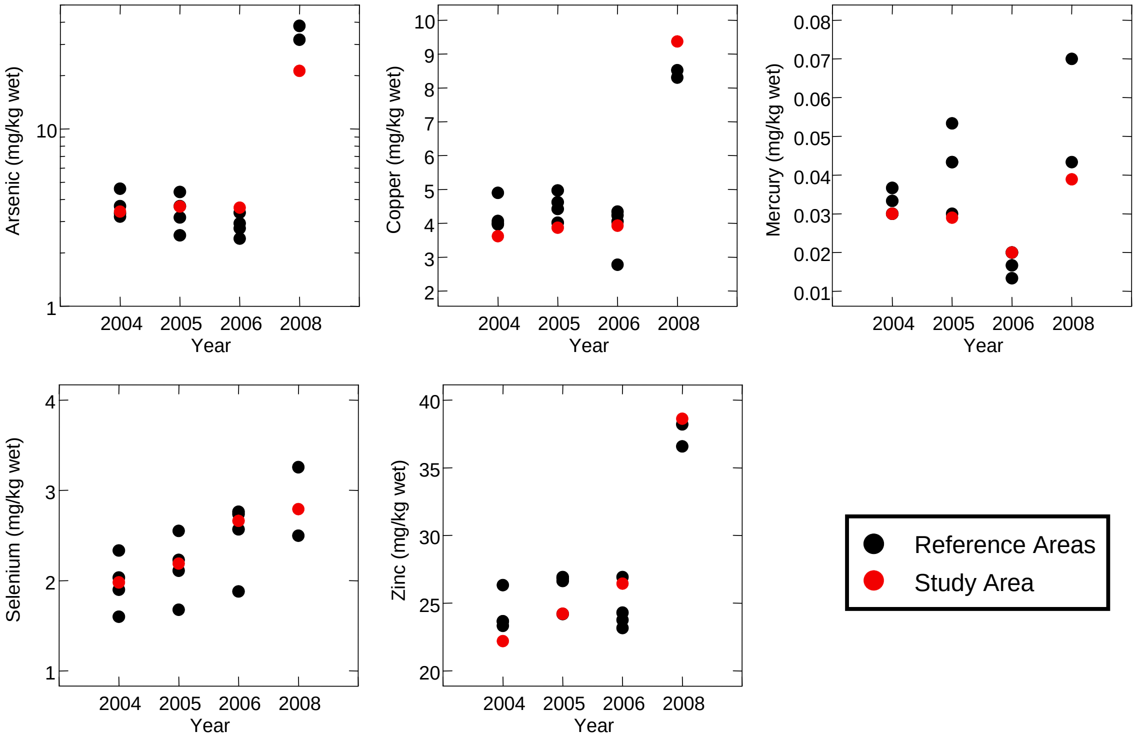

Figure 6-11 **Arsenic, Copper, Mercury, Selenium and Zinc Concentrations in Plaice Liver Composites (2004, 2005, 2006 and 2008)**

Notes: The X axes on these figures are not linear; values are Area means; some points may represent more than one mean.

The Area mean for concentrations of compounds in the >C_{10}-C_{21} range decreased progressively over time (Figure 6-12), but the overall trend and any differences among years were not significant (Table 6-19). Instead, Area means appeared to be converging on a value of approximately 50 mg/kg wet. The concentration of compounds in the >C_{21}-C_{32} range increased significantly over time (Table 6-19), primarily between 2006 and 2008 (Figure 6-12). The Year × SR interaction was significant largely because an unusually high concentration (660 mg/kg) in one (of 10) 2006 Study Area composite elevated the 2006 Study Area mean above the Reference Area means. If Area medians rather than means, or a rank- rather than log-transformation of Area means, were used, the Year × Area interaction would not be significant, but overall Year and Trend terms would still be significant because of the increase in concentrations in 2008.

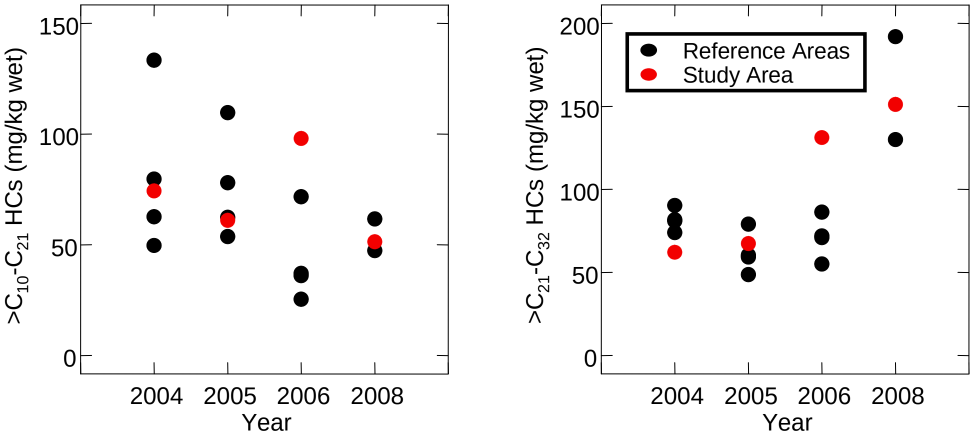

Figure 6-12 Concentrations of Compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} HC Range in Plaice Liver Composites (2004, 2005, 2006 and 2008)

Notes: The X axes on these figures are not linear; values are Area means; some points may represent more than one mean.

Fillets

Summary statistics for concentrations of detected substances in 2004, 2005, 2006 and 2008 and raw data for 2008 are provided in Appendix C-2. Moisture content (50 to 60%) measured in 2008 samples on samples archived for three to six weeks longer than samples used for other analyses was lower than moisture content (approximately 80%) measured synoptically with other variables in 2004 to 2006 samples, again indicating the drying effect of prolonged storage. 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.).

Analysis of 2008 Data

In 2008, fat content and metal (arsenic, mercury and zinc) concentrations in plaice fillets did not differ significantly between Reference Areas, or between the Study and the Reference Areas (Table 6-20).

Table 6-20 Results of ANOVA Comparing Plaice Fillet Body Burden Variables Among Areas (2008)

Variable	Between References	Study versus Reference
% fat	0.258	0.326
Arsenic	0.924	0.163
Mercury	0.401	0.892
Zinc	0.538	0.503

Notes: - $p \leq 0.05$ in bold.

Fat content and metal concentrations in fillets were positively correlated with composite mean gutted weights (i.e., size), but none of the correlations was significant at $p \leq 0.05$ or even at $p \leq 0.10$ (Table 6-21). Metal concentrations were positively correlated with each other, and with fat content but none of the correlations was significant at $p \leq 0.05$ and only the mercury-zinc correlation was significant at $p \leq 0.10$.

Table 6-21 **Spearman Rank Correlations (r_s) Among Plaice Fillet Body Burden Variables, and Between Those Variables and Composite Mean Gutted Weights (2008)**

	% fat	Arsenic	Mercury	Zinc
Gutted weight	0.265	0.123	0.307	0.190
% fat		0.232	0.184	0.179
Arsenic			0.268	0.385
Mercury				0.445

Notes: - $n = 17$ composites.
- *$p \leq 0.05$; **$p \leq 0.01$; r_s at $p \leq 0.05$ in bold.

Comparison Among Years (2004, 2005, 2006 and 2008)

Except for zinc, terms in CR ANOVA comparing plaice fillet body burden variables among Areas and years were not significant at $p \leq 0.10$ (or even at $p \leq 0.20$; Table 6-22). Most differences over space or time were small, and there was no evidence of significant project effects (i.e., significant SR or Year × SR terms) and no evidence that the large increases in metal concentrations in liver that occurred in 2008 also occurred in fillets. For example, over four years, Area mean mercury concentrations varied over a less than two-fold range, with Study Area means constant over time and intermediate in all four years (Figure 6-13). The trend for zinc common to both Study and Reference Areas was significant at $p \leq 0.10$ (Table 6-22) largely because concentrations decreased by 10 to 20% in 2008 (Figure 6-13). Note that there was a highly significant ($p < 0.001$) and much greater increase (approximately 50%) in zinc concentrations in liver in 2008 (Figure 6-11).

Table 6-22 **Results of Completely Random (CR) ANOVA Comparing Plaice Fillet Body Burden Variables Among Areas and Between Years (2004, 2005, 2006 and 2008)**

Variable	Study versus Reference (SR)	Year		Year x SR	
		Overall	Trend	Overall	Trend x SR
% fat	0.551	0.432	0.192	0.883	0.498
Arsenic	0.798	0.566	0.772	0.550	0.268
Mercury	0.768	0.991	0.877	0.989	0.851
Zinc	0.550	0.187	**0.076**	0.956	0.719

Notes: - $p \leq 0.10$ in bold.
All variables except Metals PC1 were rank-transformed.

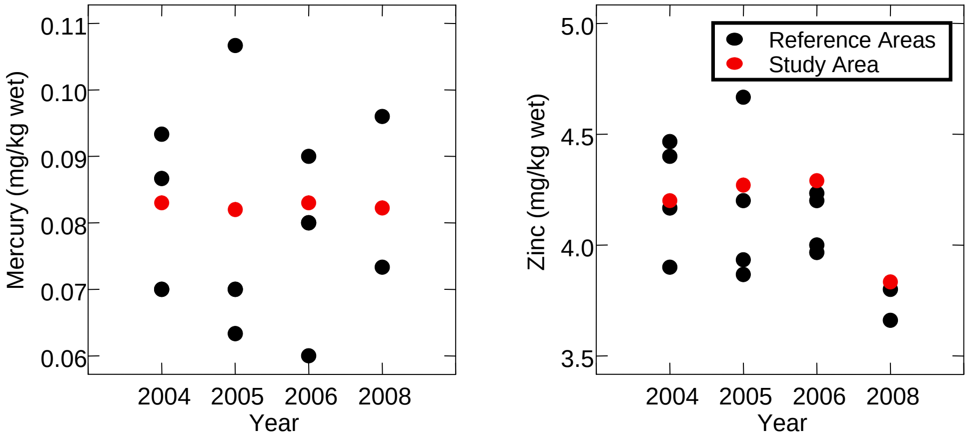

Figure 6-13 Mercury and Zinc in Plaice Fillet Composites (2004, 2005, 2006 and 2008)

Notes: The X axes on these figures are not linear; values are Area means; some points may represent more than one mean.

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 10 out of 24 samples. These results were not significant at $\alpha = 0.05$ (Appendix C-4). ANOVA statistics for hedonic scaling are provided in Table 6-23. The results were not significant ($p = 0.10$; $\alpha = 0.05$) and, from the frequency histogram (Figure 6-14), samples from both the Study and Reference Areas were assessed similarly for preference. From ancillary comments (Tables 6-24 and 6-25, and Appendix C-4), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 6-23 Analysis of Variance for Taste Preference Evaluation of Crab by Hedonic Scaling (2008)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.52	1	3.52	2.80	0.10	4.05
Within Groups	57.79	46	1.26			
Total	61.31	47				

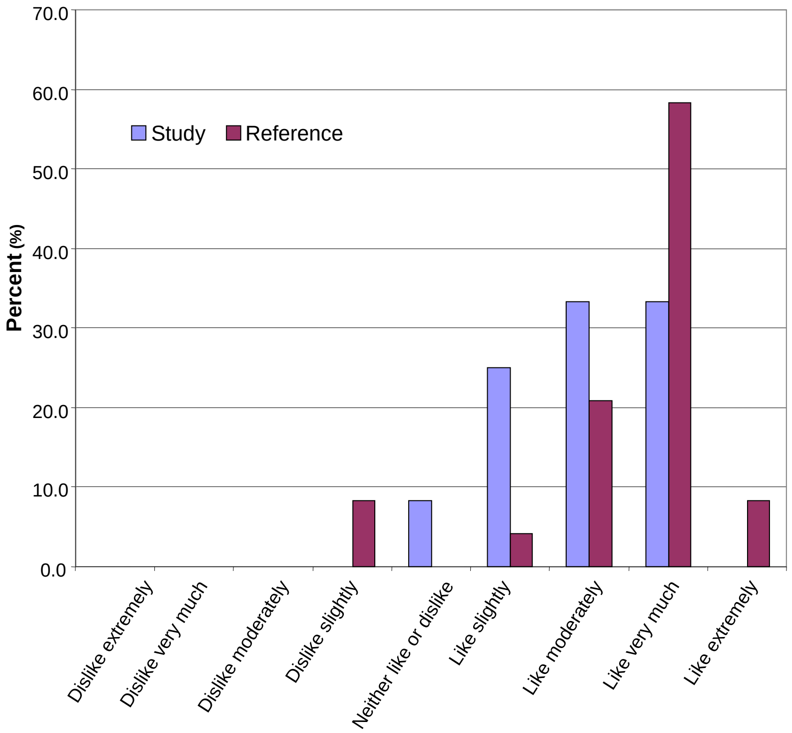

Figure 6-14 Crab Frequency Histogram for Hedonic Scaling Taste Evaluation (2008)

Table 6-24 Summary of Comments from the Triangle Taste Test for Crab (2008)

Reference Area (RA)	Study Area (SA)
Correctly identified as odd sample	**Correctly identified as odd sample**
Slight difference in odour and flavour.	Very hard to tell.
No difference to me.	All the samples had typical odour and taste. The chosen sample was slightly blander than the others.
Very similar, less taste on 340 (RA).	
The selection is only a guess. There is little or no difference in my opinion.	
All tasted good, no off odour or flavour.	
Very close but 340 (RA) had a slightly sour taste.	
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
Very difficult to distinguish. 217 (RA) slight odour difference.	Not as nice tasting, less sweet.
217 (RA) sweeter.	Not much of a difference.
Very difficult to distinguish. The only difference I found was that the first sample was slightly saltier.	
320 (RA) is more flavourable. No real difference in odour on any of the samples.	
Not a big difference. No detectable difference with regard to odour. 944 (RA) was a little more bland. Not as much crab flavour.	
Slightly different odour.	
944 (RA) and 615 (SA) had a pleasant sweet taste, while 830 (RA) had an after taste. Odours were all acceptable.	

Table 6-25 Summary of Comments from Hedonic Scaling Taste Tests for Crab (2008)

Preferred Reference Area	Preferred Study Area
Low odour and good taste on 397 (RA). Never got an odour on 192 (SA), not much of a taste.	Both taste the same.
397 (RA) – fresh odour, sweet taste, very pleasant. 192 (SA) – not as sweet as 397 (RA)	Taste the same.
Both taste the same	No difference at all, both were very good.
192 (SA) was a little sweeter, but the after taste was stronger than 397 (RA)	Sample 569 (SA) had a sweeter flavour than sample 835 (RA).
397 (RA) not sweet, no odour; 192 (SA) too sweet, no odour.	Smelled OK.
Taste the same.	Very nice, no discernable difference.
Found 687 (RA) sweeter.	Both samples smelled and tasted the same to me.
251 (SA) a little bitter after taste.	Tasted the same.
No difference at all, both were very good.	
No difference in odour. 835 (RA) was more representative of crab flavour.	
Liked both. 835 (RA) was sweeter and therefore more enjoyable.	
Very nice, no discernable difference.	
Both samples smelled and tasted the same to me.	
276 (SA) bland, 333 (RA) solid and chunky. Both smell good.	
Tasted the same.	
Not a significant difference, 333 (SA) has a sweeter taste.	

For plaice, panelists for the triangle test were successful in discriminating 10 out of 24 samples. These results are not significant at $\alpha = 0.05$ (Appendix C-4). ANOVA statistics for hedonic scaling are provided in Table 6-26. The results are significant ($p = 0.15$; $\alpha = 0.05$) and, from the frequency histogram (Figure 6-15), samples from the Reference Area were preferred. However, from ancillary comments (Tables 6-27 and 6-28, and Appendix C-4), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 6-26 Analysis of Variance for Taste Preference Evaluation of Plaice by Hedonic Scaling (2008)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	18.75	1	18.75	8.76	0.005	4.05
Within Groups	98.50	46	2.14			
Total	117.25	47				

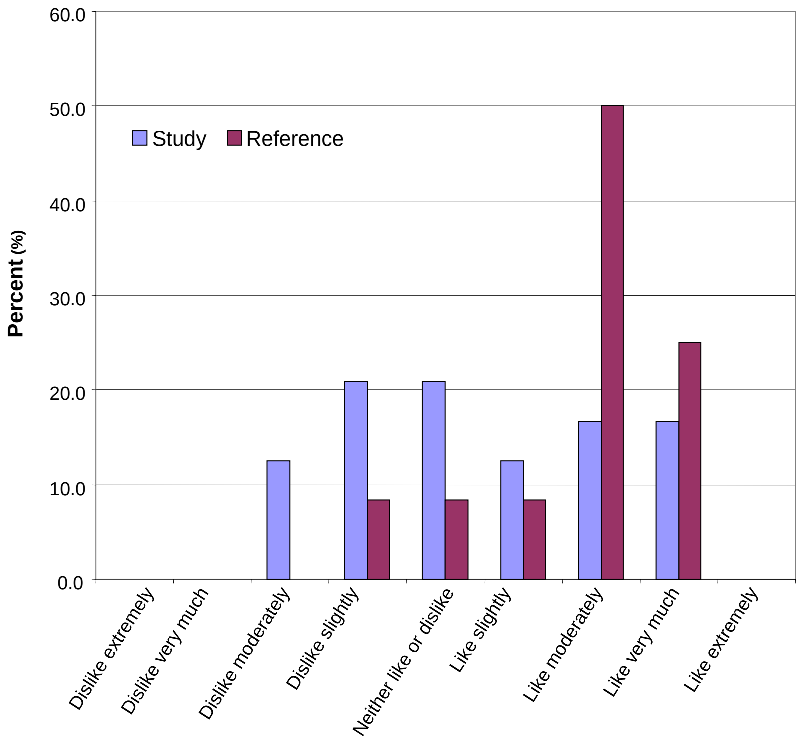

Figure 6-15 Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2008)

Table 6-27 Summary of Comments from the Triangle Taste Test for Plaice (2008)

Reference Area	Study Area
Correctly identified as odd sample	**Correctly identified as odd sample**
230 (RA) was tastier than the other two. The other two were almost tasteless.	689 (SA) most flavour, couldn't distinguish any difference in smell.
230 (RA) tasted good. 384 (SA) and 127 (SA) had a strong fishy/oily taste.	723 (SA) did not taste or smell as good as the other two samples. It had a stronger odour.
Odd sample tasted a little less sweet.	723 (SA) less flavour.
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
The odd sample had a sweeter flavour and stronger odour than the other two samples.	I found 635 (SA) to have a slightly different odour than the other two. The flavour was very close on all three, but still a slight difference.
Can't detect by odour. More steam in 265 (RA) therefore stronger odour. 265 (RA) sweeter, 689 (SA) sweet, 146 (RA) not sweet at all.	827 (SA) a little stronger, really hard to differentiate.
146 (RA) and 689 (SA) much sweeter – less fishy and more palatable than 265 (RA). 265 (RA) smells fishier.	Not too much of a taste on all three, to me they all smelled the same.
Struggled to notice any difference. 235 (RA) would be my best estimate.	Very little difference in samples.
235 (RA) and 723 (SA) had a little bit of an undesirable flavour.	Strong fishy odour.
	Different odour and off taste.

Table 6-28 Summary of Comments from the Hedonic Scaling Taste Test for Plaice (2008)

Preferred Reference Area (RA)	Preferred Study Area (SA)
259 (RA) - slight odour, product has little flavour (bland). 142 (SA) – Natural odour but not that strong, also bland taste. No objectionable odours or flavour in either sample.	259 (RA) - slight odour, product has little flavour (bland). 142 (SA) – Natural odour but not that strong, also bland taste. No objectionable odours or flavour in either sample.
Both pretty much the same.	Both pretty much the same.
Sample 142 (SA) – slightly oily taste. 259 (RA) – very good. Odours found to be the same for both.	259 (RA) – Characteristic fresh fish odour and taste. 142 (SA) – Sweet odour, fresh fish taste.
Both samples had a discernable odour. However, 142 (SA) had a bit of an off flavour. Neither of the samples had much of a flavour to them.	142 (SA) more flavourful, more pronounced desirable odour and flavour.
Preferred the 359 (RA) sample with sweeter flavour.	Not a big difference in flavour or smell.
197 (SA) tasted bland.	Both are excellent. 111 (SA) seemed to have a stronger smell, but both were pleasing.
Odour is similar, taste is slightly different.	Strong off odour (fishy) and taste (on RA sample).
359 (RA) is more pleasant, can’t put my finger on it. No huge difference.	
Not a big difference in flavour or smell.	
No difference in smell. More flavour in 365 (RA). Not much taste in 111 (SA).	
365 (RA) was more representative of a fresh seafood product. It was slightly sweet while 111 (SA) was quite bland. 365 (RA) had a better odour.	
Both are excellent. 111 (SA) seemed to have a stronger smell, but both were pleasing.	
Sample 365 (RA) has a fresher taste.	
Sample 111 (SA) seems to be bland.	
Not much difference in either one; smelled fine.	
548 (SA) had a bland taste and strong after taste.	
611 (RA) has a sweeter flavour. 548 (SA) is lacking in flavour but is not unpalatable.	
More of a taste to 611 (RA) than 548 (SA).	

6.4.4 Fish Health Indicators

A total of 113 plaice were examined for early warning effects on fish health. Fifty-nine (59) fish were sampled in the Study Area, 12 fish were sampled from Reference Area 1 and 42 fish were sampled from Reference Area 2. Necropsy data are provided in Appendix C-3 (Annex C) and the statistical analyses used for comparing the different variables are described in detail in Appendix C-3 (Annex B).

6.4.4.1 Fish Condition

No differences between the Study and Reference Areas were noted for most fish condition indices. However, liver weight relative to gutted weight was higher in male fish from the Study Area. Additional details on these analyses can be found in Appendix C-3.

6.4.4.2 Gross Pathology

Except for one fish from the Study Area that exhibited a growth on its skin, no other visible abnormalities were observed upon necropsy on the skin or fins of fish or on the external surface of the gonad, digestive tract, liver, body-cavity or spleen (Appendix C-3, Annex C).

6.4.4.3 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 112 fish. Blood smears of one fish were not suitable for cell counting due to clotting problems. For the other blood smears, 200 cells were counted per fish and the results were expressed as mean percentage ± standard deviation of each cell type for each Area (Table 6-29). 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 1) is included in Appendix C-3 (Annex H).

Table 6-29 Frequencies of Blood Cell Types in Plaice (2008)

Area	Number of Fish	% neutrophils	% thrombocytes	% lymphocytes
Study	58	0.64±0.54	17.40±2.40	81.97±2.36
Reference 1	12	1.00±0.60	17.55±1.27	81.45±1.51
Reference 2	42	0.64±0.58	18.49±1.66	80.87±1.49
Combined References	54	0.72±0.60	18.28±1.62	81.00±1.50
Total	112	0.68±0.56	17.82±2.10	81.50±2.04

Note: - All data are means ± standard deviations.

Percentages of lymphocytes and thrombocytes were compared among Areas using ANOVA (Table 6-30).

Table 6-30 Results of ANOVA Comparing Percentages of Blood Cell Types in Plaice (2008)

Group	*p* values	
	Between References (BR)	Study vs References (SR)
% lymphocytes	0.165	0.151
% thrombocytes	0.376	0.057

The slight difference in % thrombocytes (approximately 1%) between the Reference Areas and the Study Area was nearly significant at p = 0.057. Excluding fish from Reference Area 1 (ANOVA comparing Reference Area 2 and the Study Area), differences were significant at p = 0.013, with higher % thrombocytes in Reference Area 2. Comparisons of the frequency of lymphocytes by ANOVA between Reference Area 2, alone, and the Study Area also indicated a significant difference (p = 0.009), with lower % lymphocytes (approximately 1%) in Reference Area 2 than in the Study Area.

6.4.4.4 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. Within the females, data were also analyzed separately for pre-spawning and spent 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). However, for these females, no between Reference Area comparison could be performed because of low samples sizes ($n \leq 4$), and comparisons were restricted to comparisons of combined Reference Areas and Study Area data (see Appendix C-3, Annex B for details).

MFO enzyme activities, measured as EROD, in the liver of males (all maturity stages combined), pre-spawning females (DFO maturity stages F-520 to F-540) and spent females (DFO maturity stage F-560) are provided in Appendix C-3 (Annex E) and results are summarized in Figures 6-16 and 6-17.

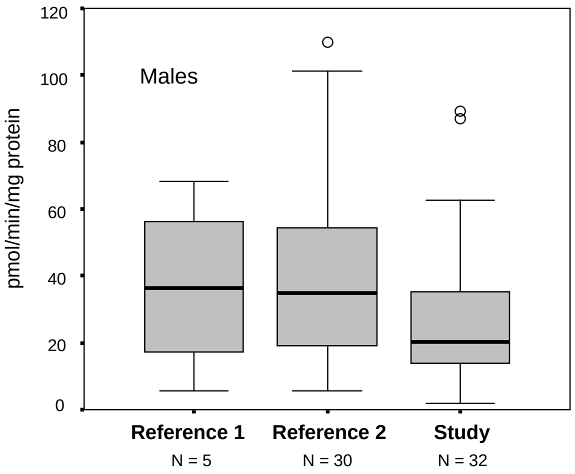

Figure 6-16 MFO Activity in the Liver of Male Plaice (All Maturity Stages)

Notes: Horizontal line in middle of box = median; box = 25th to 75th percentile; vertical lines = whiskers and 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 far outside values, >3 Hspreads from the 25th or 75th percentiles; º circles are outside values, >1.5 Hpsreads from the 25th or 75th percentiles; the number under each box is the sample size.

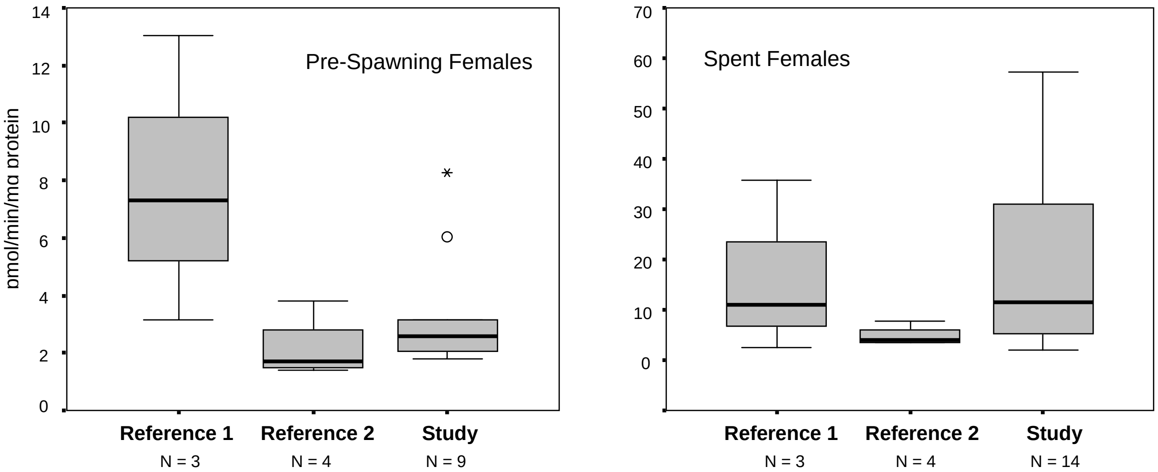

Figure 6-17 MFO Activity in the Liver of Pre-spawning (DFO Stages F-520 to F-540) and Spent (DFO Stage F-560) Female Plaice

Notes: Horizontal line in middle of box = median; box = 25th to 75th percentile; vertical lines = whiskers and 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 far outside values, >3 Hspreads from the 25th or 75th percentiles; º circles are outside values, >1.5 Hpsreads from the 25th or 75th percentiles; the number under each box is the sample size; see Appendix C-3 (Annex A) for DFO maturity stage classifications.

Hepatic MFO activity in males did not differ significantly between the Study Area and the Reference Areas (Table 6-31).

Table 6-31 Results of ANOVA Comparing MFO Activities in Male and Female Plaice (2008)

Group	*p* Values	
	Between References (BR)	Study vs References (SR)
Males (All maturity stages combined)	0.722	0.123
Pre-spawning Females (DFO stages F-520 to F-540)	Not tested	0.852
Spent Females (DFO stage F-560)	Not tested	0.162

Notes:
- MFO activities were rank-transformed.
- See Annex A for maturity stage classifications.

Likewise, MFO activity did not differ significantly between Areas for pre-spawning or spent females (Table 6-31). However, it is noted that sample sizes were small for comparison (see Figure 6-17).

6.4.4.5 Histopathology

Liver Histopathology

Detailed histopathological studies were carried out on liver tissues of plaice with observations on various lesions that have been associated with chemical toxicity. These included nuclear pleomorphism, megalocytic hepatosis, basophilic, eosinophilic and clear cell foci, fibrillar inclusions, fibrosis, carcinoma, cholangioma, cholangiofibrosis, proliferation of macrophage aggregates and hydropic vacuolation. Any other observations were also recorded and included hepatocellular vacuolation, parasitic infestation of the biliary system and inflammatory responses. Lesions were recorded for each fish as present or absent (Appendix C-3, Annex E), except for macrophage aggregation which was rated on a relative scale of 0 to 7.

Results were expressed as percentage of fish affected by each type of lesion/observation (or prevalence of lesion) in the Reference and Study Areas (Table 6-32). 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 2 and 3 representing a normal liver structure.

Table 6-32 Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions (2008)

Variable		Study	Reference 1	Reference 2	Combined References
Number of Fish		59	12	42	54
Basophillic foci	No.	0	0	0	0
	%	0	0	0	0
Cholangio-fibrosis	No.	0	0	0	0
	%	0	0	0	0
Cholangioma	No.	0	0	0	0
	%	0	0	0	0
Clear cell foci	No.	0	0	0	0
	%	0	0	0	0

Variable		Study	Reference 1	Reference 2	Combined References
Eosinophilic foci	No.	0	0	0	0
	%	0	0	0	0
Fibrillar inclusions	No.	0	0	0	0
	%	0	0	0	0
Hepatocellular carcinoma	No.	0	0	0	0
	%	0	0	0	0
Hepatocellular vacuolation	No.	7	2	5	7
	%	11.9	16.7	11.9	13
Hydropic vacuolation	No.	0	0	0	0
	%	0	0	0	0
Inflammatory response	No.	1	0	0	0
	%	0.9	0	0	0
Proliferation of macrophage aggregates[a]	No.	0	0	0	0
	%	0	0	0	0
Megalocytic hepatosis	No.	0	0	0	0
	%	0	0	0	0
Nuclear pleomorphism	No.	0	0	0	0
	%	0	0	0	0
Parasites in bile ducts	No.	6	2	8	10
	%	10.2	16.7	19	18.5

Note: - [a] Defined as scores greater than 3 on a 0-7 relative scale.

Fifty-nine (59) fish from the Study Area and 54 fish from the Reference Areas were examined and no cases of lesions that have been associated with chemical toxicity 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) that are considered as a proliferation of macrophage aggregates were observed.

With respect to other observations, a patchy distribution of hepatocellular vacuolation (Appendix C-3, Annex H, Photo 4), not associated with degenerative changes, was observed in 13% of fish from the Reference Areas and in 12% of fish from the Study Area, and an infestation of the biliary system with a myxosporean parasite (Appendix C-3, Annex H, Photo 5), possibly *Myxidium sp*., was observed in 18.5% of fish from the Reference Areas and in 10.2% of fish from the Study Area. The infestation did not appear to result in any other pathological changes in hepatic tissues. One fish from the Study Area also exhibited a mild inflammatory response (Appendix C-3, Annex H, Photo 6).

There were no significant differences in any of the hepatic indices examined between fish from the Study and Reference Areas (Fisher exact test).

Gill Histopathology

Gill sections were examined for the presence of various gill lesions associated with chemical toxicity. These included epithelial lifting, basal, distal and tip hyperplasia, fusion, telangiectasis and severe oedema. For each fish, lamellar counts were performed on four filaments, when possible, and are presented as the percentage of secondary lamellae affected by each type of lesion in relation to the total number of secondary lamellae counted (between 128 and 1,172 lamellae per fish) in Appendix C-3 (Annex G).

Gills from one fish from the Study Area were missing and accurate counts were not possible for three fish from the Reference Areas as well as two fish from the Study Area. Detailed histopathological studies were therefore carried out on gill tissues of 51 fish from the Reference Areas and 56 fish from the Study Area. There were no cases of epithelial lifting in fish from any Area and the percentages of lamellae affected by the other lesions were very low; all were less than 1.6%, except for one fish from the Study Area with 2.3% of lamellae exhibiting telangiectasis (Appendix C-3, Annex G). Representative photographs of secondary lamellae without lesions (Photo 7), as well as exhibiting tip (Photo 8), basal (Photo 9) and distal (Photo 10) hyperplasia, fusion (Photo 11) and telangiectasis (Photo 12) are included in Appendix C-3 (Annex H).

Means and SDs of percentages of lamellae presenting each type of lesion per Area are provided in Table 6-33.

Table 6-33 Occurrence of Lesions and Oedema Condition in the Gill Tissues of Plaice (2008)

Variable	Study	Reference 1	Reference 2	Combined References	Total
Number of fish	56	10	41	51	107
Distal hyperplasia[a]	0.019 ± 0.109	0.048 ± 0.078	0.117 ± 0.282	0.103 ± 0.255	0.059 ± 0.197
Epithelial lifting[a]	0.000	0.000	0.000	0.000	0.000
Tip hyperplasia[a]	0.008 ± 0.041	0.014 ± 0.044	0.039 ± 0.091	0.034 ± 0.084	0.020 ± 0.066
Basal hyperplasia 1[ac]	0.007 ± 0.049	0.000	0.012 ± 0.060	0.010 ± 0.054	0.008 ± 0.051
Basal hyperplasia 2[ad]	0.004 ± 0.030	0.000	0.000	0.000	0.002 ± 0.021
Fusion[a]	0.069 ± 0.261	0.000	0.003 ± 0.021	0.003 ± 0.019	0.037 ± 0.191
Telangiectasis[a]	0.083 ± 0.348	0.000	0.025 ± 0.131	0.020 ± 0.118	0.053 ± 0.265
Oedema condition[b]	0.982 ± 0.924	1.600 ± 0.843	0.756 ± 0.799	0.922 ± 0.868	0.953 ± 0.894

Notes:
- All data are means ± SDs.
- [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.

Degree of oedema, which was recorded on a 0-3 relative scale (0-rare, 1-light, 2-moderate and 3-heavy) in relation to the severity of the condition, was quite low in all Areas (Table 6-33). There was a significant difference in the degree of oedema between the Reference Areas (p = 0.007), with higher levels in Reference Area 1 (Table 6-33) than in Reference Area 2, but there was no significant difference between the Reference Areas and the Study Area (p = 0.312).

Since the lesions were rare or absent, being found in only a small number of fish (less than 16 fish from all sites in total), 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 number of fish exhibiting the lesions between the Study Area and the combined Reference Areas (Table 6-34), using Fisher's Exact Test. Lesions were considered "present" if those conditions occurred on any of the lamellae examined for each fish.

Basal hyperplasia 1 and 2, fusion and telangiectasis occurred in less than 10 fish and were not analyzed statistically.

Incidences of distal hyperplasia were generally 4 to 30% (Table 6-34), with greater occurrence in the combined Reference Areas (Table 6-34, *p* = 0.001; Fisher's Exact Test). Incidences of tip hyperplasia ranged from 4 to 17%, again with greater occurrence in the combined Reference Areas (Table 6-34, *p* = 0.045; Fisher's Exact Test).

Table 6-34 Number of Plaice with Specific Types of Gill Lesions and Percentages of Fish Exhibiting the Lesions (2008)

Variable		**Study**	**Reference 1**	**Reference 2**	**Combined References**
Number of Fish		56	10	41	51
Distal hyperplasia	No.	2	3	10	13
	%	4	30	24	25
Tip hyperplasia	No.	2	1	7	8
	%	4	10	17	16
Basal hyperplasia 1[a]	No.	1	0	2	2
	%	2	0	5	4
Basal hyperplasia 2[b]	No.	1	0	0	0
	%	2	0	0	0
Fusion	No.	5	0	1	1
	%	9	0	2	2
Telangiectasis	No.	5	0	2	2
	%	9	0	5	4

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.

6.5 Summary of Findings

6.5.1 Biological Characteristics

6.5.1.1 Crab

Crab size and frequencies of recent moult for the 182 crab used in body burden analyses in 2008 did not differ significantly at $p \leq 0.05$ between the two Reference Areas sampled, or between the Study and Reference Areas. Approximately 30% of crab collected in late May to early June 2008 were recent moults; 40 to 70% of crab collected in later (July) samples from 2004 to 2006 were recent moults.

6.5.1.2 Plaice

Plaice liver and body burden composites usually consisted of a mix of larger mature females and smaller mature males. Therefore, size varied considerably within composites. However, composite mean gutted weights did not differ significantly among Reference Areas, or between the Study and the Reference Areas.

6.5.2 Body Burden

6.5.2.1 Crab

In 2008, moisture content in crab claw samples was measured on samples archived for three to six weeks later than samples processed for other body burden variables (i.e., synoptic measurements were made in previous years). Moisture content in the 2008 crab (and also plaice) samples was lower than moisture content in 2004 to 2006 samples, indicating that storage decreased moisture content (i.e., “dried” samples).

Concentrations of arsenic, copper, mercury, selenium and zinc in crab claws were positively correlated over all 2004, 2005, 2006 and 2008 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.

Fat content did not differ significantly among Areas in 2008. Boron concentrations were significantly greater (by approximately 20%) in Study Area crab than in Reference crab. Copper and mercury concentrations differed significantly and by more than 20% between the two Reference Areas, with Study Area concentrations intermediate.

In 2008, metal concentrations in crab claw composites increased significantly with increasing size. Frequencies of recent moult were uncorrelated with fat content and metal concentrations.

In multi-year comparisons, there were no consistent and significant differences in fat content and metal concentrations between the Study and Reference Areas over the four EEM years (2004, 2005, 2006 and 2008). There were also no significant changes in Study versus Reference Area differences over time. Copper and silver concentrations decreased and boron concentrations increased over time in both the Study and Reference Areas.

6.5.2.2 Plaice

Liver

Compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} HC range were detected in every plaice liver composite in 2008; as they were in every liver composite in 2005 and 2006, and in all but one composite in 2004. Chromatograms for these compounds did not resemble chromatograms for drill muds and additional analyses of selected samples indicated that the compounds were primarily squalene and other naturally occurring products.

Arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc were detected in every liver composite sample from 2004, 2005, 2006 and 2008. Other metals were rarely or never detected in liver samples. Based on multivariate analyses of all liver samples from 2004 to 2006 and 2008, concentrations of frequently detected metals, except manganese, were strongly positively correlated. Therefore, high concentrations of most metals tended to co-occur; but manganese may “behave differently” from the other seven frequently detected metals.

In 2008, fat content, metal concentrations and the concentration of compounds in the >C_{10}-C_{21} HC range in plaice liver did not differ significantly between Reference Areas, or between Study and Reference Areas. The concentration of compounds in the >C_{21}-C_{32} HC range differed significantly between the two Reference Areas, with Study Area concentrations intermediate.

In 2008, correlations between liver body burden variables and mean composite gutted weight (i.e., size) were either near 0 or weakly and not significantly negative. Metal concentrations decreased significantly with increasing fat content (a negative correlation).

There were no consistent and significant differences in liver body burden variables between the Study and Reference Areas over all four EEM years. Differences between Study and Reference Areas have generally been small and relatively constant over time. In contrast, there were large (2- to 10-fold) and highly significant increases in concentrations of most metals and compounds in the $>C_{21}$-C_{32} HC range in all Areas in 2008 relative to past years.

Fillets

HCs and most metals were rarely or never detected in plaice fillet samples in 2004, 2005, 2006 and 2008. Arsenic, mercury and zinc were detected in every fillet sample in all four years.

In 2008, fat content and concentrations of arsenic, mercury and zinc did not differ significantly among Areas. There were weak positive correlations between metal concentrations and mean composite gutted weight (i.e., size) and also among metals, but none of those correlations was significant at $p \leq 0.05$ or even at $p \leq 0.10$.

As was the case for plaice liver, concentrations of metals in plaice fillets increased with increasing body size in 2008 samples, but none of the correlations was significant at $p \leq 0.05$ or even at $p \leq 0.10$.

In comparisons of all four EEM years, there were no significant differences in fat content and metal concentrations in plaice fillets between the Study and Reference Areas. Zinc concentrations decreased in both Study and Reference Areas by 10 to 20% in 2008 relative to past years.

6.5.3 Taste Tests

There was no difference in taste between Study and Reference Area crab. For plaice, panelists could not distinguish between samples in the Triangle test, but preferred plaice from the Reference Area in the Hedonic Scaling test. However, from ancillary comments on plaice, there were no consistent comments identifying abnormal or foreign odour or taste.

6.5.4 Fish Health Indicators

Some very slight differences were noted with respect to white blood cell counts and gill hyperplasia, but these differences can reasonably be attributed to natural variability. Of particular interest was the virtual absence of inter-site variability with respect to health effect indicators more commonly associated with chemical toxicity, with the one exception of enlarged livers found in male fish from the Study Area. This included not only MFO enzymes but also a wide range of liver and gill lesions as well as visible external and internal abnormalities.

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 the drilling mud indicators: barium and $>C_{10}$-C_{21} hydrocarbons.

The two approaches are complementary, since each has its own advantages and limitations.

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 baseline and EEM years was usually 1 to 2% and rarely exceeded 3%. These fines levels are similar to fines levels at Terra Nova (Petro-Canada 2007). Gravel content in White Rose sediments was lower than gravel content at Terra Nova.

Total organic carbon (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 (Canadian Council of Ministers of the Environment (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 evidence of contamination from drilling and discharge of drill cuttings on $>C_{10}$-C_{21} hydrocarbon concentrations and, to a lesser extent, on barium concentrations. Both substances are major constituents of drilling muds and elevated concentrations are expected where cuttings have been discharged. Field monitoring results for both constituents showed 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 baseline (2000), $>C_{10}$-C_{21} hydrocarbon concentrations at all 46 stations sampled were less than the laboratory detection limit (0.3 mg/kg). In all EEM years, $>C_{10}$-C_{21} hydrocarbon concentrations at stations located 10 or more km from active drill centres were low (near or below the detection limit). However, many concentrations within 10 km of active drill centres were greater than the detection limit. Concentrations above the detection limit are evidence of contamination from the use of synthetic-based drill muds (SBMs).

Since drilling started at the Northern and Southern drill centres in 2004, >C_{10}-C_{21} hydrocarbon concentrations decreased significantly with increasing distances from these two drill centres. >C_{10}-C_{21} hydrocarbon concentrations did not decrease with increasing distance from the Central drill centre in 2004, but concentrations did decrease with distance in 2005, 2006 and 2008 after drilling started at that drill centre. Estimated zones of influence based on >C_{10}-C_{21} hydrocarbon concentrations have ranged from 6 km from the nearest active drill centre in 2004 and 2006 to 10 km from the nearest active drill centre in 2008. Estimated zones of influence should be considered similar over time because confidence intervals for annual estimates were wide. The range of total petroleum hydrocarbons (TPH[15]) concentrations observed at White Rose with distance from source is provided in Table 7-1.

Table 7-1 **Total Petroleum Hydrocarbons with Distance from Source at White Rose (2000 to 2008)**

Year	Distance from Source (m)	Total Petroleum Hydrocarbon (mg/kg)
2008	300 to 750	2.2 to 1,615
	750 to 2,500	1.3 to 55.7
	2,500 to 5,000	<0.3 to 4.2
2006	300 to 750	1.5 to 576
	750 to 2,500	0.7 to 53.4
	2,500 to 5,000	<3
2005	300 to 750	<3 to 261.7
	750 to 2,500	<3 to 54.6
	2,500 to 5,000	<3
2004	300 to 750	8.99 to 275.9
	750 to 2,500	<3 to 22.2
	2,500 to 5,000	<3 to 6.9
2000	300 to 750	<3
	750 to 2,500	<3
	2,500 to 5,000	<3

Notes:
- Distance for 2000, 2005, 2006 and 2008 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.
- Station 31, near an exploration well drilled in 2007, was excluded from 2008 statistics.

Barium, as barium sulphate (barite), is a major constituent of water-based drill muds (WBMs) and SBMs. Barium occurs naturally in White Rose sediments at concentrations ranging from approximately 100 to 200 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 drill centres. Evidence of barium contamination from the Northern drill centre has never been detected. Median barium concentrations from stations sampled in all sample years have progressively increased over time, with the greatest changes occurring near drill centres. Estimated zones of influence based on barium concentrations in EEM years were 1.9 km in 2006 to 3.6 km in 2005, with no apparent increase or decrease over time. The estimated zone of influence based on barium concentration was 2.4 km in 2008 (and 2004). The range of barium concentrations observed at White Rose with distance from source is provided in Table 7-2.

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[15] TPH includes C_6-C_{32} hydrocarbons. This range is reported for comparison to other offshore operations (see Table 7-3).

Table 7-2 Barium Concentrations with Distance from Source at White Rose (2000 to 2008)

Year	Distance from Source (m)	Barium (mg/kg)
2008	300 to 750	170 to 3,400
	750 to 2,500	160 to 600
	2,500 to 5,000	160 to 210
2006	300 to 750	200 to 3,100
	750 to 2,500	150 to 770
	2,500 to 5,000	140 to 250
2005	300 to 750	210 to 810
	750 to 2,500	140 to 380
	2,500 to 5,000	150 to 220
2004	300 to 750	190 to 1,400
	750 to 2,500	120 to 470
	2,500 to 5,000	140 to 230
2000	300 to 750	140 to 180
	750 to 2,500	140 to 210
	2,500 to 5,000	150 to 210

Notes:
- Distance for 2000, 2005, 2006 and 2008 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.
- Station 31, near an exploration well drilled in 2007, was excluded from 2008 statistics.

Overall, >C_{10}-C_{21} hydrocarbons were a better indicator of drilling activity for White Rose than barium.

Elevated concentrations of hydrocarbons and barium have been observed near drill centres and platforms in other offshore oil developments. Examples of concentrations at other developments are provided in Table 7-3. Levels of hydrocarbons and barium at White Rose were within the range noted elsewhere.

Table 7-3 Hydrocarbon and Barium Concentration at Other Development Sites

Location	Year of Study	Distance from Source (m)	Total Petroleum Hydrocarbon (mg/kg)	Barium (mg/kg)
Grand Banks, Terra Nova (Petro-Canada 1998, 2001, 2002, 2003, 2005 and 2007)	2006	140 to 750	8 to 986	240 to 2,100
		750 to 2,500	0.7 to 30	100 to 340
		2,500 to 5,000	0.7 to 2	63 to 190
	2004	140 to 750	7.78 to 6,580	140 to 2,100
		750 to 2,500	2.9 to 72.2	100 to 340
		2,500 to 5,000	<3 to 4.3	63 to 190
	2002	140 to 750	<3 to 931	110 to 2,200
		750 to 2,500	<3 to 49	84 to 330
		2,500 to 5,000	<3 to 4.8	83 to 200
	2001	750 to 2,500	<3 to 29.5	100 to 190
		2,500 to 5,000	<3 to 8.13	87 to 180
	2000	750 to 2,500	0.59 to 14.4	92 to 210
		2,500 to 5,000	<3 to 5.59	80 to 230
	1997	750 to 2,500	<32.5	87 to 190
		2,500 to 5,000	<32.5	79 to 280
Gulf of Mexico, well NPO-895 (Candler et al. 1995)	1993	50	134,428	47,437
		200	80 to 11,460	542 to 5,641
		2,000	24	

Location	Year of Study	Distance from Source (m)	Total Petroleum Hydrocarbon (mg/kg)	Barium (mg/kg)
Gulf of Mexico, well MAI-686 (Kennicutt et al. 1996)	1993	200	40	1,625
		500	43	1,134
		3,000	49	1,072
Gulf of Mexico, well MU-A85 (Kennicutt et al. 1996)	1993	200	42.3	3,706
		500	31.7	1,817
		3,000	27.1	1,094
Gulf of Mexico, well HI-A389 (Kennicutt et al. 1996)	1993	200	65	13,756
		500	33	3,993
		3,000	32	1,293
North Sea, Beatrice (Addy et al. 1984)	1982	250	8 to 759	
		750	5 to 105	
		3,000	3 to 73	
Dutch Continental Shelf, well K14-13 (Daan and Mulder 1996)		200	54 to 161	
Norway, Valhall (Hartley 1996)	1985	250		19,000 to 96,000
		500		3,700 to 9,300
		3,000		280 to 430
North Sea, Brent (Massie et al. 1985)	1981	800	41 to 61	
		3,200	33 to 43	
North Sea, Forties (Massie et al. 1985)	1980	800	9 to 78	
		3,200	16 to 55	
Gulf of Mexico, Matagorda 622 (Chapman et al. 1991; Brooks et al. 1990)	1987	25	757 ±1,818	
		150		6,233
		750		12,333
		3,000		980
Santa Maria Basin, Hidalgo (Phillips et al. 1998)	1991	125		1,250
		500		975
		1,000		1,050
Norway, Ekofisk (Ellis and Schneider 1997)	1996	750		3,650
		2,000		2,214
		5,000		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, well U/a 2/7-29) (Vik et al. 1996)		200	1,000 to 2,368	
North Sea, (UKOOA 2001)	1975 to 1995	0 to 500	124 to 11,983	84 to 2,040
		>500 to 2,000	3 to 164	7 to 1,595
		>2,000 to 5,000	3 to 76	8 to 729

Note: - Absolute barium levels should not be compared across projects because of potential differences in measurement techniques (Hartley 1996) and differences in background levels.

Sulphur, as barium sulphate, is a constituent of WBMs and SBMs, but there are also many natural sources of sulphur. In 2008 and past EEM years (sulphur was not measured in the baseline program (2000)), sulphur concentrations have been elevated within 1 km of drill centres. Sulphur concentrations at most other stations have varied within a narrow range (0.02 to 0.04%, or 200 to 400 mg/kg). In 2008, as in 2006 (Husky Energy 2007), sulphide levels were elevated at a few stations near (usually within 0.5 km) drill centres.

In all years, including baseline (2000), fines content was primarily affected by depth (i.e., increased with depth). TOC content has generally varied within a narrow range of 0.8 to

1.0 g/kg (0.08 to 0.1%). Concentrations of metals other than barium have increased since 2000, but with no apparent relationship with project activity or distance to drill centres. Ammonia concentrations have varied widely over space and time, but again, with no consistent relationship with depth or distance from drill centres.

7.1.2 Project Effects

Project effects 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, potentially because the field surveys assess longer-term effects on a wide range of taxa.

7.1.2.1 Laboratory Toxicity Tests

None of the 252 sediment samples collected in 2000, 2004, 2005, 2006 and 2008 were toxic to bacteria in laboratory tests. The number of samples classified as toxic in the laboratory test with amphipods has increased over the years. No sediments were toxic to amphipods in 2000 and 2004. Sediments from one station were toxic in 2005; sediments from three stations were toxic in 2006; and sediments from eight stations were toxic in 2008. Low survival has only occurred at stations within 5 km of drill centres and usually at higher hydrocarbon and barium concentrations. However, in 2008 as in previous years, survival has been high at many other stations within 5 km of drill centres and with higher hydrocarbon or barium concentrations. Therefore, although increases in amphipod toxicity may suggest project effects, any effects have been largely unpredictable in time and space.

7.1.2.2 *In-Situ* (Field) Benthic Invertebrate Communities

In baseline and EEM years, benthic invertebrate communities in White Rose sediments were dominated by polychaetes, which accounted for approximately 75% of the number of organisms collected. Bivalves accounted for approximately 15% of the 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 2008, total abundance, standing crop and abundances of Paraonidae, Spionidae and Amphipoda increased significantly with distance from the nearest active drill centre.

Total abundance, Paraonidae, Amphipoda and, to a lesser extent, Spionidae abundances have decreased with distance from drill centres in all EEM years. The magnitude of effects have varied over time and could not always be attributed to specific drill centres after 2004 because effects from the Southern and Central drill centres were partially confounded. Effects on Spionidae were often restricted to a few stations near drill centres, and effects were greatest in 2005 and 2008. Median Spionidae abundance for 35 stations sampled in every year decreased from 2000 to 2005 but has since returned to baseline (2000) levels. Median total abundance and Paraonidae and Amphipoda abundances also decreased from 2000 to 2005. Total abundance and Amphipoda abundances increased after 2005 but have not returned to baseline levels. Median Paraonidae abundance in 2008 remained low and similar to the 2005 median.

Reliable estimates of the spatial extent of effects on total abundance, Amphipoda abundance and the abundance of Spionidae could not be obtained in 2008 because distance relationships were weak. The spatial extent of effects on Paraonidae abundance was 4 km in 2008, with a range of 2 to 7 km (95% confidence intervals). This was greater than the 2 to 3 km spatial extent of effects (range of 1 to 5 km) from 2004 to 2006. However, given the wide confidence intervals, a safe conclusion based on all sampling years would be that effects on Paranoidae extended to at least 1 to 2 km and could extend to approximately 5 km. This conclusion is consistent with qualitative estimates based on overall community composition. After 2004, communities within 2 km of drill centres became different from communities at greater distances. The differences among communities were largely dependent on reductions in Paraonidae abundance near drill centres, as expected given the strength of relationship between Paraonidae abundance and distance.

In 2008, apparent project effects on standing crop were observed to 1.5 km from source. However, when all EEM years were considered, project effects on standing crop were not significant.

In 2008, richness was uncorrelated with distance, and any effects over all years have been sporadic in time and space. Median richness values decreased from 2000 to 2005 but returned to baseline values by 2008.

The spatial extent of the benthic invertebrate response at White Rose is consistent with other studies. Benthic invertebrate responses in the North Sea and the Gulf of Mexico have generally extended to distances less than the zone of chemical contamination (Gray et al. 1990; Kingston 1992; Daan et al. 1994, 1996; Olsgård and Gray 1995; Montagna and Harper 1996). Although most of these studies were performed in areas where oil-based, rather than SBMs were used, Tait et al. (2004) showed that this general conclusion might also apply to areas where WBMs and SBMs have been used. Olsgård and Gray (1995, and references therein) indicate that subtle biological effects can reach distances of up to 2 km from source in the UK sector of the North Sea and up to 5 km in the Norwegian sector.

At White Rose, the estimated zone of influence based on $>C_{10}$-C_{21} hydrocarbon concentrations was 10 km in 2008 and the estimated spatial extent of effects on Paraonidae was 4 km. Therefore, the spatial extent of effects was generally less extensive than the zone of chemical influence and within the range seen in the North Sea. A similar conclusion can be reached based on concentration-response relationships. Estimated threshold concentrations for effects have usually been 1 mg/kg or greater, indicating that lower concentrations, although evidence of project activity, have minimal or no effects. In 2005 (Husky Energy 2006), 2006 (Husky Energy 2007) and 2008, $>C_{10}$-C_{21} hydrocarbon concentrations reached 1 mg/kg at approximately 5 km from drill centres.

Overall, the magnitude and nature of effects will be a function of the community present, which will differ among development sites. At White Rose, effects near drill centres were relatively large because Paraonidae are abundant. If Paraonidae were not abundant, effects on total abundance would be reduced and possibly not detectable, and effects would largely be restricted to reductions in the abundance of Amphipoda, a minor component of the community. This is a reasonable description of what has occurred at the nearby Terra Nova development, where Paraonidae are not abundant (Petro-Canada 2007).

In summary, the White Rose EEM program was powerful enough to detect project-related changes for total abundance and Paraonidae and Amphipoda abundance in all EEM years, including 2008. Project effects on Spionidae were largely restricted to 2005 and 2008. Although there were some reductions in Spionidae abundance near drill centres in 2008, overall median abundances of Spionidae in 2008 have returned to baseline (2000) levels. Project effects on standing crop were apparent only in 2008, and only in the immediate vicinity of drill centres.

Potential Causal Mechanisms

Elevated barium concentrations cannot directly associated with any observed effects on benthic invertebrates for two reasons. First, effects occurred within the background range of barium concentrations (concentrations of 120 to 210 mg/kg were noted during baseline sampling), and second, 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).

Similarly, reduced field abundances for benthic invertebrates at White Rose may not be direct acute toxicity from hydrocarbons. Laboratory toxicity tests with the amphipod *Rhepoxynius abronius* and drill muds from the Hibernia platform indicate that effects on this amphipod do not occur at $>C_{10}$-C_{21} concentrations less than 1,900 mg/kg (Payne et al. 2001), which is higher than any concentrations measured in White Rose sediments. As noted above, reduced survival and toxicity to laboratory amphipods tested with White Rose sediments, also *Rheposxynius abronius*, have been observed in recent years, but not necessarily at the highest hydrocarbon concentrations. *In-situ,* estimated thresholds for effects on total abundance and Paraonidae abundance in 2008 were approximately 1 mg/kg, or three orders of magnitude below the laboratory effects threshold on *Rhepoxynius*. Given the differences between field measurements and laboratory measurements, and although it is possible that direct acute toxicity of potentially more sensitive *in-situ* species is occurring, community-level effects also could be due to indirect effects or chronic toxicity.

7.1.3 CCME Guidelines

The CCME provides marine sediment quality guidelines for polycyclic aromatic hydrocarbons (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 7-4 compares maximum levels of PAHs and metals in White Rose sediments to CCME ISQG and PEL. In EEM years, no PAHs have occurred at concentrations above detection limit (0.05 mg/kg) in White Rose sediments; and detection limits of 0.05 mg/kg were less than PEL. Laboratory detection limits were higher than ISQG for acenaphthene, acenaphthylene, anthracene, dibenz(*a,h*)anthracene, fluorene, 2-methylnaphthalene and naphthalene. It is important to note that the drill mud base fluid

(PureDrill IA35-LV) used at White Rose does not contain any PAHs. Therefore, PAHs from drill fluid would not be expected in sediment.

Table 7-4 Comparison of Measured Concentrations of PAHs and Metals to Canadian Sediment Quality Guidelines

Variable	ISQG (mg/kg)	PEL (mg/kg)	Maximum value				
			2000	**2004**	**2005**	**2006**	**2008**
			(*n*=46 stations)	**(*n*=56 stations)**	**(*n*=44 stations)**	**(*n*=59 stations)**	**(n=47 stations)**
Acenaphthene	0.00671	0.0889	<0.05	<0.05	<0.05	<0.05	<0.05
Acenaphthylene	0.00587	0.128	<0.05	<0.05	<0.05	<0.05	<0.05
Anthracene	0.0469	0.245	<0.05	<0.05	<0.05	<0.05	<0.05
Benz(*a*)anthracene	0.0748	0.693	<0.05	<0.05	<0.05	<0.05	<0.05
Benzo(*a*)pyrene	0.088	0.763	<0.05	<0.05	<0.05	<0.05	<0.05
Chrysene	0.108	0.846	<0.05	<0.05	<0.05	<0.05	<0.05
Dibenz(*a,h*)anthracene	0.00622	0.135	<0.05	<0.05	<0.05	<0.05	<0.05
Fluoranthene	0.113	1.494	<0.05	<0.05	<0.05	<0.05	<0.05
Fluorene	0.0212	0.144	<0.05	<0.05	<0.05	<0.05	<0.05
2-Methylnaphthalene	0.0202	0.201	<0.05	<0.05	<0.05	<0.05	<0.05
Naphthalene	0.0346	0.391	<0.05	<0.05	<0.05	<0.05	<0.05
Phenanthrene	0.0867	0.544	<0.05	<0.05	<0.05	<0.05	<0.05
Pyrene	0.153	1.398	<0.05	<0.05	<0.05	<0.05	<0.05
Arsenic	7.24	41.6	2	<2	<2	<2	2
Cadmium	0.7	4.2	<0.05	0.08	0.07	0.06	0.097
Chromium	52.3	160	4	7	5.5	5.8	6.9
Copper	18.7	108	4	3	2.9	3.6	4.7
Lead	30.2	112	5.1	4	5.9	9.5	26
Mercury	0.13	0.7	<0.01	<0.01	<0.01	<0.01	0.06
Zinc	124	271	14	9	10	9.4	21

Notes:
- Source – CCME (2006); www.ccme.ca/ccme.
- CCME guidelines are not available for other variables measured at White Rose.

Maximum concentrations and detection limits for the seven metals with associated CCME guidelines were well below ISQG. At these low levels, most metals would be essential elements rather than toxicants.

7.1.4 Effects Unrelated to the Project

At White Rose, the strongest and most consistent natural effect observed has been an increase in Tellinidae abundance with depth. These depth effects were unexpected given the relatively narrow range of depth (115 to 135 m) for most stations. Any project effects (i.e., reductions in abundance) on Tellinidae were infrequent and sporadic in time and space, and the most extreme (i.e., low) values usually occurred at shallower depths rather than near drill centres. Tellinidae abundance increased by approximately 7% per metre of depth, which would lead to a 4-fold increase over 20 m (Appendix B-5). In general, Tellinidae can be regarded as a Reference taxon, unaffected by project activity and useful for providing perspective on project effects on other biological variables.

7.2 Commercial Fish Component

7.2.1 Biological Characteristics

In 2008, commercial fish (crab and plaice) sampling occurred in late May to early June because of logistics constraints. This sampling date was earlier than the July sampling in 2004 to 2006. Ideally, sampling should occur at the same time every year to maintain comparability among years. Catches have also been higher in July trawls than in the earlier 2008 trawls. However, the earlier sampling period in 2008 provided additional information on the basic biology of the two species.

Frequencies of recent moults for crab collected in 2008 (30%) were lower than frequencies of recent moults for crab collected in 2004 to 2006 (40 to 70%). In 2008, frequencies of recent moults were negatively but not significantly correlated with size (carapace width, claw height). In 2004 to 2006, negative correlations between frequencies of recent moults and size were generally stronger and often significant. Collectively, these results suggest that substantial numbers of crab, especially smaller crab, moult in June. In 2008, crab size and frequencies of recent moults did not differ significantly between the two Reference Areas or between the Study and the Reference Areas. In 2008, as in past years, Biological Characteristics of crab generally varied more within and among composites (and trawls) within Areas (small-scale spatial variance) than among Areas (large-scale spatial variance).

In 2004, 2005 and 2006, when sampling occurred in July, partly spent, post-spawning and immature females dominated catches. In 2008, when sampling occurred in late May to early June, few immature females were collected, most mature females were pre-spawning or spawning, and males were more abundant than in past years. These results suggest that plaice spawning occurs at the White Rose development site in late May to early June. In 2008, as in past years, mean composite gutted weights did not differ significantly between Reference Areas or between the Study and Reference Areas. In all EEM years, weights (i.e., size) varied mostly within composites.

7.2.2 Body Burden

In all EEM years, concentrations of metal and compounds in $>C_{10}$-C_{21} and $>C_{21}$-C_{32} range (when detected) in crab claws, plaice livers and plaice fillets from the Study Area were generally “intermediate” relative to Reference Area concentrations (i.e., within the “Reference Range”). In fact, *p* values for Study versus Reference Area comparisons were often greater than 0.50. These results can readily be explained if it is assumed that project effects on metal and hydrocarbon body burdens are non-existent or minimal and that natural differences among Areas (i.e., large-scale spatial variance for body burden) will generally increase with increasing distance between Areas. Given these assumptions, body burdens in the Study Area, which is spatially intermediate between widely separated Reference Areas, should also be intermediate.

In 2008 relative to past years (2004 to 2006), 2- to 10-fold increases in concentrations of most metals and compounds in the $>C_{21}$-C_{32} range in plaice liver occurred in both the Study and Reference Areas. These presumably natural temporal changes common to all Areas in 2008 were much greater than differences between the Study versus Reference Areas within years, which were usually less than 20%, with concentrations often lower in Study Area samples. The increases in plaice liver body burdens could have been related to differences in feeding or differences in sex ratios and reproductive status in 2008 versus 2004 to 2006. Similar increases in metal concentrations relative to past years were not observed in edible tissues (crab claws and plaice fillets), which are more relevant for taste tests and human health or ecological risk assessment in general.

Given the absence of differences between the Study and Reference Areas, many of the metals frequently detected in crab claw and plaice liver and fillet samples should be regarded as "essential elements" rather than contaminants originating from White Rose project activity (or any other anthropogenic source). Hydrocarbons have rarely been detected in edible tissue (crab claws and plaice fillets). Compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} range frequently detected in plaice liver appear to be naturally compounds (predominantly squalene[16]), rather than evidence of contamination from drill muds.

In all EEM years, metal concentrations in crab claws and plaice livers and fillets has generally increased with increasing mean size of crab or plaice in composites, although the strength and significance of positive correlations has varied among years. Some metals (e.g., mercury) may increase in concentration (biomagnify) with increasing size/age, particularly if taken up via the diet. However, the relationship between metal body burdens and size has been largely a "within-Area" (including Reference Areas) phenomenon, which suggests that metal uptake and regulation differs naturally with size.

Finally, in 2008, moisture content was not measured at the same time as other body burden variables, but instead was measured three to six weeks later on archived tissue homogenates. Comparison of 2008 to past results suggests that moisture content will decrease (i.e., samples will "dry") with storage. In future years, moisture content should be measured synoptically with other body burden variables. However, the 2008 results and the "drying effect" of prolonged storage suggest that archiving tissue samples, which is standard QA/QC practice, may have limited value. The best solution may be to measure dry rather than wet weight concentrations on archived samples, should it ever become necessary to reproduce or verify past results.

7.2.3 Taste Tests

There was no difference in taste between Study and Reference Area crab. For plaice, panelists could not distinguish between samples in the Triangle test but preferred plaice from the Reference Area in the Hedonic Scaling test. However, from ancillary comments on plaice, there were no consistent comments identifying abnormal or foreign odour or taste. Results do not indicate the presence of taint in either of the resources.

7.2.4 Fish Health Indicators

7.2.4.1 Fish Condition

No differences between the Study and Reference Areas were noted for most fish conditions indices. However, liver weight relative to gutted weight was higher in male fish from the Study Area.

The relative size of liver can vary naturally with feeding and reproductive status of fish (Dutil et al. 1995; Maddock et al. 1999; Barton et al. 2002). But liver enlargement (also

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[16] Squalene is a naturally occurring organic compound commonly found in the liver of bony and cartilaginous fishes. Its relative concentration in liver can be related to diet (Joe Kiceniuk, pers. comm.).

referred to clinically as hepatomegaly) has also been found in association with contaminants in a variety of fish species (Sloof et al. 1983; Fabacher and Baumann 1985; Hodson et al. 1992; Munkittrick et al. 1992; Servos et al. 1992; Everaarts et al. 1993; Adams et al. 1996; Billiard 1996; Leblanc et al. 1997; Lye et al. 1997; Arcand-Hoy and Metcalfe 1999; Orlando et al. 1999; Billiard et al. 2003; Corsi et al. 2003). Interestingly, such enlargement has on occasion only been observed in males (Lye et al. 1997; Orlando et al. 1999). However, it is important to point out that in many of the studies where liver enlargement has been observed, it has been accompanied by other bioindicator changes, such as liver histological differences and/or hepatic mixed function oxygenase (MFO) induction. This was not the case in the present survey and, although a contaminant-related aetiology for the enlarged livers found in fish from the Study Area cannot be ruled out, a natural cause such as feeding differences could also be responsible.

7.2.4.2 Gross Pathology

Gross pathology was assessed visually in all fish during the necropsies. There were no visible lesions on the skin, fins or internal organs of any fish. However, one fish from the Study Area exhibited a growth on its skin.

7.2.4.3 Haematology

Haematology, including the analysis of red and white blood cells, can be used to assess the overall health of fish, as well as to indicate immunological effects that may be important in disease susceptibility. Payne et al. (2005) have noted changes in white blood cells[17] in cunner chronically exposed to relatively high levels of produced water under laboratory conditions.

There were no apparent qualitative differences in morphology or staining characteristics of red blood cells in samples of plaice from the different Areas.

There was an indication of a slightly higher percentage of thrombocytes in the Reference Areas, particularly in Reference Area 2. However, the changes in cell numbers in the different comparisons were quite small (less than 2 cells on 200 cells counted). Such small changes can be attributed to natural variation (De Pedro et al. and references therein, 2005).

7.2.4.4 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. For females, data were analyzed separately for pre-spawning and spent females, since maturity stage can probably result in some loss of sensitivity for resolving contaminant-mediated differences in female fish (e.g., Whyte et al. 2000).

MFO enzyme activity in males did not differ significantly between the Study Area and the Reference Areas. Likewise, no significant differences were observed in females.

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[17] Differences in the range of 50% were noted.

7.2.4.5 Histopathology

Liver Histopathology

No hepatic lesions commonly 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, proliferation of macrophage aggregates, carcinoma, cholangioma, cholangiofibrosis, fibrillar inclusions and hydropic vacuolation.

However, a mild inflammatory response was observed in one fish from the Study Area. A “patchy distribution” of hepatocellular vacuolation, not associated with degenerative changes and likely linked to gonadal maturation (Timashova 1981; Bodammer and Murchelan 1990; Couillard et al. 1997), was observed in similar proportions in fish from the Study Area and Reference Areas. Also, liver tissues of some fish contained myxosporean parasites but no significant differences in the prevalence of affected fish were found between the Study Area and Reference Areas.

Although these latter observations are of value in relation to providing general information on their presence in the survey area, it is important to note from an EEM perspective that liver lesions more commonly associated with chemical toxicity were absent.

Gill Histopathology

The percentages of secondary gill lamellae affected by various lesions were very low (less than 2.3%) and found in only a small number of fish (less than 16 fish). However, when results were expressed as percentages of fish exhibiting a type of lesion (whatever the severity), slight but statistically significant differences in distal and tip hyperplasia of secondary lamellae were observed between the Study Area and the Reference Areas, with the highest percentages of fish affected found in the Reference Areas. The degree of severity of oedema was also quite low in all Areas and no significant differences were observed between the Study Area and the Reference Areas.

The slight differences observed in gills are likely due to natural variation. More importantly, microstructural changes that could be pathological in nature, such as epithelial lifting, severe lamellar hyperplasia, and/or extensive gill oedema, telangiectasis and fusion (e.g., Mallat 1985), were absent or found at very low frequencies in all Areas.

Overall, the fish health survey in 2008 indicated that the present health of plaice is similar between the Study and the Reference Areas.

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 estimate physical and chemical zones of influence.

These hypotheses (reiterated in Table 7-5) were set up to guide interpretation of results. As noted in Section 1.7, the “null” hypotheses (H_0) always state that no pattern will be observed.

Table 7-5 Monitoring Hypotheses

Sediment Component
H_0: There will be no change in SQT variables with distance or direction from project discharge sources over time.
Commercial Fish Component
H_0(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.
H_0(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 was 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 2008 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 modeling and EIS predictions do indicate that there should be change in Sediment Quality Triad (SQT) variables with distance from discharge sources. The following re-iterates and summarizes project effects.

As indicated above, there was clear evidence that concentrations of $>C_{10}-C_{21}$ hydrocarbons and barium were elevated by drilling activity near drill centres. There was more equivocal evidence that sulphur concentrations and, potentially, sulphide levels were elevated by drilling. Elevated concentrations of $>C_{10}-C_{21}$ hydrocarbons and barium at White Rose in 2008 are comparable to levels observed at other developments.

Original predictions on the spatial extent of the zone of influence of drill cuttings (9 km from source; Hodgins and Hodgins 2000; Section 1.5) are very similar to the estimated zone of influence based on hydrocarbon concentrations. $>C_{10}-C_{21}$ contamination extended to 10 km from source. Barium contamination extended to 2 km from source. Sulphur contamination was limited to within 1 km from source and increased sulphide levels were noted only in the immediate vicinity (0.5 km) of drill centres.

Eight of the 47 samples tested in 2008 were toxic to amphipods in laboratory tests. This is an increase from previous years. However, there has never been a clear relationship between toxicity and distance to drill centres or hydrocarbon concentrations in any EEM year.

In 2008, there was evidence of project effects on *in-situ* benthic invertebrate abundance (total abundance), standing crop and Paraonidae, Spionidae and Amphipoda abundance.

The spatial extent of effects on Paraonidae was approximately 4 km from drill centres and the spatial extent of effects on standing crop was approximately 1.5 km from drill centres. This is further than the 500-m predicted in the White Rose EIS. Nevertheless, the spatial extent of effects on Paraonidae and standing crop in 2008 appears to be generally consistent with the recent literature on effects of contamination from offshore oil developments. The spatial extent of effects on total abundance, Spionidae and Amphipoda abundance could not be determined because distance relationships were very weak.

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

In 2008 and in previous years, depth was the major factor affecting Tellinidae abundance, with abundance increasing with increasing depth.

Commercial fish sampling in 2008 occurred approximately one month earlier than in previous EEM years (May/June rather than July). This earlier sampling provided additional information on the basic biology of crab and plaice at White Rose. For crab, frequencies of recent molts in 2008 were 30% lower than in previous years. For plaice, although females had always been more abundant than males in July, the reverse occurred in May/June in 2008. In addition, most mature females were either pre-spawning or spawning, compared to the prevalence of partly spent to post-spawning females in previous years.

7.5 Response to Previous Regulatory and WRAG Recommendations

Husky Energy actions and responses to comments from the regulatory community on the 2006 report are provided in Appendix A, as are Husky Energy responses and WRAG comments on the 2008 report.

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