Husky Energy

REPORT

REPORT TITLE

White Rose

Environmental Effect Monitoring (EEM) Program – 2010

SUBMITTED TO

Canada-Newfoundland and Labrador Offshore Petroleum Board

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Environmental Effects Monitoring Report on Sediment Quality, Water Quality 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 modelling 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, 2008 and 2010.

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) have been collected in 2004, 2005, 2006, 2008 and 2010 to assess environmental effects. Sediment samples have been processed for physical characteristics, chemical characteristics, toxicity 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), have been processed for contaminants (chemical body burden), taint and, for plaice, various health indices. A series of measurements (e.g., length, weight, maturity) are also made on each species.

Water samples were collected at White Rose in conjunction with the 2008 and 2010 EEM programs. Samples were processed for chemistry and total suspended solids. The Water Quality sampling program in 2008 was preliminary, with fewer stations and variables sampled in that year than in 2010. The Water Quality monitoring program for 2010 also included a produced water modelling component to assess which constituent of produced water (the main liquid discharge from White Rose) would have a higher probability of being detected in water samples.

Figure 1 illustrates the components of the EEM program.

This report provides the results from the fifth year of sampling under the program conducted in the spring (commercial fish survey) and fall (sediment survey) of 2010. The findings are interpreted in the context of results of previous sampling years and the baseline data collected pre-development.

In 2010, seafloor sediments were sampled at 63 locations surrounding the Northern, Central, Southern and 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.

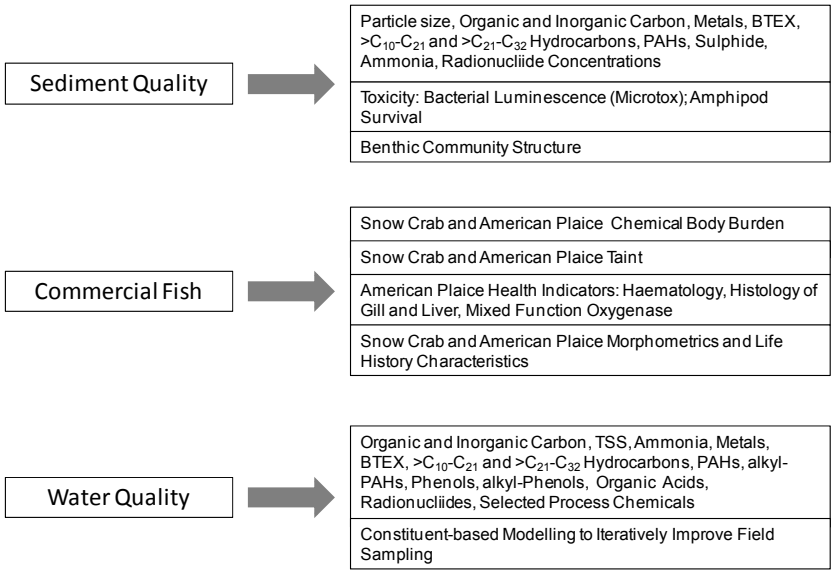

Figure 1 EEM Program Components

Notes: BTEX: Benzene, toluene, ethylbenzene, xylene; PAH: Polyaromatic hydrocarbon.
TSS: Total suspended solids.

Analysis of sediment physical and chemical characteristics showed that concentrations of drill mud hydrocarbons and barium were elevated near drill centres and concentrations decreased with distance from drill centres, as expected. Sulphur concentrations were also mildly elevated at stations located 0.3 km from drill centres. Sediments fines concentration may have been affected (increase in % fines) at one station located 0.29 km from the North Amethyst Drill Centre. Otherwise, there were no project effects on chemical or physical parameters measured in sediments.

Maximum drill mud hydrocarbon (hydrocarbons in the $>C_{10}$-C_{21} range) and barium concentrations at White Rose in 2010 were 810 mg/kg and 2,700 mg/kg, respectively. This is lower than the maxima noted in 2008 but, overall, there has been no statistically significant change (increase or decrease) in project-related contamination at White Rose since drilling began in 2004. The zone of influence of project contaminants estimated from hydrocarbon concentrations extended to 3.6 km from source. This is less than predictions from drill cuttings dispersion modelling that estimated a zone of influence of approximately 9 km. The zone of influence estimated from barium concentrations extended to 2 km from source.

Discharges, including produced water, from the *SeaRose* floating production, storage and offloading (FPSO) facility had no detectable influence on sediment physical and chemical characteristics after taking into account the influences associated with active drill centres.

One of 49 sediment samples tested for toxicity in the laboratory was toxic to luminescent bacteria (Microtox) in 2010. Toxicity occurred at station C5-C, located 0.3 km from the Central Drill Centre and where hydrocarbon, barium and sulphur levels were relatively high. No samples tested for amphipod toxicity were toxic in 2010. Results indicate that sediments around White Rose are fundamentally non-toxic.

There were few effects on benthic invertebrates. There continue to be no detectable project effects on benthic invertebrate community richness[1]. As noted in 2008, evidence of effects on total invertebrate abundance was marginal and benthic invertebrate biomass was affected by project activity. There was also evidence of effects on one family of polychaete (Paraonidae: a marine worm), as in previous years. Unlike previous years, there was no evidence of project effects on the polychaete Spionidae and amphipods in 2010. Total abundance, biomass and the abundance of Paraonidae were lower near drill centres. Like sediment contamination with drill mud hydrocarbons, barium and sulphur, there has been no intensification of effects on benthic invertebrates since drilling began in 2004.

During the summer of 2010, samples of American plaice and snow crab were collected near White Rose (the Study Area) and at four Reference Areas, located approximately 28 km to the southwest, northwest, southeast and southwest 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.

In 2010, metal and hydrocarbon concentrations in American plaice and snow crab tissue indicated 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 there was no evidence of taint for either species. Indicators of fish health used to evaluate potential effects, or precursors of effects, on America plaice showed that the general health and condition of this species was similar in the Study and Reference Areas.

In the fall of 2010, water samples were collected in the vicinity of the *SeaRose* FPSO and in two Reference Areas located approximately 28 km to the northeast and northwest. Samples were processed for parameters listed in Figure 1. Results indicated no difference in water chemistry between the Study and Reference Areas in 2010 other than higher levels of the metals molybdenum and sulphur in Reference Area samples. Produced water modelling, undertaken to fine-tune seawater sampling at White Rose, indicated that naphthalene could be a good indicator of the presence of produced water in seawater samples; that the program could benefit from sampling approximately 1 to 5 km downstream of the *SeaRose* FPSO, based on prevailing seasonal currents; that near-field stations should not be at fixed location but should be positioned downstream of currents and winds on the day of sampling; and that the lowest reasonable laboratory detection limits for chemicals should be used for processing of seawater samples.

Conclusions: Variables affected by the White Rose development in 2010 were sediment concentrations of drill mud hydrocarbons, barium and sulphur, total benthic invertebrate abundance and biomass and the abundance of one family of polychaete. In spite of changes in sediment contamination and benthic invertebrate responses since drilling began at White Rose in 2004, there has not been any consistent accentuation of contamination or responses over those years. Zones of influence of project contaminants and effects on benthic community indices and taxa have not increased in severity or extent over time. As there has been no continued degradation at White Rose, sediment contamination and the benthic invertebrate responses justify continued monitoring, without further mitigation.

[1] Number of taxonomic groups per unit area.

Sediment contamination and effects on benthos noted in 2010 and in previous years have never translated into effects on the fisheries resources as indicated by fish health and taint tests. 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. These results indicate that changes in sediments and benthic community have not affected fish.

There was no evidence of project-related effects on water quality.

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1.0 Introduction

1.1 Project Setting and Field Layout

Husky Energy, with its joint-venture partner Suncor Energy, is developing the White Rose oilfield on the Grand Banks, offshore Newfoundland. The field is approximately 368 km east-southeast of St. John's, Newfoundland and Labrador, and 50 km from both the Terra Nova and Hibernia fields (Figure 1-1). To date, development wells have been drilled at four drill centres, the Northern, Central, Southern and North Amethyst Drill Centres (Figure 1-2). Nalcor Energy is a partner in the North Amethyst Drill Centre development.

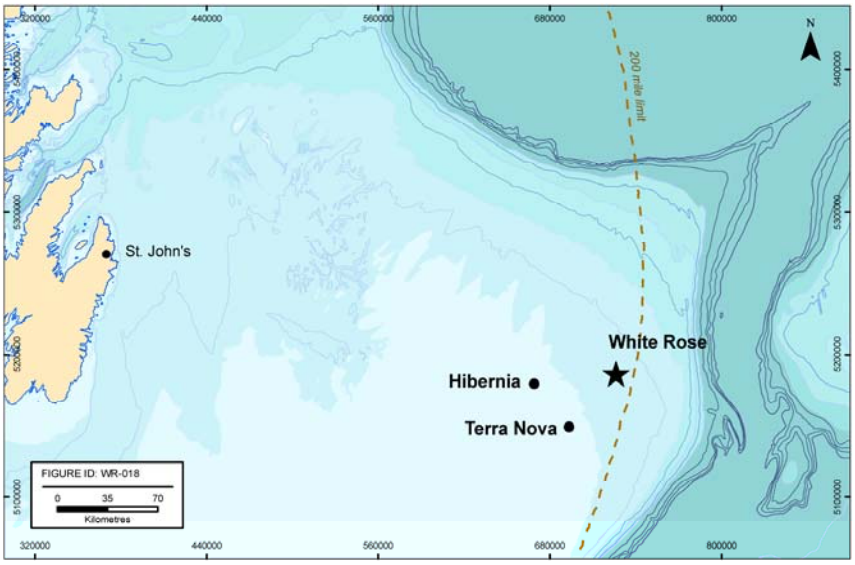

Figure 1-1 Location of the White Rose Oilfield

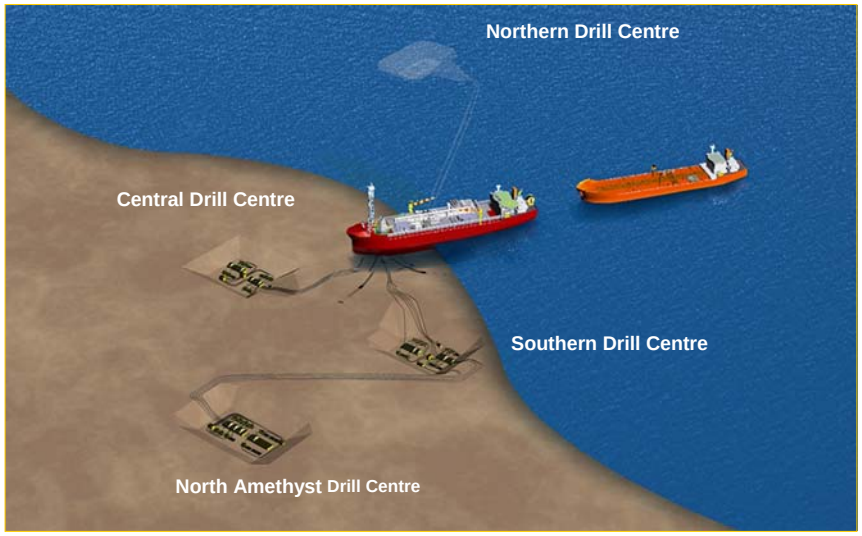

Figure 1-2 Field Layout

1.2 Project Commitments

Husky Energy committed in its Environmental Impact Statement (EIS) (Part One of the White Rose Oilfield Comprehensive Study (Husky Oil 2000)) to develop and implement a comprehensive Environmental Effects Monitoring (EEM) program for the marine receiving environment. This commitment was integrated into Decision 2001.01 (Canada-Newfoundland Offshore Petroleum Board 2001) as a condition of project approval.

Also, as noted in Condition 38 of Decision 2001.01 (Canada-Newfoundland Offshore Petroleum Board 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".

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 development of the North Amethyst Drill Centre was submitted to the C-NLOPB in July 2008. The program was revised again in 2010 to include a water quality monitoring component.

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. Also, operational EEM programs on the Grand Banks, in general, provide information for the C-NLOPB to consider during its periodic reviews of the Offshore Waste Treatment Guidelines (OWTG) (National Energy Board (NEB) et al. 2010).

Objectives to be met by the White Rose EEM program are to:

- estimate the zone of influence of project contaminants;
- test biological effects predictions made in the EIS;
- 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 environmental 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[2] for these two waste streams, predicted from a modelling study for White Rose (Hodgins and Hodgins 2000), was not expected to extend beyond approximately 9 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 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[3] 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. These predictions and the rankings used to assess effects are described in greater detail in Husky Oil (2000). Further discussion on environmental assessment predictions are also provided in Section 8.

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 of effects on sediment and water quality, anticipated effects on Fish and Fish Habitat and Commercial Fisheries were assessed as not significant in the White Rose EIS (Husky Oil 2000).The development of the North Amethyst Drill Centre was assessed in the New Drill Centre Construction and Operations Program Environmental Assessment (LGL 2006). Predictions in the New Drill Centre EA were consistent with the White Rose development EIS (Husky Oil 2000) in that, based on modelling, 500 m was estimated as the radius of each well's biological zone of influence (i.e., potential smothering due to a minimum of 1 cm thickness of deposited cuttings and mud). Cumulative effects from New Drill Centre Construction and Operations were assessed as non-significant.

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

[3] 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 percent of individuals.

Further details on environmental assessment methodologies can be obtained from the White Rose EIS and the New Drill Centre Construction and Operations Program EA (Husky Oil 2000, LGL 2006). For the purpose of the EEM program, testable hypotheses that draw on effects predictions were developed as part of EEM design and are discussed in Section 1.7.

1.6 EEM Program Components and Monitoring Variables

The White EEM program is divided into three components, dealing with effects on Sediment Quality, Commercial Fish species and Water Quality (Figure 1-3).

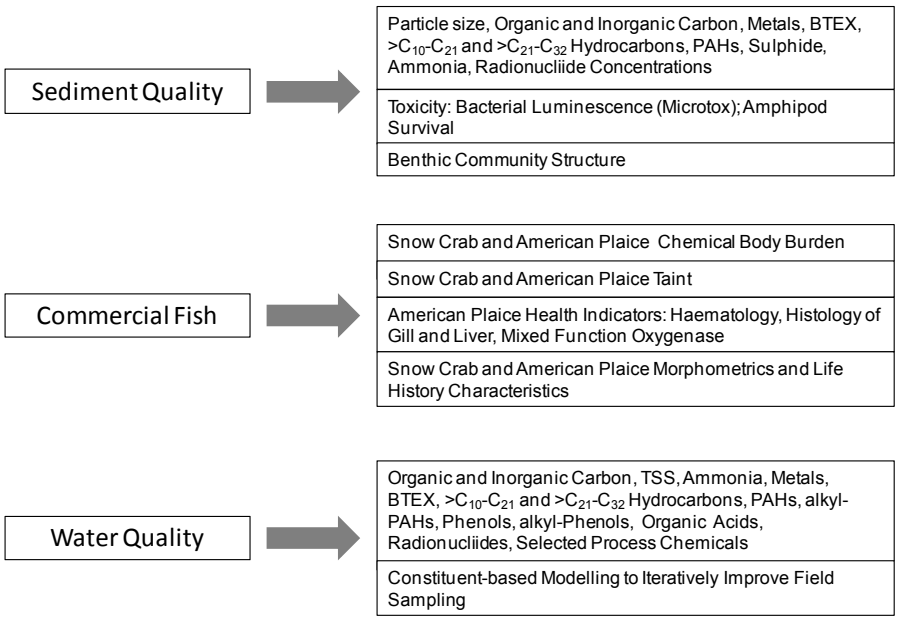

Figure 1-3 EEM Program Components

Notes: BTEX: Benzene, toluene, ethylbenzene, xylene.
PAH: Polyaromatic hydrocarbon.
TSS: Total suspended solids.

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 (Long and Chapman 1985; Chapman et al. 1987, 1991; Chapman 1992). These tests are used to assess drilling effects (Section 1.5). Potential deposition of selected constituents from liquid discharges to sediments is also assessed as part of the Sediment Quality program[4].

Assessment of effects on Commercial Fish species includes measurement of chemical body burden, taint, morphometric and life history characteristics for snow crab and American plaice and measurement of various health indices for American plaice.

[4] Modelling of constituents that might settle to sediments is planned for 2011/2012 to better guide field sampling in future years.

Assessment of Water Quality includes measurement of alteration of physical and chemical characteristics in the water column. Because contamination from liquid discharges from offshore installations is expected to be difficult to detect, constituent-based modelling is also undertaken for White Rose to attempt to identify constituents that would have a higher chance of being detected.

Further details on the selection of monitoring variables are provided in the White Rose EEM Program Design documents (Husky Energy 2004, 2008, 2010).

1.7 Monitoring Hypotheses

Monitoring, or null (H_0), hypotheses were established as part of the White Rose EEM program 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.

The following monitoring hypotheses were developed for the White Rose EEM program:

- Sediment Quality:
  - H_0: There will be no change in Sediment Quality Triad 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.
- Water Quality:
  - H_0: The distribution of produced water from point of discharge, as assessed using moorings data and/or vessel-based data collection, will not differ from the predicted distribution of produced water.

No hypotheses were developed for American plaice and snow crab chemical 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). Plaice and crab morphometrics are provided in the Commercial Fish Survey Cruise Report (Stantec 2010).

1.8 EEM Sampling Design

Sediment samples are collected at stations in the vicinity of drill centres and at a series of stations located at varying distances from drill centres, extending to a maximum of 28 km along north-south, east-west, northwest-southeast and northeast-southwest axes. The sediment sampling design is commonly referred to as a gradient design. This type of design assesses change in monitoring variables with distance from source.

Commercial fish are sampled near White Rose, in the vicinity of the drill centres, and at four distant Reference Areas located approximately 28 km to the northeast, northwest, southeast and southwest.

Water samples are collected in the vicinity of the *SeaRose* floating, production, storage and offloading (FPSO) facility and in two Reference Areas located approximately 28 km to the northeast and northwest. The water quality and commercial fish designs are control-impact designs (Green 1979). This design compares conditions near discharge source(s) to condition in areas unaffected by the discharge(s).

1.8.1 Modifications to the Sediment Component

There are some differences between sediment stations sampled for baseline (2000) and for EEM programs (2004, 2005, 2006, 2008 and 2010). A total of 48 sediment stations were sampled during baseline (Figure 1-4), 56 stations were sampled for the 2004 EEM program (Figure 1-5), 44 stations were sampled for the 2005 EEM program (Figure 1-6), 59 stations were sampled in 2006 (Figure 1-7), 47 stations were sampled in 2008 (Figure 1-8) and 63 stations were sampled in 2010 (Figure 1-9). In all, 36 stations were common to all sampling programs (including baseline), 42 stations were common to all EEM years and 47 stations were common to 2008 and 2010.

As part of EEM program design (Husky Energy 2004, 2008), seven redundant stations in the immediate vicinity of drill centres were eliminated. 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).

Stations added during EEM program design (Husky Energy 2004) 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 and 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 (NN) and more southerly (SS) drill centres to provide additional baseline data should drilling occur at these drill centres (see Figure 1-5). 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 1-7).

In 2008, stations C5 and 17 could not be sampled because of drilling activity. Four new stations were added to the EEM program around the North Amethyst Drill Centre (Figure 1-8). 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.

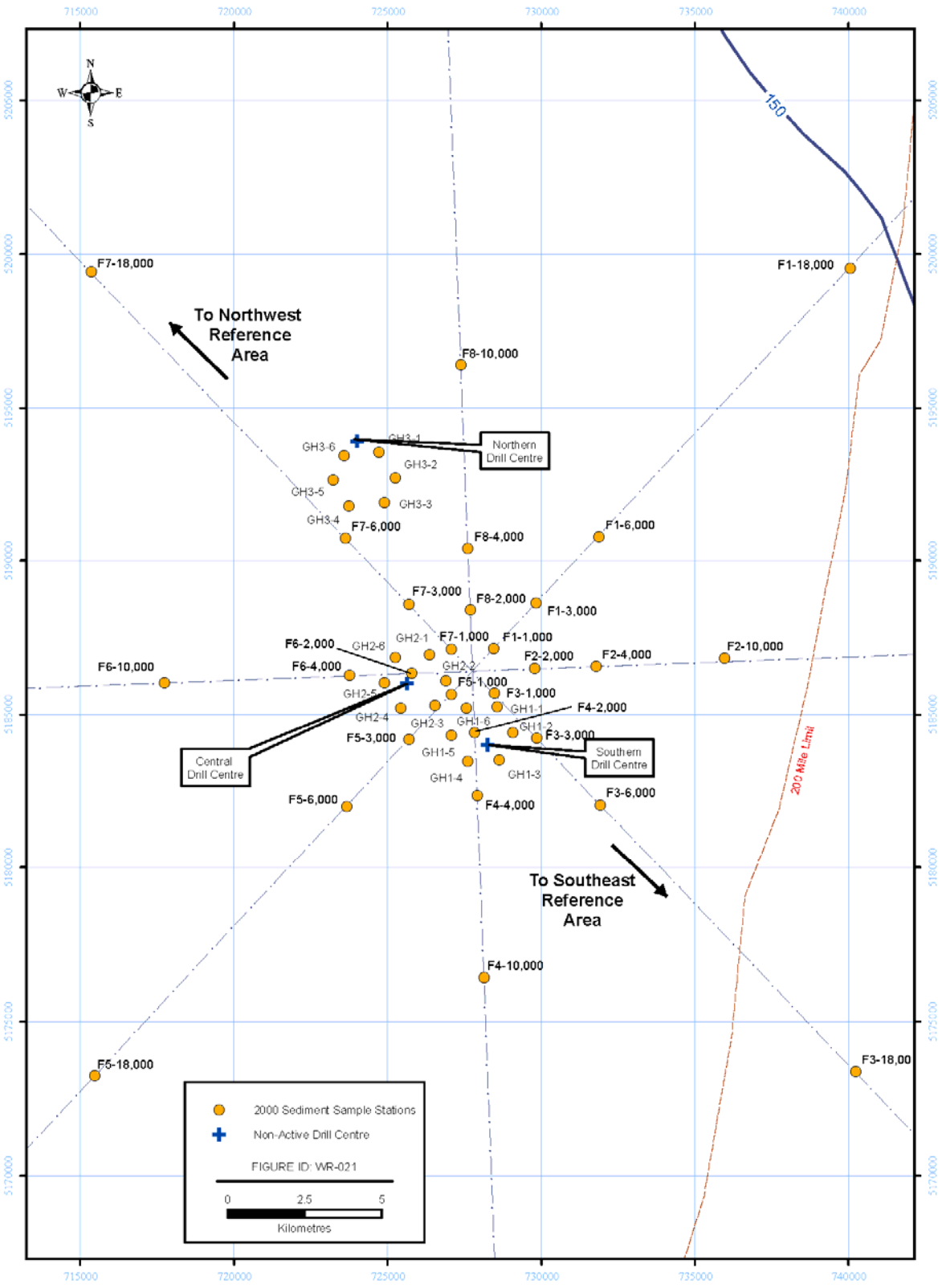

Figure 1-4 2000 Baseline Program Sediment Stations

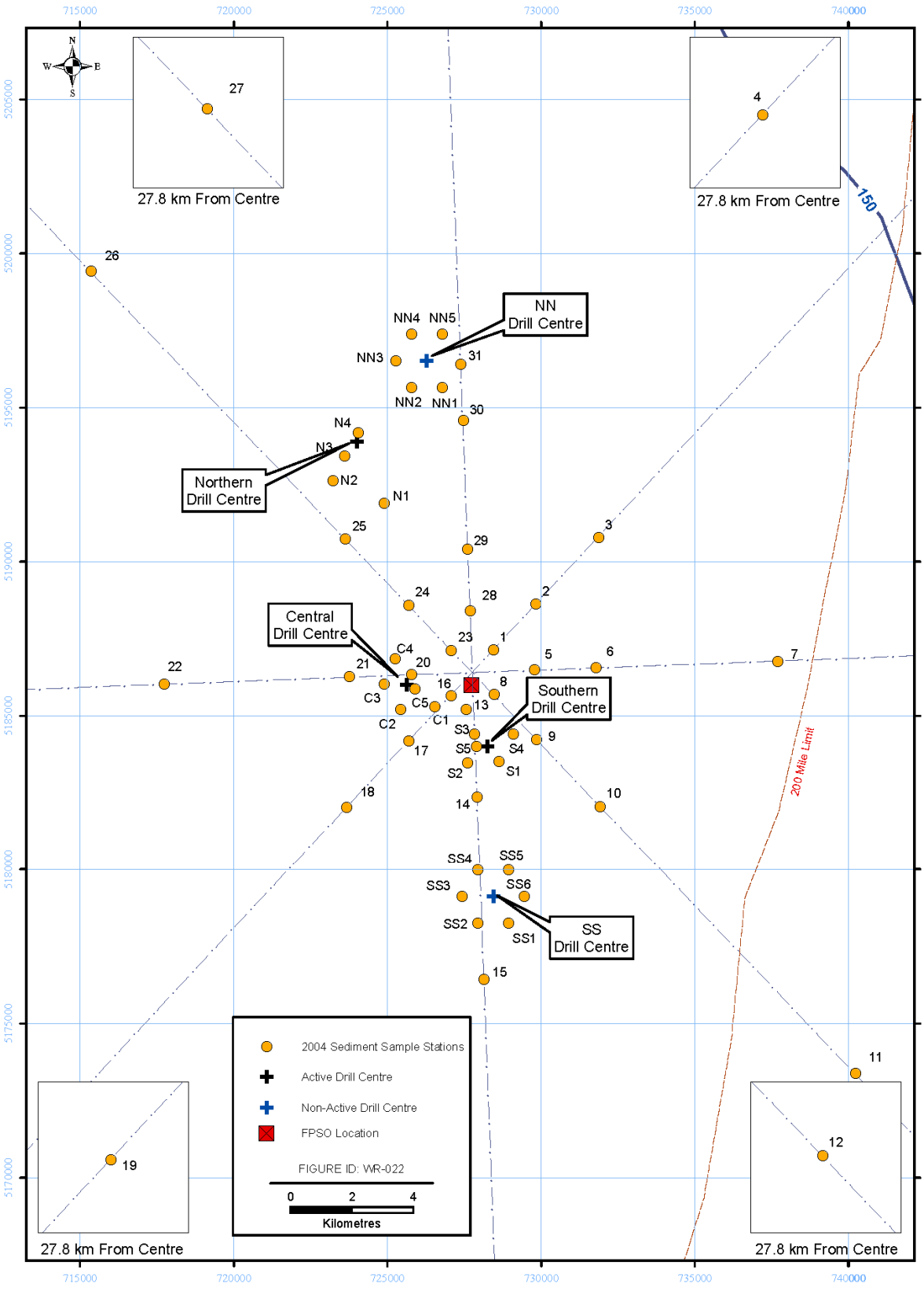

Figure 1-5 2004 EEM Program Sediment Stations

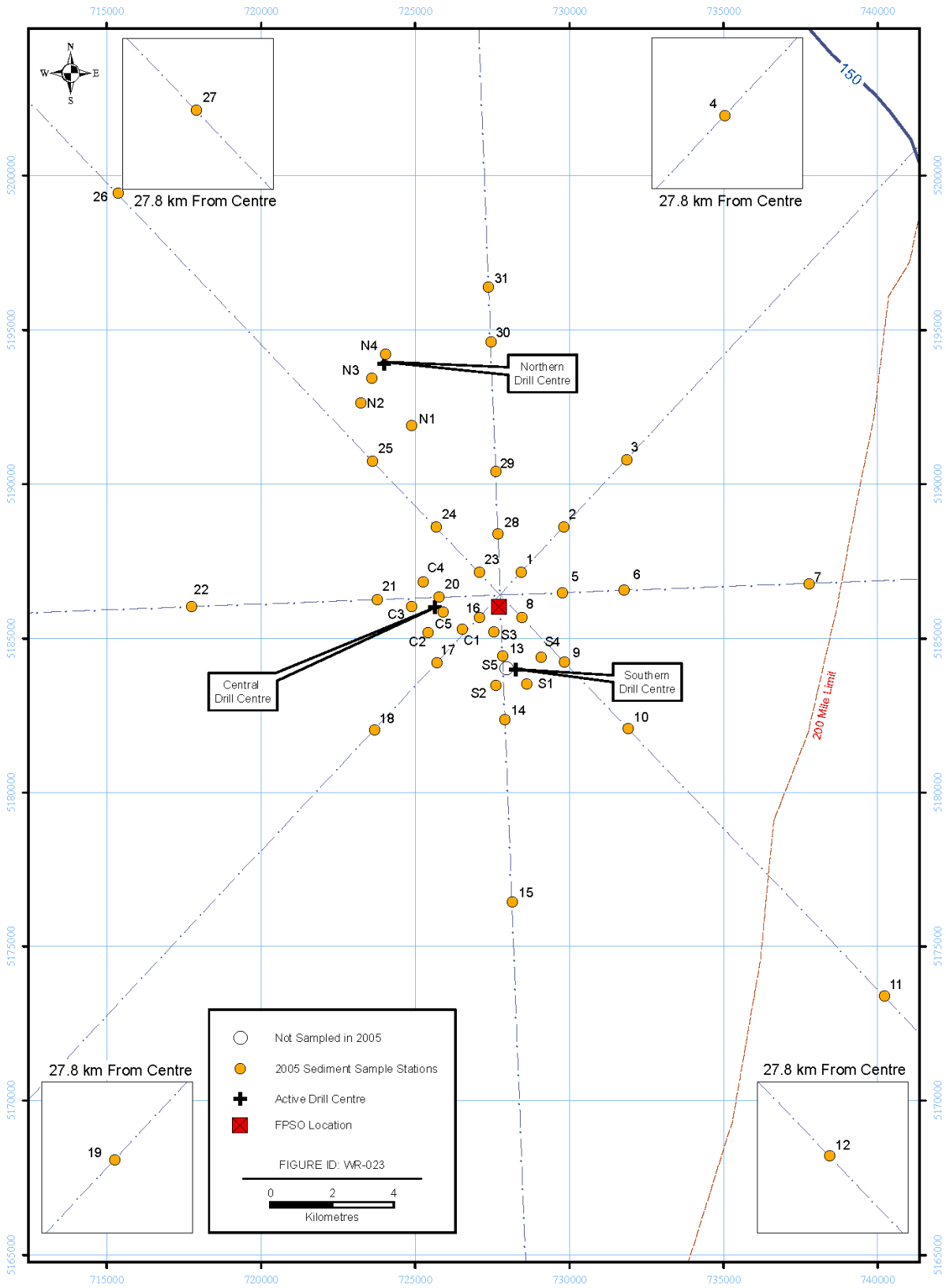

Figure 1-6 2005 EEM Program Sediment Stations

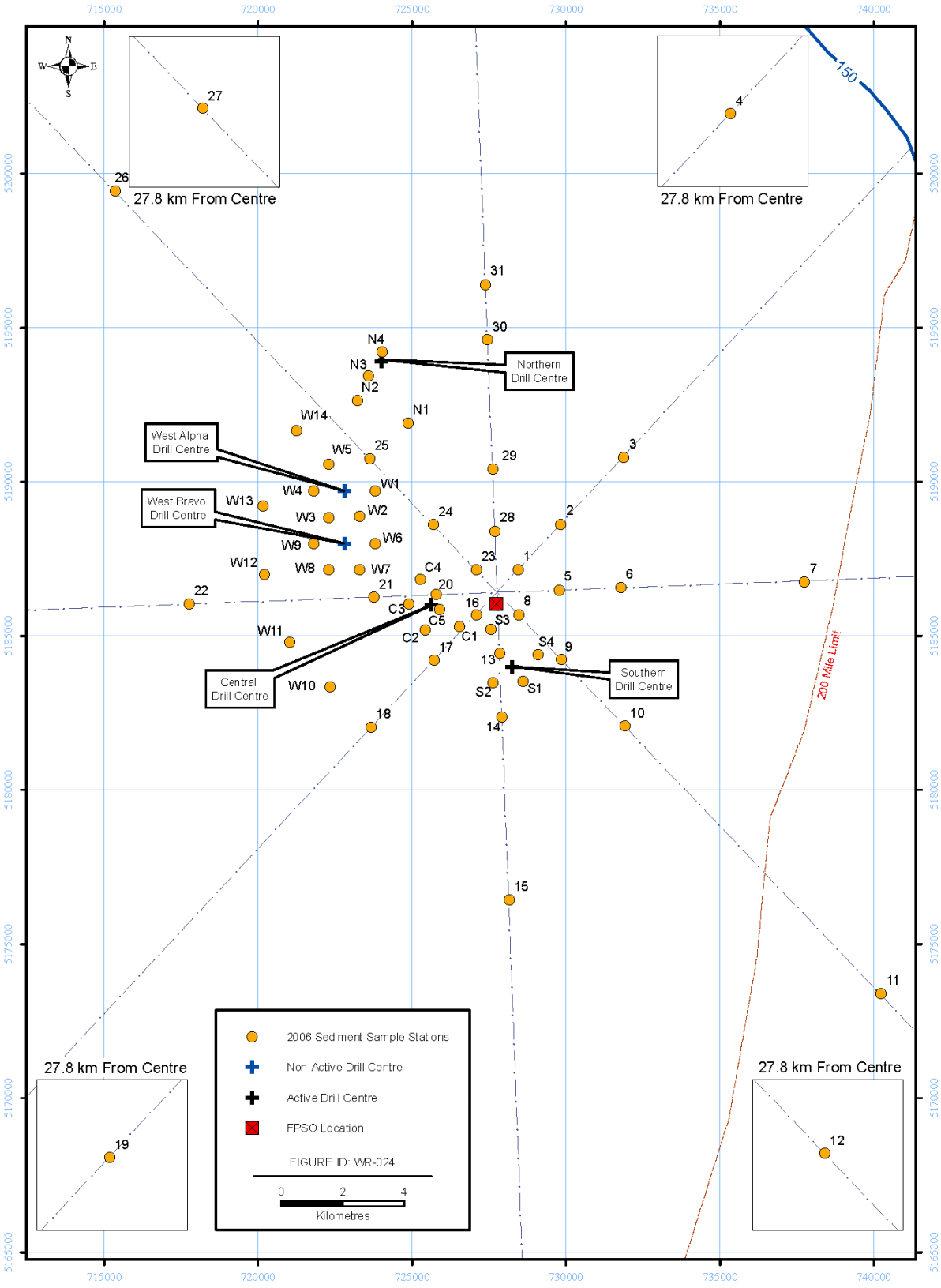

Figure 1-7 2006 EEM Program Sediment Stations

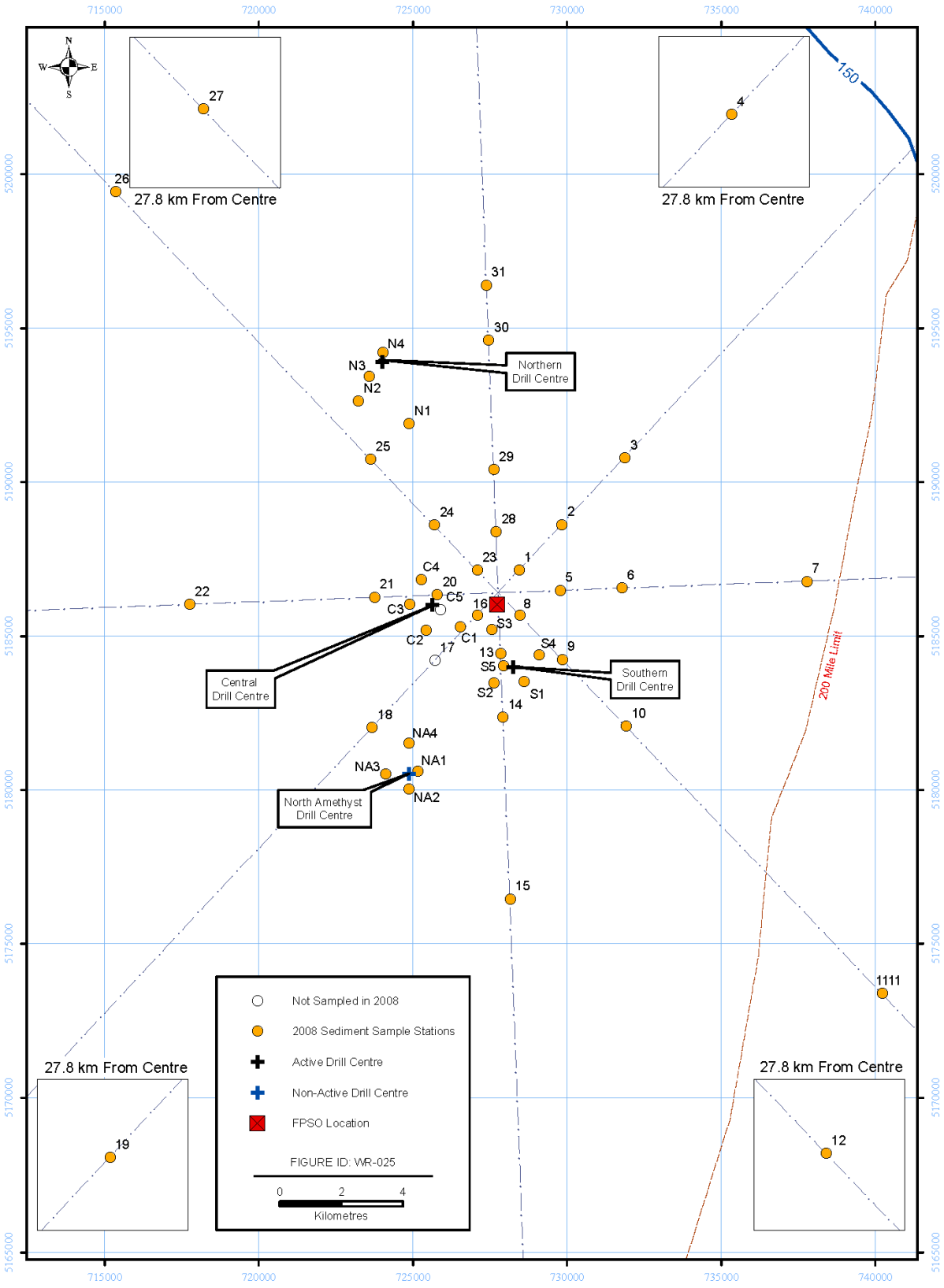

Figure 1-8 2008 EEM Program Sediment Stations

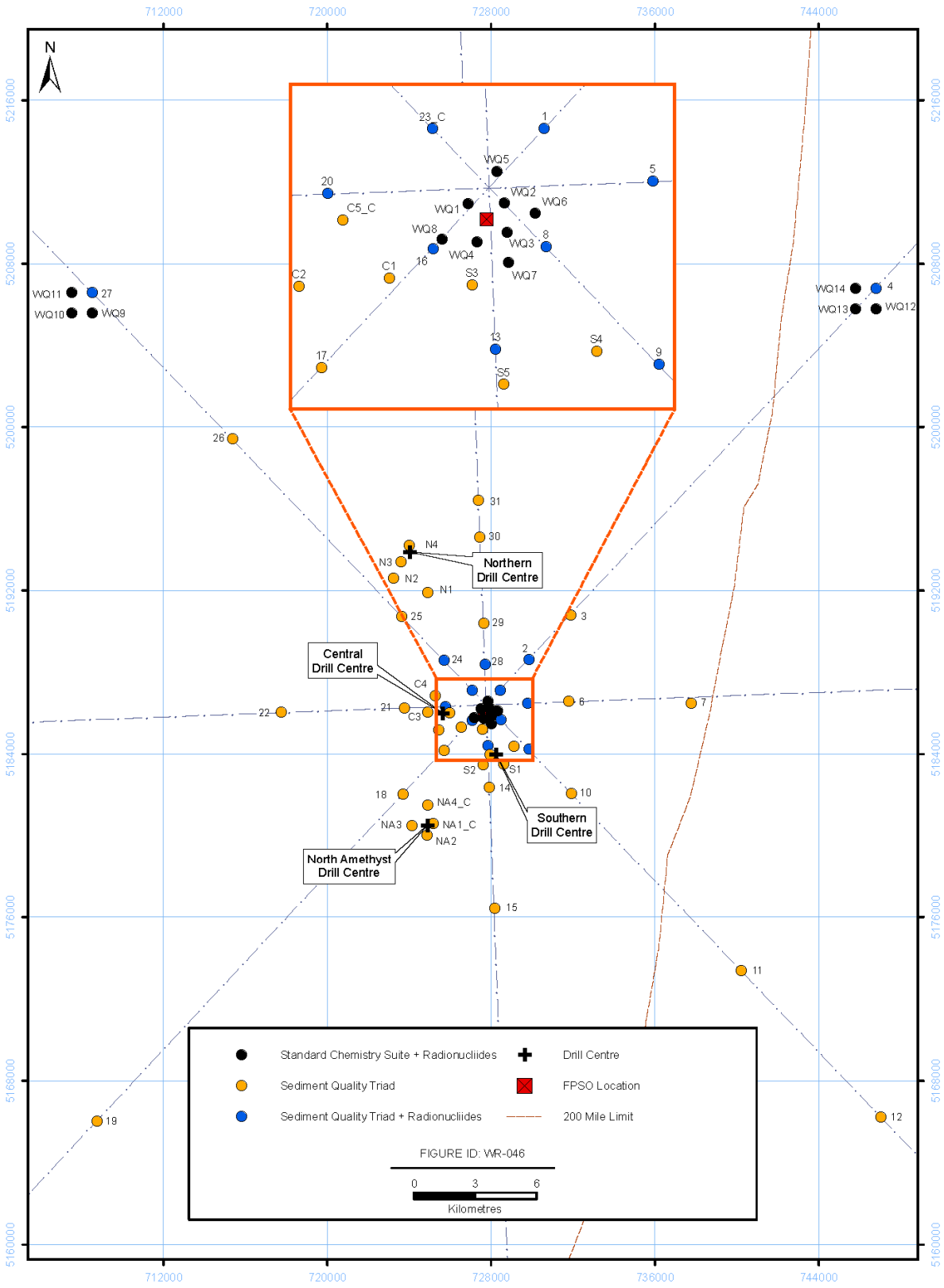

Figure 1-9 2010 EEM Program Sediment Stations

In 2010, 14 new stations were added to sample for constituents that may precipitate from produced water. These stations were sampled for sediment radionucliide concentrations, standard EEM sediment chemistry and particle size analysis. Remaining stations were sampled for all Sediment Quality Triad components, as in previous years. Of these, 13 were also sampled for radionucliide concentrations, for a total of 27 radionucliide stations (see Figure 1-9 for details). Stations NA1, NA4, C5 and 23 could not be sampled because of drilling activity. Given the greater number of inaccessible stations in 2010 compared to previous years, these stations were replaced with stations NA1-C, NA4-C, C5-C and 23-C[5]. Table 1-1 provides a summary of changes between the 2000 baseline program and the 2010 EEM program for sediment, as well as station name changes that were proposed in the EEM design document to simplify reporting of results.

Table 1-1 Table of Concordance Between Baseline (2000) and 2010 EEM Sediment 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-C	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

[5] NA4-C, 23-C and C5-C are located less than 15 m from the original locations. NA1-C is located approximately 85 m from the original location but at the same distance from the drill centre as the original station.

EEM Program Station Name	Corresponding Station Name during the 2000 Baseline Program
C5**-C	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-C	Not Sampled in 2000
NA2-C	Not Sampled in 2000
NA3	Not Sampled in 2000
NA4	Not Sampled in 2000
WQ1	Not Sampled in 2000
WQ2	Not Sampled in 2000
WQ3	Not Sampled in 2000
WQ4	Not Sampled in 2000
WQ5	Not Sampled in 2000
WQ6	Not Sampled in 2000
WQ7	Not Sampled in 2000
WQ8	Not Sampled in 2000
WQ9	Not Sampled in 2000
WQ10	Not Sampled in 2000
WQ11	Not Sampled in 2000
WQ12	Not Sampled in 2000
WQ13	Not Sampled in 2000
WQ14	Not Sampled in 2000

Notes: - Tests performed at each station in 2010 are provided in Figure 1-9.
- For 2000 baseline stations, only those stations retained for the EEM program are listed.
- Additional baseline stations sampled in 2004 and 2006 are not listed in the above Table, but see text and Figures for details.
- Stations labeled -C are stations located in close proximity to original station locations in 2010 (see text).
- * Not sampled in 2005 because of drilling activity.
- ** Not sampled in 2008 because of drilling activity.

1.8.2 Modifications to the Commercial Fish Component

For American plaice and snow crab, sampling for the baseline program (2000 and 2002) occurred near White Rose and in one Reference Area located 85 km to the northwest. For the EEM program, this Reference Area was replaced with four Reference Areas located approximately 28 km northwest, northeast, southwest and southeast of the development. Figures 1-10 to 1-14 provide transect locations for the 2004, 2005, 2006, 2008 and 2010 EEM programs, respectively. The fisheries exclusion zone was larger in 2004 than in 2005 and 2006 to accommodate possible drilling at the NN and SS Drill Centres. The zone was again increased in size in 2008 and 2010, from 2005 and 2006, to accommodate the North Amethyst Drill Centre. In 2008, heavy commercial fishing activity for crab in Reference Areas 3 and 4 precluded sampling.

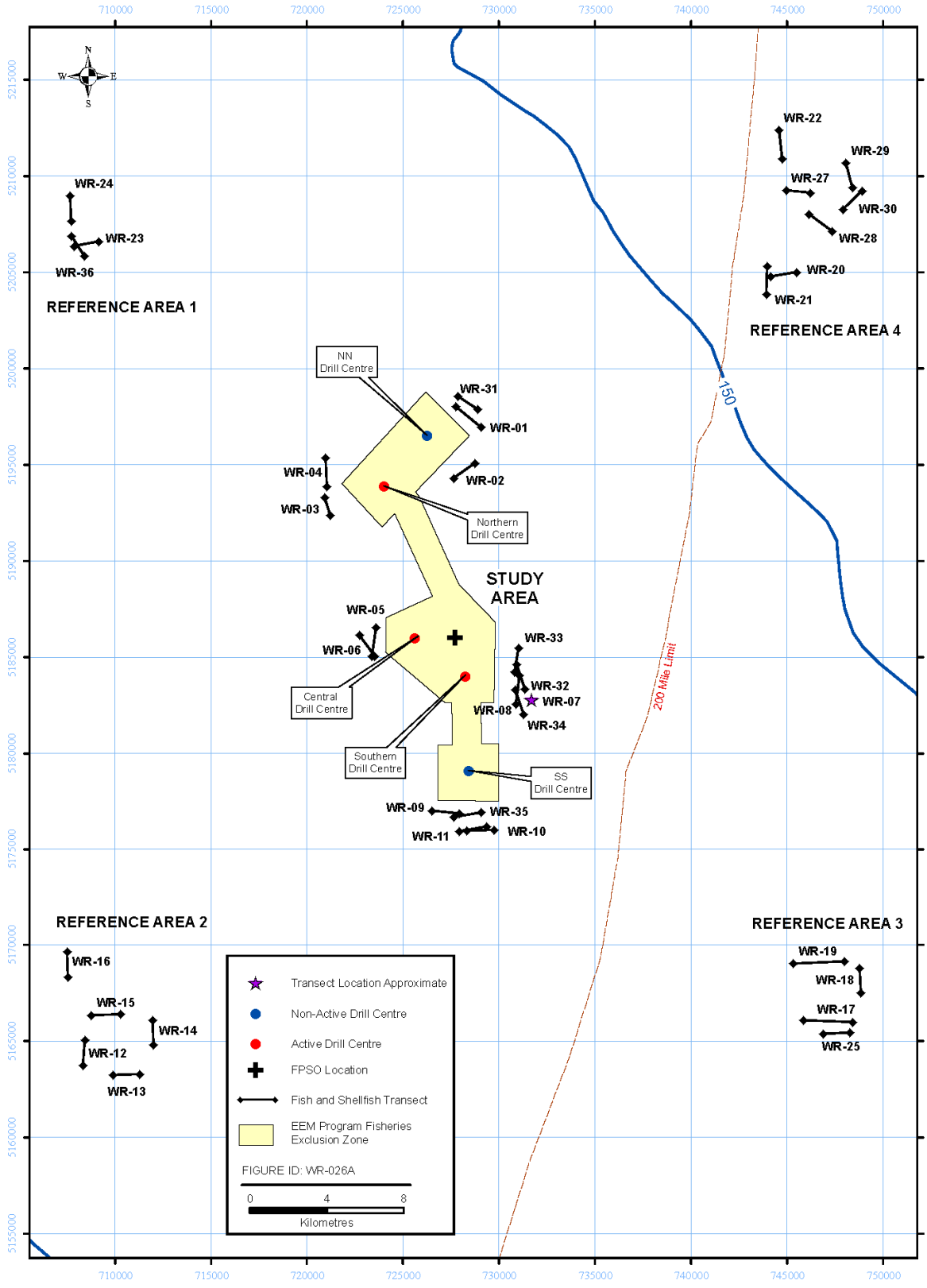

Figure 1-10 2004 EEM Program Commercial Fish Transect Locations

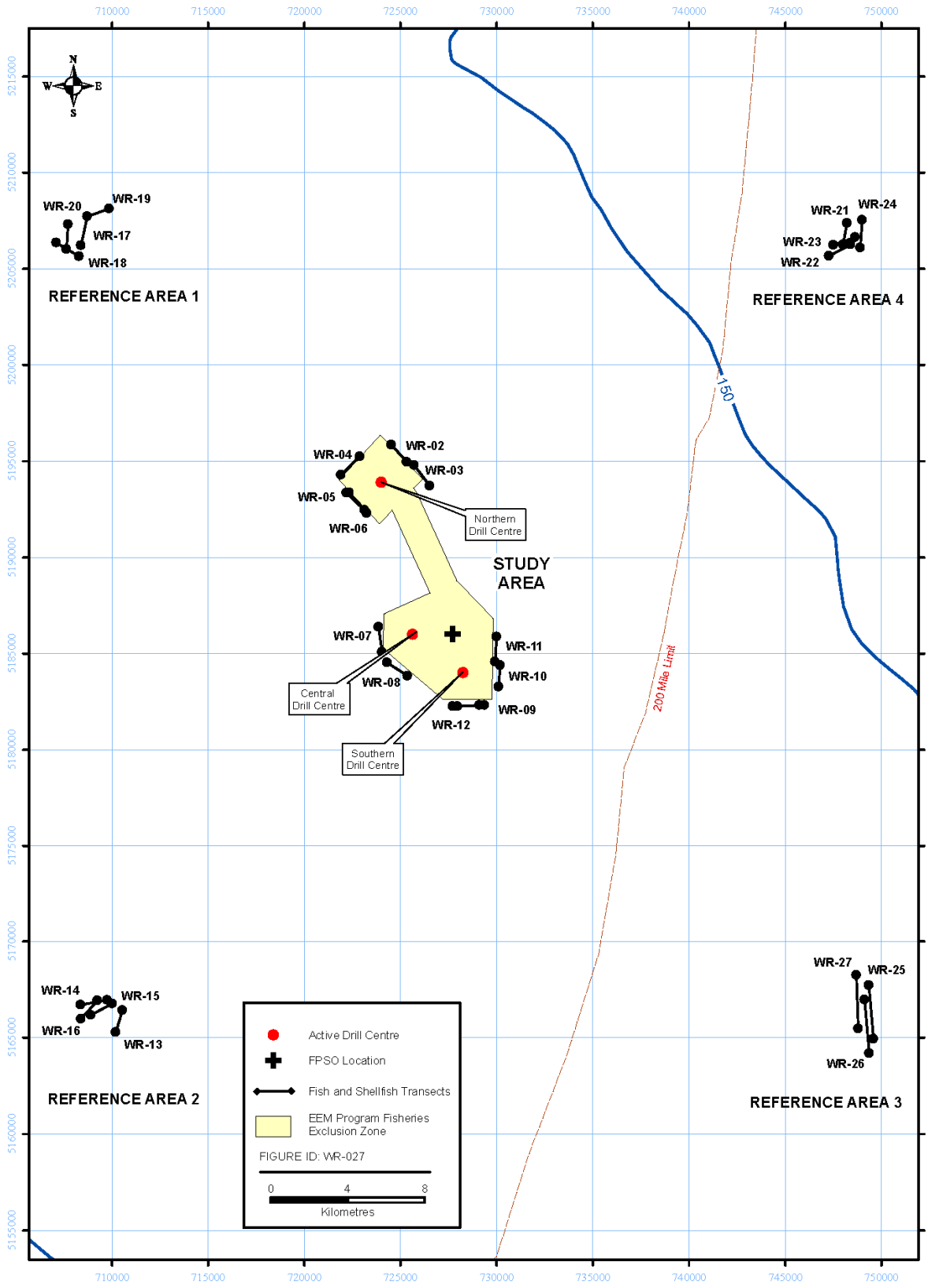

Figure 1-11 2005 EEM Program Commercial Fish Transect Locations

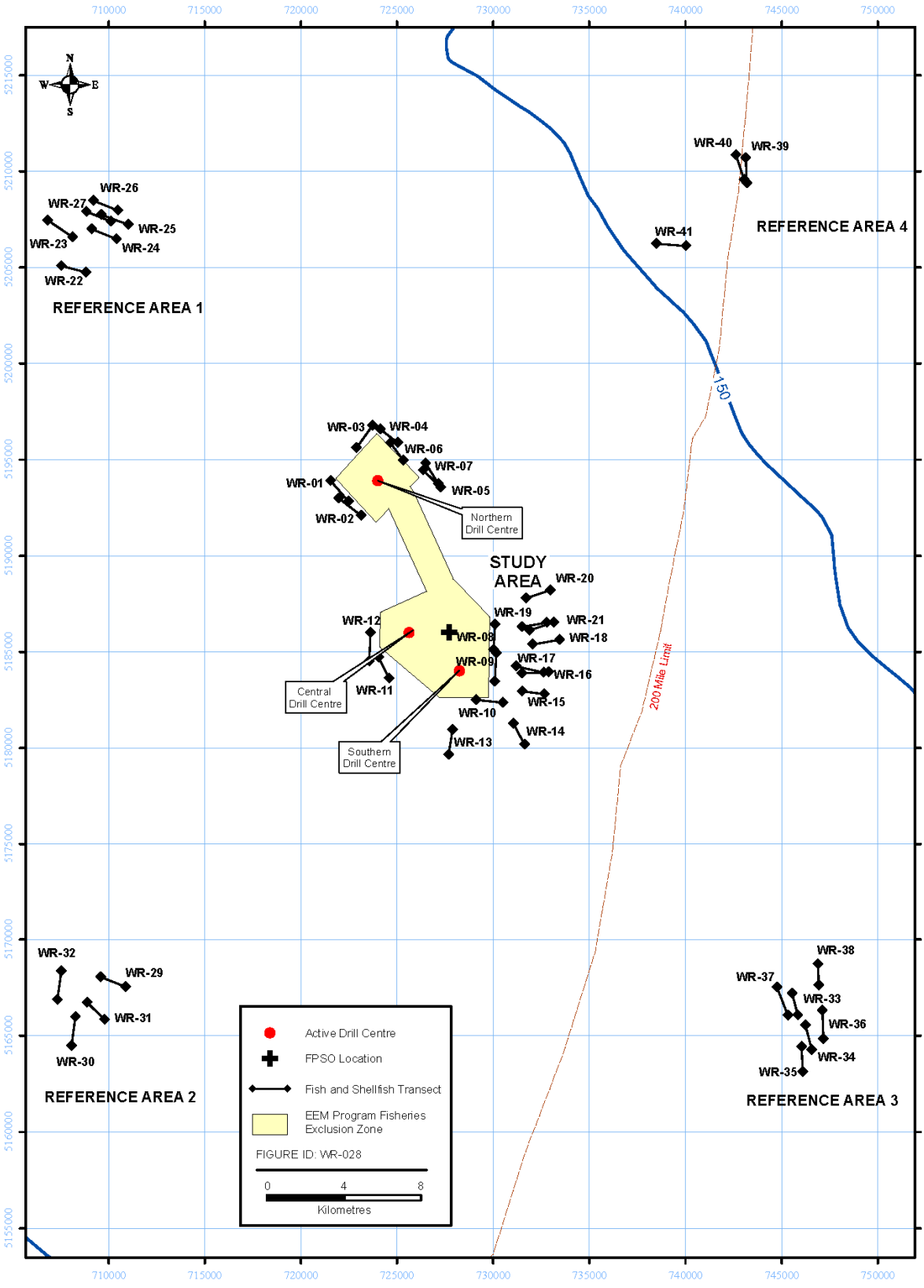

Figure 1-12 2006 EEM Program Commercial Fish Transect Locations

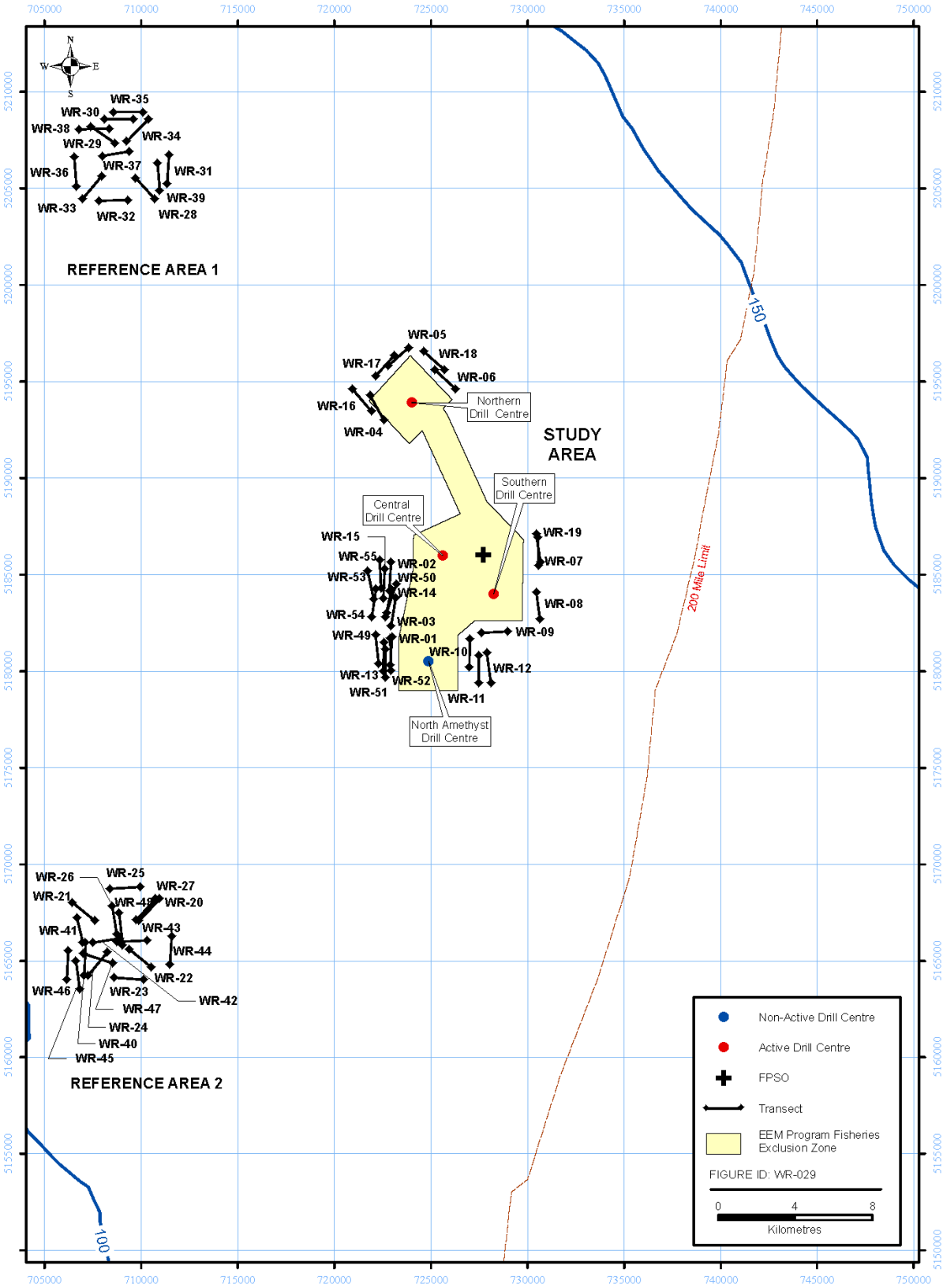

Figure 1-13 2008 EEM Program Commercial Fish Transect Locations

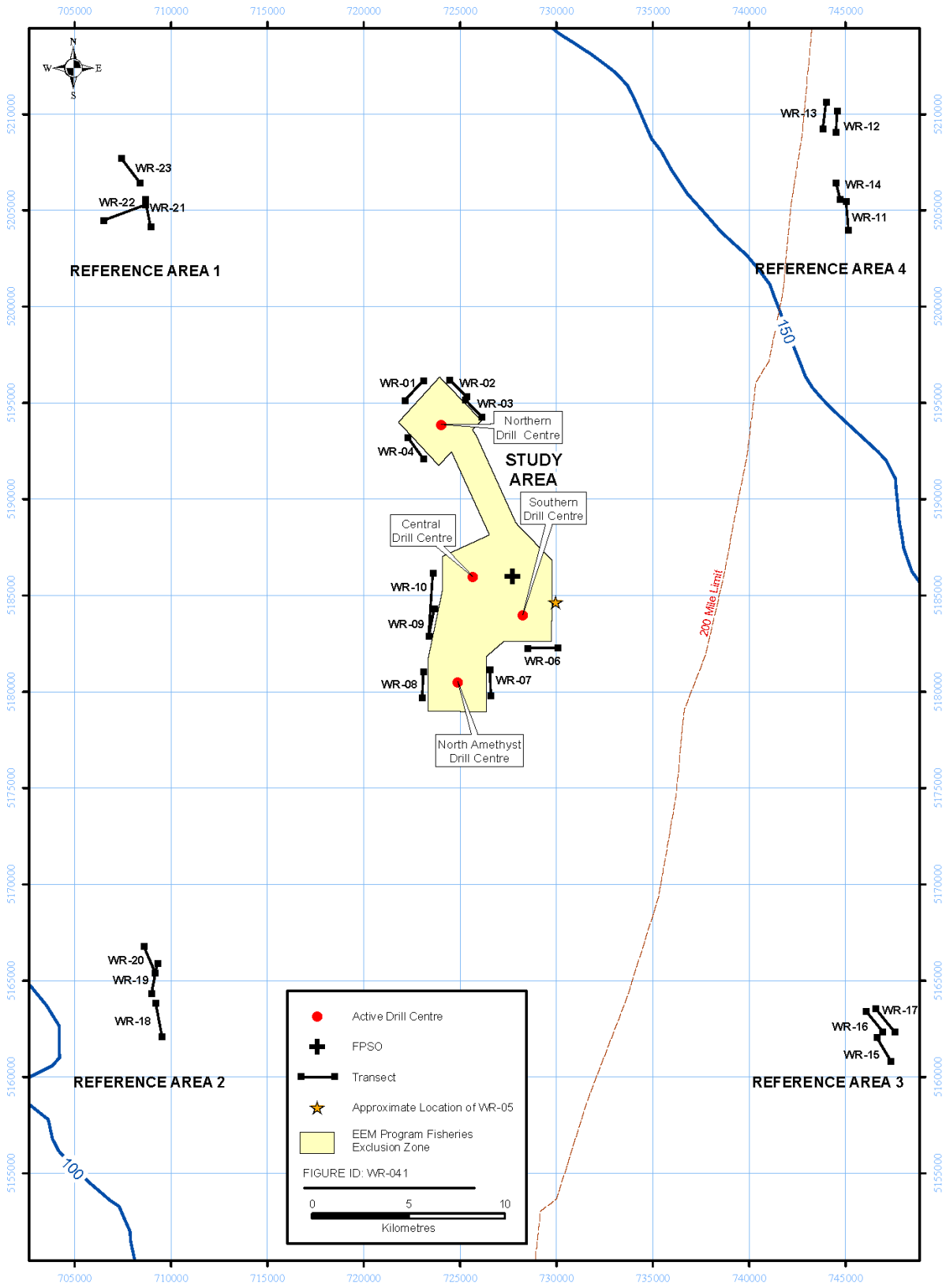

Figure 1-14 2010 EEM Program Commercial Fish Transect Locations

1.8.3 Modifications to the Water Quality Component

Water samples were collected at 13 randomly selected sediment stations during baseline sampling in 2000 (Figure 1-15[6]). Produced water discharge began from the *SeaRose* FPSO in 2007. A preliminary EEM water sampling program was executed in 2008, with eight stations near the *SeaRose* FPSO (the main source of liquid discharge) and one station located approximately 28 km to the northwest (Figure 1-16). A greater number of stations (18) are now sampled as part of the water quality sampling program, with 10 stations located near the *SeaRose* FPSO and eight stations located in Reference Areas to northwest and northeast (Figure 1-17). Water samples are processed for a larger number of constituents and at lower detection limits than in baseline (see Section 7 and Husky Energy 2010 for details). A modelling component has been added to the 2010 program to assess the probability of detection of measured constituents given anticipated dilution of produced water (the main liquid discharge) and laboratory detection limits. Modelling results will be used iteratively in the EEM program to help better target field sampling, as appropriate (Husky Energy 2010).

[6] Figure 1-15 excludes water samples collected at the two control stations sampled during baseline and subsequently excluded from the EEM sampling.

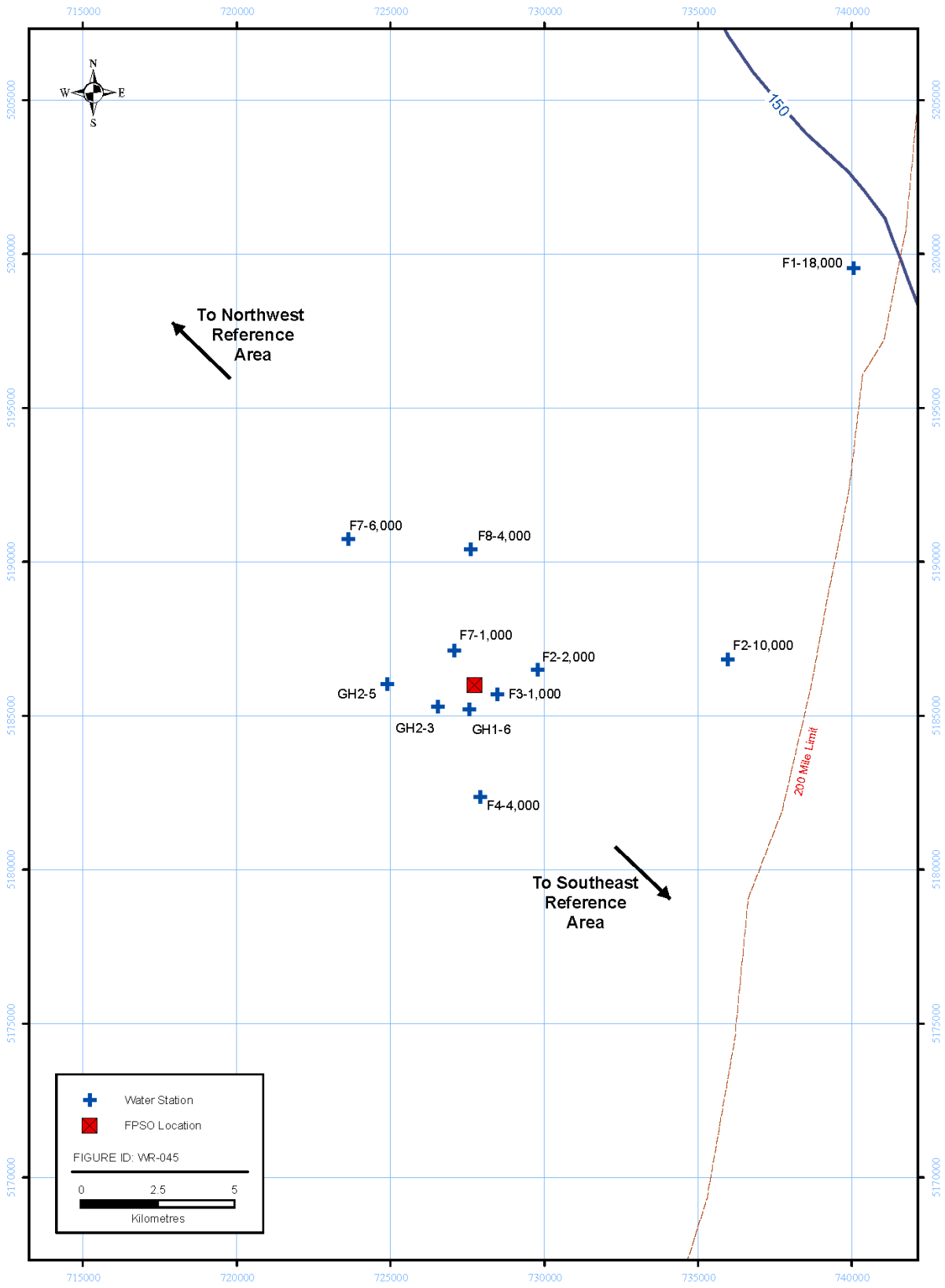

Figure 1-15 2000 Baseline Program Water Stations

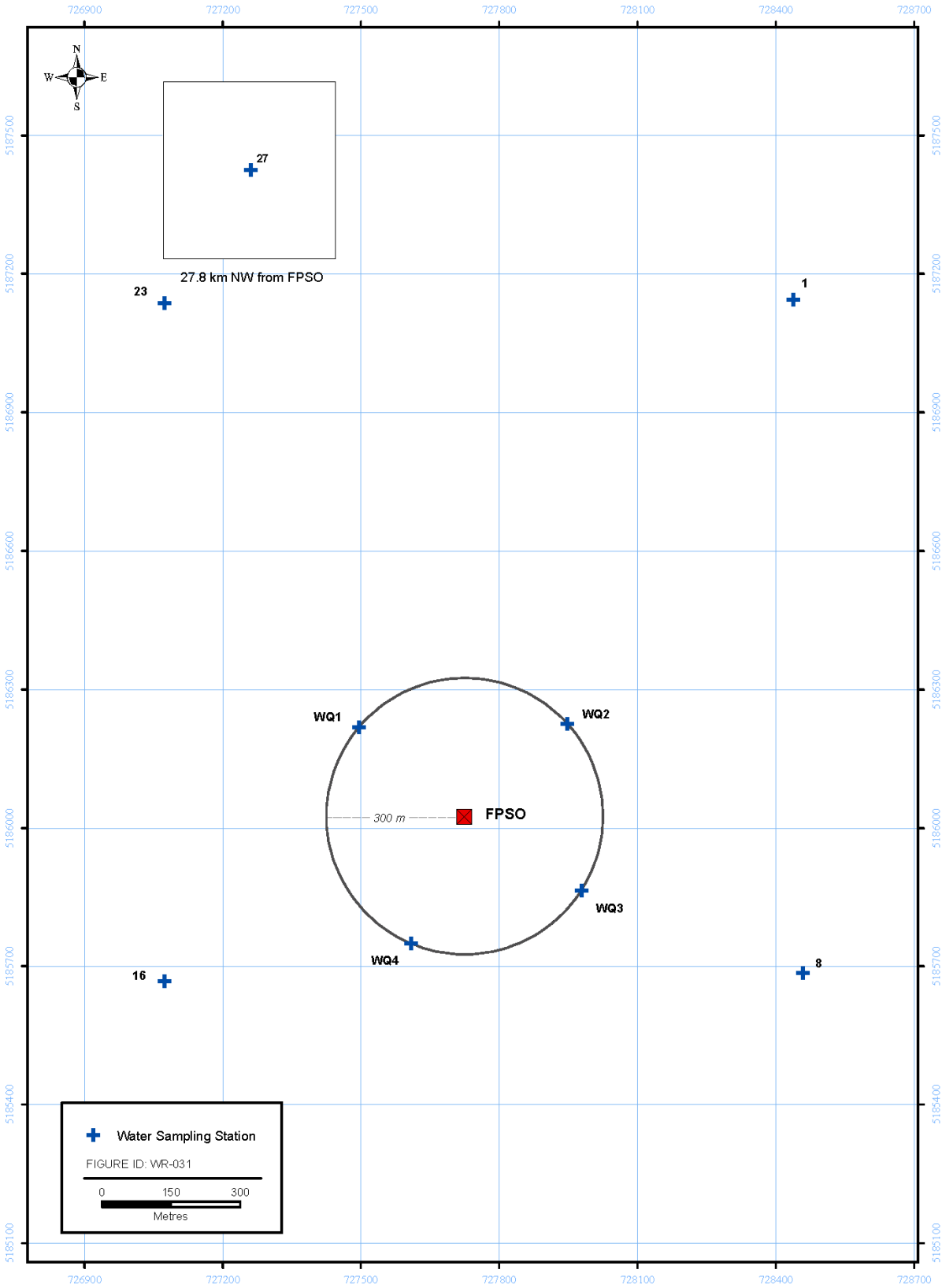

Figure 1-16 2008 EEM Program Water Stations

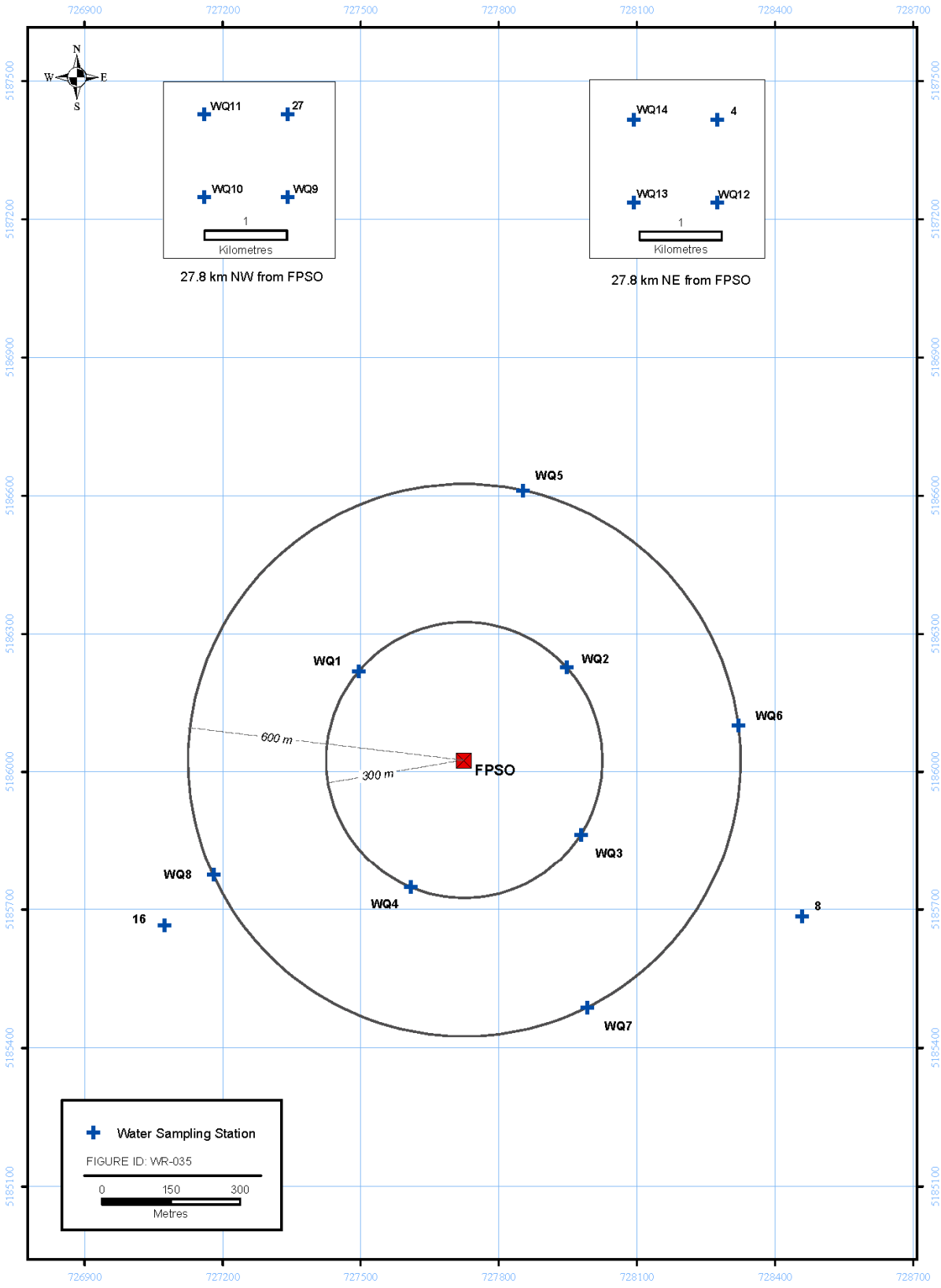

Figure 1-17 2010 EEM Program Water Stations

2.0 Scope

This document, *White Rose Environmental Effects Monitoring Program 2010 (Volume 1)*, provides summary results, analysis and interpretation for the White Rose 2010 EEM program. Where feasible, results from the baseline and previous EEM programs are compared to 2010 results. Since analyses 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 2010 (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
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
CCME	Canadian Council of Ministers of the Environment
CF	Condition Factor
CI	Confidence Interval
CL	Confidence Limit
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CR	Completely Random
CTD	Conductivity, Temperature, Depth
CV	Coefficient of Variation
DREAM	Dose-Related Risk and Effects Assessment Model
EEM	Environmental Effects Monitoring
EIS	Environmental Impact Statement
EQL	Estimated Quantification Limit
EROD	7-ethoxyresorufin O-deethylase
FPSO	Floating, Production, Storage and Offloading Facility
GSI	Gonadosomatic Index
HSI	Hepatosomatic Index
ISQG	Interim Sediment Quality Guidelines
MFO	Mixed Function Oxygenase
NMDS	Non-Metric Multidimensional Scaling
OWTG	Offshore Waste Treatment Guidelines
PAH	Polycyclic Aromatic Hydrocarbon
PC	Principal Component
PCA	Principal Component Analysis
RDL	Reportable Detection Limit
ROV	Remotely Operated Vehicle
SBM	Synthetic-Based Mud
SD	Standard Deviation
SR	Study versus Reference Areas
TOC	Total Organic Carbon
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 (see Husky Energy 2006); flowlines and protective berms were installed to connect the North Amethyst Drill Centre to the Southern Drill Centre in 2009;
- drilling operations including development, delineation and exploration (ongoing for the foreseeable future by one or more drill rigs);
- *SeaRose* FPSO operations (ongoing for the foreseeable future); and
- supply vessel operations (ongoing for the foreseeable future).

In mid-November of 2005, production operations (i.e., oil and gas production, storage and offloading to a tanker) began at the White Rose Field once hook-up, commissioning and introduction of hydrocarbons to the *SeaRose* FPSO were completed. In May 2010, White Rose started producing from the North Amethyst Drill Centre.

4.3 Drilling and Completions Operations

Drilling activities continued in 2008 through 2010. 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.

Husky's Operational Integrity Management System and Waste Management Procedures commit to an active program to manage the generation, reuse or recycling and disposal of waste materials generated by any of Husky's East Coast offshore or onshore operations.

This is achieved through the following objectives:

- Limit or minimize the waste generated from East Coast operations.
- Ensure all waste from East Coast operations is handled in an environmentally responsible manner.

There are several tools currently in place to assist with the implementation:

- White Rose Waste Management Plan (WR-HSE-PR-4006).
- *SeaRose* Waste Management Procedure (WR-O-00-X-PR-00001-001).
- Internal reviews of waste manifesting procedures.
- Management of key contractors.

4.3.1 Drilling Mud and Completion Fluids Discharges

Table 4-1 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 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.

Upon 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 4-3 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 4-1 Cuttings and WBM Discharges from 2003 to December 2010

Year	Drill Centre	Months with Drilling Activity												Total Cuttings Discharged (mt)	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
	EEM Program							F		S	S				
2005	Northern													N/A	N/A
	Central													1,748	1,674
	Southern													552	783
	EEM Program							F		S					
2006	Northern													N/A	N/A
	Central													1,749	1,282
	Southern													638	932
	EEM Program							F	S						
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
	EEM Program					F	F			SW					
2009	Northern													N/A	N/A
	Central													N/A	N/A
	Southern													N/A	N/A
	NADC**													1,482	1,772
2010	Northern													N/A	N/A
	Central													706	1,553
	Southern													N/A	N/A
	NADC**													1,331	2,703
	EEM Program							F			SW				
Total Discharge at Northern Drill Centre														1,335	1,182
Total Discharge at Central Drill Centre														6,164	6,834
Total Discharge at Southern Drill Centre														3,760	4,817
Total Discharge at North Amethyst Drill Centre														2,813	4,475
Total Field Discharge														14,691	18,026

Note: - * Well K 03 is a Delineation Well.
- ** NADC – North Amethyst Drill Centre.
- F = Commercial Fish portion of the EEM program.
- S = Sediment Quality portion of the EEM program.
- W = Water Quality portion of the EEM program.

Table 4-2 Cuttings and SBM Discharges from 2003 to December 2010

Year	Drill Centre	Months with Drilling Activity												Total Cuttings Discharged (mt)	Total Solids Discharged (mt)	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
	EEM Program							F		S	S					
2005	Northern													N/A	N/A	N/A
	Central													1,291	2,382	482
	Southern													741	1,464	157
	EEM Program							F		S						
2006	Northern													N/A	N/A	N/A
	Central													1,268	3,163	335
	Southern													1,028	1,927	185
	EEM Program							F	S							
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
	EEM Program					F	F			SW						
2009	Northern													106	186	22
	Central													N/A	N/A	N/A
	Southern													N/A	N/A	N/A
	NADC**													752	1,345	117
2010	Northern													N/A	N/A	N/A
	Central													524	1,141	130
	Southern													N/A	N/A	N/A
	NADC**													1,371	3,149	327
	EEM Program							F			SW					
Total Discharge at Northern Drill Centre														1,636	3,144.6	330
Total Discharge at Central Drill Centre														5,110	11,244	1,417
Total Discharge at Southern Drill Centre														4,046	9,224	1,233
Total Discharge at North Amethyst Drill Centre														2,123	4.494	444
Total Field Discharge														12,915	28,881.6	3,484

Notes: - * Well K 03 is a Delineation Well.
- ** NADC – North Amethyst Drill Centre.
- F = Commercial Fish portion of the EEM program.
- S = Sediment Quality portion of the EEM program.
- W = Water Quality Portion of the EEM program.

Table 4-3 Completion Fluid Discharges from 2003 to December 2010

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													1,619
	EEM Program													
2005	Northern							F		S	S			N/A
	Central													1,015
	Southern													1,372
	EEM Program							F		S				
2006	Northern													N/A
	Central													901.1
	Southern													476
	EEM Program							F	S					
2007	Northern													150
	Central													573
	Southern													N/A
	Well K 03*													N/A
2008	Northern													N/A
	Central													186
	Southern													250
	EEM Program					F	F			SW				
2009	Northern													235
	Central													N/A
	Southern													N/A
	NADC**													29
2010	Northern													N/A
	Central													N/A
	Southern													N/A
	NADC**													2,293
	EEM Program							F			SW			
Total Discharge at Northern Drill Centre														385
Total Discharge at Central Drill Centre														2,675.1
Total Discharge at Southern Drill Centre														3,717
Total Discharge at North Amethyst Drill Centre														2,322
Total Field Discharge														9,099.1

Notes: - * Well K 03 is a Delineation Well.
- ** NADC – North Amethyst Drill Centre.
- F = Commercial Fish portion of the EEM program.
- S = Sediment Quality portion of the EEM program.
- W = Water Quality portion of the EEM program.

4.3.2 Other Discharges from Drilling Operations

Between October 2008 and October 2010, a total of 475 m³ of bilge water from drilling operations has been discharged. All bilge water is treated in an oily water separator prior to release to reduce hydrocarbon content to 15 ppm or less (in accordance with Husky's Environmental Protection and Compliance Monitoring Plans). In total, 7 kg of dispersed hydrocarbons were released to the marine environment from bilge water. Similarly, all deck drainage is collected and treated to reduce hydrocarbon content to 15 ppm or less.

There has been approximately 4,938 m³ of deck drainage reported during this period, which represents a transfer of 67.3 kg of dispersed hydrocarbons 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 267 m³ of water and glycols have been discharged from these sources, at between 25% and 35% of total volume, approximately 82.1 m³ of which have been active ingredients.

4.4 *SeaRose* FPSO Production Operations

The primary points of hydrocarbon 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 Husky's Environmental Protection and Compliance Monitoring Plans, following a separation process, to reduce the oil in water content to less than 15 ppm. 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 hydrocarbon as per Husky's Environmental Protection and Compliance Monitoring Plans. Between October 2008 and October 2010, a total of 4,987 m³ of water was released from the slops tanks, representing 23.1 kg (4.5 ppm) of dispersed hydrocarbons 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 Husky's Environmental Protection and Compliance Monitoring Plans; 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. Between October 2008 and October 2010, 4,521,634m³ of produced water was released, representing 107,134 kg (24.99 ppm) of dispersed hydrocarbons 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 m³ 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 1.0 ppm or less, approximately the same as drinking water. Between October 2008 and October 2010, the monthly average concentration of chlorine prior to release was 0.27 ppm.

4.5 Supply Vessel Operations

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

5.0 Sediment Component

5.1 Methods

5.1.1 Field Collection 2010

The Sediment Component of the 2010 EEM Program was conducted from October 4 to October 13, 2010, using the offshore supply vessel *M/V Maersk Gabarus*. Sampling dates for the baseline program and sediment component of the EEM programs are summarized in Table 5-1. Sediment stations for the baseline and EEM programs are shown in Figures 1-4 to 1-10 (Section 1). Differences in sampling locations among years are described in Section 1. More details on the baseline survey and the Year 1, 2, 3 and 4 EEM programs can be found in Husky Energy (2001, 2005, 2006, 2007, 2009). Geographic coordinates and distances to drill centres for EEM stations sampled in 2010 are provided in Appendix B-1.

Table 5-1 Date of Sediment Component 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
EEM Program Year 5	October 4 to October 13, 2010

Sediment was collected using a large-volume corer (mouth diameter = 35.6 cm, depth = 61 cm) designed to mechanically take an undisturbed[7] sediment sample over approximately 0.1 m^2 (0.0995 m^2) of seabed (Figures 5-1 and 5-2). In 2010, sediments were sampled for physical and chemical characteristics, toxicity and benthic community structure at most stations. These three sets of variables constitute the Sediment Quality Triad (see Section 1). Physical and chemical characteristics variables included particle size, organic and inorganic carbon, metal, hydrocarbon, sulphide and ammonia. Toxicity variables included bacterial luminescence (Microtox) and amphipod survival. Stations sampled for the full suite of sediment quality triad variables are shown in Figure 5-3. Remaining stations were sampled for sediment physical and chemical characteristics. At a select set of stations, sediments were also sampled for radionucliide concentration (Figure 5-3).

[7] Cores that have been disturbed are rejected and another core is taken.

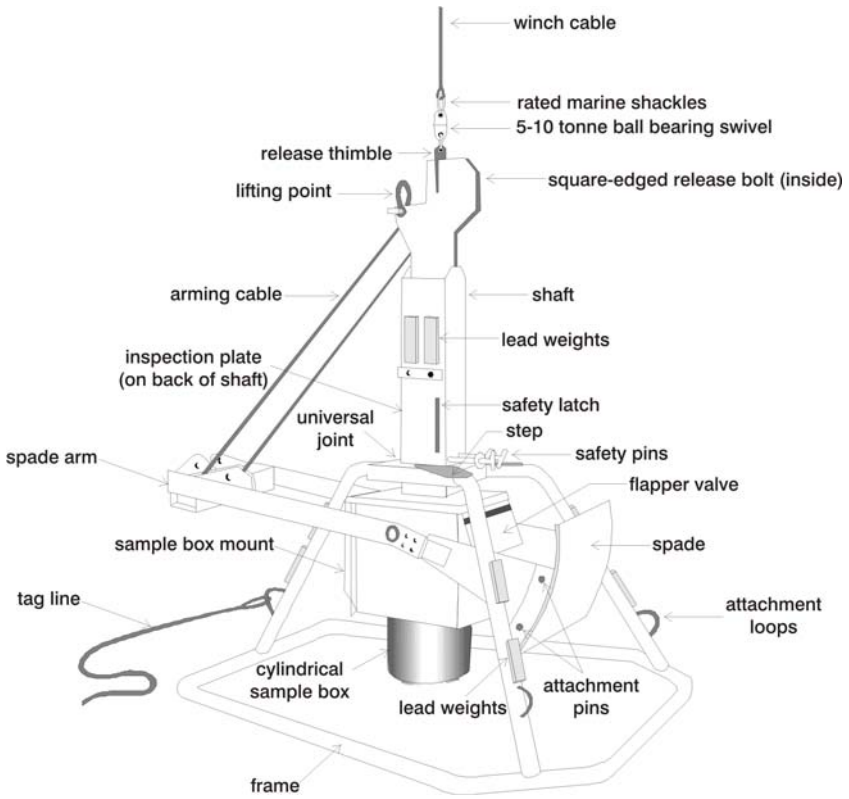

Figure 5-1 Sediment Corer Diagram

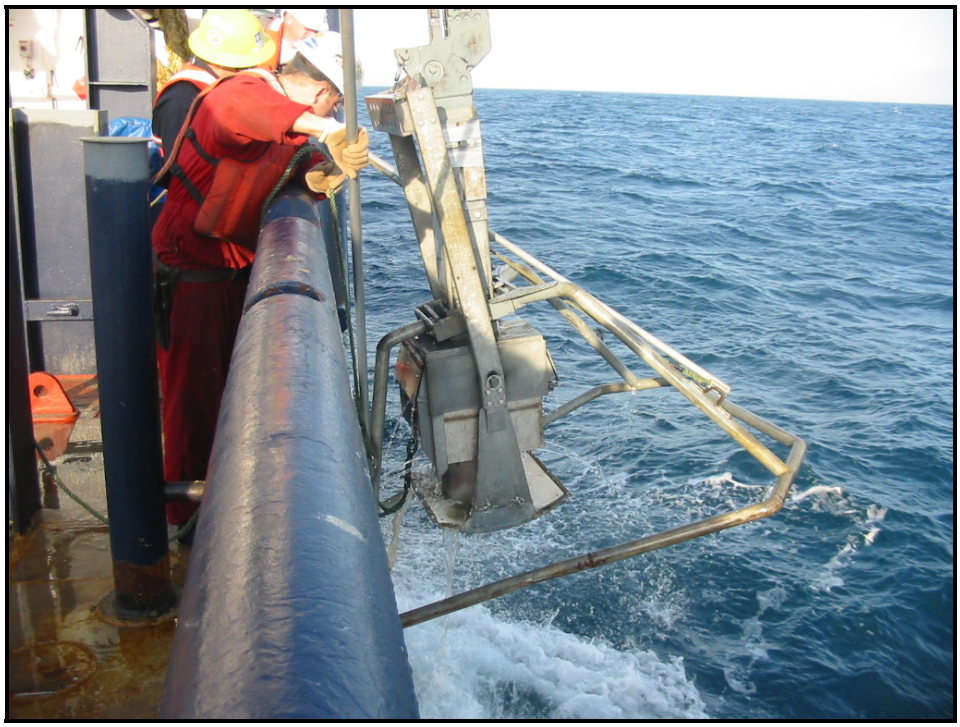

Figure 5-2 Sediment Corer

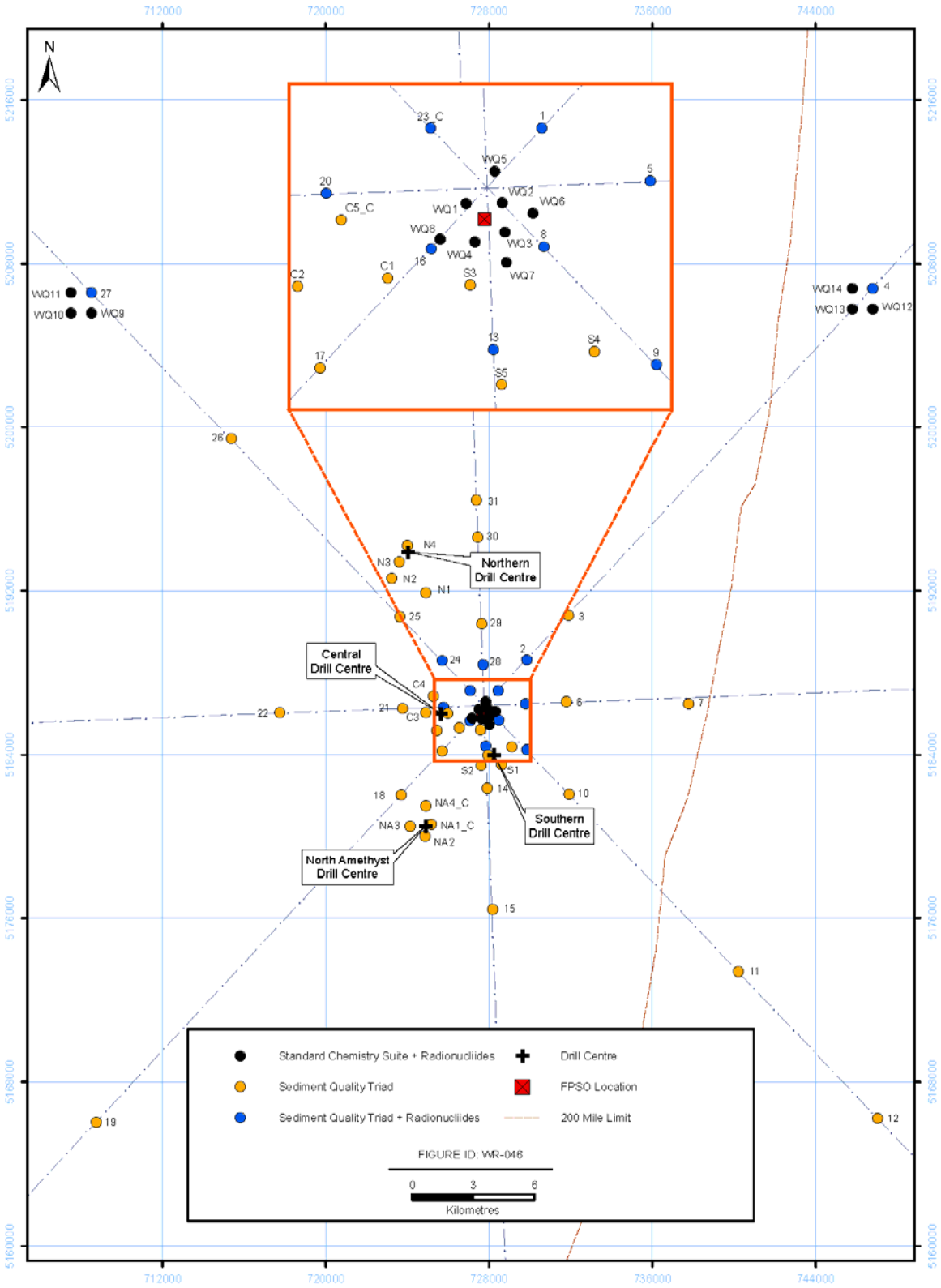

Figure 5-3 2010 Sediment Sampling Stations and Monitoring Variables

At Sediment Quality Triad stations, sediment samples collected for physical and chemical analyses were a composite from the top layer of three cores per station. At stations where analyses focused on sediment physical and chemical characteristics alone, only one core was collected. 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 2 to 3 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[8]. These samples were preserved with approximately 1 L of 10% buffered formalin. Benthic invertebrate counts from these two samples were later pooled for analysis. Sediment sampled for radionucliide concentration was scraped from the very surface of cores - as shallow as possible while obtaining appropriate sample volume. A sample was collected from one core when only one core was collected at any given station. If three cores per stations were collected, the radionucliide sample was a composite from sediments collected from the surface of the three cores. Radionucliide samples were stored in pre-labelled 250-mL glass jars at -20°C.

Sediment chemistry field blanks composed of clean sediment obtained from Maxxam Analytics were collected for stations 6, 26 and NA4-C. 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 2, 15, 17, 25 and S1. 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.

5.1.2 Laboratory Analysis

5.1.2.1 Physical and Chemical Characteristics

Sediment particle size analysis was conducted by Stantec Consulting Ltd. in St. John's, Newfoundland and Labrador, following the Wentworth particle size classification scale (Table 5-2). Most chemical analyses were conducted by Maxxam Analytics in Halifax, Nova Scotia. Radionucliide analysis was performed at RPC, in Fredericton, New Brunswick (Table 5-3). The full suite of chemical analyses is provided in Table 5-3.

[8] 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.

Methods summaries from these three laboratories are provided in Appendices B-2 (Particle Size) and B-3 (Chemistry), 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, 2008 and 2010)

Variables	Method	Laboratory Detection Limit						Units
		2000	2004	2005	2006	2008	2010	
Hydrocarbons								
Benzene	Calculated	0.025	0.025	0.025	0.03	0.03	0.03	mg/kg
Toluene	Calculated	0.025	0.025	0.025	0.03	0.03	0.03	mg/kg
Ethylbenzene	Calculated	0.025	0.025	0.025	0.03	0.03	0.03	mg/kg
Xylenes	Calculated	0.05	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	3	mg/kg
>C_{10}-C_{21}	GC/FID	0.25	0.25	0.3	0.3	0.3	0.3	mg/kg
>C_{21}-C_{32}	GC/FID	0.25	0.25	0.3	0.3	0.3	0.3	mg/kg
PAHs								
1-Chloronaphthalene	GC/FID	NA	0.05	0.05	0.05	0.05	0.01	mg/kg
2-Chloronaphthalene	GC/FID	NA	0.05	0.05	0.05	0.05	0.01	mg/kg
1-Methylnaphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
2-Methylnaphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Acenaphthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Acenaphthylene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Benz[*a*]anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Benzo[*a*]pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Benzo[*b*]fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Benzo[*ghi*]perylene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Benzo[*k*]fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Chrysene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Dibenz[*a,h*]anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Fluorene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Indeno[1,2,3-*cd*]pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Naphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Perylene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Phenanthrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Carbon								
Carbon	LECO	0.1	0.2	0.2	0.2	0.2	0.2	g/kg
Organic Carbon	LECO	0.1	0.2	0.2	0.2	0.2	0.2	g/kg
Inorganic Carbon	By Diff	0.2	0.3	0.2	0.2	0.2	0.2	g/kg
Metals								
Aluminum	ICP-MS	10	10	10	10	10	10	mg/kg
Antimony	ICP-MS	2	2	2	2	2	2	mg/kg
Arsenic	ICP-MS	2	2	2	2	2	2	mg/kg
Barium	ICP-MS	5	5	5	5	5	5	mg/kg
Beryllium	ICP-MS	5	2	2	2	2	2	mg/kg
Cadmium	GFAAS	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Chromium	ICP-MS	2	2	2	2	2	2	mg/kg
Cobalt	ICP-MS	1	1	1	1	1	1	mg/kg
Copper	ICP-MS	2	2	2	2	2	2	mg/kg
Iron	ICP-MS	20	50	50	50	50	50	mg/kg
Lead	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Lithium	ICP-MS	5	2	2	2	2	2	mg/kg

Variables	Method	Laboratory Detection Limit						Units
		2000	2004	2005	2006	2008	2010	
Manganese	ICP-MS	2	2	2	2	2	2	mg/kg
Mercury	CVAA	0.01	0.01	0.01	0.01	0.01	0.01	mg/kg
Molybdenum	ICP-MS	2	2	2	2	2	2	mg/kg
Nickel	ICP-MS	2	2	2	2	2	2	mg/kg
Selenium	ICP-MS	2	2	2	2	2	2	mg/kg
Strontium	ICP-MS	5	5	5	5	5	5	mg/kg
Thallium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	mg/kg
Tin	ICP-MS	2	2	2	2	2	2	mg/kg
Uranium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	mg/kg
Vanadium	ICP-MS	2	2	2	2	2	2	mg/kg
Zinc	ICP-MS	2	5	2	5	5	5	mg/kg
Other								
Ammonia (as N)	COBAS	NA	0.25	0.3	0.3	0.3	0.3	mg/kg
Sulphide	SM4500	NA	2	0.2	0.2	0.2	0.2	mg/kg
Sulphur	LECO	NA	0.02	0.02	0.002	0.01	0.03	%(w)
Moisture	Grav.	0.1	0.1	0.1	1	1	1	%
Radium-226	Gamma Spec.	NA	NA	NA	NA	0.02	0.02	Bq/g
Radium-228	Gamma Spec.	NA	NA	NA	NA	0.003	0.003	Bq/g
Lead-210	Gamma Spec.	NA	NA	NA	NA	0.01	0.01	Bq/g

Notes:
- Total metals concentrations were assessed. Assessment of total metals concentration does not differentiate between bioavailable and non-bioavailable fractions.
- The Estimated Quantification Limit was used in previous years instead of laboratory 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 laboratory detection limit is the lowest concentration that can be detected reliably within specified limits of precision and accuracy during routine laboratory operating conditions. Laboratory detection limit may vary from year to year because instruments are checked for precision and accuracy every year as part of QA/QC procedures[9].
- NA = Not Analyzed.

Within the hydrocarbons, benzene, toluene, ethylbenzene and xylene (BTEX) are aromatic organic compounds that 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. Hydrocarbons 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 hydrocarbons in the C_6-C_{32} range (see Appendix B-3). When complex hydrocarbon 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 synthetic-based drill mud base oil (PureDrill IA35-LV) used at White Rose is a synthetic isoalkane fluid consisting of molecules ranging from >C_{10}-C_{21}. Most of the components of PureDrill IA35-LV form an UCM that starts around the retention time of C_{11} n-alkane (2.25 min) and ends around

[9] Typically, Maxxam Analytics sets the laboratory detection limit at 2 to 10 times the Method Detection Limit calculated using the US Environmental Protection Agency protocol. The 2 to 10 times Method Detection Limit factor for the laboratory detection limit 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 or physical property of the real world sample that can affect the analytical determination.

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.

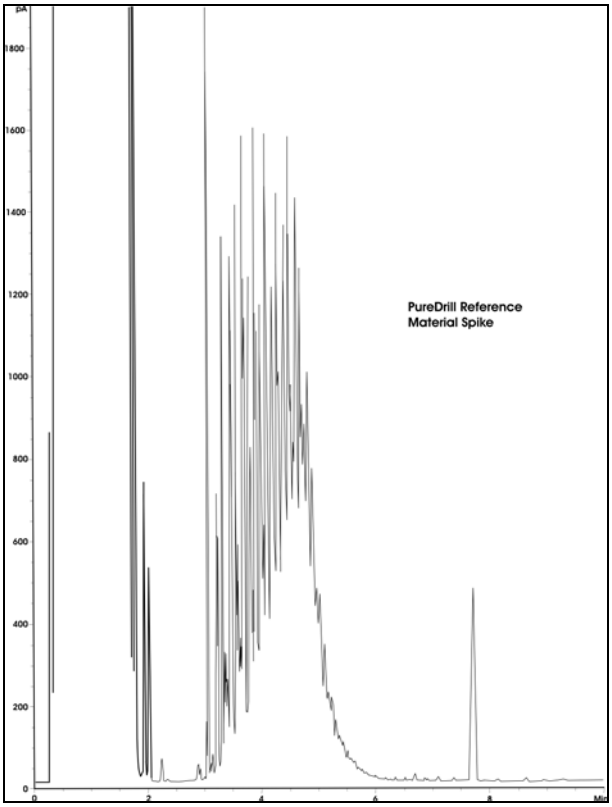

Figure 5-4 Gas Chromatogram Trace for PureDrill

5.1.2.2 Toxicity

Analytical Methods

Stantec Consulting Ltd.'s Science Laboratory in St. John's, Newfoundland and Labrador, conducted the sediment toxicity analyses. 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 of Canada, 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 against which test organisms can be compared. Negative control sediment, known to support a viable population, was obtained from the collection site (Washington State) 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, 2008 and 2010 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).

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 Multiple Comparison Test using the CETIS computer program (©2001-2010 Tidepool Scientific, LLC). 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}[10] value.

Sample toxicity was assessed using standard toxicity testing statistical programs coupled with interpretation guidelines. The amphipod survival tests results for sediments were considered toxic if: the endpoint (mortality) exhibited a greater than 30% reduction in survival as compared to negative control sediment; and the result was statistically significantly different from 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.

The Solid Phase Microtox Testing reference method (Environment Canada 2002) contains 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.

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

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

(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.

5.1.2.3 Benthic Community Structure

All 2010 benthic invertebrate samples were provided whole to Arenicola Marine Limited (Wolfville, Nova Scotia). Individual core samples were processed separately but data were pooled for data analysis.

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.

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 2010 samples (see Husky Energy 2001 for details).

5.1.3 Data Analysis

5.1.3.1 Changes from the 2008 Program

The approach used to analyze the sediment quality data in 2010 was very similar to previous years, with some changes to make the analysis more direct. In prior years, correlations among sets of sediment quality variables were produced. In 2010, in order to assess covariation among variables, an overall Principal Component Analysis was conducted instead.

In prior years, a repeated-measures regression was carried out that included an assessment of the effect of distance to individual drill centres. In 2010, the repeated-measures analysis was carried out using distance to the nearest active drill centre as the only covariable. The repeated-measures regressions also tested slightly different hypotheses. Rather than test various year combinations, the analysis tested for changes from baseline to the average of the drilling period, as well as trends over time.

The analysis in prior years included an assessment of threshold models of the relationship between indices of benthic community composition and barium and $>C_{10}$-C_{21} hydrocarbons. That analysis was not carried out for this report. Threshold models were produced for sediment chemistry in relation to distance to nearest active drill centre, and between indices of benthic community composition and distance to the nearest active drill centre. Those two analyses were considered redundant with threshold models between biota indices and chemistry.

5.1.3.2 General Approach

The White Rose sediment quality survey is based on a gradient design, with sampling locations radiating out from the general operations area defined by the Northern, Southern, Central and North Amethyst Drill Centres. Effects during development drilling periods at White Rose have historically been most evident close to drill centres and have decreased with distance away from them. The general approach for the examination of the sediment quality data was to confirm the presence of spatial patterns (i.e., changes in response variables with distance from drill centres) that were consistent with development drilling effects and to identify the potential zone of influence[11] for sediment chemistry.

As indicated in Husky Energy's response to regulator comments on the 2008 EEM program (Appendix A-1), the 2010 EEM report relies on both statistical analysis and visual display of information in order to assess effects. Occurrence above or below the range of values observed during baseline sampling (2000) is used to assess effects from individual drill centres.

Station 31 was excluded from all analyses on distance to drill centres in 2008 and 2010 because hydrocarbon and barium levels at that station were elevated because of delineation rather than development drilling. Station 31 is located 4 km from the nearest development drill centre but the station is located 0.4 km from the site of a delineation well drilled in 2007. Higher hydrocarbon and barium levels at Station 31 obscured the relationship between distance and development drill centres.

[11] The zone of influence has been defined as the zone where physical and chemical alterations might occur (see Section 1).

In 2010, additional analyses were performed to assess if effects with distance from the *SeaRose* FPSO could be distinguished from effects from drill centres. The *SeaRose* FPSO is not a source of drilling discharge but is a source of produced water and constituents of produced water could settle to sediments (Azetsu-Scott et al. 2007). However, drill centres and the *SeaRose* FPSO are in close proximity.

5.1.3.3 Physical and Chemical Characteristics

Data were first screened to identify and exclude variables that frequently occurred below detectable concentrations. A multivariate Principal Component Analysis (PCA) was subsequently used to identify sets of variables that covaried and, from those, a subset of variables on which to carry out more detailed analyses of spatial variation. The variables selected in 2010 included barium and $>C_{10}$-C_{21} hydrocarbons, because they had been shown to vary with distance from drill centres in previous years. The subset of variables in 2010 also included percent of sediment as fines (% fines), concentrations of total organic carbon (TOC), ammonia and sulphur, redox potential and a summary measure of metals concentrations (derived from PCA; see below). All these variables had been measured in previous years.

Five statistical tools were used to explore the spatial variations of these selected variables as they might relate to drilling. The first tool (Tool 1) was graphical for visual inspection of the data. Scatterplots of concentration (or percent as appropriate) in relation to distance from the nearest active drill centre were produced in order to visualize the nature of the relationship with distance. Plots were made for each of the variables brought forward for inspection.

Rank regression (Tool 2) was used to statistically test for general associations between distance from the nearest active drill centre and concentration of the subset of variables selected for detailed analysis. A significant relationship between analyte concentrations and distance from active drill centres was considered evidence of drilling effects. Threshold models (Tool 3) were constructed in order estimate the spatial extent (distance) of influence of drill centres, overall, on concentrations of substances in sediments, in particular barium and $>C_{10}$-C_{21} hydrocarbons. The presence of significant threshold models indicates that drilling influenced a relatively finite area within the drilling-field. Maps (Tool 4) indicating barium and $>C_{10}$-C_{21} hydrocarbon concentrations within and exceeding the variability observed in baseline (2000) were also generated to visually assess the effects of individual drill centres on these two variables and to provide per-drill centre insight into the estimate of the spatial extent of effects based on threshold models.

Repeated-measures regression (Tool 5) was used to test for variations both spatially and temporally (i.e., over years) for barium and $>C_{10}$-C_{21} hydrocarbons, as well as the other variables brought forward for detailed analysis. The repeated-measures regression method was used to determine if there were changes over time both in terms of changes in concentration that may have affected all sampling locations (i.e., an increase in or decrease in concentration that is similar across all stations), or a change in the nature of the relationship between distance to nearest active drill centre and concentration (i.e., the slope of the relationship may get steeper over time, indicating an increase in concentrations adjacent to drill centres).

Effects of distance from the *SeaRose* FPSO were examined in Appendix B-5 using a combination of Rank Correlations and partial regression.

All methods are described in greater detail in Appendix B-5.

5.1.3.4 Toxicity

In 2010 and in previous years, no statistical analyses of results for bacterial toxicity tests were conducted. All but one sample (station C5-C) in 2010 were non-toxic, with IC_{50}s greater than the highest concentration tested (197,000 mg/kg in later years). The IC_{50} for the sediment sample from station C5-C was 61,224 mg/L (dry weight).

The evidence that amphipod survival was influenced by drilling was tested using multiple-rank regressions between survival (%) and distance to the nearest active drill centre, as was done in 2008. The analysis considered the influence of sediment physical and chemical characteristics. Details on this analysis are provided in Appendix B-5.

5.1.3.5 Benthic Community Structure

In 2010, three summary indices of benthic community composition were analyzed in detail:

- total abundance (number of organisms per m2);
- biomass (wet weight of organisms per m2); and
- taxonomic richness (number of families per station).

Abundances (numbers per m^2) of four taxa were also analyzed in some detail. These analyses were secondary to analyses of indices of benthic community composition and were performed to provide insight on the more general indices. Taxa examined were:

- Paraonidae (Polychaeta);
- Spionidae (Polychaeta);
- Tellinidae (Bivalvia); and
- Amphipoda.

Paraonidae, Spionidae and Tellinidae were the three most abundant taxa. Although Amphipoda were less abundant in comparison to polychaetes and bivalves, 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 relatively high $>C_{10}$-C_{21} hydrocarbon concentrations in past years (Husky Energy 2009).

An additional multivariate method (Non-Metric Multidimensional Scaling (NMDS)) was used to develop “derived” indices of community composition. Two “axes”, or derived indices, from this analysis were brought forward for detailed analysis.

As with the sediment chemistry and amphipod toxicity results, the objective of the detailed analysis of the benthic community data was to test for evidence of drill centre effects on community composition. Five statistical tools were used to explore the spatial variations of the selected indices of benthic community composition. The first tool (Tool 1) was graphical, used to visually inspect the data. Scatterplots of index values in relation to distance from the nearest active drill centre were produced in order to assist in visualizing the nature of the relationship with distance. Plots were made for each of the indices of composition brought forward for detailed analysis. Rank regression (Tool 2), threshold models (Tool 3), and maps (Tool 4) were used to provide per-drill centre insight into the estimate of the spatial extent of effects based on threshold models. For individual taxa, only those taxa that showed project effects were examined using maps.

All of these methods are described in greater detail in Appendix B-5.

5.2 Results

5.2.1 Physical and Chemical Characteristics

Appendix B-3 provides summary statistics for sediment physical and chemical characteristics occurring at or above the laboratory detection limit in 2000, 2004, 2005, 2006, 2008 and 2010. All variables measured on sediment are provided above in Table 5-3. Toluene was detected at levels close to the laboratory detection limit in one sample in 2005 and was not detected in other years. $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons have been detected in sediments since 2004, but were not detected in 2000, the baseline year. Most PAHs were at non-detectable concentrations in most samples. Five samples in 2010 contained PAHs at levels near the laboratory detection limit of 0.01 mg/kg (range 0.02 to 0.03 mg/kg; Appendix B-3). Commonly detected metals in all six sampling years were aluminum, barium, chromium, iron, lead, manganese, strontium, uranium, vanadium and zinc.

As in previous years, sediments collected in 2010 were predominantly sand, with gravel-sized materials comprising up to 9% of the sediment (Table 5-4). Organic carbon content was low, generally less than 1% TOC. All detectable metals for which there is a sediment quality guideline were measured below their Interim Sediment Quality Guidelines (ISQG) (Canadian Council of Ministers of the Environment (CCME) 2010; see Table 5-4). Adverse biological effects are rare below ISQG (CCME 2010). Barium concentrations measured in 2010 varied between background levels of 110 mg/kg and enriched levels of 2,700 mg/kg. Concentrations of $>C_{10}$-C_{21} hydrocarbons varied between non-detectable concentrations and 810 mg/kg (Table 5-4).

Table 5-4 Summary of Commonly Detected Sediment Variables (2010)

Variable	Units	ISQG	N of Cases	Minimum	Maximum	Arithmetic Mean
Aluminum	mg/kg		63	6,100	15,000	9,030
Barium	mg/kg		63	110	2,700	318
Chromium	mg/kg	52.3	63	2.7	6.3	4.3
Iron	mg/kg		63	1300	3600	2178
Lead	mg/kg	32	63	2	8.4	3.2
Manganese	mg/kg		63	36	130	70
Strontium	mg/kg		63	34	110	53
Uranium	mg/kg		63	0.16	0.32	0.23
Vanadium	mg/kg		63	4.8	11	6.8
Zinc.	mg/kg	124	63	5.3	12	7.5
$>C_{10}$-C_{21}	mg/kg		63	0.15	810	23
$>C_{21}$-C_{32}	mg/kg		63	0.15	8.80	0.73
Fines	%		63	1	4	1
Sand	%		63	89	99	97
Gravel	%		63	<1	9	1
TOC	g/kg		63	0.7	1.3	0.9
Moisture	%		63	6	20	18
Redox	mV		62	197	322	280
Ammonia	mg/kg		63	0.15	27	3.44
Sulphur	mg/kg		63	0.03	0.15	0.06
Water Depth	m		63	113	176	128

Note: - Values below laboratory detection limit were set to ½ laboratory detection limit for the purpose of computing averages in this Table and for other detailed statistics.

The PCA of the physical and chemistry data from 2010 is summarized in Table 5-5. There were two PCA axes that explained at least 10% of the total variation in sediment variables (Jackson 1993). PC1 explained 32% of the variation in sediment variables; PC2 explained 18%. The first PCA axis described a gradient of increasing to decreasing concentrations of metals. All of the metals (except manganese) and concentrations of $>C_{21}$-C_{32} hydrocarbons were relatively strongly and positively correlated with PCA axis 1 scores (i.e., had correlations exceeding |0.6|; Table 5-5).

The second axis described a gradient of increasing to decreasing concentrations of $>C_{10}$-C_{21} hydrocarbons and barium. Metals other than barium generally did not covary with this second axis, indicating that metals concentrations were predominantly independent of barium and $>C_{10}$-C_{21} hydrocarbons, and that sources of barium and $>C_{10}$-C_{21} hydrocarbons were not sources of other metals. Manganese and iron were associated with the second axis and the first axis, indicating a somewhat more complicated distribution of those metals.

Sulphur content, redox potential, sediment moisture content and sediment TOC content did not covary with either of the PCA axes, indicating a general low level of variation of these parameters and lack of influence or relationship with other variables. Water depth did not correlate strongly with the PCA axes, indicating a lack of covariation with the measured metals, $>C_{10}$-C_{21} hydrocarbons, barium and other variables. Sediment grain size (% Fines) was weakly associated with the first PCA axis (i.e., the metals axis), which was consistent with what is frequently observed in aquatic environments: metals concentrations tend to increase in sediments with finer-textured substrates because more metal can be stripped from the surface of a fine-grained inert particle than from a large inert particle (Filipek and Owen 1979).

Table 5-5 Principal Component Analysis of Sediment Physical and Chemical Characteristics (2010)

Variables	Principal Component	
	1	2
Aluminum	**0.80**	0.24
Barium	**0.60**	**-0.72**
Chromium	**0.68**	0.53
Iron	**0.67**	**0.65**
Lead	**0.67**	-0.46
Manganese	0.53	**0.68**
Strontium	**0.88**	-0.33
Uranium	**0.62**	0.10
Vanadium	**0.79**	0.47
Zinc	**0.63**	0.41
$>C_{10}$-C_{21}	0.43	**-0.69**
$>C_{21}$-C_{32}	**0.62**	-0.50
Fines	0.57	-0.37
Sand	-0.43	0.02
Gravel	0.36	0.02
TOC	0.50	-0.21
Moisture	-0.10	-0.25
Redox Potential	-0.16	-0.16
Sulphur	0.48	-0.50
Ammonia	0.09	0.26
Depth	0.51	0.17
Percent of Total Variance	32.3	18.1

Note: - Variables with correlations with a PCA axis in excess of |0.6| are bolded to indicate a relatively strong association with that axis.

Analysis of sediment chemistry data in previous years has demonstrated that metal concentrations tend to covary. Rather than analyze the spatial-temporal variations of individual metals, one option, since the metals tend to covary, is to produce a synthetic variable that reflects the increasing and decreasing concentrations of metals. A second PCA was carried out to produce a synthetic variable that summarized general variations in metals concentrations among stations and years. The PCA of metals concentrations (logarithms of concentrations) produced two strong axes, or synthetic variables (Table 5-6). Most metals (except barium) were strongly associated with the first PCA axis, and all with the same sign, indicating that those metals all increased and decreased in concentration in approximately the same way. Only barium concentrations correlated more strongly on the second PCA axis, suggesting that barium had a separate source (drilling) than the other metals. Scores on the first PCA axis were used as the synthetic variable (Metals PC1) summarizing variations in metals concentrations in subsequent analyses. Barium concentrations were analyzed separately.

Table 5-6 Principal Component Analysis of Metals Concentrations (all Years)

Variable	Principal Component	
	1	2
Aluminum	**0.80**	0.07
Barium	0.57	**-0.72**
Chromium	**0.80**	0.25
Iron	**0.90**	0.34
Lead	**0.64**	-0.68
Manganese	**0.84**	0.38
Strontium	**0.82**	-0.48
Uranium	**0.73**	0.13
Vanadium	**0.81**	0.30
Zinc	**0.71**	0.01
Percent of Variance Explained	58.9	16.5

5.2.1.1 >C_{10}-C_{21} Hydrocarbons

Concentrations of >C_{10}-C_{21} hydrocarbons in 2010 were significantly correlated with distance from the nearest drill centre (Spearman rank correlation (r_s) = -0.88, p < 0.01). A threshold model describing the relationship between concentrations of >C_{10}-C_{21} hydrocarbons and distance from the nearest active drill centre was significant (p < 0.001). In 2010, the threshold distance was estimated to be 3.6 km, which compares to a distance of 10.4 km observed in 2008, and distances of 5.9 to 8.9 km observed in previous years (Table 5-7). Although confidence intervals overlapped for most years, confidence intervals did not overlap between 2008 and 2010 (Table 5-7). Figure 5-6 provides a graphical representation of threshold models. The estimated hydrocarbon zone of influence in 2010 is the lowest it has been in all EEM years.

Table 5-7 Results of Threshold Regressions on Distance from the Nearest Active Drill Centre for >C_{10}-C_{21} Hydrocarbons

Year	Threshold Distance
2004	6.3 (4.1, 9.7)
2005	8.9 (4.9, 16)
2006	5.9 (4.2, 8.5)
2008	10.4 (5.2, 20.9)
2010	3.6 (2.9, 4.4)

Note: - 95% confidence limits are provided in brackets.

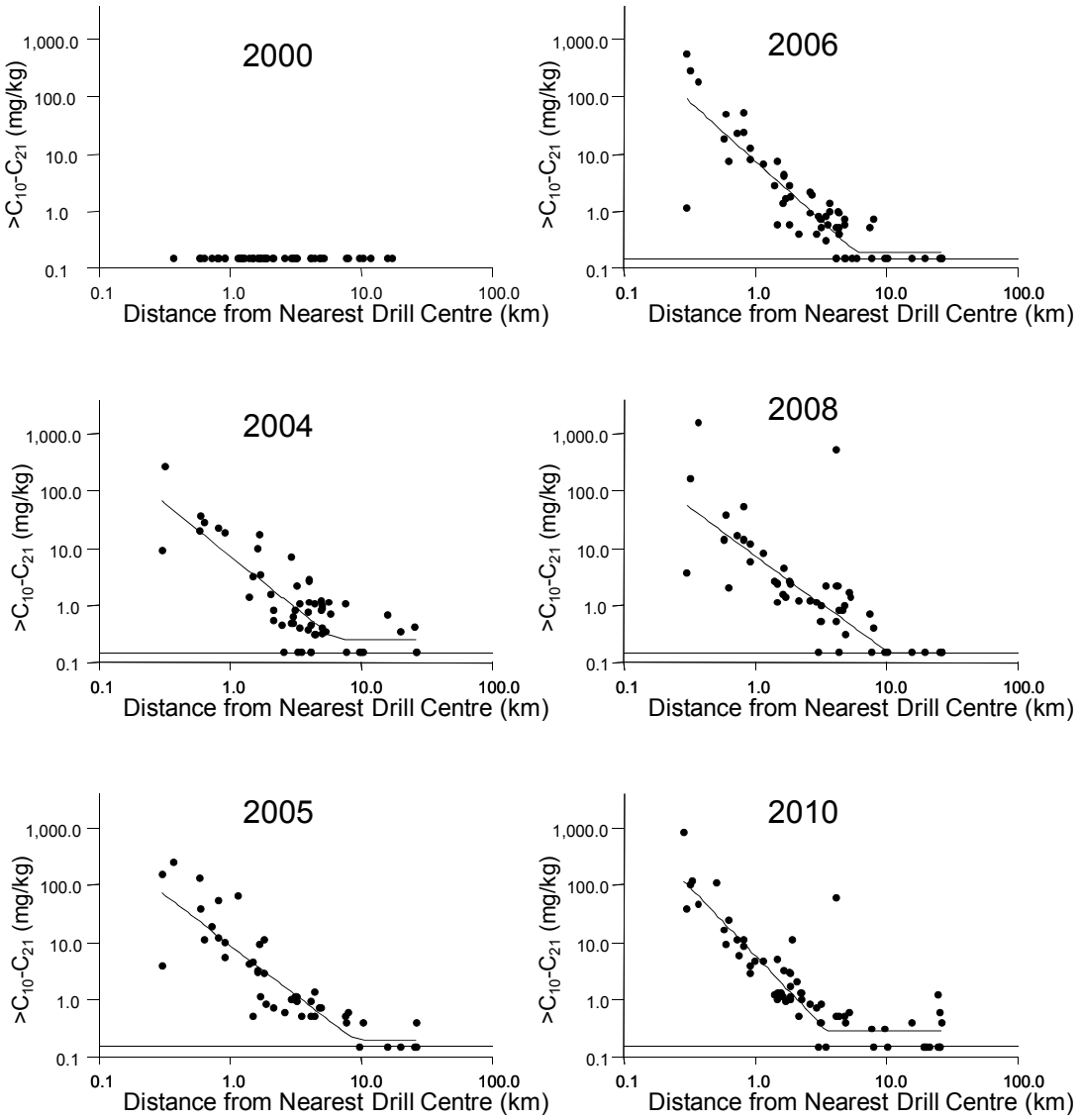

Figure 5-6 Variations in $>C_{10}$-C_{21} Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Note: the detection limit is indicated in each graph by a horizontal dotted line, to indicate the levels observed in the baseline year (2000). Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

As indicated in Figure 5-6, no hydrocarbons were detected in White Rose sediments during baseline sampling. As in previous EEM years $>C_{10}$-C_{21} hydrocarbon concentrations were enriched around all active drill centres in 2010, with potential overlap between enrichment from the Central and Southern Drill Centre (Figure 5-7). $>C_{10}$-C_{21} hydrocarbons were also enriched at station 31, located near the site of a delineation well drilled in 2007. $>C_{10}$-C_{21} hydrocarbon concentrations near drill centres were higher from 2006 to 2010 than they were in 2004 and 2005. Levels near drill centres were highest in 2008 (Figure 5-6).

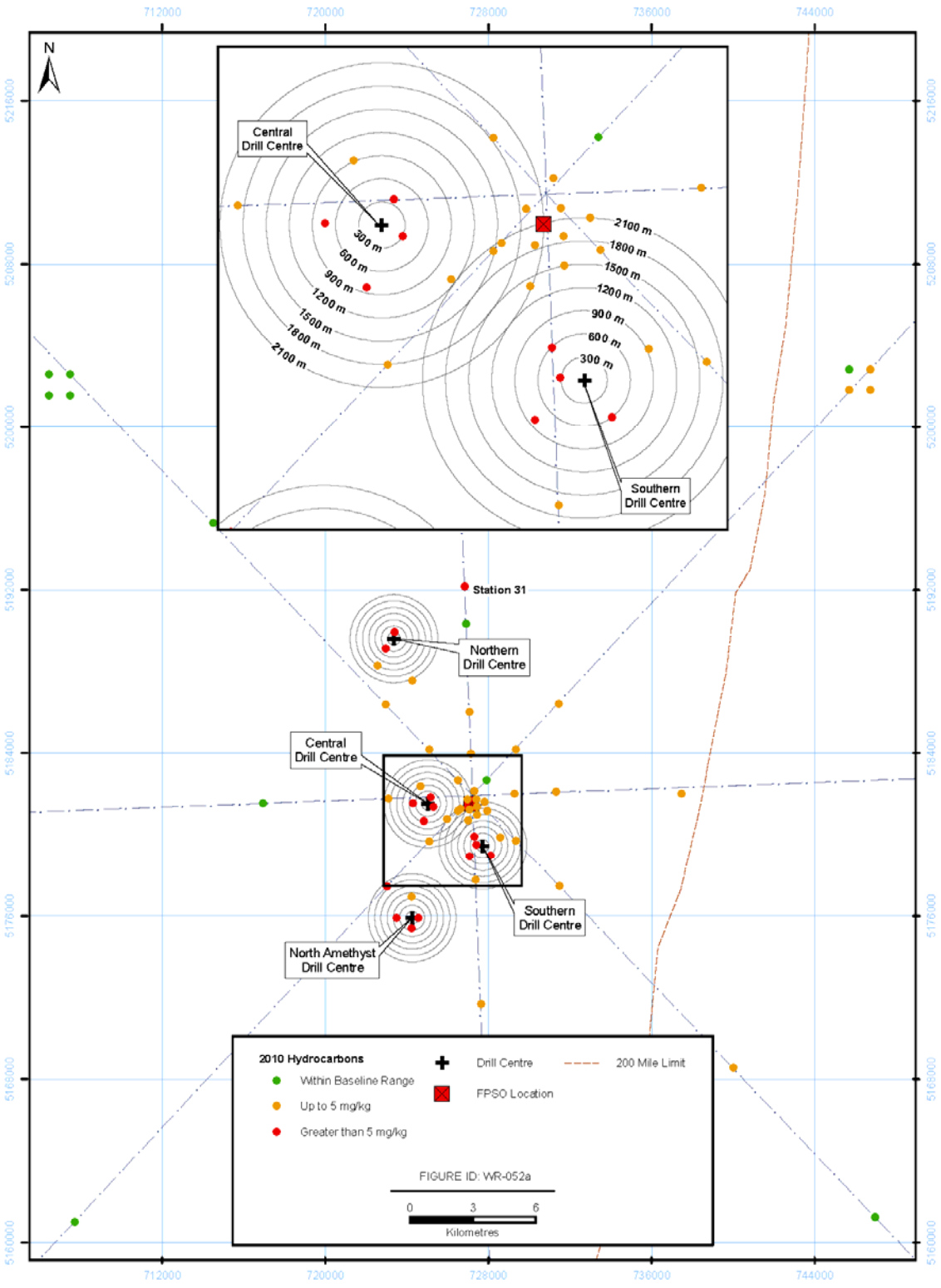

Figure 5-7 **Location of Stations with >C_{10}-C_{21} Hydrocarbon Values Within the Baseline Range (not detected), Showing Mild Enrichment up to 5 mg/kg and with Values Greater than 5 mg/kg (2010)**

Repeated-measures regression indicated no strong change over time in the relationship between distance and concentrations of $>C_{10}$-C_{21} hydrocarbons (p = 0.058). Repeated measured also indicated no changes in area-wide concentrations over time (p = 0.129; Table 5-8). The conclusion of no change in the distance trend over time applies to the time period from 2004 to present (2010) and should be made cautiously given the nearly-significant result. However, Concentrations of $>C_{10}$-C_{21} hydrocarbons were non-detectable in 2000, and have been generally at detectable concentrations since 2004 (Figure 5-6).

Table 5-8 Repeated-measures Regression Testing for Changes in $>C_{10}$-C_{21} Concentrations over Time

Trend Over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.058	0.129	NA	NA

Notes:
- Values are probabilities.
- NA = not applicable/not tested in this case because the concentrations have *de facto* increased since the baseline year 2000.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 and the mean in the period including 2004 to 2010.
- The Before to After contrast test was not applicable (NA) to hydrocarbons, because they were non-detectable in 2000.

5.2.1.2 Barium

Like $>C_{10}$-C_{21} hydrocarbons, barium produced a significant Spearman Correlation (r_s = -0.816, $p < 0.001$) with distance to drill centres, indicating a strong influence of proximity to a drill centre on concentrations in sediment. The threshold model was also significant ($p < 0.001$). The estimated threshold distance in 2010 was 2 km (Table 5-9), which was consistent with what had been observed in previous years (2004 to 2008).

Table 5-9 Results of Threshold Regressions on Distance from the Nearest Active Drill Centre for Barium (all Years)

Year	Threshold Distance
2004	2.4 (1.6 to 3.5)
2005	3.6 (2.1 to 6.2)
2006	1.9 (1.4 to 2.6)
2008	2.4 (1.5 to 3.8)
2010	2.0 (1.6 to 2.5)

Note: - 95% confidence limits are provided in brackets.

Figure 5-8 provides a graphical representation of threshold models. As was the case for hydrocarbons (Section 5.5.1.1), barium concentrations near drill centres were higher from 2006 to 2010 than they were in 2004 and 2005 (Figure 5-6).

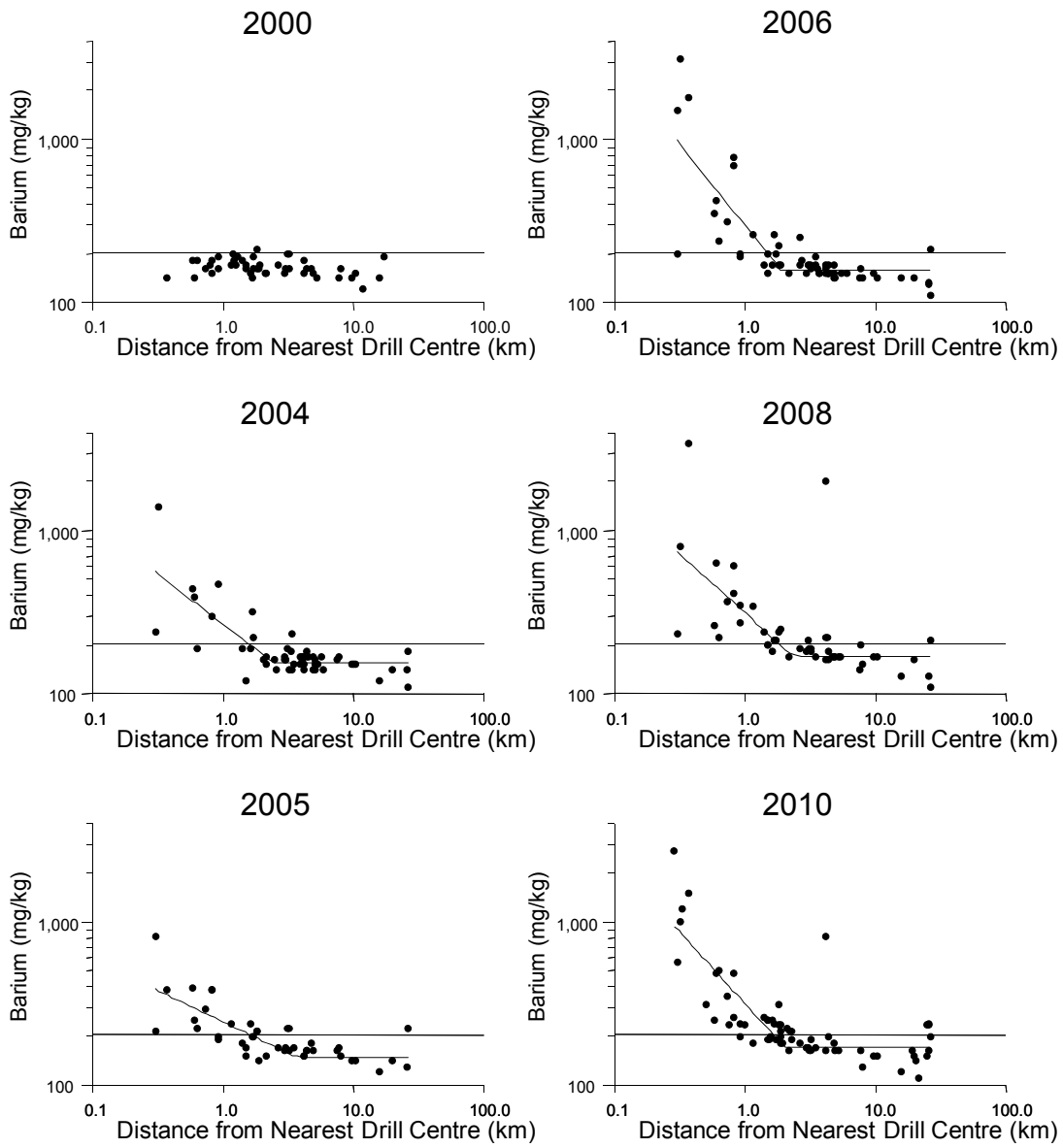

Figure 5-8 Variations in Barium Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Notes: a concentration of 202 mg/kg is indicated in each graph by a horizontal line, based on the mean values + 2 SDs from 2000 (baseline). Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

As indicated in Figure 5-8, the "normal range" of variation for barium concentration in sediments across the sampling area, was computed from the 2000 baseline data. Values in 2000 ranged between 120 and 210 mg/kg. The value 202 mg/kg was used as "benchmarks" against which to judge spatial variation in the sampling area in Figure 5-9.

Barium was enriched to levels exceeding 300 mg/kg around the Central, Southern, North Amethyst and Northern Drill Centres. Barium was also enriched at station 31, located near the site of a delineation well drilled in 2007. At lower levels of enrichments (between the baseline range and 300 mg/kg), there was overlap between effects from the Central and Southern Drill Centres (Figure 5-9).

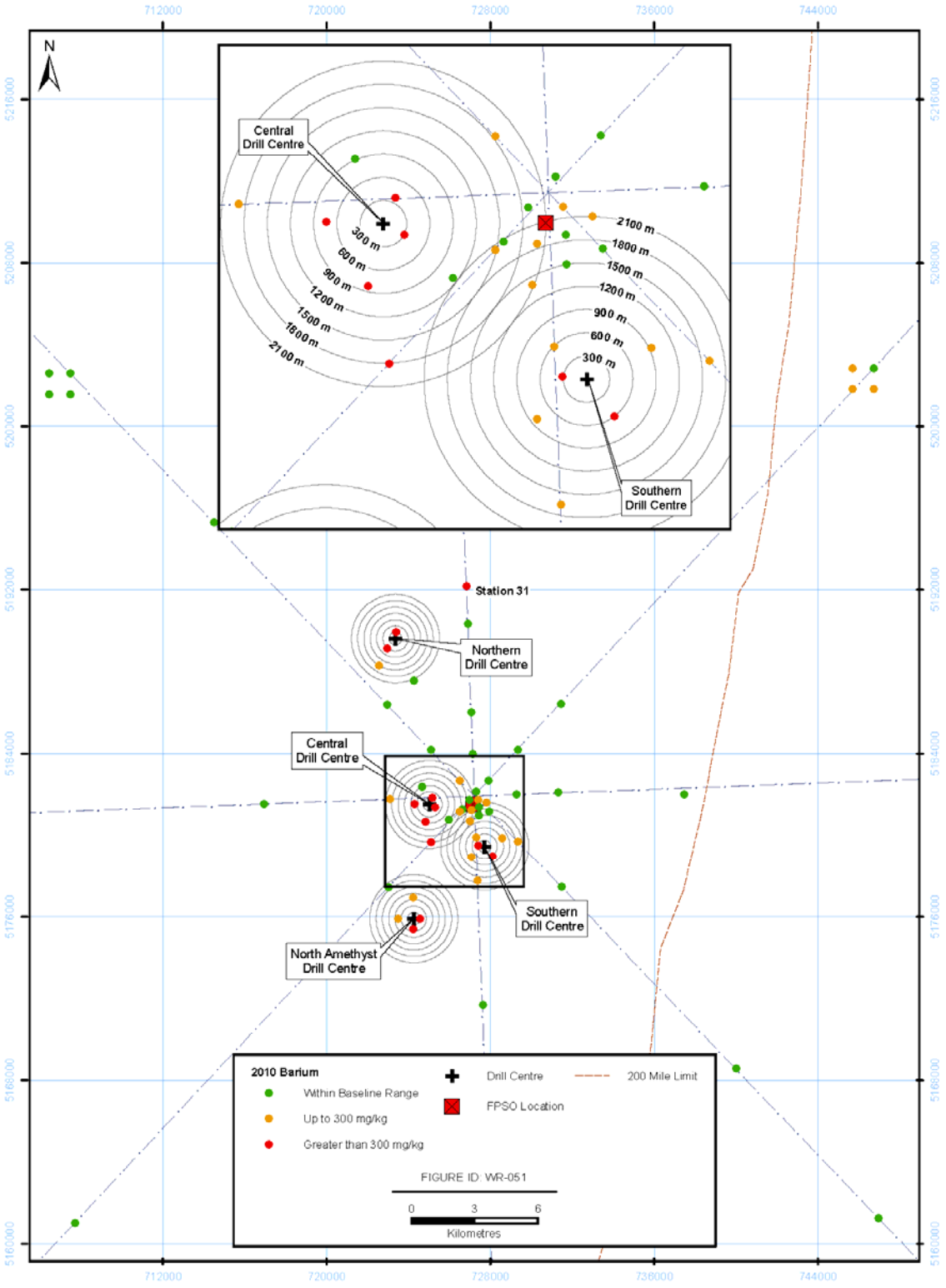

Figure 5-9 Location of Stations with Barium Levels Within the Baseline Range, Showing Mild Enrichment up to 300 mg/kg and with Values Greater than 300 mg/kg (2010)

Repeated-measures regression indicated that there was no change over time in the relationship between distance and concentrations of barium from 2004 to 2010 (p = 0.992; Table 5-10). However, slopes did differ from before to after drilling operations began (p = 0.004). Concentrations of barium in year 2000 averaged 168 mg/kg, with the normal range of concentrations (i.e., the mean concentration + 2 SDs) including 202 mg/kg. Concentrations have been generally below 202 mg/kg beyond the "threshold" distance in all years (Figure 5-8). Concentrations have been significantly higher since drilling operations began (p < 0.001; Table 5-10).

Table 5-10 Repeated-measures Regression Testing for Changes in Barium Concentrations over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.992	0.139	0.004	<0.001

Notes:
- Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000, and the mean in the period including 2004 to 2010.

5.2.1.3 Fines

Percent of the sediment as fines (silt and clay) generally varied between 1% and 2% across the sampling area and was not correlated with distance from the nearest active drill centre in 2010 (r_s = -0.063, p > 0.5). Figure 5-10 provides a graphical representation of % fines with distance from drill centres. The Figure indicates potential enrichment of fines at one station, located closest to the North Amethyst Drill Centre (highest value for 2010 in Figure 5-10).

Repeated-measures regression indicated that there was no trend over time in the slope of the relationship between fines and distance from the nearest active drill centre, and no difference in slope from before to after drilling operations began (p = 0.475; Table 5-11). However, there was a significant difference in percent fines across the sampling area from before to after drilling operations (p < 0.001).

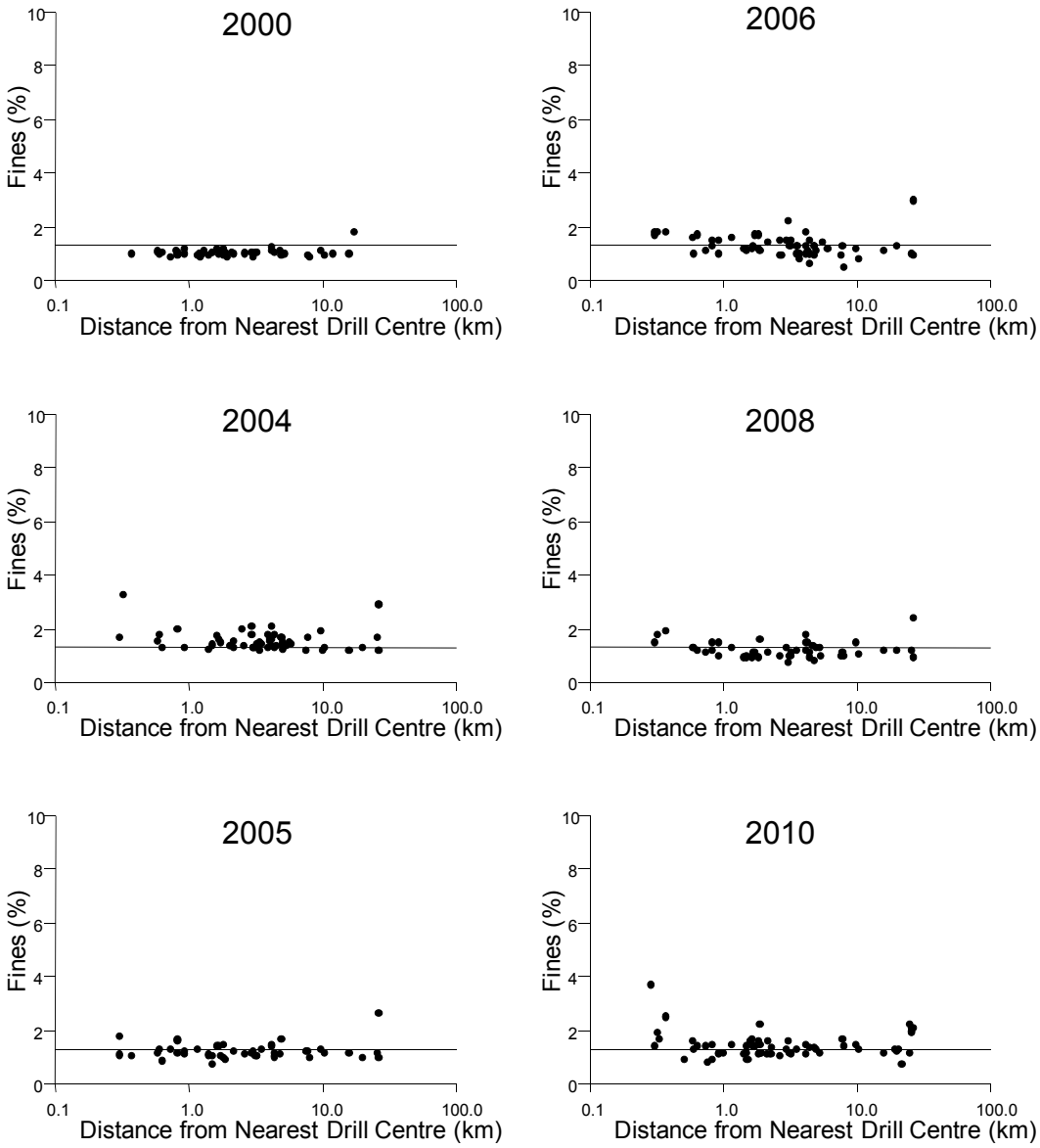

Figure 5-10 Variations in Percent Fines with Distance from the Nearest Active Drill Centre (all Years)

Notes: a concentration of 1.3% is indicated in each graph by a horizontal line, based on the mean values + 2 SDs in 2000 (baseline). Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

Table 5-11 Repeated-measures Regression Testing for Changes in Percent Fines over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.389	0.120	0.475	<0.001

Notes: - Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000, and the mean in the period including 2004 to 2010.

The scatterplot of percent fines illustrated that percent fines have generally not varied with distance from a drill centre, but did generally increase across the sampling area (Figure 5-10). The upper limit of the normal range of percent fines was approximately 1.3%, based on the mean observed in 2000 + 2 SD. Approximately half of the sediment samples in 2010 had more fines than the upper limit of baseline range for the sampling area (Figure 5-11). It is not clear if the increase in percent fines is a real effect or an artifact. The report for the 2008 EEM program (Husky Energy 2009) suggested that increases in fines may in part be artifacts of the measurement method. The overall increase in fines was generally minor, considering the increase was from approximately 1% to 2% overall. Given that percent fines has increased across the entire sampling area and was unrelated to distance from active drill centres, there is no evidence that the overall change in percent fines is related to drilling operations. However, localized effects on fines in 2010 may have occurred at one station, NA1-C, located 0.3 km from the North Amethyst Drill Centre (highest level in Figure 5-10).

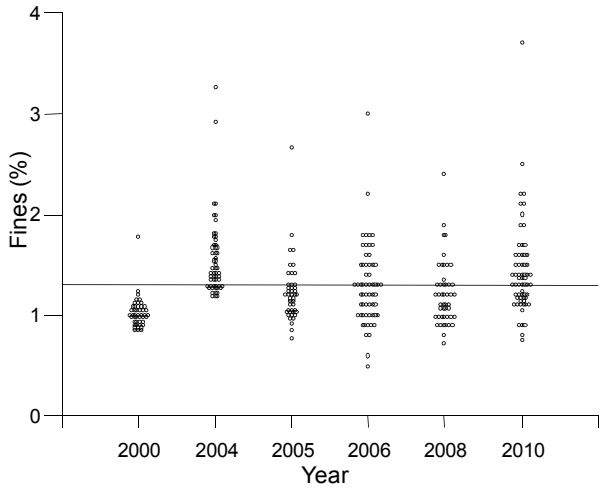

Figure 5-11 Dot Density Plot of Percent Fines by Year

Notes: a concentration of 1.3% is indicated in each graph by a horizontal line, as based on the mean values + 2 SDs using data from 2000.

5.2.1.4 Total Organic Carbon

TOC content (g/kg) varied between approximately 0.75 and 1.25 g/kg in 2010 across the sampling area and was not correlated with distance from the nearest active drill centre in 2010 (r_s = -0.131, p > 0.2). Figure 5-12 provides a graphical representation of TOC concentration with distance from drill centres.

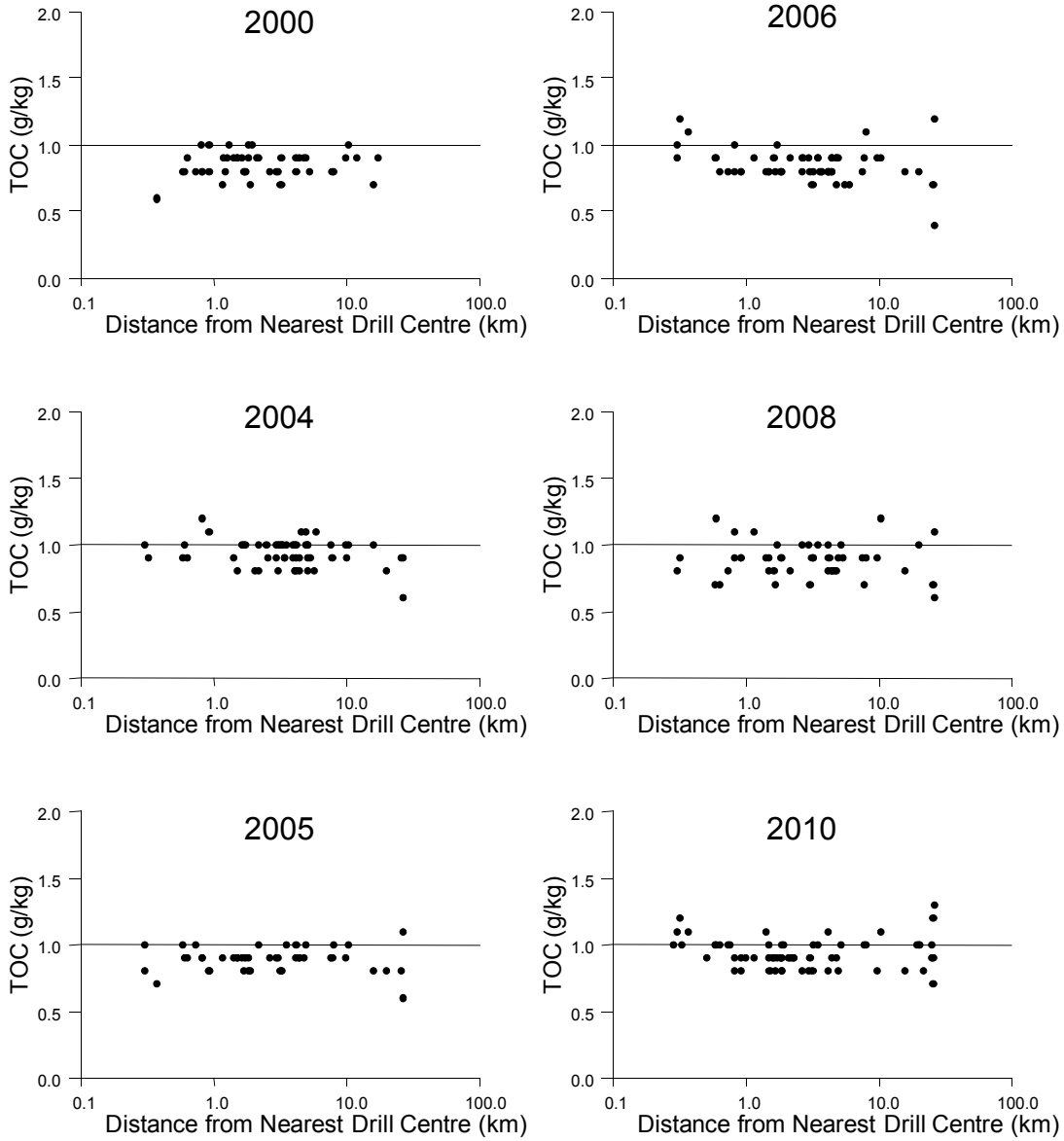

Figure 5-12 Variations in Total Organic Carbon with Distance from the Nearest Active Drill Centre (all Years)

Notes: a concentration of 1 g/kg is indicated in each graph by a horizontal line, based on the mean values + 2 SDs in 2000 (baseline). Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

Repeated-measures regression indicated that the relationship between TOC and distance from the nearest active drill centres did not vary linearly over time during the period of active drilling (p = 0.982), and there was also no overall relationship between

TOC and distance to the nearest active drill centre (p = 0.975; Table 5-12). There were also no trends over time in the mean TOC (p = 0.851), and no strong difference from before to after drilling operations (p = 0.055). Therefore, there was no strong indication of any effect of drilling operations on TOC in sediments. Figure 5-13 provides dot density plots across years.

Table 5-12 Repeated-measures Regression Testing for Changes in Percent Total Organic Carbon over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.982	0.851	0.975	0.055

Notes: - Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

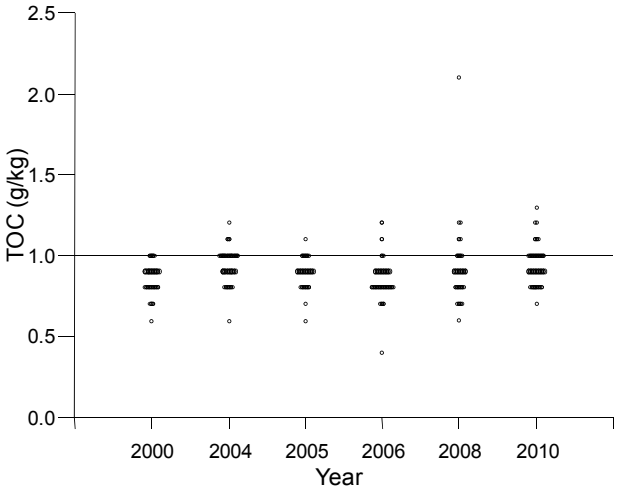

Figure 5-13 Dot Density Plot of Total Organic Carbon by Year

Notes: a concentration of 1 g/kg is indicated in each graph by a horizontal line, based on the mean values + 2 SDs in 2000 (baseline).

5.2.1.5 Ammonia

Ammonia concentrations were generally less than 5 mg/kg in EEM years. One station had a concentration of 27 mg/kg in 2010. A few high levels were also noted in previous years (Figure 5-14). Ammonia concentrations were not correlated with distance from the nearest active drill centre in 2010 (r_s = -0.036, p > 0.5).

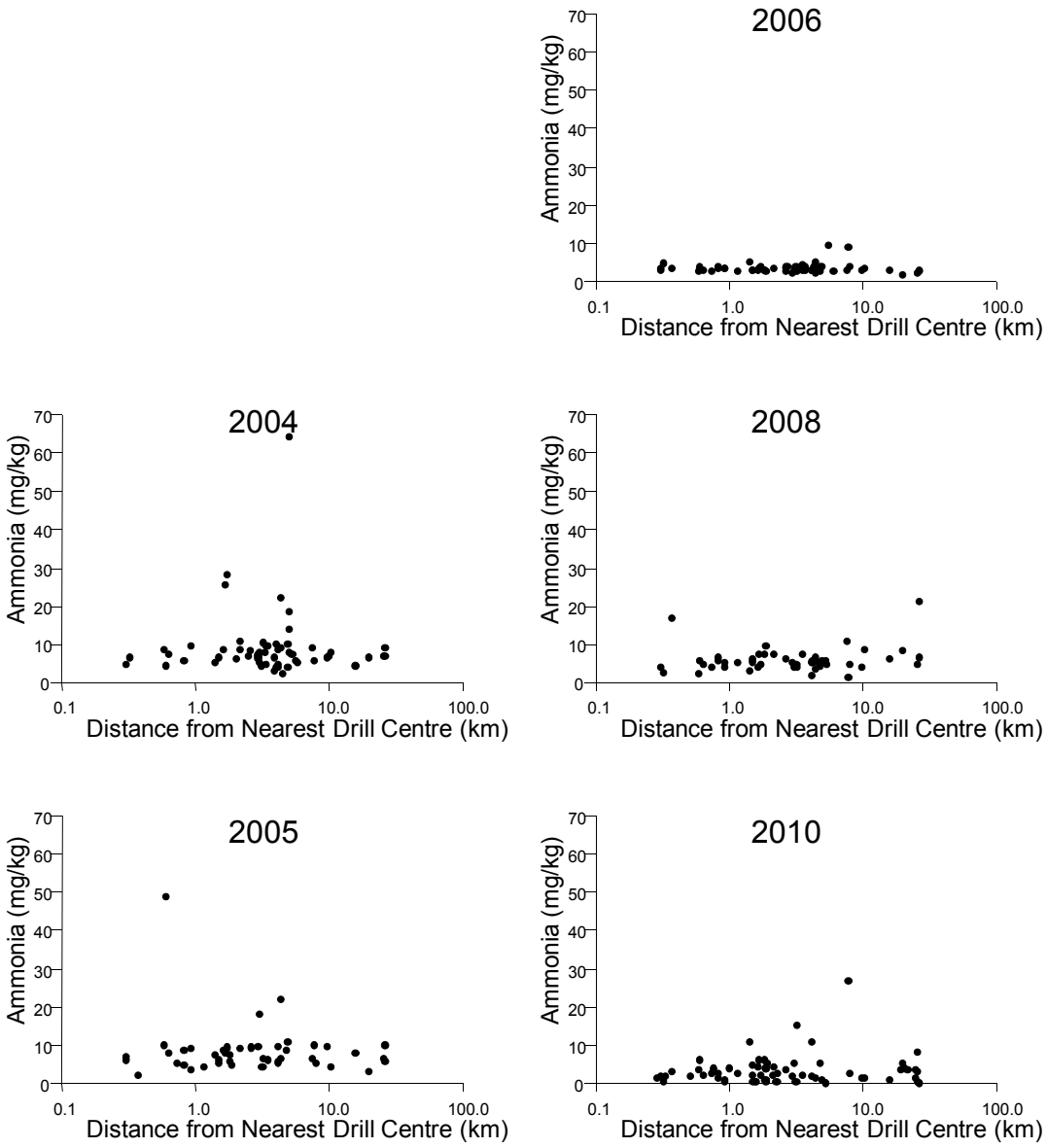

Figure 5-14 Variations in Ammonia Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Note: Ammonia was not measured in 2000

Repeated-measures regression indicated that there was no change in the relationship between ammonia and distance over the period of active drilling (i.e., 2004 to 2010; p = 0.75, Table 5-13), but there was a significant linear trend over time in average concentrations across the sampling area (decreasing concentrations over time, p < 0.001).

Table 5-13 Repeated-measures Regression Testing for Changes in Ammonia Concentrations over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.750	<0.001	NA	NA

Notes:- Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

The scatterplot of ammonia concentrations (Figure 5-14) illustrated that concentrations have not varied with distance from a drill centre. The dot density plot of ammonia concentrations illustrates that mean concentrations of ammonia in sediments has decreased over the course of the five years that ammonia has been measured (Figure 5-15). This was the first year that ammonia has been observed at concentrations less 1 mg/kg. Concentrations prior to 2010 had always varied between 1 and 10 mg/kg. Given the lack of relationship between ammonia concentration and distance from active drill centre, and the general decrease in ammonia levels over time, there is no indication of any effects of drilling operations on ammonia concentrations.

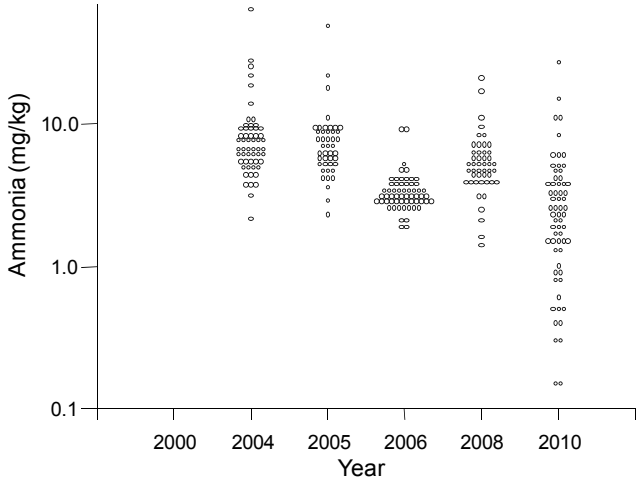

Figure 5-15 Dot Density Plot of Ammonia Concentrations by Year

5.2.1.6 Sulphur

Percent sulphur varied between 0.1% near the drill centres to values closer to 0.05% at distances further away 2010 (Figure 5-16). Distance to the nearest active drill centre was significantly correlated with percent sulphur in 2010, with a r_s of -0.345 (significant at $p <$ 0.01). However, when the four nearest stations (0.3 km) to drill centres (see Figure 5-16) were removed from the data set, the correlation between sulfur and distance to drill centres was not significant, indicated that mild sulfur contamination could have been limited to 0.3 km stations. There was no significant threshold model using the 2010 data.

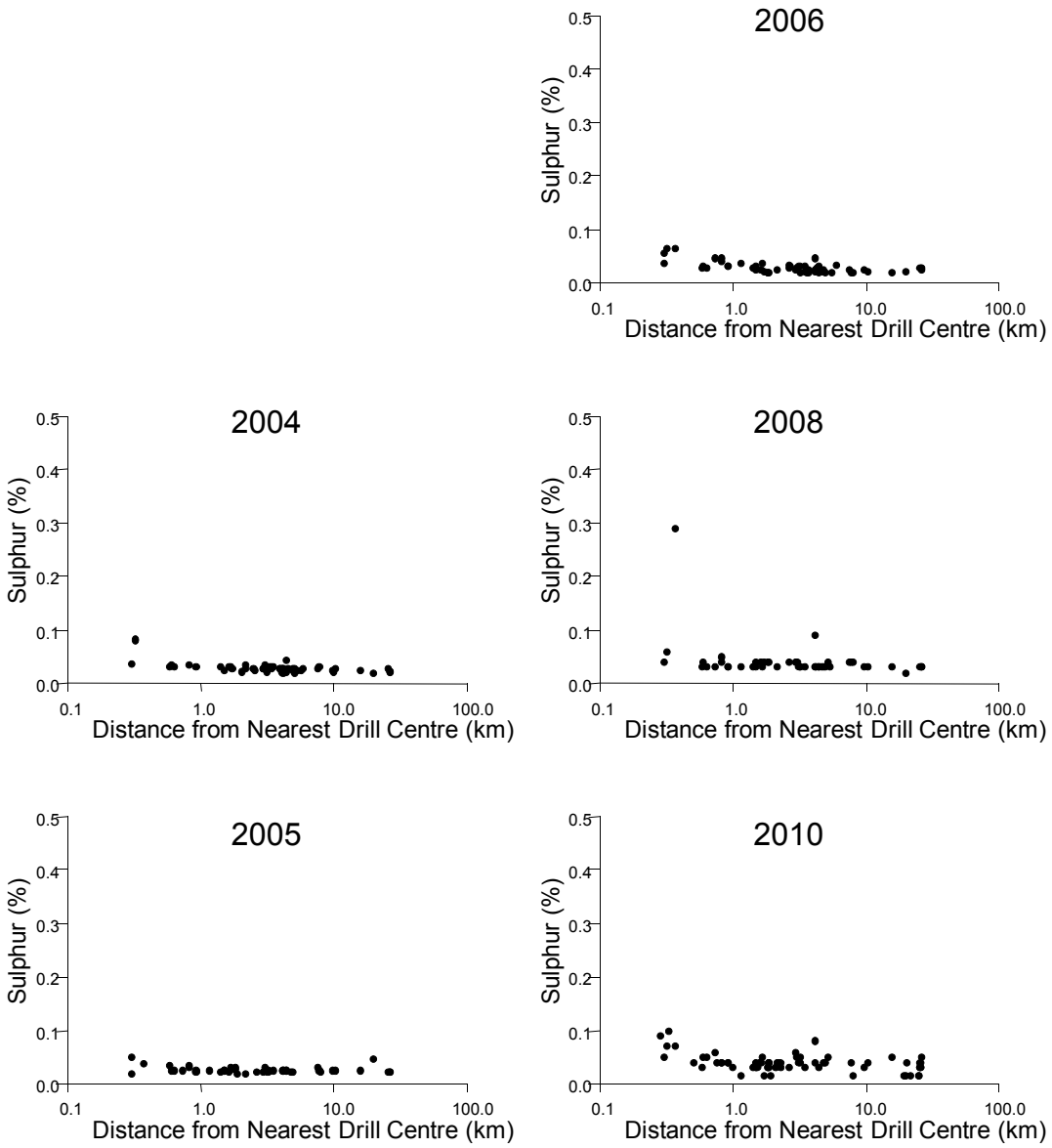

Figure 5-16 Variations in Sulphur Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Note: Sulphur was not measured in 2000.

Repeated-measures regression indicated that there was no change in the relationship between sulphur and distance over the period of active drilling (p = 0.317), but there was a significant linear time trend in average sulphur concentrations in the overall sampling area (p < 0.001; Table 5-14).

Table 5-14 Repeated-measures Regression Testing for Changes in Sulphur Concentrations over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.317	0.002	NA	NA

Notes:- Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

The scatterplot of percent sulphur (Figure 5-16) illustrated that concentrations generally have not varied greatly with distance from the nearest active drill centre across years. The dot density graph of percent sulphur illustrated that mean values in sediments have been higher in 2008 and 2010 compared to prior sample years (Figure 5-17). However, comparisons among years could be confounded by the fact that the precision of values reported in 2008 and 2010 was less than that reported in previous years (note the relatively discrete distribution of values in 2008 and 2010 in Figure 5-17 compared to previous years).

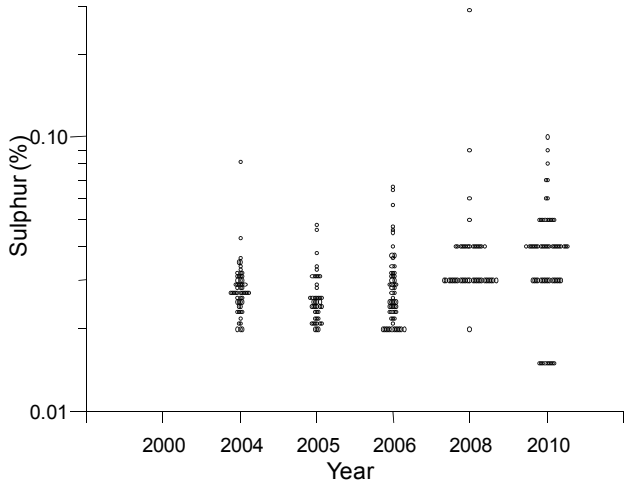

Figure 5-17 Dot Density Plot of Sulphur Concentrations by Year

5.2.1.7 Metals PC1

Metals PC1 scores (and therefore, metals concentrations) were not correlated with distance from the nearest active drill centre in 2010 (r_s = -0.015, p > 0.5). Figure 5-18 provides a graphical representation of metals concentration with distance from drill centres.

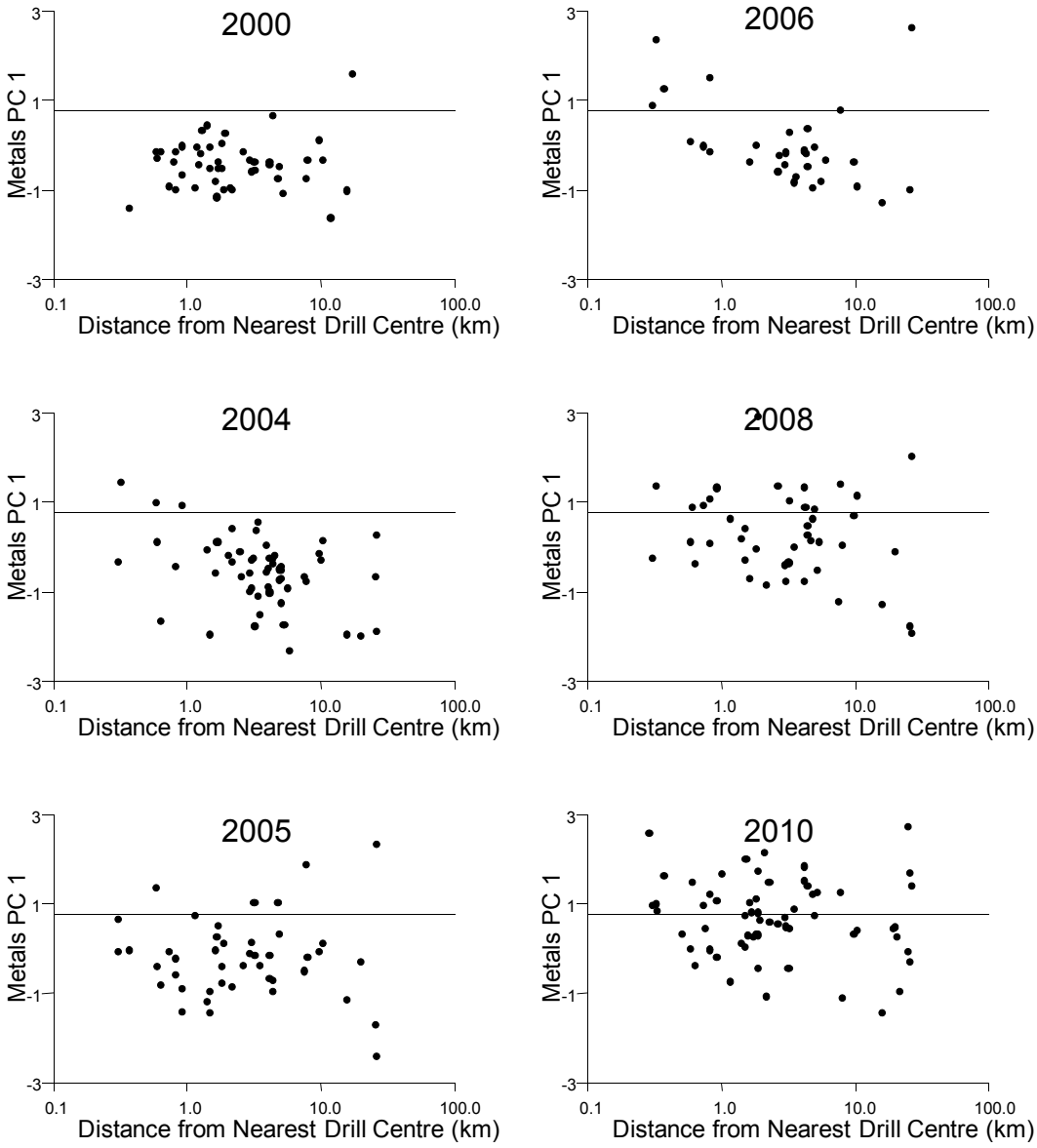

Figure 5-18 Variations in Metals PC1 Scores with Distance from the Nearest Active Drill Centre (all Years)

Notes: background PC1 scores are indicated by a horizontal line, based on the mean values + 2 SDs using data from 2000. Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

Repeated-measures regression indicated that there was no change in the relationship between Metals PC1 scores and distance to the nearest active drill centre over the period of the active drilling period (p = 0.481), but there was a significant linear time trend in average PC1 axis scores in the overall sampling area (p = 0.019: Table 5-15).

Table 5-15 Repeated-measures Regression Testing for Changes in Metals PC1 Scores over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.481	0.019	0.931	0.082

Notes: - Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

The scatterplot of metals PC1 scores (Figure 5-18) illustrated that metals concentrations have not varied with distance from the nearest active drill centre across years but have generally increased over the entire sampling area. The upper limit of "normal" PC1 scores was determined using PC axis 1 scores from year 2000 data prior to any active drilling. The upper baseline range was 0.77 based on the mean + 2 SD. The dot density graph of scores (Figure 5-19) showed the same time trend: metals PC1 scores (and therefore, metals concentrations in sediments) generally increased across the sampling area across years. As previously discussed above, no metals exceeded sediment quality guidelines in 2010 (Table 5-4). Therefore, there is no undue risk to biota from exposure to metals in sediments. Given that concentrations were unrelated to distance from active drill centres, the source of metals is likely not drilling related.

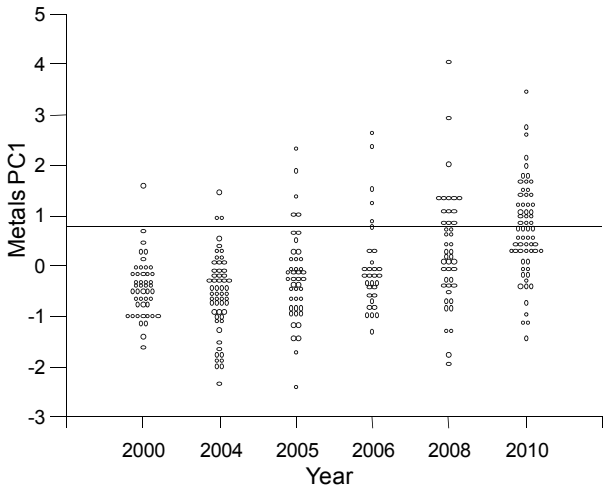

Figure 5-19 Dot Density Plot of Metals PC1 Scores by Year

Note: background PC1 scores are indicated by a horizontal line, based on the mean values + 2 SDs using data from 2000.

5.2.1.8 Redox Potential

Redox potential varied between about 200 and 300 mV in 2010 but did not significantly correlate with distance from the nearest active drill centre in 2010 (r_s = 0.112, p > 0.2). Figure 5-20 provides a graphical representation of the relationship between redox potential and distance to drill centres.

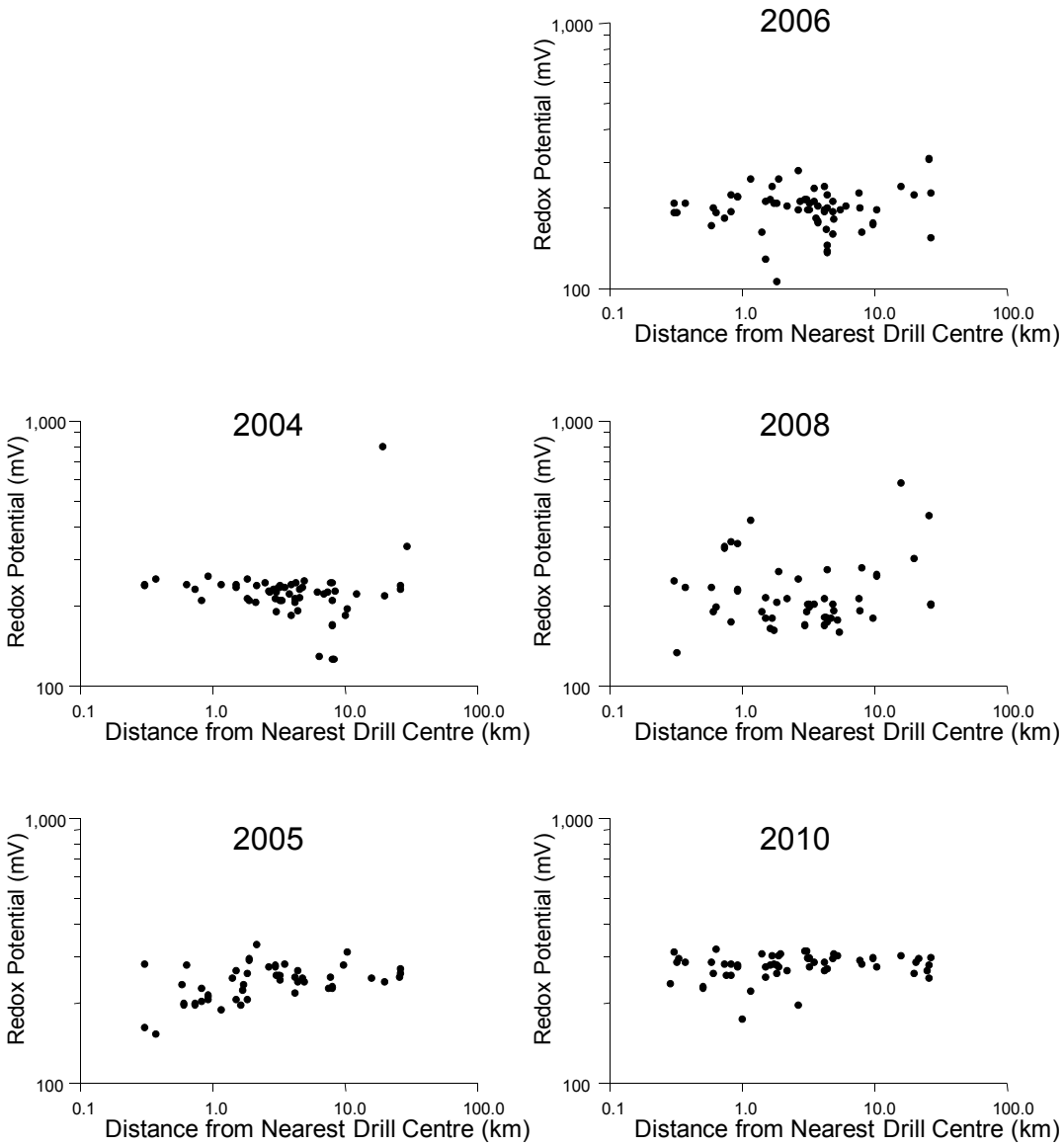

Figure 5-20 Variations in Redox Potential with Distance from the Nearest Active Drill Centre (all Years)

Note: Redox data are unavailable for 2000.

Repeated-measures regression indicated that there was no linear change in the relationship between redox potential and distance to the nearest active drill centre over the period of active drilling (p = 0.758), but there was a significant linear time trend in average redox potential in the overall sampling area (p = 0.009, Table 5-16).

Table 5-16 Repeated-measures Regression Testing for Changes in Redox Potential over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.758	0.009	NA	NA

Notes: - Values are probabilities.
- Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

The scatterplot of redox potential (Figure 5-20) illustrated that redox potential did not vary strongly with distance from active drill centres across years. The dot density graph of redox potentials (Figure 5-21) illustrated that values were generally higher in 2010 than in previous years. There were no redox potential data collected in 2000, so there was no opportunity to compute a normal range of redox potentials for this specific sampling area. The absence of a correlation between redox potential and distance from an active drill centre implies that the variation was not drilling related. Beyond this, the observed redox data indicate that the sediments are oxic. An increase in redox potential over time should not be a stress on benthic communities (Rosenberg et al. 2001).

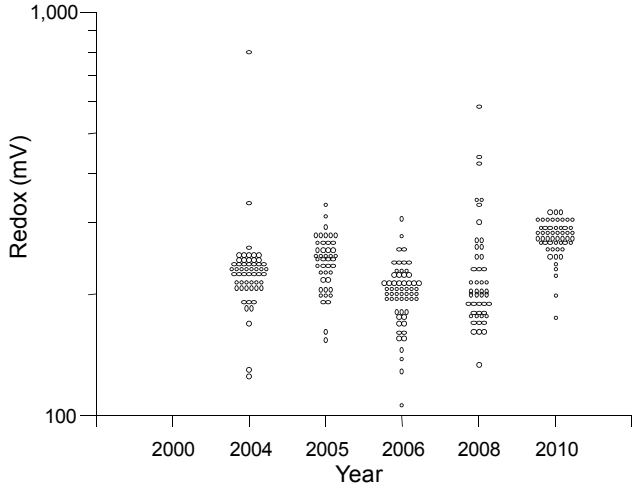

Figure 5-21 Dot Density Plot of Redox Potential by Year

5.2.1.9 Effects of Distance from the *SeaRose* FPSO

In 2010, distance relationships from the *SeaRose* FPSO were examined to determine if releases from this facility influenced the physical and chemical characteristics of sediment. The full analysis results are provided in Appendix B-5.

Concentrations of $>C_{10}$-C_{21} hydrocarbons and barium were the only variables that correlated with distance from the *SeaRose* FPSO. Concentrations of $>C_{10}$-C_{21} hydrocarbons and barium were higher near the *SeaRose* FPSO and decreased with increasing distance (see Table 3-3, Appendix B-5). However, after controlling for the influence of the nearest active drill centre, there was no association between these two variables and distance from the *SeaRose* FPSO.

5.2.2 Toxicity

In previous years, all samples tested for Microtox toxicity were non-toxic. In 2010, 52 of 53 Microtox IC_{50}s were greater than the highest concentration tested (i.e., were non-toxic). The single toxic sample in 2010 was collected from station C5-C, with an IC_{50} of 70,490 mg/L. Full results for 2010 in Appendix B-6.

In all EEM years including 2010, amphipod survival in toxicity tests in most White Rose sediment samples has been greater than 80% and often greater than 90%, therefore declared non-toxic (Figure 5-22 and Appendix B-7). Rank correlations (r_s) between amphipod survival in 2010 and distance to the nearest active drill centre and sediment physical and chemical characteristics are provided in Table 5-17. Distance from the nearest active drill centre, $>C_{10}$-C_{21} hydrocarbons and barium concentrations were each significantly correlated with amphipod survival. As in 2008, distance from the nearest drill centre was positively correlated with amphipod survival, indicating higher survival at greater distances from drill centres. Percent survival was lower in 2008, compared to 2010 and 8 of 47 samples were classified as toxic in 2008. In 2010, all samples produced a minimum of 77% survival. Samples with 70% survival or greater have also never been classified as toxic based on comparison to Reference sediments. Therefore, all of the amphipod toxicity tests in 2010 were classified as non-toxic.

Table 5-17 Spearman Rank Correlations (r_s) Between Amphipod Survival versus Distance from the Nearest Active Drill Centre and Sediment Physical and Chemical Characteristics (2010)

Variable	Correlation (r_s) with Amphipod Survival
Distance from nearest active drill centre	0.35*
$>C_{10}$–C_{21} hydrocarbons	-0.37**
Barium	**-0.48*** **
% fines	-0.01
% gravel	-0.15
TOC	-0.29
Metals PC1	-0.06
Ammonia	-0.02
Sulphide	-0.19
Sulphur	-0.08

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).
- n = 48 stations for physical and chemical variables; n = 47 stations for distance (station 31 excluded).

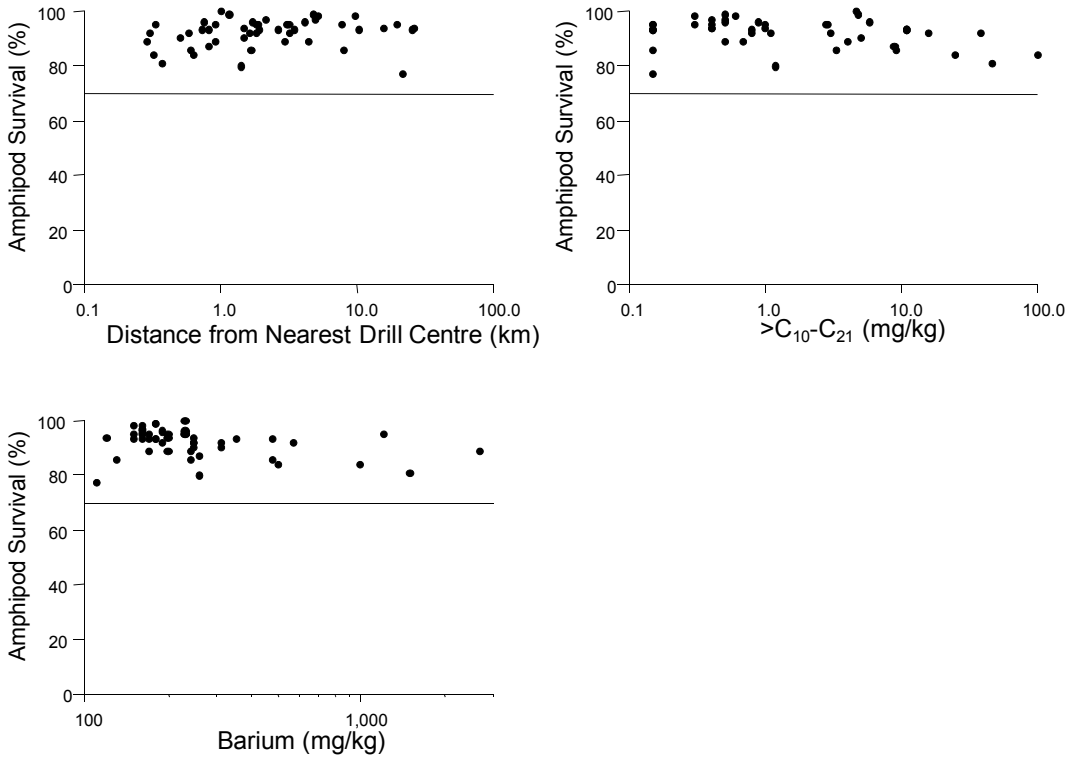

Figure 5-22 Percent Amphipod Survival versus Distance from the Nearest Drill Centre, Barium Concentrations and >C_{10}-C_{21} Hydrocarbon Concentrations (2010)

Note: the horizontal line denotes 70% survival. Values above 70% are considered to indicate a normal, non-toxic response.

5.2.3 Benthic Community Structure

5.2.3.1 General Composition

A total of almost 24,000 invertebrates were collected from 49 stations in 2010. The totals exclude nemerteans, nematodes, oligochaetes, ostracods and copepods. These were excluded because they are inefficiently retained on the 0.5 mm mesh used to collect invertebrates. Over all sample years (2000 to 2010), 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[12]. Raw data for benthic community structure in 2010 are provided in Appendix B-4.

[12] Six stations around the North Amethyst Drill Centre were sampled in 2007 to provide baseline data for that drill centre. No other stations were sampled in that year.

In all sample years, polychaetes have accounted for 70% to 80% of the invertebrates collected and bivalves accounted for approximately 15% of total abundance (Table 5-18). 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 families of Gastropoda and 16 families of Amphipoda were collected.

Table 5-18 Percent Abundances of Major Taxonomic Groups Across all Stations (all years)

Major Group	Class or Order	No. Families	2000	2004	2005	2006	2008	2010
Porifera		1		<1	<1		<1	<1
Cnidaria		6	<1	<1	<1	<1	<1	1
Sipuncula		1			<1			
Platyhelminthes	Turbellaria	1				<1		
Annelida	Polychaeta	33	77	74	72	78	81	72
Mollusca	Total	44	17	17	19	14	13	14
	Aplacophora	1						
	Bivalvia	22	17	17	18	14	12	14
	Gastropoda	21	<1	<1	<1	<1	<1	1
Crustacea	Total	28	4	6	7	6	5	5
	Amphipoda	16	3	3	3	2	2	3
	Cirrepedia	1	<1	<1	<1	<1	<1	<1
	Cumacea	5	<1	<1	<1	<1	<1	<1
	Decapoda	1	<1			<1	<1	<1
	Isopoda	4	<1	<1	<1	<1	<1	<1
	Tanaidacea	1	1	3	3	3	2	2
Echinodermata		8	2	2	2	2	<1	2
Hemichordata		1					<1	<1
Urochordata	Ascidiacea	3			<1	<1		
Total Numbers		128	3,750	2,270	1,790	2,415	30,764	23,571

Table 5-19 lists all families that represented 1% or more of the total number of organisms collected in all sample years. The families are listed in descending order of abundance in 2010. 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, as they were in all previous years. 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 5-19 were similar among years. However, abundances of some Families varied among years. Haustoridae amphipods were absent in 2008 and 2010. Carditidae bivalves were absent in 2004, 2008 and 2010. The polychaete Sigalionidae was only present in baseline (2000) and in 2008.

Table 5-19 Percent Abundance of Dominant Benthic Invertebrate Families (all years)

Major Taxon	Family	2000	2004	2005	2006	2008	2010
Polychaeta	Spionidae	37	37	36	36	48	37
Bivalvia	Tellinidae	13	20	15	21	11	12
Polychaeta	Paraonidae	15	15	16	12	10	11
Polychaeta	Phyllodocidae	3	3	3	6	6	5
Polychaeta	Orbiinidae	4	6	5	6	5	4
Tanaidacea		1	2	3	3	2	3
Polychaeta	Sabellidae	<1	2	2	2	2	2
Polychaeta	Maldanidae	1	1	2	2	2	2
Polychaeta	Capitellidae	1	1	1	1	1	2
Polychaeta	Syllidae	1	1		1	1	1
Amphipoda	Dexaminidae	<1	1	1	1	1	1
Polychaeta	Cirratulidae	13	1	2	1	1	1
Echinodermata	Echinarachnidae	1	<1	1	1	1	1
Amphipoda	Haustoriidae	2	1	<1	<1		
Bivalvia	Carditidae	1		<1	<1		
Polychaeta	Sigalionidae	<1				1	

5.2.3.2 Correlations with Sediment Physical and Chemical Characteristics

In 2010, none of the indices of benthic community composition were related to percent of substrate as gravel (% gravel), TOC or metals PC1 (Table 5-20). However, there were a variety of significant correlations between indices of benthic community composition and other environmental descriptors. Numbers of Tellinidae bivalves were more abundant in deeper water (r_s = 0.59), while numbers of Spionidae polychaetes were negatively associated with percent of substrate as fines (silt and clay; r_s = -0.31) and sulphur (r_s = 0.28), and positively associated with ammonia (r_s = 0.47). Taxa richness (i.e., number of benthic Families) was moderately positively correlated with sediment redox potential (r_s = 0.31) and ammonia (r_s = 0.37). The abundance of amphipods*, in-situ*, was uncorrelated with physical and chemical sediment variables.

Table 5-20 Spearman Rank (r_s) Correlations of Indices of Benthic Community Composition with Environmental Descriptors (2010)

Environmental Descriptor	Index of Community Composition						
	Abundance	Biomass	Richness	Paraonidae	Spionidae	Tellinidae	Amphipoda
% Fines	-0.30*	-0.36**	-0.21	-0.26	-0.31*	-0.02	-0.06
% Gravel	0.09	-0.19	0.13	-0.04	-0.06	0.06	-0.16
TOC	0.05	-0.17	-0.17	-0.18	0.20	-0.05	-0.13
$>C_{10}$-C_{21}	-0.27*	-0.38**	-0.18	**-0.59*** **	0.10	-0.25	-0.10
Barium	-0.25	-0.46**	-0.10	**-0.64*** **	0.06	-0.19	-0.11
Metals PC1	0.01	-0.19	-0.03	-0.11	-0.09	0.04	-0.18
Ammonia	0.49**	0.06	0.37*	0.30*	0.47**	0.09	-0.02
Sulphur	-0.29*	-0.32*	-0.05	-0.43**	-0.28*	0.10	0.16
Redox Potential	0.06	0.07	0.30*	-0.07	-0.18	0.22	0.01
Distance to nearest drill centre	0.21	0.33*	0.06	**0.59*** **	-0.12	0.23	0.05
Laboratory Amphipod survival	0.11	0.13	0.05	0.33*	0.04	0.01	-0.10
Water Depth	0.03	-0.10	0.19	-0.04	-0.27	**0.59*** **	0.13

Note: - *p < 0.05; **p < 0.01; ***p < 0.001 (**in bold**).
- n = 48 stations for physical and chemical variables; n = 47 stations for distance (station 31 excluded).

Abundance, biomass and numbers of Paraonidae polychaetes varied with the sediment characteristics that related to potential influences of drilling activity. Total abundance and biomass, as well as numbers of Paraonidae polychaetes, were higher in sediments that had lower concentrations of $>C_{10}$-C_{21} hydrocarbons and barium. Both barium and $>C_{10}$-C_{21} hydrocarbons were shown to have higher concentrations near drill centres (Section 5.5.1). Abundance, biomass and numbers of Paraonidae were also lower in sediments with higher concentrations of sulphur. Numbers of Paraonidae increased with distance from drill centres and in sediments that had higher laboratory amphipod survival.

On the basis of these results, total abundance, biomass and numbers of Paraonidae polychaetes were analyzed in greater detail in the Sections that follow (Sections 5.5.3.3 to 5.5.3.6) in: 1) scatterplots examining significant relationship between these variables and distance to active drill centres; 2) threshold models to quantify the distance within which effects were apparent and 3) maps of occurrences above and below the baseline range to identify the potential influence of individual drill centres All of the key benthic indices (abundance, biomass and richness) as well as numbers of Paraonidae, Spionidae, Tellinidae and Amphipoda, were examined using repeated-measures regression to test for broad-scale effects over time.

5.2.3.3 Total Abundance

In 2010, total abundance of all benthic invertebrates varied between just under 1,000 organisms per m^2 to over 5,000 per m^2 across the sampling area. There was a significant relationship between total abundance and distance from the nearest active drill centre and that relationship was improved with the inclusion of a threshold (p = 0.018, see Table 3-4, Appendix B-5). The threshold distance for total abundance in 2010 was 1.4 km (Table 5-21). Threshold models were not significant for total abundance for all years prior to 2010. However, the threshold model in 2010 was also not significant if Station 20 (with approximately 500 organisms per m^2; lowest value in Figure 5-23 for 2010) was removed from the data set. Therefore, the significance of the threshold model for abundance needs to be carefully considered. Indeed, with Station 20 removed from the data set, there was no linear relation between abundance and distance (linear regression, p = 0.69). Station 20 is located approximately 380 m from Station C5-C, the only station where Microtox toxicity was noted (Section 5.5.2).

Table 5-21 Results of Threshold Regressions on Distance from the Nearest Active Drill Centre for Total Abundance

Year	Threshold Distance (km)
2010	1.4 (0.5 to 3.6)*

Notes: - 95% confidence limits for slopes and threshold distances provided in brackets.
- * = significant at $p < 0.05$.

As indicated in Figure 5-23, the “normal range” of variation for total abundance across the sampling area, was computed from the 2000 baseline data. Values in 2000 ranged between 1,885 and 6,776 individuals per m^2. Those values were also used as “benchmarks” against which to judge spatial variations in the sampling area, as well as variations over time in Figures 5-24 and 5-25.

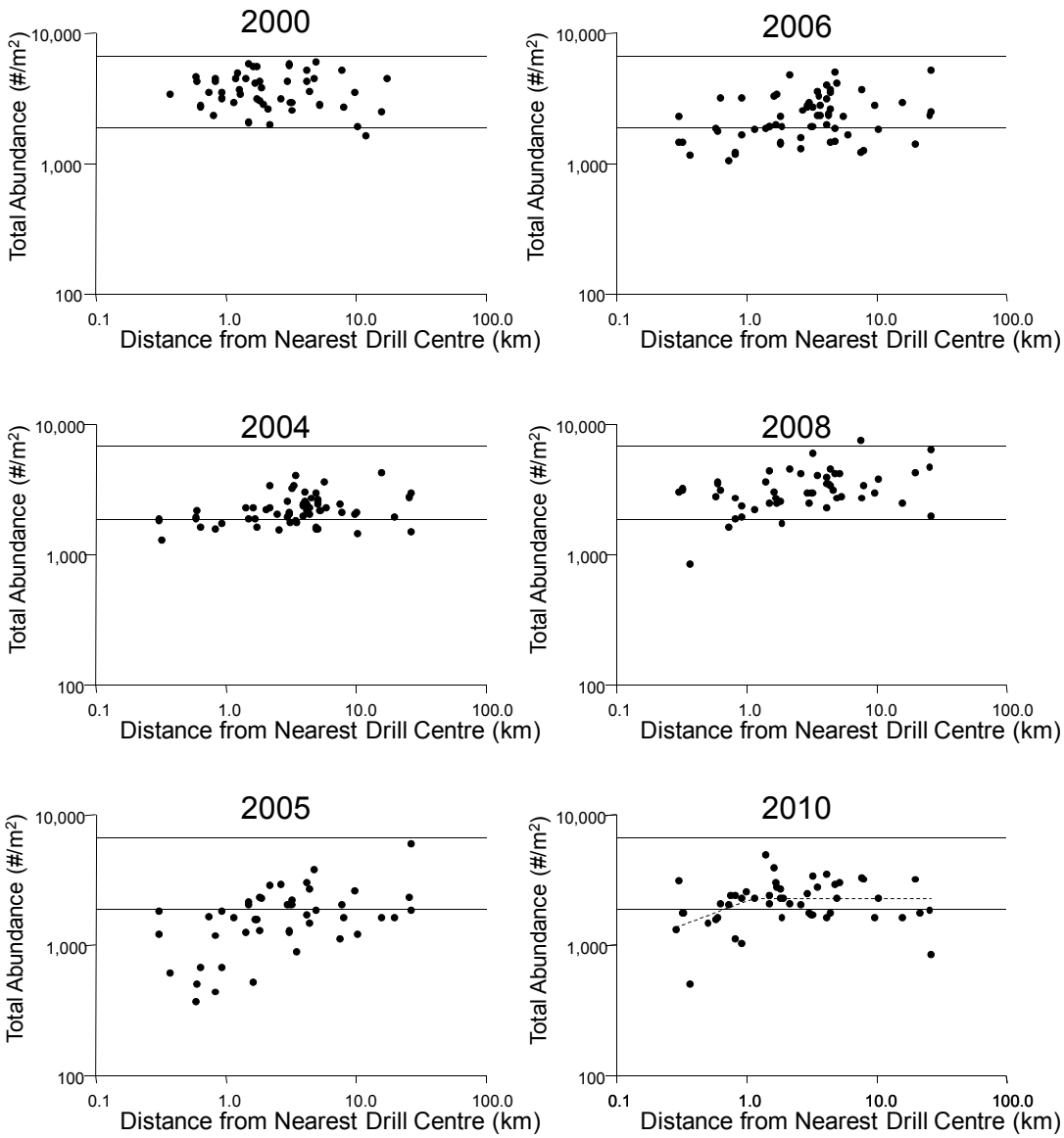

Figure 5-23 Variation in Total Abundance (#/m^2) with Distance from Nearest Active Drill Centre (all Years)

Notes: background total abundances are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline). Distances in year 2000 were distances to nearest drill centre, regardless of its operating status. The dotted line in 2010 indicates a weak threshold model.

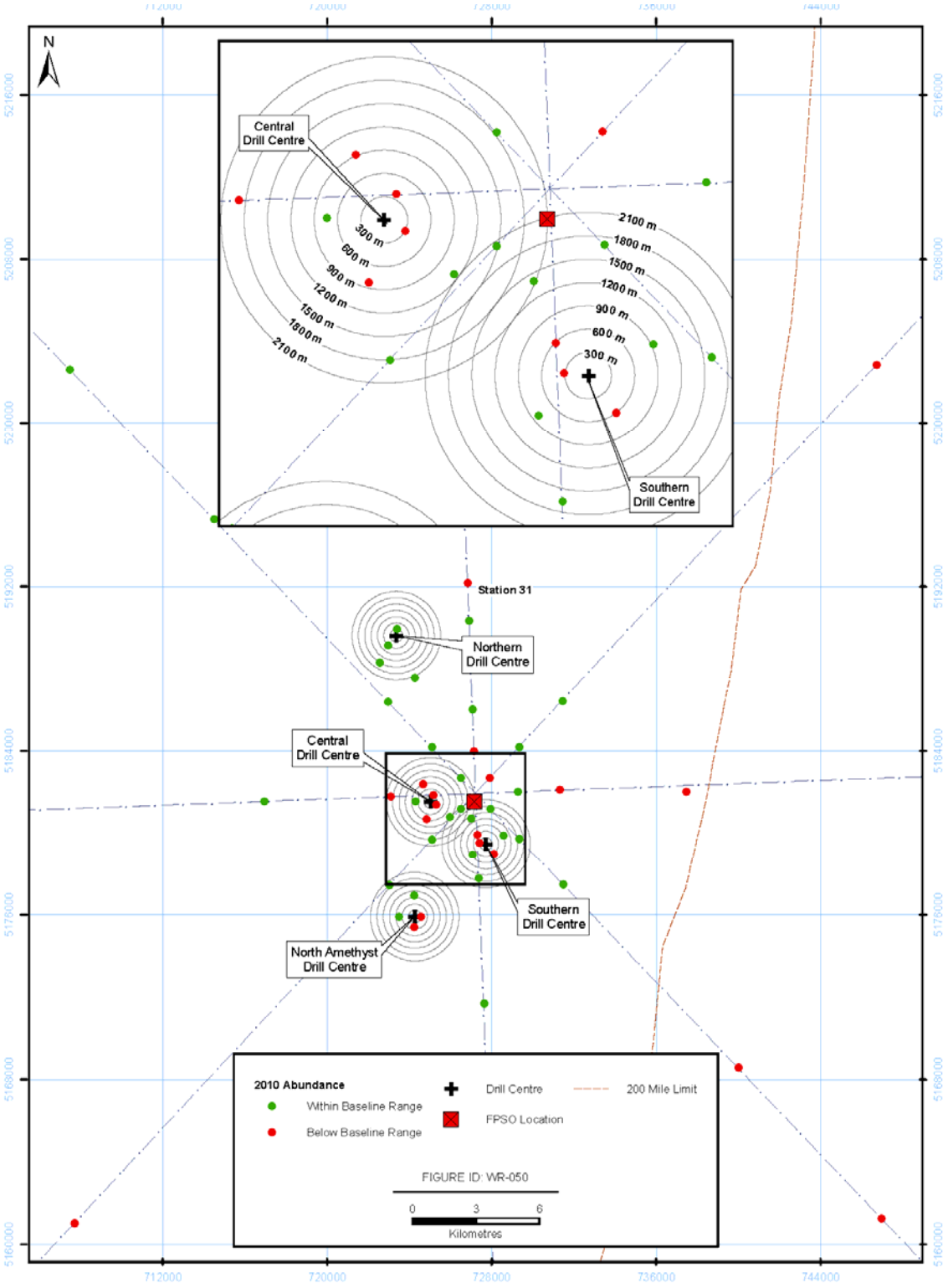

Figure 5-24 Location of Stations with Total Abundance Values Within and Below the Baseline Range (2010)

There was a tendency for stations near the Central, Southern and North Amethyst Drill Centres to have lower abundance (Figure 5-24). Abundance was also lower at station 31 located near the location of a delineation well drilled in 2007. However, many stations further away from drill centres (or wells), including the most distant stations, also showed abundances lower than the baseline range indicating natural annual variability. Therefore, the evidence of drilling-related effects on total abundance in 2010 was not strong. Furthermore, there was no evidence of effects from the Northern Drill Centre on total abundance (Figure 5-24).

In 2010, approximately 40% of stations had total abundances below the baseline range. Total abundances were most obviously depressed in 2005, with more than 60% of stations having abundances below the baseline range as far away as 10 km from the nearest drill centre. Total abundance has increased across the sampling area since 2005 (Figure 5-25).

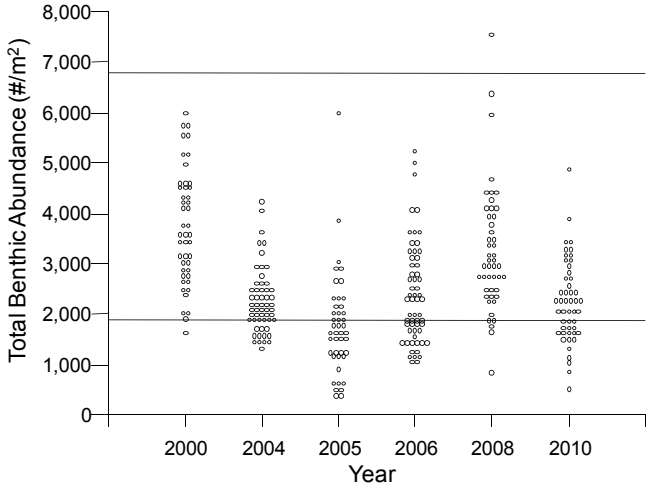

Figure 5-25 Dot Density Plot of Total Benthic Abundance by Year

Note: background total abundances are indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000

The repeated-measures regression analysis demonstrated that the relationship between abundance and distance from nearest active drill centre did not vary linearly over time during periods of drilling activity (i.e., years 2004 to 2010) (p = 0.492; Table 5-22), and did not vary from before to after drilling activity (p = 0.590), a result consistent with the absence of strong (or significant) threshold models. The repeated-measures regression analysis did suggest that there was a general (i.e., area-wide, including 'far-field' stations) change in the mean total abundance from before to after drilling operations (p < 0.001; Table 5-22), a result that was consistent with the visual observation from Figures 5-23 and 5-25 that, on average, total abundance was higher in the baseline year (2000) than in most of the years that have followed. The lower abundances in the far-field appear to have been caused by natural variability. Barium concentrations at those stations were at baseline levels, while hydrocarbon concentrations were measured at levels not known to cause effects on the benthic community.

Table 5-22 Repeated-measures Regression Testing for Changes in Total Benthic Abundance over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.492	0.508	0.590	<0.001

Notes:
- Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

5.2.3.4 Total Biomass

In 2010, total biomass varied from a low of approximately 200 g/m^2 near drill centres to a high of approximately 2,000 g/m^2 at sampling stations more distant from the drill centres. Variations in total biomass were significantly related to distance from active drill centres in 2010 (r_s = -0.33, Table 5-20). Threshold models have not been significant for biomass in any year, including 2010 (p > 0.05 in all cases). Figure 5-26 provides a graphical representation of the relationship between biomass and distance from active drill centres.

As indicated in Figure 5-26, the “normal range” of variation for total biomass across the sampling area was computed from the 2000 baseline data. Values ranges between 367 and 1,400 mg/m^2 (i.e., mean from year 2000 ± 2 SDs). Those values were also used to judge spatial variation in the sampling area (Figure 5-27), as well as variation over time in Figure 5-29.

Abundance was reduced to below the baseline range near the Central, Southern and Northern Amethyst Drill Centres, indicating project effects, but there was no evidence of effects around the Northern Drill Centre. There was potential overlap in effects from the Southern and Central Drill Centres (Figure 5-27).

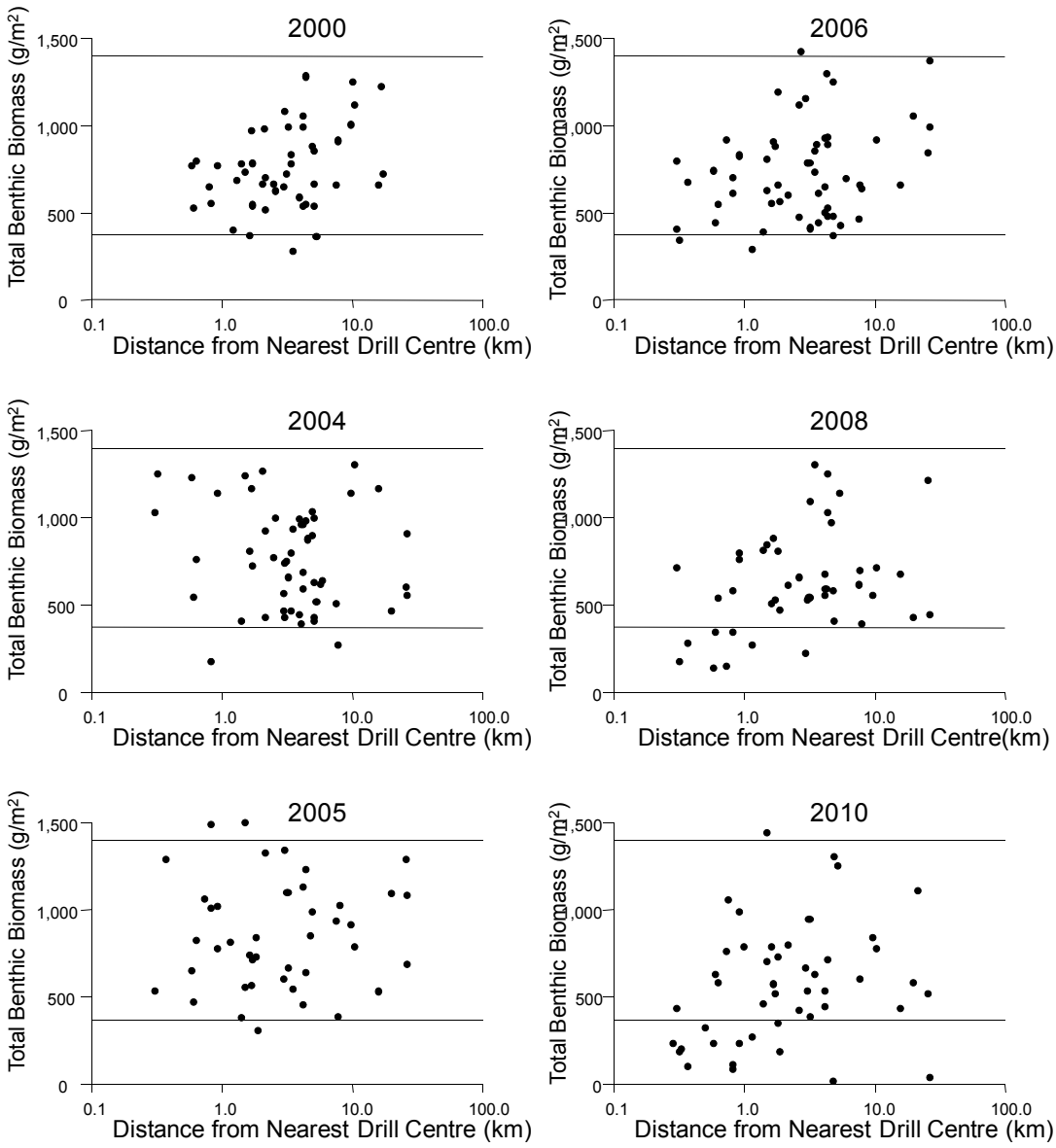

Figure 5-26 Variation in Total Benthic Biomass (g/m^2) with Distance From Nearest Active Drill Centre (all Years)

Notes: background biomass is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000. Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

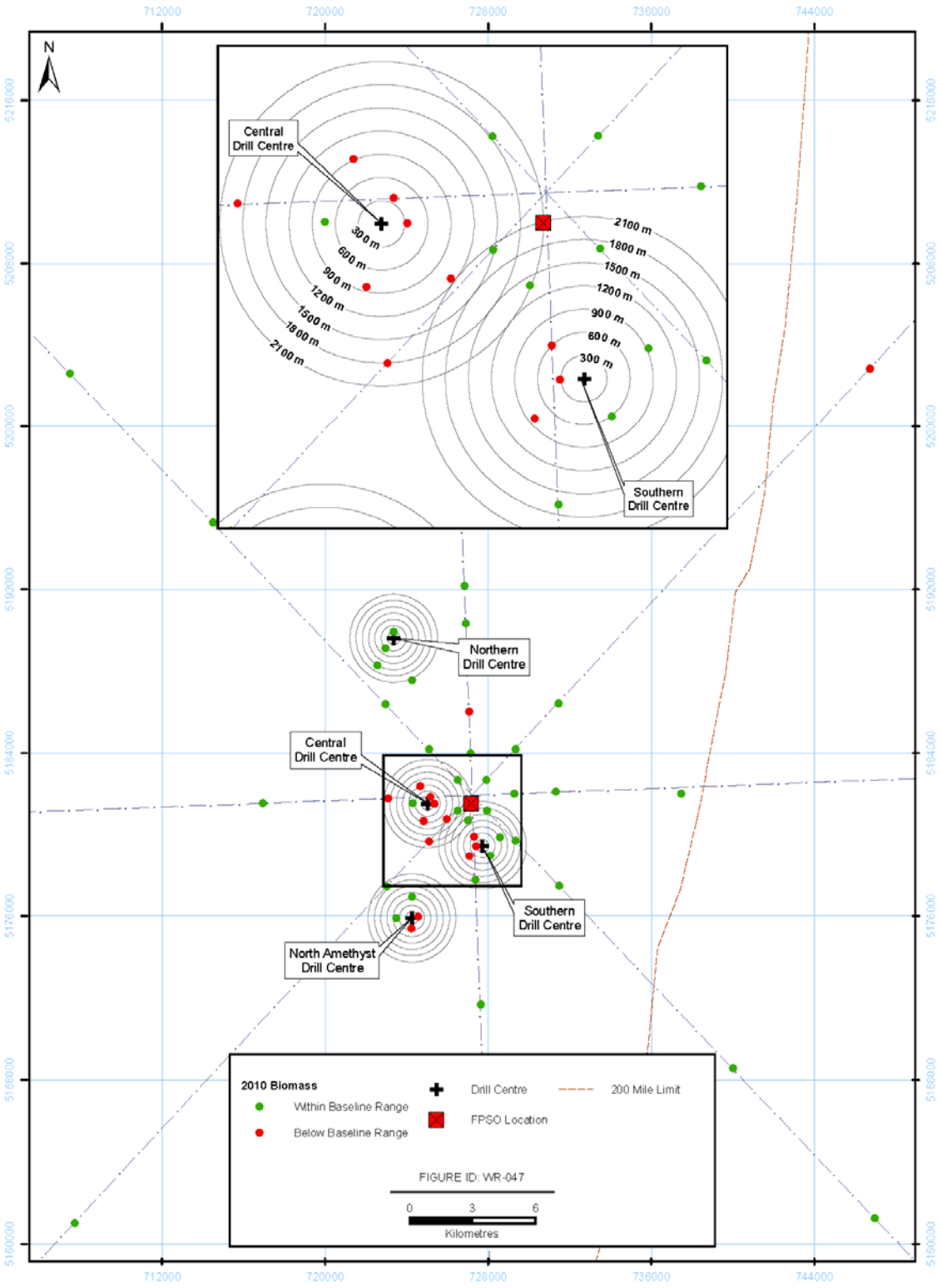

Figure 5-27 Location of Stations with Total Biomass Values Within and Below the Baseline Range (2010)

The effect on biomass was more apparent than the effect on total abundance. Considering that the evidence for a drilling-related effect on total abundance was weak, it was not a reduction in numbers that can be assumed to be the cause of the reduction in biomass. Of the major taxonomic groups, numbers of Paraonidae polychaetes (r_p=0.49) and Echinodermata (r_p=0.58) were the most strongly associated with total biomass in 2010. Paraonidae polychaetes are generally quite small (approximately 0.0002g per worm; P. Pocklington, pers. comm.), while echinoderms are much larger and heavier. The reduction in biomass near drill centres was therefore associated with reductions in the numbers of echinoderms. Echinoderms have historically accounted for a small fraction of the total numbers of organisms (between 10 and 20 individuals per sample, or 50 to 100 individuals per m^2). In 2010, however, numbers of echinoderms in samples near drill centres were lower than in previous years, and in some cases were absent (Figure 5-28). Members of this Phylum included the sand dollar *Echinarachnius parma*, and the urchin *Strongylocentrotus droebachiensis*, both of which are relatively large and heavy.

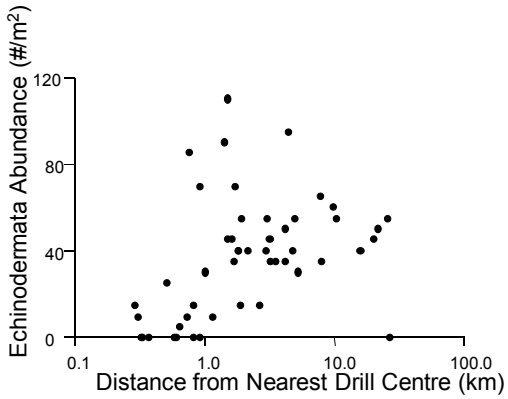

Figure 5-28 Variation in Echinoderm Abundance (#/m^2) with Distance From Drill Centres (2010)

Overall, benthic biomass in 2010 fell below the baseline range at 20% of stations, generally less than 2 km away from the nearest drill centre. There were 16% of stations below the baseline range in 2008, also generally around drill centres. Biomass from 2000 (baseline) to 2006 was relatively stable (Figure 5-29).

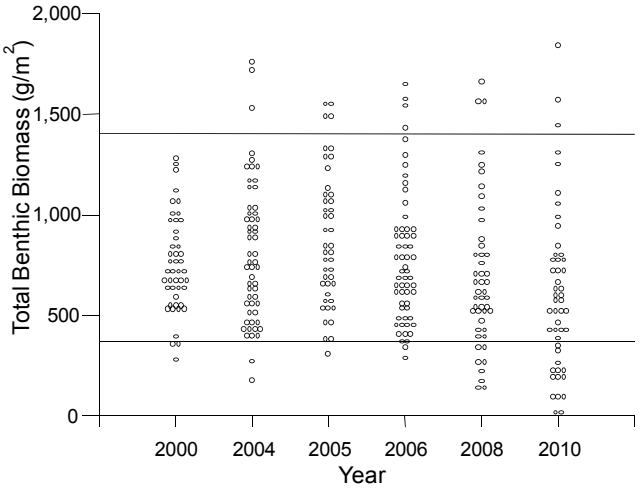

Figure 5-29 Dot Density Plot of Total Benthic Biomass by Year

Note: background biomass is indicated by horizontal lines, as based on the mean values + 2 SDs using data from 2000.

Repeated-measures regression indicated that there was no change in the slope of the relationship between biomass and distance from the nearest active drill centre (p = 0.124), and no difference in slopes from before to after drilling operations (p = 0.232; Table 5-23). However, there was evidence for a decreasing trend in mean biomass from 2004 to 2010 (p = 0.002; Table 5-23). The scatterplots and dot density graphs (Figures 5-26 and 5-29) illustrate more stations below the baseline range in 2008 and 2010, compared to previous years.

Table 5-23 Repeated-measures Regression Testing for Changes in Total Benthic Biomass over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.124	0.002	0.232	0.989

Notes: - Values are probabilities.
- Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000, and the mean in the period including 2004 to 2010.

5.2.3.5 Richness

Number of families per station (i.e., richness) varied between 18 and 45 in 2010, which compared well to the normal range from baseline (2000) of between 21 and 38 families. There was no significant influence of drill centre on number of families (r_s = 0.06, p > 0.5). Figure 5-30 provides a graphical representation of the relationship between richness and distance to active drill centres.

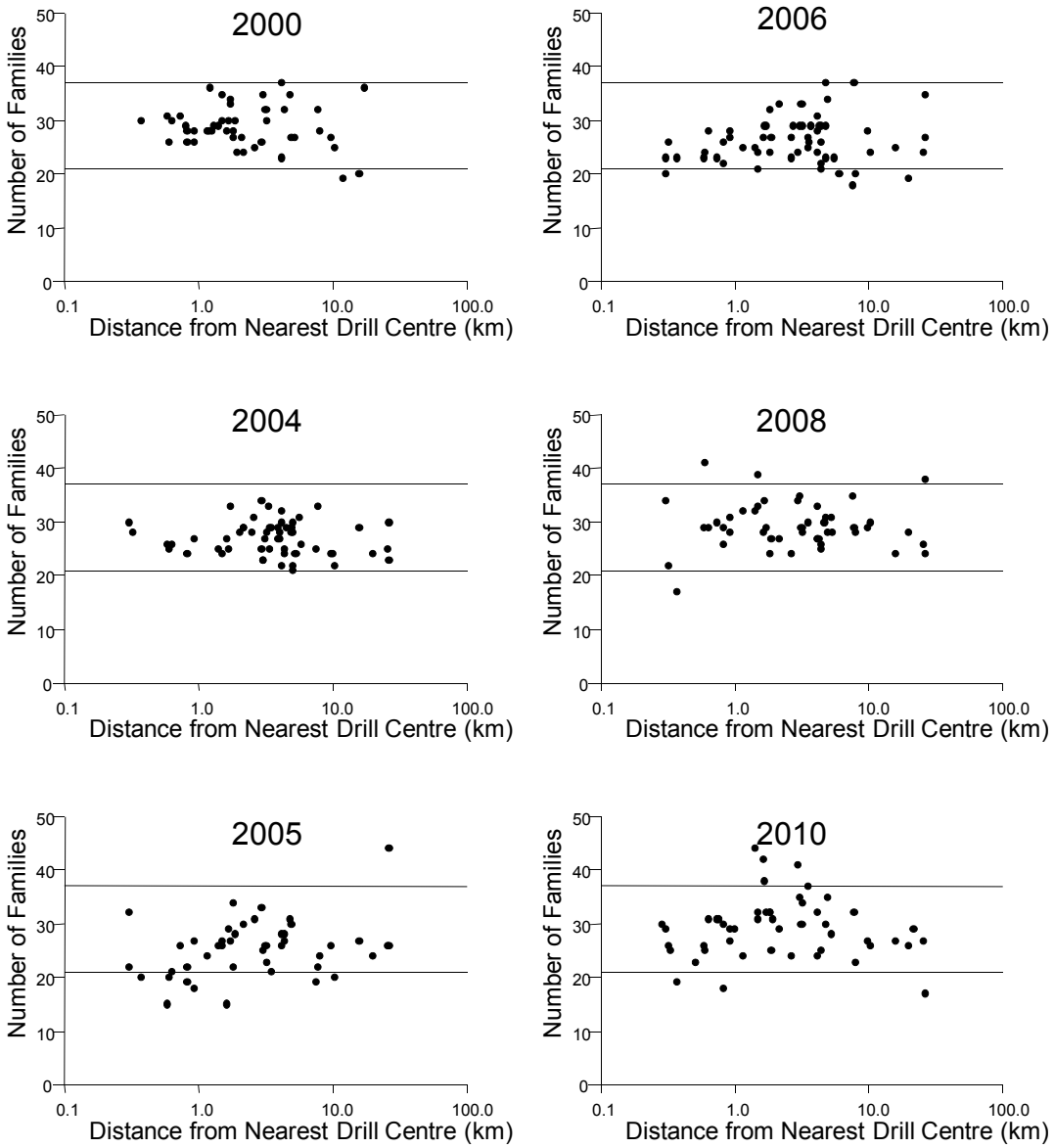

Figure 5-30 Variation in Number of Families per Station with Distance From Nearest Active Drill Centre (all Years)

Notes: background number of families is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000. Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

Two stations around the Central Drill Centre showed richness values below the baseline range (Figure 5-31). However, those values were near the baseline range (see Figure 5-30) and one station more than 28 km from drill centres had similar richness values (Figures 5-30 and 5-31). From these figures, there is insufficient evidence to conclude that richness was affected by project activities.

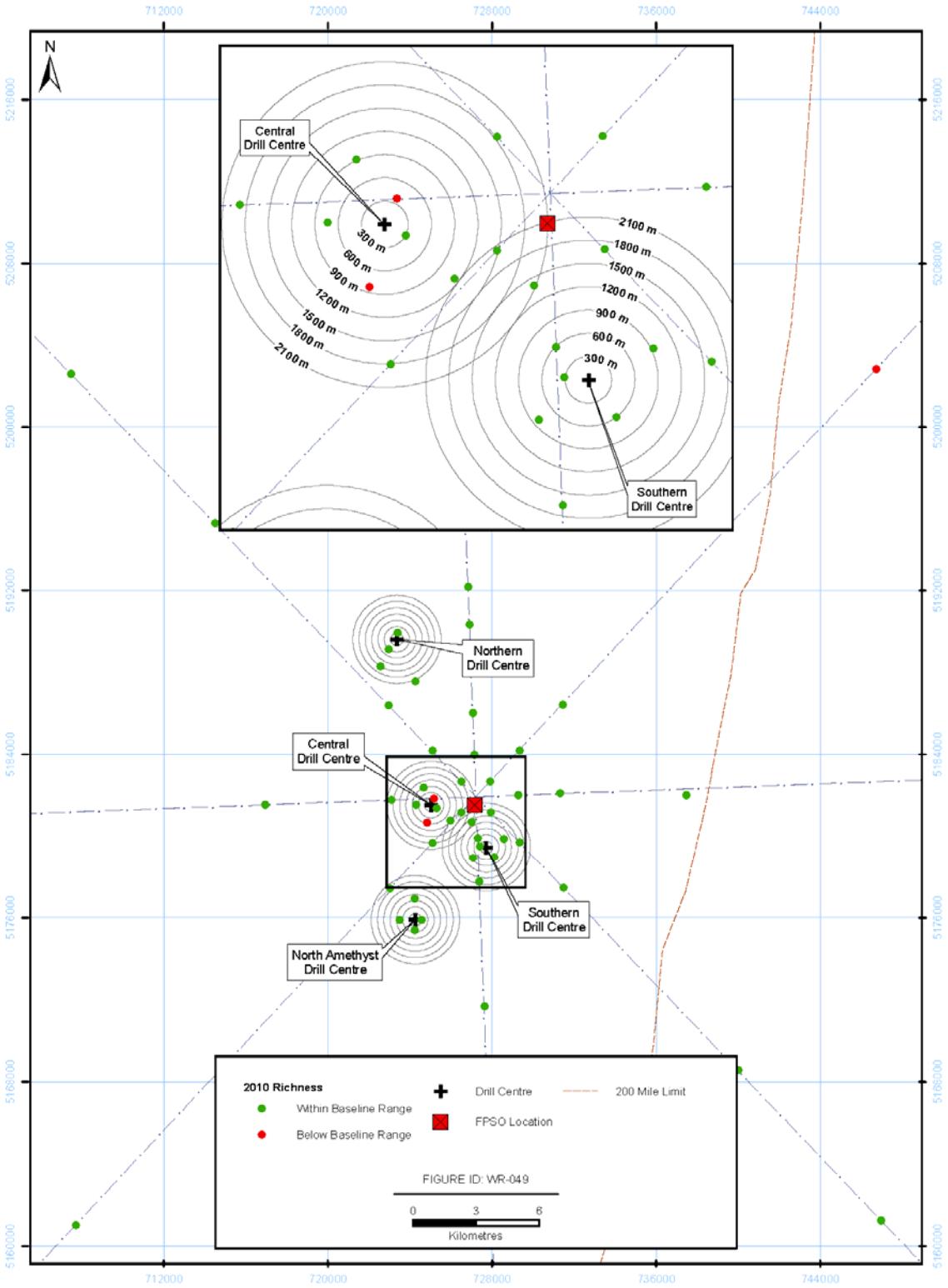

Figure 5-31 Location of Stations with Richness Values Within and Below the Baseline Range (2010)

Repeated-measures regression indicated no linear variations in the slope of the relationship between number of families and distance from the nearest active drill centre over time (p = 0.603), or from before to after active drilling (p = 0.877; Table 5-24), but there was a significant linear trend (potential increase; see Figure 5-30) in number of families during the active drilling period of 2004 to 2010. In 2010, only 6% of observations fell below the estimated limits of the normal range (i.e., below 21 families) (Figure 5-32), about the frequency expected on the basis of the calculation for the normal range (i.e., to enclose 95% of potential observations). Results indicate that there has been no reduction in the number of families (richness) in the sampling area and, in fact, there has been a slight increase in richness since 2005.

Table 5-24 Repeated-measures Regression Testing for Changes in Number of Families over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.603	0.032	0.877	0.324

Notes: - Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

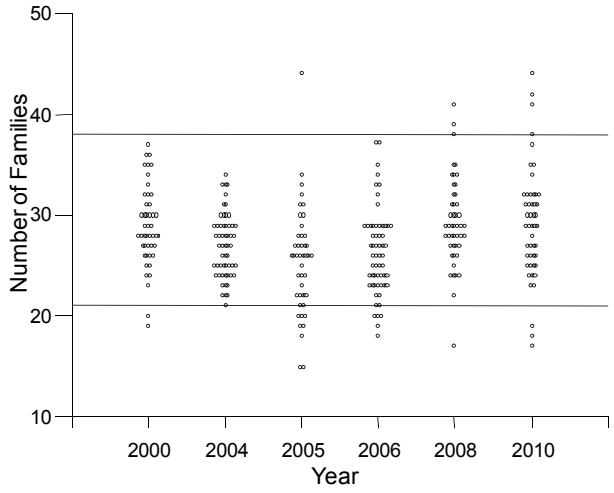

Figure 5-32 Dot Density Plot of Number of Families by Year

Note: background number of families is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.

5.2.3.6 Numbers of Paraonidae

Threshold models were significant for Paraonidae polychaete abundance for all years from 2004 to 2010. The threshold distances computed from those models are presented in Table 5-25. Threshold distances have been variable (1.6 km in 2010 to 4.1 km in 2004), but with no statistically significant differences among years (i.e., confidence limits all overlapped). Although, in 2010, the threshold distance was less than half the 2008 threshold distance. Figure 5-33 provides a graphical representation of the relationship between Paraonidae abundance and distance to active drill centres.

Table 5-25 Threshold Distances Computed from Threshold Regressions on Distance from the Nearest Active Drill Centre for Paraonidae Abundance

Year	Threshold Distance (km)
2004	4.1 (2.0 to 8.6)*
2005	2.6 (1.5 to 4.5)*
2006	2.8 (1.9 to 4.2)*
2008	3.8 (2.1 to 6.9)*
2010	1.6 (1.0 to 2.7)*

Notes: - 95% confidence limits for slopes and threshold distances provided in brackets.
- * = significant at $p < 0.05$.

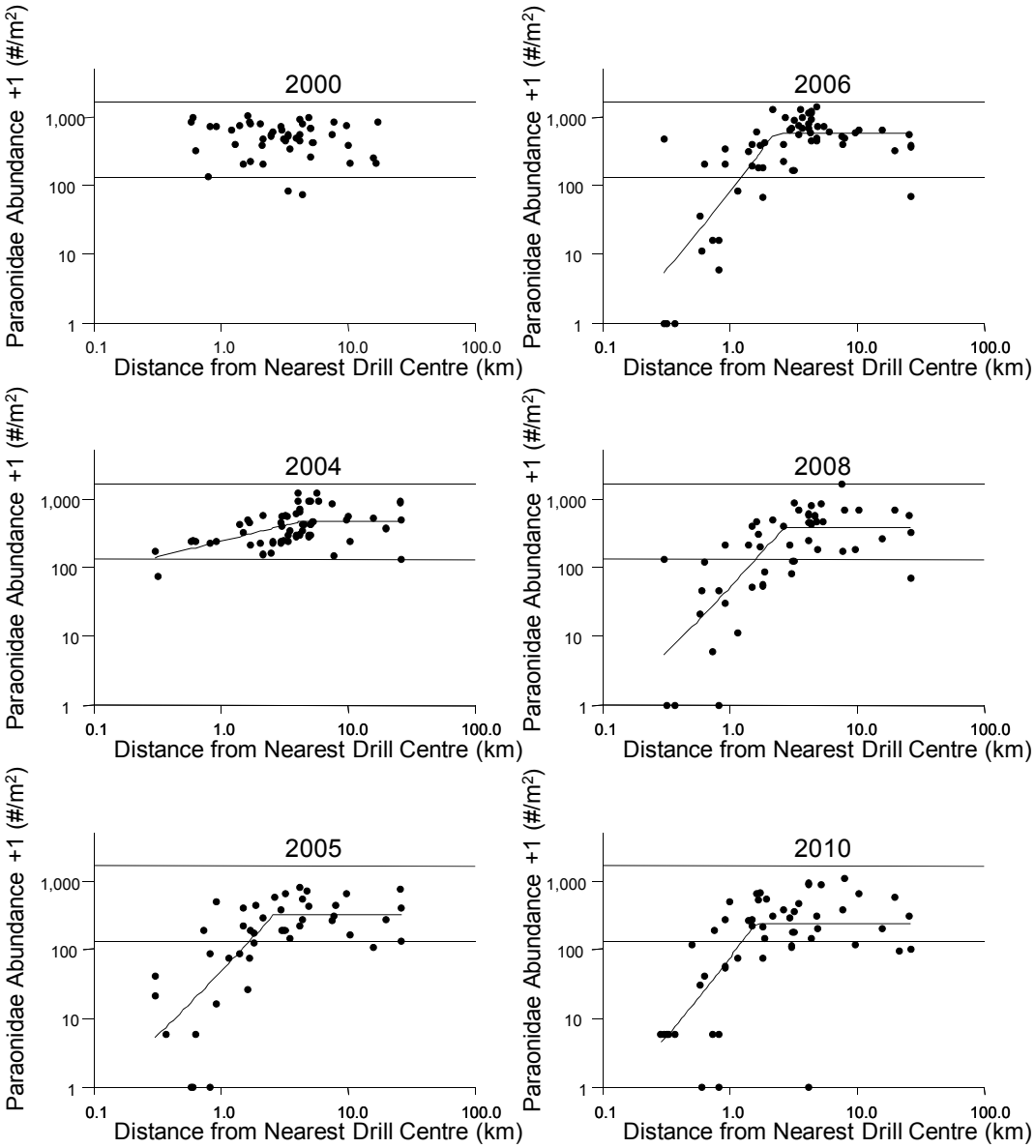

Figure 5-33 Variation in Paraonidae Abundance (#/m^2) with Distance from Nearest Active Drill Centre (all Years)

Notes: background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000. Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

As indicated in Figure 5-33, the “normal range” of variation for Paraonidae abundance across the sampling area was computed from the 2000 baseline data. Values ranged from 130 to 1,671 per m^2 in 2000. That range of values was skewed higher because of a back-transformation of the limits from logarithms. Regardless, the lower value of 130 individuals per m^2 appears appropriate, and reductions, rather than increases, in Paraonidae abundances are the concern at White Rose. The lower range of 130 individuals per m^2 was used as a “benchmark” against which to judge spatial variations in the sampling area, as well as variations over time in Figures 5-34 and 5-35.

Paraonidae abundances were reduced at several stations around the Central, Southern, North Amethyst and Northern Drill Centres in 2010 (Figure 5-34). Paraonidae abundance was also reduced at station 31 located near a delineation well drill in 2007. There was a potential overlap in effects on Paraonidae from the Central and Southern Drill Centres (Figure 5-34). The data show project-effects on Paraonidae abundance.

Across years, there were more stations with Paraonidae abundance below the lower baseline range in 2010 than in other years, with 2% below the baseline range in 2004, 28% below the range in 2005, 24% below the range in 2006, 32% below range in 2008 and 40% below range in 2010 (Figure 5-35).

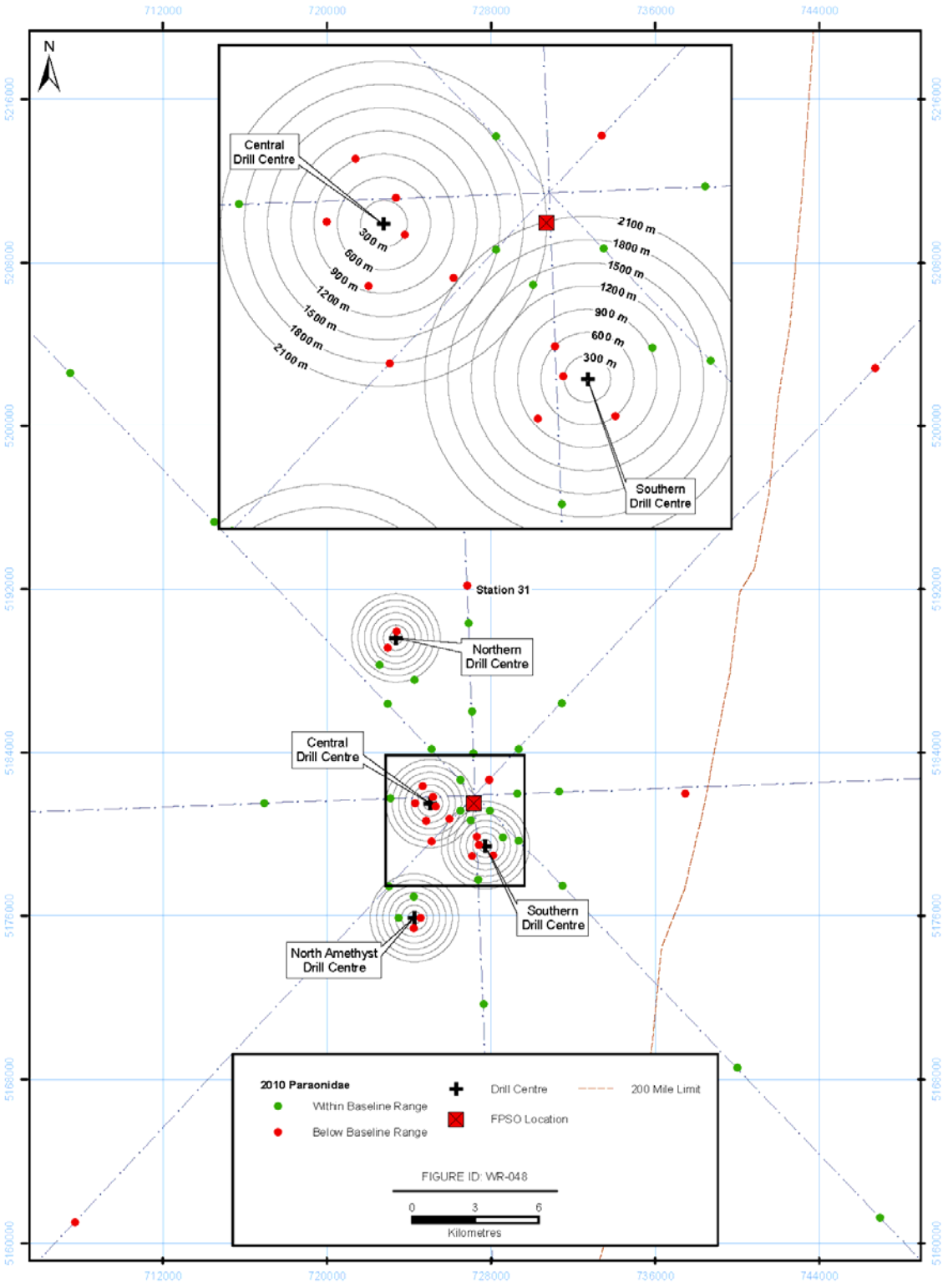

Figure 5-34 Location of Stations with Paraonidae Abundance Values Within and Below the Baseline Range (2010)

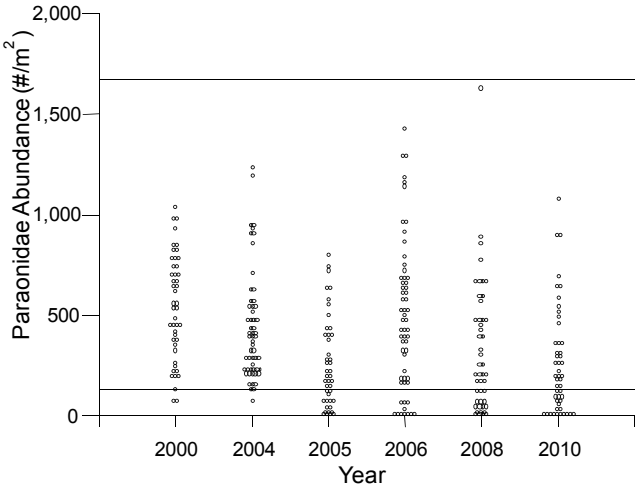

Figure 5-35 Dot Density Plot of Paraonidae Abundance by Year

Note: background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.

Repeated-measures regression indicated no change over time in the relationship between distance and Paraonidae abundance during the period of drilling operations, and no change in the relationship between baseline and drilling periods (p = 0.566; Table 5-26). However, there were significant changes in mean abundances of Paraonidae abundances over the active drilling period (p = 0.022), and a significant change (decrease) in mean abundances over that same active drilling period (p = 0.019). The lack of difference in the slope of the relationship between abundance and distance from before to after active drilling was probably a function of the repeated-measures model being unable to accommodate the non-linearity of the threshold response.

Table 5-26 Repeated-measures Regression Testing for Changes in Paraonidae Abundance over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.251	0.022	0.566	0.019

Notes:
- Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

5.2.3.7 Spionidae Abundance

Spionidae abundances varied between 130 and 2,055 individuals per m^2, averaging approximately 1,000 per m^2 in 2010. Variation in abundances of Spionidae polychaetes in 2010 was correlated with percent fines in the sediment (r_s = -0.3, p < 0.001). There was no significant influence of drill centres on the abundance of this group in 2010 (r_s = -0.12, p > 0.2). Figure 5-36 provides a graphical representation of the relationship between Spionidae abundance and distance to active drill centres.

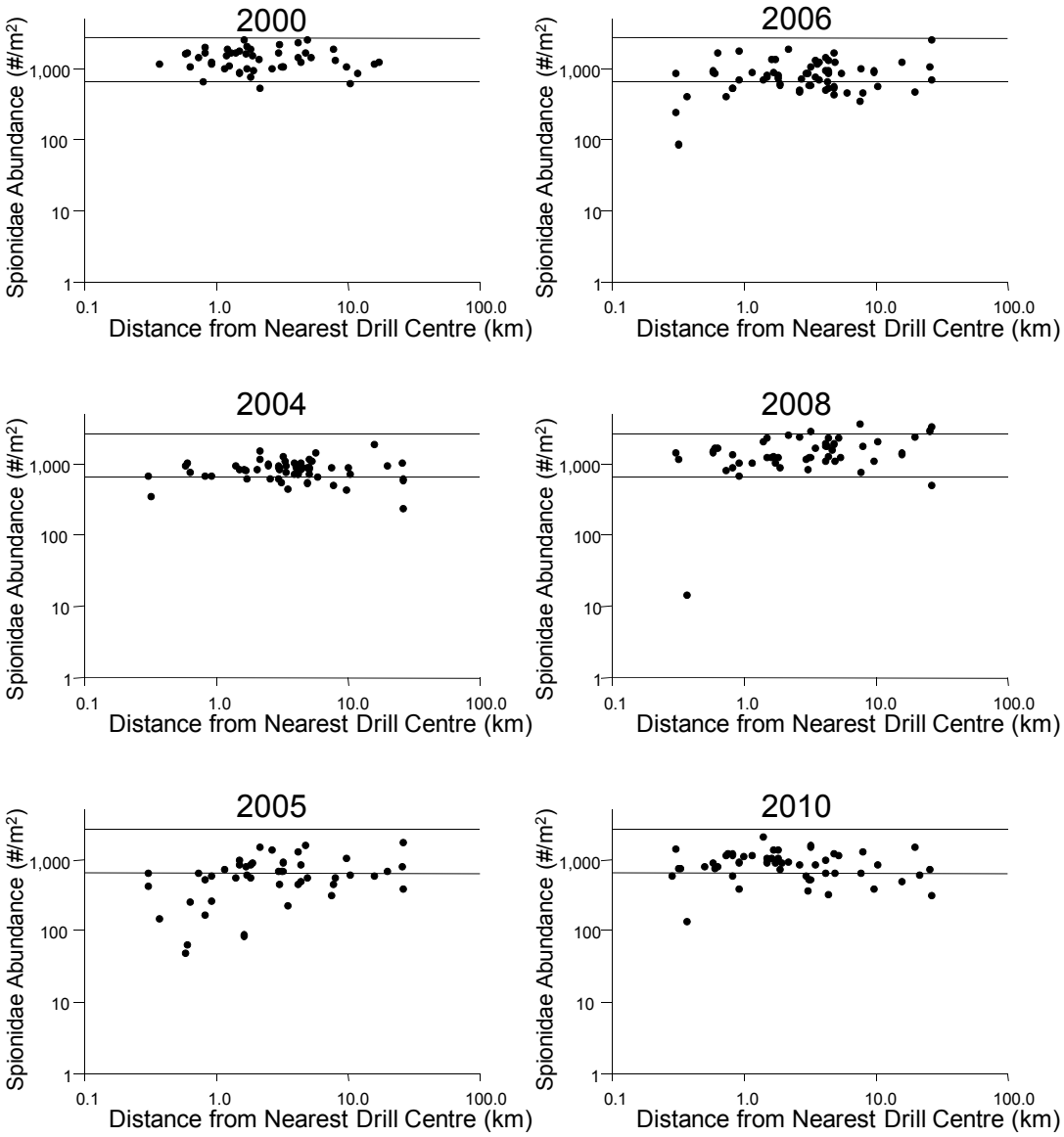

Figure 5-36 Variation in Spionidae Abundance (#/m^2) with Distance From Nearest Active Drill Centre (all Years)

Notes: background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000. Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

Repeated-measures regression indicated no significant change in the slope of the relationship between Spionidae abundance and distance from the nearest active drill centre over time (p = 0.300; Table 5-27), and no difference in slope from before to after active drilling operations. There was a difference in mean Spionidae abundance across the sampling area from before to after active drilling (p = 0.011), with abundances lower from 2004 to 2010 (Table 5-27).

Table 5-27 Repeated-measures Regression Testing for Changes in Spionidae Abundance over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.300	0.926	0.824	0.011

Notes: - Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

The normal range of Spionidae abundances from year 2000 was between 643 and 2,682 individuals per m^2. In 2010, approximately 35% of stations had Spionidae abundances below the lower baseline range of 643 per m^2 (Figures 5-36 and 5-37). These levels were comparable to levels noted in 2006, when 34% of stations were below the baseline range and lower than those noted in 2005, when 63% of stations were below the baseline range. Spionidae abundance in 2008 was similar to abundance noted in baseline, with 4% of abundances below the baseline range (approximately what would be expected). The lack of association between Spionidae abundances and distance from the nearest active drill centre indicates that the reduction across the sampling area is likely unrelated to drilling operations.

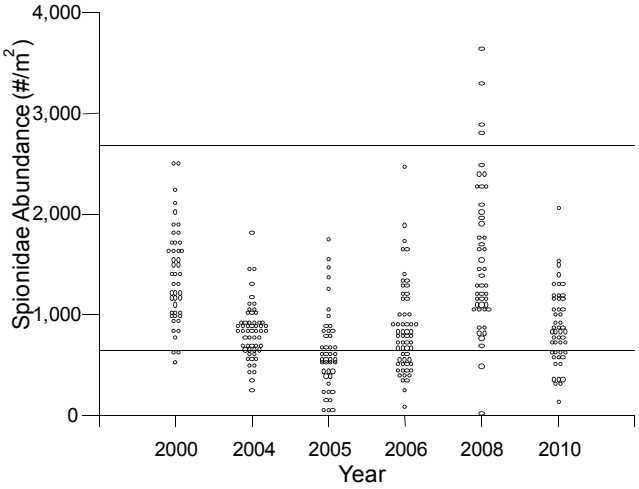

Figure 5-37 Dot Density Plot of Spionidae Abundance by Year

Note: background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.

5.2.3.8 Tellinidae Abundance

Tellinidae abundances varied between 25 and 920 individuals per m^2, with an area-wide average of about 300 to 400 per m^2 in 2010. Variations in abundances of Tellinidae bivalves was strongly correlated with water depth (r_s = 0.58 p < 0.0001). There was no significant influence of drill centre on the abundance of this group in 2010 (r_s = 0.23, p > 0.05). Figure 5-38 provides a graphical representation of the relationship between Tellinidae abundance and distance to active drill centres.

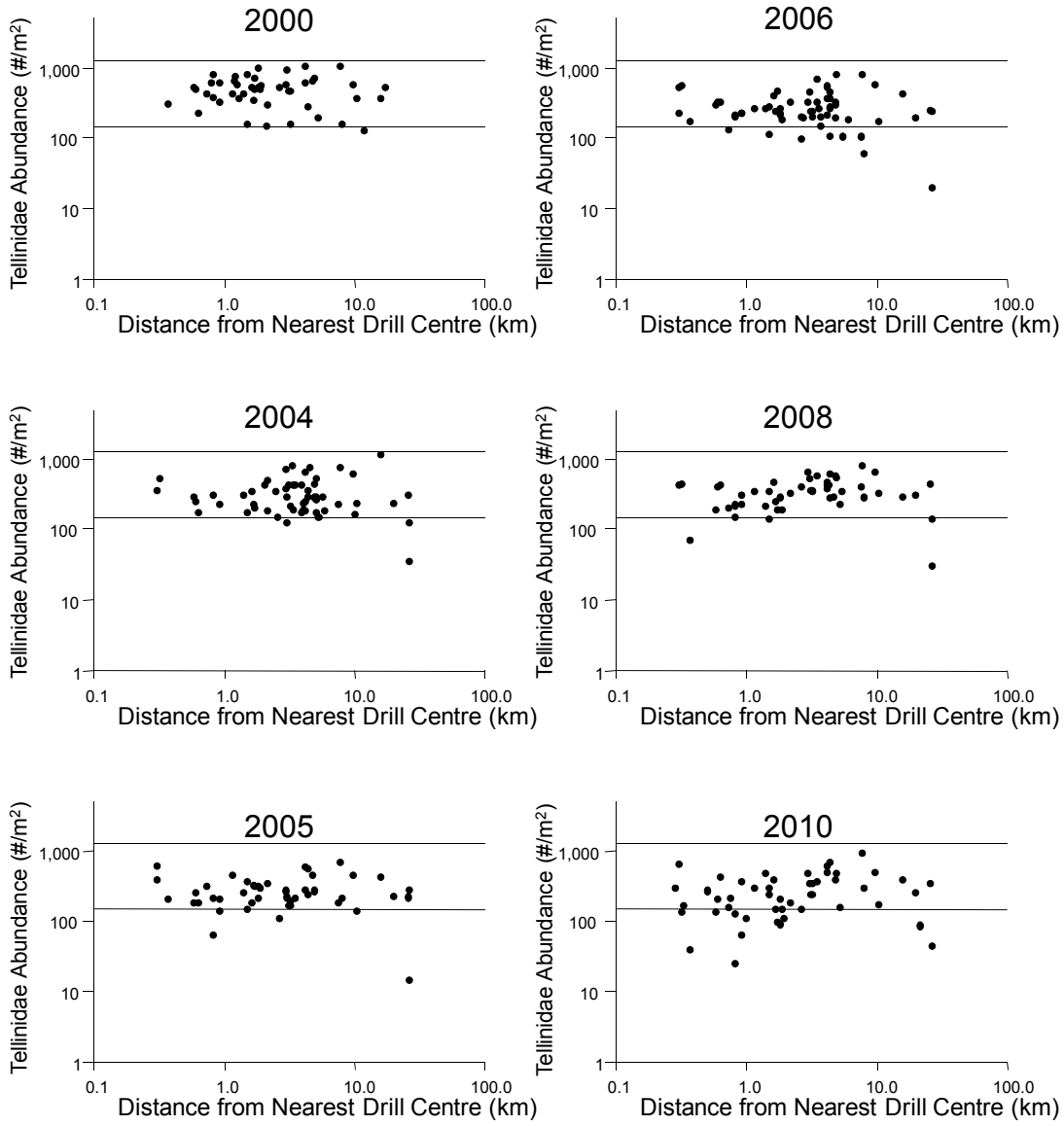

Figure 5-38 Variation in Tellinidae Abundance (#/m^2) with Distance From Nearest Active Drill Centre (all Years)

Notes: background abundance biomass is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000. Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

Repeated-measures regression indicated no significant linear trend in the slope of the relationship between Tellinidae abundance and distance from the nearest active drill centre (p = 0.822; Table 5-28) across years, and no difference in slope from before to after active drilling operations (p = 0.723). There was a difference in mean Tellinidae abundance across the sampling area from before to after active drilling (p = 0.005), with abundances lower from 2004 to 2010.

Table 5-28 Repeated-measures Regression Testing for Changes in Tellinidae Abundance over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.822	0.819	0.723	0.005

Notes: - Values are probabilities.
- The Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

The normal range of Tellinidae abundances from year 2000 was between 151 and 1,303 individuals per m^2. Approximately 30% of stations had Tellinidae abundances in 2010 that were below the lower baseline value of 151 per m^2 (Figures 5-38 and 5-39). The frequency of abundances below the baseline benchmark was higher than in previous years (5% in 2004, 9% in 2005, 16% in 2006, 11% in 2008). The absence of a correlation with distance from the nearest active drill centre implies that reductions are likely unrelated to drilling operations.

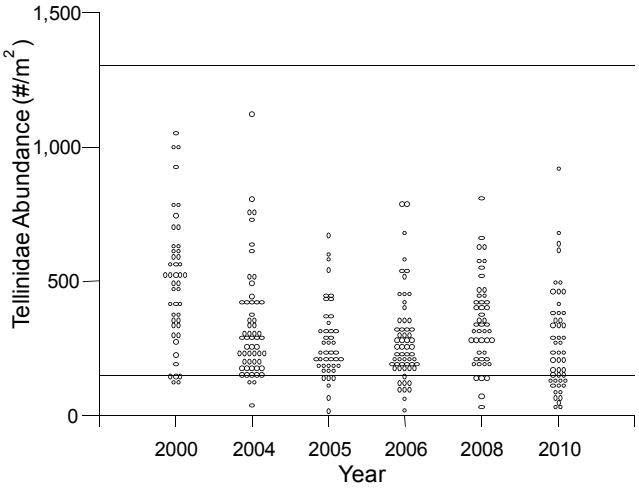

Figure 5-39 Dot Density Plot of Tellinidae Abundance by Year

Note: background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.

5.2.3.9 Amphipoda Abundance

Amphipod abundances varied between 10 and 200 individuals per m^2, with an area-wide average of about 80 to 90 per m^2 in 2010. Variation in abundances of Amphipoda was not correlated with any measured physical, chemical or toxicological variables. There was no significant influence of drill centres on the abundance of this group in 2010 (r_s = 0.05, p > 0.5). Figure 5-40 provides a graphical representation of the relationship between amphipod abundance and distance to active drill centres.

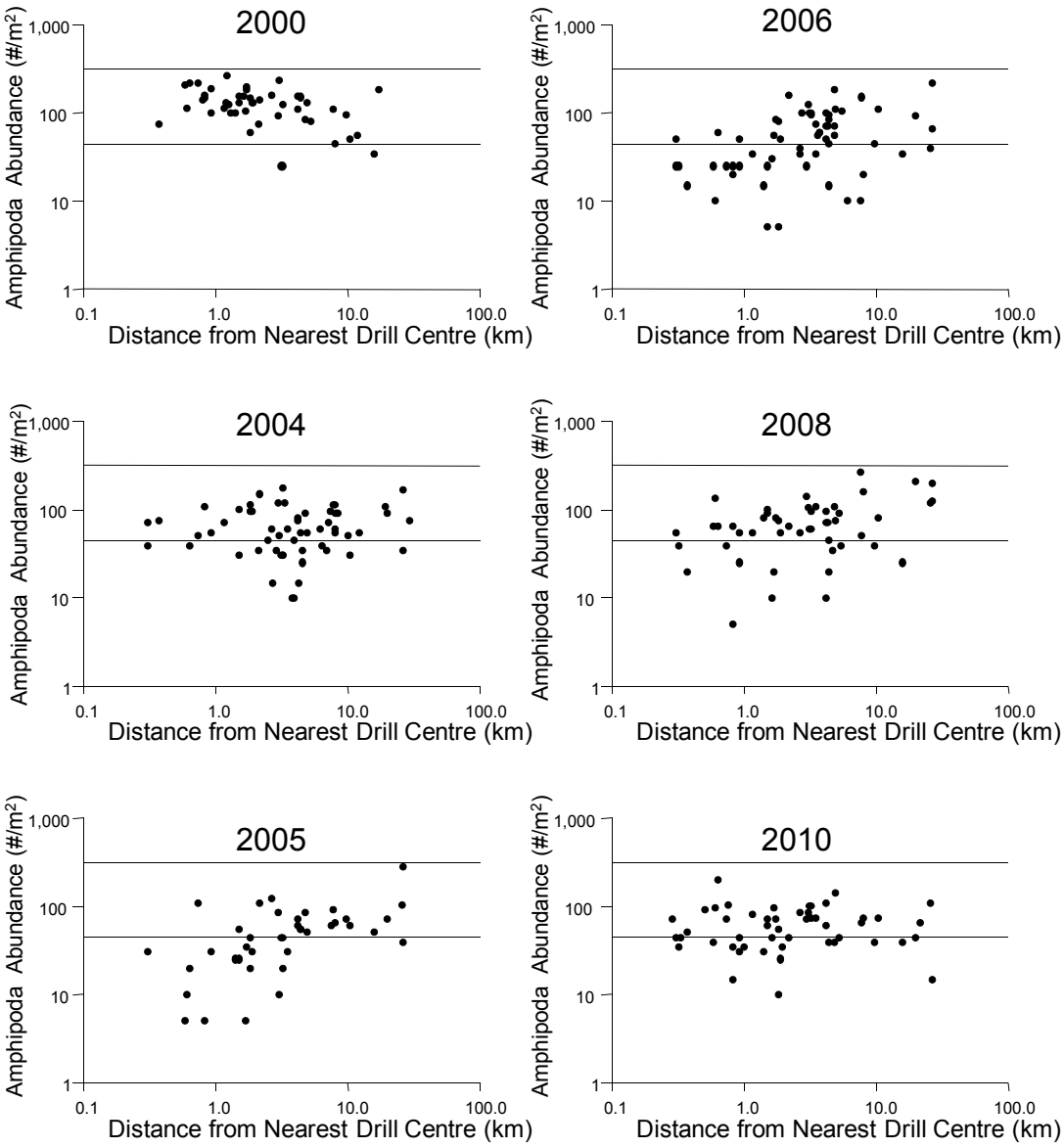

Figure 5-40 Variation in Amphipoda Abundance (#/m^2) with Distance From Nearest Active Drill Centre (all Years)

Notes: background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000. Distances in year 2000 were distances to nearest drill centre, regardless of its operating status.

Repeated-measures regression indicated that slopes of the relationship between amphipod abundance and distance to the nearest drill centre did not vary over time (p = 0.791; Table 5-29), and there was no difference in slope from before to after active drilling operations (p = 0.092). There was a difference in mean amphipod abundance across the sampling area from before to after active drilling (p < 0.001), with abundances lower from 2004 to 2010.

Table 5-29 Repeated-measures Regression Testing for Changes in Amphipoda Abundance over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.791	0.764	0.092	< 0.001

Notes: - Values are probabilities.
- Trend over Time contrast tests for trends over time since operations began (i.e., from 2004 to 2010).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2010.

The normal range of amphipod abundances from year 2000 was between 44 and 313 individuals per m^2. In 2010, approximately 30% of stations had amphipod abundances below the lower benchmark of 44 per m^2 (Figures 5-40 and 5-41). Amphipod abundances have been below the lower baseline benchmark with similar frequency in the previous years (41% in 2004, 38% in 2005, 45% in 2006, 30% in 2008).

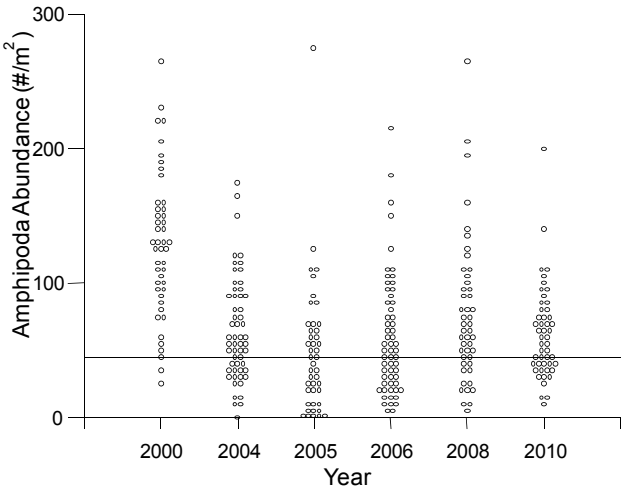

Figure 5-41 Dot Density Plot of Amphipoda Abundance by Year

Note: background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.

5.2.3.10 Non-Metric Multidimensional Scaling

NMDS is a multivariate ordination technique, commonly used with benthic invertebrate community data, which was used to generate synthetic indices of composition for this study. The analysis produced two synthetic variables, NMDS Axis 1 and NMDS Axis 2. The technique is similar to Principal Components Analysis in that “scores” for each station were produced. Relative differences in scores between stations can indicate

similarities or differences in composition. The NMDS Axis scores were analyzed like the conventional indices of composition, assessing correlations with distance from active drill centres, and with other environmental descriptors.

The detailed results for the NMDS axis scores are presented in Appendix B-5. NMDS results generally confirmed the observations made with the major indices of community composition (abundance, biomass) and major taxa (abundances of Paraonidae, Spionidae, Tellinidae). Summary figures are presented in Figure 5-42. Total abundances, abundances of Polychaeta including Paraonidae and Spionidae, abundance of Amphipoda and Number of Families were strongly correlated with the first NMDS axis. Variations in Axis 1 scores can be interpreted as broadly representing variations in total abundances.

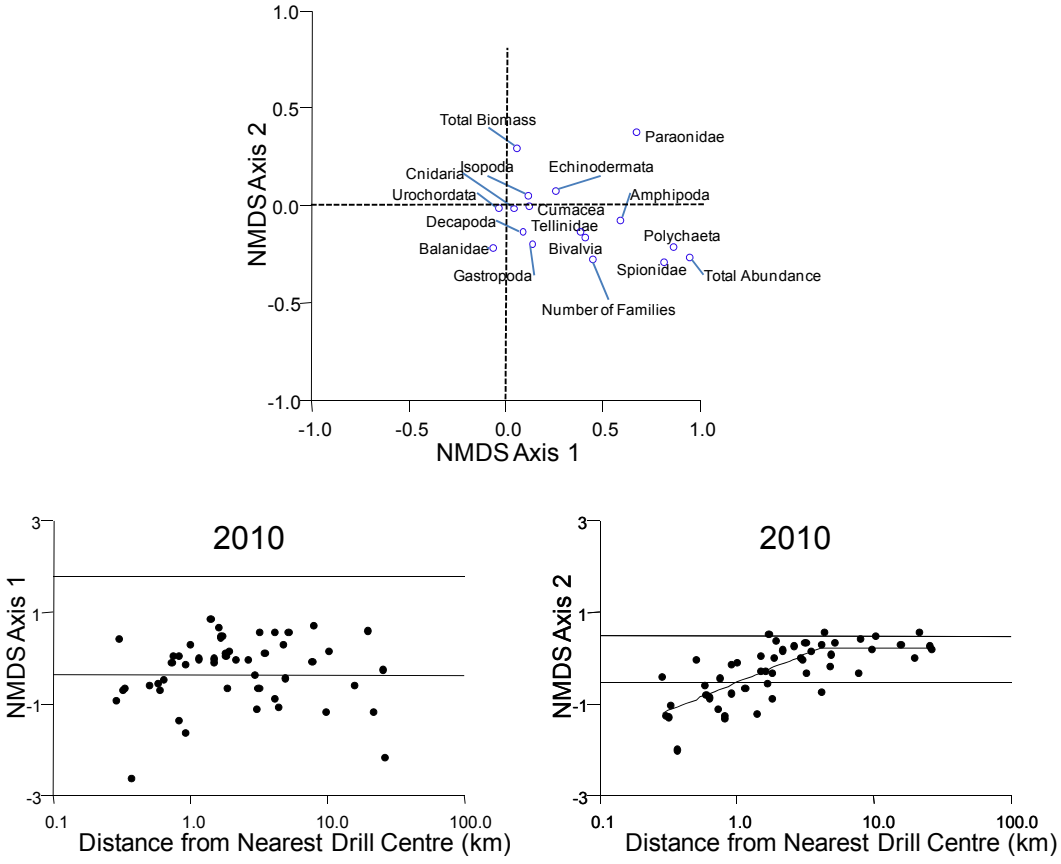

Figure 5-42 Correlations Between Major Group Taxa Abundances and Station Scores (top panel) and Scatterplots of NMDS Station Scores (in 2010, lower panel)

Notes: Values in the top panel are Pearson Correlation coefficients (r_p). Background axis scores are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

Variations in Axis 1 scores in 2010 were most strongly associated with ammonia (r_s = 0.44), sulphur (r_s = -0.36) and percent fines (r_s = -0.30) (Table 3-6, Appendix B-5). Axis 1 scores were not strongly associated with distance from the nearest active drill centre in 2010 (r_s = 0.16, Appendix B-5). Therefore, this first axis (variation in total abundance) in

2010 reflected variations in factors that were predominantly unaffected by drilling activity (ammonia, sulphur and fines[13]).

Abundances of Paraonidae were most strongly associated with variations in Axis 2 scores such that larger axis scores reflected higher abundances of Paraonidae. Biomass and Spionidae abundances were weakly associated with the second axis such that larger scores reflected higher total biomass and lower abundances of Spionidae. Variations in Axis 2 scores can be interpreted as representing variations in composition independent of total abundance. Axis 2 scores were strongly associated with barium (r_s = -0.79) and >C_{10}-C_{21} hydrocarbon concentrations (r_s = -0.71) and distance from the nearest active drill centre (r_s = 0.76) in 2010 (Table 3-6, Appendix B-5). Therefore, the second axis appears to have reflected the drilling operations effect on Paraonidae abundances.

Threshold models were tested using the NMDS Axis 2 station scores, since they correlated with distance in 2010. Threshold models were significant in 2005, 2006, 2008 and 2010 (Table 3-7, Appendix B-5). Threshold distances varied between 2.0 km (in 2010) and 5.2 km (in 2005) (Table 3-8, Appendix B-5).

5.3 Summary of Findings

5.3.1 Whole-Field Response

>C_{10}-C_{21} hydrocarbons and barium in sediments were clearly influenced by drilling operations in 2010, with concentrations elevated up to calculated threshold distances of 3.6 km and 2.0 km from the nearest active drill centre, respectively. Sulphur concentrations increased modestly at 0.3 km stations around the Central, Southern and North Amethyst Drill Centres and potentially, at the 0.3 km station around the Northern Drill Centre. Sulphur concentrations were unrelated to distance from the nearest active drill centre when the four stations nearest (0.3 km) drill centres were removed from the analysis, which suggests that effects did not extend beyond 0.3 km. There was an indication that fines were elevated by drilling at the 0.3 km station around the North Amethyst Drill Centre. Fines and metals concentrations increased somewhat across the sampling area, but other than at the one station for fines, concentrations were unrelated to distance from the nearest active drill centre. Therefore, these overall increases were likely not related to drilling operations. There was no indication of project effects on sediment TOC, redox potential and ammonia concentrations; although redox increased and ammonia decreased across the sampling area (with no association with distance from active drill centres). There was no influence of releases from the *SeaRose* FPSO on sediment physical and chemical characteristics.

Sediments were generally non-toxic, with amphipod survival exceeding 70% in all samples and only 1 of 49 samples were declared toxic in Microtox testing.

Total benthic abundances, benthic biomass and numbers of Paraonidae were lower in proximity to active drill centres in 2010, as in 2008, although the evidence for effects on total abundance in 2010 was weak. The biomass response was primarily related to a

[13] Ammonia was unaffected by project activity and sulphur and fines were predominantly unaffected except at one or two stations very near drill centres.

decrease in the number of echinoderms near drill centres. Richness was unaffected by project activity.

Total abundances and Paraonidae abundances exhibited a threshold response. However, the threshold model and a linear regression model for total abundance were not significant if one station (Station 20, located 0.37 km from the Central Drill Centre) was removed from the data set. Therefore, evidence of project effects on total abundance beyond that station was weak.

Total benthic biomass did not produce a threshold response in relation to distance from the nearest active drill centre but did exhibit a significant linear increase in abundance with distance from drill centre. Paraonidae abundance was affected to a calculated threshold distances of approximately 1.6 km from the nearest active drill centre. Abundances of Spionidae polychaetes, Tellinidae bivalves and Amphipods were reduced in the sampling area relative to what had been observed in the baseline year (2000), but there were no relationships with distance from the nearest active drill centre in 2010, which indicates that drilling was not likely influencing these indices of community composition.

5.3.2 Effects of Individual Drill Centres

Concentrations of hydrocarbons and barium and Paraonidae abundance were affected at each drill centre. In these three cases, there was an indication of overlap in effects from the Central and Southern Drill Centres. There was no evidence of effects on biomass at the Northern Drill Centre, but effects from the Central and Southern Drill Centres for biomass also appeared to overlap. There was no decrease in abundance around the Northern Drill Centre, but abundance tended to be lower near the other drill centres.

Graphical representation of effects on benthic invertebrates generally agreed with calculated threshold distances for effects, with effects noted within 2 km of drill centres. Because of the overlapping effect between the Central and Southern Drill Centres, it is difficult to estimate a zone of effects around any one of these two drill centres. To date, effects have not been confounded with other drill centres for the Northern and North Amethyst Drill Centres. Figures indicated that effects were restricted to within 630 m from the Northern Drill Centre and 500 m from the North Amethyst Drill Centre Station. Station N3, located 630 m from the Northern Drill Centre, was the furthest station showing an effect from the Northern Drill Centre. Station NA2, located 500 m from the North Amethyst Drill Centre, was the furthest station showing an effect from the North Amethyst Drill Centre.

The one station that was toxic to Microtox (Station C5-C) was located 0.37 km from the Central Drill Centre. $>C_{10}$-C_{21} hydrocarbon and barium concentrations were elevated at that station, and abundance and biomass were reduced.

In terms of magnitude of effect, and examining only the Drill Centre stations, $>C_{10}$-C_{21} and barium concentrations were highest around the North Amethyst Drill Centre in 2010, followed by the Central Drill Centre. Conversely, biomass and Paraonidae abundance were most depressed around the Central Drill Centre, followed by the Southern Drill Centre (Table 5-30). These results indicate a lagged effect between sediment

contamination and benthic invertebrate responses because most drilling occurred at the Central and Southern Drill Centres in 2008 (see Section 4).

Table 5-30 Values at Drill Centre Stations for Selected Variables

Station	Distance to Drill Centre (km)	$>C_{10}$-C_{21} (mg/kg)	Barium (mg/kg)	Richness	Abundance (#/m^2)	Biomass (g/m^2)	Paraonidae (#/m^2)
Central Drill Centre							
C5-C*	0.30	120	1,200	25	1,760	204**	5**
C2	0.83	11	480	18	1,135**	87**	0**
C3	0.74	11	350	31	2,045	764	5**
C1	1.14	5	180	24	2,275	264**	75**
C4	0.92	3	200	27	1,035**	235**	55**
Mean		**30**	**482**	**25**	**1,650**	**311**	**28****
Range		**3 to 120**	**180 to 1,200**	**18 to 27**	**1,035 to 2,275**	**87 to 764**	**0 to 75**
Northern Drill Centre							
N4	0.30	38	570	29	3,155	434	5**
N3	0.63	25	500	31	2,090	584	40**
N2	1.49	1	250	31	2,085	1,441	225
N1	2.18	1	160	29	2,075	799	315
Mean		**16**	**370**	**30**	**2,351**	**814**	**146**
Range		**1 to 38**	**160 to 570**	**29 to 31**	**2,075 to 3,155**	**434 to 1441**	**5 to 315**
North Amethyst Drill Centre							
NA1-C	0.29	810	2,700	30	1,315	230**	5**
NA2	0.50	110	310	23	1,495	323	120**
NA3	0.76	6	230	31	2,435	1,052	190
NA4-C	1.00	5	230	29	2,555	786	495
Mean		**233**	**868**	**28**	**1,950**	**598**	**203**
Range		**5 to 810**	**230 to 2,700**	**23 to 31**	**1,315 to 2,555**	**230 to 1,052**	**5 to 495**
Southern Drill Centre							
S5	0.32	100	1,000	26	1,785	184**	5**
S1	0.60	9	480	25	1,640	630	0**
S2	0.83	9	260	30	2,445	110**	5**
S4	0.92	4	240	29	2,310	988	280
S3	1.40	1	260	44	4,865	466	265
Mean		**25**	**448**	**31**	**2,609**	**476**	**111**
Range		**1 to 100**	**240 to 1,000**	**25 to 44**	**1,640 to 4,865**	**110 to 988**	**0 to 280**

Notes:
- * Station C5-C was also toxic to Microtox.
- ** and shading indicate values 25% or less below the baseline range for the three benthic variables that showed project effects. 75% of the baseline range for total abundance, biomass and Paraonidae abundance is 1,414 #/m^2, 275 g/m^2 and 98 #/m^2, respectively.
- Three other stations within 2 km of drill centres had total abundance and/or biomass and/or Paraonidae abundance reduced by 25% or less than the baseline range. Station 20, located 0.37 km from the Central Drill Centre, had an abundance of 510 #/m^2, a biomass of 98 g/m^2 and Paraonidae abundance of 5 #/m^2. Station 13, located 0.59 km from the Southern Drill Centre, had a biomass of 227 g/m^2 and Paraonidae abundance of 30 #/m^2. Station 21, located 1.89 km from the Central Drill Centre, had a biomass of 186 g/m^2.

6.0 Commercial Fish Component

6.1 Methods

6.1.1 Field Collection 2010

American plaice (plaice) and snow crab (crab) were collected on-board the commercial trawler *M/V Aqviq* between July 2 and July 5, 2010. 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
2010 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	July 2 to July 5, 2010

Note: - Since the location of Reference Areas sampled from 2004 to 2010 differs from locations sampled in 2000 and 2002, data from Reference Areas collected during baseline cannot be compared to EEM Reference Area data.

Details on the collection and processing of 2000, 2002, 2004, 2005, 2006 and 2008 samples are presented in Husky Energy (2001, 2003, 2005, 2006, 2007, 2009). Sampling for the 2010 program was conducted under an experimental fishing license issued by Fisheries and Oceans Canada (DFO). A total of 100 plaice and 102 crab from the White Rose Study Area were retained for analysis in 2010. A total of 121 plaice and 95 crab were retained from Reference Areas. Plaice and crab that were not retained were released with as little damage as possible. Location of transects are provided in Figure 6-1 and Appendix C-1[14].

[14] In previous years, trawl by-catch was also provided in this Appendix. However, because a commercial trawl, rather than DFO's Campelen trawl, was used in 2010, by-catch was minimal and not comparable to by-catch obtained in previous years.

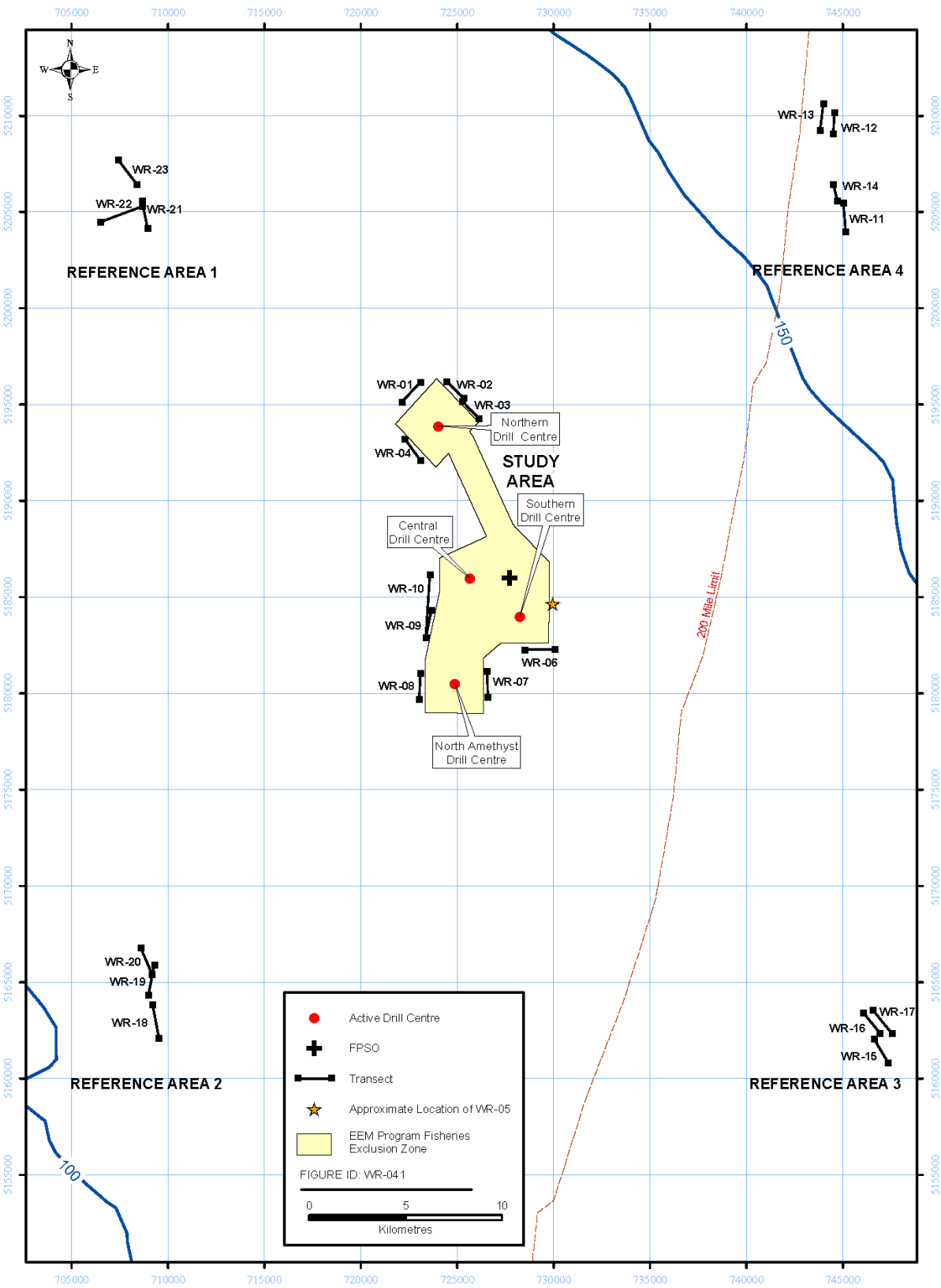

Figure 6-1 2010 EEM Program Transect Locations

Preliminary processing of samples was done on board the vessel. 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 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 plaice larger than 250 mm in length and crab larger than 60 mm in carapace width were retained for analysis.

The following procedures were adhered to 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 labelled 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 Mixed Function Oxygenase (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. Processed samples were transferred to a -20ºC freezer within one hour of collection where applicable.

6.1.2 Laboratory Analysis

6.1.2.1 Allocation of Samples

Plaice from 10 trawls in the Study Area and 12 trawls in the Reference Areas were used for body burden analysis, taste tests and fish health. Plaice bottom fillets and liver tissues were composited to generate 10 individual body burden samples for fillet and liver for the Study Area and three composites for each of the Reference Areas. When sufficient tissue was available, tissue from individual fish was archived for subsequent 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 fillets selected from the Study Area and the Reference Areas were allocated to the triangle test and the hedonic scaling test (see Section 6.1.2.3 for details on taste tests) and then randomly assigned to panelists. Fish health analyses were conducted 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 (2010)

Transect No.	Area	No. of Fish Retained	Body Burden Composites (Bottom Fillet, or Liver)	Taste Test (wt. (g) of Top Fillets)	Fish Health (No. of Fish)
WR-1	Study Area	10	Composite 1 (6 fish)	242	6
WR-2	Study Area	10	Composite 2 (10 fish)	241	6
WR-3	Study Area	10	Composite 3 (6 fish)	265	6
WR-4	Study Area	10	Composite 4 (10 fish)	245	6
WR-5	Study Area	10	Composite 5 (10 fish)	243	6
WR-6	Study Area	10	Composite 6 (6 fish)	235	6
WR-7	Study Area	10	Composite 7 (6 fish)	265	6
WR-8	Study Area	10	Composite 8 (6 fish)	251	6
WR-9	Study Area	10	Composite 9 (6 fish)	246	6
WR-10	Study Area	10	Composite 10 (6 fish)	251	6
Total		**100**	**10**	**2,484**	**60**
WR-11	Reference Area 4	10	Composite 11 (10 fish)	205	10
WR-12	Reference Area 4	10	Composite 12 (10 fish)	214	10
WR-13	Reference Area 4	10	Composite 13 (10 fish)	204	10
WR-15	Reference Area 3	10	Composite 14 (10 fish)	199	10
WR-16	Reference Area 3	10	Composite 15 (10 fish)	207	10
WR-17	Reference Area 3	11	Composite 16 (10 fish)	211	10
WR-18	Reference Area 2	10	Composite 17 (10 fish)	213	10
WR-19	Reference Area 2	10	Composite 18 (10 fish)	216	10
WR-20	Reference Area 2	10	Composite 19 (10 fish)	214	10
WR-21	Reference Area 1	10	Composite 20 (10 fish)	202	10
WR-22	Reference Area 1	10	Composite 21 (10 fish)	202	10
WR-23	Reference Area 1	10	Composite 22 (10 fish)	212	10
Total		**121**	**22**	**2,499**	**120**

Notes:
- Ten, rather than six, fish were needed from WR-2, WR-4 and WR-5 for chemistry analysis because of insufficient liver volume. Otherwise, the norm is to process only those fish processed for health analyses in chemistry analyses. The number of fish required to obtain sufficient tissue for both tests was estimated during the EEM design phase (Husky Energy 2004) and these numbers have been adequate for all years except this (2010) year. Given results in 2010, additional supplies for fish health analyses may be brought on board vessel in future years to process more fish if liver volume appears insufficient to perform both sets of tests on the same group of fish.
- For taste tests, tissue weights were selected 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 10 trawls in the Study Area and 12 trawls in the Reference Areas were used for body burden and taste analyses. No soft shell crabs were noted in samples. From each trawl, tissue from right legs was composited to generate 10 body burden samples for the Study Area and three samples for each of the four Reference Areas (Table 6-3). Left leg tissue was used in taste analysis. In this test, leg tissue selected from the Study Area and the Reference Areas were allocated to the triangle test and the hedonic scaling test (see Section 6.1.2.3 for details on taste tests) and then randomly assigned to panelists.

Table 6-3 Crab Selected for Body Burden and Taste Analysis (2010)

Transect No.	Area	No. of Crab	Body Burden Composites (Right Legs)	Taste Tests (wt. (g) of Crab, Left Legs)
WR-01	Study Area	12	Composite 1 (12 crab)	800
WR-02	Study Area	12	Composite 2 (12 crab)	756
WR-03	Study Area	12	Composite 3 (12 crab)	791
WR-04	Study Area	12	Composite 4 (12 crab)	779
WR-05	Study Area	12	Composite 5 (12 crab)	764
WR-06	Study Area	12	Composite 6 (12 crab)	800
WR-07	Study Area	12	Composite 7 (12 crab)	763
WR-08	Study Area	6	Composite 8 (6 crab)	802
WR-09	Study Area	6	Composite 9 (6 crab)	573
WR-10	Study Area	6	Composite 10 (6 crab)	637
Total		**102**	**10**	**7,465**
WR-11	Reference Area 4	6	Composite 11 (6 crab)	706
WR-12	Reference Area 4	12	Composite 12 (12 crab)	706
WR-13/14	Reference Area 4	11	Composite 13 (11 crab)	715
WR-15	Reference Area 3	6	Composite 14 (6 crab)	718
WR-16	Reference Area 3	6	Composite 15 (6 crab)	568
WR-17	Reference Area 3	6	Composite 16 (6 crab)	620
WR-18	Reference Area 2	12	Composite 17 (12 crab)	728
WR-19	Reference Area 2	6	Composite 18 (6 crab)	601
WR-20	Reference Area 2	6	Composite 19 (6 crab)	445
WR-21	Reference Area 1	6	Composite 20 (6 crab)	645
WR-22	Reference Area 1	12	Composite 21 (12 crab)	702
WR-23	Reference Area 1	6	Composite 22 (6 crab)	714
Total		**95**	**12**	**7,868**

Note: - 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.

6.1.2.2 Body Burden

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

Table 6-4 Body Burden Variables (2000, 2002, 2004, 2005, 2006, 2008 and 2010)

Variables		Laboratory Detection Limits					Units
	Method	2000	2002	2004 & 2005	2006	2008 & 2010	
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

Variables		Laboratory Detection Limits					Units
	Method	2000	2002	2004 & 2005	2006	2008 & 2010	
Fluorene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Indeno[1,2,3-cd]pyrene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Naphthalene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Perylene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Phenanthrene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Pyrene	GC/MS	0.05	0.05	0.05	0.05	0.05	mg/kg
Metals							
Aluminum	ICP-MS	2.5	2.5	2.5	2.5	2.5	mg/kg
Antimony	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Arsenic	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Barium	ICP-MS	1.5	1.5	1.5	1.5	1.5	mg/kg
Beryllium	ICP-MS	1.5	1.5	0.5	0.5	0.5	mg/kg
Boron	ICP-MS	1.5	1.5	1.5	1.5	1.5	mg/kg
Cadmium	GFAAS	0.08	0.05	0.05	0.05	0.05	mg/kg
Chromium	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Cobalt	ICP-MS	0.2	0.2	0.2	0.2	0.2	mg/kg
Copper	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Iron	ICP-MS	5	5	15	15	15	mg/kg
Lead	ICP-MS	0.18	0.18	0.18	0.18	0.18	mg/kg
Lithium	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Manganese	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Mercury	CVAA	0.01	0.01	0.01	0.01	0.01	mg/kg
Molybdenum	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Nickel	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Selenium	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Silver	ICP-MS	0.12	0.12	0.12	0.12	0.12	mg/kg
Strontium	ICP-MS	1.5	1.5	1.5	1.5	1.5	mg/kg
Thallium	ICP-MS	0.02	0.02	0.02	0.02	0.02	mg/kg
Tin	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Uranium	ICP-MS	0.02	0.02	0.02	0.02	0.02	mg/kg
Vanadium	ICP-MS	0.5	0.5	0.5	0.5	0.5	mg/kg
Zinc	ICP-MS	0.5	0.5	0.5	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 Estimated Quantification Limit was used in previous years instead of laboratory detection limit. The two terms are fully interchangeable and mean the lowest concentration that can be detected reliably within specified limits of precision and accuracy during routine laboratory operating conditions. Laboratory detection limits may vary from year to year because instruments are checked for precision and accuracy every year as part of QA/QC procedures[15].

- NA = Not Analyzed.

6.1.2.3 Taste Tests

Plaice and crab samples were delivered frozen to the Fisheries and Marine Institute of Memorial University for sensory evaluation, using 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.

[15] Typically, Maxxam Analytics sets the laboratory detection limits at 2 to 10 times the Method Detection Limit calculated using the US Environmental Protection Agency protocol. The 2 to 10 times Method Detection Limit factor for laboratory detection limits 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.

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.

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 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

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 or 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 nor	_____ neither like nor
_____ dislike	_____ 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

6.1.2.4 Fish Health Indicators

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 was counted.

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 27°C, 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 controls (pools of liver homogenates from uninduced cunners (negative control) and cunners induced with petroleum (positive control)) were run with each batch of samples to ensure consistency of measurements.

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 labelled 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; Feist et al. 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. Proliferation of Macrophage aggregates
10. Hydropic vacuolation
11. Fibrillar inclusions

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

Inflammatory response was rated on a scale of 0 to 3 (0-absent, 1-mild, 2-moderate and 3-heavy).

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

Gill

Each gill sample was examined microscopically, first under low 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 two-thirds 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 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) and 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.

6.1.3 Data Analysis

6.1.3.1 Changes from the 2008 Program

The approach used to analyze the tissue chemistry data in 2010 was very similar to previous years, with some changes to make the analysis more direct. In prior years, Principal Component Analysis was used to produce a derived variable (metals PC1) that was used like an analyte in subsequent analysis of variance testing for differences between Reference and Study Areas. That analysis was not used here to simplify the analysis and make it more direct by analyzing the individual analytes rather than a derived variable (i.e., a PC axis score). This approach to the analysis is equivalent to, and potentially more rigorous than what has been done in previous years because all analytes were examined. The direct assessment of individual analytes also ensured a fuller understanding of the degree of bioaccumulation of the various metals, in particular mercury that can biomagnify.

The 2008 report also relied on a completely randomized design analysis of variance (ANOVA) to test for differences in temporal trends between Reference and Study Areas. That design, rather than a repeated-measured ANOVA, was used in 2008 because two of the four Reference Areas were not sampled in 2008. The analysis of the 2010 data, which had four Reference Areas to contrast with the single Study Area, used a repeated-measures ANOVA, excluding the 2008 data. This use of the repeated-measures ANOVA was consistent with what had been done in years prior to 2008, and is consistent with the approaches used with other data components, including sediment quality and benthic invertebrate community composition. The repeated-measures ANOVA methodology is described in greater detail in Section 6.1.3.3.

6.1.3.2 Biological Characteristics

Biological characteristics (morphometric and life history characteristics) of plaice and crab were analyzed to determine if there were differences among composites that could affect results of body burden analyses. Analyses were restricted to plaice and crab used for body burden analyses in 2010. Formal comparisons among years were not conducted.

Plaice

Analyses of plaice biological characteristics were restricted to gutted weights (i.e., size) of fish in composite samples. Composite mean weights were compared among Areas in

ANOVA to test for differences in body size between Reference and Study Areas. Additional analyses on plaice biological characteristics were performed within the context of fish health analyses (Section 6.1.3.4).

Crab

Biological characteristics of crab included carapace width and claw height (i.e., size), and frequency of recent moults based on the shell condition index. 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.

ANOVA was used to test for significant differences in carapace width and claw height between the Reference and Study Areas, with variation among the four Reference Areas was used to judge the difference between the Reference Areas (overall) and the Study Area.

6.1.3.3 Body Burden

Plaice

Spatial Variations in 2010

Body burden data from composite samples were available for both liver and fillet tissue. Variables associated with liver tissue that were statistically analyzed included fat content, moisture content, concentrations of eight metals frequently detected (arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc), and $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons concentrations.

Variables analyzed in fillets were fat content and concentrations of arsenic, mercury and zinc. These compounds were detected in every composite in 2004, 2006, 2008 and 2010.

Log-transformed values for liver and fillets were compared among Areas in one-way ANOVA.

Variations in Temporal Trends

Differences in temporal trends in plaice liver variables were tested using repeated-measures ANOVA of area-average tissue concentrations from 2004, 2005, 2006 and 2010. Data from 2000 were not included because Reference Area data were collected in different locations during that year. Data from 2008 were not included because data were not collected from Reference Areas 3 and 4 because of intense fishing activity in those two Reference Areas at the time of the survey. However, the data from the Study Area and Reference Area in 2008 were included in scatter plots, so it was possible to visually inspect those data and compare them to data before and after that year.

Crab

Spatial Variations in 2010

Crab 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 laboratory detection limits were set at laboratory detection limit rather than ½ laboratory

detection limits. The two-fold difference between the laboratory detection limit and ½ laboratory detection limit in fat content, boron and selenium concentrations in crab claws was larger than most differences in detectable values within and among Areas, so using ½ laboratory detection limit to replace values less than laboratory detection limit was considered likely to bias analyses.

Differences in fat content, moisture content and concentrations of the seven frequently detected metals were tested using ANOVA, with variations among Reference Areas used as the error term against which to judge differences between the Reference Areas (overall) and the Study Area.

Variations in Temporal Trends

Differences in temporal trends in fat content, moisture content and concentrations of metals in crab tissue were tested using a repeated-measures ANOVA of area-average tissue concentrations. Data from 2004, 2005, 2006 and 2010 were used in this analysis. Data from 2000 were not included because Reference Area data were collected in different locations in that year. Data from 2008 were not included because data were not collected from Reference Areas 3 and 4 because of intense fishing activity in those two Reference Areas at the time of the survey. However, data from the Study Area and Reference Area in 2008 were included in scatter plots, so it was possible to visually inspect those data and compare them to data before and after that year.

6.1.3.4 Taste Tests

Unlike analyses on biological characteristics (Section 6.1.3.1), body burdens (Section 6.1.3.2) and fish health indicators (Section 6.1.3.4), triangle tests and hedonic scaling tests compared Study Area samples to pooled Reference Area samples (see Section 6.1.2.3).

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-3 (after Larmond 1977) to determine statistical significance. For a panel size of 24, a statistically significant discrimination between Areas (at α = 0.05) would require that 13 panelists correctly identify samples.

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

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

6.1.3.5 Fish Health Indicators

The commercial fish component of the White Rose EEM program uses a multiple-reference design, with four Reference Areas and a single Study Area. Two comparisons or contrasts were of interest:

- Study versus Reference Areas (SR)
- Among Reference Areas (AR)

The Reference Areas were the appropriate replicates for testing the SR contrast, with exceptions noted below.

Sex Ratio and Maturity Stages

Fisher's Exact Test or Pearson Chi-Square Test was used to compare sex ratios (male : female) and maturity stages between the Study Area and combined Reference Areas (SR contrast).

Size, Age and Condition

Continuous variables for each sex were compared among Areas via ANOVA (or ANCOVA equivalents for condition or liver and gonad indices; see below). Both the Among-Reference and Study versus Reference contrasts were tested.

Total length, gutted weight and age were analyzed using ANOVA (i.e., with no covariate or *X* variable).

The regression analogues of three condition indices (Fulton Condition Factor (CF), Hepatosomatic Index (HSI) and Gonadosomatic Index (GSI)) were analyzed via ANCOVA, which compares regression intercepts or adjusted means among Areas.

MFO Activity

ANOVAs were used to compare MFO activity among Areas for mature males, and for pre-spawning and spent females. Reference Areas were separated for analysis of males and combined for analysis of females. MFO values were log-transformed for analyses.

Haematology

Numbers of lymphocytes and thrombocytes counted in samples of 200 cells were converted to percentages and analyzed with ANOVA, with the Reference Areas separated. Both male and female fish were combined for the analysis, since there was no reason to expect differences between sexes or maturity stages. No analyses were conducted on neutrophils, which were rare or absent in samples.

Histopathology

Liver Histopathology

Both male and female fish were combined for analysis of liver histopathology. Fisher's Exact Test was used to compare presence versus absence of hepatocellular vacuolation and biliary parasites between the Study Area versus combined Reference Areas. Other liver abnormalities were rare or absent and were not statistically analyzed.

Gill Histopathology

Both male and female fish were combined for analysis of gill histopathology. Percentages of lesions were analyzed using ANOVA between the Study Area and combined Reference Areas. Fisher's Exact Test was used to compare frequencies of fish with at least one lamella affected by tip and distal hyperplasia between the Study Area and combined Reference Areas. Other lesions were too rare for meaningful robust analyses.

A more detailed description of analysis methods for fish health indicators is provided in Appendix C-3 (Annex B).

6.2 Results

6.2.1 Biological Characteristics

6.2.1.1 Plaice

Summary statistics for composite mean gutted weights of plaice are provided in Table 6-5. Variations in mean fish weight within composites did not differ significantly among Reference Areas (p = 0.23) or between the Study and Reference Areas (p = 0.17, Table 6-6). The average Reference Area fish was 518 g ± 22 g, while the average Study Area fish was 555 g ± 60 g. Therefore, there was considerable overlap in the sizes of fish from the Reference and Study Areas that were analyzed for body burden. Differences in chemistry between Reference and Study Area fish, if any, will therefore not be due to differences in fish size.

Table 6-5 Summary Statistics for Plaice Composite Mean Gutted Weight (g) (2010)

Area	*n*	Min	Max	Mean	SD
Reference Area 1	3	560	567	563	3
Reference Area 2	3	498	537	518	19
Reference Area 3	3	451	510	480	30
Reference Area 4	3	472	541	511	35
Reference Average		495	539	518	22
Study Area	10	475	645	555	60

Table 6-6 Results of ANOVA Comparing Plaice Composite Mean Gutted Weight Among Areas (2010)

Source	SS	df	MS	F-Ratio	*p*-Value
Study vs Reference (SR)	7,329	1	7,329	3.332	0.165
Among Reference (AR)	10,557	3	3,519	1.600	0.226
Error	37,390	17	2,199		

Additional analyses on biological characteristics of plaice related to fish health indicator assessment are provided within the context of fish health analyses (Section 6.2.4).

6.2.1.2 Crab

Shell condition index values for the crab collected in 2010 and used for body burden analyses are provided in Table 6-7. Shell condition was recorded for all crab used for body burden analysis. None of the crabs collected had moulted in 2010, while most had moulted in 2008 or earlier. The frequency of crabs that had moulted in 2008 or earlier was approximately even in Reference (85%) and Study Areas (83%).

Table 6-7 Number (and %) of Crab and Associated Index Values (2010)

Index Value	Year of Moult	Area					
		Reference Total	Ref 1	Ref 2	Ref 3	Ref 4	Study
2	2010						
6	2009	14 (15%)	12 (40%)			2 (9%)	17 (17%)
3,4	2008 or earlier	81 (85%)	18 60%)	24 (100%)	18 (100%)	21 (91%)	85 (83%)
Total Crab			**95**	**30**	**24**	**18**	**23**

Summary statistics for composite means for carapace width and claw height are provided in Table 6-8. Crab analyzed for chemistry and morphometry were generally similar in size (Table 6-9), with an average carapace width of ~103 mm (± ~20 to 24 mm, i.e., ± 2 Standard Deviations (SDs)) in both Reference and Study Areas, and an average claw height of 23 to 24 mm (Table 6-8). The ANOVA in Table 6-9 reflected that carapace width and claw height did not vary significantly among Reference Areas, and did not vary significantly between Reference and Study Areas. Differences in chemistry between Reference and Study Area crab, if any, will therefore not be due to differences in size.

Table 6-8 Summary Statistics for Biological Characteristics of Crab Based on Composite Mean Carapace Width and Claw Height (2010)

Variable	Area	*n*	Min	Max	Mean	SD
Carapace width (mm)	Reference Area 1	30	73	138	101	14
	Reference Area 2	24	85	120	100	11
	Reference Area 3	18	98	117	108	7
	Reference Area 4	23	85	122	104	9
	Reference mean	95	85	124	103	10
	Study Area	102	71	127	103	12
Claw height (mm)	Reference Area 1	29	16	33	23	5
	Reference Area 2	23	15	32	22	4
	Reference Area 3	18	17	29	25	3
	Reference Area 4	22	14	29	23	4
	Reference mean	92	16	31	23	4
	Study Area	96	12	34	24	5

Note: - Claw height was not recorded for some individuals, producing lower sample sizes.

Table 6-9 Results of ANOVA Comparing Crab Biological Characteristics Among Areas (2010)

Variable	Source	SS	df	MS	F-Ratio	*p*-Value
Carapace Width	Study vs Reference	15	1	15.5	0.15	0.697
	Among Areas	593	3	197.7	1.95	0.124
	Composite (Area)	8944	18	496.9	4.89	0.000
	Error	17672	174	101.6		
Claw Height	Study vs Reference	17	1	16.6	1.09	0.297
	Among Areas	36	3	12.0	0.79	0.502
	Composite (Area)	1282	18	71.2	4.69	0.000
	Error	2503	165	15.2		

6.2.2 Body Burden

6.2.2.1 Plaice

Liver

Summary statistics for detected substances in plaice liver in 2004, 2005, 2006, 2008 and 2010 and raw data for 2010 are provided in Appendix C-2. Hydrocarbons detected in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} range in all years have shown no resemblance to drill fluid (J. Kiceniuk, pers. comm.) Most of the hydrocarbon peaks observed on chromatograms for liver (Appendix C-2; also see Husky Energy (2005, 2006, 2007, 2009) for chromatograms for 2004, 2005, 2006 and 2008 samples, respectively) were consistent with those expected for natural compounds (Maxxam Analytics, pers. comm.; J. Kiceniuk, pers. comm.) and similar compounds also have been consistently observed at the nearby Terra Nova site. In 2010, four samples from White Rose were analyzed further to more precisely determine the nature of the compounds and results indicated

that many of the identified compounds were naturally occurring. These additional analyses are provided in Appendix C-2.

Spatial Variations in 2010

The results of ANOVA are presented in Table 6-10 while the spatial variations in analyte concentrations are illustrated in the box plots in Figure 6-5. Concentrations of several analytes varied significantly among Reference Areas including fat, moisture, selenium, mercury and $>C_{10}$-C_{21} hydrocarbons. Zinc concentrations in livers of plaice were significantly lower in Study Area fish than in Reference Area fish (i.e., median of ~27 mg/kg in the Study Area versus a median of ~29 to 30 mg/kg in the Reference Areas). The concentration of naturally occurring compounds in the $>C_{21}$-C_{32} hydrocarbon range was higher in livers of Study Area fish (nearly 150 mg/kg) compared to Reference Area fish (generally less than 100 mg/kg). The concentration of other analytes in liver did not differ between Reference and Study Areas.

Table 6-10 Results of ANOVA Comparing Plaice Liver Body Burden Variables among Areas (2010)

Analyte	*p*-values	
	Among Reference (AR)	**Study vs Reference (SR)**
Fat	0.004**	0.567
Moisture	0.030*	0.744
Arsenic	0.507	0.557
Cadmium	0.388	0.998
Copper	0.776	0.885
Iron	0.677	0.311
Manganese	0.119	0.267
Mercury	0.011*	0.963
Selenium	**0.000*** **	0.925
Zinc	0.605	**0.008*** **
$>C_{10}$-C_{21}	**0.000*** **	0.641
$>C_{21}$-C_{32}	0.142	0.023*

Notes: - Analyte concentrations were $\log_{10}$ transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

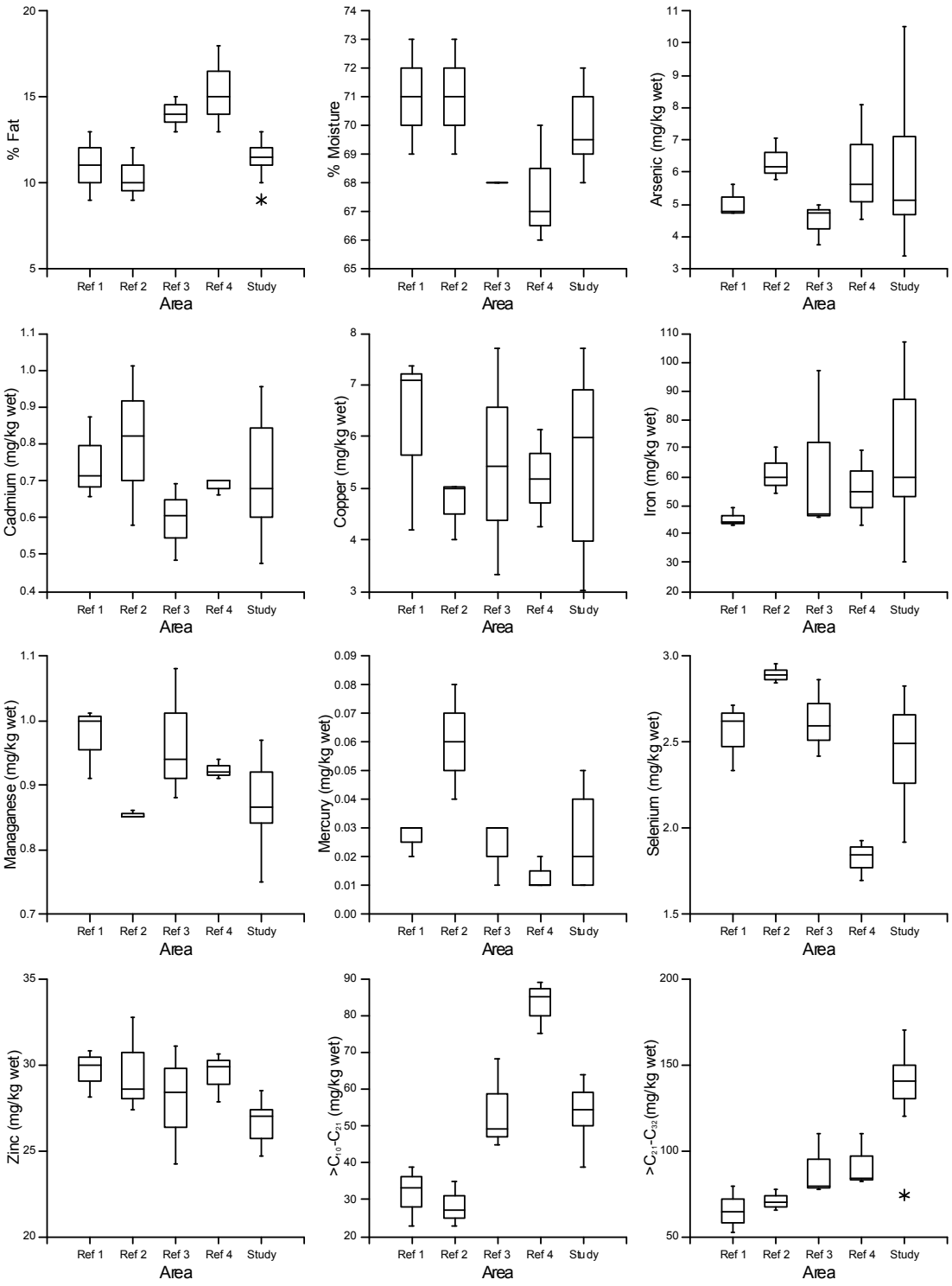

Figure 6-5 Box Plots of Analyte Concentrations in Plaice Livers in Reference and Study Areas (2010)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ± 1.5 x interquartile spread. Asterisks indicate values falling within the quartile ± 3 x interquartile spread.

Variations in Temporal Trends

Variations in mean analyte concentrations in plaice livers between 2004 and 2010 are illustrated in Figure 6-6. Arsenic, cadmium, copper, selenium and zinc concentrations all significantly increased in livers of plaice between 2004 and 2010 in the Reference and Study Areas with no difference between Areas (Table 6-11). The only two analytes that produced a significant linear or quadratic effect[16] for differences in temporal trends between Reference and Study Areas were the naturally occurring hydrocarbons. Concentrations compounds in the $>C_{10}$-C_{21} hydrocarbon range decreased more over time in Reference Area plaice livers than in Study Area plaice livers. Concentrations of the compounds in the $>C_{21}$-C_{32} hydrocarbon range increased over time in the Study Area, and remained stable in plaice livers in the Reference Areas. The concentration of compounds in the $>C_{21}$-C_{32} hydrocarbon range was below 70 mg/kg wet weight in the first two years of monitoring, but has been above 130 mg/kg wet weight since 2006. The high concentrations on $>C_{21}$-C_{32} in 2008 were considered somewhat anomalous in the 2008 report (Husky Energy 2009) because of a long holding time, drying of tissues and associated magnification of the overall tissue concentrations. However, the concentrations in 2008 were not unusual relative to what was observed in 2006 and now in 2010.

Table 6-11 Results of Repeated Measures ANOVA Testing for Differences in Average Plaice Liver Body Burden Variables and Temporal Trends Between the Reference Areas and the Study Areas (2004 to 2010)

Analyte	Area-Wide Temporal Trends		Differences in Temporal trends Between Reference and Study Areas	
	Linear	Quadratic	Linear	Quadratic
Fat	0.222	0.102	0.954	0.602
Moisture	0.357	0.177	0.534	0.730
Arsenic	0.005**	0.179	0.128	0.744
Cadmium	0.015*	0.192	0.331	0.904
Copper	0.030*	0.075	0.214	0.990
Iron	0.100	0.378	0.667	0.555
Manganese	0.434	0.927	0.956	0.849
Mercury	0.294	0.596	0.787	0.923
Selenium	0.009**	0.193	0.916	0.582
Zinc	0.008**	0.468	0.915	0.349
$>C_{10}$-C_{21}	**0.001*** **	0.850	0.005**	0.655
$>C_{21}$-$_{32}$	0.015*	0.313	0.015*	0.231

Notes: - Analyte concentrations were $\log_{10}$ transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

[16] A quadratic "effect" means that the analyte concentration increases then decreases over time, or *vice versa*.

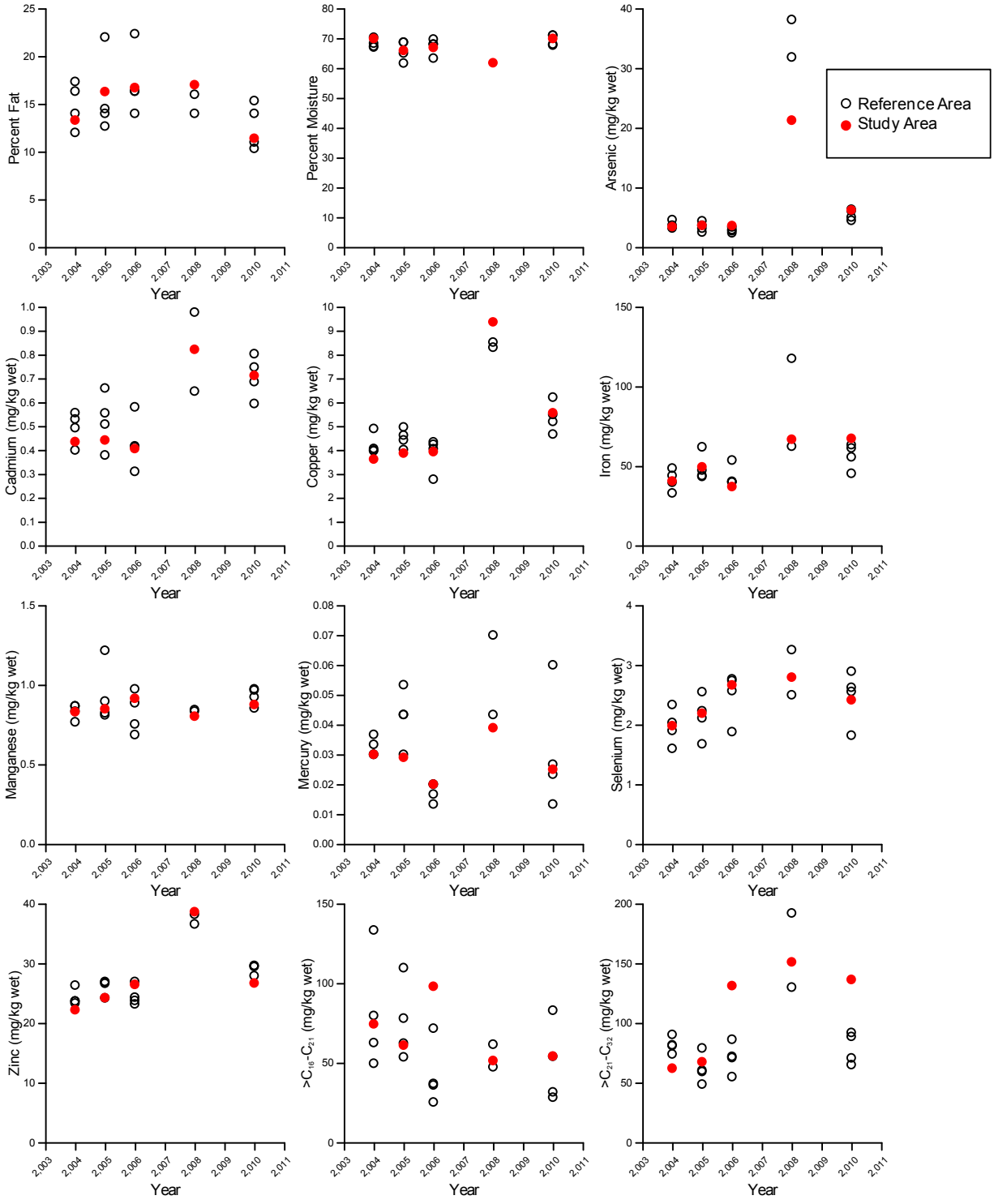

Figure 6-6 Variations in Area Means of Detectable Metals and Hydrocarbons in Plaice Liver Composites from 2004 and 2010

Note: Values shown are annual averages within Areas.

Fillets

Summary statistics for concentrations of detected substances in 2004, 2005, 2006, 2008 and 2010 and raw data for 2010 are provided in Appendix C-2. One fillet sample from Reference Area 4 had detectable hydrocarbons in the $>C_{10}$-C_{21} range in 2005, and one 2006 sample from the same Area had detectable hydrocarbons in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} ranges, but the chromatograms for these samples did not indicate the presence of hydrocarbons from drill muds (Maxxam Analytics, pers. comm.).

Spatial Variations in 2010

ANOVA was used to test for differences between the Reference Areas and the Study Area in %fat, %moisture and metals (mercury, arsenic, zinc) concentrations of plaice fillets. There were no differences in analyte concentration among Reference Areas. Place fillets from the Study Area had significantly (p = 0.018) higher fat content (1.2%) compared to Reference Areas (≤1%). All other tissue parameters were either statistically similar among sampling Areas (Table 6-12), within the range of values observed in the Reference Areas (Figure 6-7), or were below reportable detection limits.

Table 6-12 Results of ANOVA Comparing Plaice Fillet Body Burden Variables Among Areas (2010)

Analyte	*p*-values	
	Among Reference (AR)	**Study vs Reference (SR)**
Fat	0.539	0.018*
Moisture	0.736	0.403
Arsenic	0.202	0.464
Mercury	0.558	0.365
Zinc	0.820	0.184

Notes: - Analyte concentrations were $\log_{10}$ transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

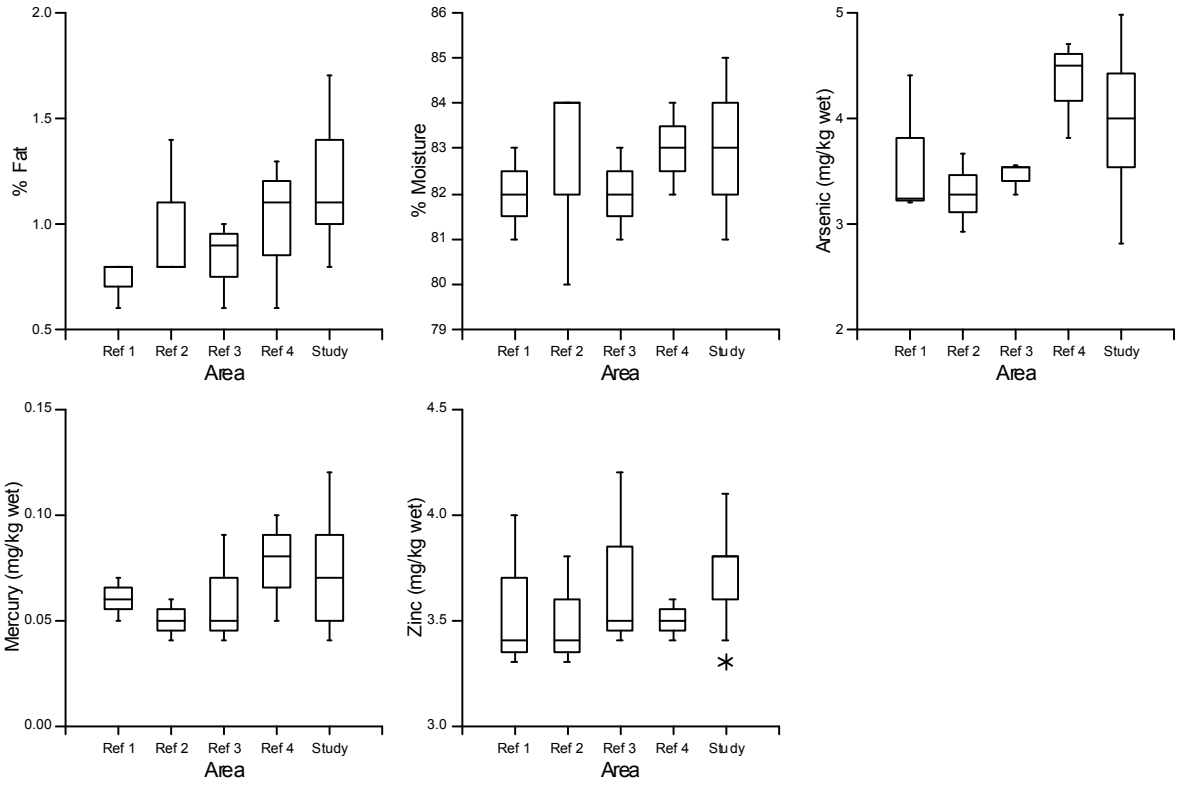

Figure 6-7 Box Plots of Analyte Concentrations in Plaice Fillets in Reference and Study Areas (2010)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ± 1.5 x interquartile spread. Asterisks indicate values falling within the quartile ± 3 x interquartile spread.

Variations in Temporal Trends

Fat content and zinc concentrations generally decreased over time in both Study and Reference Areas, while percent moisture and arsenic concentrations in plaice fillets increased over time across both Study and Reference Areas (Figure 6-8, Table 6-13). Fillet moisture was near the highest recorded (i.e., >80%) in 2010, in contrast to the values reported in 2008, which were considerably lower than in other years (i.e., <60%; Figure 6-8), when the samples were kept in storage for an extended period[17]. There were no differences in temporal trends between the Reference Areas and the Study Area for fat, moisture or any of the metals in plaice filets (Table 6-13).

[17] As a result, the 2008 report recommended that samples not be stored for extended periods of time.

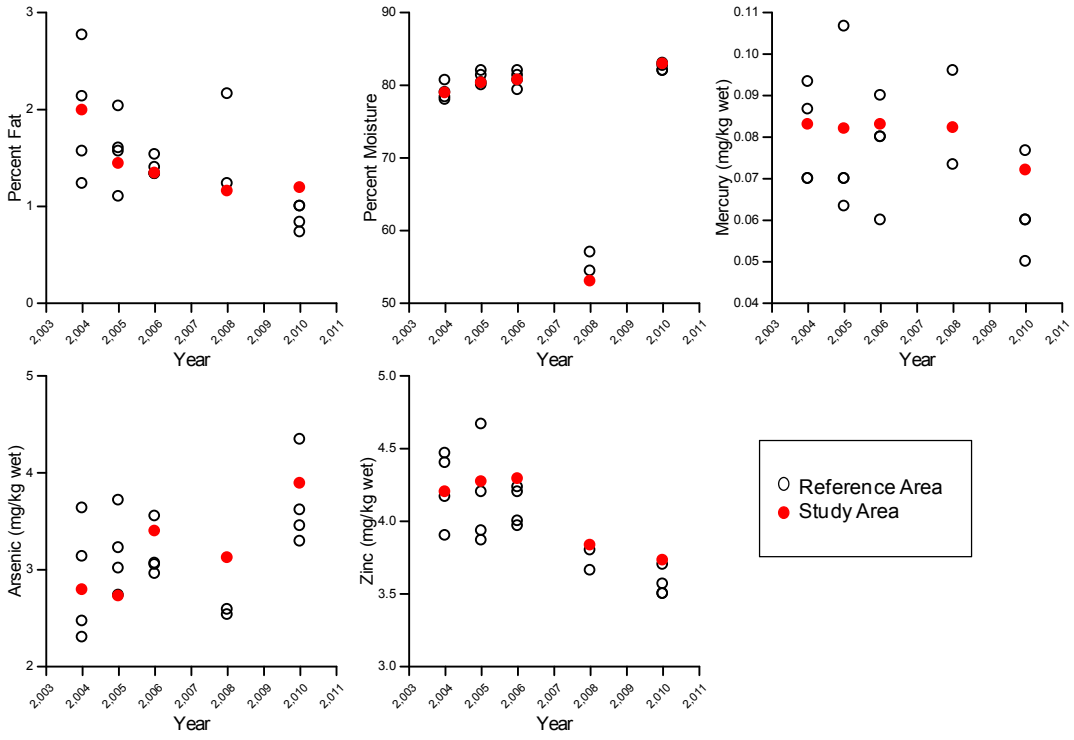

Figure 6-8 Variations in Fat, Moisture, Mercury, Arsenic and Zinc Concentrations in Plaice Fillets from 2004 to 2010

Note: Values shown are annual averages within Areas.

Table 6-13 Results of Repeated Measures ANOVA Testing for Differences in Average Fillet Body Burden Variables and Temporal trends Between the Reference Areas and the Study Areas (2004 to 2010)

Analyte	Area-Wide Temporal trends		Differences in Temporal trends Between Reference and Study Areas	
	Linear	Quadratic	Linear	Quadratic
Fat	0.11	0.31	0.72	0.83
Moisture	0.01**	0.25	0.58	0.86
Mercury	0.06	0.87	0.53	0.24
Arsenic	0.23	0.68	0.68	0.92
Zinc	0.02*	0.35	0.45	0.99

Notes:
- Values are probabilities of no temporal trend or no difference in temporal trends.
- Analytes were $\log_{10}$ transformed prior to analysis.
- $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (**in bold**).

6.2.2.2 Crab

Summary statistics for concentrations of detected substances in crab claw composites in 2004, 2005, 2006, 2008 and 2010 are provided in Appendix C-2, as are raw data for 2010.

Spatial Variations in 2010

There were significant differences in copper and silver concentrations among Reference Areas in 2010, but not in other analytes (Table 6-14). ANOVA confirmed no significant differences between Reference Areas and the Study Area with respect to percent fat, moisture content and metal concentrations of crab claws (Table 6-14). The average fat (~0.75%) and moisture (~76%) content of Study Area crab tissue were within the range of average values for Reference Area crab tissues (Figure 6-9).

Table 6-14 Results of ANOVA Comparing Crab Body Burden Variables Among Areas (2010)

Analyte	*p*-value	
	Among Reference (AR)	**Study vs Reference (SR)**
Arsenic	0.693	0.154
Boron	0.494	0.256
Copper	0.042*	0.816
Mercury	0.340	0.249
Selenium	0.073	0.752
Silver	**0.001*** **	0.427
Strontium	0.642	0.605
Zinc	0.961	0.210

Notes: - Values are probabilities of no difference among or between the Areas.
- Analyte concentrations were $\log_{10}$ transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

Variations in Temporal Trends

All of the metals in crab tissue in 2010 were within the range of values reported in previous years, with one exception (Figure 6-10). Mercury concentrations of Study Area crab were approximately 0.07 mg/kg, down from the long-term average of approximately 0.1 mg/kg from previous years. Concentrations of mercury in Reference Area crab were also lower in 2010 than in previous years.

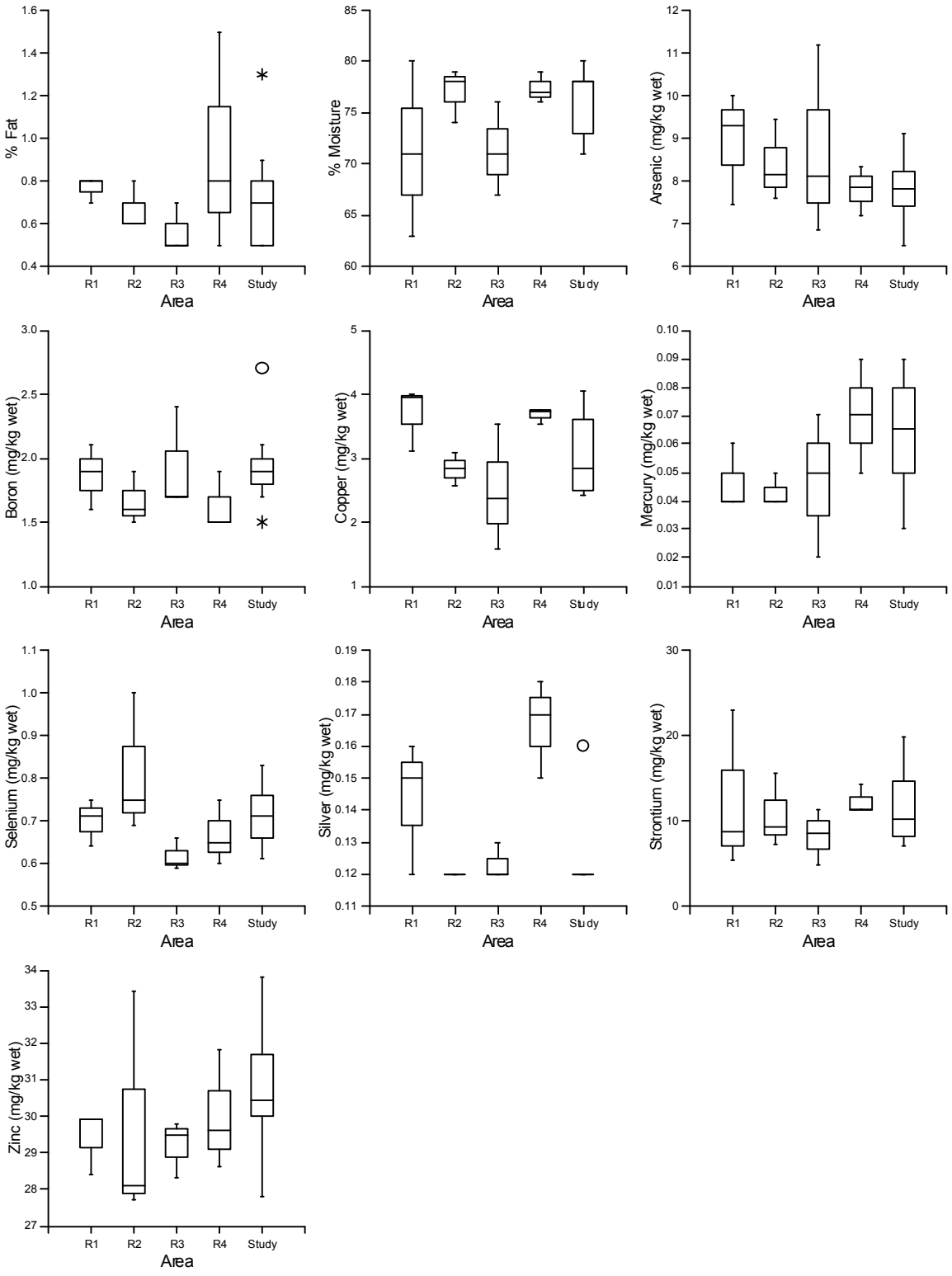

Figure 6-9 Box Plots of Analyte Concentrations in Crab Claw in Reference and Study Areas (2010)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ± 1.5 x interquartile spread. Asterisks indicate values falling within the quartile ± 3 x interquartile spread. Open circles indicate values falling outside the quartile ± 3 x interquartile spread.

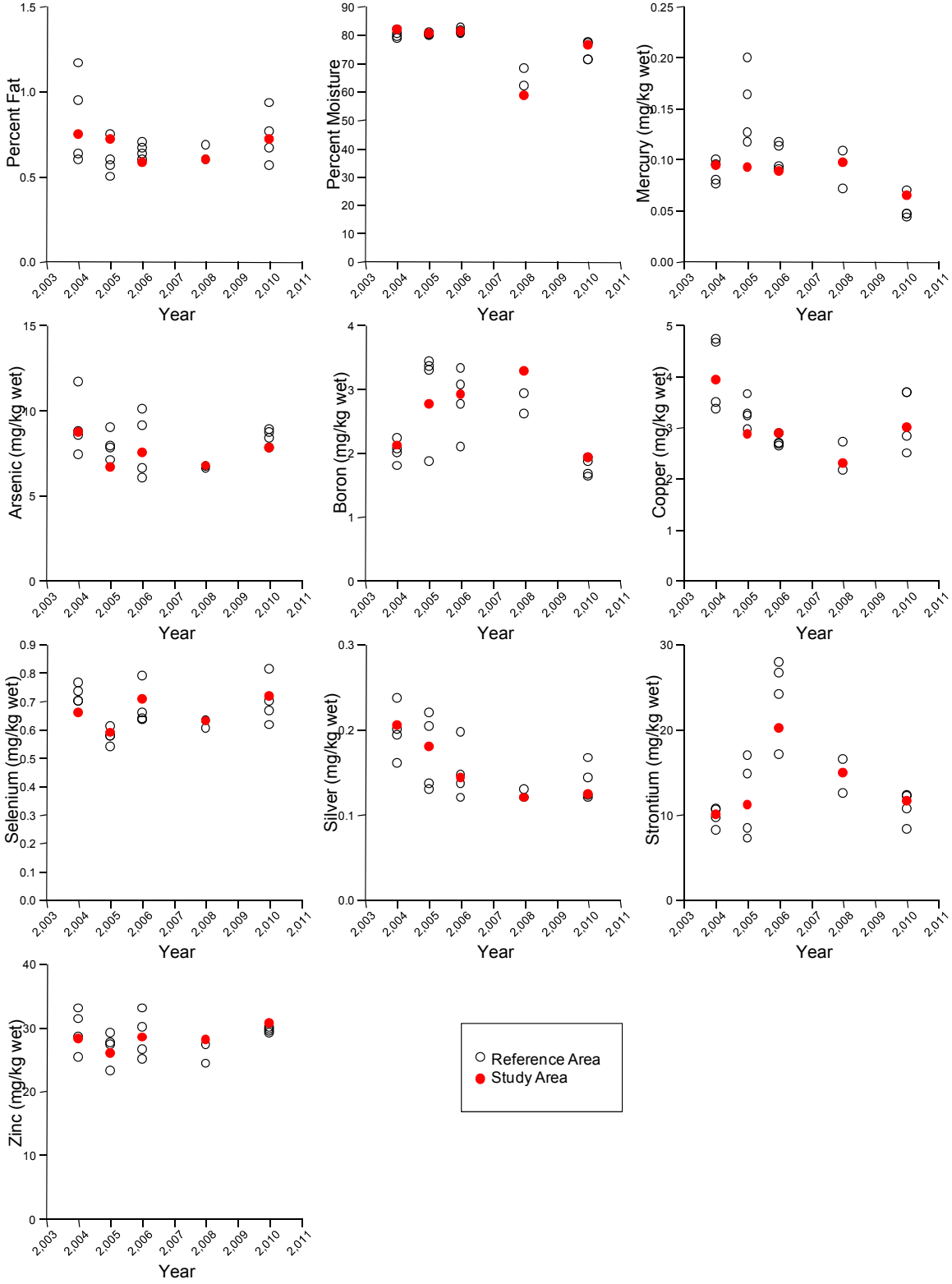

Figure 6-10 Variation in Area Means of Detectable Analyte Concentrations in Crab Claw Composites from 2004 to 2010

Note: Values shown are annual averages within Areas.

There were significant ($p < 0.05$) temporal trends in fat content (lower in 2006), mercury (decreasing over time in both the Reference Areas and the Study Area), boron (higher in 2006 in all Areas), silver (decreasing over time in all Areas) and strontium (higher in 2006 in all Areas) (Table 6-15). Temporal trends differed between Reference Areas and the Study Area only for mercury concentrations (see the *p*-value for the quadratic temporal trend, Table 6-15). The significant difference in mercury temporal trends reflected a larger increase in mercury concentrations in Reference Area crab in 2005 and 2006 compared to other years. Regardless, mercury concentrations in both Reference and Study area Crab was lower in 2010 than in previous years (Figure 6-10).

Table 6-15 Results of Repeated Measures ANOVA Testing for Differences in Average Crab Body Burden Variables and Temporal trends Between the Reference Areas and the Study Areas (2004 to 2010)

Analyte	Area-Wide Temporal trends		Differences in Temporal trends Among Zones	
	Linear	Quadratic	Linear	Quadratic
Fat	0.817	0.006**	0.98	0.64
Moisture	0.080	0.067	0.91	0.42
Mercury	0.005**	0.003**	0.12	0.02*
Arsenic	0.974	0.142	0.44	0.61
Boron	0.305	0.073	0.56	0.75
Copper	0.155	0.108	0.91	0.93
Selenium	0.302	0.212	0.39	0.61
Silver	0.007**	0.364	0.19	0.38
Strontium	0.232	0.015*	0.94	0.37
Zinc	0.413	0.189	0.60	0.98

Notes: - Values are probabilities of no difference in temporal trends.
- Analyte concentrations were log-transformed prior to the analyses.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

6.2.3 Taste Tests

No significant difference in taste was noted between plaice from the Study and Reference Areas in both the triangle and hedonic scaling tests. 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-3). ANOVA statistics for hedonic scaling are provided in Table 6-16. The results were not significant ($p = 0.12$; $\alpha = 0.05$) and, from the frequency histogram (Figure 6-11), samples from both the Study and Reference Areas were assessed similarly for preference. From ancillary comments (Tables 6-17 and 6-18, and Appendix C-4), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 6-16 ANOVA for Taste Preference Evaluation of Plaice by Hedonic Scaling (2010)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5.33	1	5.33	2.49	0.12	4.05
Within Groups	98.33	46	2.14			
Total	103.67	47				

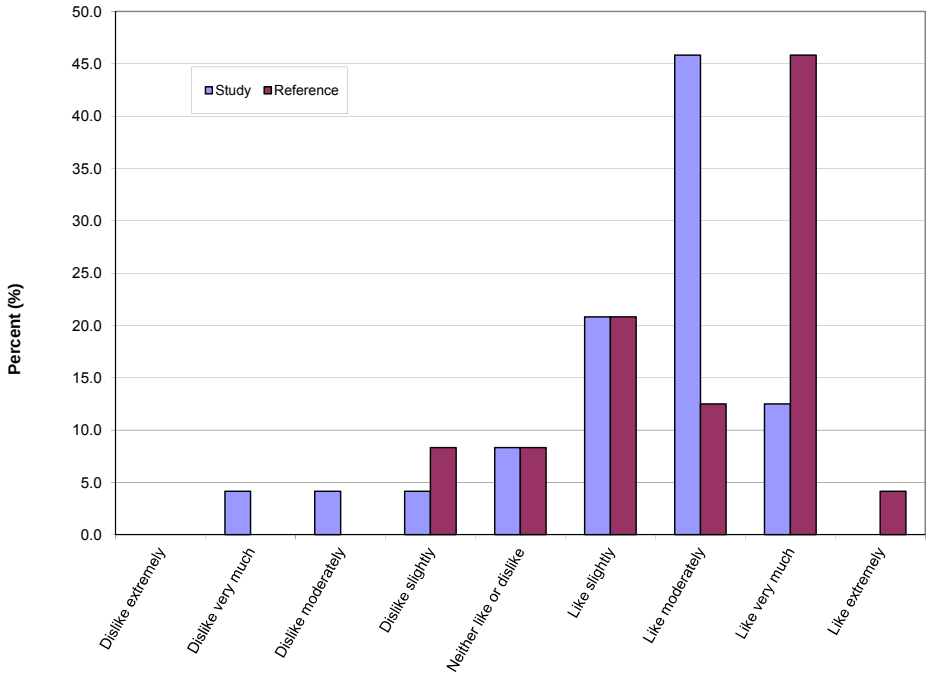

Figure 6-11 Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2010)

Table 6-17 Summary of Comments from the Triangle Taste Test for Plaice (2010)

Reference Area (RA)	Study Area (SA)
Correctly identified as odd sample	**Correctly identified as odd sample**
964 (RA) had a slight off flavour. Odour of all samples was acceptable.	Very little difference in any of the samples but 211 (SA) has a slightly fishier taste, but slightly less odour.
Taste not as strong on sample 964 (RA), but not much difference.	576 (SA) - mild scent, bitter flavour. 205 (RA) - slight scent, mild flavour. 844 (RA) - minimal scent, mild flavour.
Flavour was slightly different on 238 (RA). The other two smelled more similar.	
Preferred taste of 238 (RA) - sweeter taste.	
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
593 (RA) was preferable over the other two samples in terms of taste.	Can't put my finger on it but 354 (SA) is slightly different.
The taste and odour of 593 (RA) is less appealing.	354 (SA) had very little taste compared to the other two samples.
593 (RA) tasted bland.	Close taste.
Minor differences in smell.	Oily taste in 899 (SA).
205 (RA) had a slightly stronger smell.	493 (SA) smelled and tasted a little different.

Table 6-18 Summary of Comments from the Hedonic Scaling Taste Test for Plaice (2010)

Preferred Reference Area	Preferred Study Area
Off taste on 126 (SA)	Never liked either too much, 168 (RA) had bitter after taste.
126 (SA) tasted sour.	157 (RA) seems milder, and very mild smell.
179 (SA) had a less desirable flavour. Odour of both samples was acceptable.	189 (RA) was very bland.
179 (SA) had a more off taste (fishy).	695 (SA) had more flavour, sample 189 (RA) was very bland.
157 (RA) had a better flavour, 179 (SA) was slightly bland.	189 (RA) is bland.
Insignificant difference in samples.	
Both were very pleasant, yet I found 157 (RA) to be slightly more flavourful with a sweeter odor.	
Only a marginal difference in taste.	
639 (RA) had a sweeter flavour.	
639 (RA) had a faint smell, fish flavour is pleasant and not overpowering. 761 (SA) had a stronger smell, flavour is nothing special.	
639 (RA) was bland, wet, soft with not much flavour. 761 (SA) was also bland with a slight after taste.	
Not much difference in taste.	
Not a good taste on 695 (SA) also had a slight odour. Liked 189 (RA) - tasted fine.	

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 9 out of 24 samples. These results were not significant at α = 0.05 (Appendix C-3). ANOVA statistics for hedonic scaling are provided in Table 6-19. The results were not significant (p = 0.40; α = 0.05) and, from the frequency histogram (Figure 6-12), samples from both the Study and Reference Areas were assessed similarly for preference. From ancillary comments (Tables 6-20 and 6-21, and Appendix C-4), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 6-19 ANOVA for Taste Preference Evaluation of Crab by Hedonic Scaling (2010)

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.02	1	1.02	0.72	0.40	4.05
Within Groups	64.96	46	1.41			
Total	65.98	47				

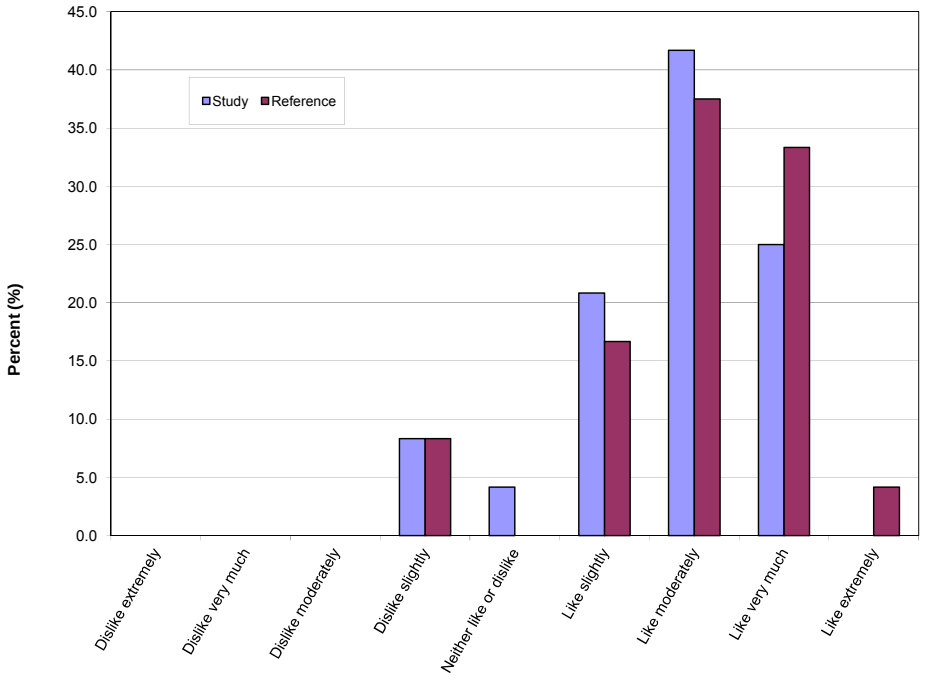

Figure 6-12 Crab Frequency Histogram for Hedonic Scaling Taste Evaluation (2010)

Table 6-20 Summary of Comments from the Triangle Taste Test for Crab (2010)

Reference Area (RA)	Study Area (SA)
Correctly identified as odd sample	**Correctly identified as odd sample**
399 (RA) - a little bitterness noted.	Not much of a difference at all.
I had a really hard time identifying the odd sample. They all tasted and smelled very similar.	Small taste difference in 939 (SA). They all smell the same.
276 (RA) lacked flavour, very bland.	The difference in flavour of 939 (SA) appears to be difficult to identify.
All three were very similar, hard to tell the difference.	Sweeter taste on 839 (SA).
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
Very slight difference.	399 (RA) and 576 (SA) have a little sweeter flavour, but more stronger odour.
Not much difference, but 926 (RA) seemed to have a fresher odour.	More crab flavour in 317 (SA) and 399 (RA). However, all samples had an acceptable odour and flavour.
Very slight difference in taste and odour..	317 (SA) - mild flavour, did have a few bits of shell in it. 399 (RA) - mild flavour, next to no scent. 576 (SA) - strong seafood taste compared to others, smells a lot stronger.
Very similar flavour with all three samples.	No perceived taste difference between all three. 576 (SA) may smell different and might be sweeter.
Better taste and less odour on 261 (RA).	Found small piece of shell in 276 (RA).
Difficult to distinguish.	Sample 181 (SA) seems to have less odour and more bland taste.
Slightly stronger odour on 261 (RA). All had a pleasant crab flavour, but favorite was 261 (RA). Not fond of the shell pieces.	181 (SA) had a slightly less fishy odour, taste was very similar.

Table 6-21 Summary of Comments from Hedonic Scaling Taste Tests for Crab (2010) Fish Health Indicators

Preferred Reference Area	Preferred Study Area
No difference in taste or odour.	No difference in taste or odour.
308 (RA) is sweeter and had more characteristic taste of crab. 668 (SA) more bland and less flavour.	Bitterness aftertaste on 308 (RA).
891 (RA) had a much sweeter taste than 334 (SA) and a slightly stronger odour. Both were acceptable quality.	Like flavour and texture of 308 (SA) more.
891 (RA) was slightly sweeter in taste.	Found 334 (SA) a bit sweeter.
Both taste fresh. I prefer the taste of 891 (RA) very slightly over 334 (SA).	Both taste very similar.
891 (RA) was more preferable in terms of flavour and odour. I found 334 (SA) a little bland.	703 (RA) has a stronger odour than 865 (SA).
Both taste very similar.	685 (SA) was a little tastier than 696 (RA). Not too much difference.
703 (RA) - Delightful flavour. A distinct flavour that is not overpowering. Smell is excellent, mild, but characteristic. 865 (SA) - Flavour wasn't as great, almost a bit bitter. Scent is no different from previous sample.	685 (SA) tastes better.
703 (RA) tastes more fresh, less salty.	
Similar in flavour.	
696 (RA) had better taste but had some shell fragments.	
Not a big difference in flavour, however I sided more with 696 (RA).	
Preferred taste of 696 (RA).	

6.2.4 Fish Health

6.2.4.1 Sex Ratios and Maturity Stages

Details on analyses of sex ratios and maturity stages are provided in Appendix C-4.

Females outnumbered males in every Area, accounting for 152 or 84% of the 180 fish processed. Sex ratios (F:M≈8.5:1) did not differ (p = 0.515; Fisher's Exact Test) between the Reference (F:M≈8.6:1) and Study Areas (F:M≈8.2:1).

All 28 males sampled were mature, but either partly spent (n = 7) or spent (n = 21). There were no significant differences (p = 1.0; Fisher's Exact Test) in frequencies of any maturity stage between the combined Reference Areas and the Study Area for males.

Most (>90%) of the females examined were mature and most of these were spent (n = 142 of 152 fish). Frequencies of pre-spawning and spent mature females varied significantly between the combined Reference Areas (97%) and the Study Area (86%) (Chi-Square test, p = 0.0077). A Fisher's Exact Test was not possible because of low cell frequencies.

6.2.4.2 Size, Age and Condition

Details on analyses of size, age and condition are provided in Appendix C-4.

Size, age and condition for male plaice varied between 249 to 414 g for gutted weights; seven to nine years for age; 3.7 to 7 g for liver weight; 2 to 3 g for testes weight; 0.75 to 0.81 for CF; 1.35 to 1.71% for HSI and 0.68 to 1.15% for GSI. None of the variables differed among Reference Areas or between Study and Reference Areas.

There were no immature female fish collected from the Reference Areas, and only four immature fish collected from the Study Area. There, immature fish averaged 223 g for gutted weights; eight years of age; had 3.8 g for liver weights; 2 g for ovary weight; 0.73 for CF; 1.66 for HSI and 0.78 for GSI. The data were not analyzed statistically because there were no immature female fish in the Reference Areas.

Size, age and condition for pre-spawning mature females ranged from 389 to 601 g for gutted weight; 10 to 11 years for age; 6.0 to 13.3 g for liver weight; 63 to 114 g for ovary weight; 0.74 to 0.79 for CF; 1.11 to 2.10 for HSI and 13.3 to 18.9 for GSI. None of the age or body-size variables differed between Study and Reference Areas or among Reference Areas.

Size, age and condition for spent females ranged from 537 to 594 g for gutted weight; 9 to 11 years for age; 9.2 to 11 g for liver weight; 18 to 22 g for ovary weight; 0.74 to 0.80 for CF; 1.55 to 1.99 for HSI and 2.84 to 4 for GSI. Age of spent females differed among Reference Areas (p = 0.022). Fish from Reference Area 4 were nine years old, whereas fish from Reference Areas 1 and 2 were 11 years old and fish from Reference Area 3 were 10 years old. No other body size variables differed among Reference Areas, or between Reference and Study Areas.

6.2.4.3 Gross Pathology

No 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 from any of the sampled Areas in 2010 (Appendix C-4, Annex C).

6.2.4.4 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. Colouration 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 180 fish from the Study and Reference areas. 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 ± SD of each cell type for each Area (Table 6-32). The complete data set on the different cells examined is provided in Appendix C-4, Annex D.

Table 6-22 Frequencies of Blood Cell Types in Plaice (2010)

Statistics	Area					
	Ref 1	Ref 2	Ref 3	Ref 4	Study	Grand Total
Number of Fish	30	30	30	30	60	180
% Lymphocytes	83.7±1	83.4±1.1	83.4±1	83.1±1.5	83.4±1.2	83.4±1.2
% Thrombocytes	15.8±1.1	16.0±1.2	16.1±1.1	16.4±1.6	16.3±1.3	16.2±1.3
% Neutrophils	0.55±0.53	0.57±0.54	0.48±0.46	0.43±0.41	0.33±0.41	0.45±0.47

Note: - All data are means ± SDs (except for the number of fish).

Percentages of lymphocytes and thrombocytes were compared among Areas using ANOVA (Table 6-33). There were no differences in percentages among Reference Areas, or between Reference and Study Areas.

Table 6-23 Results of ANOVA Comparing Percentages of Blood Cell Types in Plaice (2010)

Variable	*p*-value	
	Among Reference (AR)	Study vs Reference (SR)
Lymphocytes	0.236	0.987
Thrombocytes	0.280	0.575

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

6.2.4.5 MFO 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 result in some loss of sensitivity for resolving contaminant mediated differences in female fish during spawning (e.g., Whyte et al. 2000).

MFO enzyme activities, measured as EROD, in the liver of males (all maturity stages combined), pre-spawning (DFO maturity stages F-520 and F-540) and spent (DFO maturity stage F-560) females are provided in Appendix C-4 (Annex E) and results are summarized in Figures 6-13 and 6-14.

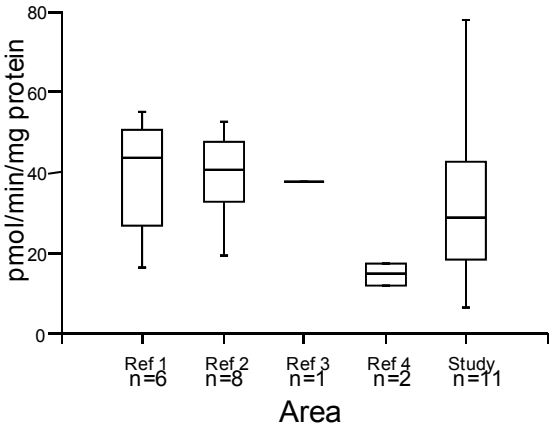

Figure 6-13 Box Plots of MFO Activity in the Liver of Male Plaice (All Maturity Stages Combined)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ± 1.5 x interquartile spread.

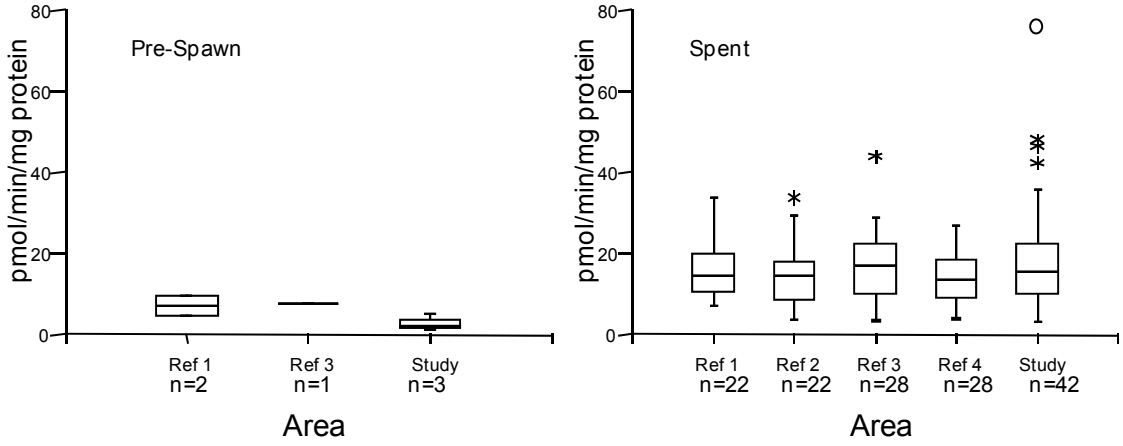

Figure 6-14 Box Plots of MFO Activity in the Liver of Pre-spawning (F-520 to F-540; left panel) and Spent (F-560; right panel) Female Plaice

Notes: See Appendix C-4 (Annex A) for DFO maturity stage classifications. Box plot interpretation: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ± 1.5 x interquartile spread. Asterisks indicate values falling within the quartile ± 3 x interquartile spread. Open circles indicate values falling outside the quartile ± 3 x interquartile spread.

MFO activity was greater in males (generally 20 to 40 pmol/min/mg protein) than in pre-spawning (<10 pmol/min/mg protein) or spent females (generally 10 to 20 pmol/min/mg). MFO activity in the five immature females ranged between 16 and 39 pmol/min/mg protein. No figures are provided for immature females because immature fish were only collected from the Study Area.

EROD activity did not differ significantly among Reference Areas or between Reference and Study Areas, regardless of gender or spawning condition (Table 6-34).

Table 6-24 Results of ANOVA Comparing MFO Activities in Male and Female Plaice (2010)

Variable	*p*-value	
	Among Reference (AR)	Study vs Reference (SR)
Males	0.206	0.615
Female Pre-Spawn	0.899	0.124
Female Spent	0.827	0.264

Notes: - MFO activities were log-transformed for analysis.
- See Appendix C-4 (Annex A) for maturity stage classifications.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

6.2.4.6 Histopathology

Liver Histopathology

A total of 178 fish livers were examined: 60 from the Study Area; and 118 from the Reference Areas. Representative photographs of normal liver, as well as a number of histological changes, are included in Appendix C-4 (Annex H).

The percentage of fish affected by each type of lesion/observation (or prevalence of lesion) in the Reference and Study Areas is provided in Table 6-35. The complete data set is provided in Appendix C-4 (Annex F).

Table 6-25 Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of *Lesions (2010)*

Hepatic Lesions	Measure	Area					
		Ref 1	Ref 2	Ref 3	Ref 4	Study	Total
Number of Fish	Number	30	29	30	29	60	178
Nuclear Pleomorphism	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0
Megalocytic Hepatosis	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0
Eosinophilic Foci	Number	0	0	0	1	0	1
	%	0	0	0	3	0	3
Basophilic Foci	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0
Clear Cell Foci	Number	0	0	0	0	2	2
	%	0	0	0	0	3	3
Hepatocellular Carcinoma	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0
Cholangioma	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0
Cholangiofibrosis	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0
Macrophage Aggregates[a]	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0
Hydropic Vacuolation	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0
Fibrillar Inclusions	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0
Inflammation Response	Number	0	0	1	0	1	2
	%	0	0	3	0	2	1
Golden Ring Around Bile Duct	Number	0	2	0	0	1	3
	%	0	7	0	0	2	2

Hepatic Lesions	Measure	Area					
		Ref 1	Ref 2	Ref 3	Ref 4	Study	Total
Hepatocellular Vacuolation	Number	3	1	3	4	5	16
	%	10	3	10	14	8	9
Parasites	Number	5	7	1	4	15	32
	%	17	24	3	14	25	18

Note: [a] Moderate to high macrophage aggregation: >3 rating on a 1-7 relative scale.

A few foci of cellular alteration were observed. Foci of cellular alteration are zones of hepatocytes with morphology and/or staining characteristics of the cytoplasm different from the surrounding tissue. Two cases of a single small clear cell focus (Appendix C-4, Annex H, Photo 2) were noted in the Study Area and one case of a single small eosinophilic focus (Appendix C-4, Annex H, Photo 3) was found in a fish from Reference Area 4.

Golden rings around bile ducts (Appendix C-4, Annex H, Photo 4) were detected in three fish, one from the Study Area and two from the Reference Areas. The rings are most likely melanization at the margin of the bile duct.

No cases of moderate to severe macrophage aggregation were found in any of the fish from the Study or Reference Areas.

One fish from Reference Area 3 and one from the Study Area exhibited a mild hepatic inflammatory response (Appendix C-4, Annex H, Photo 5). An inflammatory response typically involves a defensive reaction by vertebrate tissue to infection or injury caused by chemical or physical agents. The process is characterized by local vasodilation and extravasation of plasma into intercellular spaces as well as infiltration of white blood cells and macrophages in tissues.

Hepatocellular vacuolation and presence of parasites were also recorded in a number of fish. Although these lesions are of interest, they are generally not a result of the presence of chemical pollutants, and were not associated with any other structural perturbations.

With respect to other indices, the liver of one fish from Reference Area 3 contained a granuloma (Appendix C-4, Annex H, Photo 6), which can most likely be attributed to the presence of a parasite.

Overall, there were no significant differences in any of the hepatic indices examined between fish from the Study and Reference Areas (Fisher's exact test) (Appendix C-4).

Gill Histopathology

Gills from one fish from the Study Area were missing and accurate counts were not possible for a few fish from the Reference and Study Areas. Detailed histopathological studies were thus carried out on gill tissues of 107 fish from the Reference Areas and 50 fish from the Study Area. The percentages of lamellae affected by lesions were very low, all less than 5% per fish (Appendix C-4, Annex G). No gills exhibited telangiectasis.

Minor epithelial lifting was found in all gill samples (Reference and Study Areas). However, this was an artefact of tissue fixation, unrelated to exposure to xenobiotic substances.

Means and SDs of percentages of lamellae presenting each type of lesion per site are provided in Table 6-36.

Table 6-26 Occurrence of Lesions in the Gill Tissues of Plaice (2010)

Statistics	Area					
	Ref 1	Ref 2	Ref 3	Ref 4	Study	Grand Total
Number of Fish	29	26	22	30	50	157
Distal hyperplasia	0.055±0.18	0.081±0.23	0.12±0.287	0.166±0.267	0.209±0.752	0.139±0.469
Tip hyperplasia	0.445±0.554	0.286±0.379	0.205±0.39	0.491±1.042	0.227±0.533	0.324±0.635
Basal hyperplasia 1[a]	0.038±0.104	0.11±0.318	0.058±0.189	0.188±0.462	0.212±1.086	0.137±0.662
Basal hyperplasia 2[b]	0±0	0.01±0.051	0±0	0±0	0.004±0.027	0.003±0.026
Fusion	0.122±0.391	0.025±0.105	0.065±0.171	0.054±0.246	0.028±0.125	0.055±0.225
Telangiectasis	0±0	0±0	0±0	0±0	0±0	0±0

Notes:
- All data are mean percentage of lamellae presenting the lesion ± SDs (except for the number of 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.

There were no significant differences in the percentages of lamellae presenting each type of lesion between Reference and Study Areas (ANOVA; $p > 0.05$).

Statistical comparisons were also carried out on the number of fish exhibiting the lesions between the Study Area versus the combined Reference Areas (Table 6-37), using Fisher's Exact Test. Lesions were considered "present" if those conditions occurred on any of the lamellae examined for each fish.

Table 6-27 Number of Plaice with Specific Types of Gill Lesions and Percentages of Fish Exhibiting the Lesions (2010)

Gill Lesions	Measure	Area					
		Ref 1	Ref 2	Ref 3	Ref 4	Study	Grand Total
Number of Fish	Number	29	26	22	30	50	157
Distal Hyperplasia	Number	3	5	5	12	9	34
	%	10	19	23	40	18	22
Tip Hyperplasia	Number	17	13	6	15	17	68
	%	59	50	27	50	34	43
Basal Hyperplasia 1[a]	Number	4	4	2	6	8	24
	%	14	15	9	20	16	15
Basal Hyperplasia 2[b]	Number	0	1	0	0	1	2
	%	0	4	0	0	2	1
Fusion	Number	3	2	3	2	3	13
	%	10	8	14	7	6	8
Telangiectasis	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0

Notes:
- Hyperplasia and fusion were considered "present" if those conditions occurred on any of the lamellae examined for each fish.
- [a] Basal hyperplasia 1: increase in thickness of the epithelium reaching 1/3 to 2/3 of total lamellar length.
- [b] Basal hyperplasia 2: increase in thickness of the epithelium reaching more than 2/3 of total lamellar length.

None of the gill lesions occurred more or less frequently in Study Area fish compared to Reference Area fish ($p > 0.05$ in all cases).

6.3 Summary of Findings

6.3.1 Biological Characteristics

There was no significant difference in body size of plaice or crab between the Reference and Study Area.

6.3.2 Body Burden

In 2010, as in previous years, there were no significant differences between the Study and Reference Areas for most analytes detected in plaice liver. In 2010, zinc concentrations in liver were significantly lower in Study Area fish than in Reference Area fish (i.e., median of approximately 27 mg/kg in the Study Area versus a median of approximately 29 to 30 mg/kg in the Reference Areas). The concentration of compounds in the $>C_{21}$-C_{32} hydrocarbon range was higher in livers of Study Area Fish (nearly 150 mg/kg) compared to Reference Area fish (generally less than 100 mg/kg). Across years, concentrations of compounds in the $>C_{10}$-C_{21} hydrocarbon range decreased more over time in Reference Area plaice livers than in Study Area plaice livers. Concentrations of compounds in the $>C_{21}$-C_{32} hydrocarbon range increased over time in plaice livers in the Study Area, and remained stable in plaice livers in the Reference Areas. No other differences were noted in the multi-year comparison. As in previous years, additional laboratory analyses on livers indicated that compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon range were primarily natural, perhaps diet related, rather than petrogenic in origin.

Place fillets from the Study Area had significantly higher fat content (1.2%) compared to Reference Areas (≤1%) in 2010. All other tissue parameters were either statistically similar among sampling Areas, within the range of values observed in the Reference Areas, or were at non-detect concentrations. Across years, there were no differences in temporal trends (increases/decreases over time) between the Reference Areas and the Study Area for any analyte.

There were no statistically significant differences between the Reference and the Study Areas for any of the analytes detected in crab claw in 2010. Across years, temporal trends (increases/decreases over time) differed between the Reference and Study Areas only for mercury, with a larger increase in mercury in Reference Area crab in 2005 and 2006 compared to other years. Regardless, mercury concentrations in both Reference and Study Area crab was lower in 2010 than in previous years.

6.3.3 Taste Tests

There was no difference in taste test results between Study and Reference Area plaice or crab. From ancillary comments, there were no consistent comments identifying abnormal or foreign odour or taste.

6.3.4 Fish Health Indicators

The Fish Health survey in 2010 indicated that the present health of American plaice, as assessed by condition indices, external and internal abnormalities, haematology, hepatic MFO enzymes and detailed studies on liver and gill histopathology, is similar between the Reference and Study Areas. Of particular interest was the virtual absence of inter-site variability with respect to health effect indicators more commonly associated with chemical toxicity. This included not only MFO enzymes but also a wide range of liver and gill lesions, as well as visible external and internal abnormalities. However, foci of cellular alteration, which may be background in nature, were noted for the first time in the Husky EEM Program in the liver of two fish from the Study Area and one fish from the Reference Area.

7.0 Water Quality Component

7.1 Background

In 2004, Husky Energy designed the Sediment and Commercial Fish components of its EEM program and made a commitment to design a Water Quality component (Husky Energy 2004). In 2008, Husky Energy collected some preliminary seawater samples around White Rose in order to aid in the design of the Water Quality program. In 2010, Husky Energy submitted a Water Quality monitoring program design to the Canada-Newfoundland and Labrador Offshore Petroleum Board (Husky Energy 2010).

The Water Quality monitoring program at White Rose involves collection of seawater samples around White Rose and in two Reference Areas located approximately 28 km to the northeast and northwest of White Rose. The program also involves modelling of constituents of produced water (the largest liquid discharge at White Rose) to identify constituents that would be most likely to be detected in the seawater samples (details are provided in Husky Energy 2010; also see Section 1).

7.2 Seawater Samples

7.2.1 Field Collections

Water sample collection for the 2010 EEM Program was conducted from October 4 to October 13, 2010, in conjunction with sediment sample collection using the offshore supply vessel *M/V Maersk Gabarus*. Water collection stations for the 2010 program are shown in Figure 7-1. Geographic coordinates and distance to the *SeaRose* FPSO are provided in Appendix D-1.

Water samples were collected at 10 m below surface, 40 m below surface and 10 m above bottom using a string of three Teflon-lined, 10 L Niskin-X bottle water samplers (Figure 7-2). All stations were sampled for physical and chemical characteristics. Groups or specific compounds analyzed included BTEX, $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, PAHs and alkyl PAHs, phenols and alkyl phenols, organic acids, metals, the naturally-occurring radionucliides radium-226, radium-228 and lead-210, total inorganic and organic carbon (TIC and TOC, respectively), total suspended solids (TSS), ammonia and a water-soluble scale inhibitor (SCW4453) and a biocide (XCide450) injected into the produced water stream. Samples were stored as detailed in Table 7-1.

A conductivity, temperature and depth (CTD) profiler (Seabird Model 25) was use at all water quality stations to assess the depth of the thermocline relative to Niskin bottle sample location if warranted by results.

Field blanks for BTEX, $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, PAHs and alkyl PAHs, phenols and alkyl phenols, organic acids, metals, radionucliides and ammonia were collected at stations WQ3 (surface), WQ8 (mid-depth) and 27 (bottom). QA/QC samples were collected at those same locations.

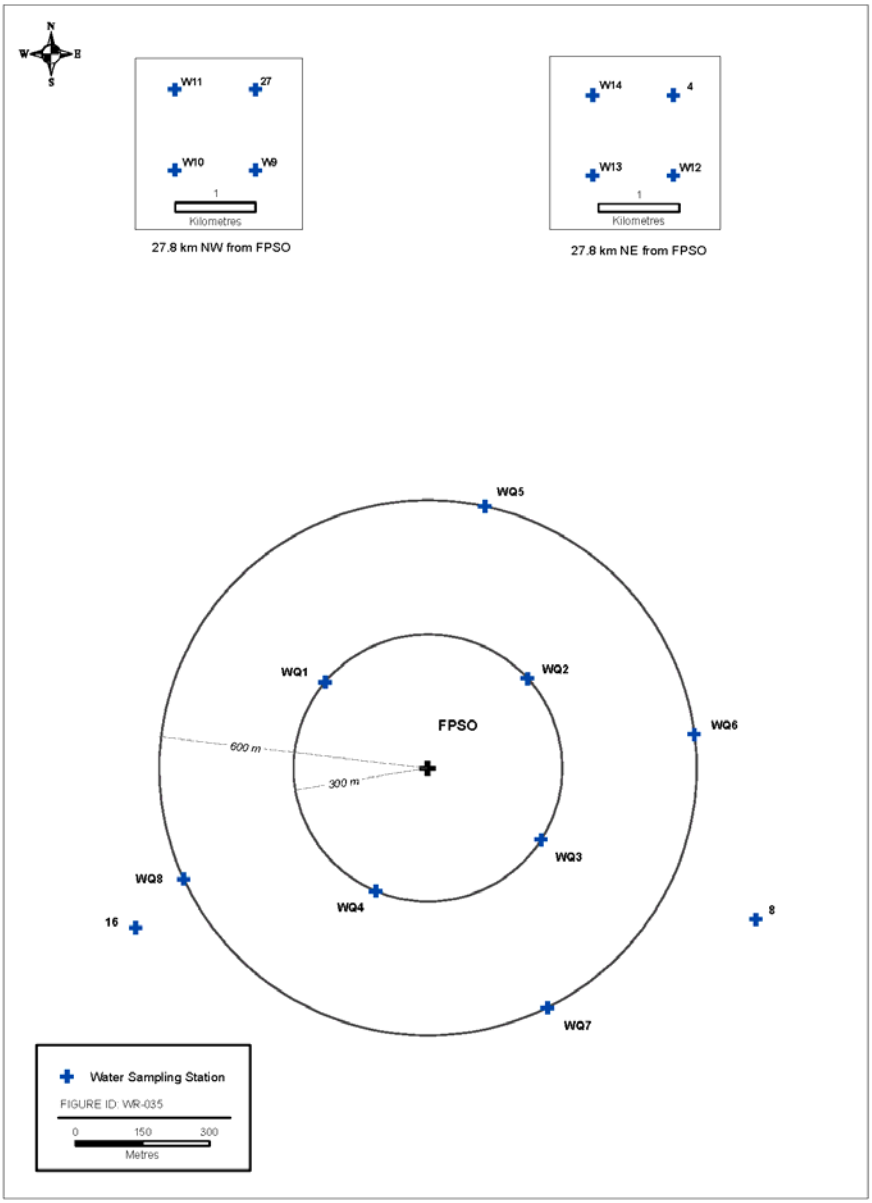

Figure 7-1 Water Quality Stations (2010)

Figure 7-2 Niskin Bottle Water Samples

Table 7-1 Water Sample Storage

Analysis	Storage Container	Preservative Description and Comments	Storage Temperature	Holding Time
Trace Metals & Mercury	1 – 50 ml plastic tube (acid washed) 1 – 250 ml plastic bottle (acid washed	Nitric Acid (<ph 2) Nitric Acid (<ph2)	4 ºC	6 months
Ra226, 228 & Pb210	1 – 1 L plastic bottle	Nitric Acid (<ph 2)	4 ºC	6 months
Atlantic MUST[a]	2 – 250 ml and 2 – 40 ml glass bottles	Sodium bisulphate	4 ºC	7 days
PAHs & Alkyl PAHs	1 – l L amber glass bottle	None	4 ºC	7 days
Phenols & Alkyl Phenols	1 – 1 L amber glass bottles	None	4 ºC	7 days
Volatile Organic Acids	1 – 1 L amber glass bottle	None	4 ºC	7 days
Ammonium & Ammonia	1 – 250 ml plastic bottle	None	4 ºC	7 days
TIC/TOC/TSS	1 L Plastic Bottles	No preservative required. Fill to top	4° C	7 Days
XCide450	1 – 40 ml glass bottle	Test to be conducted as soon as water sample is retrieved	none	None – test conducted on-site
SCW4453	1,500 ml plastic bottle	None	4 ºC	14 days

Note: - [a] BTEX, >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons.

7.2.2 Laboratory Processing

Water samples were processed for analytes listed in Table 7-2. Most samples were processed at RPC, located in Fredericton, N.B. That analytical laboratory was selected because it could provide results for alkyl PAHs, phenol and alkyl phenols. TIC was processed at Maxxam Analytics, in Halifax N.S. XCide450 was processed onboard vessel by Stantec Consulting Ltd. using a test kit from Hach Company. SCW4453 was processed by Baker Petrolite laboratories in the United Kingdom. Details on analytical methods for RPC and Maxxam Analytics are provided in Appendix D-2.

Table 7-2 Water Chemistry Analytes (2010)

Analyte	Unit	Detection Limit
Hydrocarbons		
Benzene	mg/L	0.001
Toluene	mg/L	0.001
Ethylbenzene	mg/L	0.001
Xylenes	mg/L	0.001
C_6-C_{10} (less BTEX)	mg/L	0.01
>C_{10}-C_{21}	mg/L	0.05
>C_{21}-C_{32}	mg/L	0.1
Phenols and Alkyl Phenols		
Phenol	µg/L	10
o-cresol	µg/L	10
m,p-cresol	µg/L	10
Total C2 Phenols	µg/L	20
Total C3 Phenols	µg/L	20
Total C4 Phenols	µg/L	20
Total C5 Phenols	µg/L	20
4-n-hexylphenol	µg/L	10
2,5-diisopropylphenol	µg/L	10
2,6-diisopropylphenol	µg/L	10
2-tert-butyl-4-ethylphenol	µg/L	10
6-tert-butyl-2,4-dimethyphenol	µg/L	10
4-n-heptylphenol	µg/L	10
2,6-dimethyl-4-(1,1-dimethypropyl)phenol	µg/L	10
4-(1-ethyl-1-methylpropyl)-2-methylphenol	µg/L	10
4-n-octylphenol	µg/L	10
4-tert-octylphenol	µg/L	10
2,4-di-sec-butylphenol	µg/L	10
2,6-di-tert-butylphenol	µg/L	10
4-n-nonylphenol	µg/L	20
2-methyl-4-tert-octylphenol	µg/L	10
2,6-di-tert-butyl-4-methylphenol	µg/L	10
4,6-di-tert-butyl-2-methylphenol	µg/L	10
PAHs and Alkyl PAHs		
Naphthalene	µg/L	0.01
Acenaphthylene	µg/L	0.01
Acenaphthene	µg/L	0.01
Fluorene	µg/L	0.01
Phenanthrene	µg/L	0.01
Anthracene	µg/L	0.01
Fluoranthene	µg/L	0.01
Pyrene	µg/L	0.01
Bz(a)anthracene	µg/L	0.01
Chrysene/Triphenylene	µg/L	0.01
Bz(b)fluoranthene	µg/L	0.01
Bz(k)fluoranthene	µg/L	0.01
Bz(e)pyrene	µg/L	0.01
Bz(a)pyrene	µg/L	0.01
Indenopyrene	µg/L	0.01
Bz(g,h,i)perylene	µg/L	0.01
Dibz(a,h)anthracene	µg/L	0.01

Analyte	Unit	Detection Limit
C1-Naphthalenes[a]	µg/L	0.05
C2-Naphthalenes[a]	µg/L	0.05
C3-Naphthalenes	µg/L	0.05
C1-Phenanthrenes	µg/L	0.05
C2-Phenanthrenes	µg/L	0.05
C3-Phenanthrenes	µg/L	0.05
Dibenzothiophene	µg/L	0.05
C1-Dibenzothiophenes	µg/L	0.05
C2-Dibenzothiophenes	µg/L	0.05
C3-Dibenzothiophenes	µg/L	0.05
Perylene	µg/L	0.01
Biphenyl	µg/L	0.01
Organic Acids		
Acetic Acid	mg/L	2.0
Propionic Acid	mg/L	2.0
Iso-butyric Acid	mg/L	2.0
Butyric Acid	mg/L	2.0
Iso-valeric Acid	mg/L	2.0
n-valeric Acid	mg/L	2.0
Radionucliides		
Radium-228	Bq/L	1
Radium-226	Bq/L	0.3
Lead-210	Bq/L	1
Metals		
Aluminum	µg/L	5
Antimony	µg/L	1
Arsenic	µg/L	10
Barium	µg/L	0.1
Beryllium	µg/L	0.05
Boron	µg/L	10
Cadmium	µg/L	0.05
Calcium	µg/L	50
Chromium	µg/L	2
Cobalt	µg/L	0.5
Copper	µg/L	5
Iron	µg/L	10
Lanthanum	µg/L	0.2
Lead	µg/L	0.05
Lithium	µg/L	5
Magnesium	µg/L	10
Manganese	µg/L	1
Mercury	µg/L	0.025
Molybdenum	µg/L	0.1
Nickel	µg/L	5
Potassium	µg/L	20
Selenium	µg/L	10
Silver	µg/L	0.02
Sodium	µg/L	50
Strontium	µg/L	10
Sulfur	µg/L	50
Tellurium	µg/L	0.5
Thallium	µg/L	2
Uranium	µg/L	0.1
Vanadium	µg/L	1
Zinc	µg/L	1
Other		
Ammonia (as N)	mg/L	0.05
TIC	mg/L	0.5
TOC	mg/L	0.5
TSS	mg/L	5
XCide450	mg/L	0.5
SCW4453	mg/L	1

Note: - [a] includes 1- and 2-Chloronaphthalene.

7.2.3 Data Analysis

Data from 2010 are examined in this report. Data collected during baseline (2000) are not comparable to 2010 data because the Water Quality monitoring program at White Rose measures a greater number of constituents, many at lower laboratory detection limits, than in 2000. Similarly, preliminary data collected in 2008 are not discussed here because not all constituents were measured at all depths. Data from 2000 and 2008 are reported in Husky Energy (2001) and Husky Energy (2010).

In 2010, the Water Quality component of the White Rose EEM program used a multiple-reference design, with two Reference Areas and one Study Area. ANOVA was used to test for differences between the Study and the Reference Areas (Table 7-3). The test compared depth profiles between Reference Areas (DXBR). That effect was judged relative to the overall error (Error 4). If DXBR was significant at $p < 0.25$, then that effect (MS(DXBR)) was the error term (Error 3) used to judge differences in depth profiles between Reference and Study Areas (i.e., DXSR). If there were no differences in depth profiles, then the main effect of Location (L) was appropriate for testing. For main effects, the first test was the difference between Reference Areas (BR), which was judged relative to the MS(S(L)) or Error 2. If that effect was significant it became the error term for the difference between Study and Reference areas (i.e., MS(SR), at $p < 0.25$), otherwise Error 2 was used.

Table 7-3 ANOVA Model Used to Test for Study Reference Differences

Source	Mean Square (MS)	df	Error Term for F-test
Location (L)	MS(L)	2	Error 2
Study vs Reference (SR)	MS(SR)	1	Error 1 if it is significant at $p < 0.25$, otherwise Error 2
Between Reference (BR)	MS(BR)=Error 1	1	Error 2
Station(Location) = Error 1	MS(S(L))=Error 2	15	
Depth	MS(D)	2	Error 4
Location x Depth (LXD)	MS(LxD)	4	
Study vs Reference x Depth (SRxD)	MS(SRx D)	2	Error 3 if it is significant at $p < 0.25$, otherwise Error 4
Between Reference x Depth (BRxD)	MS(BRxD)=Error 3	2	Error 4
Station(Location) x Depth	MS(S(L)xD)=Error 4	30	

Variables that occurred above laboratory detection limit either in all or most samples[18] were examined in ANOVA. These variables were also examined in box plots. Variables with a sufficient number of values above laboratory detection limit (zinc and SCW4453, with 69% of values above detection limit) were rank transformed before analysis. Rank transformation treats values below detection limit as tied for the lowest rank. Zinc and SCW4453 values below detection limit were set to ½ the detection limit for plotting.

7.2.4 Results

Summary statistics for analytes measured in seawater samples (Table 7-2) are provided in Appendix D-2. CTD depth profiles are provided in Appendix D-3. The thermocline during sample collection (October, 2010) was between approximately 10 to 25 m depth in the Study Area; between approximately 25 and 45 m depth in the Northwest (NW)

[18] Frequency of detection for all constituents is provided in Section 7.2.4.

Reference Area; and between approximately 30 and 40 m depth in the Northeast (NE) Reference Area.

BTEX, >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons, PAHs and alkyl PAHs, phenols and alkyl phenols, organic acids, radium-228, ammonia and XCide450 were not detected in water samples. Barium, boron, calcium, lithium, magnesium, molybdenum, potassium, sodium, strontium, sulphur, uranium, vanadium, TIC and pH were detected in all samples. SCW4453 and zinc were frequently detected in water samples. SCW4453 was above the laboratory detection limit of 1 mg/L in 37 of 54 samples. Zinc was above the laboratory detection limit 1 μg/L in 37 of 54 samples. Variables detected consistently or frequently are analyzed in greater detail below, with the exception of pH which varied over a narrow range (the only recorded values were 7.8, 7.9, 8.0 and 8.1).

Cadmium was above and near the laboratory detection limit of 0.05 μ/L in 10 of 30 Study Area samples and 1 of 24 Reference Area samples. Lead was above the laboratory detection limit of 0.05 μg/L in 9 of 30 Study Area samples and 6 of 24 Reference Area samples. Lead-210 was detected at values near the laboratory detection limit of 1 Bq/L in 4 of 30 Study Area samples and in 2 of 24 Reference Area samples. Radium-226 was detected at levels near the laboratory detection limit of 1 Bq/L 3 of 30 Study Area samples and in 2 of 24 Reference Area samples. Copper (laboratory detection limit: 5 μg/L) was detected in two Reference Area samples. Iron (laboratory detection limit: 10 μg/L) was detected in two Study Area sample and in one Reference Area sample. Aluminum (laboratory detection limit: 5μg/L) was detected in two Study Area samples (Appendix D-2).

Box plots by area and depth for variables reported in all samples are provided in Figure 7-3. Box plots are also provided for zinc and SCW4453 with values below laboratory detection limit set to ½ the laboratory detection limit (no box plots are provided for pH because values varied over a very narrow range (four values were reported - 7.8, 7.9, 8.0 and 8.10)).

There was a clear and significant increasing trend in the concentration of most metals and TIC with depth (Figure 7.3, Table 7-4). A trend was not apparent in Figure 7-3 for vanadium, which varied over the narrow range of 1 to 2 μg/L, although depth differences were significant (Table 7-4). There were no depth differences for zinc and SCW4453 (Figure 7-3, Table 7-4).

Barium concentrations differed significantly between the two Reference Areas but did not differ between the Study Area and the Reference Areas (Table 7-4). Barium concentration was lower in water samples from near the seafloor in the NE Reference Area compared to the NW Reference Area. Conversely, concentrations were higher in mid-depth and surface water samples in the NW Reference Area compared to the NE Reference Area (Figure 7-3; hence the significant DepthxBR interaction term in Table 7-4). Molybdenum and sulphur concentrations differed significantly between the Study Area and the Reference Areas (Table 7-4) with concentrations lower in the Study Area (Figure 7-3). No other significant (α = 0.05) differences were noted (Table 7-4).

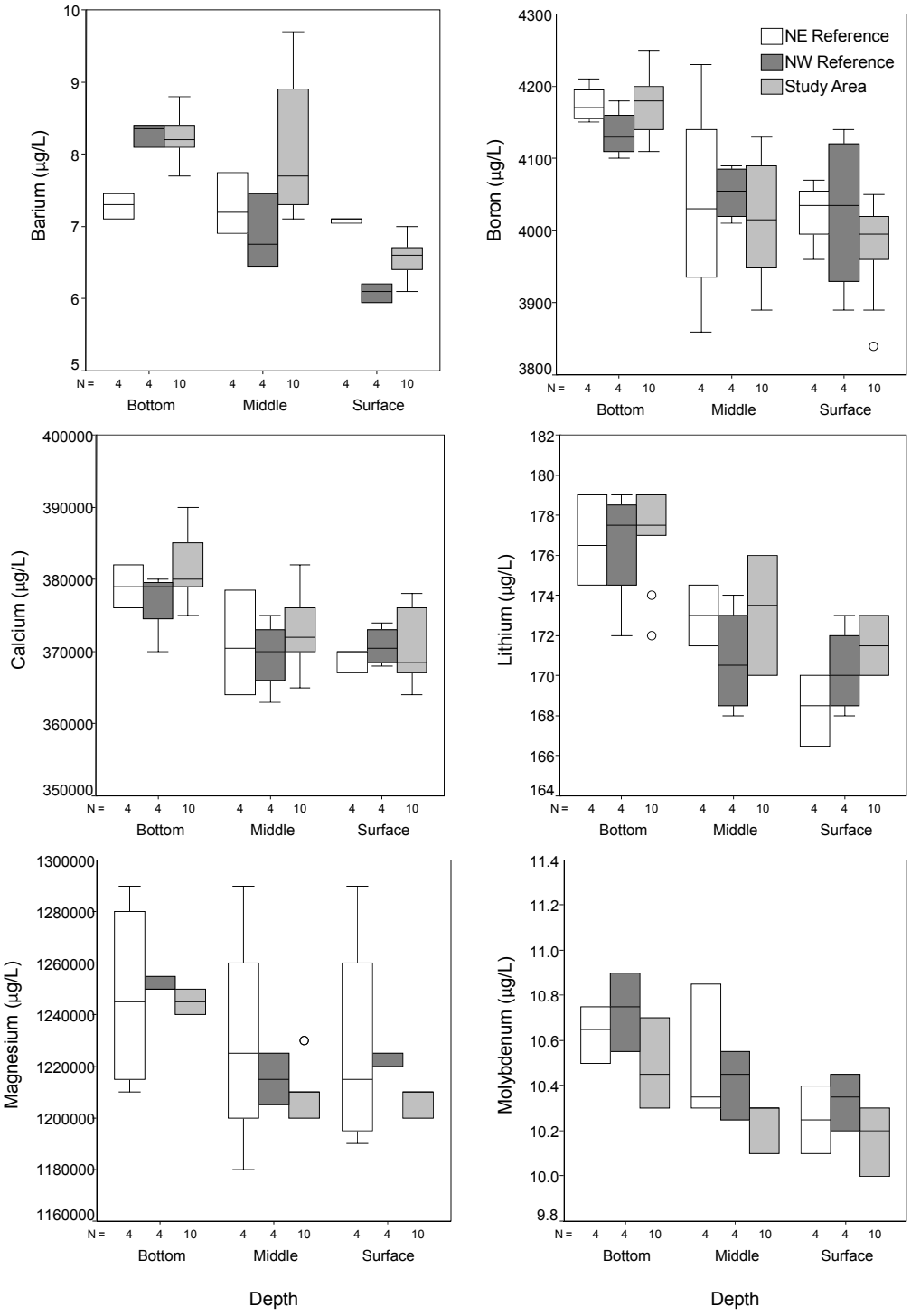

Figure 7-3 Box Plots of Water Chemistry by Area and Depth

Note: Box plot interpretation: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ± 1.5 x interquartile spread. Asterisks indicate values falling within the quartile ± 3 x interquartile spread. Open circles indicate values falling outside the quartile ± 3 x interquartile spread.

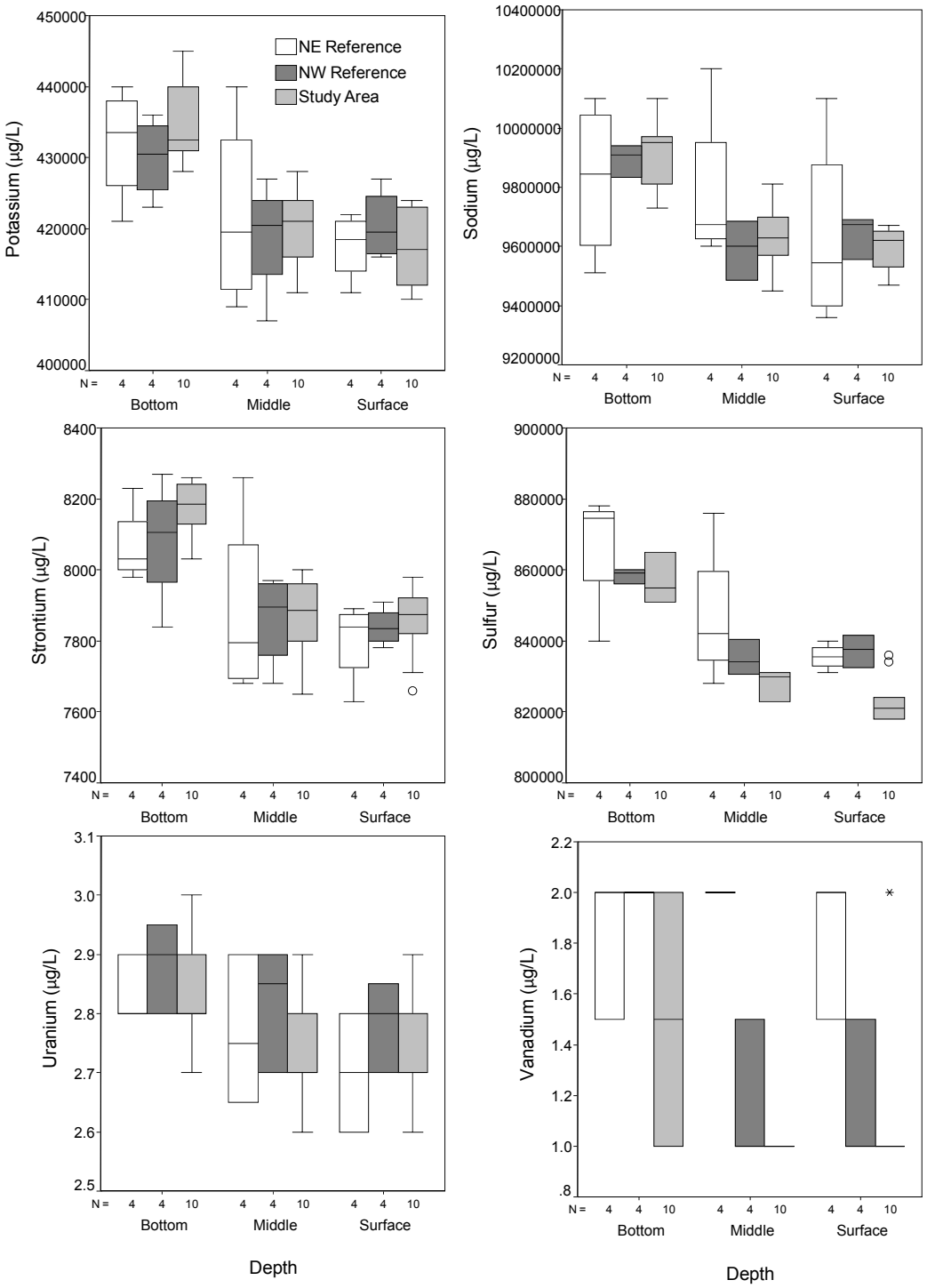

Figure 7-3 Box Plots of Water Chemistry by Area and Depth (cont.)

Note: Box plot interpretation: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ± 1.5 x interquartile spread. Asterisks indicate values falling within the quartile ± 3 x interquartile spread. Open circles indicate values falling outside the quartile ± 3 x interquartile spread.

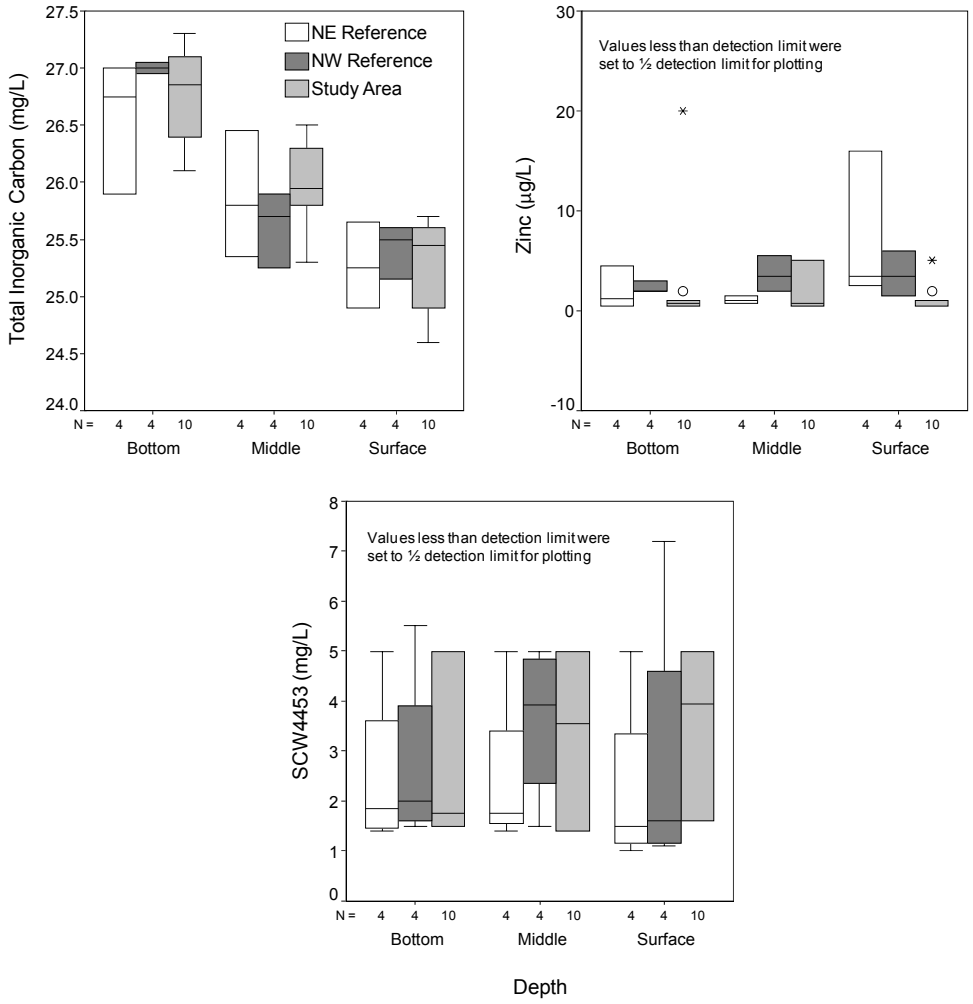

Figure 7-3 Box Plots of Water Chemistry by Area and Depth (cont.)

Note: Box plot interpretation: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ± 1.5 x interquartile spread. Asterisks indicate values falling within the quartile ± 3 x interquartile spread. Open circles indicate values falling outside the quartile ± 3 x interquartile spread.

Table 7-4 Results of ANOVA (*p*-values) Testing Differences Between Reference Areas and Between the Study Area and the Reference Areas

	***p*-values**				
Variable	**Depth (D)**	**BR**	**SR**	**BRXD**	**SRXD**
Barium	**<0.0001*** **			**0.0020**	0.6854
Boron	**<0.0001*** **	0.7921	0.5539	0.7827	0.2965
Calcium	**<0.0001*** **	0.8128	0.1015	0.6762	0.5629
Lithium	**<0.0001*** **	0.8922	0.1814	0.3833	0.6045
Magnesium	**<0.0001*** **	0.6873	0.0889	0.8218	0.6619
Molybdenum	**<0.0001*** **	1.0000	0.0028**	0.4873	0.6694
Potassium	**<0.0001*** **	0.8080	0.9343	0.7042	0.3462
Sodium	**<0.0001*** **	0.5389	0.9712	0.4294	0.4446
Strontium	**<0.0001*** **	0.8326	0.2665	0.8769	0.2152
Sulphur	**<0.0001*** **	0.2787	**0.0010*** **	0.6359	0.4424
Uranium	**<0.0001*** **	0.1709	0.8247	0.7462	0.6380
Vanadium	0.0080**	0.1206	0.4321	0.1014	0.8654
TIC	**<0.0001*** **	0.6843	0.6999	0.4221	0.6826
Zinc	0.5680	0.1052	0.3945	0.1428	0.6303
SCW4453	0.4525	0.0864	0.6466	0.8925	0.8417

Notes:
- Zinc and SCW4453 were rank transformed.
- 'Depth' tests for depth differences, overall.
- 'BR' tests for differences between the Reference Areas.
- 'SR' tests for differences between the Reference Areas and the Study Area.
- 'BRXD' tests for differences in depth gradients between the two Reference Areas.
- 'SRXD' tests for differences in depth gradients between the Study Area and the Reference Areas.
- SR and BR contrasts are not reported if significant depth interactions are present.
- F(SR) = MS(SR)/MS(BR) if $p < 0.25$ for the BR term (Quinn and Keough 2002).
- F(SRXD) = MS(SRXD)/MS(BRXD) if $p < 0.25$ for the BRXD term (Quinn and Keough 2002).
- Reported *p*-values for Depth, BR and SR are from models with the interaction term removed when the interaction term was not significant.
- pH was not tested because it varied over a very narrow range (four values were reported: 7.8, 7.9, 8.0 and 8.1).
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

7.2.5 Summary of Findings

Few differences in water chemistry were found between the Study Area and the Reference Areas in 2010. Quantitative analyses were performed on those variables that occurred above the laboratory detection limit in all instances or frequently. Barium, boron, calcium, lithium, magnesium, molybdenum, potassium, sodium, strontium, sulphur, uranium, vanadium and TIC were detected in all instances. Zinc and SCW4453 were detected in 69% of samples. Of these, the only variables that indicated a difference between the Study Area and the Reference Areas were molybdenum and sulphur, with values lower in the Study Area.

Low levels of cadmium, lead, lead-210, radium-226, copper, iron and aluminum were detected in a few samples from both the Study and the Reference Area. All other analytes, including BTEX, $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, PAHs and alkyl PAHs, phenols and alkyl phenols, organic acids, radium-228, ammonia and XCide450, were below the laboratory detection limit.

7.3 Produced Water Modelling

The purpose of the modeling work was to assess the probability of detecting selected constituents of produced water in seawater samples during the White Rose EEM program. The ultimate goal of the exercise was to find a potential tracer for produced water and/or fine-tune the water quality sampling program at White Rose.

7.3.1 Constituent Selection

Constituents chosen for modelling were those that occur in high concentrations in produced water relative to seawater or, for the two process chemicals, have been identified as contributing to environmental risk (Husky Energy 2010). Modelled constituents were (in alphabetical order) acetic acid, *m,p*-cresol, naphthalene, *o*-cresol, phenol, radium-228 and the process chemicals SCW4453 and XCide450).

Other than SCW4453, none of the modelled constituents were detected in seawater samples in 2010 (Section 7.1). This was expected because, with the exception of October 4 and 5, no produced water was being released at White Rose at the time of sampling. Note that the rust inhibitor used on the *MV Gabarus* may contain ingredients that are also part of the proprietary ingredients of SCW4453.

7.3.2 Model and Model Inputs

The Dose-Related Risk and Effects Assessment Model (DREAM) was used to predict concentrations of produced water constituents in the receiving environment. DREAM can simultaneously account for up to 200 chemical constituents within a plume (see Appendix D-4 for details on DREAM). Spatial distributions can be mapped for constituents of interest and concentrations can be compared to available laboratory detection limits to identify those constituents that have some potential of being detected in field samples[19].

Produced water chemical characterization data (Husky Energy 2010), physical discharge parameters (Table 7-5), water column temperature and salinity, local wind and current data were used as input to DREAM. Wind data were provided to Husky Energy by Provincial Aerospace Limited. Temperature, salinity and current data were provided by AMEC Earth and Environmental Ltd. These data are summarized in Appendix D-4. Discharge concentrations for each constituent, along with achievable laboratory detection limits (RPC, pers. comm.), are provided in Table 7-6. Chemical properties (biodegradation properties, partitioning coefficients, density, vapour pressure and boiling point) required to effectively model these constituents were identified by SINTEF (Norway) and SINTEF provided input parameters for the naturally-occurring constituents (Appendix D-4). Chemical properties for the two process chemicals were provided by Baker Petrolite.

[19] Probability of detection (%) for any given cell is calculated as the number of model outputs above a set threshold (the laboratory detection limit) in that cell over the total number of outputs in a 30-day simulation X 100. Thresholds can be changed to match theoretical laboratory detection limits.

Table 7-5 Physical Discharge Parameters

Discharge Parameter	Model Input
Discharge volume	28,000 m^3/day
Vertical orientation of discharge	Vertical facing seabed
Geographic location of discharge	46°51.79'N; 48°3.88'W
Pipe diameter	30 inches (0.762 m)
Temperature of discharge	81°C
Salinity of discharge	31 ppt
Discharge depth	11 to 18 m below surface: 15 m entered
Bottom depth	120 m

Table 7-6 Discharge Concentrations and Laboratory Detection Limits for Selected Produced Water Constituents

Constituent	Discharge Concentration	Laboratory Detection Limit
Acetic acid	565 ppm	1 ppm
m,p-cresol	2.05 ppm	0.1 ppb
Naphthalene	0.370 ppm	0.005 ppb
o-cresol	1.350 ppm	0.1 ppb
Phenol	2.7 ppm	0.1 ppb
Radium 228	2.85 Bq/L	0.3 Bq/L
SCW4453	20 ppm	1 ppm
XCide450	8 ppm	0.5 ppm

Note: - Laboratory detection limits are those available at RPC, in Fredericton, NB. This Canadian analytical laboratory offered the lowest detection limits overall and could provide results for phenol and alkylated phenols – both constituents of interest.

All modelled constituents were assumed to be 100% soluble. Assuming 100% solubility ignored the possibility that some constituents could be present in dissolved and/or particulate form (or both). Laboratory extractions currently performed on seawater samples do not differentiate between concentrations of dissolved and particulate material. The assumption for this modelling exercise was that particulates remained in suspension in the water column. Because particulates may settle to marine sediments (Azetsu-Scott et al. 2007), another modelling exercise is planned to examine potential accumulation on the sea floor.

A produced water discharge volume of 28,000 m^3/day was used. This is the maximum discharge volume presently allowed for White Rose. The rationale for using the maximum discharge was that if modelling showed that constituents have low probabilities of being detected in field samples at maximum discharge, then probabilities would be lower at lower discharge volume.

Modelling simulated a continuous discharge over a 30-day period using wind and current data from June 2006. Future modelling could use wind and current data for a time period overlapping field sampling, with a discharge volume similar to that at the time of sampling. In 2010, no produced water was being discharged during sampling and current data were not readily available during the sampling period because of Hurricane Igor. For the purpose of this theoretical modelling exercise, June 2006 data were sufficient. June is a relatively calm month on the Grand Banks of Newfoundland and concentrations of produced water constituents would be expected to be at their highest in the water column during in this month (as well as July and, to an extent, August) relative to fall or winter months, when storm activity would quickly disperse produced water constituents.

Model output intervals ranged from 6 hrs to 12 hrs. Time-step was set at 10 minutes. Cell size was set at approximately 145 m X 130 m. The modelling window (modelled area) was 220 X 200 km. Depth intervals were set at 12 m (to 120 m depth (i.e., 10 depth intervals)). A cell size smaller than 145 m X 130 m was not possible because of file size limitation, given the spatial extent of the area modelled (44,000 km^2). Modelling over a large spatial area was performed to capture the movement of the entire plume. A sensitivity analysis on cell size was performed for cells sizes ranging from 2 X 2 km down to the smallest cell size tested (145 to 130 m).

7.3.3 Overview of Results

Figures 7-4 to 7-11 provide probability of detection above laboratory detection limit for the modelled constituents (Figures are provided in alphabetical order of constituents)[20]. The detailed modelling report is provided in Appendix D-4. Based on this exercise, the constituent with the highest probability of detection in seawater samples during release of produced water was naphthalene, followed by phenol, *m,p*-cresol and *o*-cresol. Other tested constituents had a zero (radium-228, SCW4453 and XCide450) or near-zero (acetic acid) probability of being detected in seawater samples. This indicates that concentrations of these constituents were diluted to levels near or below detection limit shortly after release. Detectable concentrations of naphthalene phenol, *m,p*-cresol and *o*-cresol were found predominantly near the surface (vertical cross sections in Figures 7-5 to 7-8, with details in Appendix D-4).

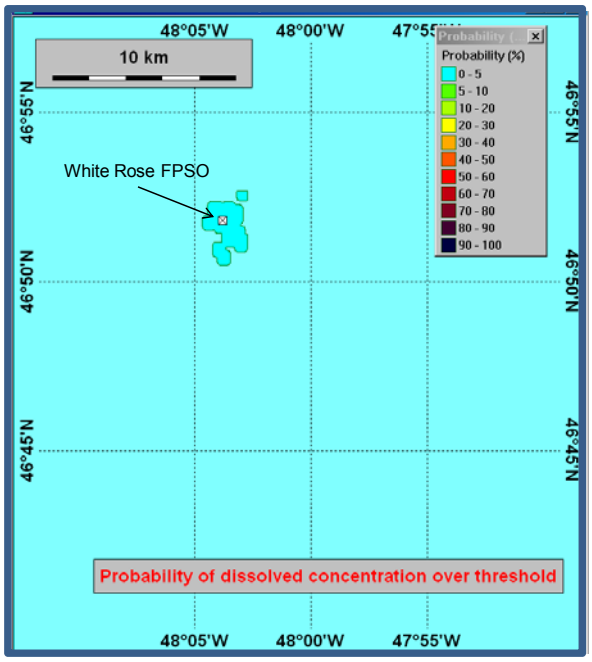

Figure 7-4 Probability of Detecting Acetic Acid Over the Laboratory Detection Limit of 1 mg/L

Note: The plot represents maximum probability in any cell at a given location regardless of depth (see Appendix D-4 for details).

[20] Laboratory detection limits used were the lowest laboratory detection limits achievable at RPC (RPC, pers. comm., December 2010) and many are lower than laboratory detection limits listed in Table 7-2.

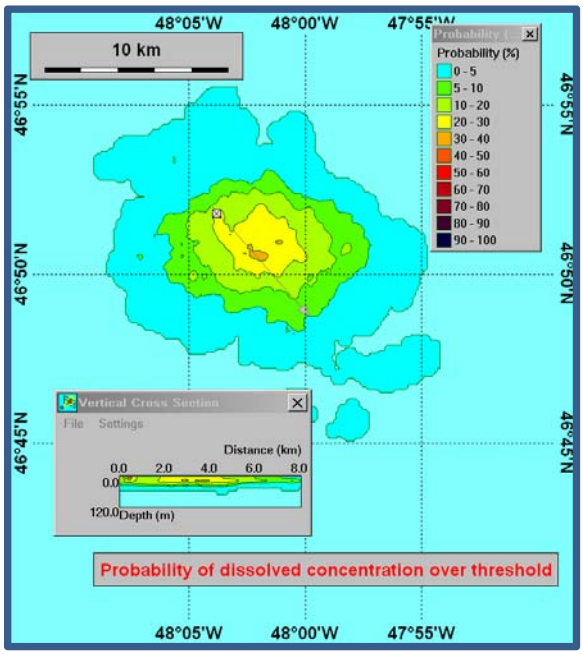

Figure 7-5 Probability of Detecting *m,p*-cresol Over the Laboratory Detection Limit of 0.1 µg/L

Notes: The horizontal plot represents maximum probability in any cell at a given location regardless of depth. The vertical cross section shows probability over depth over the transect line identified in the horizontal plot (see Appendix D-4 for details).

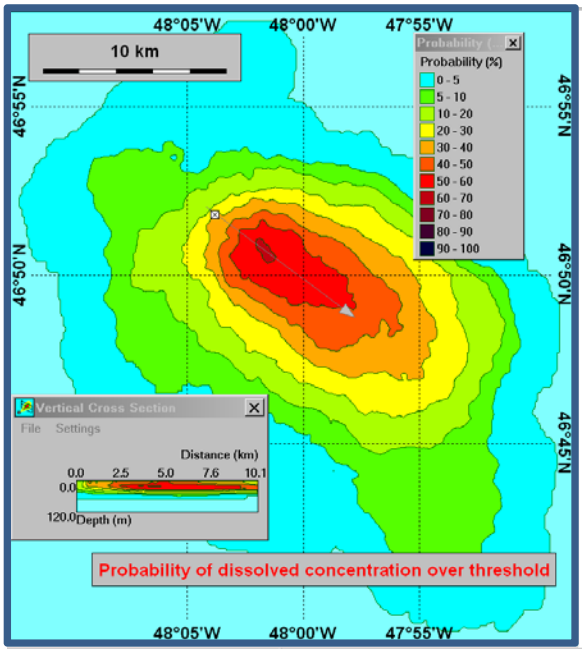

Figure 7-6 Probability of Detecting Naphthalene Over the Laboratory Detection Limit of 0.005 µg/L

Notes: The horizontal plot represents maximum probability in any cell at a given location regardless of depth. The vertical cross section shows probability over depth over the transect line identified in the horizontal plot (see Appendix D-4 for details).

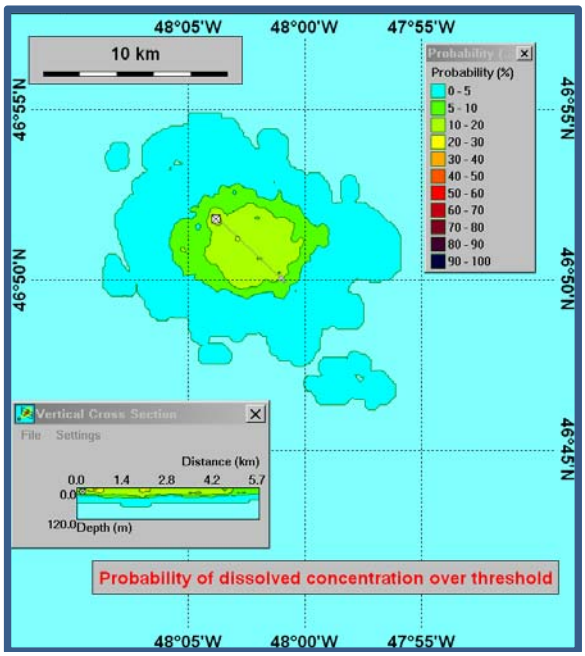

Figure 7-7 Probability of Detecting *o*-cresol Over the Laboratory Detection Limit of 0.1 µg/L

Notes: The horizontal plot represents maximum probability in any cell at a given location regardless of depth. The vertical cross section shows probability over depth over the transect line identified in the horizontal plot (see Appendix D-4 for details).

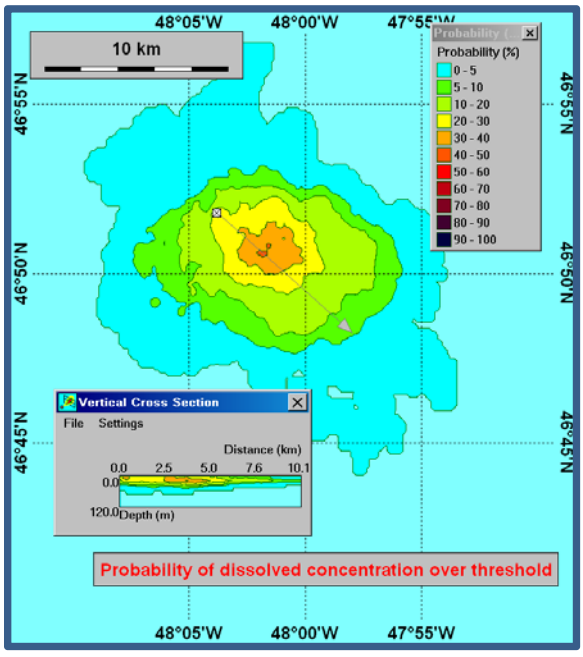

Figure 7-8 Probability of Detecting Phenol Over the Laboratory Detection Limit of 0.1 µg/L

Notes: The horizontal plot represents maximum probability in any cell at a given location regardless of depth. The vertical cross section shows probability over depth over the transect line identified in the horizontal plot (see Appendix D-4 for details).

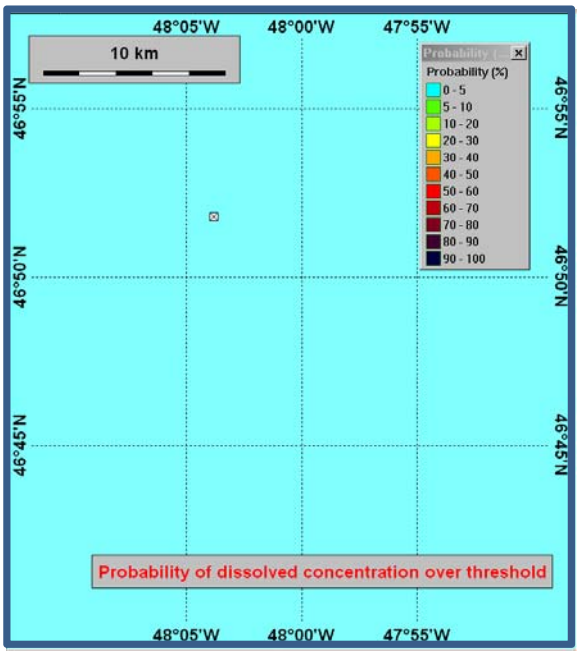

Figure 7-9 Probability of Detecting Radium-228 Over Laboratory Detection Limit of 0.3 Bq/L

Note: The plot represents maximum probability in any cell at a given location regardless of depth (see Appendix D-4 for details).

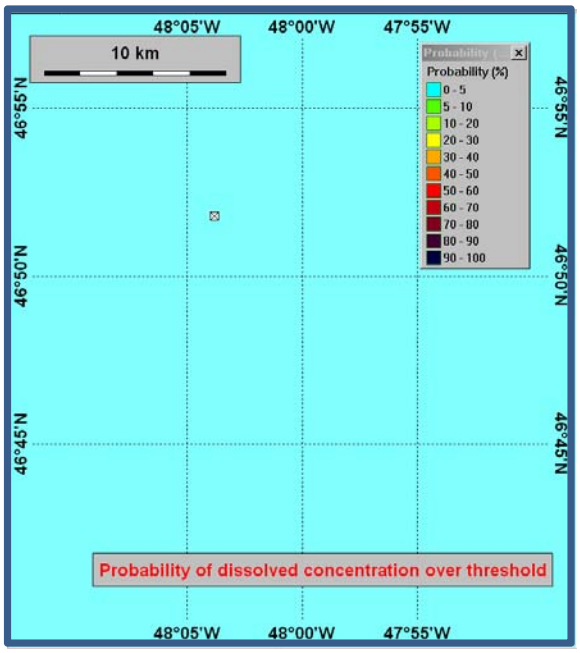

Figure 7-10 Probability of Detecting SCW4453 Over the Laboratory Detection Limit of 1 mg/L

Note: The plot represents maximum probability in any cell at a given location regardless of depth (see Appendix D-4 for details).

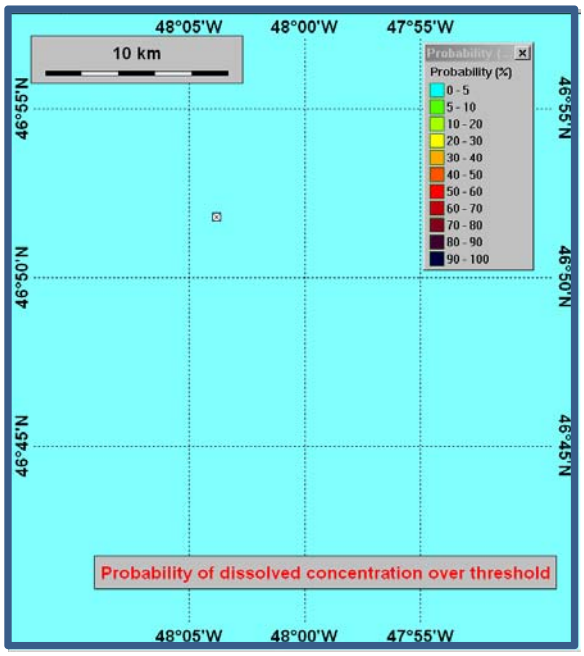

Figure 7-11 Probability of Detecting XCide450 Over the Instrumentation[21] Threshold of 0.5 mg/L

Note: The plot represents maximum probability in any cell at a given location regardless of depth (see Appendix D-4 for details).

Modelling results indicated that the probability of detecting constituents further away from source, in the direction of the prevailing current, is higher than it is near source (e.g., Figures 7-5 to 7-8). In other words, concentrations at set locations further away from source can be expected to be above laboratory detection limits more often than concentrations at set locations near source. Concentrations near source result from episodic changes in current/wind direction. Concentrations away from source are affected predominantly by prevailing seasonal currents and winds.

A good example of this is provided in Figure 7-12, showing the concentration of naphthalene on day 20 of the simulation. Concentrations in some cells near source are high, but the exact location of these high concentrations will be subject to the vagaries of currents at the time of sampling (the AVI files provided as separate files show this quite clearly). Conversely, concentrations at locations approximately 1 to 2 km to the southeast are more consistently above the laboratory detection threshold (0.005 ppb) for this compound (the plume is more spread out and concentrations remain high enough to be detected).

[21] Biodegradation properties of XCide450 are such that the constituent needs to be measured at the time of sampling.

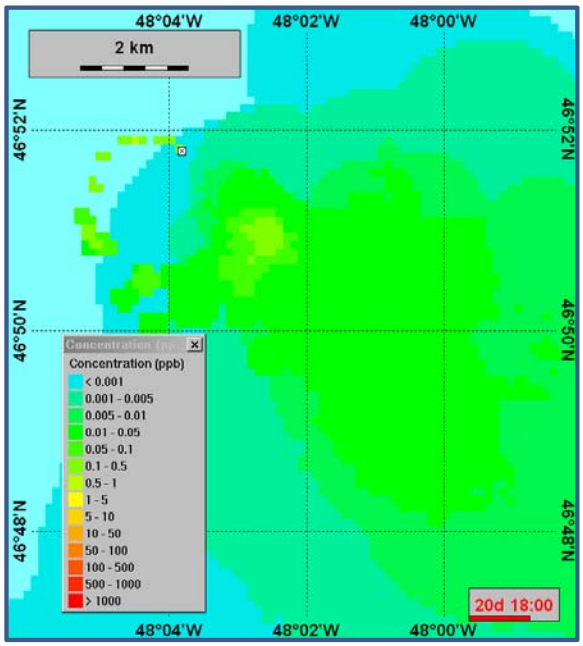

Figure 7-12 Naphthalene Plume on Day 20

Sensitivity analysis on cell size (Appendix D-4) showed that probabilities near source would most likely have been lower than those indicated here if a smaller cell size had been achievable. A cell size of 145 m X 130 m X 12 m represents a much larger volume than that sampled with a 10 L Niskin bottle. Therefore, the probability of detecting any constituent in the near-field with Niskin bottles is lower than what is indicated by modelling results. Importantly, cell size had little to no effect on probabilities further away from source (Appendix D-4).

7.3.4 Summary of Findings

Some of the results presented here were unexpected and counter to the commonly held view that produced water constituents can only be detected very near the discharge source. If concentrations remain above laboratory threshold, then constituents can be detected further downstream in the direction of the prevailing current.

The following conclusions were drawn from the modelling study (Appendix D-4):

- In the absence of other sources, naphthalene is likely a good indicator of the presence of produced water from White Rose.
- To be most effective, near-field sampling should be adaptive, with stations positioned in relation to current direction at the time of sampling (i.e., station should not be fixed).
- Sampling at far-field stations (approximately 1 to 5 km from source) should be effective for those constituents with a high probability of detection. Far-field stations should be at fixed locations in the direction of the prevailing seasonal current.

- Aside from biological/chemical reactivity and physical properties, the probability of detection of a constituent is dictated by its release concentration and its laboratory detection limit. Therefore, the lowest reliable detection limit should be used for the analysis of field samples.

8.0 Discussion

8.1 Sediment Quality Component

Examination of sediment quality is standard in many EEM programs (e.g., Hurley and Ellis (2004) and references therein; Bjørgesaeter and Gray (2008); Netto et al. (2009); Pozebon et al. (2009); Santos et al. (2009)). The White Rose EEM program examines potential project effects on sediment chemistry, sediment toxicity and benthic community structure. These three sets of measurements are known as the Sediment Quality Triad (Chapman 1992). The assessment of effects at White Rose is based on the change in relationships between Sediment Quality Triad variables and distance from the development. Distance to the nearest active drill centres is used to assess drilling effects at the whole-field level. Occurrence above or below the range of values observed during baseline sampling (2000) is used to assess effects from individual drill centres. In the 2010 program, changes in sediment variables with distance to the *SeaRose* FPSO were also examined to identify potential effects from the discharge of produced water.

8.1.1 Physical and Chemical Characteristics

The concentration of $>C_{10}$-C_{21} hydrocarbons and barium in sediments was affected by project activity, with higher concentrations near active drill centres and decreases in concentration with distance from active drill centres. In 2010, concentrations of $>C_{10}$-C_{21} hydrocarbons and barium were elevated around all active drill centres, as they were in previous EEM years. Estimates of the zone of influence for $>C_{10}$-C_{21} hydrocarbons and barium from threshold models[22] in 2010 were less than those estimated in 2008. For $>C_{10}$-C_{21} hydrocarbons, a threshold distance (distance at which concentrations are reduced to low or background levels) of 10.4 km was noted in 2008 and a threshold distance of 3.6 km was noted in 2010. For barium, a threshold distance of 2.4 km was estimated in 2008 and a threshold distance of 2 km was estimated in 2010. However, since confidence intervals on threshold distances for all post-drilling sampling years (2004 to 2010) have overlapped, it cannot be concluded that there has been a significant change in the spatial extent of contamination since drilling began at White Rose[23].

Consistent with threshold model results, the magnitude of sediment contamination with $>C_{10}$-C_{21} hydrocarbons and barium has not increased significantly over post-drilling years (slopes of decreases in concentration with distance from drill centres were similar among years in repeated-measures regression). The maximum $>C_{10}$-C_{21} hydrocarbon concentration in 2010 was 810 mg/kg and the maximum barium concentration was 2,700 mg/kg. These were increases from baseline maxima (below detection limit for $>C_{10}$-C_{21} hydrocarbons and 210 mg/kg for barium), but values noted in 2010 were decreases from maxima noted in 2008 (1,600 and 3,400 mg/kg, respectively). Maxima in 2010 occurred at station NA1-C, the station nearest to the North Amethyst Drill Centre (0.3 km from the drill centre). Drilling started at the North Amethyst Drill Centre in 2009 and drilling was more intense at that drill centre in 2009/2010 than at the other drill centres.

[22] Threshold models estimate the distance at which concentrations are reduced to low or background levels using distance to the nearest drill centre as the input variable. Details are provided in Section 5.

[23] In part, the variation in threshold distances is a function of tightness of the relationship between the analyte concentration and distance from nearest drill centre; strong correlations *de facto* produce shorter thresholds, while noisier relationships will produce longer threshold distances.

Elevated concentrations of hydrocarbons and barium have been observed near drill centres and platforms at other offshore oil developments. Examples of concentrations at White Rose and at other developments are provided in Table 8-1. Levels of hydrocarbons and barium at White Rose were within the range noted at fields indicated in Table 8-1.

Table 8-1 Total Petroleum Hydrocarbons and Barium with Distance from Source at White Rose and at Other Developments

Location	Year of Study	Distance from Source (m)	TPH (mg/kg)	Barium (mg/kg)
White Rose	2010	300 to 750	9.9 to 819	250 to 2,700
		750 to 2,500	0.5 to 11.40	160 to 480
		2,500 to 5,000	0.4 to 1.40	160 to 200
	2008	300 to 750	2.2 to 1,615	170 to 3,400
		750 to 2,500	1.3 to 55.7	160 to 600
		2,500 to 5,000	<0.3 to 4.2	160 to 210
	2006	300 to 750	1.5 to 576	200 to 3,100
		750 to 2,500	0.7 to 53.4	150 to 770
		2,500 to 5,000	<3	140 to 250
	2005	300 to 750	<3 to 261.7	210 to 810
		750 to 2,500	<3 to 54.6	140 to 380
		2,500 to 5,000	<3	150 to 220
	2004	300 to 750	8.99 to 275.9	190 to 1,400
		750 to 2,500	<3 to 22.2	120 to 470
		2,500 to 5,000	<3 to 6.9	140 to 230
	2000	300 to 750	<3	140 to 180
		750 to 2,500	<3	140 to 210
		2,500 to 5,000	<3	150 to 210
Grand Banks, Terra Nova (Petro-Canada 1998, 2001, 2002, 2003, 2005, 2007; Suncor Energy 2009)	2008	140 to 750 570 to 2,500 2,500 to 5,000	<3 to 343 <3 to 11 <3	130 to 7,200 89 to 280 78 to 210
	2006	140 to 750 750 to 2,500 2,500 to 5,000	8 to 986 <3 to 30 <3	240 to 16,000 110 to 340 89 to 230
	2004	140 to 750 750 to 2,500 2,500 to 5,000	8 to 6,580 3 to 72 <3 to 4	140 to 2,100 100 to 340 63 to 190
	2002	140 to 750 750 to 2,500 2,500 to 5,000	<3 to 931 <3 to 49 <3 to 5	110 to 2,200 84 to 330 83 to 200
	2001	750 to 2,500 2,500 to 5,000	<3 to 30 <3 to 8	100 to 190 87 to 180
	2000	750 to 2,500 2,500 to 5,000	<3 to 14 <3 to 6	92 to 210 80 to 230
	1997	750 to 2,500 2,500 to 5,000	<3 <3	87 to 190 79 to 280
Gulf of Mexico (NPO-895) (Candler et al. 1995)	1993	50 200 2,000	134,428 80 to 11,460 24	47,437 542 to 5,641
Gulf of Mexico (MAI-686) (Kennicutt et al. 1996)	1993	200 500 3,000	40 43 49	1,625 1,134 1,072
Gulf of Mexico (MU-A85) (Kennicutt et al. 1996)	1993	200 500 3,000	42.3 31.7 27.1	3,706 1,817 1,094

Location	Year of Study	Distance from Source (m)	TPH (mg/kg)	Barium (mg/kg)
Gulf of Mexico (HI-A389) (Kennicutt et al. 1996)	1993	200 500 3,000	65 33 32	13,756 3,993 1,293
North Sea (Beatrice) (Addy et al. 1984)	1982	250 750 3,000	8 to 759 5 to 105 3 to 73	-
Dutch Continental Shelf (K14-13) (Daan and Mulder 1996)		200	54 to 161	-
North Sea (Daan et al. 1994)	1994	200	2 to 4,700	
Norway (Valhall) (Hartley 1996)	1985	250 500 3,000	-	19,000 to 96,000 3,700 to 9,300 280 to 430
North Sea (Brent) (Massie et al. 1985)	1981	800 3,200	41 to 61 33 to 43	-
North Sea (Forties) (Massie et al. 1985)	1980	800 3,200	9 to 78 16 to 55	-
Gulf of Mexico (Matagorda 622) (Chapman et al. 1991; Brooks et al. 1990)	1987	25 150 750 3,000	757 ±1,818	6,233 12,333 980
Santa Maria Basin (Hidalgo) (Phillips et al. 1998)	1991	125 500 1,000	-	1,250 975 1,050
Norway (Ekofisk) (Ellis and Schneider 1997)	1996	750 2,000 5,000	-	3,650 2,214 667
Norway (Gyda 2/1-9) (Bakke et al. 1995)	1994	100 to 200	236	-
Norway (Tordis) (Gjøs et al. 1991)	1990	500	8,920	-
Norway (U/a 2/7-29) (Vik et al. 1996)		200	1,000 to 2,368	-
North Sea (UK) (UKOOA 2001)	1975 to 1995	0 to 500 >500 to 2,000 >2,000 to 5,000	124 to 11,983 3 to 164 3 to 76	84 to 2,040 7 to 1595 8 to 729

Notes:
- TPH (total petroleum hydrocarbon) includes C_6-C_{32} hydrocarbons. This range is reported for comparison to other offshore operations.
- Absolute barium levels should not be compared across projects because of potential differences in measurement techniques (Hartley 1996) and differences in background levels.
- Distance for White Rose in 2010 is distance from the Northern, Central, Southern and North Amethyst Drill Centres. Distance in 2000, 2005, 2006 and 2008 is distance to nearest of the Northern, Central and Southern Drill Centres. Distance in 2004 is distance to the nearest of the Northern and Southern Drill Centres.
- Station 31 at White Rose, near an exploration well drilled in 2007, was excluded from 2008 and 2010 statistics.

Effects on other sediment physical and chemical variables, if any, were subtle. In 2010, % sulphur was higher at stations 0.3 km from (nearest to) drill centres (approximately 0.1% at 0.3 km stations versus 0.05% at other stations). These marginally elevated sulphur levels were noted in the vicinity of the Central, Southern and North Amethyst Drill Centres, with little evidence of elevated levels around the Northern Drill Centre. Sulphur concentrations were significantly correlated with distance from drill centres with the 0.3 km stations included in the data set, but sulphur was not correlated with distance when those stations were excluded, indicating that sulphur contamination was likely restricted to 0.3 km stations.

Percent fines in sediment was not related to distance from drill centres but there was a general increase in fines from before to after drilling began. The increase in fines was minor. Fines levels were elevated to 3.7% at station NA1-C, located nearest to the North Amethyst Drill Centre. Remaining values ranged from 0.8% to 2.5 %. This represents an increase of approximately 1% compared to the upper limit of the normal range of 1.3% noted in baseline. The lack of a relationship between percent fines and distance from drill centres indicates that the general increase in fines was likely not drilling related, although the increase at station NA1-C was likely related to drilling.

Metals concentrations (excluding barium) were not related to distance from active drill centres in 2010 but, like percent fines, metals concentrations have generally increased since baseline. The highest concentration in 2010 was noted at station WQ12, approximately 25 km from the Northern Drill Centre. Therefore, elevated metals concentrations were not linked with project activity. Metals concentrations were not sufficiently elevated to affect biota. No metals exceeded sediment quality guidelines in 2010 (Section 5). Neff (2007) also noted that any metals from drilling fluids would not be readily bioavailable.

There was no indication of any effects from drilling operations on total organic carbon, redox potential and ammonia in sediments. However, redox increased and ammonia decreased across the sampling area over time (with no association with distance from active drill centres). Redox data from all years indicate that sediments are oxic. An increase in redox potential, as well as a decrease in ammonia, over time should not be a stress on benthic communities (Rosenberg et al. 2001; CCME 2010).

Releases from the *SeaRose* FPSO had no detectable influence on sediment physical and chemical characteristics after taking into account the influences associated with active drill centres.

8.1.2 Laboratory Toxicity Tests

In previous years, all samples tested for Microtox toxicity were non-toxic. In 2010, all but one Microtox IC_{50}s were greater than the highest concentration tested (i.e., were non-toxic). The single toxic sample in 2010 was collected from station C5-C, located 0.30 km from the Central Drill Centre and with relatively high $>C_{10}$-C_{21} hydrocarbon and barium levels. Conversely, the station with the highest hydrocarbon and barium contamination (NA1-C) was not toxic to Microtox.

Amphipod survival in toxicity tests in most White Rose samples has been high in all years. Amphipod survival in 2010 was related to distance to the nearest active drill centre, $>C_{10}$-C_{21} hydrocarbon and barium concentrations. However, all samples in 2010

produced a minimum of 77% survival and, therefore, all were classified as non-toxic. In 2008, 8 of 47 samples were classified as toxic in the Amphipod survival test.

8.1.3 Benthic Invertebrate Community Structure

As noted in 2008, evidence of effects on total abundance was marginal, benthic biomass was affected by project activity and there was no evidence of effects on richness.

Clear effects on total abundance were only apparent at one station (Station 20) near (0.37 km) the Central Drill Centre and 0.38 km away from Station C5-C. Station C5-C was toxic to Microtox, which would indicate some influence of project activity on stations near the Central Drill Centre. The influence of station 20 was most apparent in threshold and linear regression models, which were significant when station 20 was included but not significant when it was not. Beyond effects at station 20, there was a tendency for abundance to be lower near the Central, Southern and North Amethyst Drill Centres. However, many stations further away from drill centres, including the most distant stations, showed similar abundance levels, indicating annual variability and that abundance levels noted around these other two drill centres were not outside the range for 2010. There was no evidence of effects from Northern Drill Centre on total abundance.

Overall, approximately 40% of stations in 2010 had total abundance values less than the range (95% confidence intervals) noted in baseline (1,885 to 6,776 individuals per m^2). Total abundance among all stations was most obviously depressed in 2005, when more than 60% of stations had abundances lower than the baseline range[24].

Total biomass increased with distance from drill centres (i.e., biomass was lower near drill centres). No threshold distance could be estimated for biomass, indicating a linear increase in biomass with distance from drill centres. Benthic biomass was lower than the baseline range around the Central, Southern and North Amethyst Drill Centres, but biomass was not reduced around the Northern Drill Centre. The lowest biomass in 2010 (87 g/m^2) occurred at station C2, located 0.83 km from the Central Drill Centre. From graphical display of data (e.g., Figure 5-27), there was considerable overlap in effects from the Central and Southern Drill Centres making it difficult to assess distance effects from these two drill centres (i.e., stations around these two drill centres are under the influence of both drill centres). Effects around the North Amethyst Drill Centre, which were not confounded with effects from the other drill centres, were noted to approximately 500 m. Station NA2, located 500 m from the North Amethyst Drill Centre was the furthest drill centre station showing an effect from the North Amethyst Drill Centre.

Overall, benthic biomass in 2010 fell below the baseline range of 367 to 1,400 g/m^2 at 29% of stations. Biomass was generally higher in 2008, with only 16% of stations with biomass less than the lower baseline range.

Richness (number of families per station) was not related to distance from drill centres. Although there was no change in overall richness from before to after drilling began, there was a potential increase in overall richness during the active drilling period (i.e.,

[24] Calculations of the number of stations that fall below the baseline range do not provide a measure of effect size, nor do decreases below baseline overall indicate a project effect. Effect size is discussed in Section 8.4.

from 2004 to 2010). In 2010, only 6% of observations fell below the estimated limits of the normal range noted in baseline (2000). This is approximately the frequency expected on the basis of the calculation of the normal range (i.e., to enclose 95% of observations).

Responses of selected individual taxa at White Rose were examined to provide additional insight into the more general indices of community composition. Non-metric multi-dimensional scaling (NMDS) was used in a similar fashion. Of the taxa examined, Paraonidae were clearly affected by project activities, as in previous years. Changes in the abundances of other taxa, including Spionidae, Tellinidae and Amphipoda, were noted, but these were either subtle or area-wide and could indicate a response to factors unrelated to the project.

Paraonidae abundance has been related to distance from drill centres since drilling began in 2004; numbers of Paraonidae have been lower near drill centres. Effects in 2010 were arguably less extensive than in previous years, with threshold distances of 1.6 km versus distances of greater than 2 km in other years. However, since confidence intervals around threshold distances have overlapped, it is not possible to conclude that threshold distances have varied among years. Numbers of Paraonidae were reduced around all active drill centres. Number of Paraonidae was generally lower around the Central Drill Centre but there was overlap in effects from the Southern Drill Centre. Effects around the Northern and North Amethyst Drill Centres, which were not confounded with those of other drill centres, extended to 630 m and 500 m, respectively. Station N3, located 630 m from the Northern Drill Centre was the furthest station showing an effect from the Northern Drill Centre. Station NA2, located 500 m from the North Amethyst Drill Centre was the furthest station showing an effect from the North Amethyst Drill Centre.

Overall, Paraonidae abundance varied between 130 and 1,671 per m^2 in 2000 (baseline) and approximately 40% of stations had abundances of Paraonidae lower than the baseline range in 2010. There were more stations with Paraonidae abundance below the lower baseline range in 2010 than in other years, with 28% below the baseline range in 2005, 24% below range in 2006 and 32% below range in 2008.

Spionidae abundance was not related to distance from drill centres in 2010 and there was no change in distance relationships across years including baseline. However, there was a change in Spionidae abundance across the entire sampling area between 2000 and drilling years (2004 to 2010), with numbers lower in drilling years. Spionidae abundances in 2000 ranged from 643 to 2,682 individuals per m^2. Approximately 30% of stations in 2010 had Spionidae abundances below the baseline range. Spionidae abundances were most frequently below the baseline range in 2005 (62% of stations were below the baseline range). Low values occurred at a variety of distances from drill centres in 2010. In some previous years, particularly in 2005, low values occurred more frequently near drill centres. Therefore, the association between Spionidae abundance and drilling was unclear in 2010, in spite of indications of potential drilling effects noted in previous years.

As in previous years, Tellinidae abundance in 2010 was strongly correlated with depth and uncorrelated with distance from drill centres. Overall Tellinidae abundance was lower during drilling years than in baseline. Tellinidae abundance in 2000 ranged from 151 to 1,303 individuals per m^2. In 2010, approximately 30% of stations had abundances of Tellinidae lower than the baseline range. The frequency of abundances occurring

below the baseline range was lower in all previous years (5% in 2004, 9% in 2005, 16% in 2006 and 11% in 2008).

Amphipod abundance was not related to distance from drill centres in 2010. Overall amphipod abundance was lower during drilling years than in baseline. Amphipod abundance in 2000 ranged from 44 to 313 individuals per m^2. In 2010, approximately 30% of stations had abundances of amphipod lower than the baseline range. Amphipod abundances have been below the lower baseline range with similar frequencies in previous years (41% in 2004, 38% in 2005, 45% in 2006 and 30% in 2008).

The analysis with NMDS confirmed the observations made with the major indices of community composition and are not discussed further.

Overall, there was evidence of project effects on some chemical sediment characteristics and indices of benthic community at White Rose. Sediments were non-toxic at all stations, except for one. Station C5-C was toxic to Microtox in 2010 and no stations were toxic to laboratory amphipods. The benthic community response noted in 2010 was not as strong as in previous years. The only benthic community index that showed effects was benthic biomass. Biomass was most likely responding to decreases in echinoderms near drill centres. In general, echinoderms are not abundant around White Rose, but they are large organisms that account for a substantial proportion of benthic biomass. Evidence of effects on total abundance, noted since 2005, was marginal, with only a few stations affected. As in previous years, there was no evidence of project effects on richness. The taxon most substantially affected by drilling activity, in term of numbers, remains the polychaete family Paraonidae. General increases or decreases noted for other Sediment Quality Triad components across the entire sampling area cannot reasonably be attributed to White Rose in the absence of relationships with distance from discharge sources (drill centres or the *SeaRose* FPSO), although these responses are of general interest.

In spite of variability in sediment contamination and benthic invertebrate responses since drilling began at White Rose in 2004, there has not been any consistent accentuation of contamination or responses over those years. Zones of influence of project contaminants and effects on benthic community indices and taxa have not increased in severity over time. Results on sediment contamination and benthic invertebrate responses justify continued monitoring, without further mitigation.

8.2 Commercial Fish Component

8.2.1 Body Burden

On the East Coast of Canada, in the Gulf of Mexico, in the North Sea and elsewhere, fish and shellfish tissue have been examined for chemistry (body burden) to assess potential effects of offshore oil development on fisheries resources (e.g., Rushing et al. 1991; Neff et al. 2000; Husky Energy 2004 and references therein; Armsworthy et al. 2005; DeBlois et al. 2005). At White Rose, American plaice liver and fillet and crab claw tissues from the Study Area and the four distant Reference Areas, located 28 km from the centre of the White Rose development, are examined for body burden.

In 2010, as in previous years, there were no significant differences between the Study and Reference Areas for most analytes detected in plaice liver. In 2010, zinc

concentrations in liver were significantly lower in Study Area fish than in Reference Area fish (median of approximately 27 mg/kg in the Study Area versus a median of approximately 29 to 30 mg/kg in the Reference Areas). As in previous years, compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} range were detected in plaice liver from all Areas. In 2010, the concentration of compounds in the $>C_{21}$-C_{32} hydrocarbon range was higher in livers of Study Area fish (nearly 150 mg/kg) compared to Reference Area fish (generally less than 100 mg/kg). Across years, concentrations of compounds in the $>C_{10}$-C_{21} hydrocarbon range decreased more over time in Reference Area plaice livers than in Study Area plaice livers. Concentrations of compounds in the $>C_{21}$-C_{32} hydrocarbon range increased over time in plaice livers in the Study Area, and remained stable in plaice livers in the Reference Areas. No other differences were noted in the multi-year comparison. As in previous years, additional laboratory analyses on livers indicated that compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} range were primarily natural, perhaps diet related, rather than petrogenic in origin (J. Kiceniuk, pers. comm.; Maxxam Analytics, pers. comm.; Appendix C-2).

Plaice fillets from the Study Area had significantly higher fat content (1.2%) compared to Reference Areas (less than 1%) in 2010. All other tissue parameters were either statistically similar among sampling Areas, within the range of values observed in the Reference Areas (i.e., no Study versus Reference differences), or were at non-detect concentrations. Across years, there were no differences in temporal trends (increases/ decreases in concentrations over time) between the Reference Areas and the Study Area for any analyte.

For crab claw tissue, there were no statistically significant differences between the Reference and the Study Areas for any of the analytes detected in 2010. Across years, temporal trends (increases/decreases in concentration over time) differed between the Reference and Study Areas only for mercury, with a larger increase in mercury in Reference Area crab in 2005 and 2006 compared to other years. Regardless, mercury concentrations in both Reference and Study Area crab was lower in 2010 than in previous years.

Given the absence of differences between the Study and Reference Areas, many of the metals frequently detected in plaice and crab 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 natural compounds, rather than evidence of contamination from project activity.

8.2.2 Taste Tests

There was no significant difference in taste between the Study and Reference Area for both plaice and crab and there were no consistent comments from the taste panels identifying abnormal or foreign odour or taste. Results do not indicate the presence of taint in either of the resources.

8.2.3 Fish Health Indicators

Cellular and sub-cellular bioindicator responses, along with observations of visible lesions on skin and internal organs, are valuable monitoring tools for identifying adverse health conditions in animals in advance of population level responses. As such, they can provide early warning of potential health effects and aid in identifying their nature, scope and cause (see reviews by Payne et al. 1987; Peakall 1992; Society of Environmental Toxicology and Chemistry (SETAC) Special Publication Series 1992; Adams 2002; Tillitt and Papoulias 2003; Schlenk et al. 2008).

8.2.3.1 Biological Characteristics and Condition of Fish

Information on fish biological characteristics (morphometrics and life history characteristics) and condition is valuable for interpreting results of bioindicator studies (Levine et al. 1995; Barton et al. 2002). Therefore, fish biological characteristics and condition were examined within the context of these studies.

Females outnumbered males in every Area, accounting for 84% of the total fish sampled. The female:male ratio was similar between the combined Reference Areas (~8.6:1) and the Study Area (~8.2:1).

With respect to male fish, there were no significant differences in the frequencies of the various maturity stages between combined Reference Areas and the Study Area. However, frequencies of pre-spawning and spent mature females did vary significantly between combined Reference Areas and the Study Area, with greater numbers of spent individuals in the combined Reference Areas relative to the Study Area. This difference is likely attributed to low sample numbers, rather than actual variability in female biological characteristics.

Assessment of biological characteristics of male fish indicated that there were no significant differences in length, gutted weight and age among the Reference Areas or between the combined Reference Areas and the Study Area. In addition, analysis of gutted weight versus length, liver weight and gonad weight did not result in statistically significant differences between the combined Reference Areas and the Study Area in males.

Comparisons between biological characteristics of females were also carried out. Here, data were divided into maturity stages (immature, pre-spawning and spent). Data for immature females were not analyzed because there were no immature female individuals from the Study Area. There were no significant differences in length or gutted weight among the Reference Areas or between the combined Reference Areas and the Study Area for pre-spawning and spent females. Also, analysis of gutted weight versus length, liver weight and gonad weight did not result in statistically significant differences among the Reference Areas or between the combined Reference Areas and the Study Area. For pre-spawning females, there were no significant differences in age among the Reference Areas or between the combined Reference Areas and the Study Area. However, age of spent females differed among the Reference Areas. Fish from Reference Area 4 were an average of nine years old, fish from Reference Areas 1 and 2 were an average of 11 years old and fish from Reference Area 3 were an average of 10 years old. There were no significant differences in age between the combined Reference Areas and the Study Area (mean age in the Study Area was 10 years old).

Heterogeneity in biological characteristics of fish, including American plaice, can often be attributed to normal inter-site variability linked to such factors as feeding or reproductive status (e.g., Barton et al. 2002; Morgan 2003).

8.2.3.2 Gross Pathology

Gross pathology was assessed visually in all fish during the necropsies. There were no visible lesions on the skin or fins or on internal organs of any fish.

8.2.3.3 Haematology

Haematology, including the analysis of red and white blood cells, is an indicator for the overall health of fish and can point to immunological effects that may be important in disease susceptibility. Payne et al. (2005) have noted changes in white blood cells (in the 50% difference range) in cunner chronically exposed to relatively high levels of produced water under laboratory conditions. Alteration of some immunological parameters has also been observed in Atlantic cod chronically exposed for several weeks to produced water from the Grand Banks (Perez-Casanova et al. 2010).

There were no apparent qualitative differences in morphology or staining characteristics of red blood cells in samples of American plaice from the different Areas. Similarly, there were no significant differences in the number of white blood cells (lymphocytes and neutrophils) and platelets (thrombocytes) among the Reference Areas or between the combined Reference Areas and the Study Area.

8.2.3.4 Mixed Function Oxygenase (MFO) 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 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).

There were no significant differences in comparisons of Study and Reference Areas, regardless of gender or spawning condition.

8.2.3.5 Histopathology

Other than three cases of foci of cellular alteration, including one case of eosinophilic focus in Reference Area 3 and two cases of clear cell focus in the Study Area, there were no other liver lesions that have been commonly associated with chemical toxicity in field and laboratory studies (e.g., Myers and Fournie 2002). This included observations for nuclear pleomorphism, megalocytic hepatosis, basophilic and mixed cell foci, carcinoma, cholangioma, and hydropic vacuolation and fibrillar inclusions.

Hepatic cellular alteration foci often consist of four types: eosinophilic; basophilic; clear cell; and vacuolated. Some of these types of foci have been suggested as an early stage in the stepwise formation of hepatic neoplasia, although not all develop into tumours (e.g., Hinton et al. 1992; Baumann and Okihiro 2000).

It is important to note that foci of cellular alteration can be found, as in mammals, in the livers of otherwise normal fish (e.g., Wolf and Wolfe 2005). However, it has also been shown that these lesions can be induced by exposure to a number of carcinogenic (e.g., some PAHs or estrogenic compounds). A few cases of foci of cellular alteration have been observed in other areas of the Grand Banks during the last decade (Mathieu et al. 2005, 2010). This may indicate that a low prevalence of these lesions could be background in nature.

In addition to foci of cellular alteration, a few hepatic conditions not specifically associated with contamination were also noted. Golden rings around bile ducts were detected in three fish, one from the Study Area and two from the Reference Areas.

A mild inflammatory response was observed in two fish, one from the Study Area and one from Reference Area 3. Granuloma was detected in another fish from Reference Area 3. These conditions are known to appear following viral, bacterial or parasitic infections (e.g., Feist et al. 2004).

As noted in previous years, a “patchy distribution” of hepatocellular vacuolation, not associated with degenerative changes, was observed in a few fish from the Study and Reference Areas, and is likely linked to gonadal maturation (Timashova 1981; Bodammer and Murchelano 1990; Couillard et al. 1997). Also, the presence of parasites in the biliary system did not appear to result in any other pathological changes in hepatic tissues.

The observations of golden rings, parasitism, mild inflammatory responses, granuloma and hepatocellular vacuolation are of value in relation to providing general information on their presence in the area. However, it is important to note from an EEM perspective that a large number of liver lesions associated with chemical toxicity were generally absent or found only at a very low incidence.

With respect to studies on gill microstructures, the percentages of secondary lamellae affected by various lesions were very low (mean per site less than 0.5%) in all Areas and no significant differences were observed between Areas. When results were expressed as percentages of fish exhibiting a type of lesion (whatever the severity), statistically significant differences were not observed between the Study Area and the combined Reference Areas.

Microstructural changes in gills that could be pathological in nature such as severe lamellar hyperplasia and extensive fusion or telangiectasis (e.g., Mallat 1985) were absent in all Areas.

Overall, the fish health survey in 2010 indicated that the present health of American plaice as assessed by condition indices, external and internal abnormalities, haematology, hepatic MFO enzymes and detailed studies on liver and gill histopathology is similar at the four Reference Areas and the Study Area.

8.3 Water Quality Component

The Water Quality program at White Rose currently consists of sampling at three water depths at stations near the *SeaRose* FPSO (Study Area) and in two distant Reference Areas, along with modelling the distribution of produced water constituents to help fine-tune the program. Produced water constituents were modelled because that liquid discharge stream is the largest at White Rose.

8.3.1 Field Sampling

Field sampling indicated no difference in concentrations of barium, boron, calcium, lithium, magnesium, potassium, sodium, strontium, uranium, vanadium, TIC, zinc and the scale inhibitor SCW4453 between the Study and Reference Areas. Molybdenum and sulphur concentrations were lower in the Study Area. Concentrations of BTEX, $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, PAHs and alkyl PAHs, phenols and alkyl phenols, organic acids, radium-228, ammonia and the biocide XCide450 were below laboratory detection limit. Low levels of cadmium, lead, lead-210, radium-226, copper, iron and aluminum were detected in a few samples from both the Study and Reference Areas. Therefore, there was no indication of project effects on water quality at White Rose.

The probability of detecting any constituent from liquid discharges at White Rose is generally low, given the expected rapid dilutions in the water column (Neff et al. 2011). These probabilities would have been reduced further in 2010 because of mixing resulting from Hurricane Igor, which passed through the area 15 days before sampling began, and because no produced water, the main liquid discharge, was being released at White Rose during sampling.

The scale inhibitor SCW4453 was detected in water samples from both the Study and the Reference Areas, with no difference between Areas. The maximum value (7.2 mg/L) was recorded in a surface sample from the Reference Area, located 28 km to the northwest of White Rose. SCW4453, as well as XCide450, are used in the process stream for produced water and residual concentrations are discharged overboard. Given the absence of a statistically significant difference in concentrations between the Study and the Reference Areas, the source of SCW4453 probably was not the *SeaRose* FPSO or produced water, since none was being released during sampling. Further, modelling results (Sections 7.2 and 8.3.2) indicate the probability of detection for SCW4453 near the *SeaRose* FPSO is extremely low, even at maximum discharge rate. However, a rust stain remover that is permitted for use and discharge was used onboard the survey vessel that collected the water samples for the EEM program. This rust stain remover may have been the source of a chemical similar to SCW4453 that was detected in some water samples.

8.3.2 Modelling

Constituent-based modelling of the transport and dilution of produced water constituents over a 30-day simulation of continuous discharge was undertaken for White Rose. As such, the exercise helped identify the cumulative effect of a continuous 30-day discharge on constituent concentrations in the water column. The objective of the work was to assess the probability of detecting selected constituents of produced water in seawater samples collected during the White Rose EEM program. The ultimate goal was to find a

potential tracer for produced water in seawater samples and/or fine-tune the water quality survey at White Rose.

Results indicated that at a produced water release rate of 28,000 m^3/day (higher than the present release rate), the most likely produced water constituents to be detected in seawater samples would be naphthalene, followed by phenol, *m,p*-cresol and *o*-cresol. Other tested constituents had a zero or near-zero probability of being detected in seawater samples. Constituents tested in the modelling exercise included acetic acid, *m,p*-cresol, naphthalene, *o*-cresol, phenol, radium-228, SCW4453 and XCide450. These were the constituents judged most likely to be detected in water samples because of their high concentration in produced water relative to concentrations in seawater. At the time of constituent selection for modelling, it was not known that there could be a source of SCW4453 (or its proprietary components) other than produced water (see Section 8.3.1 for field results).

Based on modelling results, naphthalene would be the better indicator of the presence of soluble constituents from produced water[25]. This is supported further by the fact that naturally-occurring naphthalene concentrations in the open ocean are low (Neff 2002). Naphthalene was not detected in preliminary water samples collected around White Rose in 2008 (Husky Energy 2010), when very little produced water was being released, and it was not detected in 2010, when no produced water was being released. Yet naphthalene is often detected in water samples near sources of contamination, including near release sites of produced water (Neff 2002).

Maximum concentrations for modelled constituents occurred at the depth of produced water discharge. Produced water is being discharged at White Rose at 11 to 18 m. Maximum concentrations were observed in the 12 to 24 m depth interval and all modelled constituents were absent below 60 m, at source as well as at distance. Thermal stratification could influence the depth distribution of constituents within the produced water plume. Beyond this, the physical properties of the plume (salinity, temperature) are such that it, along with its soluble constituents, would be expected to remain at the surface layer (see also Hodgins and Hodgins 2000).

Results also indicated that probability of detection for constituents with a high probability of detection (i.e., naphthalene, phenol, *m,p*-cresol and *o*-cresol) was higher approximately 1 to 5 km downstream of the *SeaRose* FPSO than it was near-source. These results were unexpected and counter to the commonly held view that produced water constituents can only be detected very near the discharge source. If concentrations remain above laboratory detection limits, then constituents can be detected further downstream in the direction of the prevailing current (Section 7 and Appendix D-4 provide rationale).

[25] The present modelling exercise was geared toward assessing the distribution of constituents in solution or suspension in the water column. The physical and chemical properties, and therefore behaviour, of constituents within the produced water plume will differ and some constituents will settle to sediments, as was shown for metals in Azetsu-Scott et al. (2007). An additional modelling exercise is planned to assess potential deposition of selected produced water constituents to sediments. Of the constituents tested here, radium-228 is the most likely to settle to marine sediments (Neff 2002). Radium isotopes have been modelled as both suspended and settling particles in a previous modelling exercise (Rye et al. 2009).

Constituents with low probability of detection (in this case acetic acid, radium-228, SCW4453 and XCide450) could only be detected in the very near-field, if at all. Concentrations were influenced by short-term changes in current and wind direction rather than the prevailing current.

Combined, these results indicate that far-field water sampling stations at White Rose could be effective for testing the spread of soluble constituents within the produced water plume. Far-field stations should be at fixed location and 'downstream' of the *SeaRose* FPSO, based on prevailing seasonal winds and currents. Near-field stations should not be at fixed locations. Sampling should be performed 'downstream' of winds and currents at the time of sampling. Finally, aside from biological/chemical reactivity and physical properties, the probability of detection of a constituent is dictated by its release concentration and its laboratory detection limit. Therefore, the lowest reliable detection limit should be used for the analysis of field samples.

8.4 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 8-2) were set up to guide interpretation of results. As noted in Section 1.7, the "null" hypothesis (H_0) always state that no pattern will be observed.

Table 8-2 Monitoring Hypotheses

Sediment Component
H_0: There will be no change in Sediment Quality Triad 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.
Water Component
H_0: The distribution of produced water from point of discharge, as assessed using moorings data and/or vessel-based data collection, will not differ from the predicted distribution of produced water.

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 2010 EEM program, the null hypothesis is rejected for the Sediment Component of the program, but null hypotheses are not rejected for the Commercial Fish and Water Components. Rejection of the null hypothesis for the Sediment Component was expected, since drill cuttings modelling and EIS predictions do indicate that there should be change in Sediment Quality Triad variables with distance from discharge sources. The following summarizes project effects and relates them to EIS predictions and/or literature-based information, as applicable.

As expected, 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 levels were elevated by drilling at stations located 0.3 km from drill centres. There was an indication that sediment fines content was elevated by drilling at one station located 0.3 km from the North Amethyst Drill Centre. Elevated concentrations of $>C_{10}$-C_{21} hydrocarbons and barium at White Rose in 2010 remain comparable to levels observed at other developments.

The spatial extent of contamination in 2010 was less than predictions on the spatial extent of the zone of influence of drill cuttings (9 km from source; Hodgins and Hodgins 2000; Section 1.5). $>C_{10}$-C_{21} hydrocarbon contamination extended to 3.6 km from source. Barium contamination extended to 2 km from source.

One of 49 samples tested was toxic to luminescent bacteria (Microtox) in 2010. Toxicity occurred at Station C5-C, located 0.3 km from the Central Drill Centre and where hydrocarbon, barium and sulphur levels were relatively high. However, there were many other stations with high levels of these constituents that were not toxic to Microtox; and levels of hydrocarbons, barium and sulphur were not at their highest at Station C5-C.

Laboratory amphipod survival was weakly linked with distance to drill centres, $>C_{10}$-C_{21} hydrocarbon and barium concentrations, with survival increasing with increasing distance from drill centres, and decreasing with increasing hydrocarbon and barium concentrations. However, no sample was toxic to amphipods according to the Environment Canada (1998) guideline. Together, the Microtox and amphipod toxicity tests indicate that sediments at White Rose are fundamentally non-toxic.

In 2010, as in 2008, evidence of effects on total abundance was marginal, benthic biomass was affected by project activity and there was no evidence of project effects on richness. The taxon most affected by project activity remains Paraonidae. Unlike previous years, there was little evidence of project effects on Spionidae and Amphipoda abundance in 2010.

Threshold models indicated that the spatial extent of effects on benthic invertebrates estimated in 2010 was generally less than estimates reported in previous years and indicates that effects in 2010 were not as strong as in previous years. In 2010, an examination of the spatial extent of effects by drill centre indicated that effects from the Central and Southern Drill Centres overlapped. Effects around the Northern and North Amethyst Drill Centres, which were not affected by the proximity of another drill centre, extended to approximately 630 m, and 500 m from source, respectively.

As noted in previous EEM reports (also see discussion in Appendix A), the spatial extent of effects on benthic invertebrates at White Rose is generally consistent with the literature on effects of contamination from offshore oil developments. Davies et al. (1984) first described general zones of effects on benthic invertebrates around offshore platforms. The first zone was characterized by a highly disrupted benthic community within approximately 500 m of discharge source. The second zone was described as a transition zone in benthic community structure from affected to unaffected. This scheme has been generally used elsewhere. For instance, Gerrard et al. (1999) also describe a zone of approximately 500 m from source with a highly disrupted benthic community. Based on their review, the spatial extent of the transition zone from affected to unaffected could extend from 0.2 to 2 km.

The White Rose and North Amethyst EA predictions are consistent with observations of both Davies et al. (1984) and Gerrard et al. (1999); highly disrupted communities can be expected near source. The EAs estimated the spatial extent of effects around individual drill centres and predicted that effects on benthic communities from smothering would extend to approximately 500 m from any one drill centre. On a per-drill centre basis, the EEM results for 2010 appear to support EIS predictions.

Ratings of effects size are provided by Davies et al. (1984) and Kilgour et al (2005). Davies et al. (1984) describes a highly disrupted community as impoverished and highly modified with abundances at or near zero. In agreement, Kilgour et al. (2005) state that benthic community effects are large when they co-occur with effects on fish and that this normally occurs when the benthic community is reduced to one or two types of organisms, and with either very high (10x more than normal) or very low (10x less than normal) abundances. This is clearly not the condition at White Rose. In the worst case in 2010, total abundance was reduced to approximately 25% or less of the lower limit of the normal baseline range of variation at three stations near drill centres[26], biomass was reduced to 25% or less of the lower limit of the normal baseline range of biomass at nine stations near drill centres, while richness (number of families) remained within the range of values observed during baseline sampling in 2000.

In spite of changes in sediment contamination and benthic invertebrate responses since drilling began at White Rose in 2004, there has not been any consistent accentuation of contamination or responses over those years. Zones of influence of project contaminants and effects on benthic community indices and taxa have not increased in severity or extent over time. As there has been no continued degradation at White Rose, sediment contamination and the benthic invertebrate responses justify continued monitoring, without further mitigation.

Sediment contamination and effects on benthos noted in 2010 and in previous years have never translated into effects on the fisheries resources as indicated by fish health and taint tests. 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. These results indicate that changes in sediments and benthic community have not affected fish.

There was no evidence of project effects on water quality.

8.5 Recommendations for the 2012 EEM Program

8.5.1 Sediment Quality

Future analysis of the sediment quality data may consider omitting the use of repeated-measures regression. Relationships between analyte concentrations (or biota abundances) and distance from nearest active drill centres are often non-linear, approaching what is best described by a threshold model. The repeated-measures regression analysis is arguably redundant with the threshold models, and is much more restrictive in the data it requires. All stations used in the analysis must be sampled every year. This data requirement makes the future use of repeated-measures regression

[26] See Section 5 for a list of stations and distances near drill centres where values were reduced to below 75% of the baseline range.

likely inappropriate when new drill centres are added, and new monitoring stations are brought into the program to address those new drill centres.

Because of the overlapping effects of the Central and Southern Drill Centres, threshold models alone can not be used to estimate the extent of effects on benthic communities. Graphical tools like those used in this report are required.

Capitella capitata was shown to be a species that increased in abundance in the transition zone in Davies et al. (1984). This species occurs at White Rose in low abundance. Future analyses could consider examining changes in the abundance of this species since baseline and with distance from drill centres.

8.5.2 Water Quality

Water sampling at White Rose should take place during the summer months (June, July, or August), when conditions are calmer and liquid discharge constituents are more concentrated the water column.

Products should not be discharged from sampling vessels during sampling.

Weather conditions prior to and during sampling should be recorded.

Given low probability of detection, the lowest reliable laboratory detection limits should be used in analyzing water samples.

Far-field water quality stations could be added at distances of 1 to 5 km from the *SeaRose* FPSO in the direction of the prevailing current.

Sampling water quality at set locations in the near-field should be discontinued in favour of sampling stations ‘downstream’ from currents on the day of sampling.

8.6 Response to Previous Regulatory and WRAG Recommendations

Husky Energy actions and responses to comments from the regulatory community on the 2008 report are provided in Appendix A, as are Husky Energy responses and WRAG comments on the 2010 report.

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