**White Rose**

**Environmental Effect Monitoring Program**

**2012**

**Volumes 1 of 2**

**Canada-Newfoundland and Labrador Offshore Petroleum Board**

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EC-FT-00012

# White Rose

## Environmental Effects Monitoring Program

## 2012 (Volume 1 of 2)

May 2013

**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. Beyond this, EEM results are reviewed by the regulatory community after each EEM cycle. Comments from the regulatory community on the 2010 EEM program are provided in Appendix A.

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 have been collected in 2004, 2005, 2006, 2008, 2010 and 2012 to assess environmental effects. Sediment samples collected as part of the Sediment Quality Component of the EEM program have been processed for physical and chemical characteristics, toxicity and an evaluation of benthic (seafloor invertebrate) communities. These three sets of measurements are known as the Sediment Quality Triad. For the Commercial Fish Component of the EEM program, 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.

Seawater samples were collected at White Rose in 2008, 2010 and 2012. Seawater 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 and 2012. In addition to collection of seawater samples, the Water Quality Component of the EEM program in 2010 included sampling for sediment chemistry at Water Quality stations and 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 seawater samples. The 2012 Water Quality program included seawater sampling, sediment chemistry sampling at Water Quality stations and a modelling component to assess potential concentrations of produced water constituents in sediments. Modelling is used as part of the White Rose Water Quality program to iteratively improve field sampling.
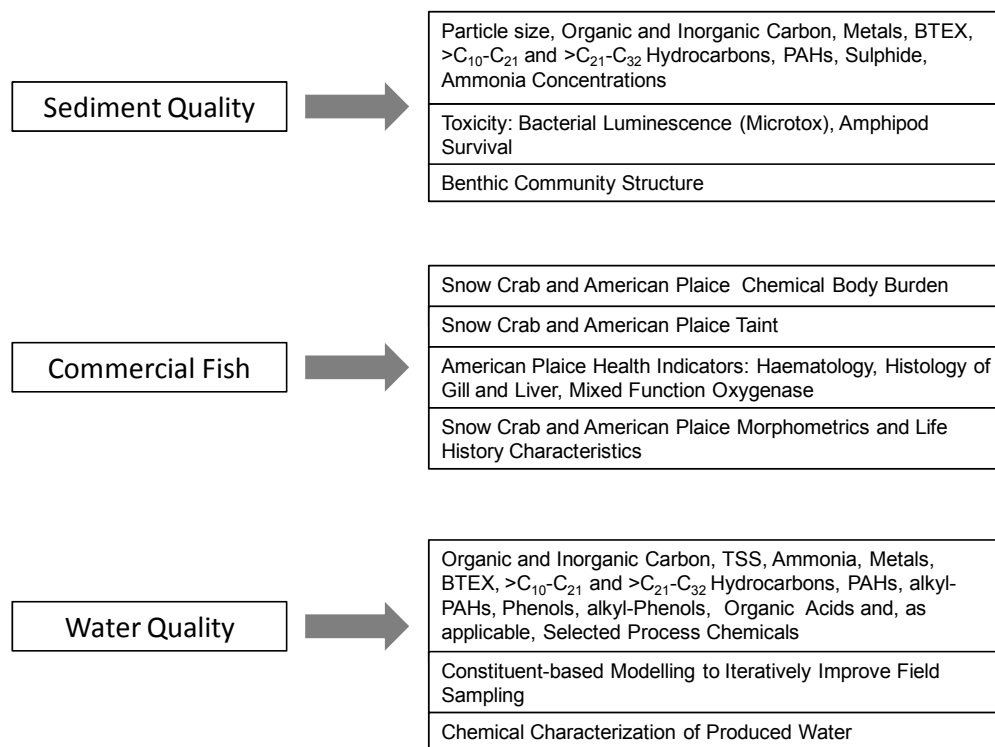
Figure 1 illustrates the components of the EEM program.

| Sediment Quality | → | Particle size, Organic and Inorganic Carbon, Metals, BTEX, $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ Hydrocarbons, PAHs, Sulphide, Ammonia Concentrations |
| --- | --- | --- |
| | | Toxicity: Bacterial Luminescence (Microtox), Amphipod Survival |
| | | Benthic Community Structure |

| Commercial Fish | → | Snow Crab and American Plaice Chemical Body Burden |
| --- | --- | --- |
| | | Snow Crab and American Plaice Taint |
| | | American Plaice Health Indicators: Haematology, Histology of Gill and Liver, Mixed Function Oxygenase |
| | | Snow Crab and American Plaice Morphometrics and Life History Characteristics |

| Water Quality | → | Organic and Inorganic Carbon, TSS, Ammonia, Metals, BTEX, $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ Hydrocarbons, PAHs, alkyl-PAHs, Phenols, alkyl-Phenols, Organic Acids and, as applicable, Selected Process Chemicals |
| --- | --- | --- |
| | | Constituent-based Modelling to Iteratively Improve Field Sampling |
| | | Chemical Characterization of Produced Water |

**Figure 1      EEM Program Components**

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

This report provides the results from the sixth year of sampling under the program conducted in the summer (commercial fish survey) and fall (sediment and water survey) of 2012. The findings are interpreted in the context of results of previous sampling years and the baseline data collected pre-development.

In 2012, seafloor sediments were sampled for Sediment Quality Triad variables at 53 locations surrounding the Northern, Central, Southern, North Amethyst and South White Rose Extension 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.

Analysis of sediment physical and chemical characteristics showed that concentrations of drill mud hydrocarbons and barium were elevated near active drill centres and concentrations decreased with distance from drill centres, as expected. To a lesser extent, lead, strontium and sulphur concentrations were also elevated near active drill centres. There was no evidence of project effects on other physical and chemical parameters measured in sediments.

Maximum drill mud hydrocarbon (hydrocarbons in the $>C_{10}$-$C_{21}$ range) and barium concentrations at White Rose in 2012 were 501 mg/kg and 4,000 mg/kg, respectively. The area over which elevated hydrocarbons occurred extended to an average 3.6 km from active drill centres in 2012, which is the same distance noted in 2010. The area over which high barium levels occurred extended to an average of 1 km from active drill centres, which is half the average distance noted in 2010. The area over which elevated lead and strontium levels

occurred was restricted to an average of 0.6 km from active drill centres, which represents a decrease in the average value since 2006. Sulphur was elevated at a few stations near active drill centres. The spatial extent of contamination estimated from EEM results was less than that predicted from drill cuttings dispersion modelling results. Modelling indicated a zone of influence of approximately 9 km from drill centres.

Of 53 sediment samples tested for toxicity, one was toxic to laboratory amphipods and none were toxic to luminescent bacteria (Microtox) in 2012. Laboratory amphipod survival in toxicity tests was unrelated to any sediment physical and chemical characteristics, including those affected by project activity. Results indicate that sediments around White Rose are fundamentally non-toxic.

There continues to be no detectable project effects on benthic invertebrate community richness[1]. As has been noted since 2008, evidence of effects on total abundance was marginal and benthic biomass was affected by project activity. There was also evidence of effects on one species of polychaete (Paraonidae: a marine worm). There was no evidence of project effects on Spionidae (a polychaete), Tellinidae (a bivalve) and amphipods (a crustacean) in 2012. Total abundance, biomass and the abundance of Paraonidae were lower near active drill centres.

During the summer of 2012, 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 2012, metal and hydrocarbon concentrations in American plaice and snow crab tissue continued to show that body burden in these species is unaffected by project activities. Furthermore, the results of taste tests, carried out at the Marine Institute, demonstrated that the two species were not tainted. Indicators of fish health used to evaluate potential effects, 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 2012, water samples were collected in the vicinity of the *SeaRose* floating, production, storage and offloading (*FPSO*) vessel 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 2012, other than lower barium concentrations in mid-depth (40 m below surface) and surface (10 m below surface) samples near the *SeaRose FPSO* and higher barium concentrations in bottom (10 m above bottom) samples. Differences among Areas were small (5 µg/L or less) and levels in all Areas were lower than the background average for oceanic regions. Although barium is a constituent of drill muds, some natural barium in seawater samples is to be expected.

Modelling results indicated that iron could be a useful tracer of produced water constituents in sediments and results from analysis of sediment chemistry data collected at both Sediment Quality and Water Quality stations indicated potential iron enrichment approximately 5 to 10 km from the *SeaRose FPSO*.

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[1] Number of taxonomic groups per unit area.

**Conclusions:** Variables affected by the White Rose development in 2012 were sediment concentrations of drill mud hydrocarbons, barium, lead, strontium and sulphur, total benthic invertebrate abundance and biomass. Of the individual taxa examined, one species of polychaetes (Paraonidae) was most affected by drilling discharge. 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. 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 2012 and in previous years have never translated into effects on the fisheries resources, as indicated by fish health assessment and taint tests. No project-related tissue contamination was noted for crab and plaice. Neither species 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.

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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 360 km east-southeast of St. John's, Newfoundland and Labrador, and 50 km from both the Terra Nova and Hibernia fields (Figure 1-1). At first oil in November 2005, the White Rose Development consisted of three drill centres – the Northern, Central and Southern Drill Centres. In 2007, the North Amethyst Drill Centre was developed and, in the summer of 2012, the South White Rose Extension (SWRX) Drill Centre was excavated (Figure 1-2). Nalcor Energy is an additional partner in the North Amethyst and SWRX Drill Centres developments.
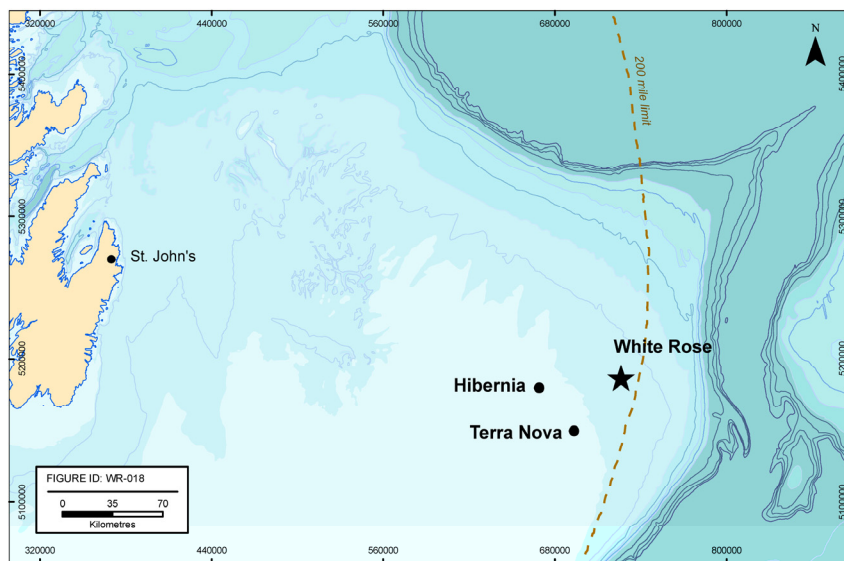


**Figure 1-1        Location of the White Rose Oilfield**
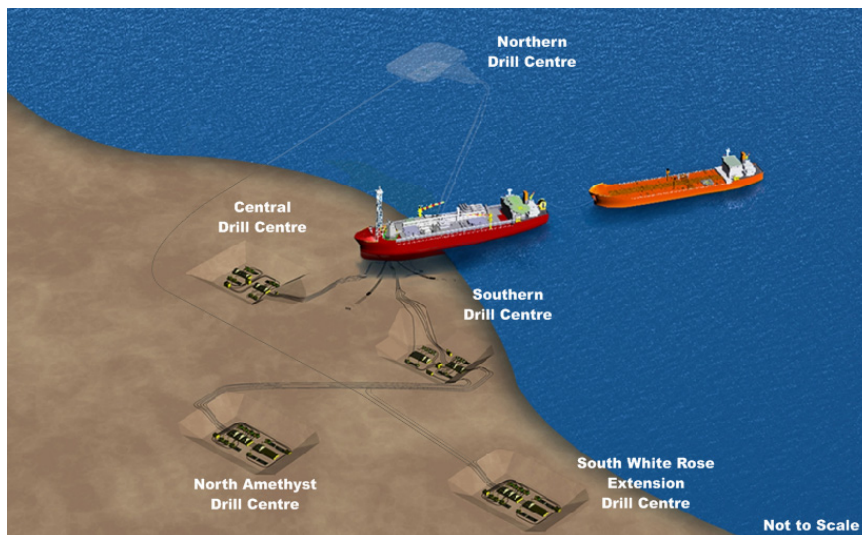


**Figure 1-2        Field Layout**

## 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 environmentally-related information available to interested parties and the general public. Husky Energy's Environmental Protection and Compliance Monitoring Plans, prerequisites for the issuance of Operating Authorizations by the C-NLOPB, state that Husky Energy will make the Baseline and EEM reports available to the public via Husky Energy's corporate website.

## 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 EEM program was revised 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 (National Energy Board *et al.* 2010).

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

- to estimate the zone of influence of project contaminants;

- to test biological effects predictions made in the EIS;

- to provide feedback to Husky Energy for project management decisions requiring modification of operations practices where/when necessary; and

- to 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 an initial 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 and SWRX Drill Centres was assessed in the New Drill Centre Construction and Operations Program Environmental Assessment (LGL 2006). Predictions in the New Drill Centre Environmental Assessment 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.

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[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 Environmental Assessment (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 and Water Quality (Figure 1-3).

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).

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.

Assessment of Water Quality includes measurement of alteration of physical and chemical characteristics in the water column and measurement of alterations in sediment chemistry as a result of liquid discharge. 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).

| Sediment Quality | Particle size, Organic and Inorganic Carbon, Metals, BTEX, $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ Hydrocarbons, PAHs, Sulphide, Ammonia Concentrations |
| | Toxicity: Bacterial Luminescence (Microtox), Amphipod Survival |
| | Benthic Community Structure |

| Commercial Fish | Snow Crab and American Plaice  Chemical Body Burden |
| | Snow Crab and American Plaice Taint |
| | American Plaice Health Indicators: Haematology, Histology of Gill and Liver, Mixed Function Oxygenase |
| | Snow Crab and American Plaice Morphometrics and Life History Characteristics |

| Water Quality | Organic and Inorganic Carbon, TSS, Ammonia, Metals, BTEX, $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ Hydrocarbons, PAHs, alkyl-PAHs, Phenols, alkyl-Phenols,  Organic  Acids and, as applicable, Selected Process Chemicals |
| | Constituent-based Modelling to Iteratively Improve Field Sampling |
| | Chemical Characterization of Produced Water |

**Figure 1-3       EEM Program Components**

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

## 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).

## 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 currently collected in the vicinity of the *SeaRose* floating, production, storage and offloading (*FPSO*) facility (at approximately 300 m), at mid-field stations located 4 km to the southeast of White Rose and in two Reference Areas located approximately 28 km to the northeast and northwest. The sampling designs for water samples and for commercial fish are control-impact designs (Green 1979). This design compares conditions near discharge source(s) to conditions 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, 2010 and 2012). 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), 49 stations were sampled in 2010 (Figure 1-9) and 53 stations were sampled in 2012 (Figure 1-10). In all, 36 stations were common to all sampling programs.

As part of EEM program design (Husky Energy 2004, 2008), seven redundant stations in the immediate vicinity of drill centres were eliminated. These stations were sampled during baseline because the final location of the Central, Northern and Southern Drill Centres had not been established. Two remote reference stations located 35 km south-southeast and 85 km northwest of White Rose were eliminated for the EEM programs

because of their distance from the development and because sediment chemistry results from baseline sampling showed that the northwest reference station might not be comparable to other stations. Two 18-km stations were eliminated because of redundancies with other stations (see Husky Energy 2004 for details).

Original station additions for the EEM program included four reference stations at 28 km from the centre of the development, one station along the north axis at approximately 8 km from the centre of the development, three drill centre stations located approximately 300 m from each of the Northern, Central and Southern Drill Centres. However, in 2005, one of these stations (station S5) could not be sampled because of drilling activity at the Southern Drill Centre.

In 2004, six drill centre stations were sampled at 1 km from the proposed location of each of more northerly (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 drill 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.

In 2010 (Figure 1-9), stations NA1, NA4, C5 and 23 were moved slightly because of proximity to subsea infrastructure. NA4, 23 and C5 were relocated less than 15 m from the original locations. NA1 was relocated approximately 85 m from its original location but at the same distance from the drill centre as the original location.

In 2012, four stations were added around the SWRX Drill Centre (Figure 1-10) and stations 23, 25, C5, NA1, NA3 and N4 were moved slightly because of proximity to subsea infrastructure. All stations were moved less than 50 m from their original location.

Table 1-1 provides a summary of changes between the 2000 baseline program and the 2012 EEM program for sediment, as well as station name changes that were proposed in the EEM design document to simplify reporting of results.
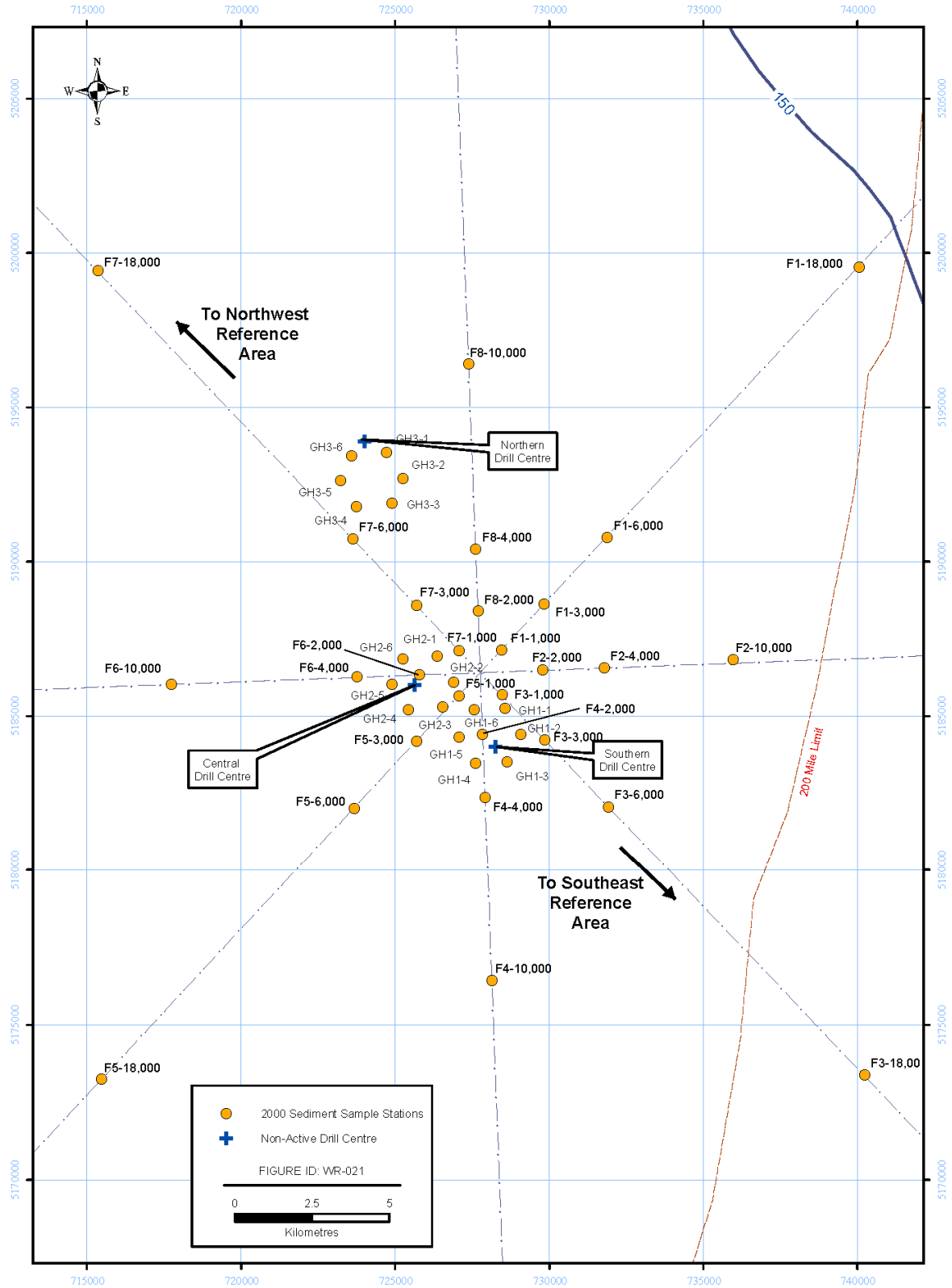
**Figure 1-4        2000 Baseline Program Sediment Quality Stations**

**Figure 1-5    2004 EEM Program Sediment Quality Stations**
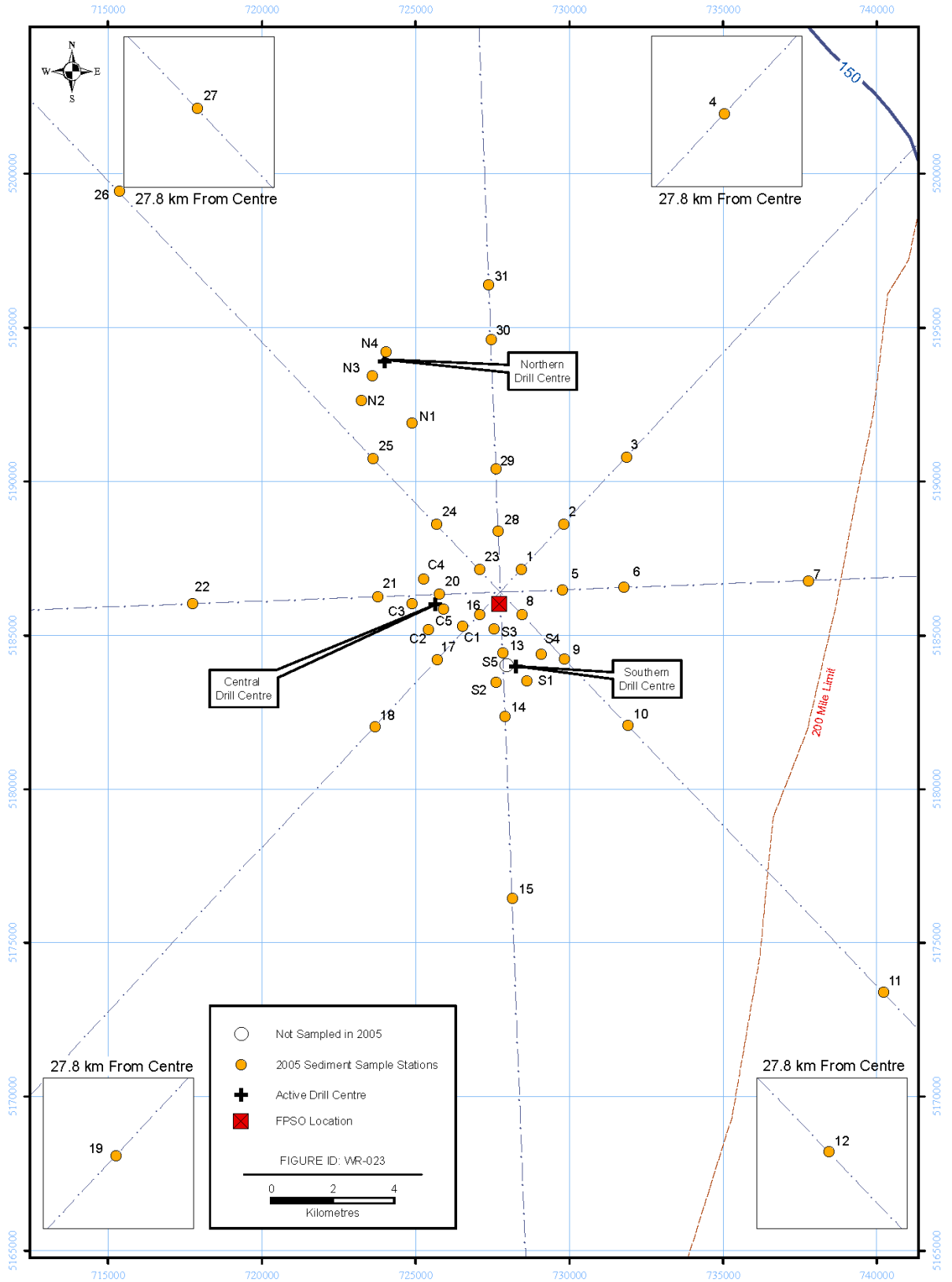
**Figure 1-6      2005 EEM Program Sediment Quality Stations**
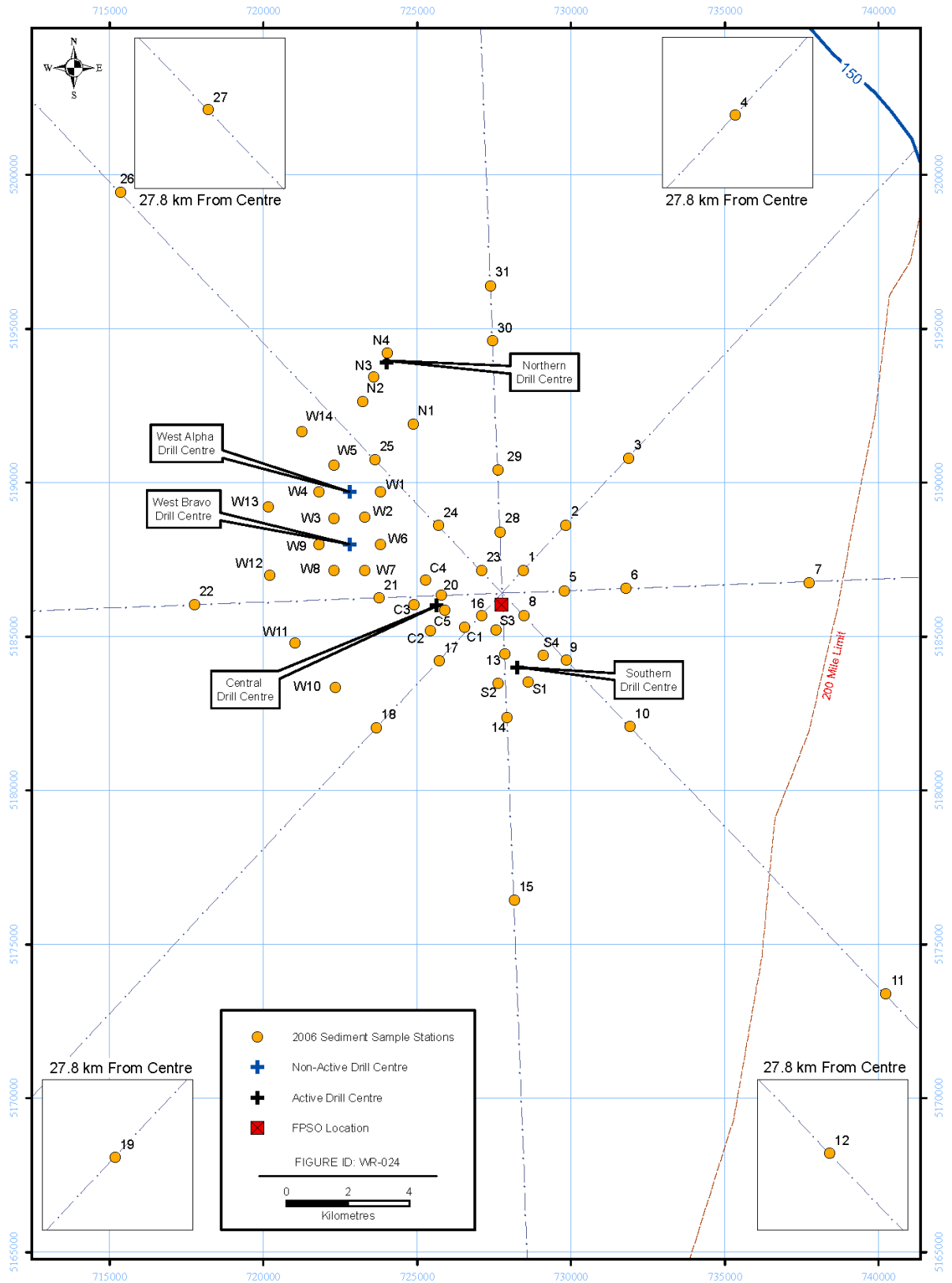
**Figure 1-7      2006 EEM Program Sediment Quality Stations**
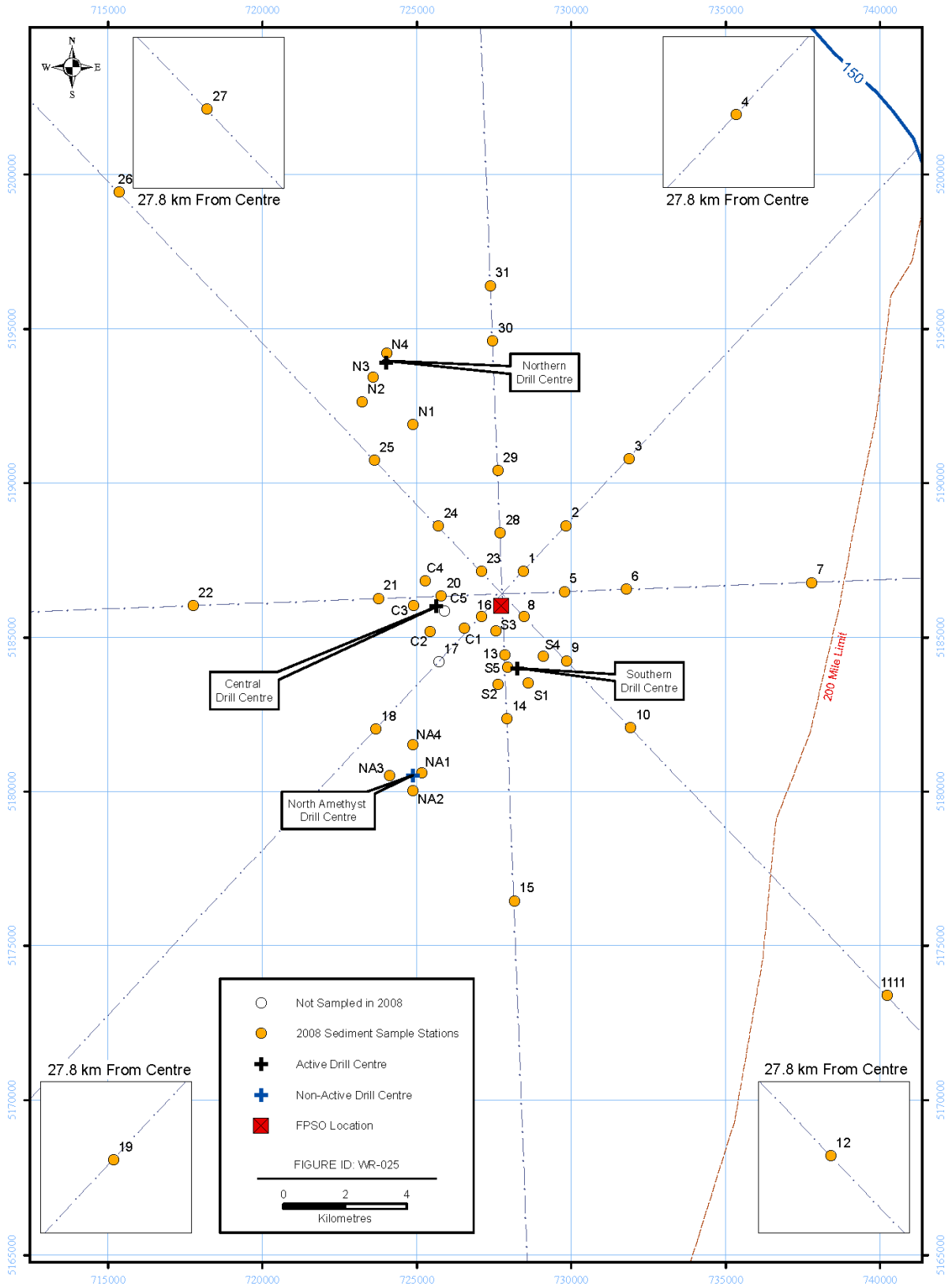
**Figure 1-8     2008 EEM Program Sediment Quality Stations**
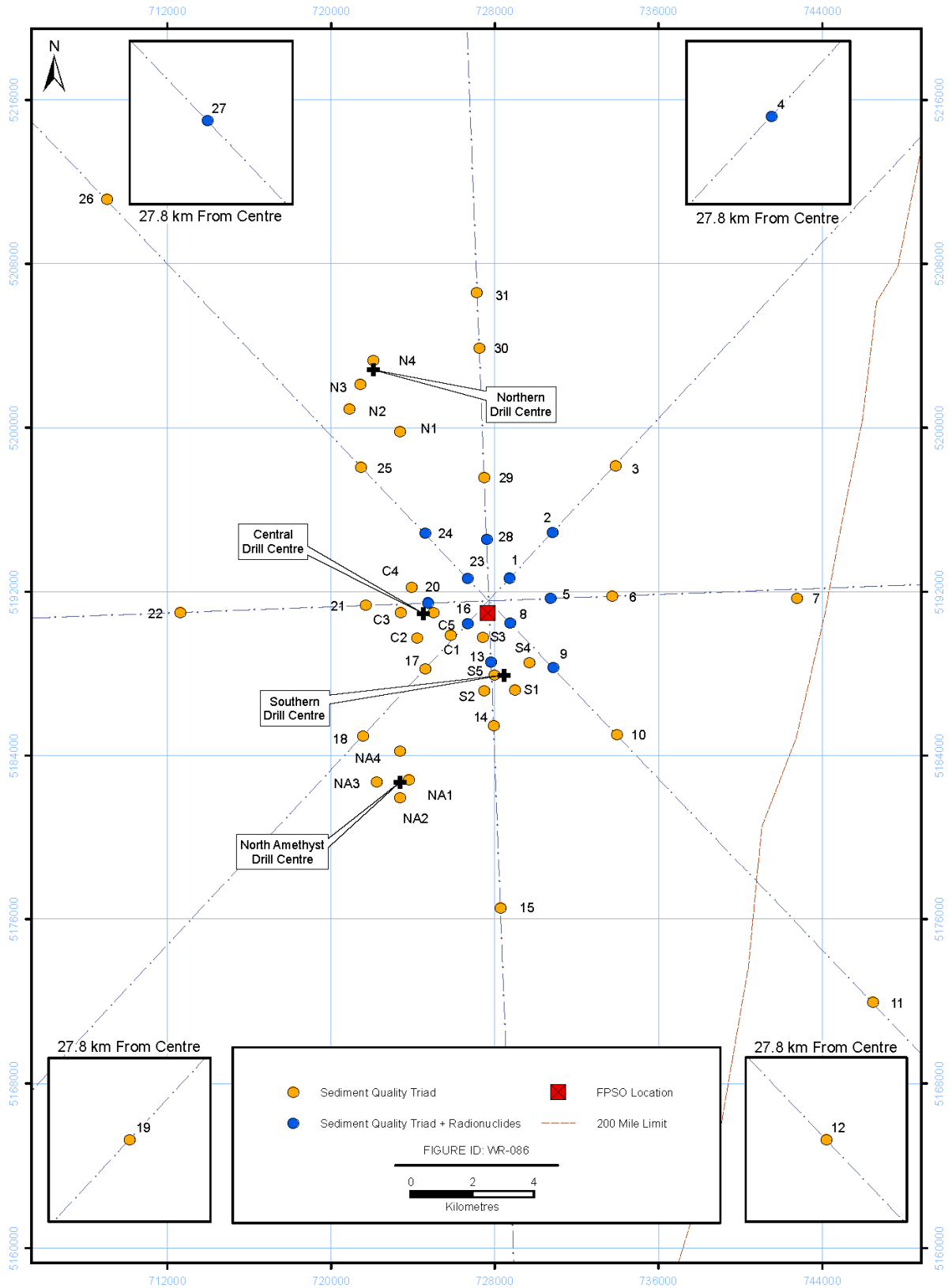
**Figure 1-9       2010 EEM Program Sediment Quality Stations**
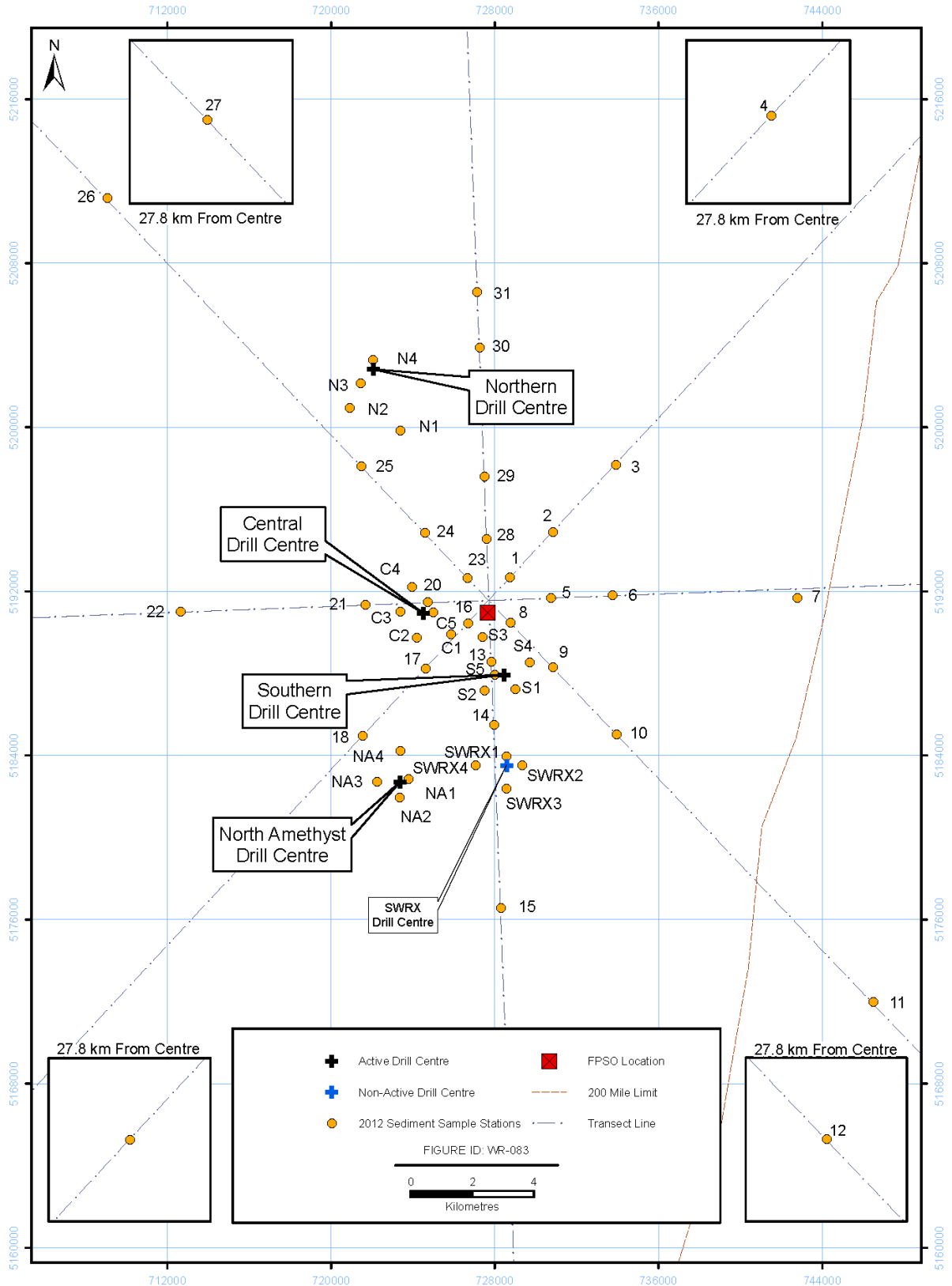
**Figure 1-10    2012 EEM Program Sediment Quality Stations**

**Table 1-1      Table of Concordance Between Baseline and 2012 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 | F7-1,000 |
| 24 | F7-3,000 |
| 25 | F7-6,000 |
| 26 | F7-18,000 |
| 27 | Not Sampled in 2000 |
| 28 | F8-2,000 |
| 29 | F8-4,000 |
| 30 | F8-10,000 |
| 31 | Not Sampled in 2000 |
| C1 | GH2-3 |
| C2 | GH2-4 |
| C3 | GH2-5 |
| C4 | GH2-6 |
| C5** | Not Sampled in 2000 |
| N1 | GH3-3 |
| N2 | GH3-5 |
| N3 | GH3-6 |
| N4 | Not Sampled in 2000 |
| S1 | GH1-3 |
| S2 | GH1-4 |
| S3 | GH1-6 |
| S4 | GH1-2 |
| S5* | Not Sampled in 2000 |
| NA1 | Not Sampled in 2000 |
| NA2 | Not Sampled in 2000 |
| NA3 | Not Sampled in 2000 |
| NA4 | Not Sampled in 2000 |
| SWRX1 | Not Sampled in 2000 |
| SWRX2 | Not Sampled in 2000 |
| SWRX3 | Not Sampled in 2000 |
| SWRX4 | Not Sampled in 2000 |

Notes:   -    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; see text
              and figures for details.
         -    * 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 1-11 to 1-16 provide transect locations for the 2004, 2005, 2006, 2008, 2010 and 2012 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. In 2012, the approved White Rose safety zone was used as the boundary for fishing (see Figure 1-16).
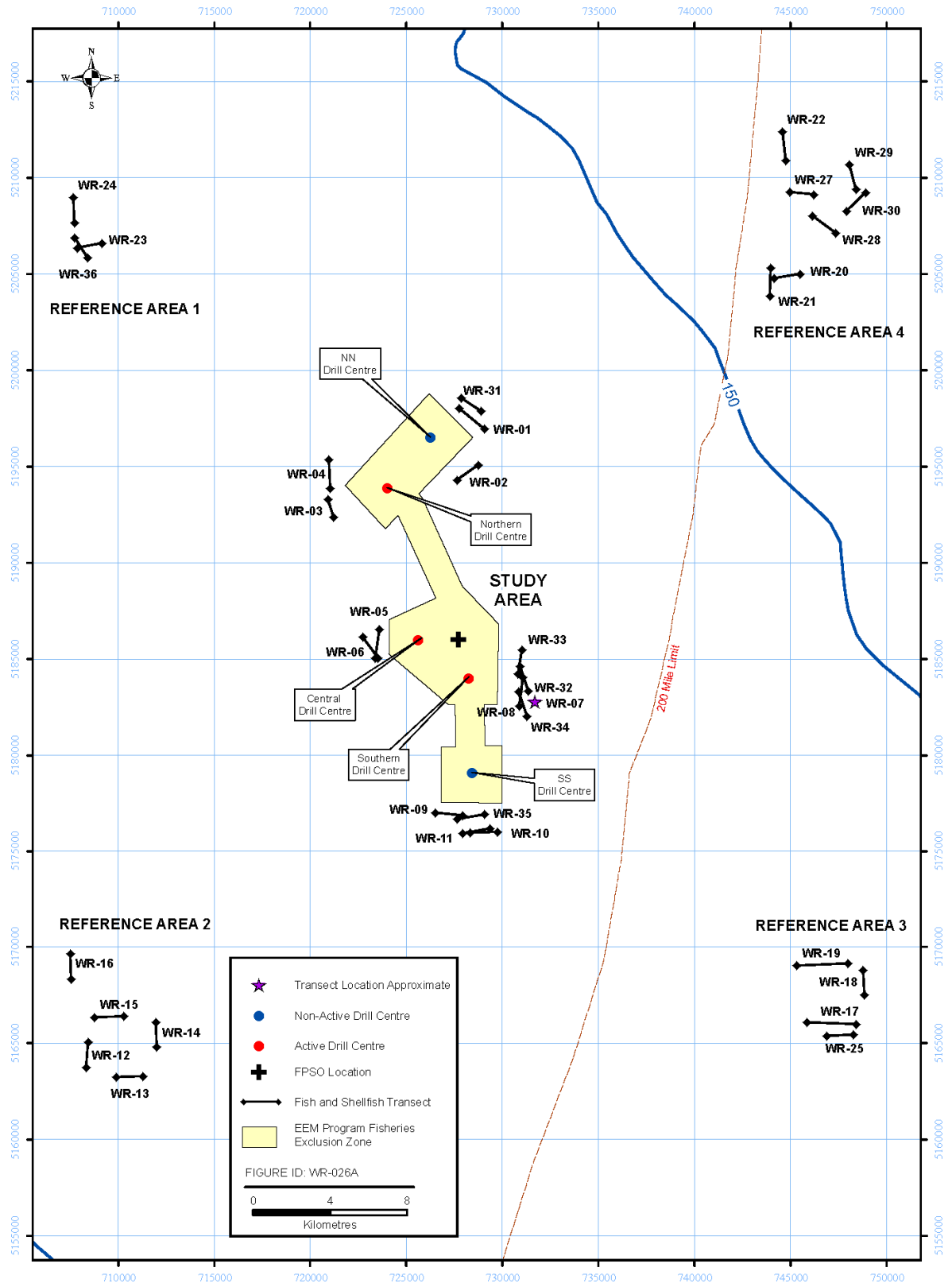
**Figure 1-11      2004 EEM Program Commercial Fish Transect Locations**
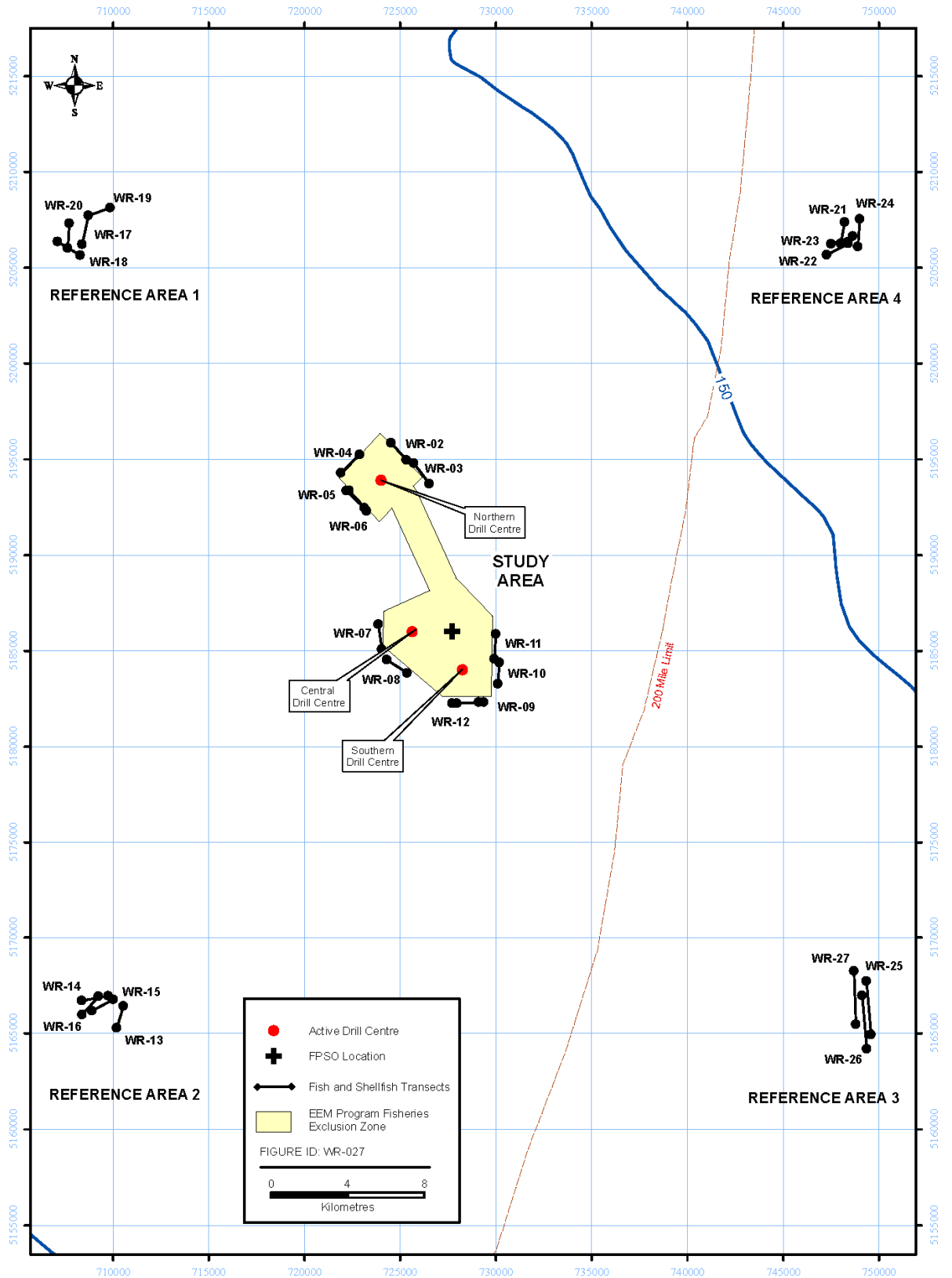
**Figure 1-12      2005 EEM Program Commercial Fish Transect Locations**
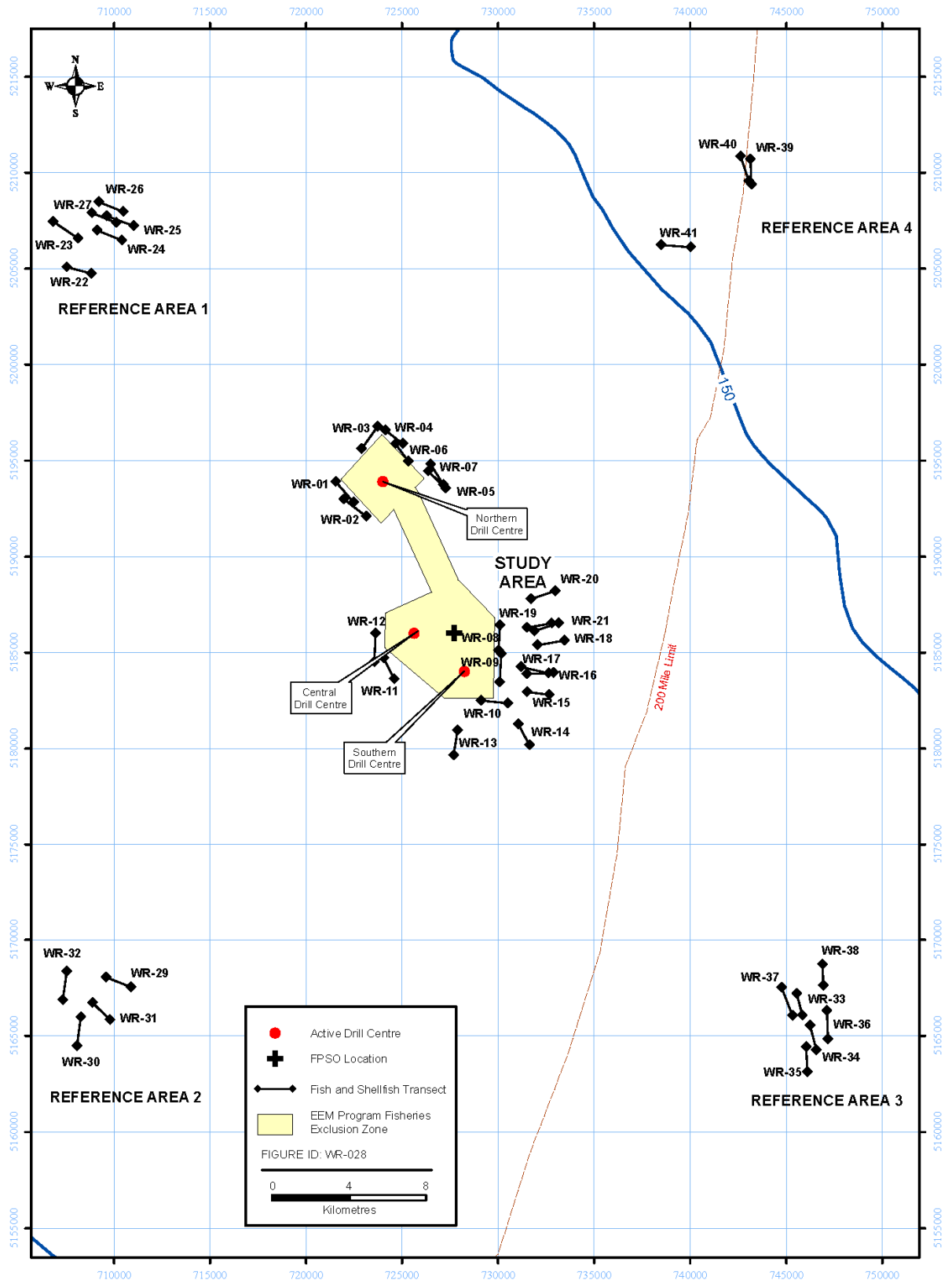
**Figure 1-13     2006 EEM Program Commercial Fish Transect Locations**
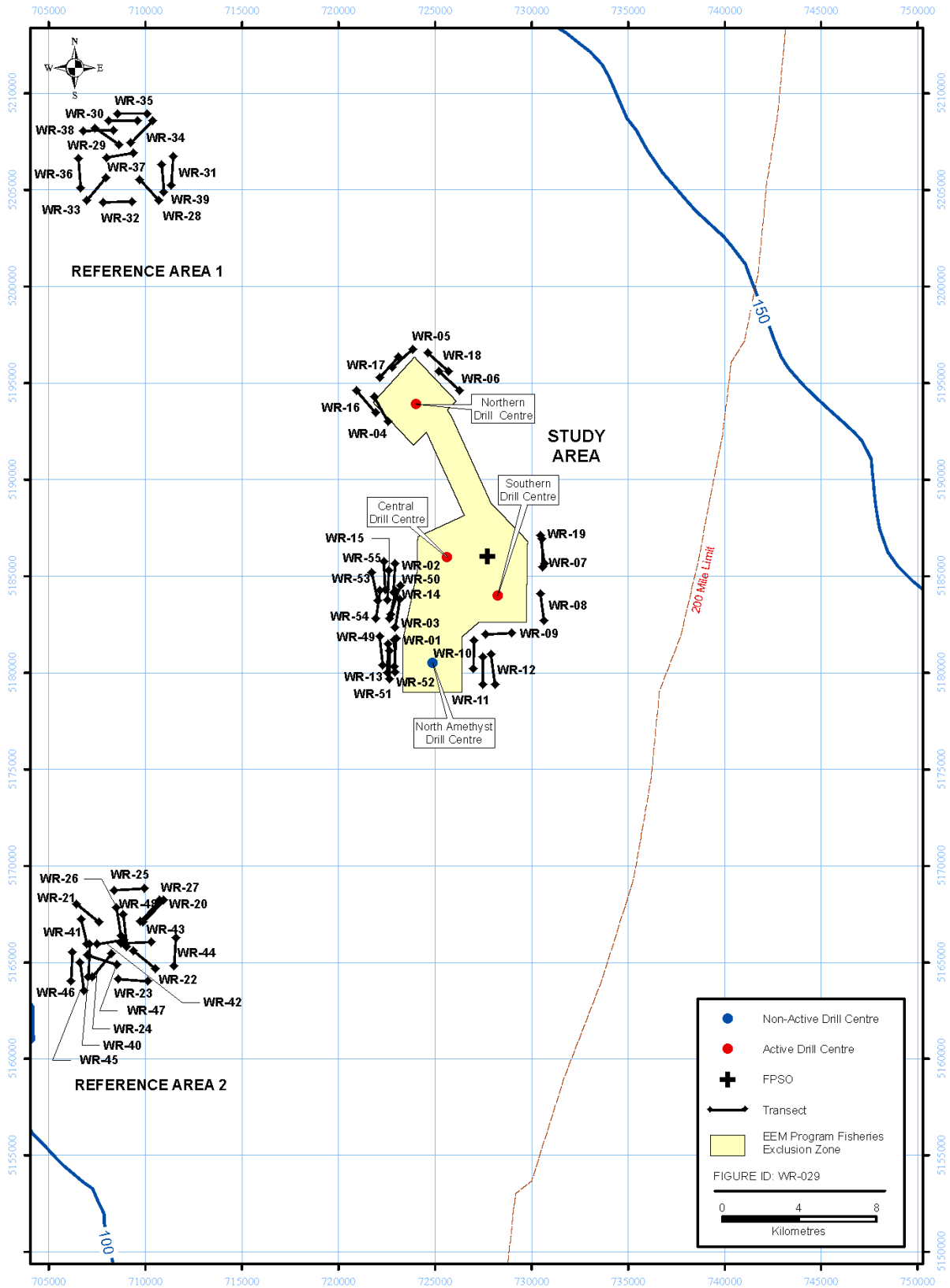
**Figure 1-14      2008 EEM Program Commercial Fish Transect Locations**
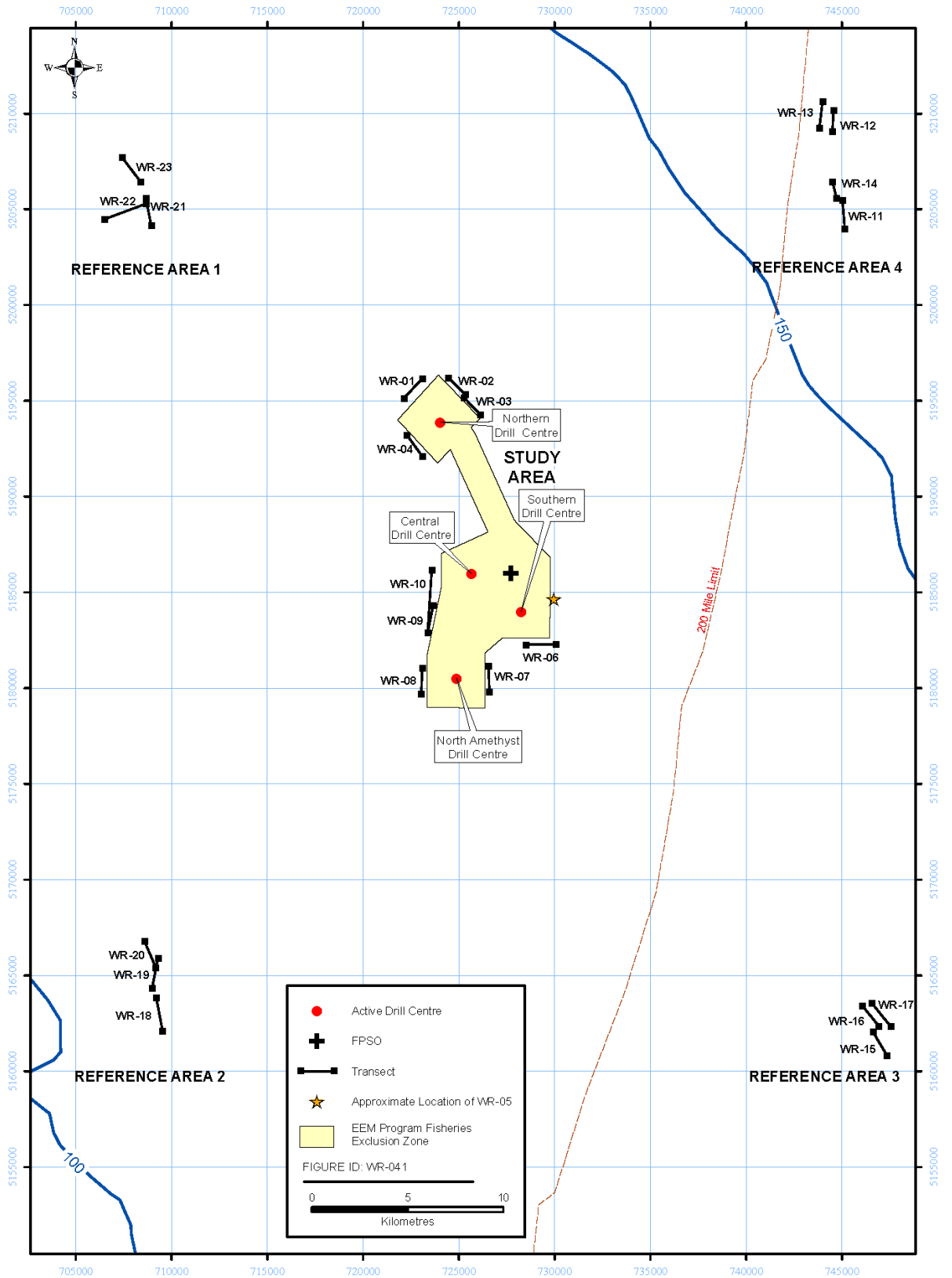
**Figure 1-15    2010 EEM Program Commercial Fish Transect Locations**
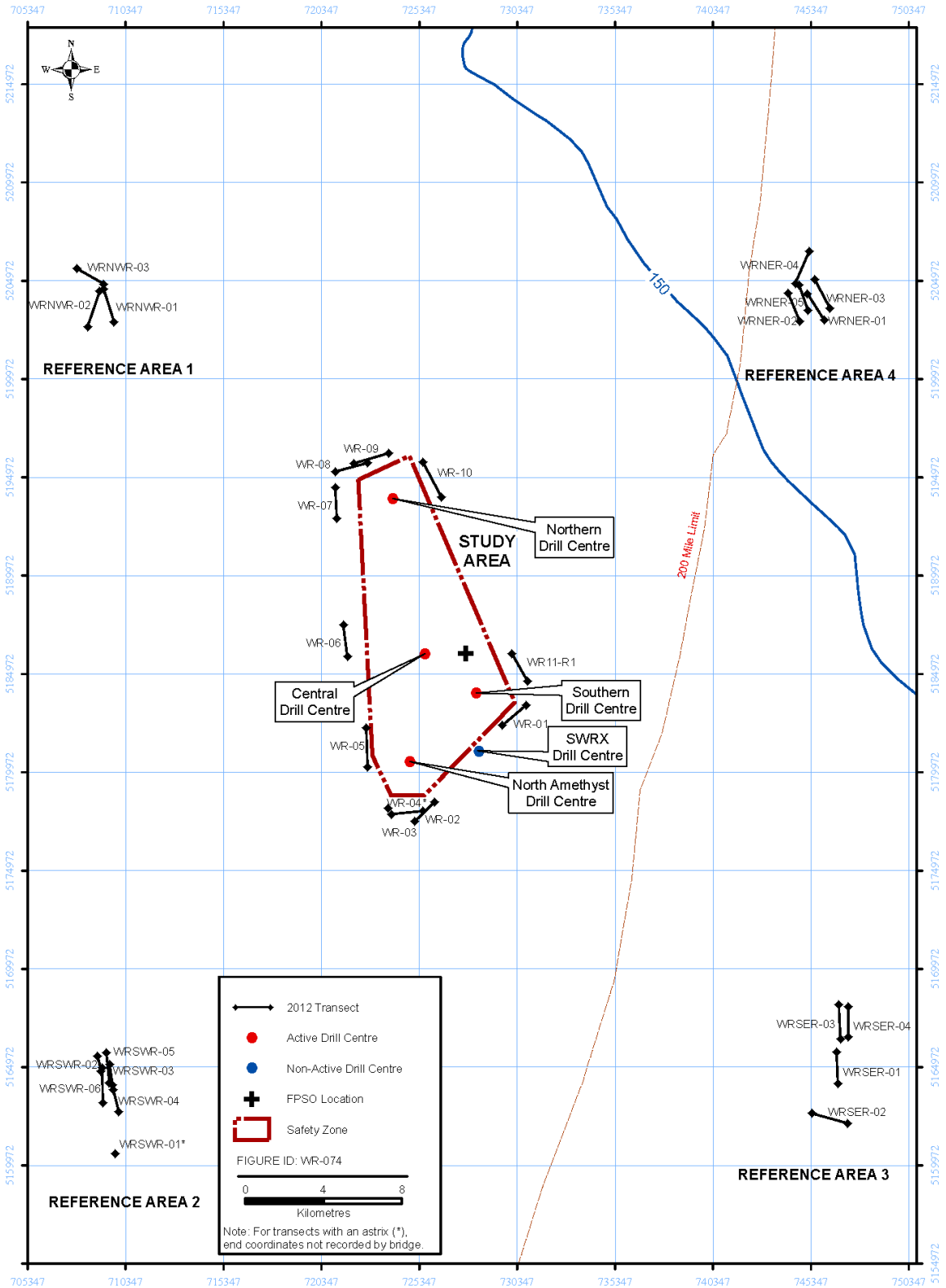
**Figure 1-16     2012 EEM Program Commercial Fish Transect Locations**

### 1.8.3   Modifications to the Water Quality Component

The Water Quality Component of the White Rose EEM targets both seawater and sediments as receiving environments for constituents from liquid discharge, predominantly produced water, from White Rose.

#### 1.8.3.1   Seawater Samples

Water samples were collected at 13 randomly selected stations during baseline sampling in 2000 (Figure 1-17[4]). Produced water discharge began from the *SeaRose FPSO* in March 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 1-18). A greater number of stations (18) were sampled in 2010, with 10 stations located near the *SeaRose FPSO* and eight stations located in Reference Areas to northwest and northeast (Figure 1-19). Modelling was used in the 2010 program to assess the probability of detection of produced water constituents given anticipated dilution and laboratory detection limits. The 2012 seawater sampling program was modified based on modelling results. Sampling of radionuclide (sampled in seawater in 2010) was discontinued in 2012; five stations were sampled near the *SeaRose FPSO* in the direction of winds and currents at the time of sampling; five stations were sampled in the mid-field (4 km from the *SeaRose FPSO*) in the direction of the prevailing seasonal current; and the same eight stations sampled in Reference Areas in 2010 were again sampled in 2012 (Figure 1-20). Since 2010, EEM water samples have been processed for a larger number of constituents and at lower detection limits than in baseline (see Section 7 and Husky Energy 2010 for details).

#### 1.8.3.2   Sediment Samples

In 2010, stations sampled for seawater (Figure 1-19) were also sampled for sediment particle size and sediment chemistry, including radionuclide concentration. Thirteen (13) stations sampled as part of the Sediment Component of the EEM program were also sampled for radionuclide concentrations, for a total of 27 radionuclide stations (see Figure 1-9 for details).

In 2012, a modelling exercise examined the probability of detection of produced water radionuclides in sediments. Based on model results, sampling of sediment radionuclides was discontinued in 2012 (also see Section 7), but all other analyses on sediments at Water Quality stations (Figure 1-20) were retained.

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[4] Figure 1-17 excludes water samples collected at the two control stations sampled during baseline and subsequently excluded from the EEM sampling.
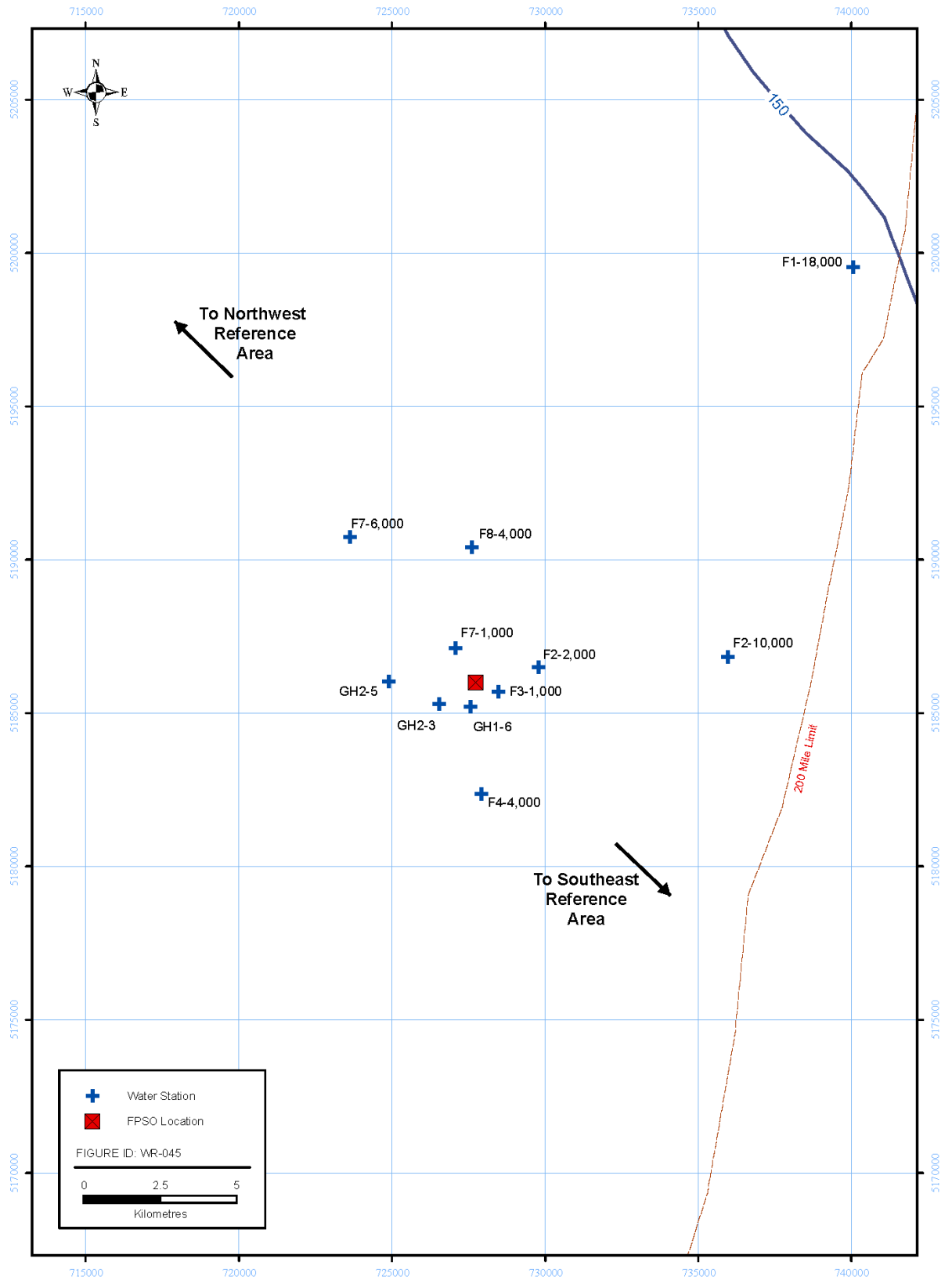
**Figure 1-17      2000 Baseline Program Water Quality Stations**
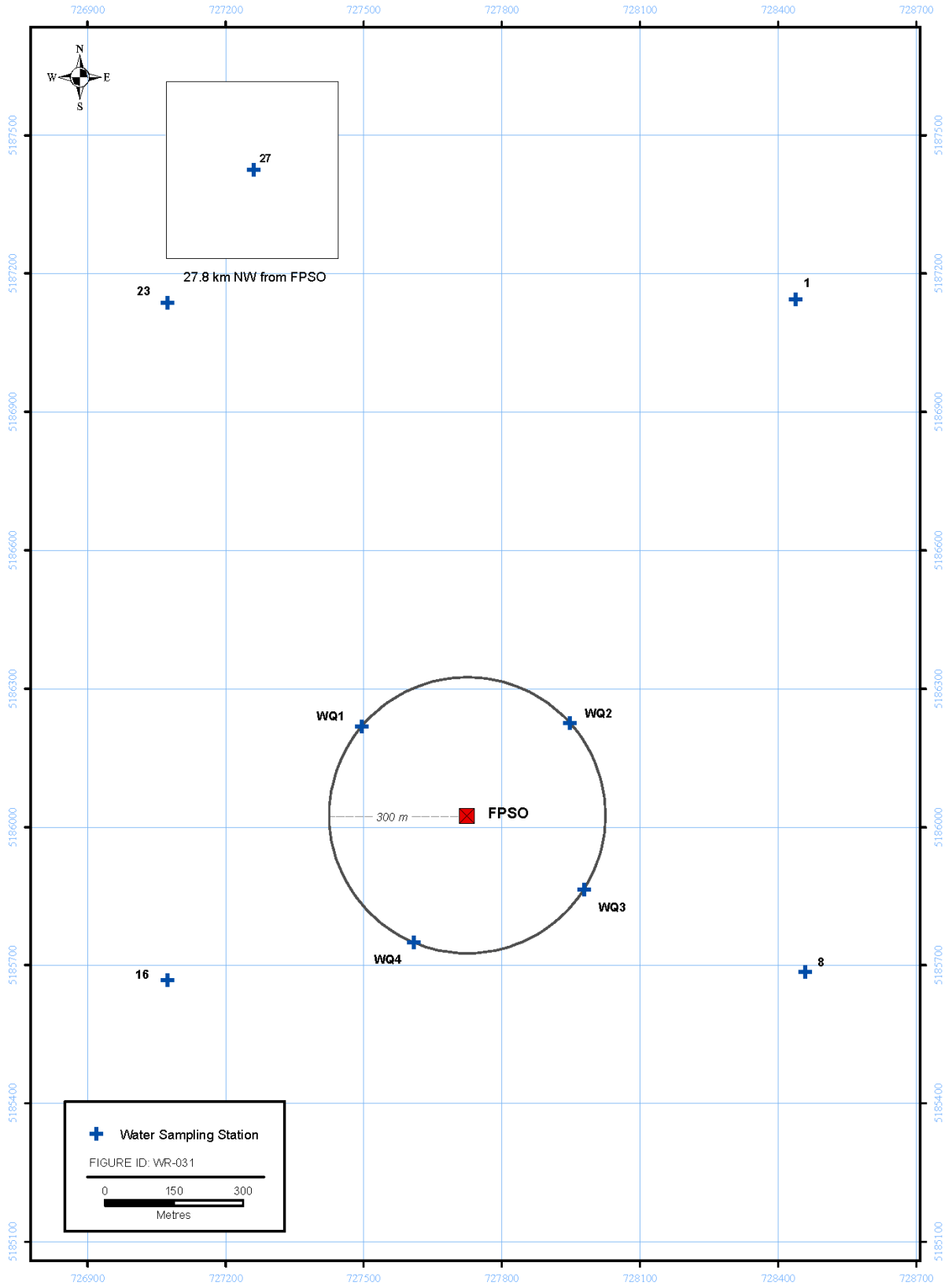
**Figure 1-18     2008 EEM Program Water Quality Stations**
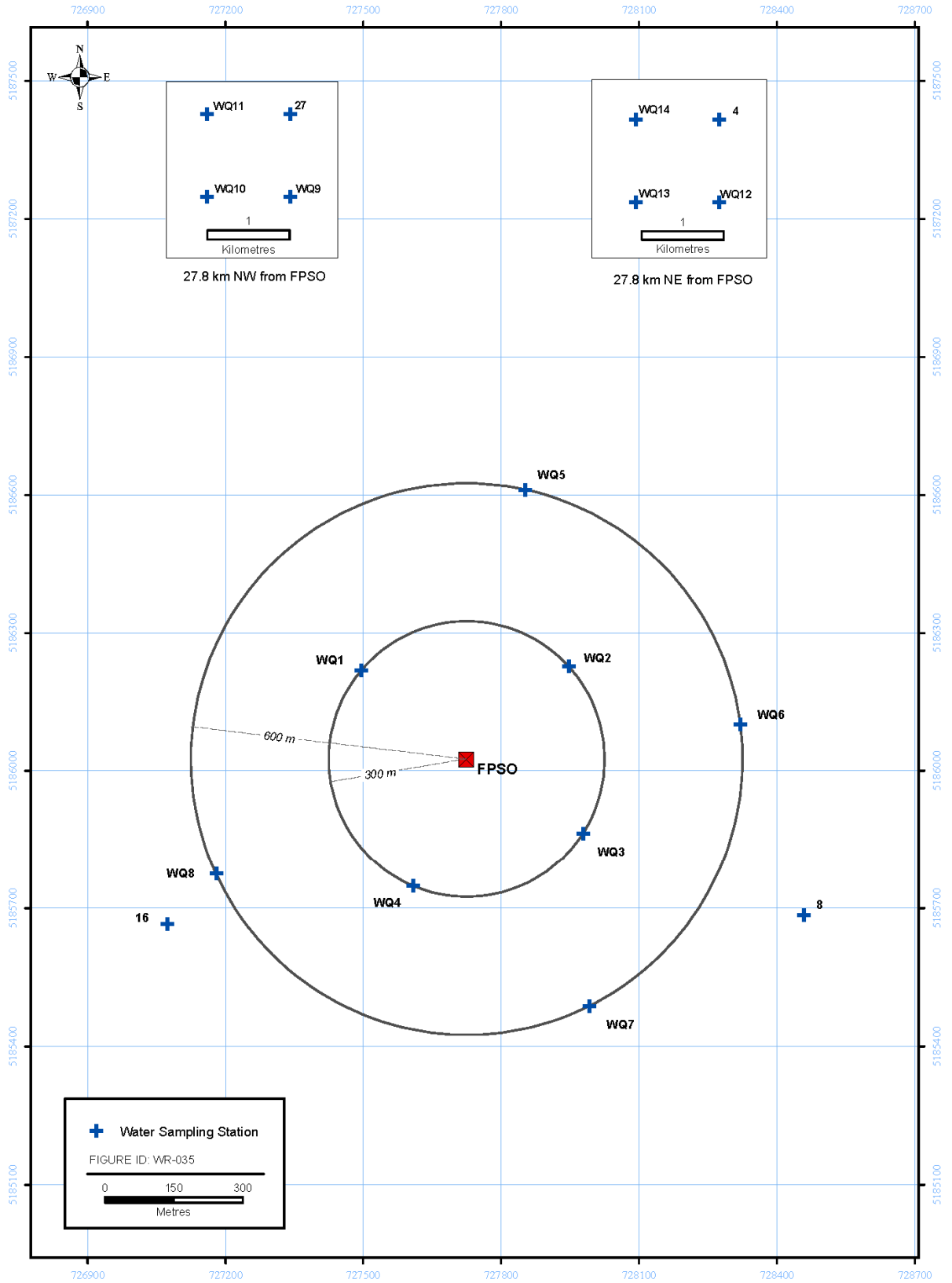
**Figure 1-19      2010 EEM Program Water Quality Stations**
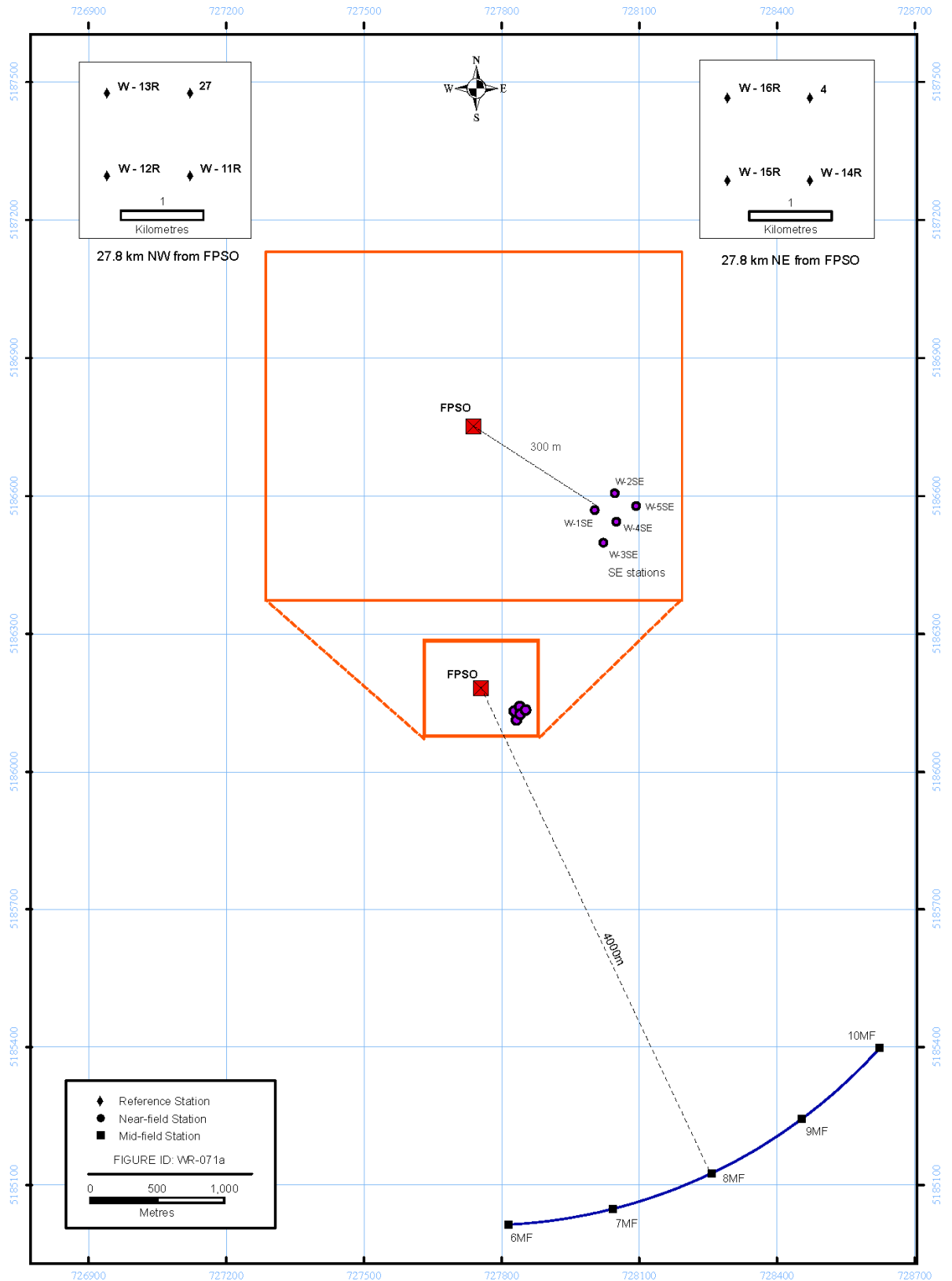
**Figure 1-20    2012 EEM Program Water Quality Stations**

## 2.0   Scope

This document, *White Rose Environmental Effects Monitoring Program 2012 (Volume 1)*, provides summary results, analysis and interpretation for the White Rose 2012 EEM program. Where sufficient, results from the baseline and previous EEM programs are compared to 2012 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 2012 (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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Environment Canada. 1998. *Reference Method for Determining Acute Lethality of Sediment to Marine or Estuarine Amphipods*. Report EPS 1/RM/35. Environment Canada Environmental Protection Service, Ottawa, ON. xviii + 56 pp.

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Green, R.H. 1979. *Sampling Design and Statistical Methods for Environmental Biologists.* John Wiley and Sons, Toronto, ON. 257 pp.

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Green, R.H., J.M. Boyd and J.S. Macdonald. 1993. Relating sets of variables in environmental studies: The Sediment Quality Triad as a paradigm. *Environmetrics,* 44: 439-457.

Ludwig, J.A. and J.F. Reynolds. 1988. *Statistical Ecology: A Primer on Methods and Computing*. John Wiley & Sons, New York, NY. 337 pp.

Quinn, G.P. and M.J. Keough. 2002. *Experimental Design and Data Analysis for Biologists*. Cambridge University Press, Cambridge, UK. 537 pp.

Schmitt, R.J. and C. W. Osenberg (Editors). 1996. *Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats.* Academic Press, San Diego, CA. 401 pp.

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

Various Authors. 1996. *Canadian Journal of Fisheries and Aquatic Science,* Volume 53(11) (this volume provides reviews of GOOMEX studies).

## 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 |
| C-NLOPB | Canada-Newfoundland and Labrador Offshore Petroleum Board |
| CR | Completely Random |
| CTD | Conductivity, Temperature, Depth |
| DREAM | Dose-Related Risk and Effects Assessment Model |
| EEM | Environmental Effects Monitoring |
| EIS | Environmental Impact Statement |
| EROD | 7-ethoxyresorufin O-deethylase |
| *FPSO* | Floating, Production, Storage and Offloading vessel |
| GSI | Gonadosomatic Index |
| HSI | Hepatosomatic Index |
| ISQG | Interim Sediment Quality Guidelines |
| MFO | Mixed Function Oxygenase |
| NMDS | Non-Metric Multidimensional Scaling |
| PAH | Polycyclic Aromatic Hydrocarbon |
| PC | Principal Component |
| PCA | Principal Component Analysis |
| SD | Standard Deviation |
| SR | Study versus Reference Areas |
| SWRX | South White Rose Extension |
| TIC | Total Inorganic Carbon |
| TOC | Total Organic Carbon |
| TPH | Total Petroleum Hydrocarbon |
| TSS | Total Suspended Sediment |
| VEC | Valued Environmental Component |

# 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 drilling platforms);

- *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. From 17 May, 2012 to 15 July, 2012, the *SeaRose FPSO* underwent a shipyard period, during which there was no production from the fields. From mid-July to late-September, 2012, the SWRX Drill Centre was excavated, becoming the fifth drill centre to be tied back to the *SeaRose FPSO*.

## 4.3   Drilling and Completions Operations

Drilling activities continued in 2010 through 2012. Husky Energy employs both water-based muds and synthetic fluid-based drill muds in its drilling programs. Water-based muds are used for the upper two drill hole sections, which is riserless drilling, while synthetic fluid-based drill muds 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 Atlantic Region offshore or onshore operations.

This is achieved through the following objectives:

- limit or minimize the waste generated from Atlantic Region operations; and

- ensure all waste from Atlantic Region operations is handled in an environmentally responsible manner.

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

- Environmental Protection and Compliance Monitoring Plan (EPCMP) – *SeaRose FPSO* Production Operations (WR-R-00-X-PG-00001-001);

- Environmental Protection and Compliance Monitoring Plan (EPCMP) – GSF Grand Banks (EC-M-99-X-PR-00102-001);

- White Rose Waste Management Plan (EC-M-99-X-PR-00109-001);

- *SeaRose* Waste Management Procedure (WR-O-00-X-PR-00001-001);

- internal reviews of waste manifesting procedures; and

- 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 water-based muds 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 synthetic fluid-based drill muds 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 Water-based Mud Discharges from 2003 to December 2012**

| Year | Drill Centre | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total Cuttings Discharged (mt) | Total Muds Discharged (m³) |
|------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|
| 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 |  |  |  |  |  |
| 2011 | Northern |  |  |  |  |  |  |  |  |  |  |  |  | N/A | N/A |
|  | Central |  |  |  |  |  |  | ● | ● | ● | ● | ● |  | 649 | 1413 |
|  | Southern |  |  |  |  |  |  |  |  |  |  |  |  | N/A | N/A |
|  | NADC** | ● | ● | ● | ● |  |  |  |  |  |  |  |  | 1261 | 2557 |
| 2012 | Northern |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Central |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | Southern |  |  |  | ● | ● | ● |  |  |  |  |  |  | 459 | 1285 |
|  | NADC** |  |  |  |  | ● | ● | ● | ● | ● | ● |  |  | 512 | 1596 |
|  | EEM Program |  |  |  |  |  |  | F | SW |  |  |  |  |  |  |
|  | Total Discharge at Northern Drill Centre |  |  |  |  |  |  |  |  |  |  |  |  | 1,335 | 1,182 |
|  | Total Discharge at Central Drill Centre |  |  |  |  |  |  |  |  |  |  |  |  | 6,813 | 8,247 |
|  | Total Discharge at Southern Drill Centre |  |  |  |  |  |  |  |  |  |  |  |  | 4,219 | 6,102 |
|  | Total Discharge at NADC** |  |  |  |  |  |  |  |  |  |  |  |  | 4,586 | 8,628 |
|  | Total Field Discharge |  |  |  |  |  |  |  |  |  |  |  |  | 16,953 | 24,159 |

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 Synthetic Fluid-based Dill Mud Discharges from 2003 to December 2012**

| Year | Drill Centre | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total Cuttings Discharged (mt) | Total Solids Discharged (mt) | Total Base Oil Discharged (m³) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | | | | | | |
| 2011 | Northern | | | | | | | | | | | | | | | |
| | Central | | | | | | ■ | ■ | ■ | ■ | ■ | | | 429 | 1,392 | 101 |
| | Southern | | | | | | | | | | | | | | | |
| | NADC** | ■ | ■ | ■ | ■ | | | | | | | | | 799 | 1309 | 111 |
| 2012 | Northern | | | | | | | | | | | | | | | |
| | Central | | | | | | | | | | | | | | | |
| | Southern | | | | ■ | ■ | ■ | | | | | | | 732 | 847 | 185 |
| | NADC** | | | | ■ | ■ | ■ | ■ | ■ | | | | | 853 | 907 | 148 |
| | EEM Program | | | | | | | F | SW | | | | | | | |
| | Total Discharge at Northern Drill Centre | | | | | | | | | | | | | 1,636 | 3,144.6 | 330 |
| | Total Discharge at Central Drill Centre | | | | | | | | | | | | | 5,539 | 12,636 | 1,518 |
| | Total Discharge at Southern Drill Centre | | | | | | | | | | | | | 4,778 | 10,071 | 1,418 |
| | Total Discharge at NADC** | | | | | | | | | | | | | 3,775 | 6,710 | 703 |
| | Total Field Discharge | | | | | | | | | | | | | 15,728 | 32,562 | 3,969 |

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 2012**

| Year | Drill Centre | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total Completion Fluids Discharged (m³) |
|------|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 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 |  |  |  |
| 2011 | Northern |  |  |  |  |  |  |  |  |  |  |  |  | N/A |
|  | Central |  |  |  |  |  | ▇ | ▇ | ▇ | ▇ |  |  |  | 673 |
|  | Southern |  |  |  |  |  |  |  |  |  |  |  |  | N/A |
|  | NADC** |  |  |  | ▇ | ▇ |  | ▇ |  |  |  |  |  | 821 |
| 2012 | Northern |  |  |  |  |  |  |  |  |  |  |  |  | N/A |
|  | Central |  |  | ▇ | ▇ |  |  |  |  |  |  |  |  | 445 |
|  | Southern |  |  |  | ▇ | ▇ | ▇ |  |  |  |  |  |  | 597 |
|  | NADC** |  |  |  |  | ▇ | ▇ | ▇ | ▇ | ▇ |  |  |  | 592 |
|  | EEM Program |  |  |  |  |  |  | F | SW |  |  |  |  |  |
|  |  |  |  |  |  |  |  | Total Discharge at Northern Drill Centre |  |  |  |  |  | 385 |
|  |  |  |  |  |  |  |  | Total Discharge at Central Drill Centre |  |  |  |  |  | 3,793 |
|  |  |  |  |  |  |  |  | Total Discharge at Southern Drill Centre |  |  |  |  |  | 4,314 |
|  |  |  |  |  |  |  |  | Total Discharge at NADC** |  |  |  |  |  | 3,735 |
|  |  |  |  |  |  |  |  | Total Field Discharge |  |  |  |  |  | 12,227 |

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 2010 and October 2012, a total of 192.8 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, 2.9 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 416 m³ of deck drainage reported during this period, which represents a transfer of 2.1 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 212.1 m³ of water and glycols have been discharged from these sources, at between 25% and 35% of total volume, approximately 68.9 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 2010 and October 2012, a total of 10,790 m³ of water was released from the slops tanks, representing 56.01 kg (average 2.78 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 volume-weighted average is to be less than 44 ppm, whereas a volume-weighted 30-day rolling average is to be less than 30 ppm. Between October 2010 and October 2012, 6,903,538m³ of produced water was released, representing 132,191 kg (average for end-of month 30-day rolling average 19.1 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. 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 2010 and October 2012, the monthly average concentration of chlorine prior to release was 0.33 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

The Sediment Component of the 2012 EEM Program was conducted from August 21 to August 26, 2012, using the offshore supply vessel *Burin Sea*. Sampling dates for the baseline program and EEM programs are summarized in Table 5-1. Sediment stations for the baseline and EEM programs are shown in Figures 1-4 to 1-10 (Section 1), with the 2012 station locations provided again in Figure 5-1 below. Differences in sampling locations among years are described in Section 1. More details on the baseline survey and the Year 1, 2 3, 4 and 5 EEM programs can be found in Husky Energy (2001; 2005; 2006; 2007; 2009; 2011). Geographic coordinates and distances to drill centres for EEM stations sampled in 2012 are provided in Appendix B-1.

**Table 5-1        Date of Sediment 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 |
| EEM Program Year 6 | August 21 to August 26, 2012 |

Sediment was collected using a large-volume corer (mouth diameter = 35.6 cm, depth = 61 cm) designed to mechanically take an undisturbed sediment sample over approximately 0.1 m$^2$ (0.0995 m$^2$) of seabed (Figures 5-2 and 5-3). In 2012, sediment quality stations were sampled for physical and chemical characteristics, toxicity and benthic community structure. 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.
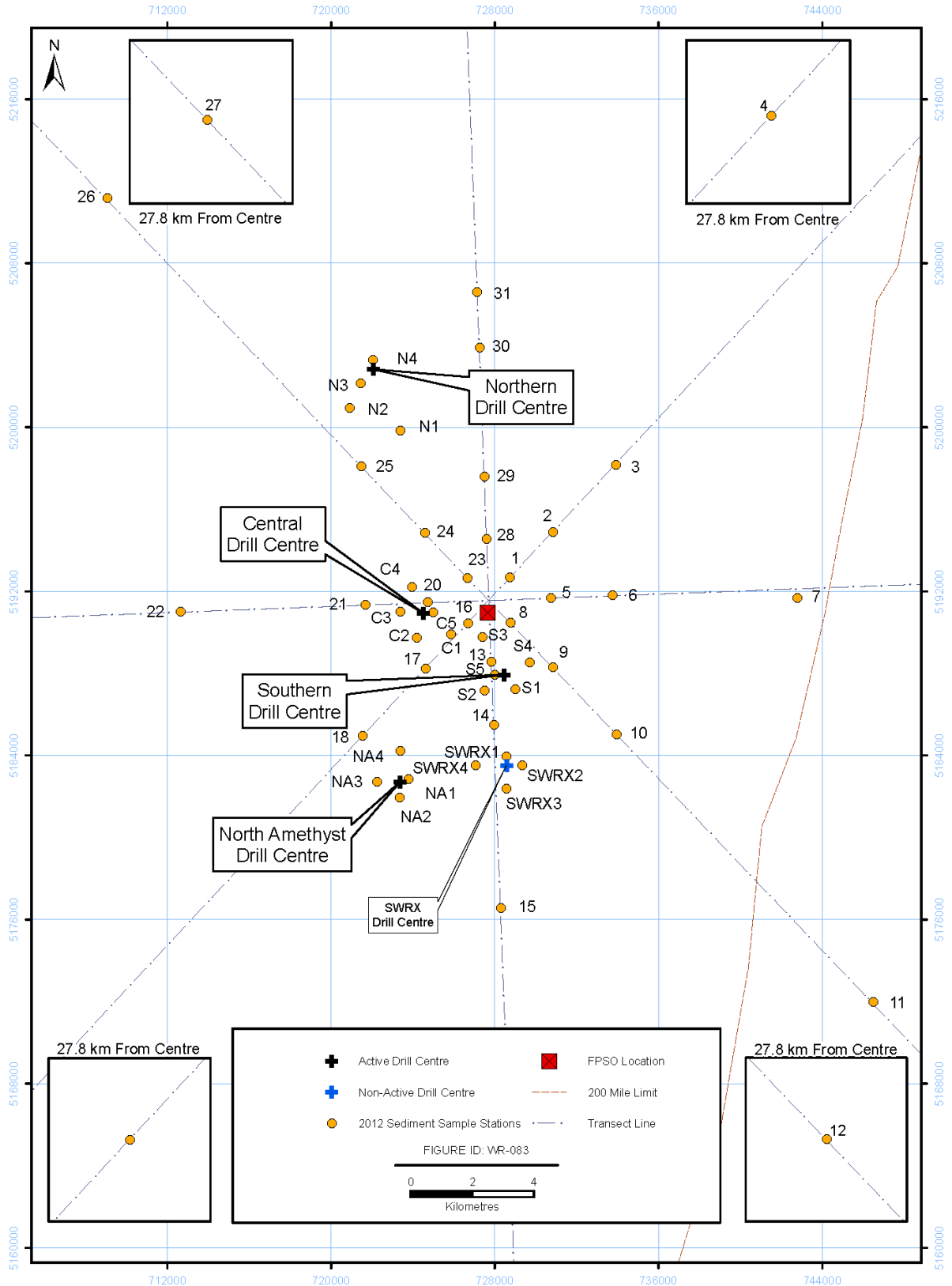
**Figure 5-1       2012 Sediment Quality Triad Stations**
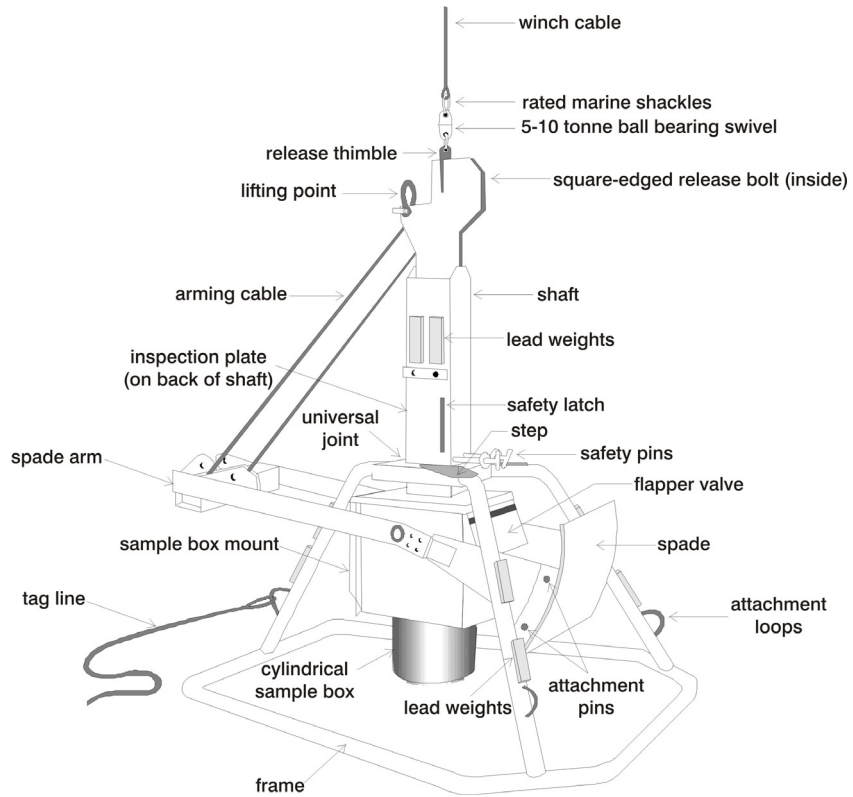
**Figure 5-2        Sediment Corer Diagram**
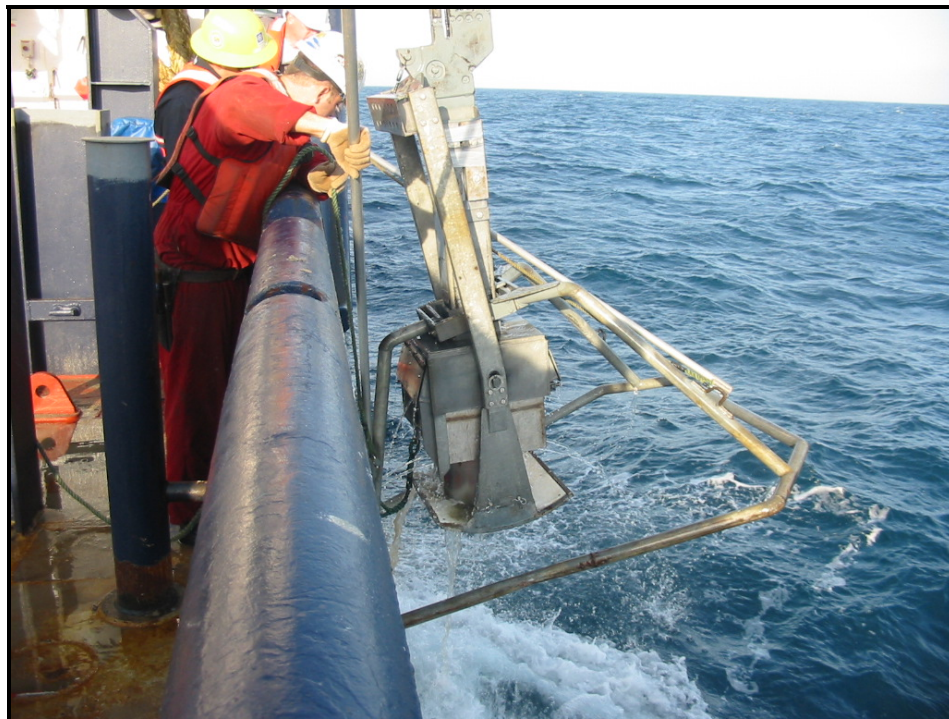


**Figure 5-3        Sediment Corer**

Sediment samples collected for physical and chemical analyses were a composite from the top layer of three cores per station. 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[5]. 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 chemistry field blanks composed of clean sediment obtained from Maxxam Analytics were collected for stations 9, N4 and SWRX1. 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 6, 24, NA4, S1 and SWRX4. 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). Chemical analyses were conducted by Maxxam Analytics in Halifax, Nova Scotia. The full suite of chemical analyses is provided in Table 5-3. Methods summaries from these three laboratories are provided in Appendices B-2 (Particle Size) and B-3 (Chemistry), respectively.

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[5] 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.

**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, 2010 and 2012)**

| Variables | Method | Laboratory Detection Limit | | | | | | Units |
|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2004 | 2005 | 2006 | 2008 | 2010/2012 | |
| *Hydrocarbons* | | | | | | | | |
| Benzene | Calculated | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | mg/kg |
| Toluene | Calculated | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | mg/kg |
| Ethylbenzene | Calculated | 0.03 | 0.03 | 0.03 | 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 | 3 | 3 | 3 | 4 | 3 | 3 | mg/kg |
| >$C_{10}$-$C_{21}$ | GC/FID | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | mg/kg |
| >$C_{21}$-$C_{32}$ | GC/FID | 0.3 | 0.3 | 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 |
| 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 |

| Variables | Method | Laboratory Detection Limit | | | | | | Units |
|---|---|---|---|---|---|---|---|---|
| | | 2000 | 2004 | 2005 | 2006 | 2008 | 2010/2012 | |
| 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/NA | Bq/g |
| Radium-228 | Gamma Spec. | NA | NA | NA | NA | 0.003 | 0.003/NA | Bq/g |
| Lead-210 | Gamma Spec. | NA | NA | NA | NA | 0.01 | 0.01/NA | Bq/g |

Notes:   -   Total metals concentrations were assessed. Assessment of total metals concentration does not differentiate between bioavailable and non-bioavailable fractions.
-   Measurement of radionucliides was discontinued in 2012 because modelling showed that the probability of detecting enrichment of these in sediments as a result of project activity at White Rose was zero.
-   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 limits may vary from year to year because instruments are checked for precision and accuracy every year as part of QA/QC procedures[6].
-   Laboratory detection limits for hydrocarbons in 2000, 2004, 2005 and 2012 were reported at one more significant digit than what is shown above. As this was not a change in detection limit but rather a change in rounding of the values, the higher of the reported detection limits (in 2006, 2008 and 2010) are used in this report.
-   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.
-   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

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[6] 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 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 the same time as $C_{21}$ n-alkanes (approximately 7.4 min) (Figure 5-4). The highest peaks in a chromatogram of PureDrill IA35-LV have retention times similar to those of n-alkanes of $C_{17}$-$C_{18}$ size.
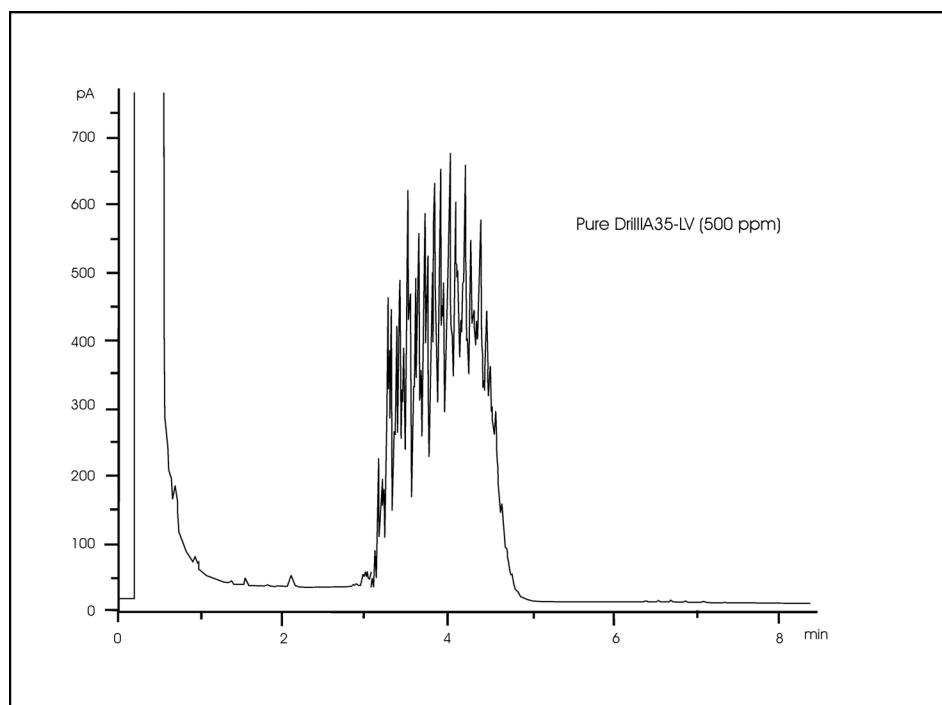


**Figure 5-4        Gas Chromatogram Trace for PureDrill IA35-LV**

## 5.1.2.2  Toxicity

### 5.1.2.2.1  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 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 are 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 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.

Most samples were processed within six weeks of sample collection, meeting the storage time requirements recommended by Environment Canada guidelines (Environment Canada 1998). However, because of an equipment malfunction, samples from Stations 18, 26, 27, S1, S2, NA1, NA2, NA3 and NA4 were processed eight weeks after collection[7].

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, 2010 and 2012 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, as recommended by Environment Canada (2002). However, one test failed the laboratory's Quality Assurance protocols and the required re-sampling occurred past this six-week period.

### 5.1.2.2.1  Results Interpretation

The statistical endpoint for the amphipod toxicity test is the determination of whether the biological endpoint (percent survival) differs statistically from the control or reference sample, calculated using the Dunnett's 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 $IC_{50}$[8] value.

Sample toxicity was assessed using standard toxicity testing statistical programs coupled with interpretation guidelines and direction provided by Environment Canada. 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

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[7] Environment Canada (1998) recommends testing within two to six weeks after sediment sample collection. Historically, some sediment samples have occasionally been analyzed beyond the six-week holding period, due to amphipod unavailability. The sediment sample chemistry may change during storage, and testing of sediment sample beyond the recommended holding period could potentially alter toxicity, depending on the chemicals present within the sediment. However, the sediment samples at White Rose traditionally do not exhibit toxicity. Therefore, there has never been a notable difference in toxicity of the sediment samples tested beyond the six-week holding period.
[8] An $IC_{50}$ (50% inhibitory concentration) is the concentration of a substance that produces 50% of the maximum possible inhibitory response to that substance.

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 (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 2012 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 (see Section 5.3.4).

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

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, 2006, 2008 and 2010 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 2012 samples (see Husky Energy 2001 for details).

### 5.1.3 Data Analysis

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, North Amethyst and SWRX Drill Centres. Effects during development drilling periods at White Rose have historically been most evident close to active 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 active drill centres) that were consistent with development drilling effects and to identify the potential zone of influence[9] for sediment chemistry. Drill centres were considered active if <u>any</u> drilling had occurred there in the past.

As indicated in Husky Energy's response to regulator comments on the 2008 EEM program (see Appendix A-1 in the 2010 EEM Program Report, Husky Energy, 2011), the EEM reports now rely 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 related to chemical and physical condition of sediments in 2008, 2010, and now in 2012 because it was and remained a clear outlier in terms of chemistry (hydrocarbons and barium in particular). Station 31 is located 4 km from the nearest development drill centre but the station is located near the site of a delineation well drilled in 2007. Station 31 was included in distance regressions in 2012 for laboratory toxicity test results and benthic indices, because it was not an outlier for biological measures.

#### 5.1.3.1 Physical and Chemical Characteristics

Data were first screened to identify and exclude variables that frequently occurred below detectable concentrations. The variables selected for detailed analysis in 2012 included $>C_{10}$-$C_{12}$ hydrocarbons, barium, sediment particle size (fines and % gravel), concentrations of total organic carbon (TOC), ammonia and sulphur, redox potential and a summary measure of concentration of metals other than barium (derived from a principal component analysis (PCA) of metals data). Also, because the metals PCA indicated that lead and strontium behaved differently from other metals, these two metals were examined separately.

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

Synthetic-based drill muds have elevated concentrations of >$C_{10}$-$C_{21}$ hydrocarbons. Barium, as barium sulphate (barite), can be a constituent of both water-based and synthetic-base drill muds. Sediment particle size (particularly % fines) and TOC content could be altered by drilling activity. Water-based and synthetic-based muds and associated drill cuttings are finer than the predominantly sand substrate on the Grand Banks, and synthetic-based muds have a higher organic carbon content than natural substrates.

Percent gravel has previously been correlated with indices of benthic community structure. As in previous years, percent sand was not examined because it is strongly negatively correlated with percent gravel (generally speaking, percent fines constitute a very small fraction of sediment particle size).

Sulphur, as sulphate in barite, is also an important constituent of drill muds. Ammonia levels are typically high, and redox levels are low, in sediments where decomposition or degradation of natural or synthetic organic matter is extensive. Metals other than barium can also be enriched in drill cuttings, albeit to a lesser extent.

Five statistical tools were used to explore the spatial variations of these selected variables as they might relate to drilling.

Spearman rank correlation (Tool 1) was used to statistically test for associations between distance from the nearest active drill centre and concentration of the subset of variables selected for detailed analysis.

Threshold models (Tool 2) were constructed in order estimate the spatial extent (threshold distance) of influence of active drill centres, overall, on concentrations of substances in sediments for those variables that were demonstrated with Spearman Ranks to be significantly correlated with distance from the nearest active drill centre.

The third tool (Tool 3) involved visual inspection of response variable data from 2000 to present. 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.

Maps (Tool 4) indicating barium and >$C_{10}$-$C_{21}$ hydrocarbon concentrations within and exceeding the variability observed in baseline (2000) were 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 spatial and temporal variation for barium and >$C_{10}$-$C_{21}$ hydrocarbons, and other variables brought forward for detailed analysis, at those stations that have been repeatedly sampled since baseline. The repeated-measures regression method was used to determine if there were changes over time both in terms of changes in mean concentration across 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 the nearest active drill centre (*i.e.*, Min D) and concentration (*i.e.*, the slope of the relationship may get steeper over time, indicating an increase in concentrations adjacent to active drill centres). The repeated-measures regression was only carried out with the 36 stations that were repeatedly sampled in baseline and EEM years. That analysis was

complimented by Spearman Rank correlations computed between response variables and Min D, by year, using all stations where sediment triad data were available. The Spearman rank correlations were based on more stations than was the repeated-measures regression, and so the results of each analysis did at times indicate different trends over time. Plots of the Spearman rank correlations, however, assisted in the interpretation of the repeated-measures regression analysis.

All statistical methods pertaining to sediment quality are described in greater detail in Appendix B-5.

### 5.1.3.2  Toxicity

In 2012 and in previous years, no analyses of results for bacterial toxicity tests were conducted. A single toxic sample was noted in 2010 (Husky Energy 2011). No toxic response was noted in any other year, including 2012.

The evidence that amphipod survival was influenced by drilling was tested using Spearman rank correlation of survival and distance to the nearest active drill centre.

### 5.1.3.3  Benthic Community Composition

In 2012, three summary indices of benthic community composition were analyzed in detail:

- total abundance (number of organisms per $m^2$);

- biomass (wet weight of organisms per $m^2$); 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 relatively rare, they were included in analyses of individual taxa because they are generally considered sensitive and were also reduced in abundance near active drill centres and at relatively high $>C_{10}$-$C_{21}$ hydrocarbon concentrations in past years (Husky Energy 2011).

Bray-Curtis values to the median baseline benthic community were also computed, following methods described by Environment Canada (2012). Bray-Curtis values provide an overall measure of community similarity. A non-metric multidimensional scaling

(NMDS) ordination of the benthic data was also computed, and is presented in Appendix B-5. The NMDS ordination technique was used in prior years as an additional means of summarizing the benthic community, and is provided in Appendix B-5 for continuity. The results of the analysis of Bray-Curtis values are provided in the main body of this report because they are considered here to be easier to communicate and simpler to illustrate, yet they were as sensitive to drilling effects as were the NMDS axis scores.

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 effects from active drill centres. Five statistical tools were used to explore the spatial variations of the selected indices of benthic community composition: rank regression (Tool 1), threshold models (Tool 2), graphical display of data (Tool 3), maps (Tool 4) and repeated-measures regression (Tool 5). For individual taxa, only those taxa that showed significant correlations with distance from active drill centres 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 at Sediment Quality Triad stations for sediment physical and chemical characteristics occurring at or above the laboratory detection limit in 2000, 2004, 2005, 2006, 2008, 2010 and 2012. All variables measured on sediment are provided above in Table 5-3. Toluene was detected at levels close to the laboratory detection limit at one station 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. No PAHs were detected at Sediment Quality Triad stations in 2012. PAHs were only detected at Sediment Quality Triad stations (five stations in total) in 2010, and levels were 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 seven sampling years were aluminum, barium, chromium, iron, lead, manganese, strontium, uranium, vanadium and zinc.

As in previous years, sediments collected in 2012 were predominantly sand, with gravel-sized materials comprising up to 6% 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) (CCME 2010; see Table 5-4). Adverse biological effects are rare below ISQG (CCME 2010). Concentrations of $>C_{10}$-$C_{21}$ hydrocarbons measured in 2012 varied between non-detectable concentrations and 510 mg/kg. Barium concentrations varied between background levels of 110 mg/kg and enriched levels of 4,000 mg/kg. (Table 5-4).

**Table 5-4      Summary of Commonly Detected Sediment Variables (2012)**

| Variable | Units | ISQG | N of Cases | Minimum | Maximum | Arithmetic Mean |
|---|---|---|---|---|---|---|
| Aluminum | mg/kg | | 53 | 5,800 | 12,000 | 8,687 |
| Barium | mg/kg | | 53 | 110 | 4,000 | 476 |
| Chromium | mg/kg | 52.3 | 53 | 2.7 | 5.2 | 3.8 |
| Iron | mg/kg | | 53 | 1,100 | 2,900 | 1,698 |
| Lead | mg/kg | 32 | 53 | 2.0 | 11 | 3.1 |
| Manganese | mg/kg | | 53 | 21 | 90 | 45 |
| Strontium | mg/kg | | 53 | 30 | 170 | 54 |
| Uranium | mg/kg | | 53 | 0.14 | 0.34 | 0.21 |
| Vanadium | mg/kg | | 53 | 4.1 | 7.5 | 5.4 |
| Zinc | mg/kg | 124 | 53 | 2.5 | 11 | 3.2 |
| $>C_{10}-C_{21}$ | mg/kg | | 53 | 0.125 | 510 | 23 |
| $>C_{21}-C_{32}$ | mg/kg | | 53 | 0.125 | 17 | 1.3 |
| Fines | % | | 53 | 0.32 | 1.9 | 0.8 |
| Sand | % | | 53 | 94.3 | 99.2 | 98 |
| Gravel | % | | 53 | 0.3 | 5.1 | 1.5 |
| TOC | g/kg | | 53 | 0.38 | 1.4 | 0.9 |
| Moisture | % | | 53 | 14 | 19 | 16 |
| Redox | mV | | 53 | 111 | 229 | 182 |
| Ammonia | mg/kg | | 53 | 1.6 | 19 | 5.3 |
| Sulphur | mg/kg | | 53 | 0.03 | 0.11 | 0.05 |
| Depth | m | | 53 | 100 | 173 | 121 |

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.

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

Concentrations of $>C_{10}-C_{21}$ hydrocarbons in 2012 were significantly correlated with distance from the nearest active drill centre, as in previous years (Figure 5-6).



**Figure 5-6      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for $>C_{10}-C_{21}$ Hydrocarbons**

Notes: Stations 31 was excluded. $n$ = 52 for All Stations. $n$ = 35 for Repeated-Measures (RM) Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year.

As in previous years, 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 2012, the threshold distance was estimated to be 3.6 km, which is unchanged from 2010 (Table 5-5). Figure 5-7 provides a graphical representation of threshold models.

**Table 5-5**    **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) |
| 2012 | 3.6 (2.6, 4.8) |

Notes:  -    95% confidence limits are provided in brackets.
-    *n* = 52 in 2012 with station 31 excluded.

As indicated in Figure 5-7, 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 2012 (Figure 5-8). $>C_{10}$-$C_{21}$ hydrocarbons were also still enriched at station 31, located near the site of a delineation well drilled in 2007.

Repeated-measures regression indicated no change over time in the relationship between distance and concentrations of $>C_{10}$-$C_{21}$ hydrocarbons ($p = 0.824$), and no changes in area-wide concentrations over time ($p = 0.367$; Table 5-6). This conclusion applies to the time period from 2004 to present (2012). Concentrations of $>C_{10}$-$C_{21}$ hydrocarbons were non-detectable in 2000, and generally have been at detectable concentrations since 2004 (Figure 5-7).
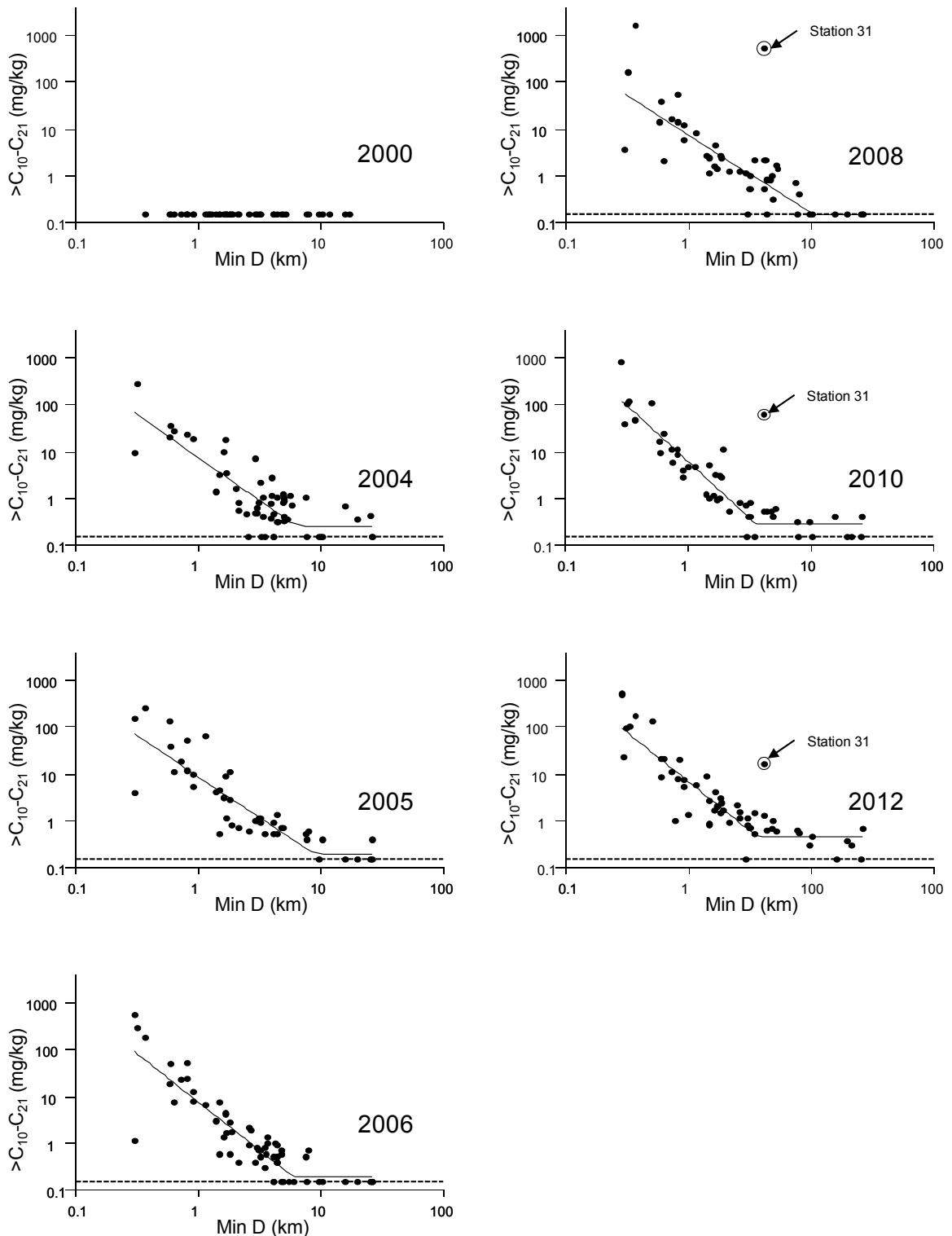
**Figure 5-7     Variations in >C$_{10}$-C$_{21}$ Concentrations with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. The detection limit is indicated in each graph by a horizontal dotted line, to indicate the levels observed in the baseline year (2000).
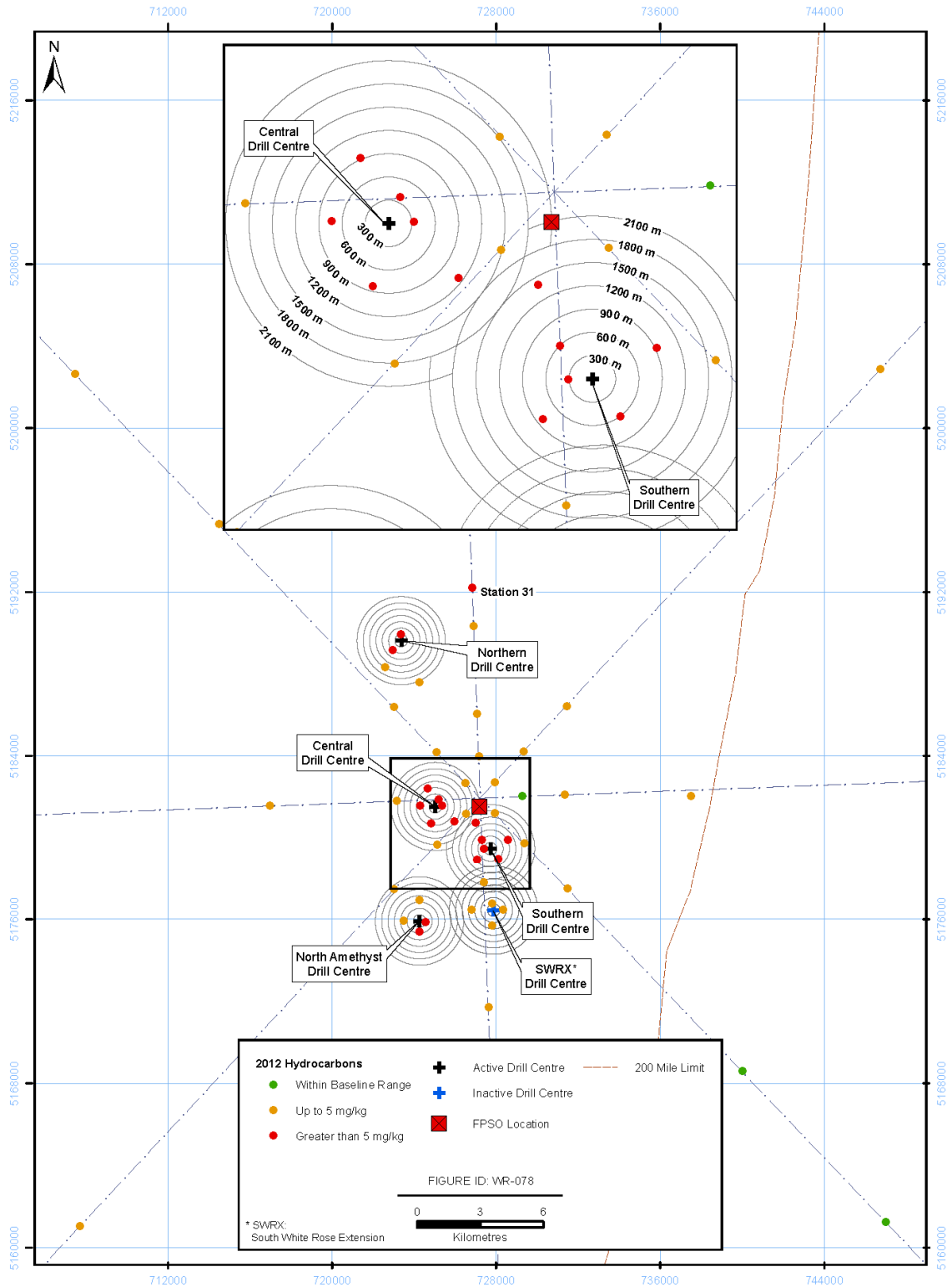
**Figure 5-8    Location of Stations with >C$_{10}$-C$_{21}$ Hydrocarbon Values Within the Baseline Range (not detected), Showing Mild Enrichment up to 5 mg/kg and with Values Greater than 5 mg/kg (2012)**

**Table 5-6**      Repeated-measures Regression Testing for Changes in $>C_{10}$-$C_{21}$ Concentrations over Time

| Trend Over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.918 | 0.380 | NA | NA |

Notes:  -    Values are probabilities.
        -    $n$ = 35 with station 31 excluded.
        -    The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
        -    The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012. The Before to After contrast cannot be performed for $>C_{10}$-$C_{21}$ hydrocarbons since all concentrations were below detection limit during baseline.

### 5.2.1.2   Barium

Like $>C_{10}$-$C_{21}$ hydrocarbons, barium produced a significant Spearman Correlation with distance to active drill centres in 2012, and in previous EEM years (Figure 5-9).



**Figure 5-9**      **Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Barium**

Notes: Station 31 was excluded. $n$ = 52 for All Stations. $n$ = 35 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year.

The threshold model in 2012 was again significant ($p < 0.001$). The estimated threshold distance in 2012 was 1 km, which is less than the average noted in all previous years (Table 5-7). Figure 5-10 provides a graphical representation of threshold models.

**Table 5-7      Results of Threshold Regressions on Distance from the Nearest Active Drill Centre for Barium**

| 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) |
| 2012 | 1.0 (0.8, 1.2) |

Notes:  -   95% confidence limits are provided in brackets.
         -   *n* = 52 in 2012 with station 31 excluded.

As indicated in Figure 5-10, 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 a "benchmark" against which to judge spatial variation in the sampling area in Figure 5-11.

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. Barium was not enriched near the SWRX drill centre (Figure 5-11). That drill centre was not yet active when sampling occurred in 2012.

Repeated-measures regression indicated that there was a nearly significant linear trend over time in the slope of the relationship between barium concentration and distance to the nearest active drill centre from 2004 to 2012 ($p$ = 0.088; Table 5-8), and there was a significant trend over time in the average barium concentration ($p$ = 0.003). Slopes differed from before to after drilling operations began ($p$ < 0.001), with the steepest slope occurring in 2012, and co-occurring with the shortest threshold distance of 1 km (Figure 5-10). Concentrations of barium in year 2000 averaged 168 mg/kg, with the baseline 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 5-10). Overall average barium concentrations have been higher since drilling operations began ($p$ < 0.001; Table 5-8), a result of elevated concentrations near active drill centres.

**Figure 5-10    Variations in Barium Concentrations with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. 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).
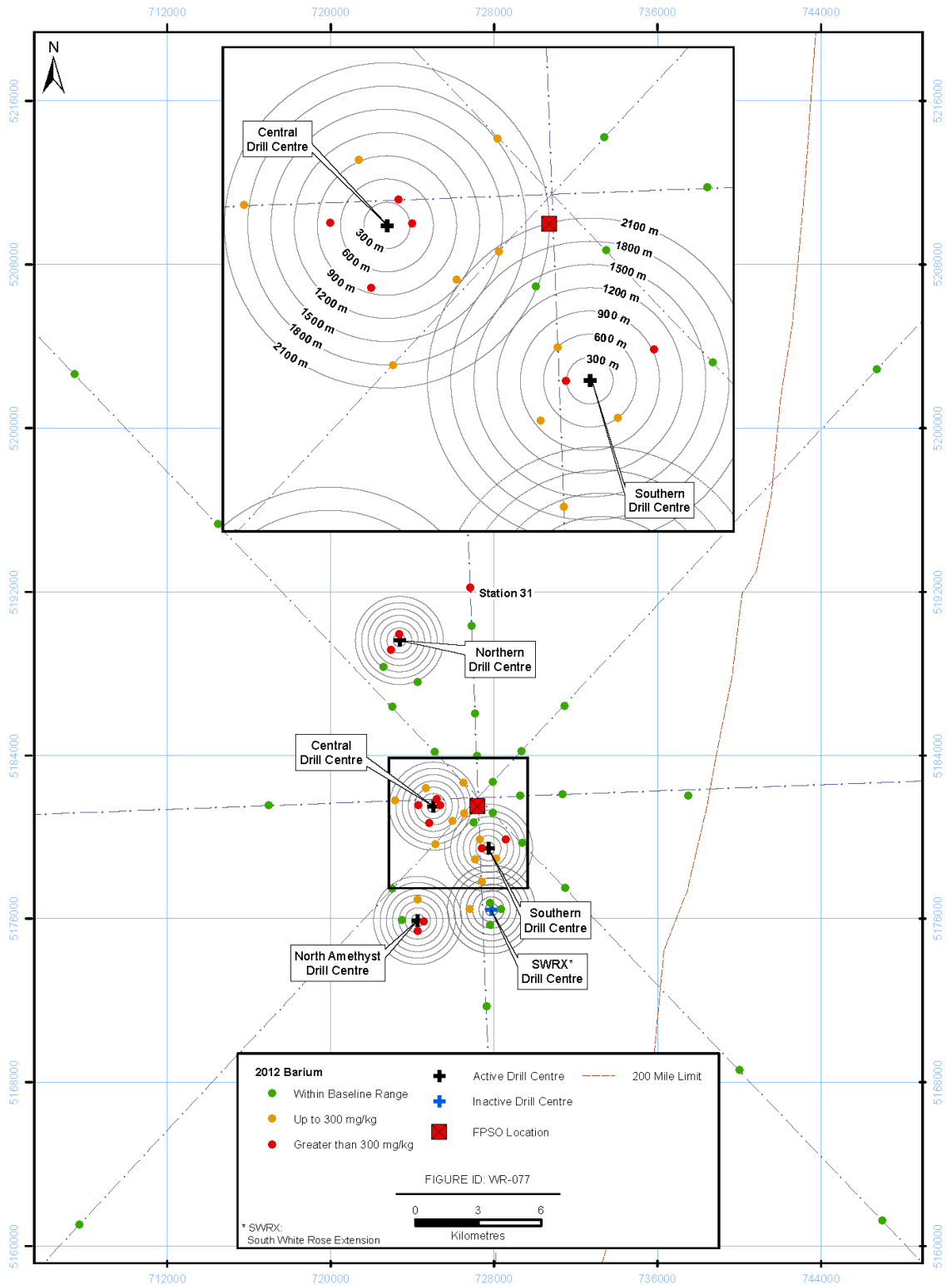
**Figure 5-11      Location of Stations with Barium Levels Within the Baseline Range, Showing Mild Enrichment up to 300 mg/kg and with Values Greater than 300 mg/kg (2012)**

**Table 5-8      Repeated-measures Regression Testing for Changes in Barium Concentrations over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.088 | 0.003 | <0.001 | <0.001 |

Notes:  -    Values are probabilities.
  -    *n* = 35 with station 31 excluded.
  -    The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
  -    The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

### 5.2.1.3   Fines

Percent of sediment as fines (silt and clay) generally varied between 1% and 2% across the sampling area and was marginally significantly correlated with distance from the nearest active drill centre in 2012 (Figure 5-12). A threshold did not account for significant variation in percent fines in 2012 (Appendix B-5), and was not significant in other years.
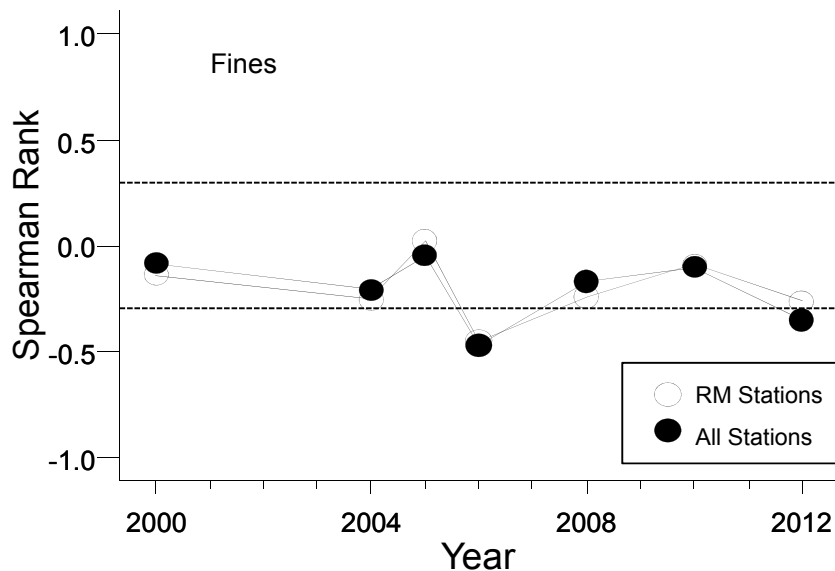


**Figure 5-12      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Fines**

Notes: Station 31 was excluded. *n* = 52 for All Stations. *n* = 35 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year.

Figure 5-13 provides a graphical representation of % fines with distance from active drill centres. Fines typically accounted for less than 2% of sediments, and were generally below the baseline background value of 1.3%.
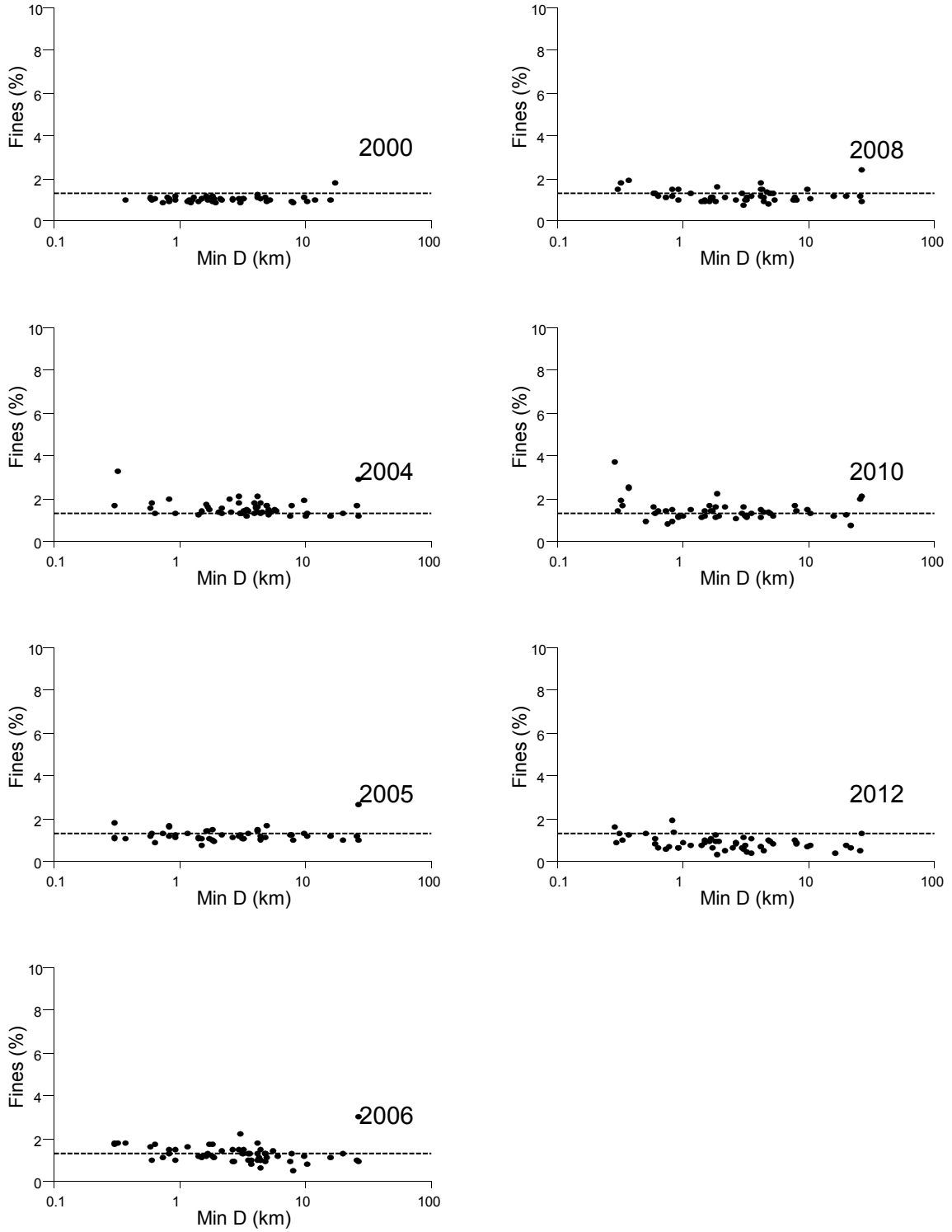
**Figure 5-13      Variations in Percent Fines with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. A concentration of 1.3% is indicated in each graph by a horizontal line, based on the mean values + 2 SDs in 2000 (baseline).

Repeated-measures regression (Table 5-9) indicated that there was a weakly significant trend over time in the slope of the relationship between fines and distance from the nearest active drill centre since drilling began in 2004 ($p$ = 0.035), but no significant differences in the nature of the relationship from before to after drilling ($p$ = 0.066). However, there was a significant difference in percent fines across the sampling area from before to after drilling operations ($p < 0.001$), and a significant trend over time in mean % fines after drilling ($p < 0.001$). The plot of Spearman rank correlations over time (Figure 5-12) indicates that the relation between fines and Min D has not typically been strong.

**Table 5-9        Repeated-measures Regression Testing for Changes in Percent Fines over Time**

| Trend over Time | | Before to After | |
| --- | --- | --- | --- |
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.035 | <0.001 | 0.066 | <0.001 |

Notes:  -    Values are probabilities.
-    $n$ = 35 with station 31 excluded.
-    The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
-    The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

Review of the plots in Figure 5-13 and the dot-density distribution (Figure 5-14) suggest that percent fines were highest in 2004, and have declined since that time. The upper limit of the baseline range of percent fines was approximately 1.3%, based on the mean observed in 2000 + 2 SD. Percent fines were generally above pre-drilling levels from 2004 to 2010, and generally at or below pre-drilling levels in 2012 (Figure 5-13 and 5-14).
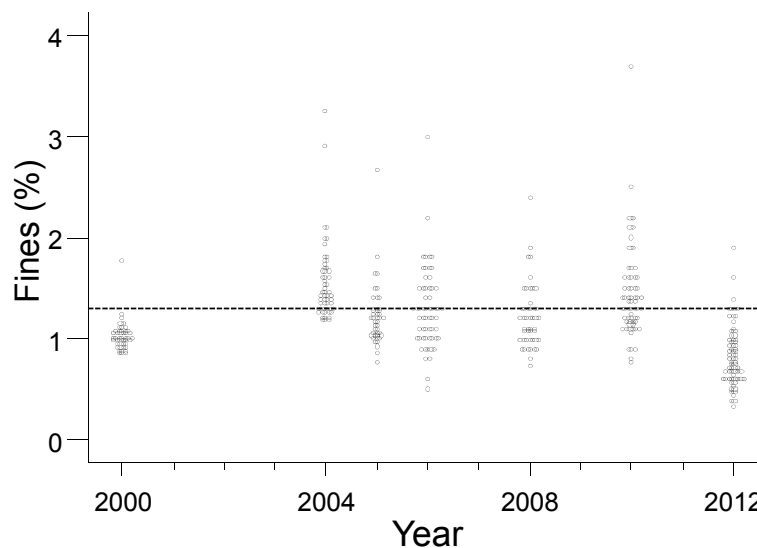


**Figure 5-14        Dot Density Plot of Percent Fines by Year**

Note: A concentration of 1.3% is indicated by a horizontal line, as based on the mean value + 2 SDs using data from 2000.

5.2.1.4   Gravel

Percent of substrate as gravel varied between 0.3 and 5.7% in 2012 across the sampling area and was not significantly correlated with distance from the nearest active drill centre in 2012, as in previous EEM years (Figure 5-15).
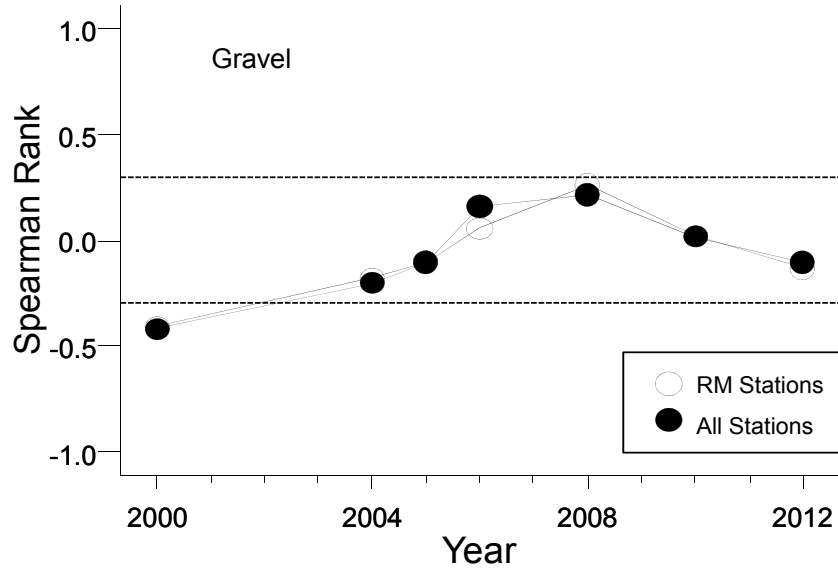


**Figure 5-15      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Gravel**

Note: Station 31 was excluded. *n* = 52 for All Stations. *n* = 35 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in the given year.

Figure 5-16 provides a graphical representation of percent gravel with distance from nearest active drill centres.

**Figure 5-16        Variations in Percent Gravel with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background levels of 1.75% are indicated, based on the mean values + 2 SDs in 2000 (baseline).

Repeated-measures regression (Table 5-10) indicated that the relationship between percent gravel and distance from the nearest active drill centres did not vary linearly over time during the period of active drilling ($p$ = 0.628), nor did it vary from before to after drilling ($p$ = 0.485). Mean percent gravel across the sampling area did vary significantly over time during the period of active drilling ($p$ = 0.005), but not from before to after drilling ($p$ = 0.270), with the percent of substrate as gravel being more variable after drilling started (Figure 5-17).

**Table 5-10    Repeated-measures Regression Testing for Changes in Percent Gravel over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.628 | 0.005 | 0.485 | 0.270 |

Notes:  -    Values are probabilities.
-    $n$ = 35 with station 31 excluded.
-    The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
-    The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.
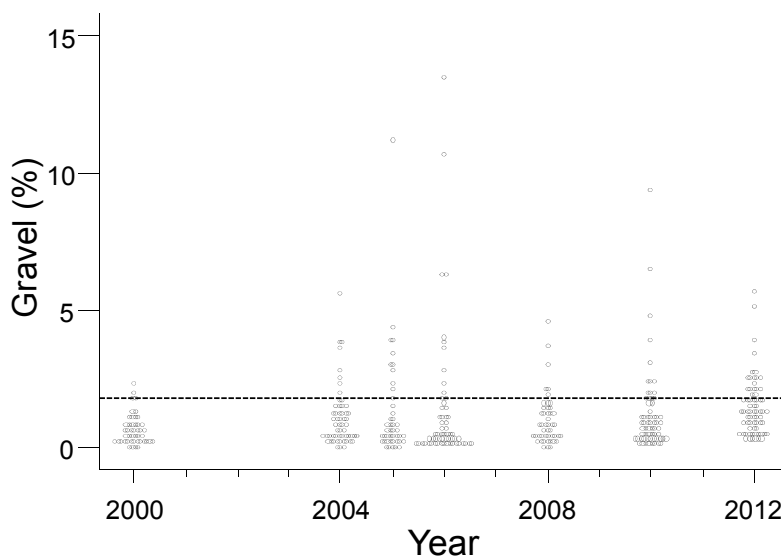


**Figure 5-17      Dot Density Plot of Percent Gravel by Year**

Note: Background levels of 1.75% are indicated, based on the mean values + 2 SDs in 2000 (baseline).

## 5.2.1.5  Total Organic Carbon

TOC content varied between approximately 0.38 and 1.4 g/kg in 2012 across the sampling area and was not correlated with distance from the nearest active drill centre (Figure 5-18). Figure 5-19 provides a graphical representation of TOC concentration with distance from active drill centres.
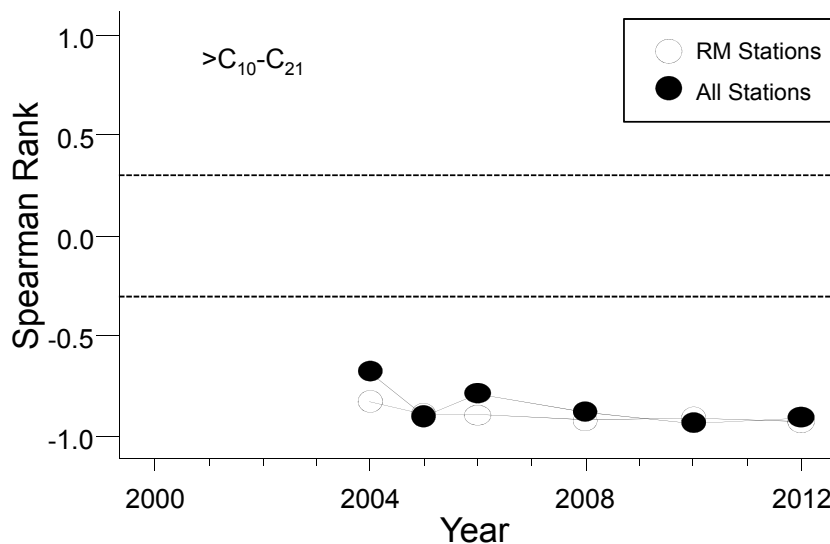
**Figure 5-18      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Organic Carbon (TOC)**

Notes: Station 31 was excluded. $n$ = 52 for All Stations. $n$ = 35 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year.

**Figure 5-19    Variations in Total Organic Carbon with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. 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).

Repeated-measures regression (Table 5-11) 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 ($p$ = 0.370), and there was also no change in the nature of the relationship from before to after drilling ($p$ = 0.319). There was also no trend over time in the mean TOC after drilling began ($p$ = 0.447). There was a significant difference in TOC from before to after drilling, with an indication from Figure 5-20 that TOC was marginally higher across the sampling area during drilling years (2004 to 2012), with some measured TOC values in excess of the upper limit of the baseline range from the baseline year (*i.e.*, greater than 1 g/kg; Figure 5-20).

**Table 5-11    Repeated-measures Regression Testing for Changes in Percent Total Organic Carbon over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.370 | 0.447 | 0.319 | 0.005 |

Notes:  -   Values are probabilities.
         -   $n$ = 35 with station 31 excluded.
         -   The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
         -   The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.



**Figure 5-20    Dot Density Plot of Total Organic Carbon by Year**

Note: 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).

### 5.2.1.6  Ammonia

Ammonia concentrations were generally less than 10 mg/kg in EEM years. Ammonia concentrations were not correlated with distance from the nearest active drill centre in 2012 (Figure 5-21). The relationship between ammonia concentrations and distance to the nearest active drill centre is illustrated in Figure 5-22.
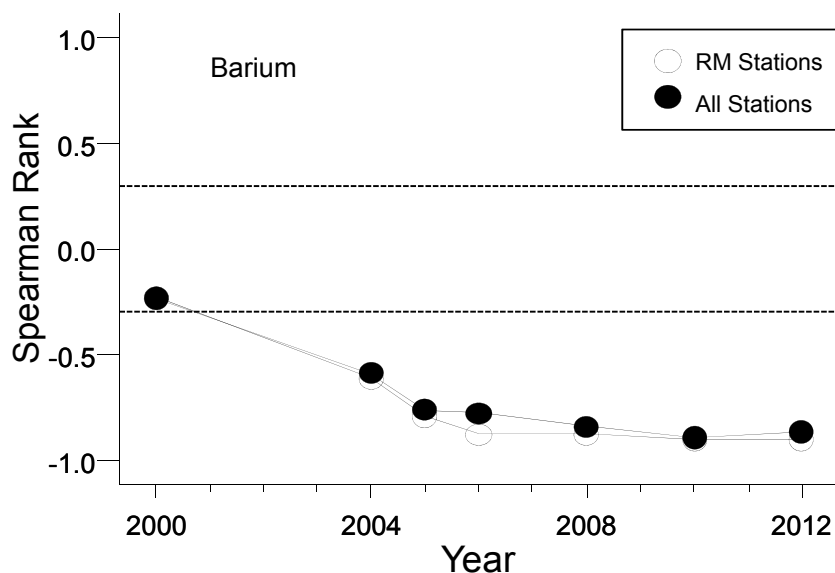
**Figure 5-21      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Ammonia**

Notes: Station 31 was excluded. *n* = 52 for All Stations *n* = 35 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at *p* < 0.01, depending on sample size in the given year. Ammonia was not measured in the 2000 baseline survey.

**Figure 5-22     Variations in Ammonia Concentrations with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre. Ammonia was not measured in 2000.

Repeated-measures regression (Table 5-12) indicated that there was no change in the relationship between ammonia and distance over the period of active drilling (*i.e.*, 2004 to 2012; *p* = 0.841; see also Figure 5-21), but there was a significant linear trend over time in average concentrations across the sampling area (*i.e.*, decreasing concentrations over time, *p* < 0.001, see Figures 5-23).

**Table 5-12      Repeated-measures Regression Testing for Changes in Ammonia Concentrations over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.841 | <0.001 | NA | NA |

Notes:  -    Values are probabilities.
  -    *n* = 35 with station 31 excluded.
  -    The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
  -    The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

The dot density plot of ammonia concentrations (Figure 5-23) illustrates that concentrations in 2010 and 2012 had broader spreads, with lower concentrations being detected, despite there being no changes in detection limits (Table 5-3). This was the second survey in which ammonia was observed at concentrations less 1 mg/kg. Concentrations prior to 2010 had always varied between 1 and 10 mg/kg.
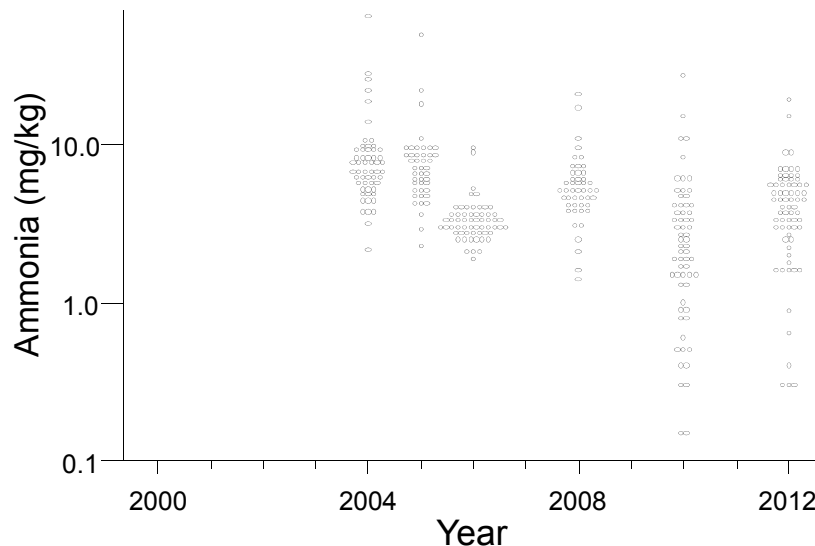


**Figure 5-23      Dot Density Plot of Ammonia Concentrations by Year**

### 5.2.1.7  Sulphur

Distance to the nearest active drill centre was significantly correlated with percent sulphur in 2012 (Figure 5-24). When stations less than 1 km from an active drill centre were removed from the dataset, the relationship was no longer significant (*p* > 0.05). Those results were similar to what was observed in 2010, and indicate mild sulphur enrichment near active drill centres. The Spearman rank correlation in 2012 was

stronger with all Sediment Quality stations, than with repeated-measures stations ($r_s$ = -0.65 *versus* $r_s$ = -0.45 for all stations *versus* repeated-measures stations; see Figure 5-24), although both sets of data produced statistically significant correlations. A threshold did not account for significant variation in sulphur in 2012 (Appendix B-5). The relationship between sulphur concentration in sediments and distance to the nearest active drill centre is illustrated in Figure 5-25.



**Figure 5-24      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Sulphur**

Notes: Station 31 was excluded. *n* = 52 for All Stations. *n* = 35 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at *p* < 0.01, depending on sample size in the given year. Sulphur was not measured in the 2000 baseline survey.
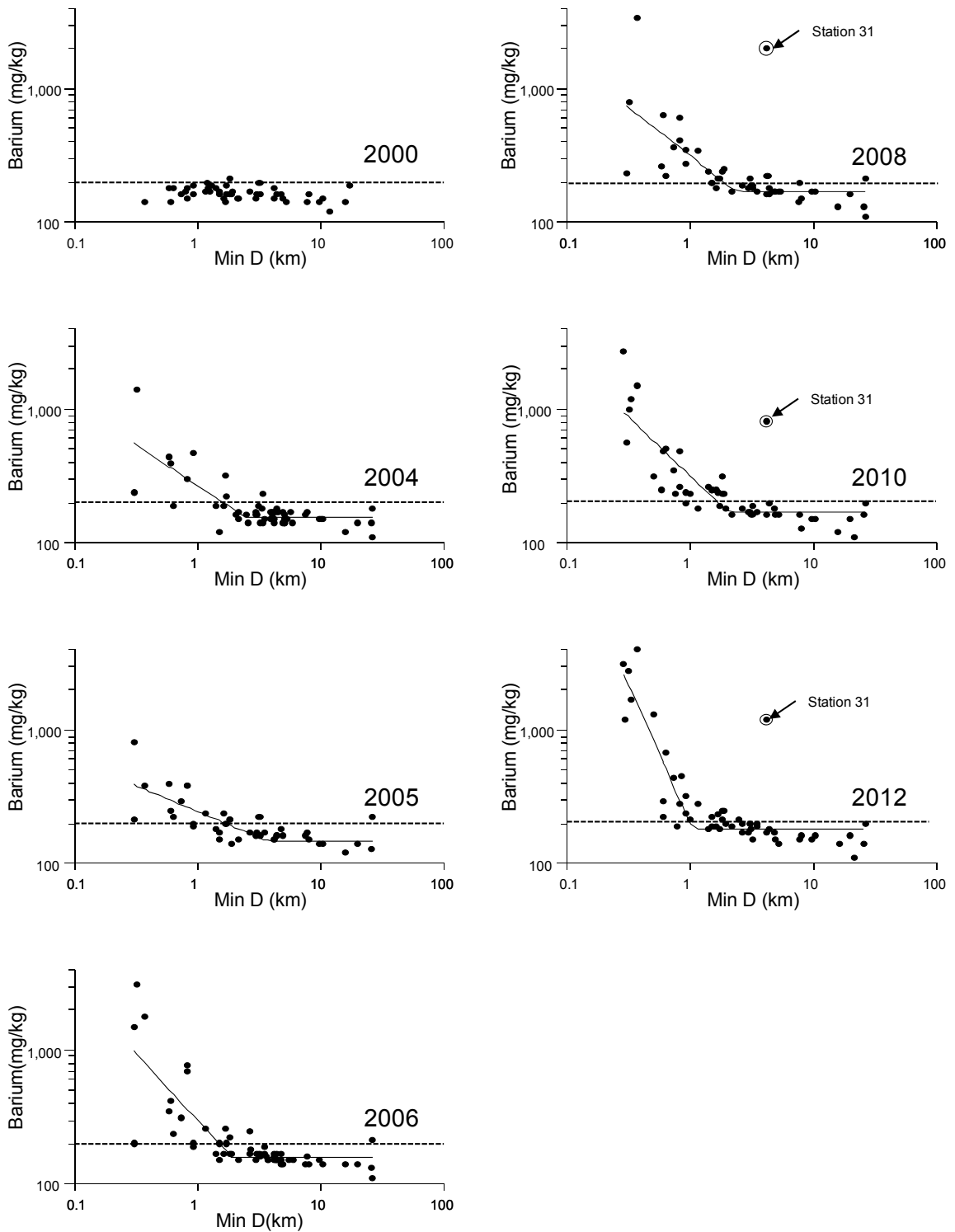
**Figure 5-25    Variations in Sulphur Concentrations with Distance from the Nearest Active Drill Centre (all Years)**

Note: Min D = distance (km) to the nearest active drill centre. Sulphur was not measured in 2000.

Repeated-measures regression (Table 5-13) indicated that there was no change in the relationship between sulphur and distance over the period of active drilling ($p$ = 0.849), a result that was consistent with Spearman rank correlations over time, as illustrated in Figure 5-24. There was a significant linear time trend in average sulphur concentrations (increasing) in the overall sampling area ($p$ < 0.001). The dot density graph of percent sulphur (Figure 5-26) illustrated that mean values in sediments have been higher in 2008, 2010 and 2012 compared to prior sample years.

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

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.849 | <0.001 | NA | NA |

Notes:  -  Values are probabilities.
   -  $n$ = 35 with station 31 excluded.
   -  The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
   -  The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.
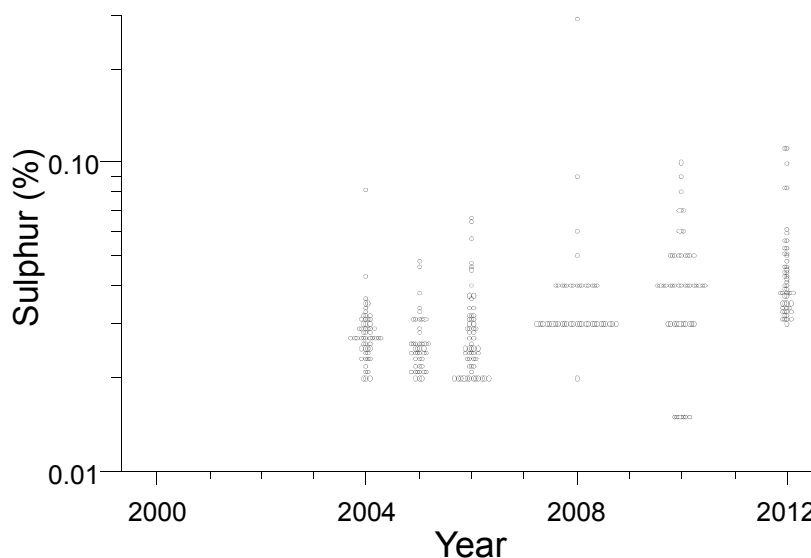


**Figure 5-26      Dot Density Plot of Sulphur Concentrations by Year**

### 5.2.1.8  Metals Other than Barium

Analysis of sediment chemistry data in previous years has demonstrated that metal concentrations covary. Rather than analyze the spatial-temporal variations of individual metals, one option, since the metals covary (increase and decrease in concentration together) is to produce a proxy variable that reflects the increasing and decreasing concentrations of metals. A PCA was carried out to produce a synthetic variable that summarized general variations in metals concentrations among stations and years.

The PCA of the concentrations ($\log_{10}$ transformed) of metals other than barium produced two strong axes, or synthetic variables (Table 5-14). All of the metals were strongly associated with the first PCA axis, and all with the same sign, indicating that metals all increased or decreased in concentration in approximately the same way. Concentrations of strontium and lead were also correlated with the second PCA axis indicating that those metals, independently of the others, covaried in relation to other factors. Scores on the first PCA axis were used as the synthetic variable (Metals PC1) summarizing variations in metals concentrations in subsequent analyses. Lead and strontium, which correlated strongly with the second PCA axis, were analyzed separately.

**Table 5-14      Principal Component Analysis of Metals Concentrations (all Years)**

| Variable | Principal Component | |
|---|---|---|
| | 1 | 2 |
| Aluminum | **0.76** | -0.10 |
| Chromium | **0.86** | 0.07 |
| Iron | **0.89** | 0.42 |
| Lead | **0.62** | **-0.70** |
| Manganese | **0.80** | 0.51 |
| Strontium | **0.68** | **-0.70** |
| Uranium | **0.65** | -0.13 |
| Vanadium | **0.93** | 0.26 |
| Percent Variance Explained | 61 | 19 |

**Metals PC1**

Metals PC1 scores were not correlated with distance from the nearest active drill centre in 2012 (Figure 5-27).
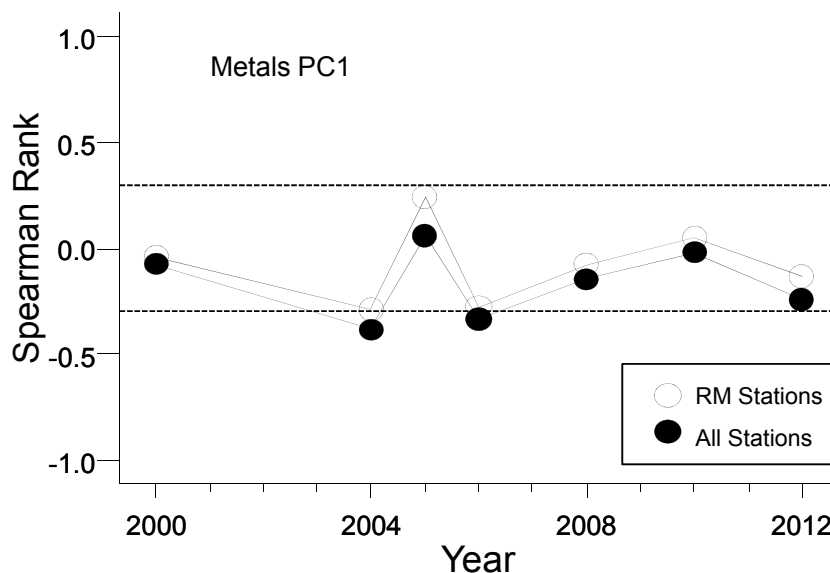


**Figure 5-27      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Metals PC1**

Notes: Station 31 was excluded. $n$ = 52 for All Stations $n$ = 35 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year.

Figure 5-28 provides a graphical representation of Metals PC1 scores with distance from active drill centres.
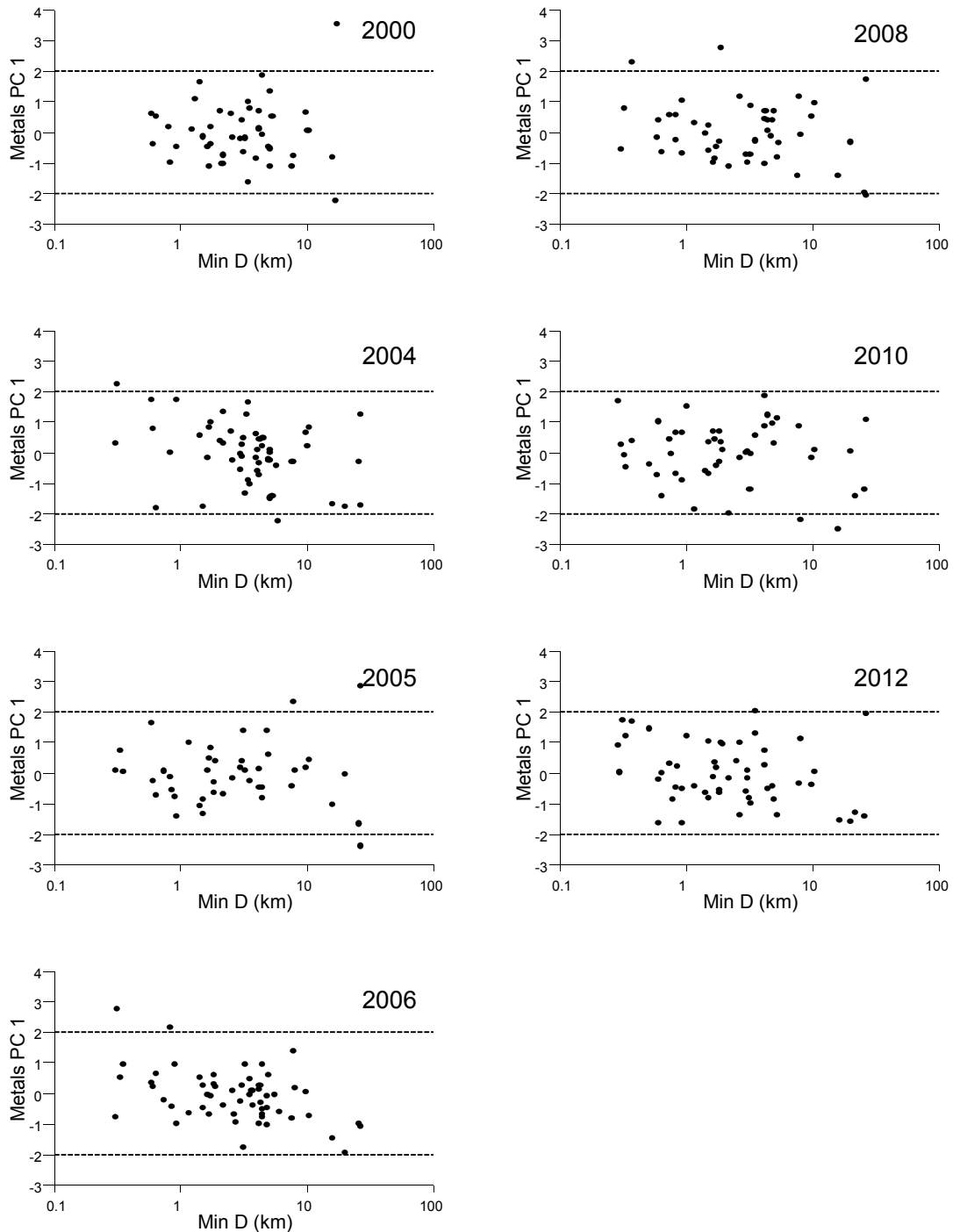


**Figure 5-28      Variations in Metals PC1 Scores with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background PC1 scores are indicated by a horizontal line, based on the mean values ± 2 SDs using data from 2000.

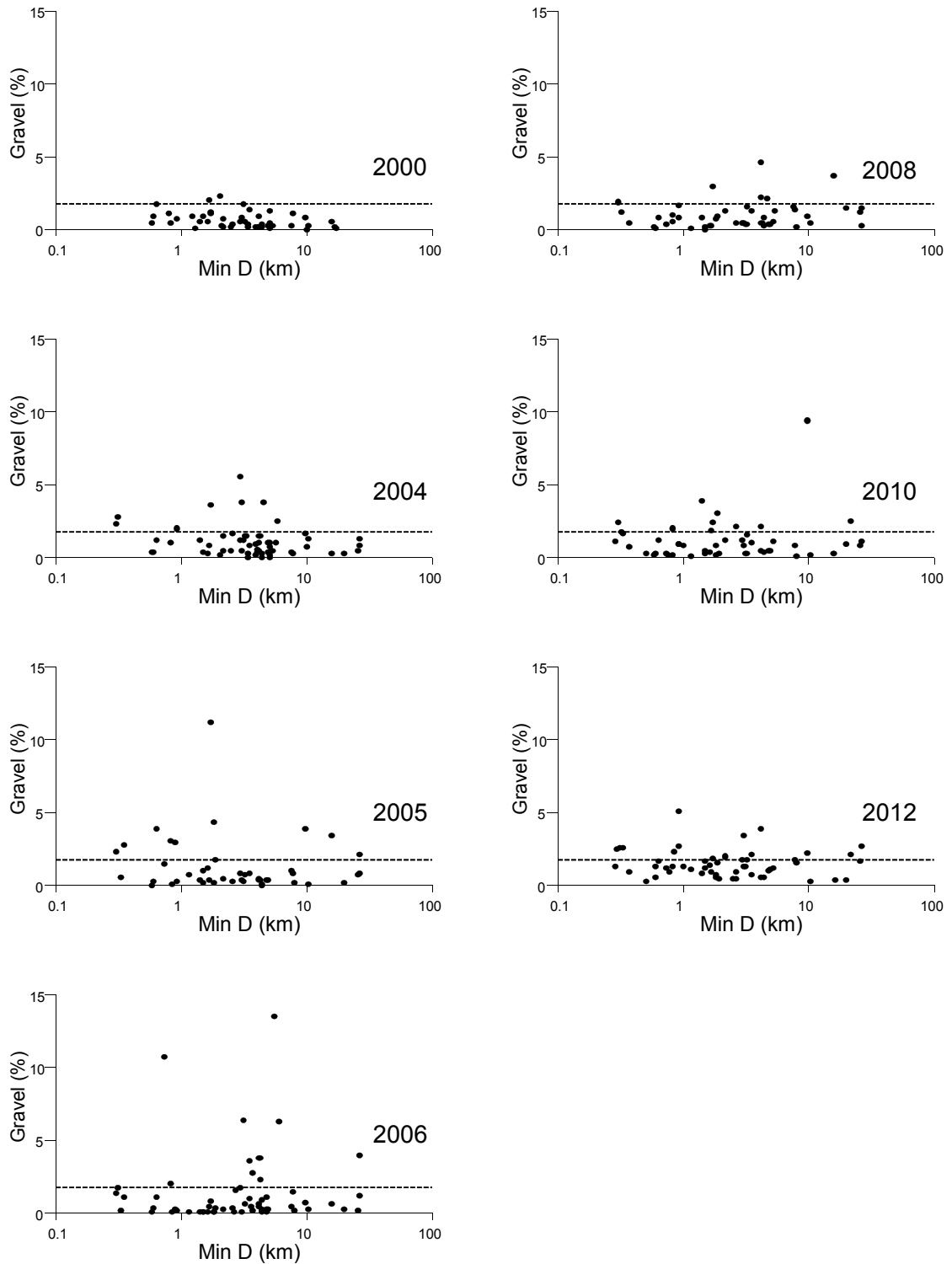Repeated-measures regression (Table 5-15) indicated that there was no change in the slope of the relationship between Metals PC1 scores and distance to the nearest active drill centre over the active drilling period ($p$ = 0.564), and no change in the slope from before to after drilling began ($p$ = 0.520). There were also no significant variations in the average PC1 axis scores in the overall sampling area, including a significant linear trend over time (increase) during the drilling period ($p$ = 0.487), and no difference from before drilling to after ($p$ = 0.431).

**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** |
| 0.564 | 0.487 | 0.520 | 0.431 |

Notes:  -    Values are probabilities.
-    *n* = 35 with station 31 excluded.
-    The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
-    The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

The scatterplot of Metals PC1 scores (Figure 5-28) illustrated that metals concentrations have not strongly covaried with distance from the nearest active drill centre across years and have not varied in mean concentration since the baseline year (2000).

The dot density graph of scores (Figure 5-29) further illustrated that Metals PC1 scores were consistent across years, with scores in 2012 within the baseline range of variation for scores in 2000.
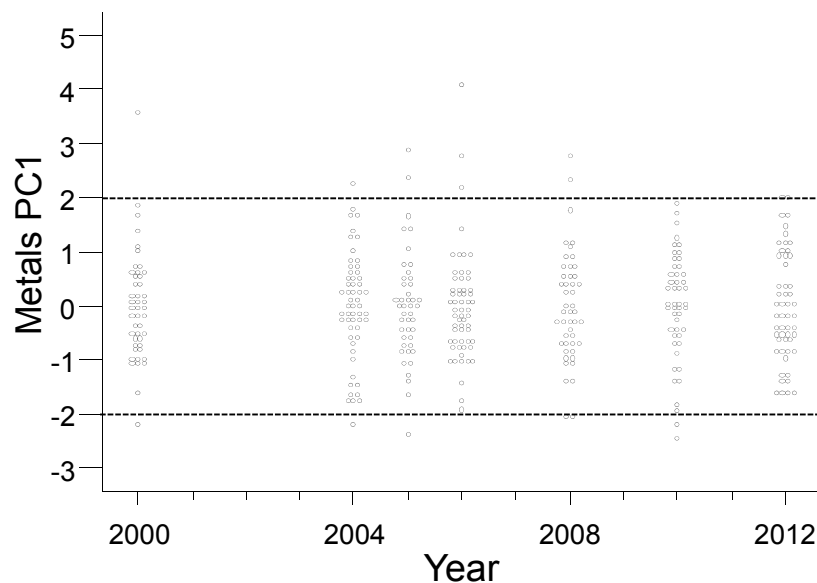


**Figure 5-29      Dot Density Plot of Metals PC1 Scores by Year**

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

**Lead**

Lead concentrations in sediments were negatively correlated with distance to the nearest active drill centre in 2012, similar to what was observed in 2006 and 2008 (Figure 5-30). The relationships between lead concentrations and Min D are illustrated in Figure 5-31. A threshold distance explained significant variation in the distance relationship in each of the surveys from 2006 to 2012 (Appendix B-5), with the threshold distance typically near 1 km. The threshold distance decreased consistently from 2006 (1.5 km) to 2012 (0.6 km) (Table 5-16).
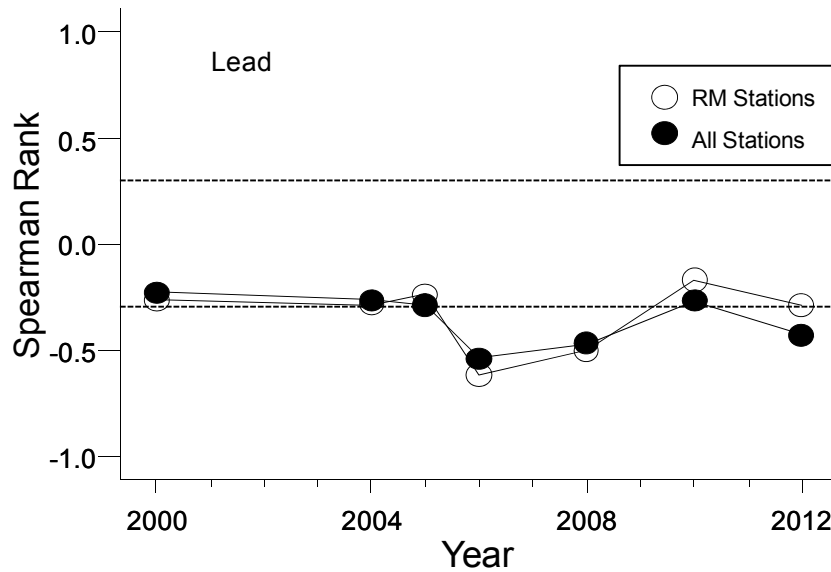


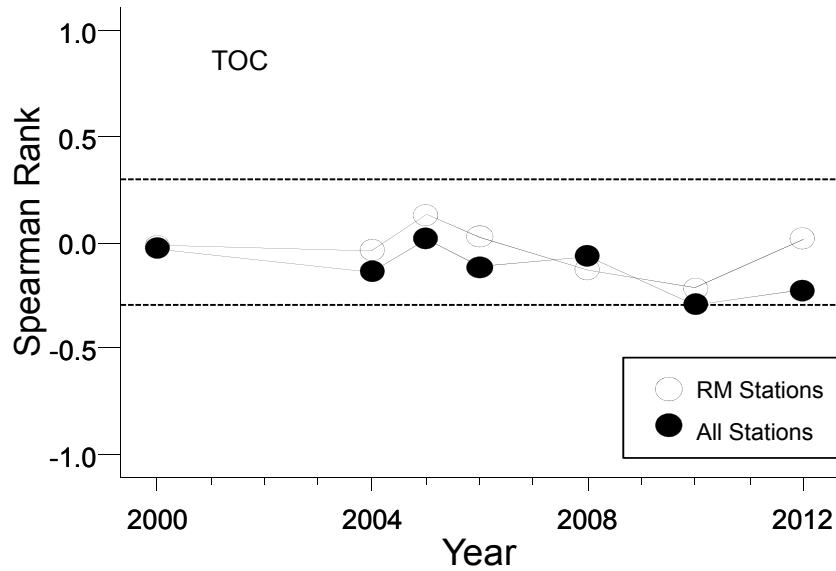**Figure 5-30    Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Lead**

Notes:  Station 31 was excluded. $n$ = 52 for All Stations. $n$ = 35 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p$ < 0.01, depending on sample size in the given year.
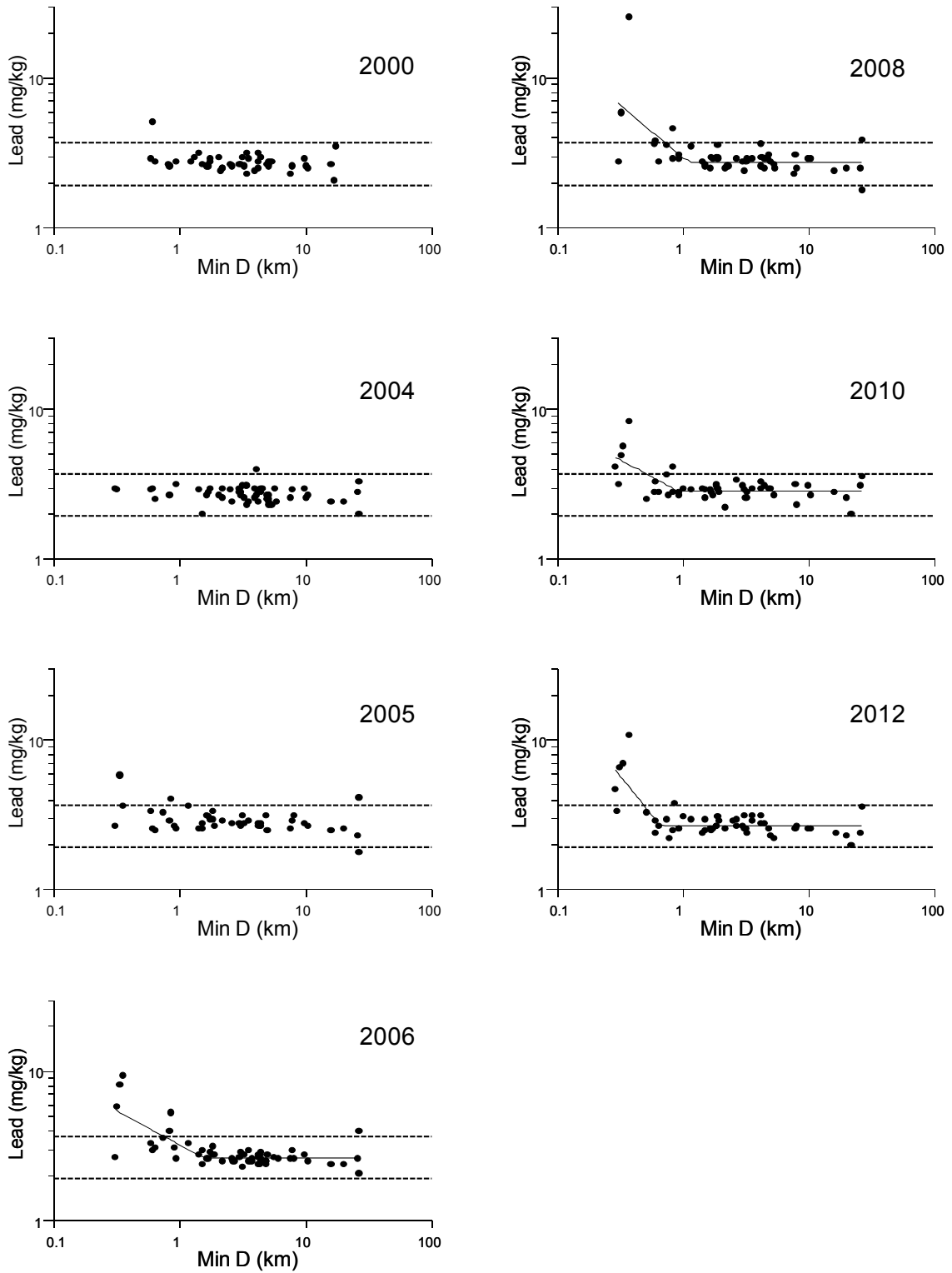
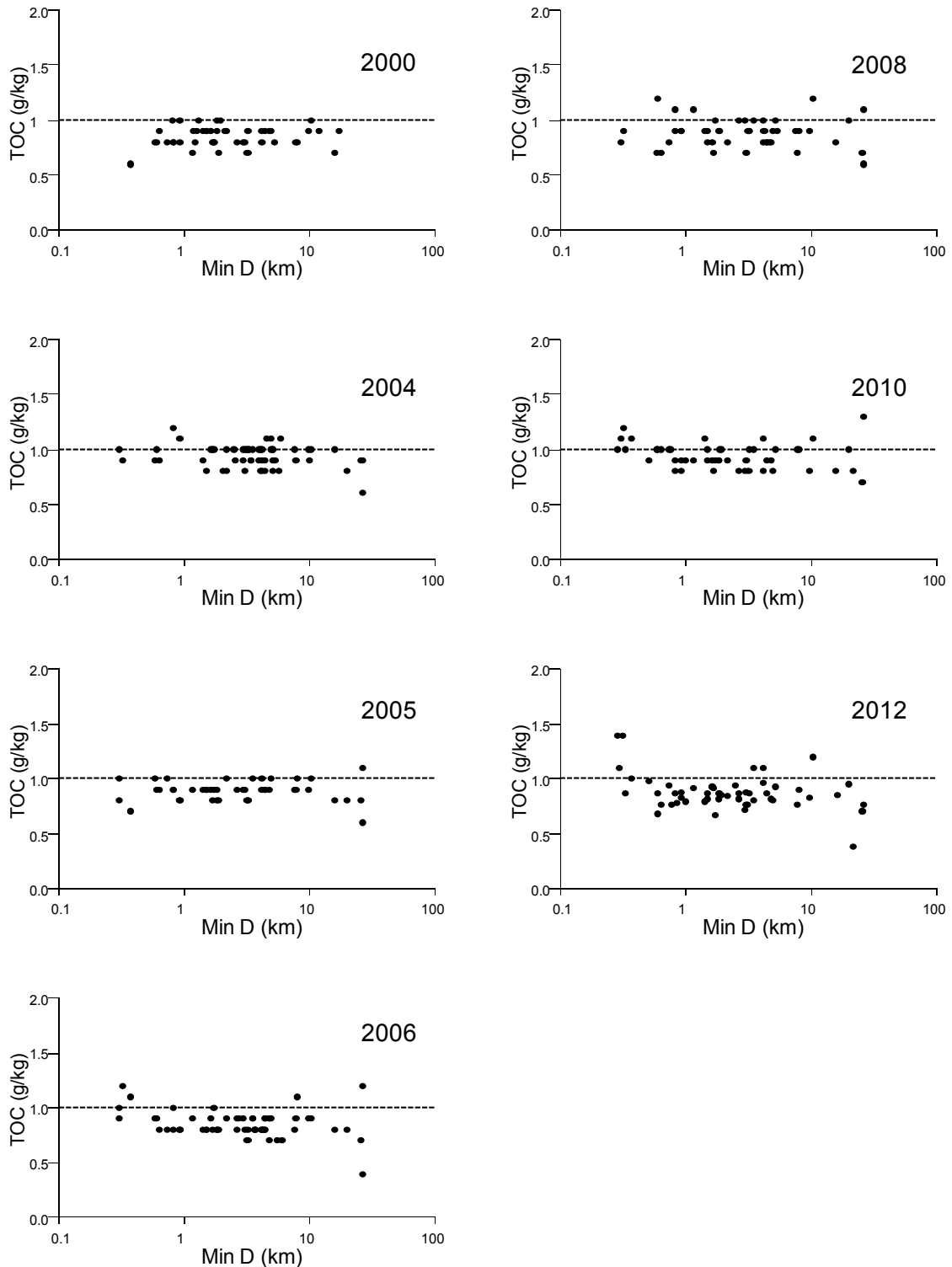**Figure 5-31**      **Variations in Lead with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background lead concentrations are indicated by a horizontal line, based on the mean values ± 2 SDs using data from 2000.

**Table 5-16    Results of Threshold Regressions on Distance from the Nearest Active Drill Centre for Lead**

| Year | Threshold Distance |
|---|---|
| 2004 | No threshold |
| 2005 | No threshold |
| 2006 | 1.5 (1.0, 2.3) |
| 2008 | 1.1 (0.7, 1.7) |
| 2010 | 0.9 (0.6, 1.4) |
| 2012 | 0.6 (0.5, 0.8) |

Notes:  -    95% confidence limits are provided in brackets.
-    *n* = 52 in 2012 with station 31 excluded.

Repeated-measures regression (Table 5-17) demonstrated that slope of the relationship between lead concentration in sediment and distance to the nearest active drill centre varied linearly during the drilling period ($p$ = 0.039; *i.e.*, became steeper), but did not vary significantly from before to after drilling ($p$ = 0.096). The mean lead concentration in the sampling area varied linearly during the drilling period ($p$ = 0.035, increasing), and was generally higher in the drilling period than the baseline period ($p$ = 0.044). The dot-density plot in Figure 5-32 illustrates that the central tendency for lead concentrations remained similar from survey to survey, but there were an increasing number of stations (near active drill centres) that had high concentrations of lead relative to the baseline range, during the period from about 2005 to 2012.

**Table 5-17    Repeated-measures Regression Testing for Changes in Lead over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.039 | 0.035 | 0.096 | 0.044 |

Notes:  -    Values are probabilities.
-    *n* = 35 with station 31 excluded.
-    The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
-    The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.
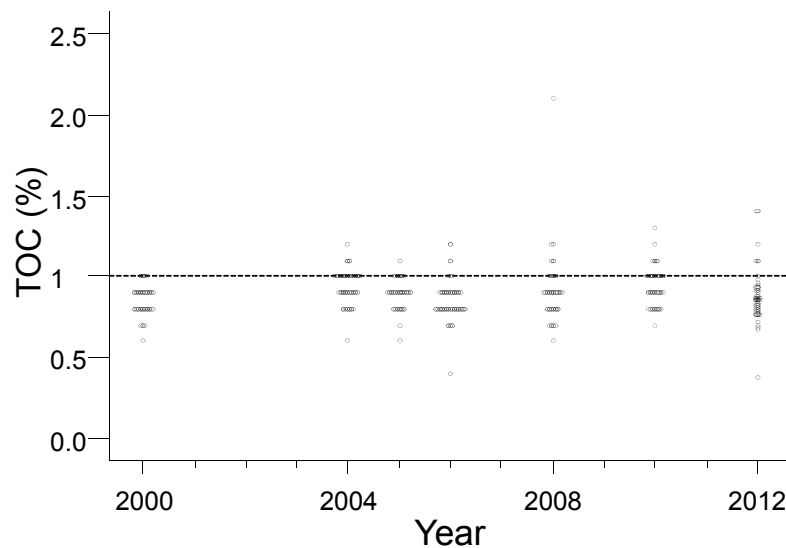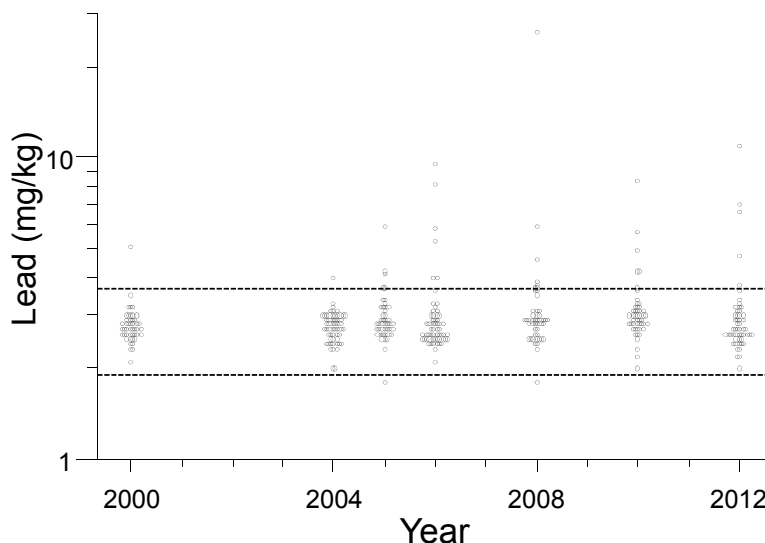


**Figure 5-32    Dot Density Plot of Lead by Year**

Note: Background concentrations are indicated by the horizontal lines, based on the mean value ± 2 SDs using data from 2000.

**Strontium**

Strontium concentrations in sediments were significantly negatively correlated with distance to the nearest active drill centre in 2012, similar to what was observed in 2004, 2006, 2008 and 2010 (for All Stations) (Figure 5-33). A threshold distance explained a significant amount of variation in strontium concentrations in 2012, as it did in 2008 and 2006 (Appendix B-5). The threshold distance in 2012 was 0.6 km, compared to 1.6 km in 2008 and 1.2 km in 2006 (Table 5-18). Threshold relationships are illustrated in Figure 5-34.
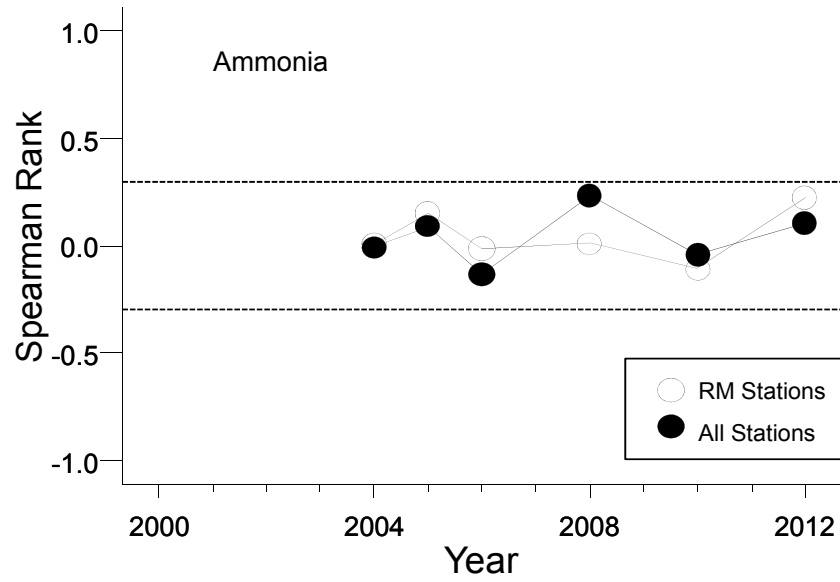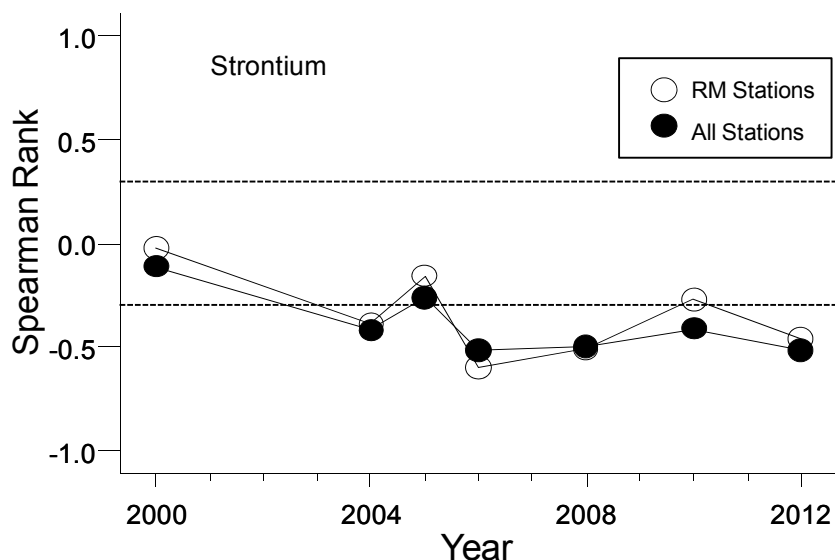


**Figure 5-33      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Strontium**

Notes: Station 31 was excluded. *n* = 52 for All Stations *n* = 35 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at *p* < 0.01, depending on sample size in the given year.

**Table 5-18      Results of Threshold Regressions on Distance from the Nearest Active Drill Centre for Strontium**

| Year | Threshold Distance |
|---|---|
| 2004 | No threshold |
| 2005 | No threshold |
| 2006 | 1.2 (0.7, 1.8) |
| 2008 | 1.6 (0.7, 3.6) |
| 2010 | No threshold |
| 2012 | 0.6 (0.5, 0.9) |

Notes:   -    95% confidence limits are provided in brackets.
         -    *n* = 52 in 2012 with station 31 excluded.

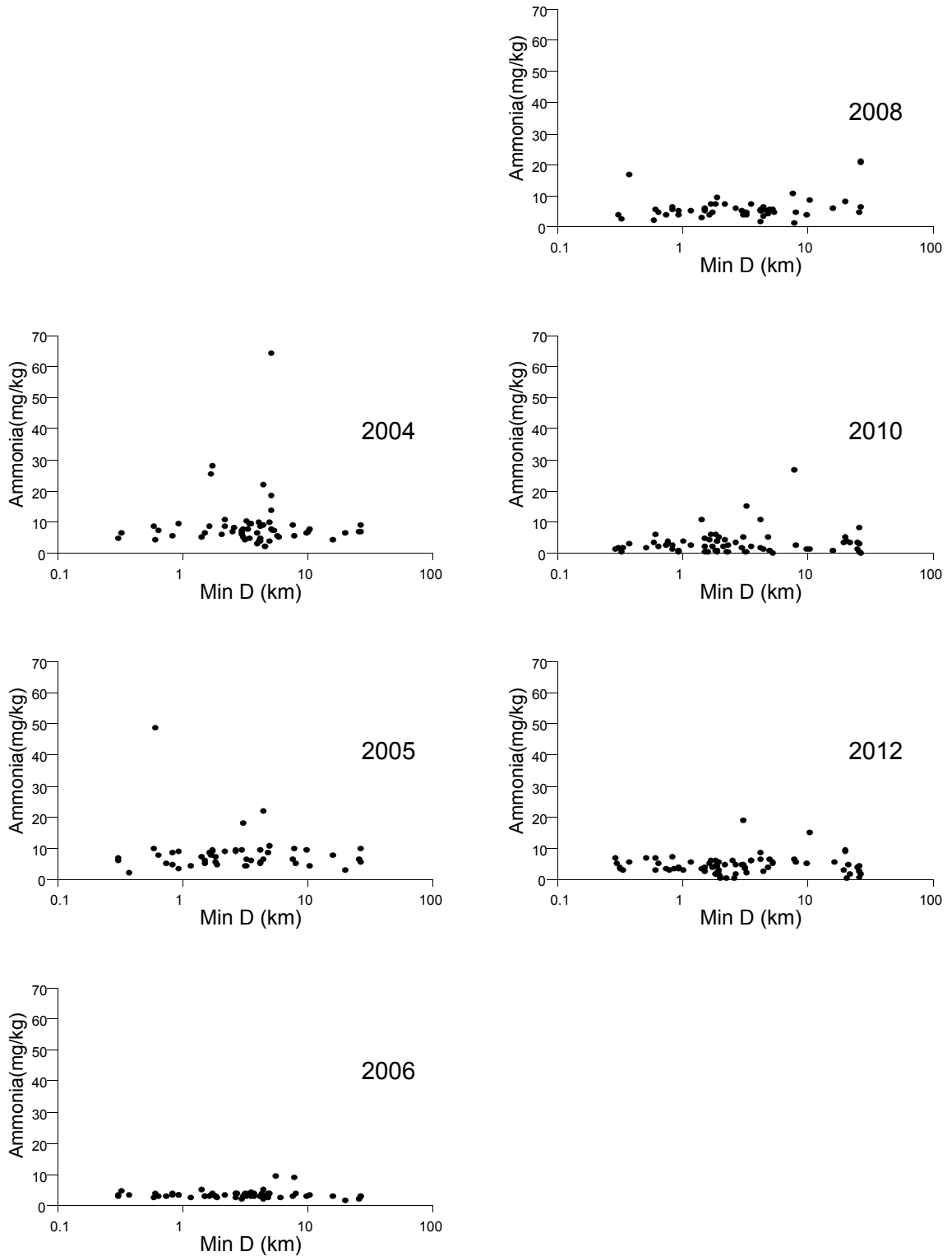**Figure 5-34     Variations in Strontium with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background strontium concentrations are indicated by a horizontal line, based on the mean values ± 2 SDs using data from 2000.

Repeated-measures regression (Table 5-19) demonstrated that the slope of the relationship between strontium concentration in sediment and distance to the nearest active drill centre varied linearly during the drilling period (*p* = 0.040; *i.e.*, became steeper), and also varied significantly from before to after drilling (*p* = 0.006). The mean strontium concentration in the sampling area varied linearly during the drilling period (*p* = 0.008, increasing), and was generally higher in the drilling period than the baseline period (*p* < 0.001). The dot-density plot in Figure 5-35 illustrates that the central tendency for strontium concentrations remained similar from survey to survey, but there were an increasing number of stations (near active drill centres) that had high concentrations of strontium relative to the baseline range, during the period from 2005 to 2012.

**Table 5-19     Repeated-measures Regression Testing for Changes in Strontium over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.040 | 0.008 | 0.006 | <0.001 |

Notes:  -   Values are probabilities.
        -   *n* = 35 with station 31 excluded.
        -   The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
        -   The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.
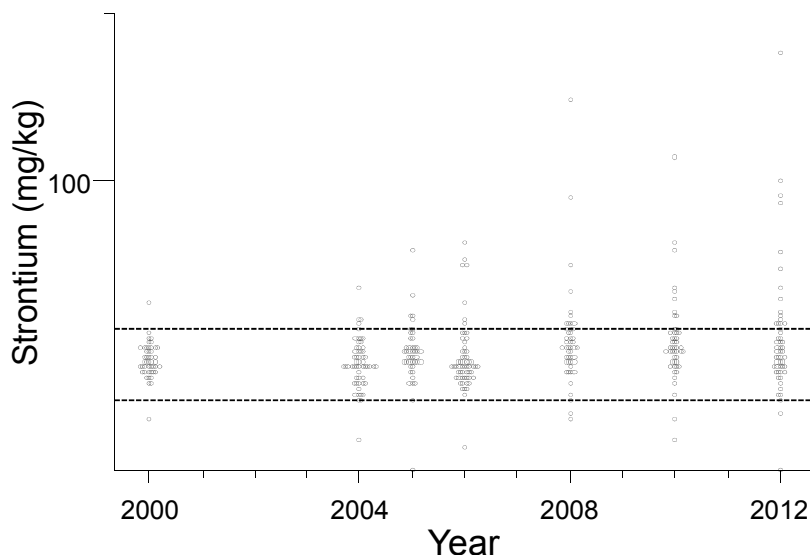


**Figure 5-35     Dot Density Plot of Strontium by Year**

Note: Background concentrations are indicated by the horizontal lines, based on the mean value ± 2 SDs using data from 2000.

## 5.2.1.9  Redox Potential

Redox potential varied between 110 and 390 mV in 2012, and did not significantly correlate with distance from the nearest active drill centre (Figure 5-36). Figure 5-37

provides a graphical representation of the relationship between redox potential and distance to nearest active drill centres.
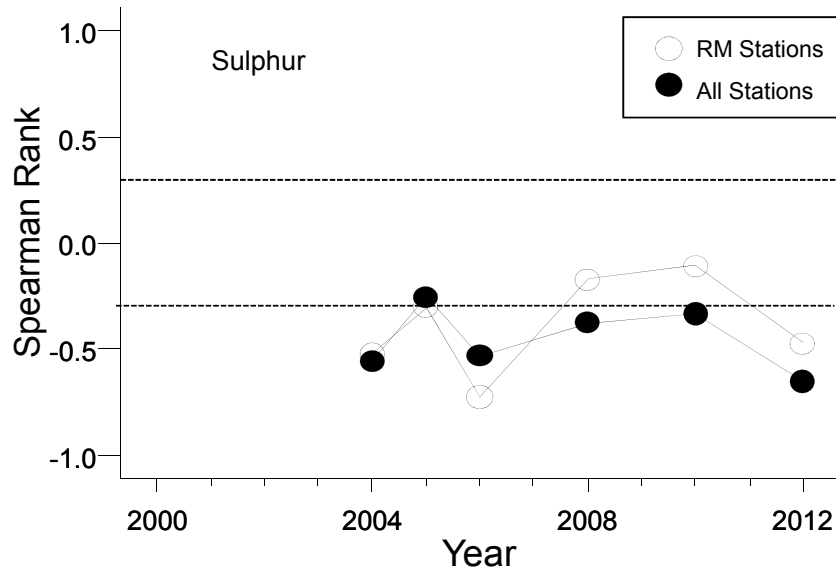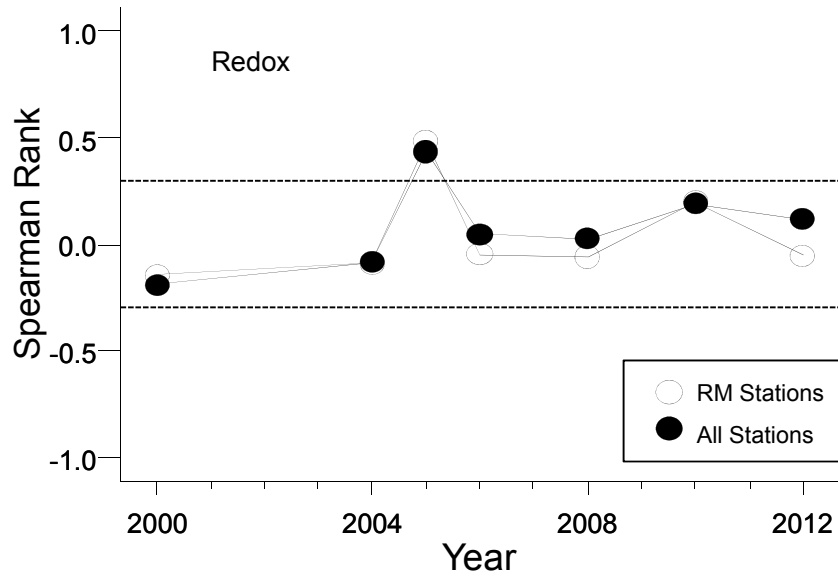


**Figure 5-36      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Redox Potential**

Notes: Station 31 was excluded. $n$ = 52 for All Stations. $n$ = 35 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year.
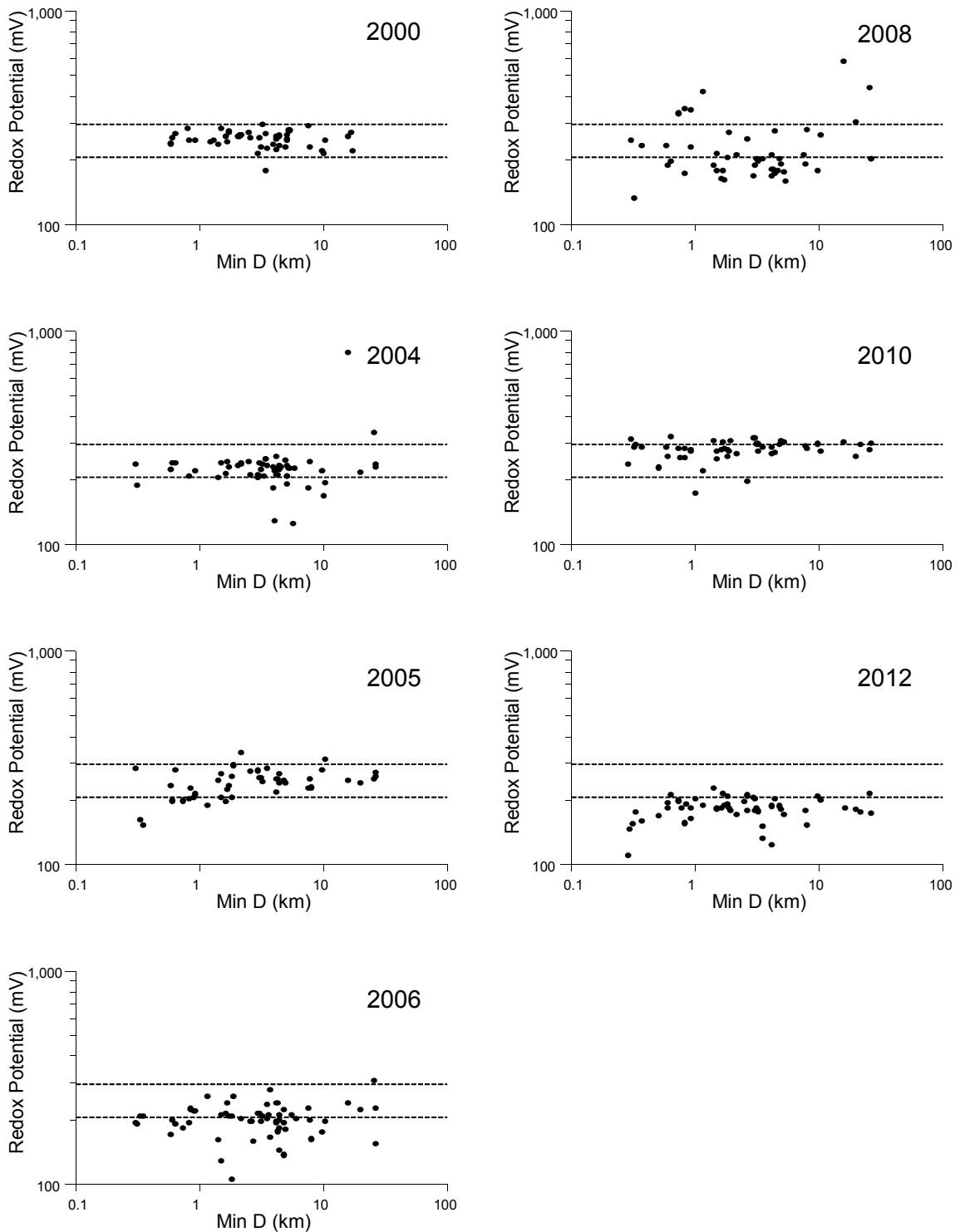
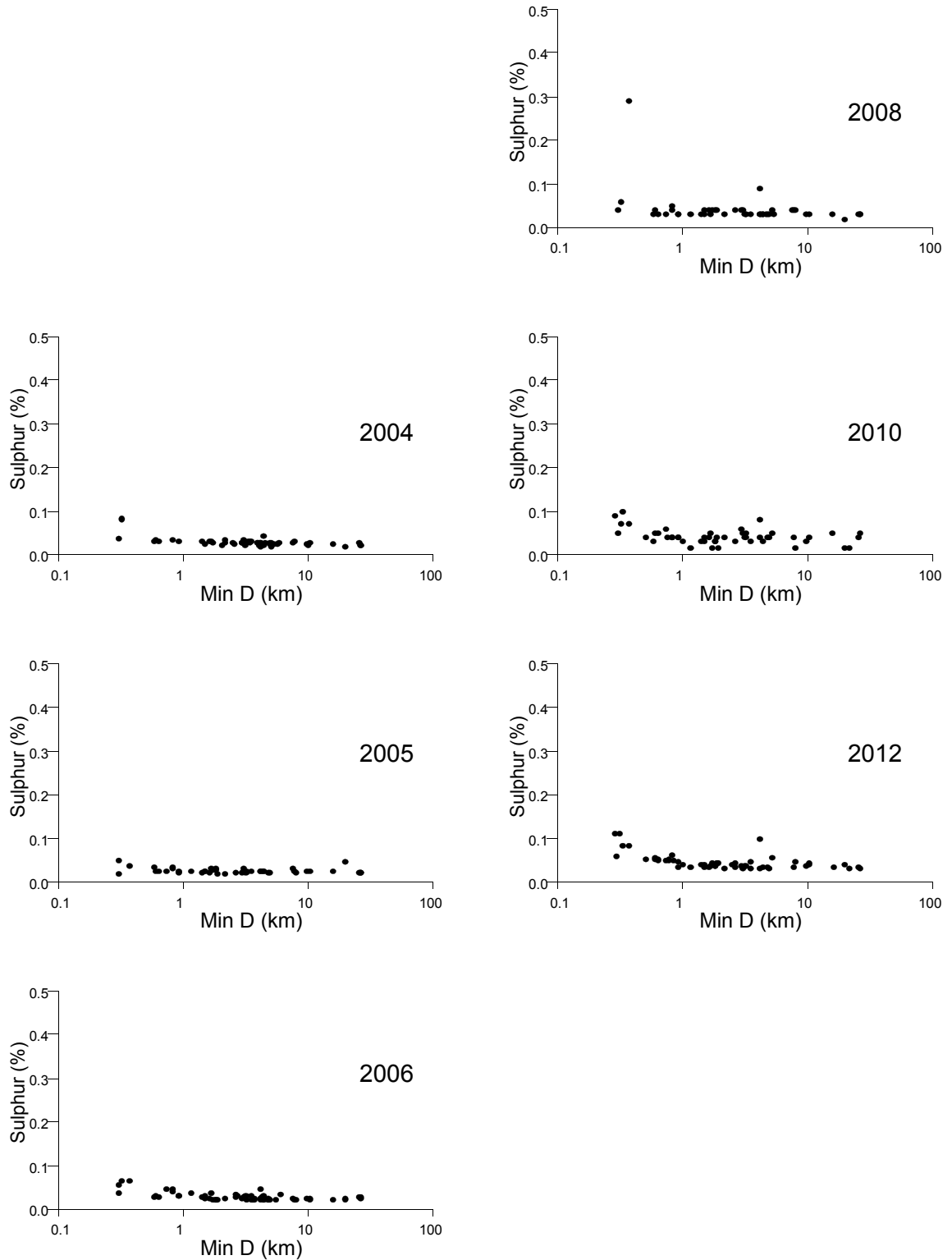**Figure 5-37        Variations in Redox Potential with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background redox potential levels are indicated by a horizontal line, based on the mean values ± 2 SDs using data from 2000.

Repeated-measures regression (Table 5-20) indicated that there was a weakly significant ($p$ = 0.034) change (increase) in the slope of the relationship between redox potential and distance to the nearest active drill centre during drilling years. However, there was no significant linear trend over time in the average redox potential across the sampling area ($p$ = 0.462), and no difference in the slope from before to after drilling.

**Table 5-20**      **Repeated-measures Regression Testing for Changes in Redox Potential over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.034 | 0.462 | 0.418 | <0.001 |

Notes: 
- Values are probabilities.
- $n$ = 35 with station 31 excluded.
- The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

The scatterplot of redox potential (Figure 5-37) illustrated that redox potential did not vary strongly with distance from active drill centres across years. There were modest tendencies for redox potential to be greater at stations further from the nearest active drill centre, and for that tendency to increase over time. That condition led to the significant linear trend over time in the slope identified in Table 5-20.

The dot density graph (Figure 5-38) illustrated that redox values were generally lower in 2012 than in 2010, and lower in 2012 than in the baseline period (year 2000). However, all sediments since baseline have been oxic.
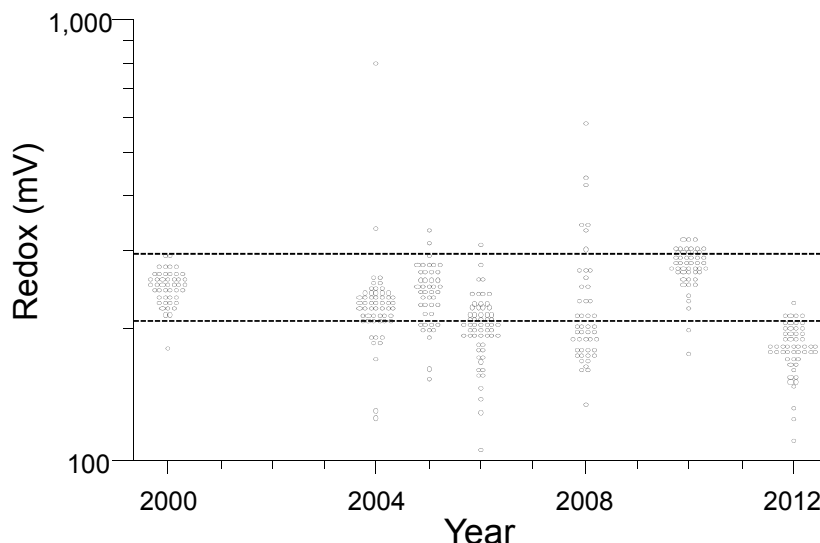


**Figure 5-38**      **Dot Density Plot of Redox Potential by Year**

Note: Background concentrations are indicated by the horizontal lines, based on the mean value ± 2 SDs using data from 2000.

### 5.2.2  Toxicity

In 2012, all samples tested for Microtox toxicity were non-toxic. Full test results for 2012 are provided in Appendix B-6.

Amphipod survival was 70% for all but one sample, and survival was generally greater than 80%. Survival greater than 70% is considered non-toxic. The only sample classified as "toxic" to amphipods was that from station N3, which was 0.6 km from the Northern Drill Centre.

Percent survival in 2012 was uncorrelated with all assessed variables with the exception of percent fines: survival increased with increasing percent fines in the sediment ($r_s$ = 0.40, $p$ < 0.01; Table 5-21).

The 2012 data, compared to toxicity data from prior years, suggest little change over time. Variation in amphipod survival was somewhat higher in 2005, 2006 and 2008, and was similar in 2012 to what was observed in 2000, 2004 and 2010 (Figure 5-39).

**Table 5-21      Spearman Rank Correlations ($r_s$) Between Amphipod Survival *versus* Distance from the Nearest Active Drill Centre and Sediment Physical and Chemical Characteristics (2012)**

| Variable | Spearman Rank Correlation ($r_S$) with Amphipod Survival |
|---|---|
| Distance from nearest active drill centre | -0.047 |
| >$C_{10}$–$C_{21}$ hydrocarbons | 0.173 |
| Barium | 0.044 |
| % Fines | **0.404\*\*** |
| % Gravel | -0.100 |
| TOC | 0.145 |
| Metals PC1 | 0.201 |
| Lead | 0.145 |
| Strontium | 0.091 |
| Ammonia | 0.065 |
| Sulphur | 0.079 |

Notes:  -   $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (**in bold**).
        -   $n$ = 53 stations.
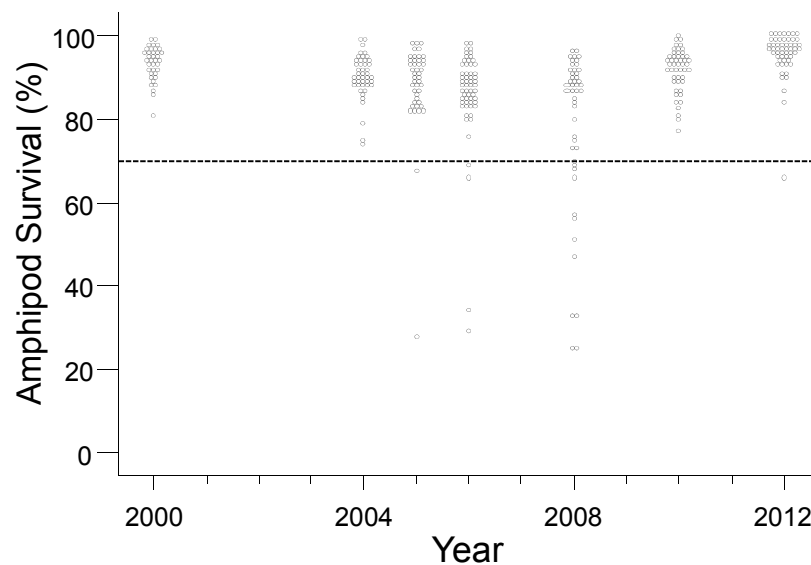
**Figure 5-39**      **Dot Density Plot of Laboratory Amphipod Survival by Year**

Note: The horizontal line denotes 70% survival. Values above 70% indicate a non-toxic response.

### 5.2.3 Benthic Community Structure

#### 5.2.3.1 General Composition

Raw data for benthic community structure in 2012 are provided in Appendix B-4. A total of 160 taxa, from 82 families, were identified from 106 samples collected from 53 stations in 2012. As in prior years, Polychaeta were numerically dominant, accounting for 79% of total numbers, while Bivalvia (12%), Amphipoda (3%) and Isopoda (3%) were sub-dominant numerically, and Cnidaria, Gastropoda, Cirrepedia, Cumacea, Decapoda, Echinodermata, Hemichordata and Urochordata were found in trace numbers (1% or less).

Table 5-22 lists all families (and their associated higher taxonomic classifications) that represented 1% or more of the total number of organisms collected in all sample years. Polychaetes in the family Spionidae (primarily *Prionospio steenstrupi* and several *Spio* species) were the most abundant (dominant) family in 2012, as in prior years. Bivalves were dominated by the family Tellinidae (primarily *Macoma calcarea*) in 2012, again as in prior years.

**Table 5-22**　　　**Relative Abundance of Dominant Benthic Invertebrates Major Groups**

| Major Taxon | Class or Order | Family | Year | | |
|---|---|---|---|---|---|
| | | | 2000 | 2004 to 2010 | 2012 |
| Porifera | | | | <1 | |
| Cnidaria | | | <1 | <1 | <1 |
| Annelida | Polychaeta | Total | 77 | 72 to 81 | 79 |
| | | Maldanidae | 1 | 2 | 2 |
| | | Orbiniidae | 5 | 4 to 6 | 6 |
| | | Paraonidae | 15 | 10 to 21 | 16 |
| | | Phyllodocidae | 3 | 3 to 6 | 3 |
| | | Spionidae | 37 | 36 to 48 | 35 |
| | | Syllidae | 1 | 1 to 2 | 1 |
| | | Capitellidae | 1 | 1 to 2 | 1 |
| | | Cirratulidae | 13 | 1 to 2 | 1 |
| Mollusca | Bivalvia | Total | 17 | 12 to 18 | 12 |
| | | Tellinidae | 13 | 11 to 16 | 10 |
| | Gastropoda | | <1 | <1 to 1 | 1 |
| Crustacea | | Total | 4 | 5 to 7 | 7 |
| | | Amphipoda | 3 | 2 to 3 | 3 |
| | Isopoda | Total | 1 | 2 to 4 | 3 |
| | | Tanaidacea | 1 | 2 to 3 | 3 |
| | Cirrepedia | | <1 | <1 | <1 |
| | Cumacea | | <1 | <1 | <1 |
| | Decapoda | | <1 | 0 to <1 | <1 |
| Echinodermata | | | 1 | 1 to 2 | 1 |
| Hemichordata | | | | 0 to <1 | <1 |
| Urochordata | | | | 0 to <1 | |

### 5.2.3.2　Correlations with Sediment Physical and Chemical Characteristics

In 2012, none of the indices of benthic community composition were related to percent of substrate as fines (% fines), gravel (% gravel), TOC, metals PC1, ammonia, redox potential, amphipod survival (laboratory test) or water depth (Table 5-23). However, there were a variety of significant correlations between indices of benthic community composition and other environmental descriptors. Concentrations of barium and $>C_{10}$-$C_{21}$ hydrocarbons, and distance to the nearest active drill centre were associated with total benthic abundance, total benthic biomass and numbers of Paraonidae polychaetes. Total abundances and biomass, and abundances of Paraonidae were inversely correlated with concentrations of barium and $>C_{10}$-$C_{21}$ hydrocarbons. Those same correlations were statistically significant in 2010, and reflected consistent relationships over the last two surveys. Higher concentrations of sulphur and, to a lesser extent strontium, in sediments also tended to co-occur with lower biomass and lower abundances of Paraonidae. Paraonidae abundance was also negatively correlated with concentrations of lead. The number of families (*i.e.*, richness), as well as abundances of Spionidae polychaetes, Tellinidae and Amphipoda did not correlate with any of the physical/ chemical descriptors in Table 5-23.

**Table 5-23    Spearman Rank ($r_S$) Correlations of Indices of Benthic Community Composition with Environmental Descriptors (2012)**

| Environmental Descriptor | Index of Invertebrate Community Composition | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Total Abundance | Biomass | Richness | Paraonidae Abundance | Spionidae Abundance | Tellinidae Abundance | Amphipoda Abundance | BC |
| % Fines | 0.039 | -0.109 | -0.171 | -0.269 | 0.090 | -0.037 | -0.003 | 0.109 |
| % Gravel | -0.082 | 0.010 | 0.192 | -0.260 | -0.099 | 0.111 | 0.126 | 0.161 |
| TOC | 0.211 | -0.131 | 0.014 | -0.025 | 0.241 | 0.264 | -0.010 | -0.156 |
| >$C_{10}$-$C_{21}$ | -0.324* | **-0.458*** | -0.154 | **-0.633*** | 0.047 | -0.220 | 0.086 | 0.377** |
| Barium | -0.314* | **-0.424*** | -0.023 | **-0.674*** | 0.077 | -0.195 | 0.097 | 0.392** |
| Metals PC1 | 0.099 | -0.221 | 0.096 | -0.147 | 0.192 | 0.090 | 0.022 | -0.001 |
| Lead | -0.073 | -0.238 | 0.047 | -0.359** | 0.078 | 0.009 | 0.027 | 0.16 |
| Strontium | -0.014 | -0.293* | 0.105 | -0.308* | 0.201 | -0.03 | 0.047 | 0.093 |
| Sulphur | -0.189 | **-0.481*** | -0.136 | **-0.49***  | 0.023 | -0.009 | -0.022 | 0.293* |
| Redox Potential | -0.020 | 0.088 | 0.217 | 0.152 | -0.027 | -0.186 | -0.041 | -0.042 |
| Distance to nearest active drill centre | **0.468*** | 0.426** | 0.204 | **0.677*** | 0.093 | 0.262 | 0.000 | **-0.519*** |
| Laboratory Amphipod survival | 0.157 | -0.109 | 0.114 | 0.021 | 0.127 | 0.096 | 0.161 | -0.117 |
| Water Depth | 0.034 | 0.153 | -0.017 | 0.184 | -0.150 | 0.232 | -0.117 | -0.15 |

Notes:  -    *$p$ < 0.05; **$p$ < 0.01; ***$p$ < 0.001 (**in bold**).

-    $n$ = 53.

-    shaded cells also produced significant correlations in the 2010 data set.

On the basis of these results, major indices of benthic community status (total abundance, biomass, richness), as well as numbers of Paraonidae polychaetes, were analyzed in greater detail in the sections that follow (Sections 5.2.3.3 to 5.2.3.6) in: 1) rank correlations to assess relationships with distance to nearest active drill centre; 2) when distance relationships were significant, threshold models to test for and quantify the distance within which effects were apparent; 3) scatterplots to visually assess distance relationships; 4) maps of occurrences above and below the baseline range to identify the potential influence of individual drill centres; and 5) repeated-measures regression as a final test for changes in distance relationships over time (before to after drilling, and trends during the drilling period). Remaining benthic community variables (Spionidae, Tellinidae and Amphipoda abundances and Bray-Curtis values) were examined with rank correlations, threshold models (when applicable), scatterplots and repeated-measures regression.

## 5.2.3.3  Total Abundance

In 2012, total abundance of all benthic invertebrates varied between approximately 500 organisms per m$^2$ to almost 4,000 per m$^2$ across the sampling area. The relationship between total abundance and distance from the nearest active drill centre was significant (Figure 5-40), but the addition of a threshold did not significantly explain additional variation in abundance (Appendix B-5). The 2010 data did produce a weakly statistically significant threshold model, which was dependent on data from one station (station 20) being included.

**Figure 5-40** **Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Benthic Abundance**

Notes: *n* = 53 for All Stations. *n* = 36 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at *p* < 0.01, depending on sample size in the given year.

As indicated in Figure 5-41, 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 5-41 and 5-42.
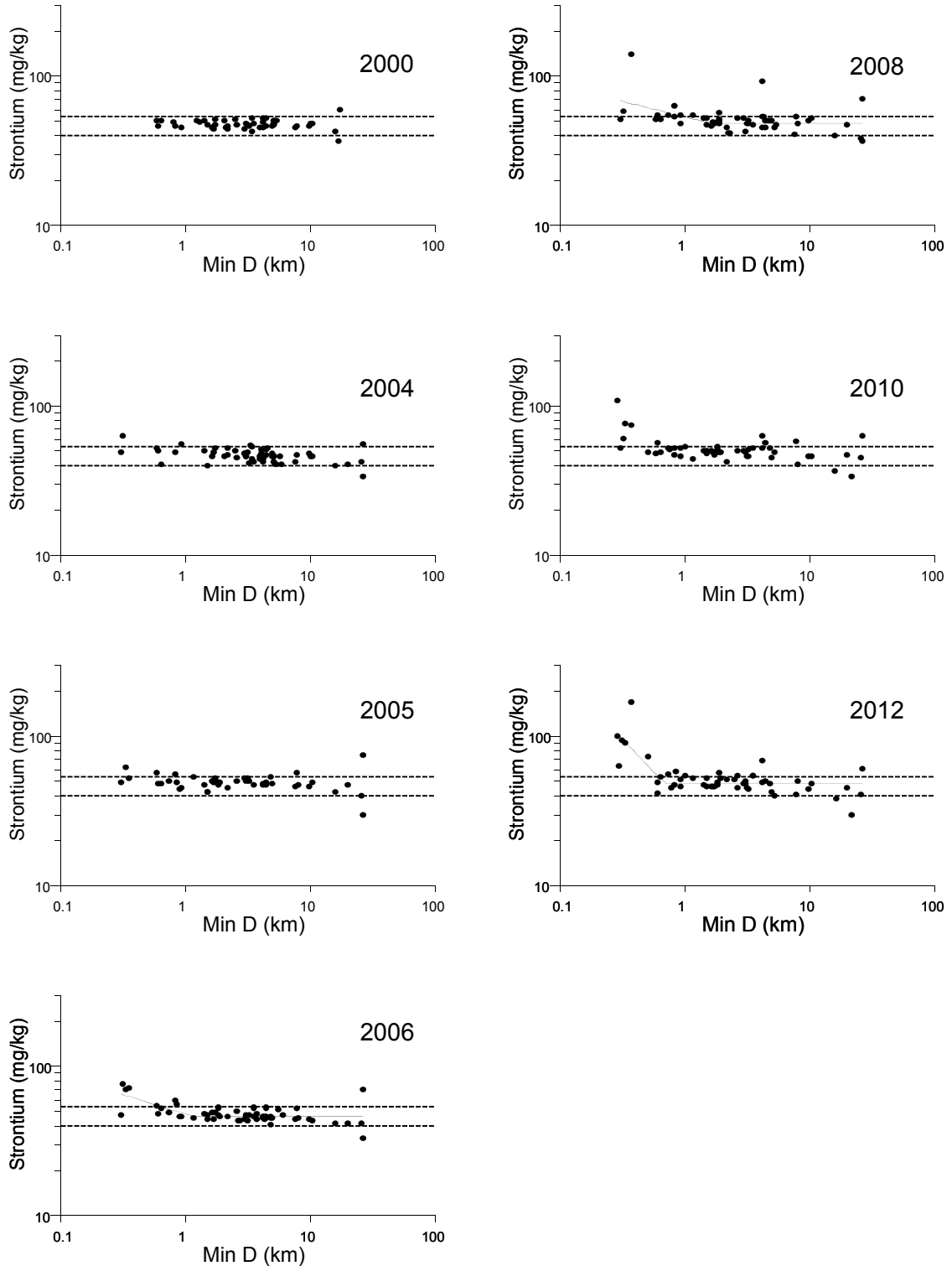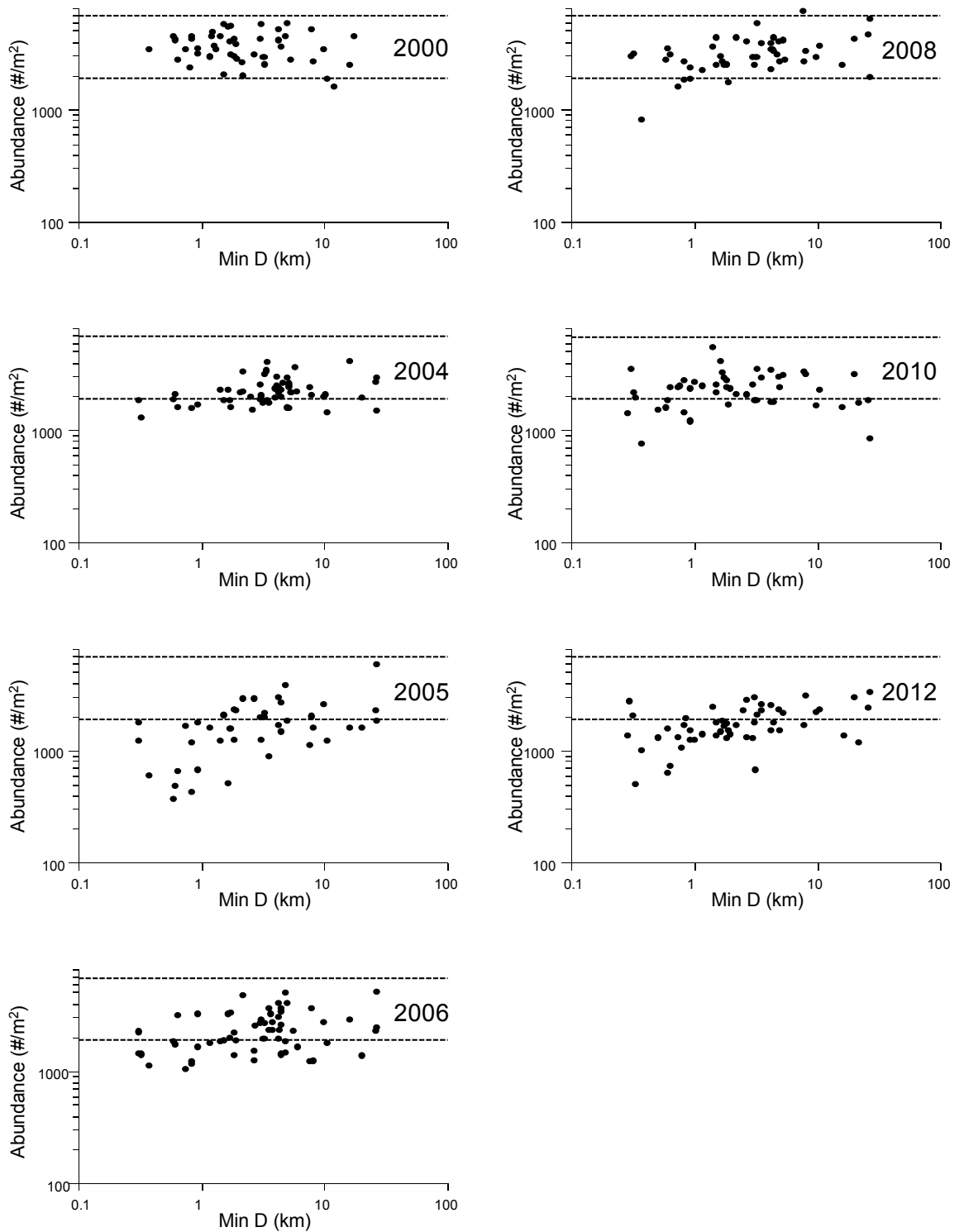
**Figure 5-41      Variation in Total Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background total abundances are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).
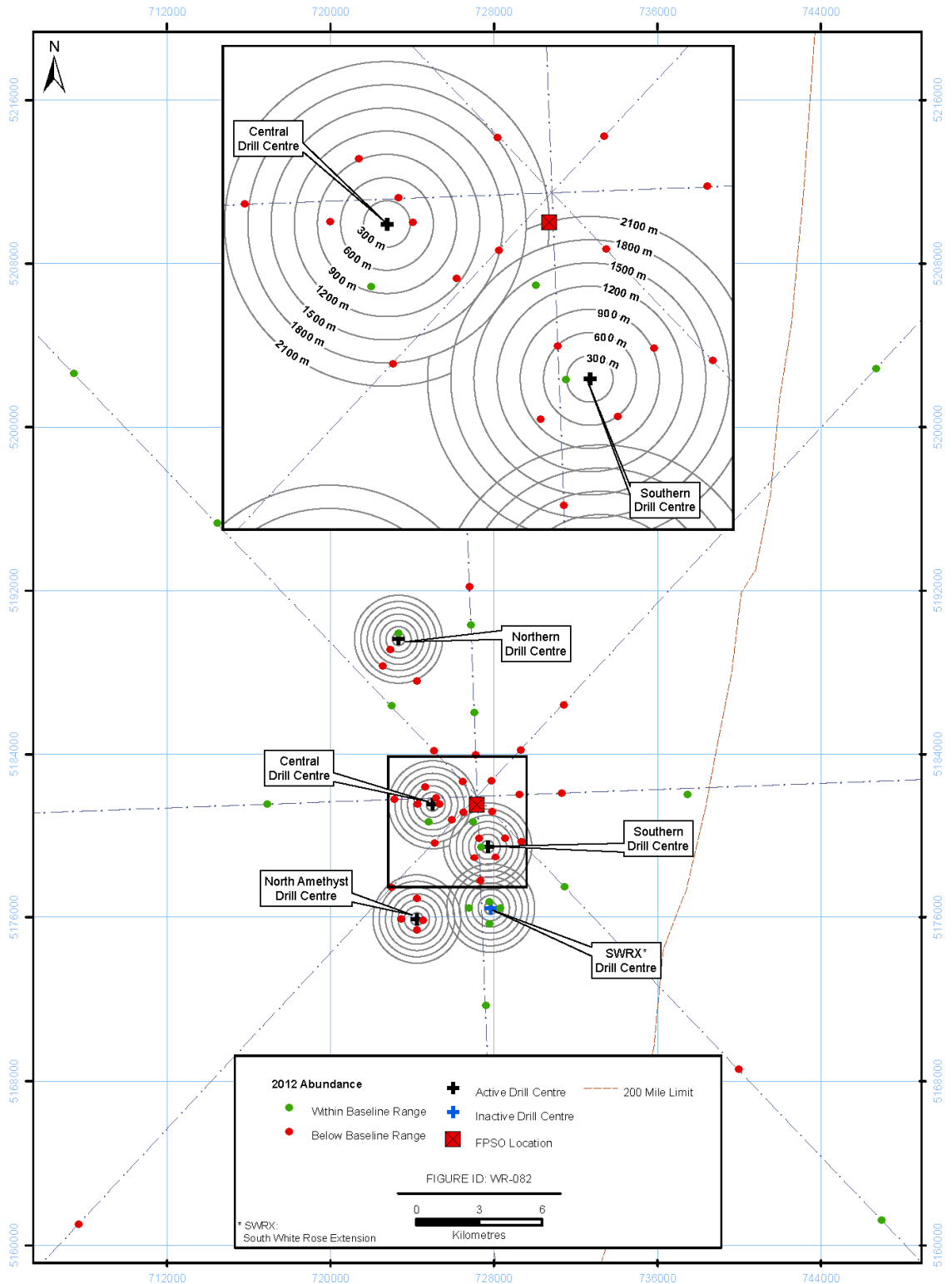
**Figure 5-42      Location of Stations with Total Abundance Values Within and Below the Baseline Range (2012)**

There was a tendency for stations near the Central, Southern and North Amethyst Drill Centres to have lower total abundance (Figure 5-42). However, many stations further away from drill centres, including the most distant stations, also showed abundances lower than the baseline range, potentially reflecting natural variations in abundance. Furthermore, the Northern Drill Centre had apparently little effect on total abundance (Figure 5-42). Therefore, the evidence of drilling-related effects on total abundance in 2012 was not strong.

In 2012, approximately 60% of stations had total abundances below the baseline range (Figure 5-43). Stations that were up to 21 km away from the nearest drill centre had total benthic abundances that were less than the lower baseline value 1,885 organisms per $m^2$ (see Figure 5-41). The range of values in 2012 was similar to what was observed in 2005, when approximately 60% of stations had abundances less than the 2000 baseline range.



**Figure 5-43      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 (Table 5-24) demonstrated that the relationship between abundance and distance from nearest active drill centre did not vary linearly over time during the drilling period (*i.e.*, years 2004 to 2012) ($p = 0.835$), but it did vary from before to after drilling ($p = 0.001$) (steeper positive slope during drilling). There was also a tendency for lower overall numbers during the drilling period ($p < 0.001$; see also Figures 5-41 and 5-43).

**Table 5-24** **Repeated-measures Regression Testing for Changes in Total Benthic Abundance over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.835 | 0.790 | 0.001 | <0.001 |

Notes: - Values are probabilities.
- $n$ = 36.
- The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

### 5.2.3.4 Total Biomass

In 2012, total biomass varied from approximately 5 to 900 g/m$^2$ near active drill centres to approximately 250 to 1,100 g/m$^2$ at stations more than 10 km from drill centres. Variations in total biomass were significantly related to distance from active drill centres in 2012 (Figure 5-44). A threshold model was also significant for 2012 data (Appendix B-5). The threshold distance was estimated to be approximately 1.5 km, ranging from 0.8 and 2.7 km (Table 5-25).



**Figure 5-44** **Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Benthic Biomass**

Notes: $n$ = 53 for All Stations. $n$ = 36 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year.

**Table 5-25** **Threshold Distances Computed from Threshold Regressions on Distance from the Nearest Active Drill Centre for Total Biomass**

| Year | Threshold Distance (km) |
|---|---|
| 2012 | 1.5 (0.8 to 2.7) |

Note: - 95% confidence limits for slopes and threshold distances provided in brackets.

Figure 5-45 provides a graphical representation of the relationship between biomass and distance from active drill centres. As indicated in Figure 5-45, the "normal range" of variation for total biomass across the sampling area was computed from the 2000 baseline data. Values ranged between 367 and 1,400 g/m$^2$ (*i.e.*, mean from year 2000 ± 2 SDs). Those values were also used to judge spatial variation in the sampling area (Figures 5-45 and 5-46).

Biomass was reduced to below the baseline range near the Central, Southern and Northern Amethyst Drill Centres. The station closest to the Northern Drill Centre had biomass below the baseline range of values, but other stations close to that drill centre had biomass values within the baseline range (Figure 5-46). Although no drilling occurred at the SWRX Drill Centre prior to 2012 sampling, the station closest to that drill centre also had biomass below the baseline range, which may indicate natural variability.

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 ($r_S$ = 0.43, *p* < 0.01), Orbiniidae polychaetes ($r_S$ = 0.42, *p* < 0.01), and Echinodermata ($r_S$ = 0.51, *p* < 0.001) were the most strongly associated with total biomass in 2012 (see Table 3-1 in Appendix B-5), similar to what was observed in 2010. Paraonidae and Orbiniidae polychaetes are generally quite small (approximately 0.0002 g per worm for Paraonidae (P. Pocklington, pers. comm.); approximately 0.001 g for Orbiniidae (Rice *et al.* 1986)), while echinoderms are much larger and heavier. The reduction in biomass near active drill centres is therefore likely associated with reductions in the numbers of echinoderms. Echinoderms have historically accounted for a small fraction of the total numbers of organisms in the sampling area (between 10 and 20 individuals per sample, or 50 to 100 individuals per m$^2$; see Figure 5-47). In 2012, however, numbers of echinoderms in samples near active drill centres were lower than in previous years, and they were absent from some stations (Figure 5-47). Members of the Echinodermata included the sand dollar *Echinarachnius parma*, and the urchin *Strongylocentrotus droebachiensis*, both of which are relatively large and heavy.
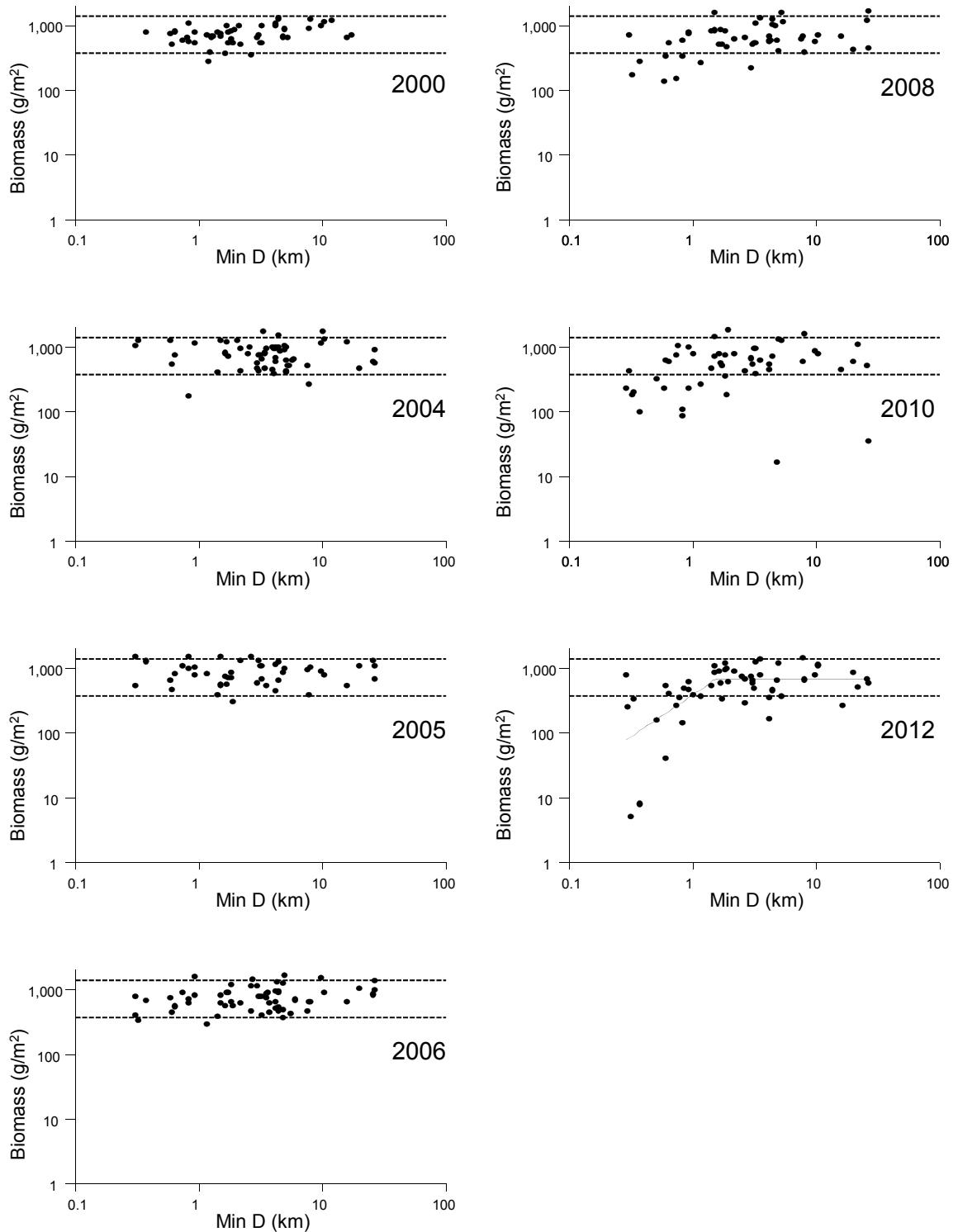
**Figure 5-45      Variation in Total Benthic Biomass (g/m$^2$) with Distance From Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background total biomass is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.
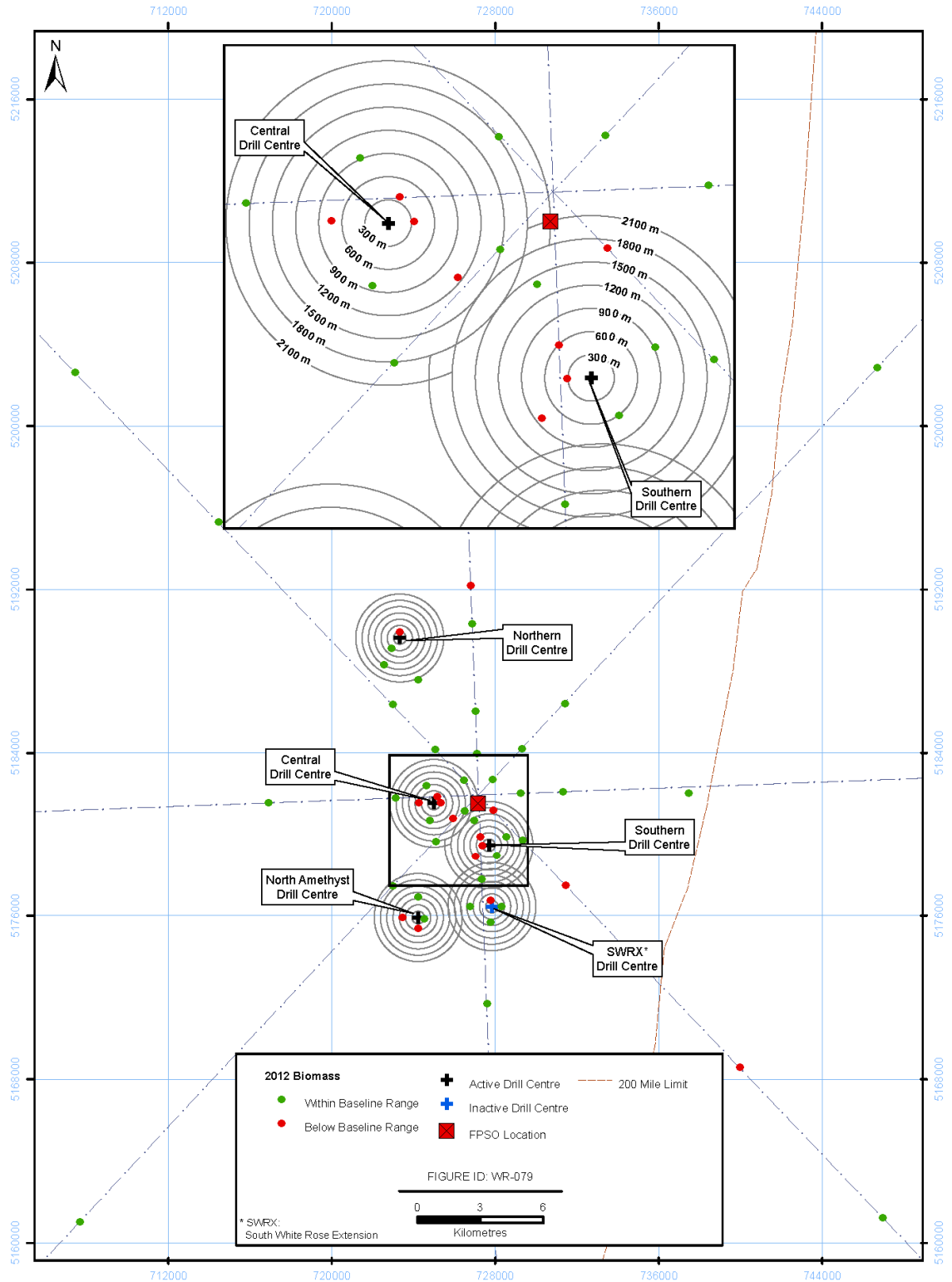
**Figure 5-46      Location of Stations with Total Biomass Values Within and Below the Baseline Range (2012)**
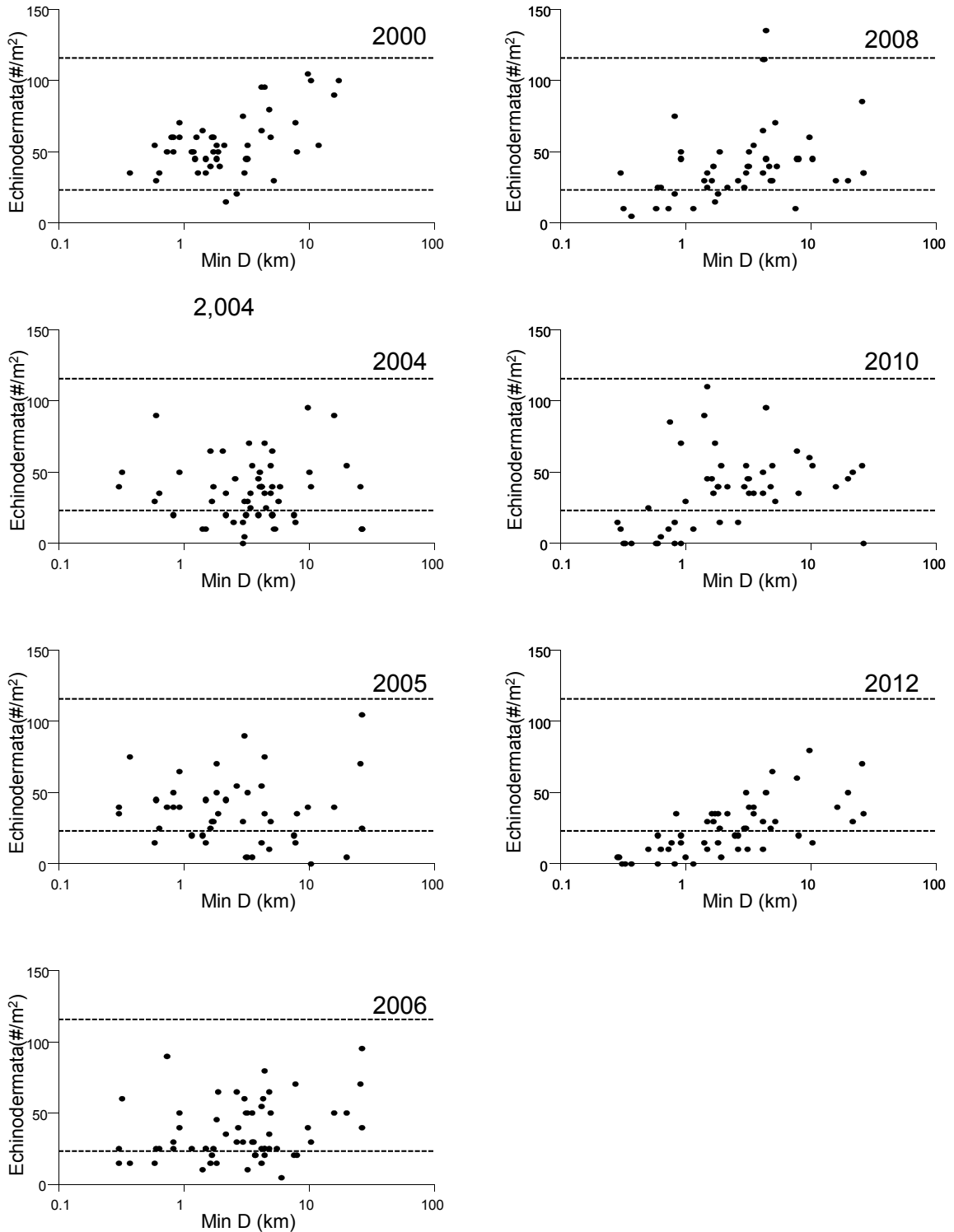
**Figure 5-47     Variation in Echinoderm Abundance (#/m$^2$) with Distance From Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background echinoderm abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.

Overall, benthic biomass in 2012 fell below the baseline range at 28% of stations, 8% more than were below the range 2010 (see Figure 5-48). Stations lacking echinoderms were generally located within approximately 1 km of an active drill centre (Figure 5-47).
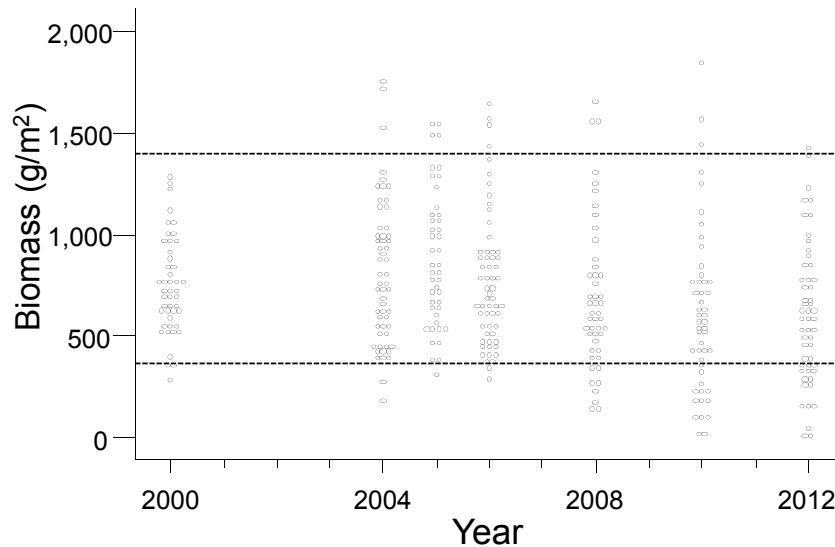


**Figure 5-48      Dot Density Plot of Total Benthic Biomass by Year**

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

Repeated-measures regression (Table 5-26) indicated that there was a significant linear trend over time in the slope of the distance relationship for biomass, becoming increasingly positive over time ($p$ = 0.032), but there was no significant difference in the slope of the relationship from before to after drilling ($p$ = 0.327). Mean biomass was greater before drilling than during drilling ($p$ = 0.014), while there was a tendency for biomass to decrease linearly over time ($p < 0.001$).

**Table 5-26      Repeated-measures Regression Testing for Changes in Total Benthic Biomass over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.032 | <0.001 | 0.327 | 0.014 |

Notes:  -   Values are probabilities.

-   *n* = 36.

-   The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).

-   The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

### 5.2.3.5  Richness

Number of families per station (*i.e.*, richness) varied between 18 and 45 in 2012, which compared well to the baseline range of between 21 and 38 families. Variation in richness in 2012 was uncorrelated with any of the physical or chemical measures assessed (Table 5-23), including distance to the nearest active drill centre (Figure 5-49). Figures 5-50 and 5-51 provide graphical representations of the relationship between richness and distance to active drill centres. Richness was reduced at the nearest stations to Southern and Central Drill Centres, but richness values at other stations around those drill centres were within baseline range.



**Figure 5-49**      **Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Taxa Richness**

Notes: *n* = 53 for All Stations. *n* = 36 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at p < 0.01, depending on sample size in any given year.

**Figure 5-50      Variation in Taxa Richness with Distance From Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background number of families is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.

**Figure 5-51     Location of Stations with Richness Values Within and Below the Baseline Range (2012)**

Repeated-measures regression (Table 5-27) indicated the slope of the relationship between number of families and distance from the nearest active drill centre has not varied over time during the drilling period ($p$ = 0.600), and has not changed significantly from before to after drilling ($p$ = 0.055). There was a significant linear trend (increase; $p$ < 0.001; see Figure 5-49) in number of families during the active drilling period of 2004 to 2012, and a generally higher number of families during the drilling period compared to the baseline year ($p$ = 0.018; see Figure 5-50).

**Table 5-27      Repeated-measures Regression Testing for Changes in Taxa Richness over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.600 | <0.001 | 0.055 | 0.018 |

Notes:  -   Values are probabilities.
-   $n$ = 36.
-   The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
-   The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

In 2012, only 6% of observations fell below the estimated limits of the baseline range (*i.e.*, below 21 families) (Figure 5-52), about the frequency expected on the basis of the calculation for the baseline 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.
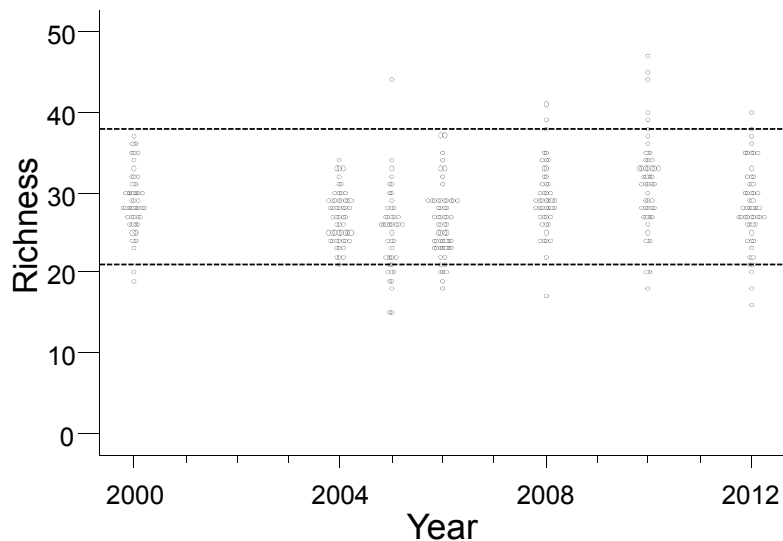


**Figure 5-52      Dot Density Plot of Taxa Richness by Year**

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

Combined, these data do not provide any evidence of project activity on richness.

### 5.2.3.6  Paraonidae Abundance

Paraonidae abundances have been strongly related to distance from active drill centres since 2005 (Figure 5-53), with abundances depressed near drill centres. Threshold models were significant for Paraonidae polychaete abundance for all years from 2004 to 2012. The threshold distances computed from those models are presented in Table 5-28. Threshold distances have been somewhat 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). Figure 5-54 provides a graphical representation of the relationship between Paraonidae abundance and distance to active drill centres.
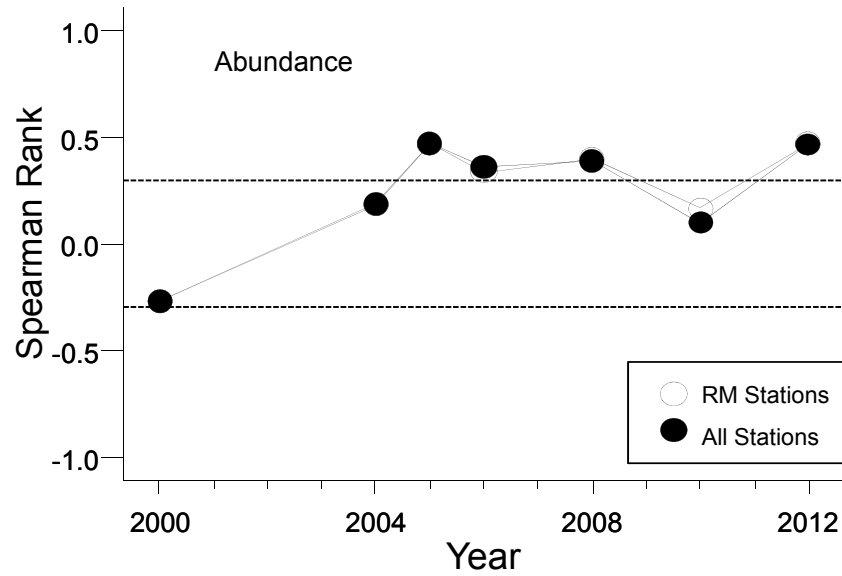


**Figure 5-53     Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Paraonidae Abundances**

Notes: *n* = 53 for All Stations. *n* = 36 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year.

**Table 5-28     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) |
| 2012 | 2.5 (1.5, 4.3) |

Note:    -    95% confidence limits for slopes and threshold distances provided in brackets.
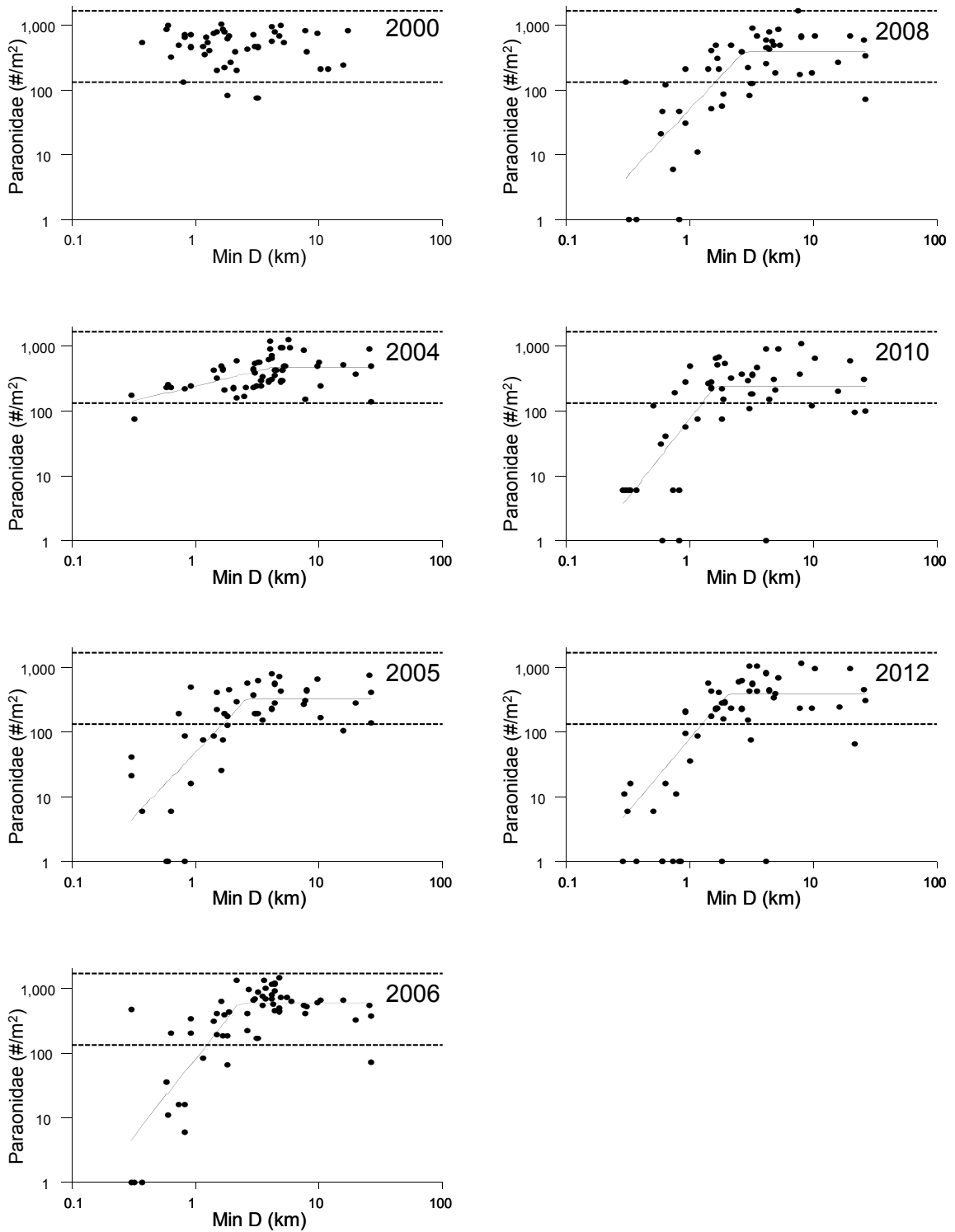
**Figure 5-54      Variation in Paraonidae Abundance (#/m$^2$) with Distance from Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.

As indicated in Figure 5-54, the "normal range" of variation for Paraonidae abundance across the sampling area was computed from the 2000 baseline data. Values ranged from 130 and 1,671 per $m^2$ in 2000. 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 5-54 and 5-55.

Paraonidae abundances were reduced at several stations around the Central, Southern, North Amethyst and Northern Drill Centres in 2012 (Figure 5-55). There were no reductions in Paraonidae abundances in the vicinity of the SWRX Drill Centre (where drilling has yet to occur). There were approximately as many stations with Paraonidae abundance below the lower baseline range of abundance (*i.e.,* < 130 per $m^2$) in 2012 (38%) as in 2010 (40%) (Figure 5-56).

Repeated-measures regression (Table 5-29) indicated there was a significant linear trend over time in the slope of the relationship between distance and Paraonidae abundance during the period of drilling operations (increase in the slope, $p = 0.008$), and a difference in the slope from before to after drilling (higher slope during drilling, $p < 0.001$). There was also a linear decrease over time in mean Paraonidae abundances during the drilling period ($p < 0.001$), and overall lower numbers of Paraonidae from before to after drilling ($p < 0.001$), but those effects were caused by the low abundances near active drill centres.
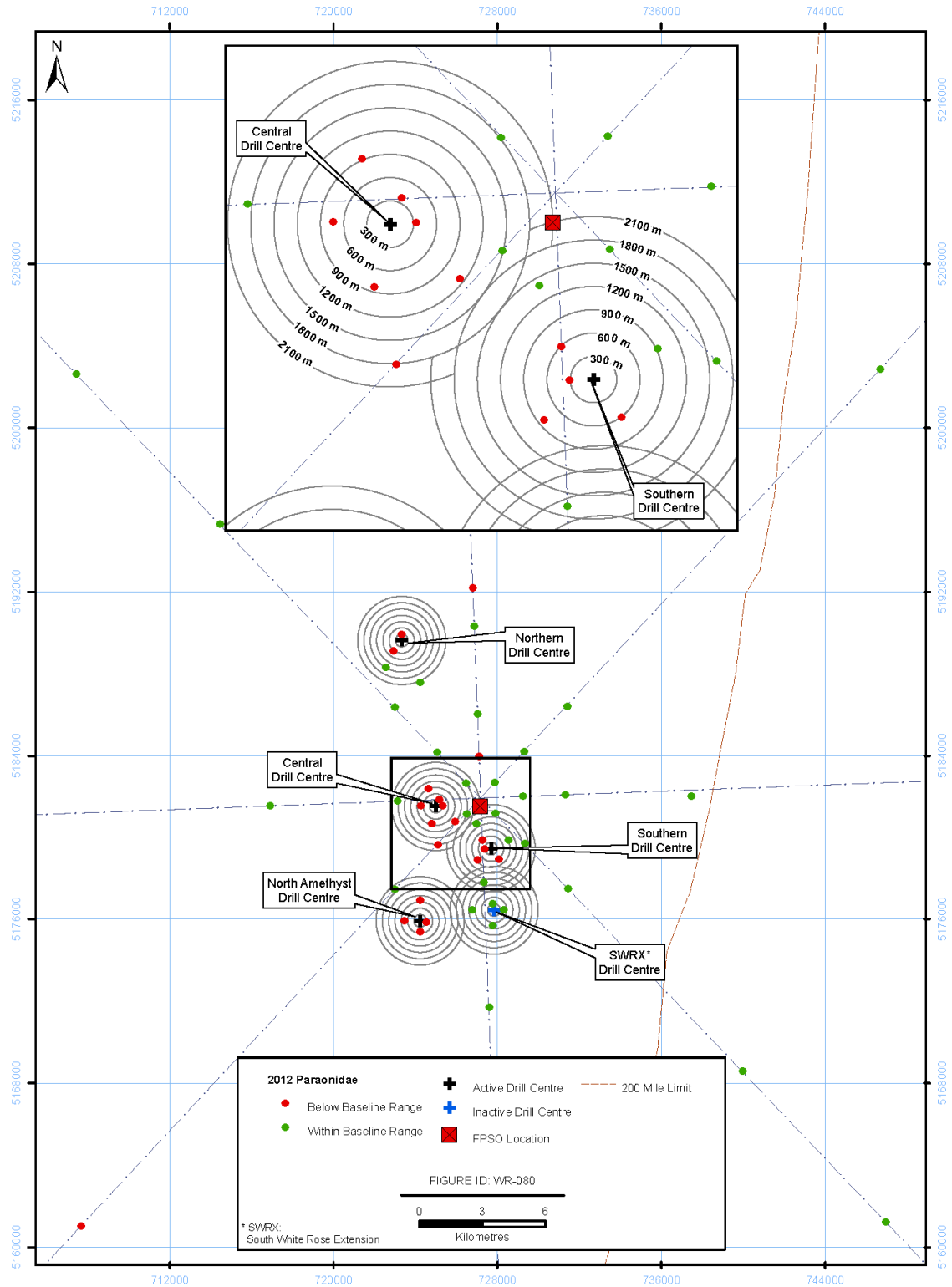
**Figure 5-55    Location of Stations with Paraonidae Abundance Values Within and Below the Baseline Range (2012)**
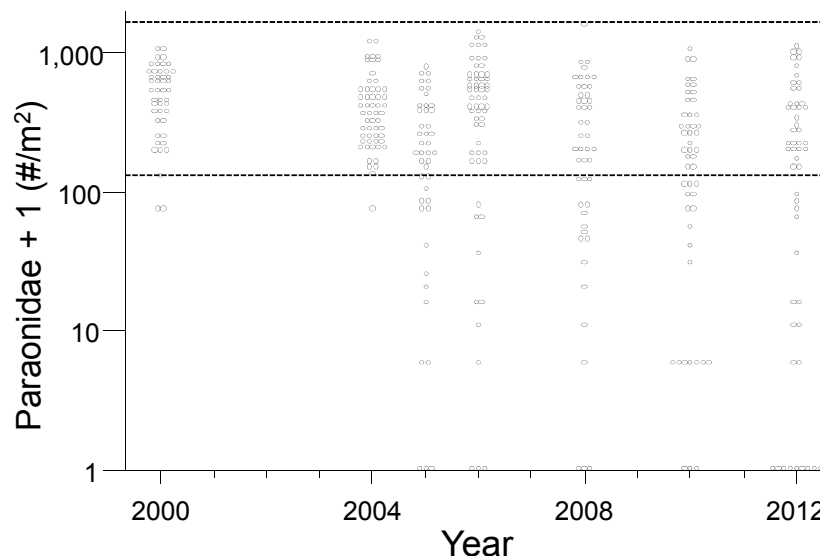
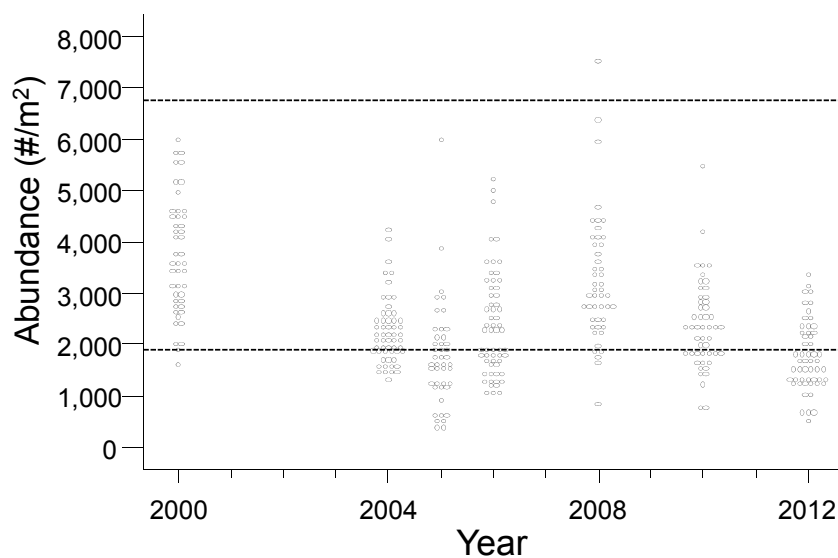**Figure 5-56      Dot Density Plot of Paraonidae Abundance by Year**

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

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

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.008 | <0.001 | <0.001 | <0.001 |

Notes:  -    Values are probabilities.

-    *n* = 36.

-    The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).

-    The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

### 5.2.3.7  Spionidae Abundance

Spionidae abundances varied between 125 and 1,300 individuals per m$^2$, averaging just over 600 per m$^2$ in 2012, compared to about 1,000 per m$^2$ in 2010. Variation in abundances of Spionidae polychaetes in 2012 was uncorrelated with any of the physical or chemical measures assessed (Table 5-23), including distance to the nearest active drill centre (Figure 5-57). Figure 5-58 provides a graphical representation of the relationship between Spionidae abundance and distance to active drill centres. The baseline range of Spionidae abundances was between 640 and 2,700 per m$^2$, based on data from the baseline year (2000) (Figure 5-58). Abundances of Spionidae in 2012 were below the lower limit at almost 60% of stations in 2012 , which is similar to 2005 (Figure 5-59).
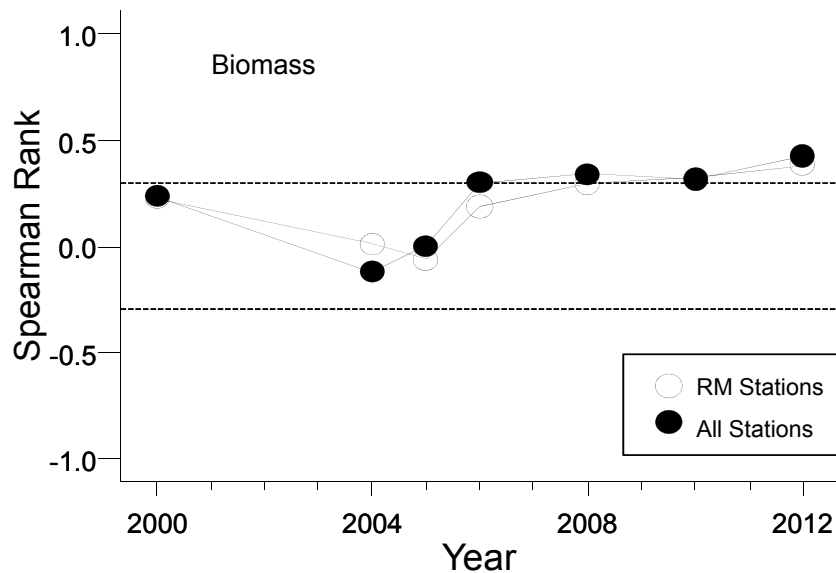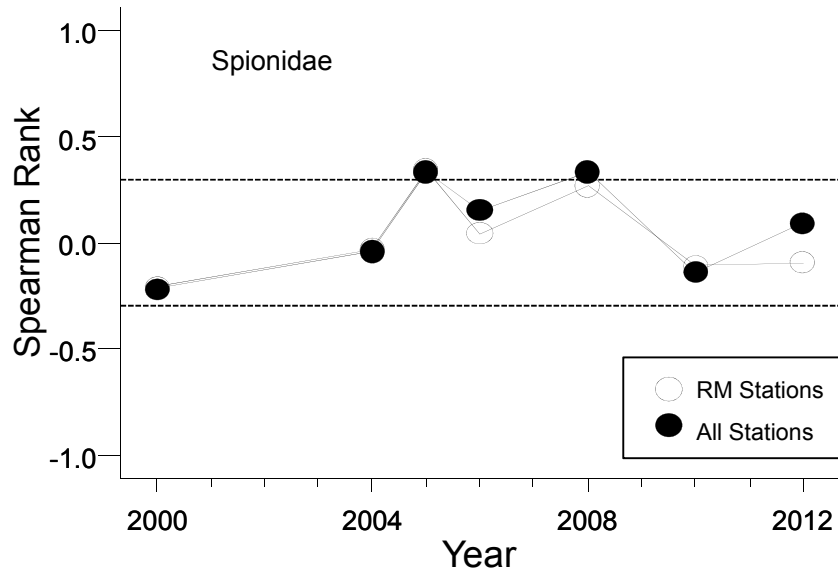
**Figure 5-57      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Spionidae Abundances**

Notes: *n* = 53 for All Stations. *n* = 36 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year.
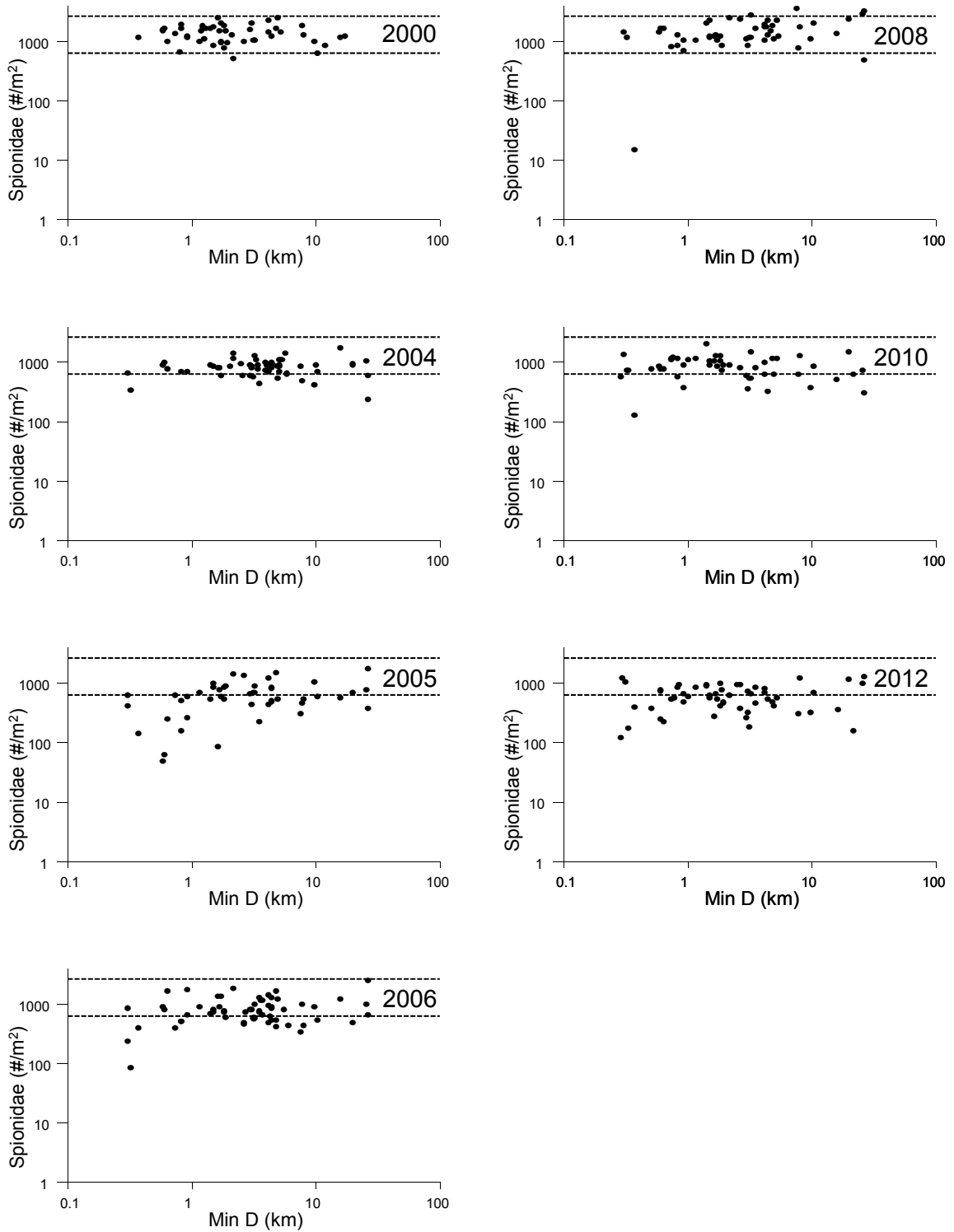
**Figure 5-58    Variation in Spionidae Abundance (#/m$^2$) with Distance From Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.
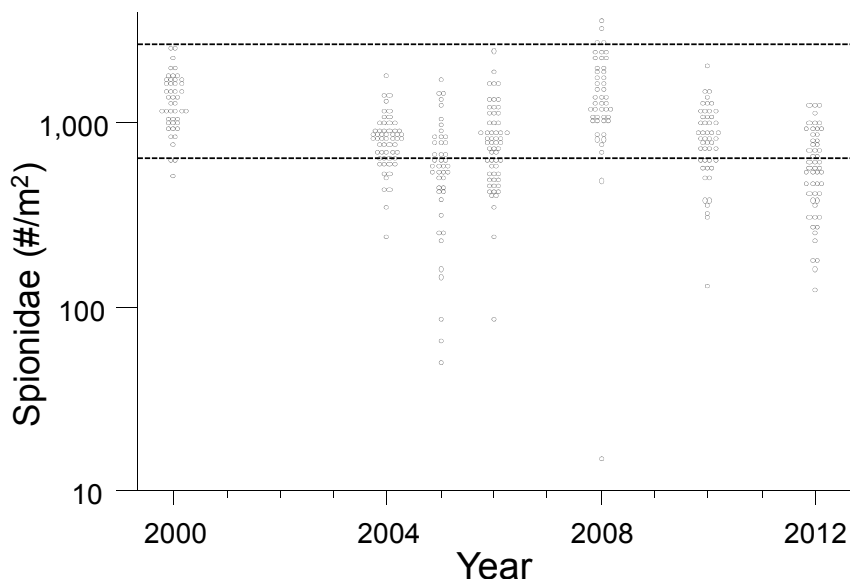
**Figure 5-59        Dot Density Plot of Spionidae Abundance by Year**

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

Repeated-measures regression (Table 5-30) indicated no significant change in the slope of the relationship between Spionidae abundance and distance from the nearest active drill centre over time ($p$ = 0.208), and no difference in slope from before to after active drilling operations ($p$ = 0.130). There was a difference in mean Spionidae abundance across the sampling area from before to after active drilling ($p < 0.001$), with abundances lower from 2004 to 2012 (Figure 5-59).

**Table 5-30        Repeated-measures Regression Testing for Changes in Spionidae Abundance over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.208 | 0.988 | 0.130 | <0.001 |

Notes:  -   Values are probabilities.
        -   $n$ = 36.
        -   The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
        -   The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

The absence of strong correlation between Spionidae abundances and distance to nearest active drill centres suggests that the observed variations were natural.

### 5.2.3.8  Tellinidae Abundance

Tellinidae abundances varied between 40 and 800 individuals per $m^2$, with an area-wide average of approximately 180 per $m^2$ in 2012. The baseline range of Tellinidae abundances from year 2000 was between 151 and 1,303 individuals per $m^2$. Variations in abundances of Tellinidae bivalves were uncorrelated with any of the physical or chemical measures assessed (Table 5-23). The distance correlation was significant in 2012, and in 2008 and 2010 when only the repeated stations were considered (Figure 5-60). Figure 5-61 provides a graphical representation of the relationship between Tellinidae abundance and distance to active drill centres.
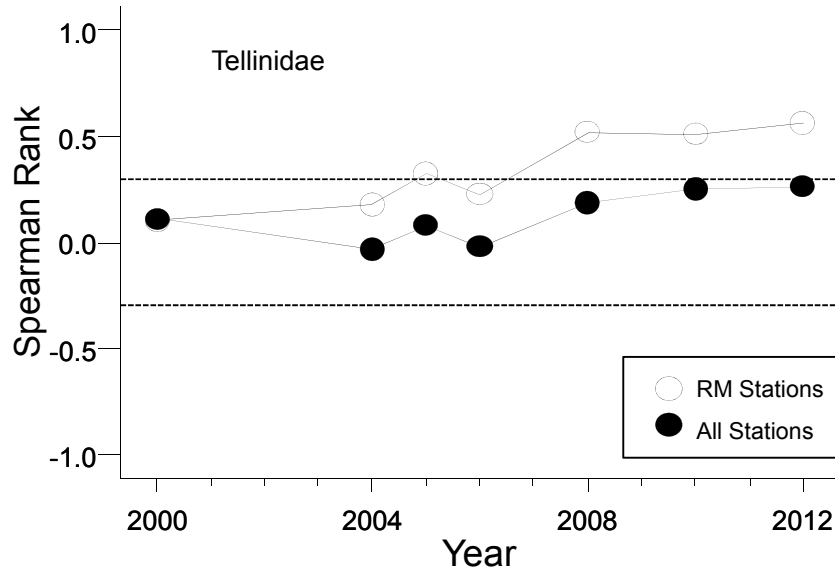


**Figure 5-60      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Tellinidae Abundance**

Notes: $n$ = 53 for All Stations. $n$ = 36 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at $p < 0.01$, depending on sample size in the given year.
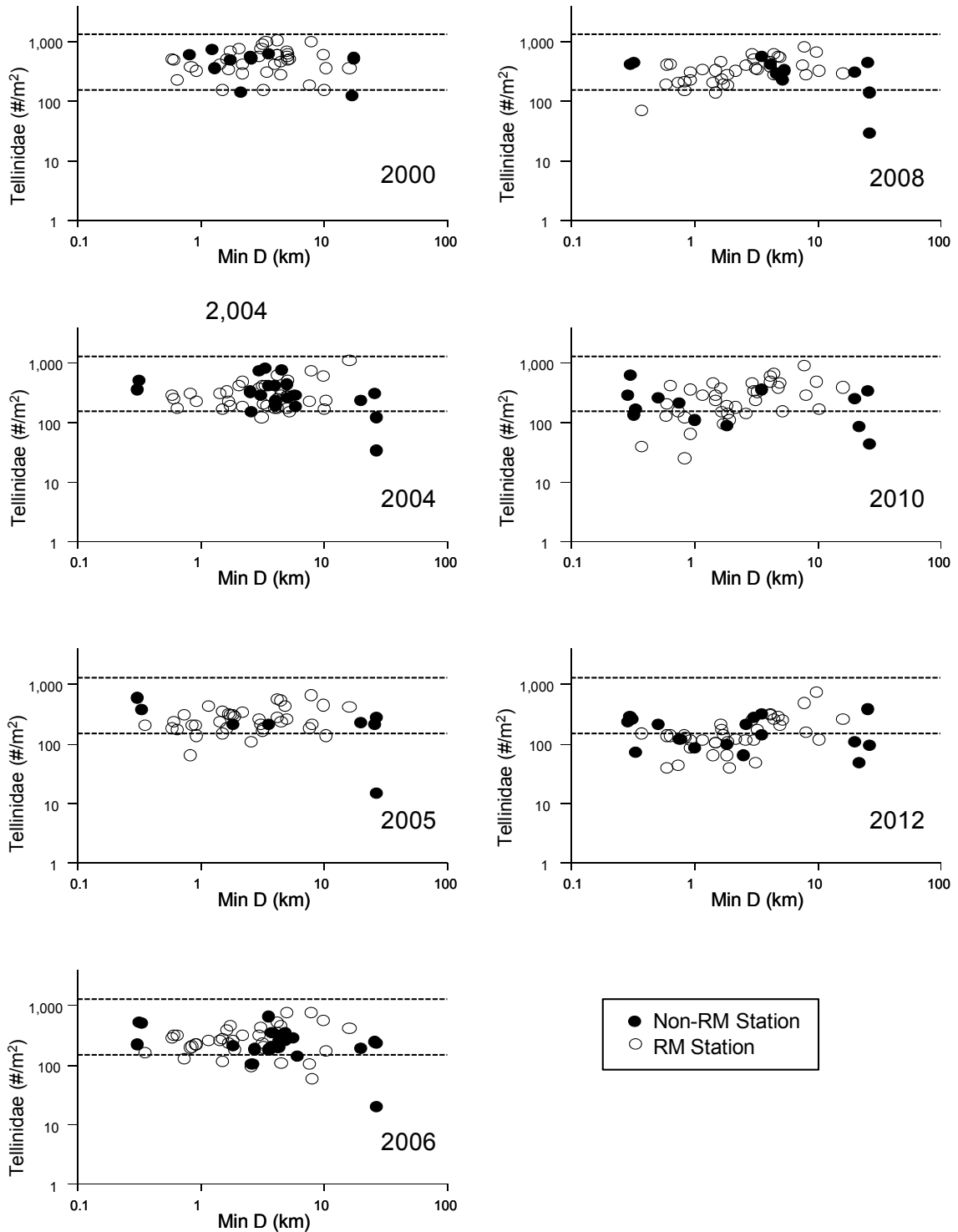
**Figure 5-61**     **Variation in Tellinidae Abundance (#/m$^2$) with Distance From Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000. Stations that have been repeatedly sampled each year are indicated by white circles (=RM Station); stations not repeatedly sampled are indicated by black circles (=Non-RM Station).

Repeated-measures regression (Table 5-31) indicated that the slope of the relationship between Tellinidae abundance and distance to the nearest active drill centre was different between drilling and pre-drilling years ($p < 0.001$), and that the slope of the relationship increased in steepness during drilling years ($p = 0.019$). There was a tendency for numbers of Tellinidae to decrease over time ($p < 0.001$), and from baseline to drilling periods ($p = 0.005$)

**Table 5-31     Repeated-measures Regression Testing for Changes in Tellinidae Abundance over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| 0.019 | <0.001 | <0.001 | 0.005 |

Notes:  - Values are probabilities.
- $n = 36$.
- The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

The repeated-measures regression results contradict the simpler Spearman rank correlation analysis and suggest that there was a relationship between abundance of Tellinidae bivalves and distance to the nearest active drill centre. The scatterplots in Figure 5-61 illustrate that when considering only the stations included in the repeated-measures regression, abundances of Tellinidae were somewhat lower nearer active drill centres in drilling years. The stations included in the repeated-measures regression, however, do not include the stations nearest and furthest from drill centres. The stations nearest active drill centres in 2004 through 2012 had abundances of Tellinidae bivalves that were within the baseline range. The repeated-measures regression results, therefore, appear to be somewhat of an artifact of the specific stations that have been repeatedly sampled, and may not reflect the area-wide tendencies in Tellinidae abundances.

Approximately 56% of stations had Tellinidae abundances in 2012 that were below the lower baseline value of 151 per m$^2$ (Figure 5-62). The absence of strong correlation of tellinid abundances with distance to nearest active drill centres suggests that the observed variations were natural.
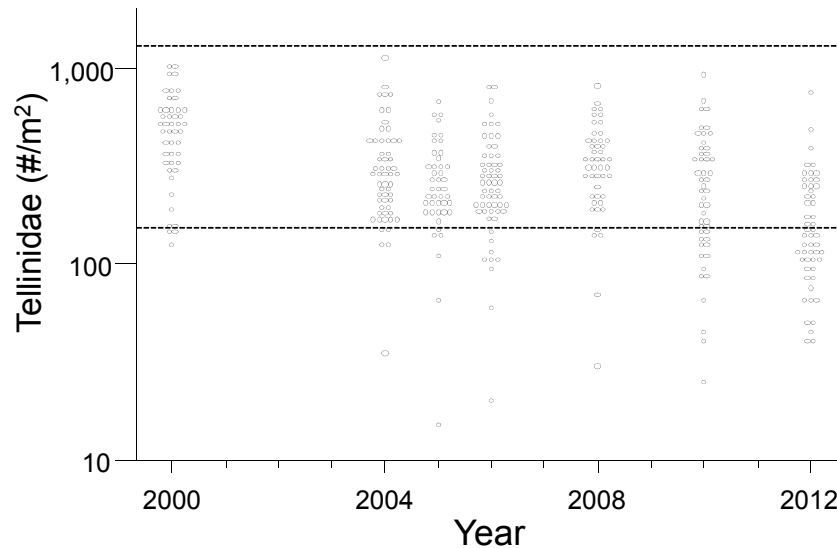
**Figure 5-62      Dot Density Plot of Tellinidae Abundance by Year**

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 345 individuals per m$^2$, with an area-wide average of approximately 60 per m$^2$ in 2012. The range of amphipod abundances from baseline (year 2000) was between 44 and 313 individuals per m$^2$. In 2012, amphipod abundance was not correlated with any measured physical, chemical or toxicological variables including distance to nearest active drill centre (Table 5-23, Figure 5-63). Figure 5-64 provides a graphical representation of the relationship between amphipod abundance and distance to active drill centres.
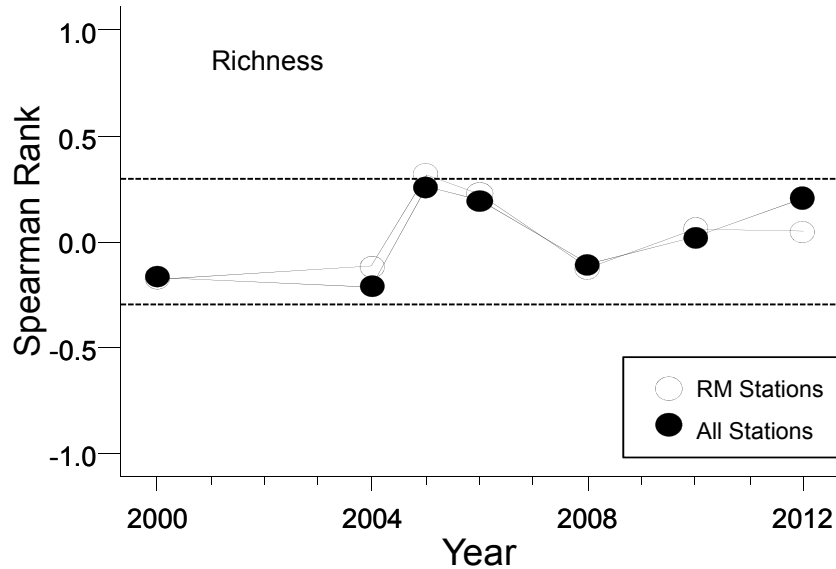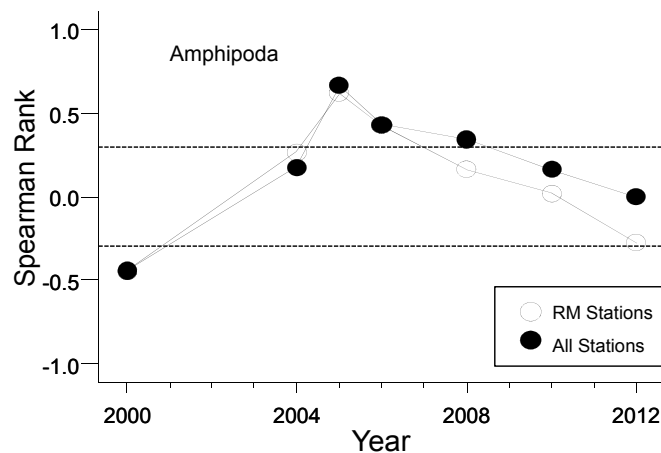


**Figure 5-63      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Amphipoda Abundance**

Notes: *n* = 53 for All Stations. *n* = 36 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at *p* < 0.01, depending on sample size in the given year.
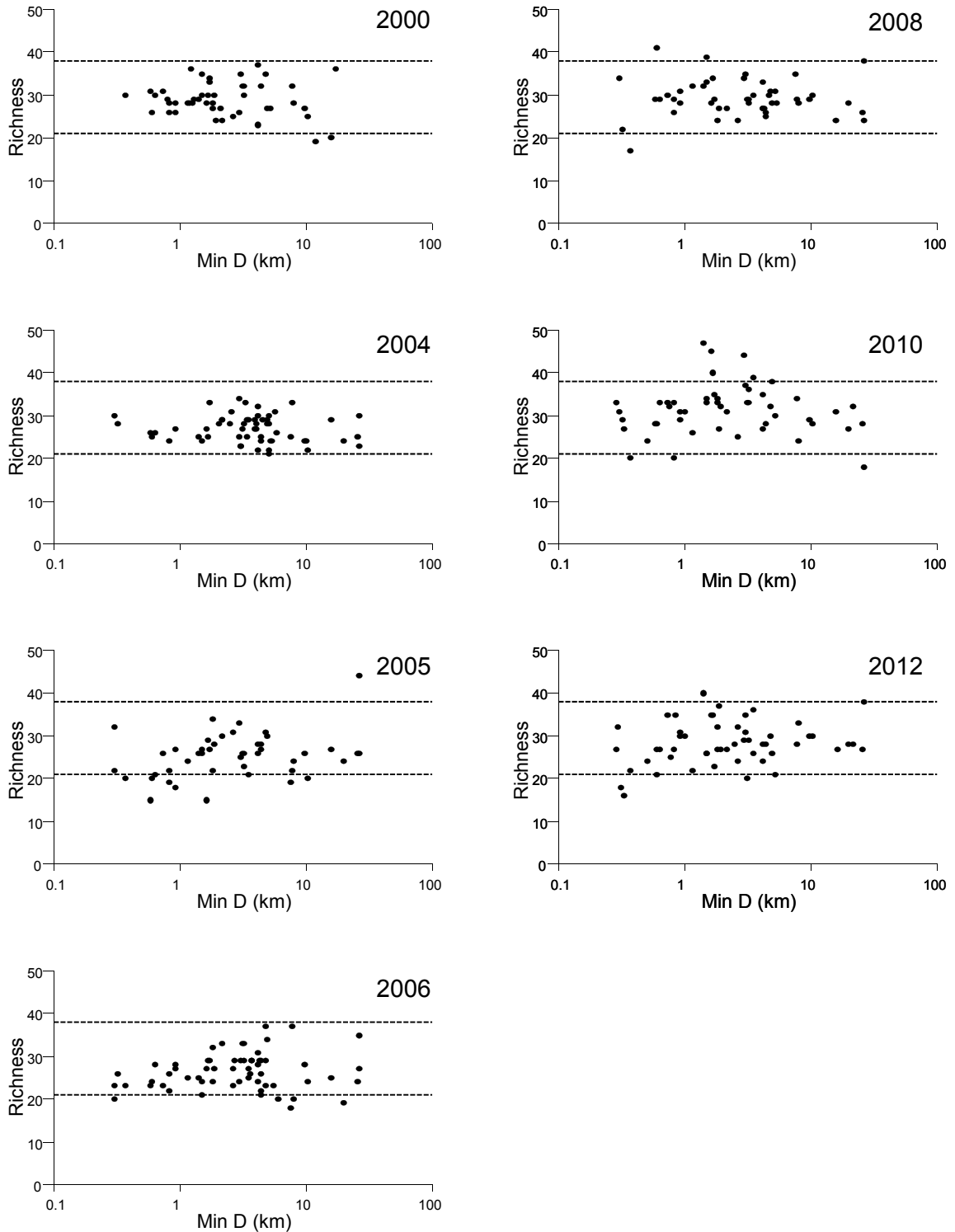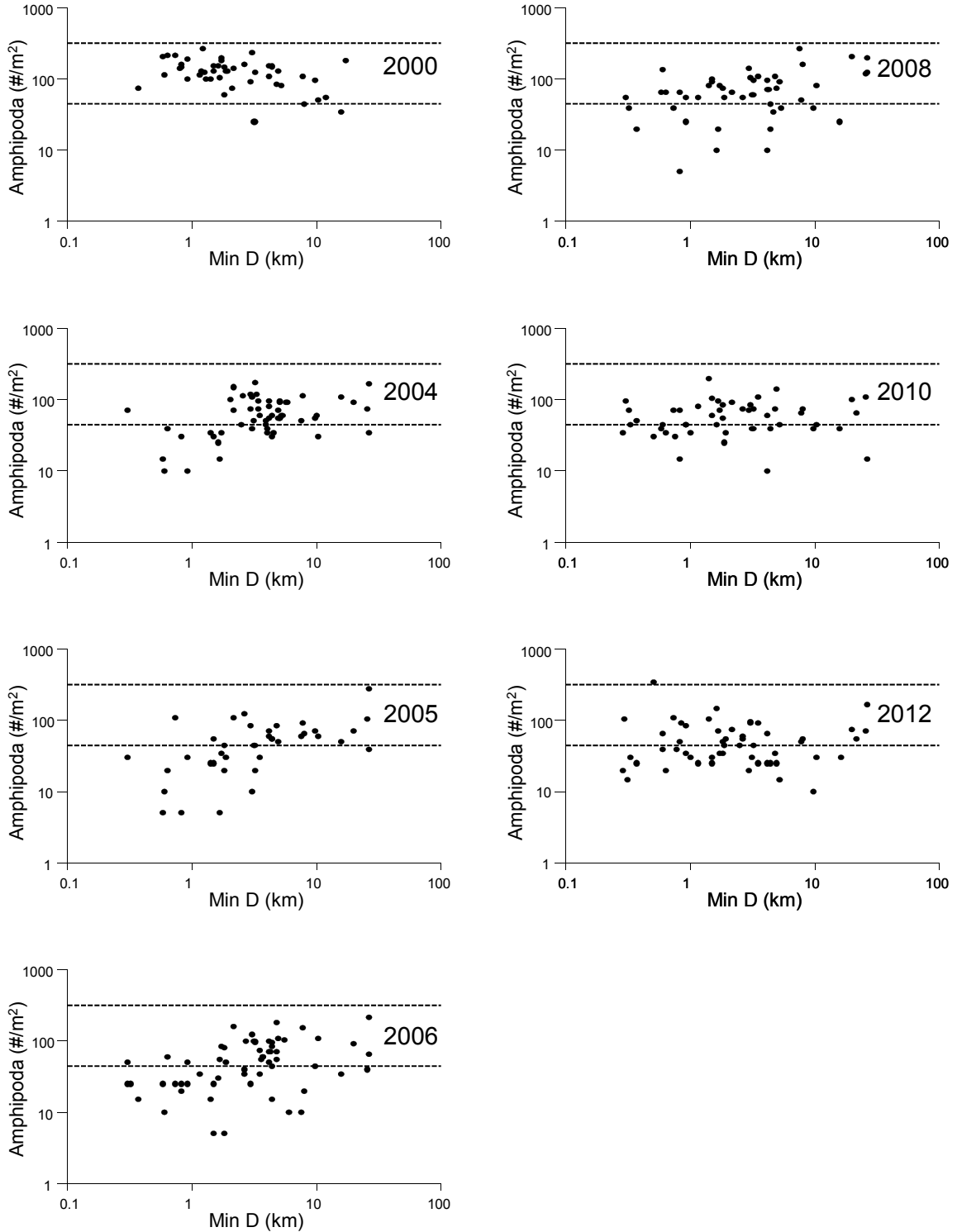
**Figure 5-64     Variation in Amphipoda Abundance (#/m²) with Distance From Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. Background abundance is indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.
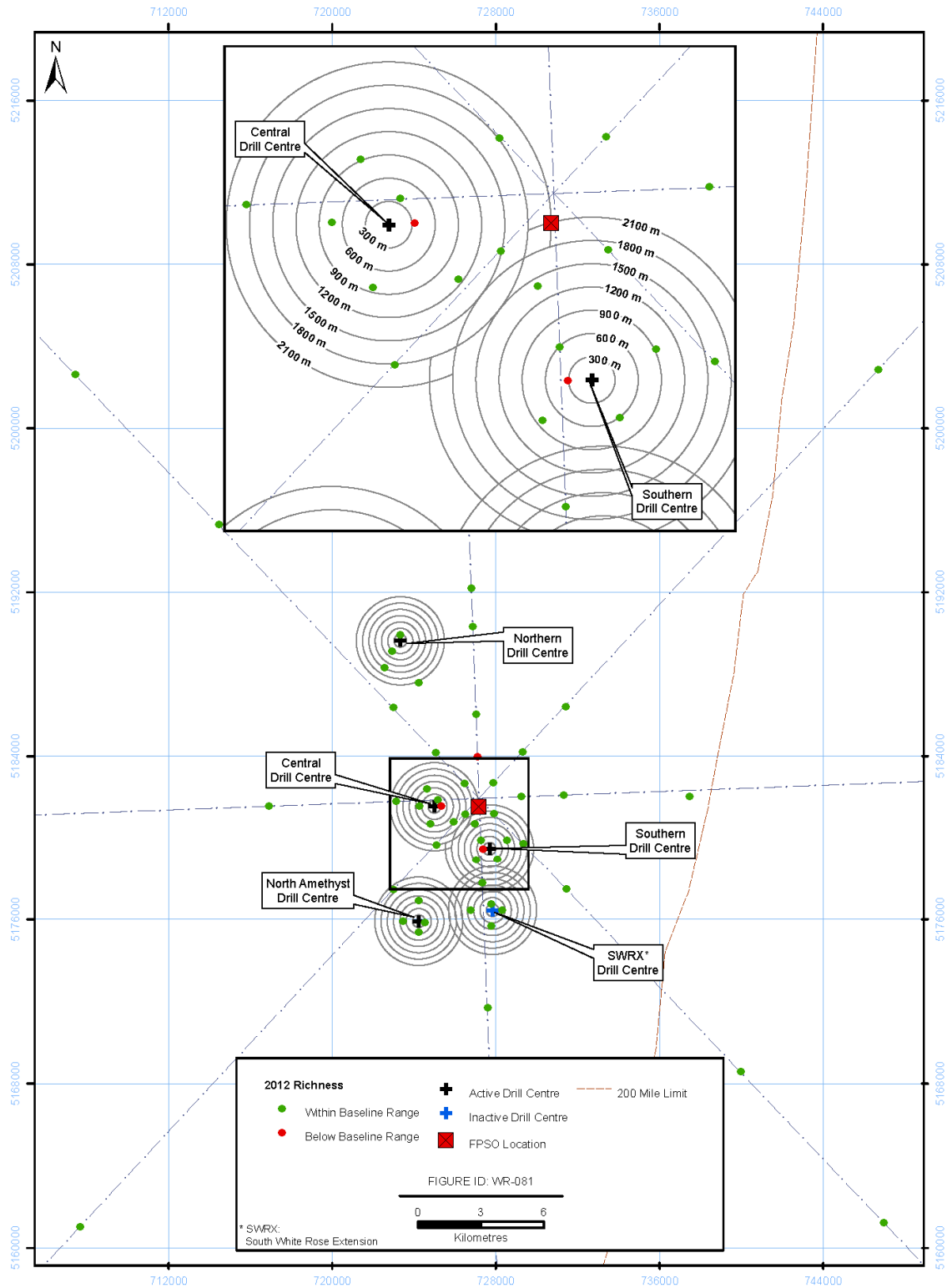
Repeated-measures regression indicated that slopes of the relationship between amphipod abundance and distance to the nearest drill centre varied linearly over the drilling period ($p < 0.001$), and from before to after drilling ($p < 0.001$, Table 5-32). The slope of the distance relationship was modestly negative during the baseline period ($r_S$ = -0.47 in 2000 for repeatedly monitored stations), and tended to be more positive during the drilling period reflecting somewhat reduced numbers of amphipods near drill centres. The linear change in slopes over time during the drilling period indicated that effects near drill centres (if any) decreased over time. There were significant variations in mean abundance over time, with numbers generally decreasing over the drilling period.

**Table 5-32    Repeated-measures Regression Testing for Changes in Amphipoda Abundance over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| **Slope** | **Mean** | **Slope** | **Mean** |
| <0.001 | <0.001 | <0.001 | < 0.001 |

Notes:  -   Values are probabilities.
-   $n$ = 36.
-   The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
-   The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.

In 2012, approximately 45% of stations had amphipod abundances below the lower benchmark of 44 per $m^2$ (Figures 5-64 and 5-65). 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, 30% in 2010). The data indicate an overall reduction in numbers of amphipods has occurred since drilling began, but there is little evidence that the reduction is due to drilling activity.
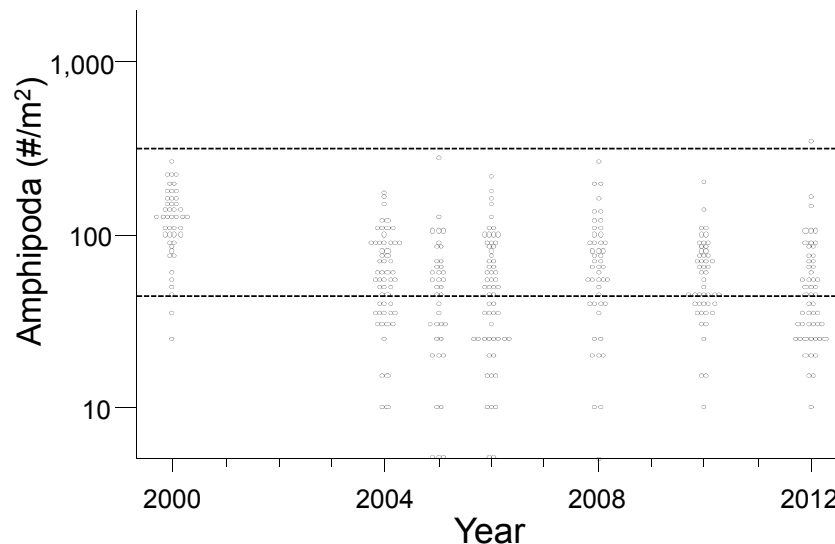


**Figure 5-65    Dot Density Plot of Amphipoda Abundance by Year**

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

### 5.2.3.10 Bray-Curtis Dissimilarity Measures

Bray-Curtis values provide a holistic measure of ecological similarity between sampling stations. Values range from 0, indicating completely similar community composition in terms of percentages of the various groups (in this case families), to 1, indicating completely different community composition (*i.e.*, no groups or families in common).

In year 2000, Bray-Curtis values to the median baseline benthic community ranged from approximately 0.1 to 0.34. In 2012, Bray-Curtis values ranged from approximately 0.3 to 0.8. Most of the stations in 2012, therefore, had Bray-Curtis values that were larger than the range of values observed in the baseline year. With a maximum value of about 0.8 in 2012, the communities in the sampling area still had similarities with the median baseline community.

The Bray-Curtis values were negatively correlated with each of the other benthic community measures (Table 5-33), but significantly correlated only for abundance, richness, and numbers of Paraonidae, Spionidae and Tellindae. Large Bray-Curtis values therefore can be considered to reflect reductions in total abundance and richness, and in abundances of Paraonidae, Spionidae, and Tellinidae.

**Table 5-33      Spearman Rank Correlations Between Bray-Curtis Values and Other Indices of Benthic Community Composition**

| Benthic Measure | $r_S$ |
|---|---|
| Abundance | **-0.897*** |
| Biomass | -0.263 |
| Richness | -0.285* |
| Paraonidae | **-0.742*** |
| Spionidae | **-0.759*** |
| Tellinidae | -0.312* |
| Amphipoda | -0.097 |

Notes:   -     *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$ (**in bold**); $n = 53$

In 2012, Bray-Curtis values were strongly negatively correlated with distance to the nearest active drill centre (Figure 5-66). However, a threshold model did not account for significantly more variation in Bray-Curtis values (Appendix B-5). See Figure 5-67 for an illustration of the relationship between Bray-Curtis values and distance to the nearest active drill centre.

Repeated-measures regression (Table 5-34) indicated that the slope of the distance relationship changed from before to after drilling ($p = 0.002$), and changed linearly over the drilling period ($p = 0.001$). Mean Bray-Curtis values also changed from before to after drilling (larger after drilling, $p < 0.001$), and increased linearly during the drilling period ($p < 0.001$). The dot-density graph illustrates the increase in Bray-Curtis values over time (Figure 5-68).
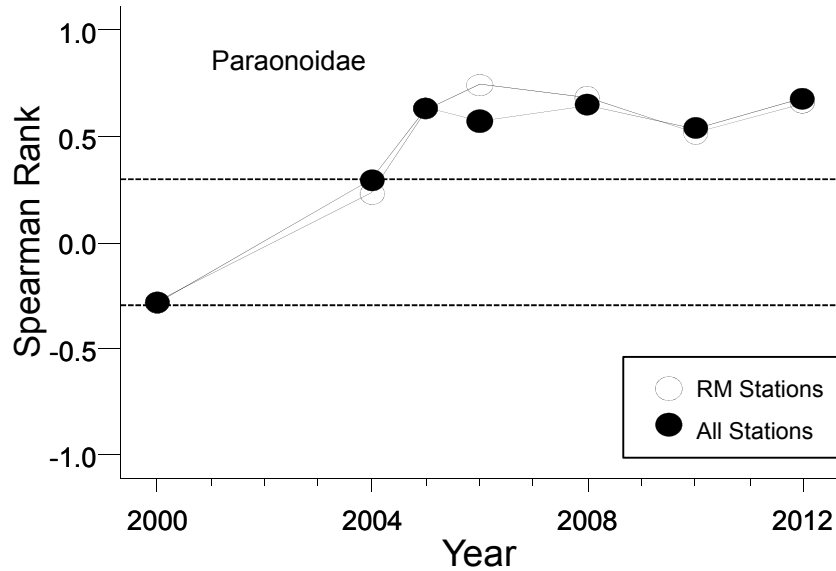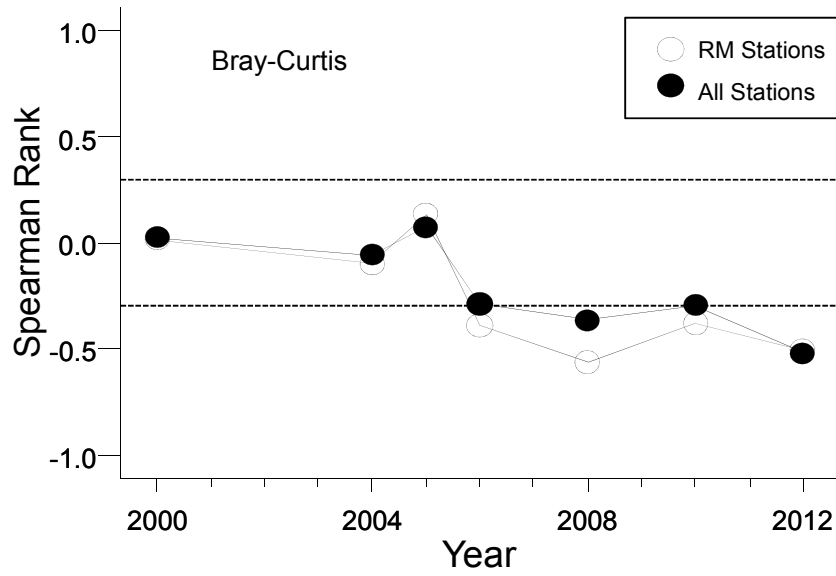
**Figure 5-66      Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Bray-Curtis Values**

Notes: *n* = 53 for All Stations. *n* = 36 for Repeated-Measures Stations. Dotted lines indicate rank correlations of |0.3|, which were generally significant at *p* < 0.01, depending on sample size in the given year.
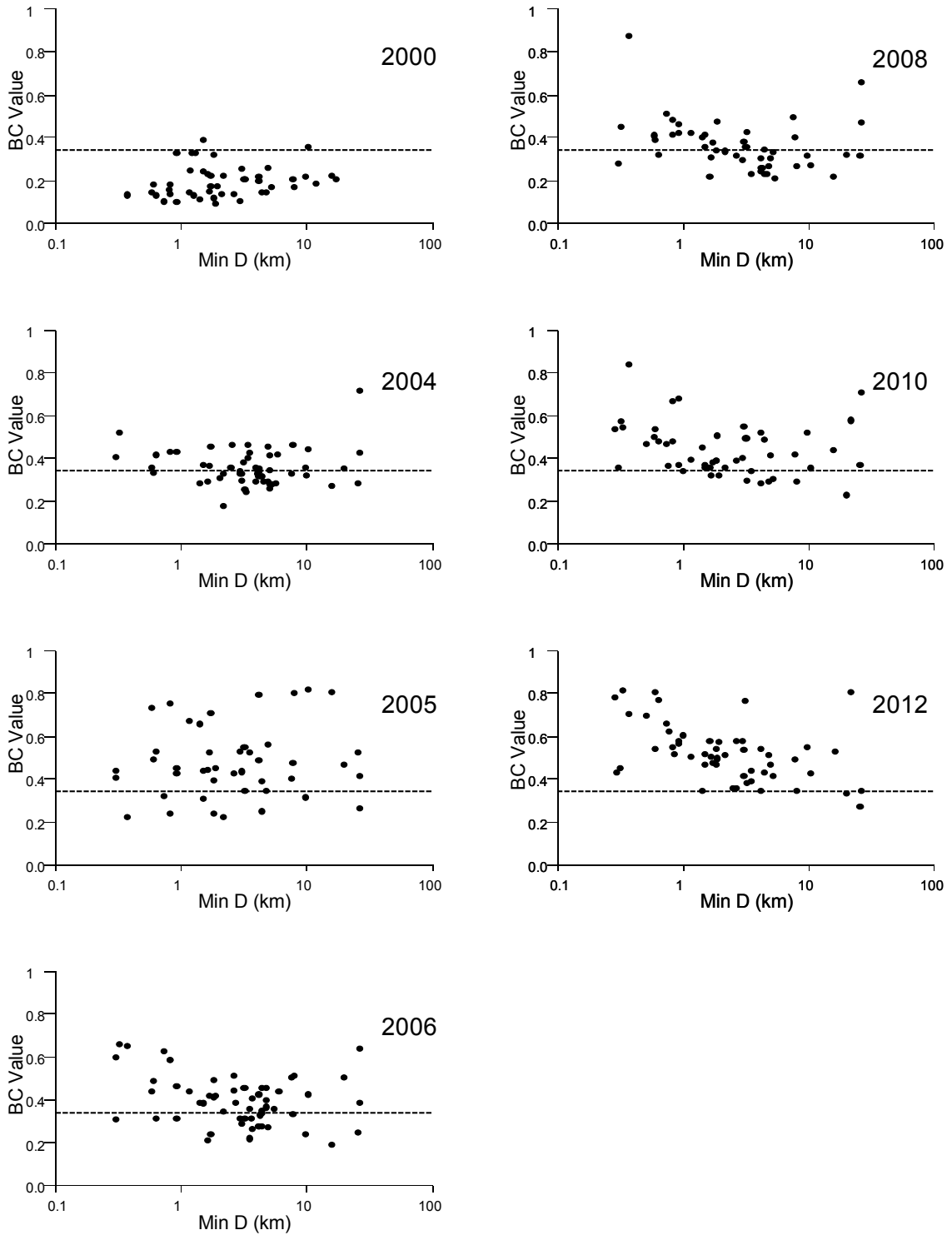
**Figure 5-67      Variation in Bray-Curtis (BC) Values with Distance From Nearest Active Drill Centre (all Years)**

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest drill centre, regardless of its operating status. The upper limit of background Bray-Curtis values is indicated by horizontal lines, based on the mean values + 2 SDs using data from 2000.

**Table 5-34     Repeated-measures Regression Testing for Changes in Bray-Curtis Values over Time**

| Trend over Time | | Before to After | |
|---|---|---|---|
| Slope | Mean | Slope | Mean |
| 0.001 | <0.001 | 0.002 | <0.001 |

Notes:  -   Numbers are probabilities.
-   *n* = 36.
-   The trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2012).
-   The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2012.
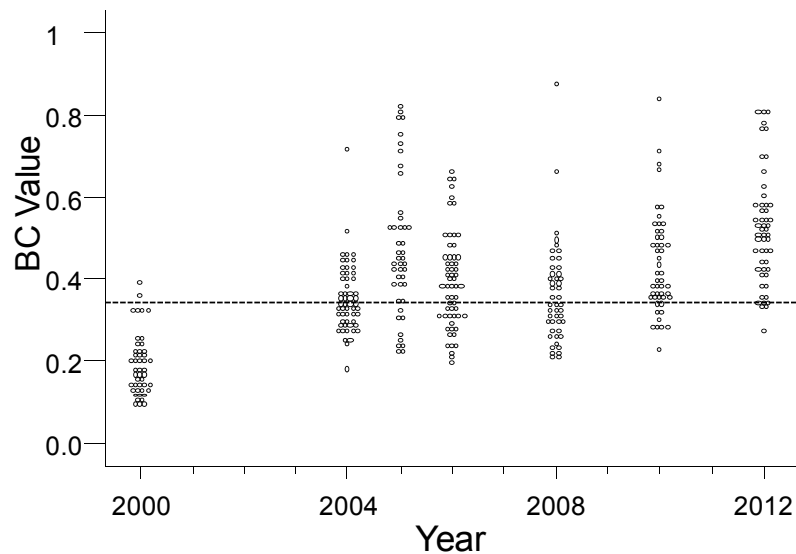


**Figure 5-68     Dot Density Plot of the Bray-Curtis (BC) Values by Year**

Note: Background values are indicated by horizontal lines, based on the mean values + 2 SDs using data from 2000.

These results based on Bray-Curtis values are considered a simpler univariate summary of what is illustrated by the non-metric multidimensional scaling (NMDS) analysis, which is provided in Appendix B-5. The relationship between Bray-Curtis values and distance to the nearest active drill centre reflects similar relationships that were observed for total abundance (somewhat weakly associated with Min D), in addition to biomass and numbers of Paraonidae polychaetes (both strongly influenced by Min D). Bray-Curtis values, and the NMDS analysis (Appendix B-5) did not identify an effect that was not previously identified through the assessment of the individual and key indicator variables.

## 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 2012, with concentrations elevated up to calculated threshold distances of 3.6 km and 1.0 km from the nearest active drill centre, respectively. Threshold distances

for hydrocarbon and barium in 2010 were estimated at 3.6 and 2.0 km, respectively. Sulphur concentrations in 2012 increased modestly at stations less than 1 km from active drill centres. The threshold model for sulphur has not been significant (*i.e.*, no exact threshold distance can be provided). Lead was elevated near active drill centres up to calculated threshold distances of 0.6 km in 2012. Higher levels near active drill centres also occurred in 2006, 2008 and 2010, but it is only in the 2012 analysis (this report) that lead was examined separately from other metals. Average threshold distances for lead have decreased from 1.5 km in 2006 to 0.6 km in 2012. As was the case for lead, strontium was examined separately in 2012. Strontium levels were elevated near active drill centres to average threshold distances of 1.2 km in 2006, 1.6 km in 2008 and 0.6 km in 2012.

There was little indication of negative project effects on sediment particle size (% fines and % gravel), TOC, ammonia, metals (other than barium, lead and strontium) and redox potential.

Sediments were generally non-toxic in 2012, with amphipod survival exceeding 70% in all but one sample. Station N3 (0.6 km from the Northern Drill Centre); was toxic to laboratory amphipods. The station nearest the Northern Drill Centre (N4 at 0.3 km) was not toxic. Amphipod survival was unrelated to sediment chemical characteristics (including those chemical characteristics influenced by project activity), but survival increased with % fines in sediment. No sample was classified as toxic in the Microtox test.

In 2012, there was weak evidence of project effects on total benthic abundances, stronger evidence of effects on total biomass and little evidence of effect on richness. For individual taxa, there was strong evidence of project effects on Paraonidae and little evidence of project effects on Spionidae, Tellinidae and Amphipoda.

Total benthic abundances, benthic biomass and numbers of Paraonidae were related to concentrations of $>C_{10}$-$C_{32}$ hydrocarbons and barium. Total abundances and biomass, and abundances of Paraonidae were lower in sediments with high concentrations of barium and $>C_{10}$-$C_{21}$ hydrocarbons. Higher concentrations of sulphur and, to a lesser extent, strontium in sediments also tended to co-occur with lower biomass and lower abundances of Paraonidae. In addition, Paraonidae abundance was negatively correlated with concentrations of lead.

The relationship between total benthic abundance and distance to active drill centres was relatively weak, with no threshold distance for effects. Total abundance ranged from approximately 500 to 2,500 organisms/m$^2$ near active drill centres (*i.e.*, drill centre stations). The range at the most distant stations (more than 10 km from drill centres) was 1,200 to 3,400 organisms/m$^2$.

Total biomass varied from 5 to 900 g/m$^2$ near active drill centres to approximately 250 to 1,100 g/m$^2$ at the most distant stations (more than 10 km from drill centres). The relationship between total biomass and distance from active drill centres was significant in 2012, with a threshold distance for effects of approximately 1.5 km (range: 0.8 to 2.7 km). Additional analyses indicated that reductions in total biomass were likely associated with reductions in the numbers of larger echinoderms near active drill centres.

Paraonidae abundance was strongly related to distance from active drill centres, as in previous years. Threshold distances for effects have been variable (1.6 km in 2010 to 4.1 km in 2004), but with no statistical differences among years. The threshold distance for effects in 2012 was 2.5 km (range: 1.5 to 4.3 km).

Analysis of Bray-Curtis values and NMDS generally agreed with the more specific analyses of indices of community structure and taxon abundances.

### 5.3.2  Effects of Individual Drill Centres

Maps of response variables outside the baseline (2000) range were used to qualitatively assess the spatial distribution of effects around individual drill centres, with a focus on benthic invertebrate responses.

In general, project effects were more pronounced around the Central, Southern and North Amethyst Drill Centres, with a clear indication of overlapping effects among drill centres. For instance, effects on sediment chemistry and benthos around the Central and Southern Drill Centres, two active drill centres located approximately 3 km from each other, were more widespread than effects around the more isolated North Amethyst and Northern Drill Centres.

Maps of effects on benthic invertebrates generally agreed with calculated threshold distances with effects noted to an average of approximately 1.5 to 2.5 km from active drill centres (Section 5.3.1). For total abundance, a zone of effects is difficult to visually estimate from the map given that abundance in 2012 was reduced at many stations, some far from drill centres. This is consistent with the relatively weak relationship between total abundance and distance from active drill centres and the lack of threshold distances for effects noted in the whole-field analysis. In general, there was a tendency for stations near the Central, Southern and North Amethyst Drill Centres to have lower total abundance.

Total benthic biomass was below the baseline range of values at distances of approximately 1.8 km from the Southern Drill Centre; 1.2 km from the Central Drill Centre and 0.9 km from the North Amethyst Drill Centre. These values are comparable to the estimated threshold of 1.5 km for the whole-field.

Paraonidae abundances were reduced within approximately 1.8 km from the Central Drill Centre; within approximately 0.9 km from the Southern Drill Centre and North Amethyst Drill Centre; and within approximately 0.6 km from the Northern Drill Centre. These distances are below the estimated threshold distance for the whole-field of 2.5 km. The combined effect of the Central and Southern Drill Centres is particularly noticeable for Paraonidae abundance, with reduced abundances apparent between the two drill centres. The proximity of these two drill centres and, consequently, their combined effect, would increase both calculated threshold distances and variability about estimates of threshold distances for the whole-field. This highlights the need for an examination of maps of effects in addition to calculation of whole-field threshold distances, especially when threshold distances are relatively large. Map results for the North Amethyst and the Northern Drill Centres, two drill centres that may not be influenced by other drill centres as much as the Central and Southern Drill Centres, indicate that effects on Paraonidae extended to between about 0.6 and 0.9 km.

In terms of magnitude of effect in 2012, and examining only the stations nearest the drill centres, $>C_{10}$-$C_{21}$ and barium concentrations were highest around the North Amethyst Drill Centre, followed by the Southern and Central Drill Centres (Table 5-35). Total abundance was reduced most frequently at the North Amethyst Drill Centre. However, as noted above, total abundance was reduced elsewhere in the survey area and the association between these reductions and proximity to active drill centres is not strong. Biomass was lowest at the Southern Drill Centre, although, with the exception of one extreme low value (5 $g/m^2$), biomass reductions at the Southern Drill Centre were similar to reductions at the North Amethyst and Central Drill Centres. Paraonidae abundances were lowest at the North Amethyst Drill Centre.

**Table 5-35    Values at Drill Centre Stations for Selected Variables**

| Station | Distance to Drill Centre (km) | $>C_{10}$-$C_{21}$ (mg/kg) | Barium (mg/kg) | Abundance (#/$m^2$) | Biomass (g/$m^2$) | Richness | Paraonidae (#/$m^2$) |
|---|---|---|---|---|---|---|---|
| **Central Drill Centre** | | | | | | | |
| C5 | 0.30 | 100 | 1700 | 505 | 330 | 16 | 15 |
| C3 | 0.74 | 11 | 440 | 1,355 | 268 | 35 | 0 |
| C2 | 0.83 | 20 | 450 | 1,985 | 492 | 35 | 0 |
| C4 | 0.92 | 6 | 240 | 1,520 | 465 | 31 | 95 |
| C1 | 1.14 | 6 | 280 | 1,400 | 366 | 22 | 85 |
| **Mean** | | **28** | **622** | **1,353** | **384** | **28** | **39** |
| **Range** | | **6 to 100** | **240 to 1,700** | **505 to 1,985** | **268 to 492** | **16 to 35** | **0 to 95** |
| **Northern Drill Centre** | | | | | | | |
| N4 | 0.30 | 23 | 1200 | 2,785 | 258 | 32 | 10 |
| N3 | 0.63 | 21 | 680 | 735 | 400 | 27 | 15 |
| N2 | 1.49 | 1 | 190 | 1,790 | 852 | 26 | 430 |
| N1 | 2.18 | 1 | 190 | 1,730 | 894 | 27 | 230 |
| **Mean** | | **11** | **565** | **1,760** | **601** | **28** | **171** |
| **Range** | | **1 to 23** | **190 to 1,200** | **735 to 2,785** | **258 to 894** | **26 to 32** | **10 to 430** |
| **North Amethyst Drill Centre** | | | | | | | |
| NA1 | 0.29 | 510 | 3100 | 1,375 | 798 | 27 | 0 |
| NA2 | 0.50 | 130 | 1300 | 1,325 | 162 | 24 | 5 |
| NA3 | 0.76 | 1 | 190 | 1,095 | 358 | 25 | 10 |
| NA4 | 1.00 | 1 | 210 | 1,280 | 387 | 30 | 35 |
| **Mean** | | **161** | **1200** | **1,269** | **426** | **27** | **13** |
| **Range** | | **1 to 510** | **190 to 3,100** | **1,095 to 1,375** | **162 to 798** | **24 to 30** | **0 to 35** |
| **Southern Drill Centre** | | | | | | | |
| S5 | 0.32 | 97 | 2800 | 2,085 | 5 | 18 | 5 |
| S1 | 0.60 | 21 | 220 | 640 | 547 | 21 | 0 |
| S2 | 0.83 | 8 | 280 | 1,730 | 146 | 27 | 0 |
| S4 | 0.92 | 8 | 320 | 1,260 | 624 | 30 | 205 |
| S3 | 1.40 | 9 | 180 | 2,520 | 543 | 40 | 565 |
| **Mean** | | **29** | **760** | **1,647** | **373** | **27** | **155** |
| **Range** | | **8 to 97** | **180 to 2,800** | **640 to 2,520** | **5 to 624** | **18 to 40** | **0 to 565** |
| **South White Rose Extension Drill Centre** | | | | | | | |
| SWRX-1 | 0.32 | 2 | 200 | 2,880 | 288 | 32 | 610 |
| SWRX-2 | 0.44 | 1 | 200 | 3,025 | 593 | 31 | 1045 |
| SWRX-3 | 0.74 | 2 | 190 | 2,645 | 800 | 26 | 1020 |
| SWRX-4 | 1.06 | 2 | 210 | 2,315 | 753 | 28 | 580 |
| **Mean** | | **2** | **200** | **2,716** | **608** | **29** | **814** |
| **Range** | | **1 to 2** | **190 to 210** | **2,315 to 3,025** | **288 to 800** | **26 to 32** | **580 to 1,045** |

Notes:  -    Station N3 was also toxic to laboratory amphipods.
-    Shading indicate values 75% below the baseline range for benthic invertebrates. Based on this threshold, cut-off levels for total abundance, biomass and Paraonidae abundance are 1,414 #/$m^2$, 275 g/$m^2$ and 98 #/$m^2$, respectively.

## 6.0   Commercial Fish Component

### 6.1   Methods

#### 6.1.1   Field Collection

American plaice (plaice) and snow crab (crab) were collected on-board the commercial trawler *M/V Aqviq* between July 8 and July 10, 2012. 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 |
| 2012 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 10, 2012 |

Notes:   Since the location of Reference Areas sampled from 2004 to 2012 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, 2008 and 2010 samples are presented in Husky Energy (2001, 2003, 2005, 2006, 2007, 2009, and 2011). Sampling for the 2012 program was conducted under an experimental fishing license issued by Fisheries and Oceans Canada (DFO). A total of 100 plaice and 81 crab from the White Rose Study Area were retained for analysis in 2012. A total of 120 plaice and 110 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[10].

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[10] 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 and 2012, by-catch is now minimal and not comparable to by-catch obtained in previous years.
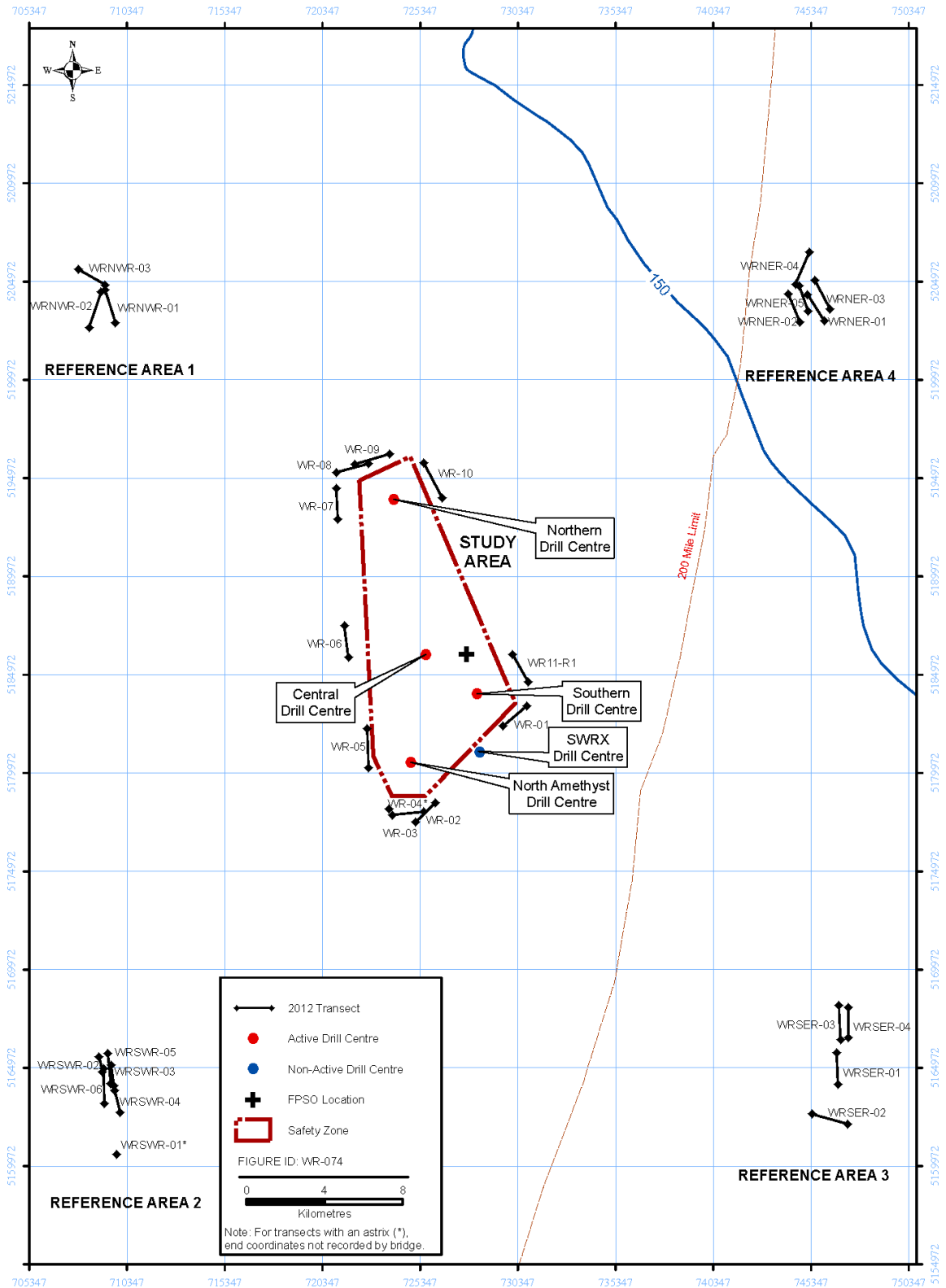
**Figure 6-1     2012 EEM Program Transect Locations**

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 Dietrich's fixative 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 Dietrich's fixative 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% Dietrich's fixative 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. All measuring instruments and work surfaces were washed with mild soap and water, disinfected with isopropyl alcohol, then rinsed with distilled water prior to the start of each transect. Sampling personnel wore new latex gloves for 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 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 (2012)**

| 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) |
|---|---|---|---|---|---|
| WR01 | Study Area | 10 | Composite 1 (10 fish) | 215 | 6 |
| WR02 | Study Area | 10 | Composite 2 (6 fish) | 173 | 6 |
| WR03 | Study Area | 10 | Composite 3 (6 fish) | 208 | 6 |
| WR04 | Study Area | 10 | Composite 4 (6 fish) | 157 | 6 |
| WR05 | Study Area | 10 | Composite 5 (6 fish) | 164 | 6 |
| WR06 | Study Area | 10 | Composite 6 (10 fish) | 158 | 6 |
| WR07 | Study Area | 10 | Composite 7 (10 fish) | 155 | 6 |
| WR08 | Study Area | 10 | Composite 8 (10 fish) | 164 | 6 |
| WR09 | Study Area | 10 | Composite 9 (6 fish) | 167 | 6 |
| WR10 | Study Area | 10 | Composite 10 (10 fish) | 171 | 6 |
| **Total** | | **100** | **10** | **1,732** | **60** |
| WRNE01 | Reference Area 4 | 10 | Composite 11 (10 fish) | 0 | 10 |
| WRNE02 | Reference Area 4 | 10 | Composite 12 (10 fish) | 275 | 10 |
| WRNE03 | Reference Area 4 | 10 | Composite 13 (10 fish) | 554 | 10 |
| WRSE01 | Reference Area 3 | 10 | Composite 14 (10 fish) | 189 | 10 |
| WRSE02 | Reference Area 3 | 10 | Composite 15 (10 fish) | 182 | 10 |
| WRSE03 | Reference Area 3 | 11 | Composite 16 (10 fish) | 187 | 10 |
| WRSW01 | Reference Area 2 | 10 | Composite 17 (10 fish) | 273 | 10 |
| WRSW02 | Reference Area 2 | 10 | Composite 18 (10 fish) | 0 | 10 |
| WRSW03 | Reference Area 2 | 10 | Composite 19 (10 fish) | 272 | 10 |
| WRNW01 | Reference Area 1 | 10 | Composite 20 (10 fish) | 286 | 10 |
| WRNW02 | Reference Area 1 | 10 | Composite 21 (10 fish) | 275 | 10 |
| WRNW03 | Reference Area 1 | 10 | Composite 22 (10 fish) | 0 | 10 |
| **Total** | | **121** | **22** | **3,882** | **120** |

Notes:  -   Ten, rather than six, fish were needed for chemistry analysis in some cases 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 2010 and 2012. Given results in 2010 and 2012, larger fish (with larger livers) may be selected for analysis in future years.
        For taste tests, some of the plaice tissues suffered partial thawing before testing. Tissues that had suffered partial thawing were avoided in taste tests and, as much a feasible, tissue weights were selected to generate relatively constant weights over all composites within the Study or over each of the Reference Areas.

Crab from 11 trawls in the Study Area and 18 trawls in the Reference Areas were used for body burden and taste analyses. Only hard shell crab were retained from these trawls. 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 (2012)**

| Transect No. | Area | No. of Crab | Body Burden Composites (Right Legs) | Taste Tests (wt. (g) of Crab, Left Legs) |
|---|---|---|---|---|
| WR01 | Study Area | 6 | Composite 1 (6 crab) | |
| WR02 | Study Area | 13 | Composite 2 (13 crab) | |
| WR03 | Study Area | 6 | Composite 3 (6 crab) | |
| WR04 | Study Area | 12 | Composite 4 (12 crab) | 5,261 |
| WR05 | Study Area | 6 | Composite 5 (6 crab) | |
| WR06 | Study Area | 10 | Composite 6 (10 crab) | |
| WR11R1 | Study Area | 6 | Composite 7 (6 crab) | |
| WR07 | Study Area | 6 | Composite 8 (6 crab) | |
| WR08 | Study Area | 8 | Composite 9 (8 crab) | 1,478 |
| WR09/WR10 | Study Area | 8 | Composite 10 (8 crab) | |
| **Total** | | **81** | **10** | **6,739** |
| WRNER1 | Reference Area 4 | 12 | Composite 11 (12 crab) | |
| WRNER2/WRNER3 | Reference Area 4 | 7 | Composite 12 (7 crab) | 2,064 |
| WRNER4/WRNER5 | Reference Area 4 | 7 | Composite 13 (7 crab) | |
| WRSER01 | Reference Area 3 | 6 | Composite 14 (6 crab) | |
| WRSER02/WRSER04 | Reference Area 3 | 6 | Composite 15 (6 crab) | 2,049 |
| WRSER03 | Reference Area 3 | 15 | Composite 16 (15 crab) | |
| WRSWR01/WRSWR03 | Reference Area 2 | 8 | Composite 17 (8 crab) | |
| WRSWR06 | Reference Area 2 | 8 | Composite 18 (8 crab) | 1,903 |
| WRSWR02/WRSWR04/WRSWR05 | Reference Area 2 | 11 | Composite 19 (11 crab) | |
| WRNWR01 | Reference Area 1 | 18 | Composite 20 (18 crab) | |
| WRNWR02 | Reference Area 1 | 6 | Composite 21 (6 crab) | 2,322 |
| WRNWR03 | Reference Area 1 | 6 | Composite 22 (6 crab) | |
| **Total** | | **110** | **12** | **8,338** |

Notes:  -   For taste tests, tissue weights were selected so as to generate relatively constant weights for each of the Reference Areas. All crab caught in the northern portion of the Study Area were used in taste tests (trawls WR07, WR08, WR09 and WR10). Approximately equal weights were obtained from remaining Study Area trawls to generate a minimum required tissue weight of approximately 6,000 g for that Area.

### 6.1.2.2  Body Burden

Samples were delivered frozen to Maxxam Analytics in Halifax, Nova Scotia, and processed for the variables 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, 2010 and 2012)**

| Analytes | Method | Laboratory Detection Limits | | | | | Units |
|---|---|---|---|---|---|---|---|
| | | 2000 | 2002 | 2004 & 2005 | 2006 | 2008, 2010 &2012 | |
| *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 |

| Analytes | Method | Laboratory Detection Limits | | | | | Units |
|---|---|---|---|---|---|---|---|
| | | 2000 | 2002 | 2004 & 2005 | 2006 | 2008, 2010 &2012 | |
| Benzo[*b*]fluoranthene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Benzo[*ghi*]perylene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Benzo[*k*]fluoranthene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Chrysene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Dibenz[*a,h*]anthracene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Fluoranthene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Fluorene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Indeno[1,2,3-*cd*]pyrene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Naphthalene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Perylene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Phenanthrene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| Pyrene | GC/MS | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | mg/kg |
| *Metals* | | | | | | | |
| Aluminum | ICP-MS | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | mg/kg |
| Antimony | ICP-MS | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | mg/kg |
| Arsenic | ICP-MS | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | mg/kg |
| Barium | ICP-MS | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | mg/kg |
| Beryllium | ICP-MS | 1.5 | 1.5 | 0.5 | 0.5 | 0.5 | mg/kg |
| Boron | ICP-MS | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | mg/kg |
| Cadmium | ICP-MS | 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 | AOAC922.06 | 0.1 | 0.5 | 0.5 | 0.5 | 0.5 | % |
| Moisture | Gravimetry | 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[11].

-   NA = Not Analyzed.

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[11] 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.

### 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.

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).

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**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).

Blood smears collected in 2012 were considered of insufficient uniformity for carrying out reliable differential cell counts.

**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 enzymatic conversion of 7-ethoxyresorufin to resorufin was measured at an excitation wavelength of 544 nm and an emission wavelength of 590 nm at 27°C using a FLUOStar Optima multi-mode microplate reader. The reaction mixture in each well, final volume of 340 µl, contained 50 mM Tris buffer, pH 7.5, 2 µM ethoxyresorufin (Sigma) dissolved in dimethyl sulphoxide, 0.15 mM NADPH and 6.7 µl of S9 fraction (diluted 10 times in accordance with linearity considerations). All samples and five concentrations of resorufin (from 2.89 to 23.45 pmol/ml) were run in triplicate. An external positive control (a pool of liver homogenates with known activity) was also run in triplicate with each batch of samples to ensure consistency of measurements. Protein concentration of each S9 sample 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 readings against concentrations of resorufin.

**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 Histopathology*

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

1. Nuclear pleomorphism
2. Megalocytic hepatosis
3. Eosinophilic foci
4. Basophilic foci
5. Clear cell foci
6. Hepatocellular carcinoma
7. Cholangioma
8. Cholangiofibrosis
9. Proliferation of Macrophage aggregates
10. Hydropic vacuolation
11. Fibrillar inclusions
12. Bile duct hyperplasia

Any other observations were also recorded. Among them, hepatocellular vacuolation, parasitic infestation of the biliary system, inflammatory response, pronounced cytoplasmic vacuolation of hepatocytes and golden rings around the bile ducts.

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

Macrophage aggregation was recorded on a relative scale from 0 to 7 and prevalence was calculated for fish showing a 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 Histopathology*

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 epithelial lifting (separation of the epithelial layer from the basement membrane), telangiectasis (dilation of blood vessel at the tip of the secondary lamellae), lamellar hyperplasia (thickening of the epithelium due to an increase in the number of epithelial cells), fusion (fusion of two or more adjacent secondary lamellae) or oedema (swelling within cells).

A semi-quantitative examination was carried out for the various lesions (with the exception of oedema), 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 998 lamellae were counted per fish.

The prevalence of the various types of lesions (presence or absence of each lesion for each fish) was also examined.

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

### 6.1.3  Data Analysis

#### 6.1.3.1  Changes from the 2010 Program

The analysis of variance (ANOVA) method used in this report was similar to that used in 2008, and was a Completely Random (CR) ANOVA. The analysis in 2010 used a repeated-measures ANOVA with data from five Areas (*i.e.*, five observations) and four time periods. The repeated-measures ANOVA had just enough degrees of freedom in 2010 to be used as an analysis tool. A repeated-measures ANOVA was not possible in 2012 because the number of repeated observations (*i.e.*, Areas) must exceed the number of years (*i.e.*, parameters, and in 2012 this was five – 2004, 2005, 2006, 2010, 2012). The CR ANOVA used a slightly different error term from what is used in the repeated-measures ANOVA, as explained 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 2012. Formal comparisons among years were not conducted.

**Plaice**

Analyses of plaice biological characteristics were restricted to composite mean gutted weights (*i.e.*, size). Composite mean weights were compared among Areas in ANOVA to test for differences in size between Reference and Study Areas. Additional analyses on plaice biological characteristics were performed within the context of Fish Health analyses (Section 6.1.3.5).

**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 1 or 2. Non-recent moults included crab with condition index values of 6 (probably one year since moult) and 3 or 4 (two or more years since moult).

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 used to judge the difference between the Reference Areas (overall) and the Study Area.

### 6.1.3.3  Body Burden

**Plaice**

***Spatial Variations in 2012***

Body burden data from composite samples were available for both liver and fillet tissue. Variables associated with liver tissue that were statistically analyzed were those that were frequently detected across years and 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.

Fewer variables were detected in plaice fillets. Variables analyzed in fillets were fat content and concentrations of arsenic, mercury and zinc.

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

***Variations in Temporal Trends***

Differences in temporal trends in plaice liver variables were tested using a CR ANOVA of composite tissue concentrations from 2004, 2005, 2006, 2010 and 2012 (Table 6-5). In this ANOVA, linear orthogonal contrasts (Hoke *et al.* 1990) were used to test for differences in linear and quadratic time trends between Reference and Study Areas. Variations were judged relative to variations in average concentrations among Reference Areas (*i.e.*, the Among-Reference Term in Table 6-5).

**Table 6-5      Completely Random (CR) ANOVA Used for Comparison of Body Burden Variables Among Years (2004, 2005, 2006, 2010, 2012)**

| Source/Term | df | Description |
|---|---|---|
| Study vs Reference (SR) | 1 | Tests for differences in concentration between Study and Reference Areas that are consistent across years |
| Year (overall) | 4 | Tests for differences in concentration among years that are consistent in both Study and Reference Areas |
| Linear Trend | 1 | Tests for a linear trend that is similar across all areas |
| Quadratic Trend | 1 | Tests for a trend that involves an increase followed by a decrease (or vice versa), in a fashion that is similar across all areas |
| SR x Year | 4 | Tests for variations in concentration between Study and Reference Areas that change from year to year |
| SR x Linear Trend | 1 | Tests for differences in linear time trends between the Reference and Study Areas |
| SR x Quadratic Trend | 1 | Tests for differences in quadratic time trends between the Reference and Study Areas |
| Among References (AR) (= Error) | 12 | Natural variance in concentrations among Reference Areas within years |

Data from 2000 were not included in CR ANOVA because Reference Area data were collected in different locations during that year. Data from 2008 were also excluded 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 Areas 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 2012*

Crab body burden variables analyzed were moisture content and concentrations of eight frequently detected metals (arsenic, boron, copper, mercury, selenium, silver, strontium and zinc). Boron, selenium and silver 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 for these variables 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 moisture content and concentrations of the eight 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 crab tissue variables were tested using the CR ANOVA of composite tissue concentrations from 2004, 2005, 2006, 2010 and 2012 (Table 6-5), as described above. As for plaice liver and fillets, linear orthogonal contrasts (Hoke *et al.* 1990) were used to test for differences in linear and quadratic time trends between Reference and Study Areas. Variations were judged relative to variations in average concentrations among Reference Areas (*i.e.*, the Among-Reference Term in Table 6-5).

As with plaice, data from baseline were not included in CR ANOVA because Reference Area data were collected in different locations. Data from 2008 were excluded 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 Areas 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 6.1.3.2), body burdens (Section 6.1.3.3) and fish health indicators (Section 6.1.3.5), 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 $\alpha$ = 0.05) requires 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 was used to compare sex ratios (female:male) (F:M) and maturity stages between the Study Area and combined Reference Areas (SR contrast).

**Size, Age and Condition**

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 in mature males (all maturity stages combined) as well as separately in immature, pre-spawning and spent females. MFO values were log-transformed for analyses.

**Histopathology**

Both male and female fish from each Area were combined for histopathological analysis.

*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*

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 the different lesions 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 6-6. Variations in mean fish weight within composites differed significantly among Reference Areas ($p < 0.001$) but did not vary significantly between the Study and Reference Areas ($p = 0.21$, Table 6-7). The average Reference Area fish was 470 g ±47 g, while the average Study Area fish was 517 g ±28 g. The box plot in Figure 6-5 illustrates the spread of gutted weights among the Reference Areas, and shows that the range of gutted weights in Reference Area fish was greater than the range of gutted weights in Study Area fish. Therefore, there is no evidence from mean gutted weight that differences in chemistry between Reference and Study Area fish, if any, would be due to differences in fish size.

**Table 6-6        Summary Statistics for Plaice Composite Mean Gutted Weight (g) (2012)**

| Area | *n* | Min | Max | Mean | SD |
|------|-----|-----|-----|------|-----|
| Reference 1 | 3 | 530 | 621 | 579 | 46 |
| Reference 2 | 3 | 468 | 507 | 488 | 19 |
| Reference 3 | 3 | 352 | 545 | 475 | 107 |
| Reference 4 | 3 | 528 | 561 | 546 | 17 |
| Reference Average | 12 | 470 | 558 | 522 | 47 |
| Study | 10 | 517 | 591 | 555 | 28 |

Note:    -    *n* = number of composites per Area. Refer to Table 6-2 for number of fish per composite.

**Table 6-7        Results of ANOVA Comparing Plaice Composite Mean Gutted Weight Among Areas (2012)**

| Source | SS | df | MS | F-Ratio | *p*-value |
|--------|-----|-----|-----|---------|-----------|
| Reference vs Study | 7,228 | 1 | 7,228 | 1.70 | 0.210 |
| Among Reference | 139,619 | 3 | 46,540 | 10.92 | <0.001 |
| Error | 72,438 | 17 | 4,261 | | |
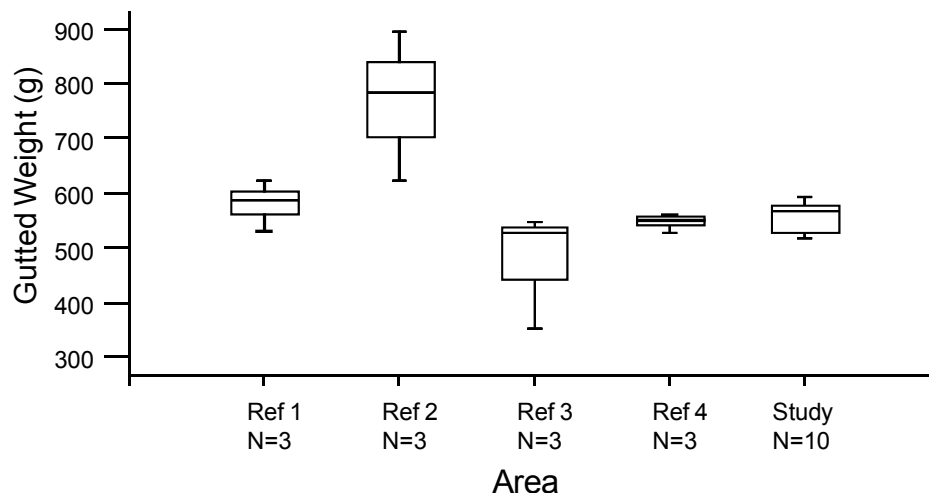
**Figure 6-5       Box Plot of Plaice Gutted Weight (g)**

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, were they present, would indicate values falling within the quartile ±3 x interquartile spread. Open circles would indicate values falling outside the quartile ±3 x interquartile spread.

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 2012 and used for body burden analyses are provided in Table 6-8. Shell condition was recorded for all crab used for body burden analysis. Most (~60% in both Reference and Study Areas) of the crabs had moulted in 2010 or earlier (Table 6-8). At least 10% had moulted in either 2011 or 2012 in each of the Reference and Study Areas.

**Table 6-8       Number (and %) of Crab and Associated Index Values (2012)**

| Index Value | Year of Molt | Area | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ref 1 | Ref 2 | Ref 3 | Ref 4 | All Ref | Study |
| 1,2 | 2012 | 67% | 22% | 4% | 38% | 34% | 16% |
| 6 | 2011 | 10% | 11% | 11% | 8% | 10% | 20% |
| 3,4 | 2010 or earlier | 23% | 67% | 85% | 54% | 56% | 64% |
| Total Crabs (*n*) | | 30 | 27 | 27 | 26 | 110 | 81 |

Summary statistics for composite means for carapace width and claw height are provided in Table 6-9. Crab analyzed for chemistry and morphometry were similar in size (Table 6-9), with an average carapace width of approximately 100 mm in both Reference and Study Areas, and an average claw height of 22 mm (Table 6-9). The ANOVA results in Table 6-10 reflected that carapace width and claw height did not vary significantly among Reference Areas, and did not vary significantly between Reference and Study

Areas. Therefore, there is no evidence that differences in chemistry between Reference and Study Area crab, if any, would be due to differences in size.

**Table 6-9      Summary Statistics for Biological Characteristics of Crab Based on Composite Mean Carapace Width and Claw Height (2012)**

| Variable | Area | *n* | Min | Max | Mean | SD |
|---|---|---|---|---|---|---|
| Carapace width (mm) | Reference Area 1 | 3 | 102.17 | 103.39 | 102.63 | 0.66 |
| | Reference Area 2 | 3 | 94.88 | 107.25 | 103.10 | 7.13 |
| | Reference Area 3 | 3 | 89.60 | 103.67 | 95.64 | 7.24 |
| | Reference Area 4 | 3 | 96.71 | 111.25 | 102.46 | 7.73 |
| | Reference mean | 12 | 95.84 | 106.39 | 100.96 | 5.69 |
| | Study Area | 10 | 83.67 | 115.50 | 97.23 | 11.64 |
| Claw height (mm) | Reference Area 1 | 3 | 21.33 | 22.00 | 21.72 | 0.35 |
| | Reference Area 2 | 3 | 21.71 | 24.86 | 23.58 | 1.65 |
| | Reference Area 3 | 3 | 19.83 | 22.33 | 21.21 | 1.27 |
| | Reference Area 4 | 3 | 21.29 | 25.50 | 23.07 | 2.18 |
| | Reference mean | 12 | 21.04 | 23.67 | 22.40 | 1.36 |
| | Study Area | 10 | 17.67 | 26.17 | 21.57 | 2.88 |

**Table 6-10     Results of ANOVA Comparing Crab Biological Characteristics Among Areas (2012)**

| Variable | Source | Type III SS | df | Mean Squares | F-Ratio | *p*-value |
|---|---|---|---|---|---|---|
| Carapace Width | Study vs Reference | 76 | 1 | 76 | 0.83 | 0.374 |
| | Among Reference | 114 | 3 | 38 | 0.42 | 0.743 |
| | Error | 1546 | 17 | 91 | | |
| Claw Height | Study vs Reference | 4 | 1 | 3.699 | 0.68 | 0.423 |
| | Among Reference | 11 | 3 | 3.736 | 0.68 | 0.576 |
| | Error | 93 | 17 | 5.483 | | |

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

## 6.2.2  Body Burden

### 6.2.2.1  Plaice

**Liver**

Summary statistics for detected substances in plaice liver in 2004, 2005, 2006, 2008, 2010 and 2012 and raw data for 2012 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, 2011) for chromatograms for 2004, 2005, 2006, 2010 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 2012, 14 samples from White Rose were analyzed further to more precisely determine the nature of the compounds and results again indicated that many of the identified compounds were naturally occurring. These additional analyses are provided in Appendix C-2.

### Spatial Variations in 2012

The results of ANOVA are presented in Table 6-11 while the spatial variations in analyte concentrations are illustrated in the box plots in Figure 6-6. Selenium concentrations varied significantly among Reference Areas. None of the analytes varied significantly between the Reference Areas and Study area ($p > 0.05$ in all cases).

**Table 6-11    Results of ANOVA Comparing Plaice Liver Body Burden Variables among Areas (2012)**

| Analyte | p-values | |
|---|---|---|
| | Among Reference | Reference vs Study |
| Fat | 0.918 | 0.419 |
| Moisture | 0.601 | 0.473 |
| Arsenic | 0.459 | 0.552 |
| Cadmium | 0.560 | 0.283 |
| Copper | 0.055 | 0.671 |
| Iron | 0.569 | 0.286 |
| Manganese | 0.263 | 0.262 |
| Mercury | 0.511 | 0.920 |
| Selenium | 0.033* | 0.218 |
| Zinc | 0.246 | 0.521 |
| $>C_{10}$-$C_{21}$ | 0.090 | 0.734 |
| $>C_{21}$-$C_{32}$ | 0.222 | 0.387 |

Notes: - Values are probabilities of no difference among areas, or 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

Variations in mean analyte concentrations in plaice livers between 2004 and 2012[12] are illustrated in Figure 6-7. Arsenic, cadmium, copper, selenium, zinc and $>C_{21}$-$C_{32}$ concentrations all significantly increased in livers of plaice between 2004 and 2012 across all Areas (Table 6-12, Figure 6-7). Manganese and $>C_{10}$-$C_{21}$ hydrocarbons decreased significantly between 2004 and 2012, again in the Reference and Study Areas. Selenium produced a strong quadratic effect ($p < 0.001$), which means that concentrations increased and then decreased. This occurred in all Areas (Figure 6-7). Other analytes that produced weaker quadratic effects across all Areas included fat, arsenic, manganese and $>C_{21}$-$C_{32}$. None of the analytes produced statistically significant differences between the Reference Areas and the Study Area (all $p > 0.05$). There was a nearly significant difference ($p = 0.055$) in the rate of change in concentrations of $>C_{21}$-$C_{32}$, with concentrations in the Reference Areas potentially increasing at a slower rate over time. The near-significant result was influenced by lower concentrations of $>C_{21}$-$C_{32}$ in the Reference Areas in 2006 and 2010 (Figure 6-7).

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[12] Data from 2000 were not included in CR ANOVA because Reference Area data were collected in different locations during that year. Data from 2008 were also excluded 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

**Figure 6-6        Box Plots of Analyte Concentrations in Plaice Livers in Reference and Study Areas (2012)**

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 6-7    Variations in Area Means of Detectable Metals and Hydrocarbons in Plaice Liver Composites from 2004 and 2012**

Note:    Values shown are annual averages within Areas.

**Table 6-12**     **Results of ANOVA Testing for Differences in Average Plaice Liver Body Burden Variables and Temporal Trends Between the Reference Areas and the Study Areas (2004 to 2012)**

| Analyte | Linear | | Quadratic | |
|---|---|---|---|---|
| | Area-Wide Trend | Difference Between Reference and Study | Area-Wide Trend | Difference Between Reference and Study |
| Fat | 0.006** | 0.362 | 0.018* | 0.171 |
| Moisture | 0.141 | 0.962 | 0.110 | 0.248 |
| Arsenic | **<0.001*** | 0.852 | 0.013* | 0.147 |
| Cadmium | 0.003** | 0.081 | 0.243 | 0.522 |
| Copper | 0.010* | 0.076 | 0.518 | 0.752 |
| Iron | 0.064 | 0.220 | 0.261 | 0.267 |
| Manganese | 0.010* | 0.714 | 0.003** | 0.530 |
| Mercury | 0.452 | 0.449 | 0.017* | 0.978 |
| Selenium | 0.035* | 0.630 | **<0.001*** | 0.890 |
| Zinc | **<0.001*** | 0.697 | 0.127 | 0.173 |
| >$C_{10}$-$C_{21}$ | 0.005** | 0.488 | 0.169 | 0.430 |
| >$C_{21}$-$C_{32}$ | **<0.001*** | 0.055 | 0.460 | 0.288 |

Notes:    -    Values are probabilities of no temporal trend or no difference in temporal trends.
           -    Analyte concentrations were $\log_{10}$ transformed prior to analysis.
           -    2008 data were excluded from ANOVA because all Reference Areas were not sampled in that year.
           -    *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

## Fillets

Summary statistics for concentrations of detected substances in 2004, 2005, 2006, 2008, 2010 and 2012, and raw data for 2012 are provided in Appendix C-2. Only arsenic, mercury and zinc were detected frequently in plaice fillet tissue in all years, and no other metals were detected in fillet in 2012. These metals and fat and moisture content were analyzed quantitatively. Iron, selenium and strontium have been detected sporadically in other years (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.). Otherwise, hydrocarbons were not detected in plaice fillet.

### *Spatial Variations in 2012*

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, and no differences in concentration between the Reference Areas and the Study Area (Table 6-13). Fish from the Study Area had more variation in moisture content (Figure 6-8) than the Reference Area fish, such that there was a near significant difference in moisture content in filets between Reference and Study Area fish ($p = 0.055$; Table 6-13).

**Table 6-13      Results of ANOVA Comparing Plaice Fillet Body Burden Variables Among Areas (2012)**

| Analyte | *p*-values | |
|---|---|---|
| | **Among Reference** | **Study vs Reference** |
| Fat | 0.448 | 0.411 |
| Moisture | 0.944 | 0.055 |
| Arsenic | 0.203 | 0.353 |
| Mercury | 0.179 | 0.258 |
| Zinc | 0.529 | 0.869 |

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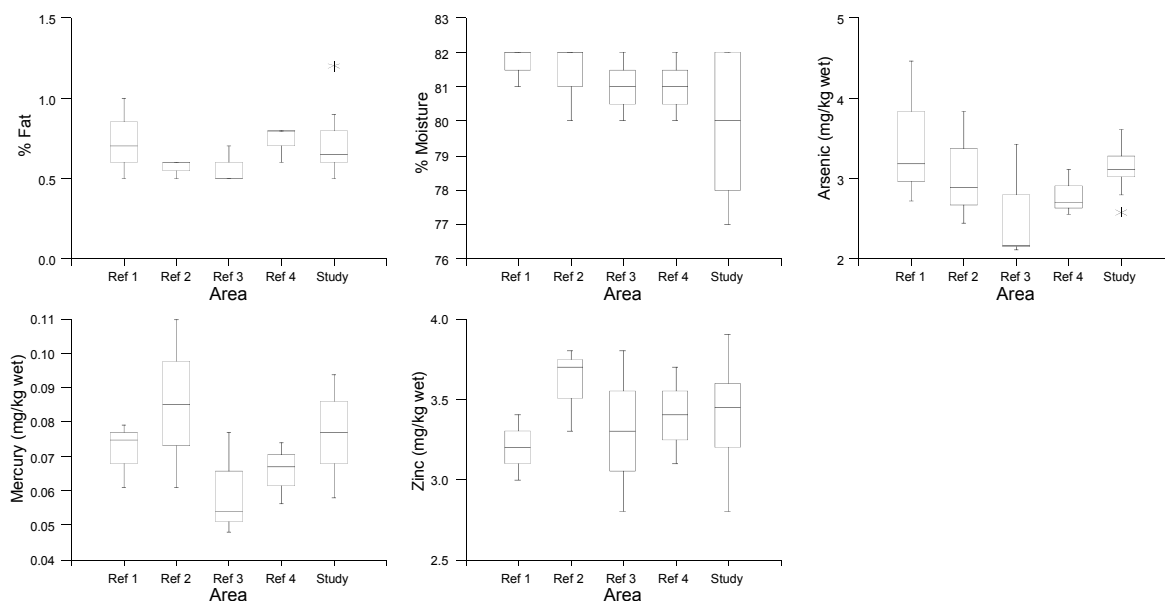


**Figure 6-8      Box Plots of Analyte Concentrations in Plaice Fillets in Reference and Study Areas (2012)**

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, were they present, would indicate values falling outside the quartile ±3 x interquartile spread.

### *Variations in Temporal Trends*

Fat content and zinc concentrations generally decreased over time in fillets of fish from both Study and Reference Areas, while percent moisture in plaice fillets increased over time across both Study and Reference Areas (Figure 6-9, Table 6-14). There were no differences in linear time trends, or quadratic time trends between the Reference Areas and the Study Area for any analyte (all *p* > 0.05; Table 6-14).
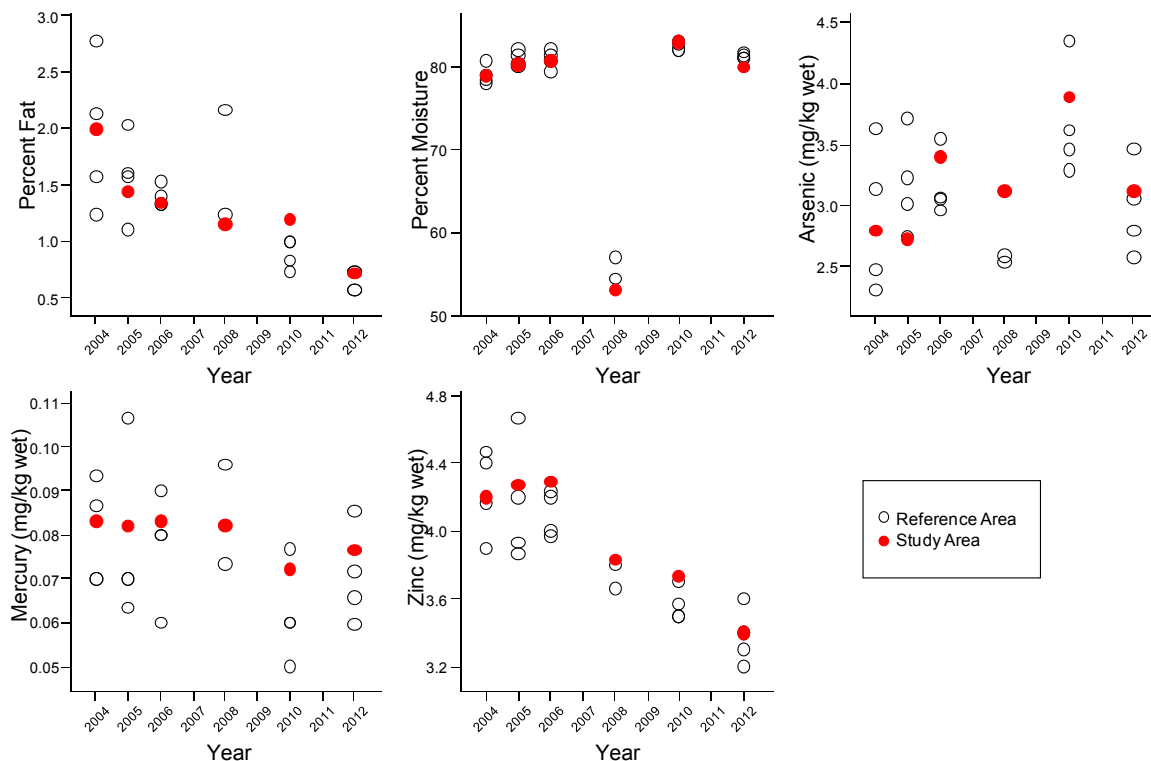
**Figure 6-9**     **Variations in Fat, Moisture, Mercury, Arsenic and Zinc Concentrations in Plaice Fillets from 2004 to 2012**

Note:     Values shown are annual averages within Areas.

**Table 6-14**     **Results of ANOVA Testing for Differences in Average Fillet Body Burden Variables and Temporal trends Between the Reference Areas and the Study Areas (2004 to 2012)**

| Analyte | Linear | | Quadratic | |
|---|---|---|---|---|
| | **Area-Wide Trend** | **Difference Between Reference and Study** | **Area-Wide Trend** | **Difference Between Reference and Study** |
| Fat | **<0.001\*\*\*** | 0.341 | 0.084 | 0.738 |
| Moisture | 0.001\*\* | 0.552 | 0.006\*\* | 0.368 |
| Mercury | 0.129 | 0.266 | 0.046\* | 0.943 |
| Arsenic | 0.126 | 0.665 | 0.626 | 0.849 |
| Zinc | **<0.001\*\*\*** | 0.689 | 0.017 | 0.313 |

Notes:   -   Values are probabilities of no temporal trend or no difference in temporal trends.
-   Analytes were $\log_{10}$ transformed prior to analysis.
-   2008 data are excluded from ANOVA because not all Reference Areas were sampled in that year.
-   $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (**in bold**).

### 6.2.2.2   Crab

Summary statistics for concentrations of detected substances in crab claw composites in 2004, 2005, 2006, 2008, 2010 and 2012 are provided in Appendix C-2, as are raw data for 2012. Arsenic, boron, copper, mercury selenium, silver, strontium and zinc were detected frequently in crab claw tissue across all years. These metals and moisture content are analyzed quantitatively. Fat content was below detection limit in all but one

composite in 2012. Aluminum, cadmium and lead were detected sporadically across all years. Hydrocarbons have never been detected in claw tissue (Appendix C-2).

### Spatial Variations in 2012

There were significant differences in arsenic, boron, mercury and silver concentrations among Reference Areas in 2012, but not in other analytes (Table 6-15, also see Figure 6-10). Differences in silver concentration among Reference Areas was driven by several non-detect values in Reference Areas 1 and 2 (Figure 6-10). There were no significant differences in analyte concentrations between the Reference Areas and the Study Area (all $p > 0.05$; Table 6-15).

**Table 6-15      Results of ANOVA Comparing Crab Body Burden Variables Among Areas (2012)**

| Analyte | *p*-value | |
|---|---|---|
|  | Among Reference (AR) | Study vs Reference (SR) |
| Moisture | 0.705 | 0.369 |
| Arsenic | 0.037* | 0.283 |
| Boron | 0.049* | 0.959 |
| Copper | 0.506 | 0.119 |
| Mercury | 0.008** | 0.888 |
| Selenium | 0.900 | 0.224 |
| Silver | 0.001** | 0.408 |
| Strontium | 0.626 | 0.249 |
| Zinc | 0.929 | 0.068 |

Note:  -  Values are probabilities of no difference among or between the Areas.
-  Analyte concentrations were $\log_{10}$ transformed prior to analysis.
-  Although analyzed in previous years, no ANOVA was computed for percent fat in 2012 because no values were above the detection limit of 0.5%.
-  *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

### Variations in Temporal trends

Most metals concentrations in tissues of crab from the Study Area were lower than had been reported in prior years, particularly arsenic, copper, selenium, silver, strontium and zinc (Figure 6-11). Those lower values contributed to many of the statistically significant trends observed (Table 6-16).

There were significant ($p < 0.05$) linear trends (decreases) over time in concentrations of percent moisture, as well as concentrations of arsenic, copper, mercury, selenium and silver (Table 6-16). There were no differences in those linear time trends between the Reference Areas and the Study Area (all $p > 0.05$; Table 6-16). Selenium produced a weakly significant ($p = 0.041$) quadratic effect (*i.e.*, increasing from 2004 to 2006, and decreasing from 2010 to 2012), but that trend did not differ significantly between the Reference Areas and the Study Areas ($p = 0.141$). Strontium produced a stronger quadratic effect ($p = 0.001$), reflecting an increase in concentration from 2004 to 2006, and a decrease from 2010 to 2012, but again, that effect did not differ significantly between the Reference Areas and the Study Area ($p = 0.798$). Zinc produced a significant difference in the quadratic effect[13] ($p = 0.018$) between the Reference Areas

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[13] A quadratic effect is an increase followed by a decrease, or vice versa. In this case, the increase followed by the decrease in zinc values was slightly more pronounced in the Study Area than in the Reference Areas.

and the Study Area, reflecting weakly higher values in Study Area crab in 2008 and 2010 compared to Reference Area crab (Figure 6-11).
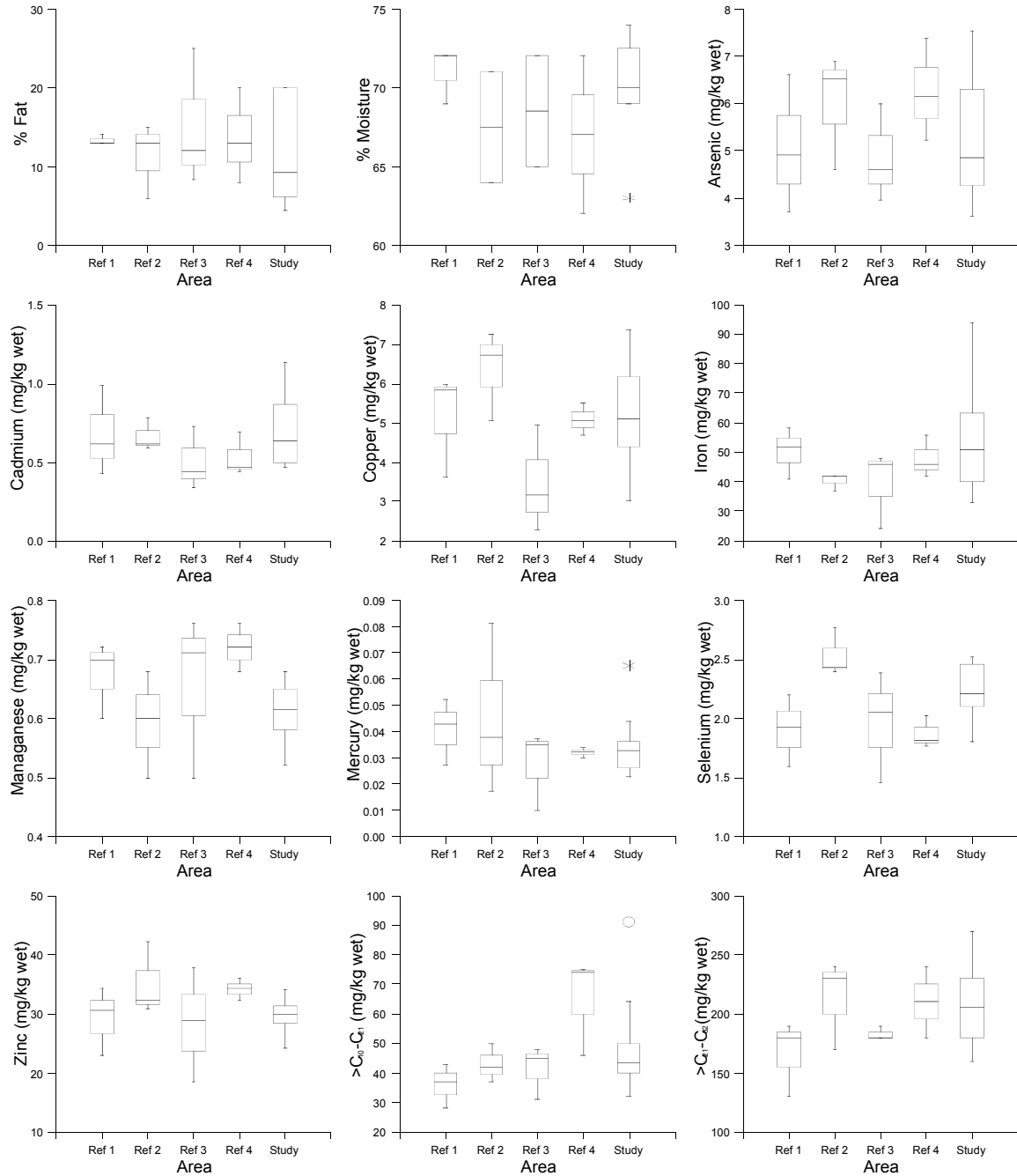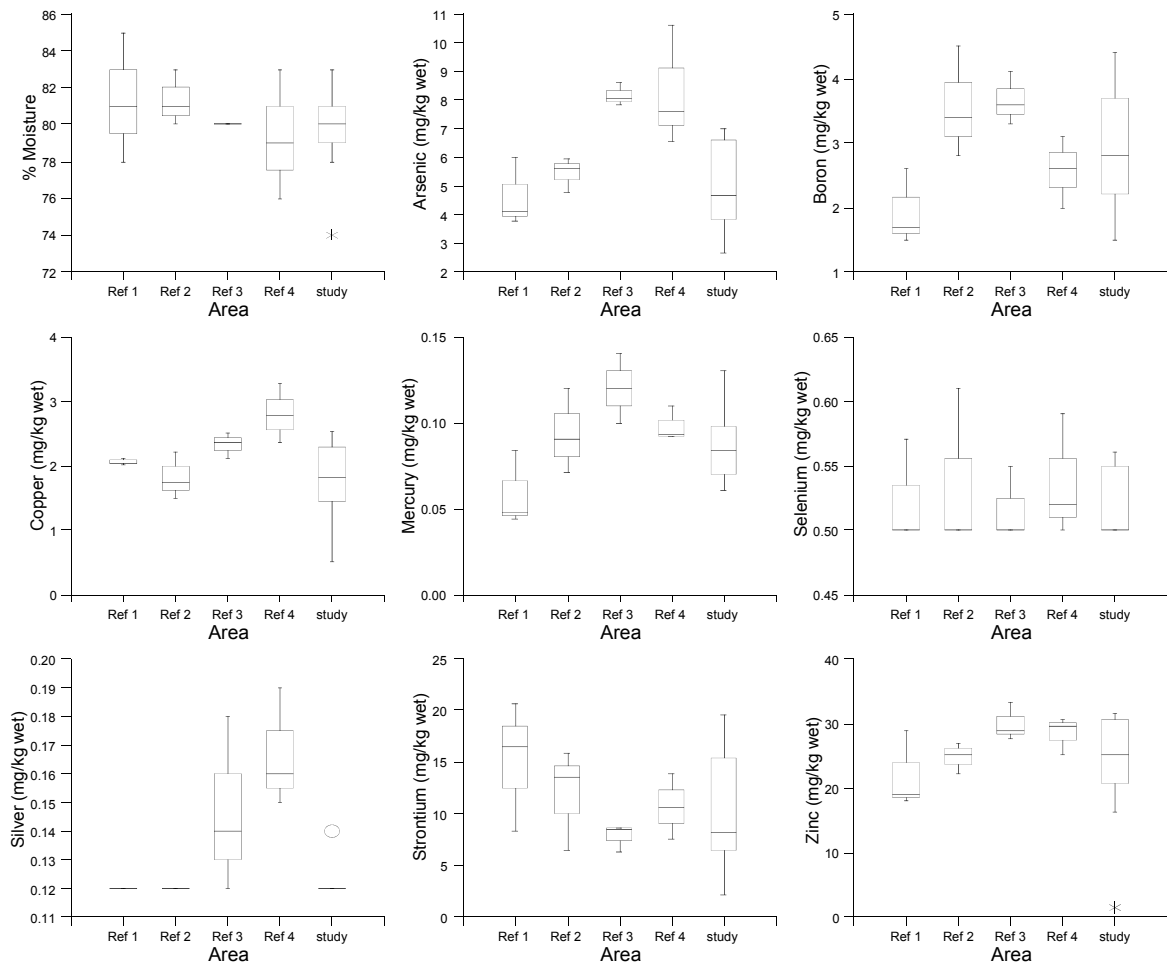


**Figure 6-10    Box Plots of Analyte Concentrations in Crab Claw in Reference and Study Areas (2012)**

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.
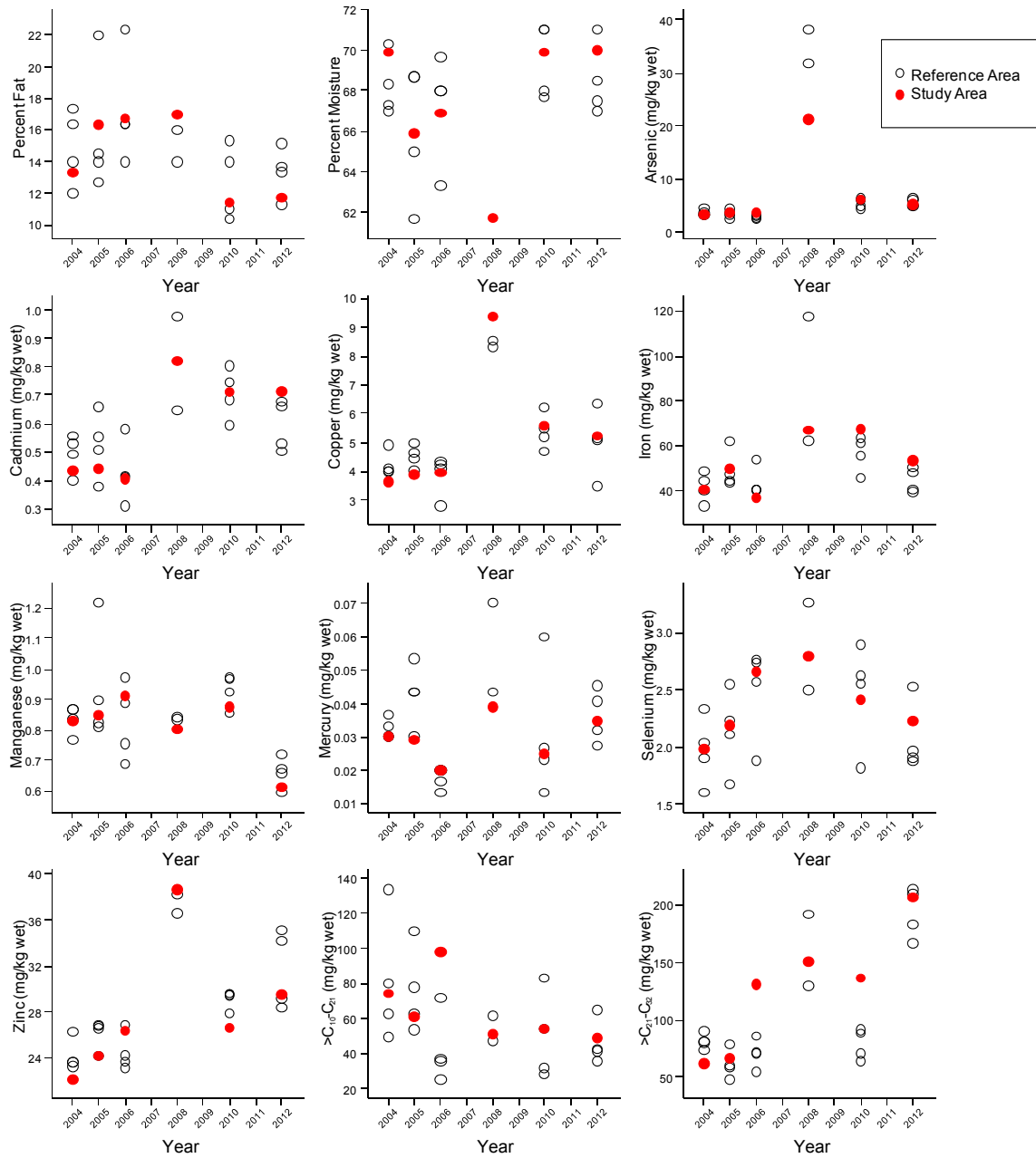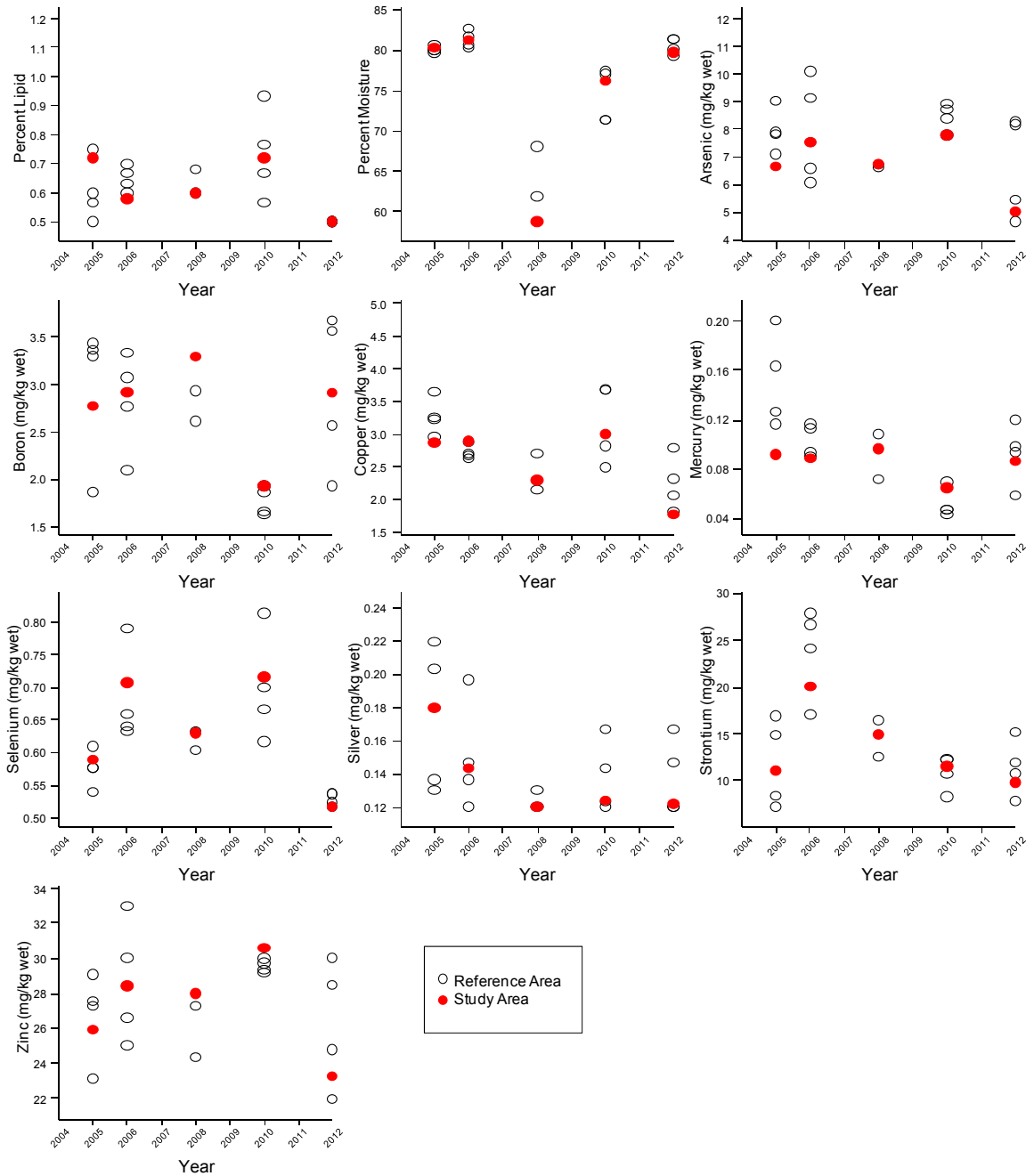
**Figure 6-11    Variation in Area Means of Detectable Analyte Concentrations in Crab Claw Composites from 2004 to 2012**

Note: Values shown are annual averages within Areas.

**Table 6-16**   **Results of ANOVA Testing for Differences in Average Crab Body Burden Variables and Temporal trends Between the Reference Areas and the Study Areas (2004 to 2012)**

| Analyte | Linear | | Quadratic | |
|---|---|---|---|---|
| | Area-Wide Trend | Difference Between Reference and Study | Area-Wide Trend | Difference Between Reference and Study |
| Moisture | 0.027* | 0.518 | 0.136 | 1.000 |
| Arsenic | 0.007** | 0.360 | 0.296 | 0.414 |
| Boron | 0.457 | 0.906 | 0.582 | 0.830 |
| Copper | **<0.001*** | 0.224 | 0.761 | 0.218 |
| Mercury | 0.004** | 0.256 | 0.885 | 0.417 |
| Selenium | 0.004** | 0.427 | 0.041* | 0.141 |
| Silver | **<0.001*** | 0.078 | 0.050 | 0.956 |
| Strontium | 0.585 | 0.525 | 0.001* | 0.798 |
| Zinc | 0.109 | 0.074 | 0.161 | 0.018* |

Notes:  -   Values are probabilities of no trend, or no difference in temporal trends.
-   Analyte concentrations were log-transformed prior to the analyses.
-   Although reported in Figure 6-11, no ANOVA was computed for percent fat because no values were above the laboratory detection limit of 0.05% in 2012.
-   *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

## 6.2.3   Taste Tests

### 6.2.3.1   Plaice

No significant difference in taste was noted between plaice from the Study and Reference Areas in 2012 in both the triangle and hedonic scaling tests. Panelists for the triangle test were successful in discriminating 11 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 ($p$ = 0.53; $\alpha$ = 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 6-17**   **ANOVA for Taste Preference Evaluation of Plaice by Hedonic Scaling (2012)**

| Source of Variation | SS | df | MS | F | *p*-value |
|---|---|---|---|---|---|
| Between Groups | 0.75 | 1 | 0.75 | 0.39 | 0.53 |
| Within Groups | 87.92 | 46 | 1.91 | | |
| Total | 88.67 | 47 | | | |
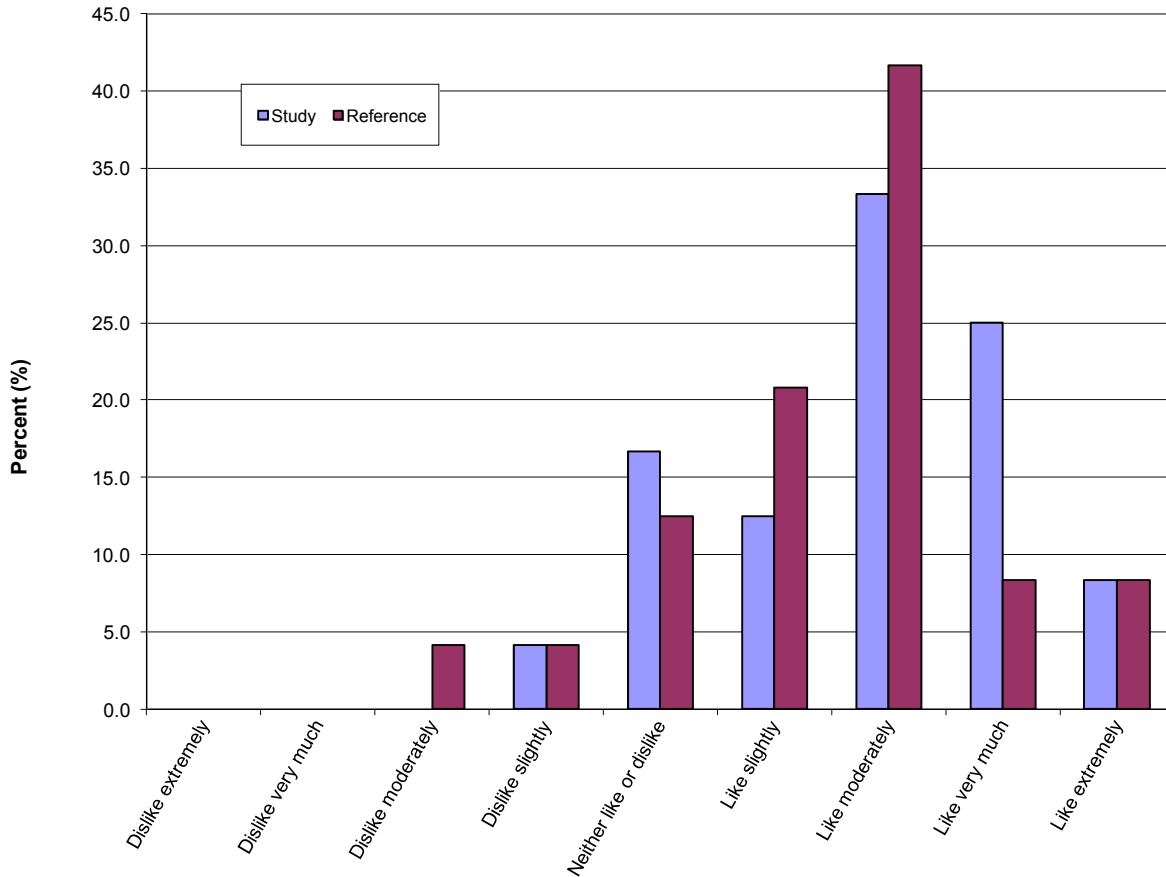
**Figure 6-12    Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2012)**

**Table 6-18        Summary of Comments from the Triangle Taste Test for Plaice (2012)**

| Reference Area (RA) | Study Area (SA) |
|---|---|
| **Correctly identified as odd sample** | **Correctly identified as odd sample** |
| Distinct flavour difference | Slightly different odour; not a strong difference in flavour |
| 432 (RA) had the nicest flavour | Flavour was not as desirable as 179 (RA) and 218 (RA) |
| The first (587 (RA)) had more texture | |
| Preferred taste of 192 (SA) and 271 (SA); slight odour on 587 (RA) and did not taste as good | |
| **Incorrectly identified as odd sample** | **Incorrectly identified as odd sample** |
| I really didn't taste a huge difference in any of the 3 samples | Most flavour #127 (SA) |
| Sample 179 (RA) has a "buttery" flavour; other 2 are drier and more bland; I liked sample 179 (RA) | Very slight difference in odd sample. All samples were very hot for tasting* |
| I liked it all; all smelled OK; not much flavour in all samples | Very slight odour and taste difference |
| No noticeable difference to me | Very mild taste and smell |
| 519 (SA) and 307 (RA) were almost tasteless | I didn't find much of a difference |

Note:    -    *Although samples are normally served at room temperature, one batch of samples was
served immediately after cooking in 2012 (M. Thompson, Marine Institute, St. John's, NL).

**Table 6-19    Summary of Comments from the Hedonic Scaling Taste Test for Plaice (2012)**

| Preferred Reference Area | Preferred Study Area |
|---|---|
| Not much taste to 331 (SA) | 331 (SA) had a codfish taste |
| I found very little difference in the two samples | I found very little difference in the two samples |
| I liked 590 (RA) better; just a little more favourable | 368 (RA) slightly more fishy; 925 (SA) more tasty |
| Not much difference in the 2 samples; 399 (SA) tasted blander to me | Texture of 925 (SA) fuller; 368 (RA) drier |
| 582 (RA) had more taste | 925 (SA) smelled good, a little bland; 368 (RA) smell not appealing, funny aftertaste |
| No real difference | 925 (SA) had a more desirable flavour |
|  | Sample 428 (RA) had small bones; fishy flavour was stronger than 875 (SA) |
|  | 428 (RA) stronger flavour |
|  | 399 (SA) and 582 (RA) were very weak in taste |
|  | No real difference |

### 6.2.3.2  Crab

No significant difference in taste was noted between crab from the Study and Reference Areas in both the triangle and hedonic scaling tests. Panelists for the triangle test were successful in discriminating only 7 out of 24 samples. These results were not significant at $\alpha$ = 0.05 (Appendix C-3). ANOVA statistics for hedonic scaling are provided in Table 6-19. The results were not significant ($p$ = 0.94; $\alpha$ = 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 6-20    ANOVA for Taste Preference Evaluation of Crab by Hedonic Scaling (2012)**

| Source of Variation | SS | df | MS | F | *p*-value |
|---|---|---|---|---|---|
| Between Groups | 0.02 | 1 | 0.02 | 0.01 | 0.94 |
| Within Groups | 153.96 | 46 | 3.35 | | |
| Total | 153.98 | 47 | | | |
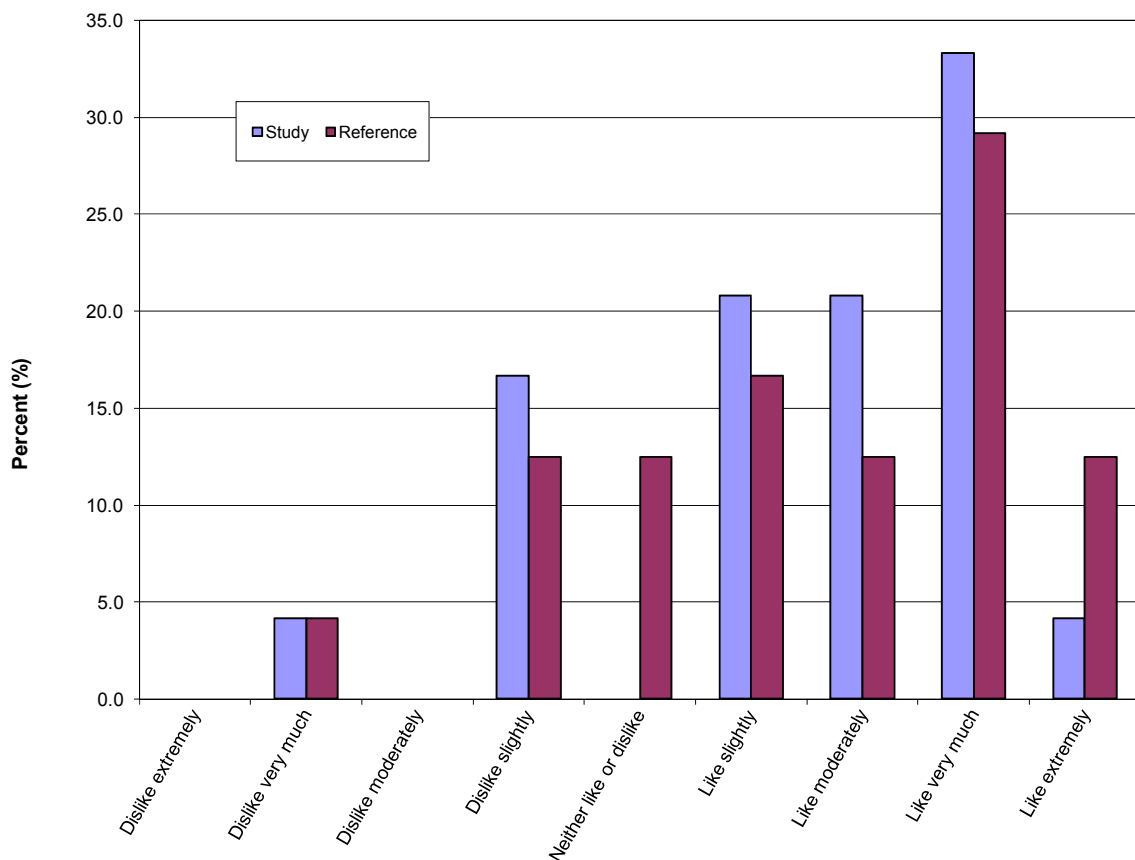
**Figure 6-13      Crab Frequency Histogram for Hedonic Scaling Taste Evaluation (2012)**

**Table 6-21      Summary of Comments from the Triangle Taste Test for Crab (2012)**

| Reference Area (RA) | Study Area (SA) |
|---|---|
| **Correctly identified as odd sample** | **Correctly identified as odd sample** |
| 657 (RA) had a stronger taste and smell | Flavour not as strong on 778 (SA) |
| Did not like | The above samples are nearly identical; all taste good and smell the same |
| 741 (RA) tasted more bland than the other two | |
| **Incorrectly identified as odd sample** | **Incorrectly identified as odd sample** |
| Extremely difficult to identify the odd one as they all have similar flavour | 868 (SA) was a little more flavourful/sweeter |
| 305 (RA) seemed to have less aroma and less flavour | Odour was not as sweet as 652 (SA) or 657 (RA); the taste was less sweet as well |
| I found 468 (RA) to be a little less bitter than the other 2 | Very little noticeable difference; 868 (SA) slightly bitter aftertaste |
| A very slight difference; difficult to choose one | 652 (SA) bland, little fishy |
| 958 (RA) bland; very little taste | Very little difference |
| Not as much flavour/taste on 118 (RA) | All taste similar; 931 (SA) a little different |
| | Couldn't detect a difference |

**Table 6-22        Summary of Comments from Hedonic Scaling Taste Tests for Crab (2012)**

| Preferred Reference Area | Preferred Study Area |
|---|---|
| Both very good | Both very good |
| Both were very good | Slightly more flavour on sample 523 (SA) |
| Tasted the same, no difference | Both were very good |
| Not much of a difference in flavour | The second was slightly tastier |
| 331 (SA) bitter | Tasted the same, no difference |
| 605 (RA) had a good, sweet crab taste; 331 (SA) was dryish and bland, not a good flavour | The flavour of the two samples is similar |
| Both samples were good | Both samples were good |
| 796 (SA) more chaulky-like than 149 (RA) | 796 (SA) - slight characteristic odour; flavour - slight sweet/pleasant; 149 (RA) neutral odour |
| Odour is fine; taste bland, pasty; seems a little less flavour; found both had after taste | I found a little bit of a bitter aftertaste on 149 (RA) |
| 883 (RA) tasted better overall | No real difference; 393 (SA) seemed to be a little more flavourful |
| 393 (SA) was a little metallic but very good. 883 (RA) I did not notice the metallic taste | |
| No real difference; 393 (SA) seemed to be a little more flavourful | |

### 6.2.4   Fish Health

#### 6.2.4.1  Sex Ratios and Maturity Stages

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

Females outnumbered males in every Area, accounting for 155 or 86% of the 180 fish processed. Sex ratios (F:M≈6.2:1) did not differ ($p$ = 0.11; Fisher's Exact Test) between the combined Reference Areas (F:M≈6.8:1) and the Study Area (F:M≈6.1:1).

All but 2 of the 25 males were mature and approximately 40% were spent. There were no significant differences ($p$ = 0.58; Fisher's Exact Test) in frequencies of maturity stages between the combined Reference Areas and the Study Area for males.

Most (60%) of the females examined were mature (n = 93 of 155 fish) and most of these (67%) were spent (n = 63 of 93 fish). Frequencies of pre-spawning and spent mature females did not vary significantly between the combined Reference Areas and the Study Area (p = 0.72, Fisher's Exact Test).

#### 6.2.4.2  Size, Age and Condition

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

None of the size or age-related variables (including ANCOVA equivalents of condition, liver and gonad indices) differed among Reference Areas or between Study and

Reference Areas for males, pre-spawning females and spent females (see Appendix C-4 for details).

For immature females, significant differences between the Study Area and the combined Reference Areas were observed for gutted weight versus length (CF equivalent) and liver weight versus gutted weight (HSI equivalent).

Immature females from the Study Area were heavier (10%, based on least squares means) than immature females from the Reference Areas ($p$ = 0.004). One immature female from the Study Area was considerably heavier (828 g) than other fish of the same length. When this fish was excluded from the data set, immature females from the Study Area remained on average heavier (6% heavier with the heaviest fish removed).

The average liver weight of immature females from the Study Area was 5.8 g, whereas the average from the Reference Areas was 7.2 g (*i.e.*, a difference of approximately 23%, and significant at a *p*-value of 0.023).

Significant differences were also observed among Reference Areas for immature female length, gutted weight, age and gonad weight versus gutted weight (GSI equivalent), with immature females from Reference Area 3 generally lighter and younger.

### 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 (Appendix C-3, Annex C).

### 6.2.4.4   Haematology

Blood smears collected this year displayed signs of clotting and were considered of insufficient uniformity for carrying out reliable differential cell counts. Preliminary screening of the smears indicated that counts could vary by ± 20% or more upon examination of different regions of a slide. In human haematology, when 200 cells are counted, the variability is normally in the ±7 to 10% range (Lynch *et al.* 1969). Oceans Ltd. considered the quality of smears too poor and the variability too high in the 2012 fish for carrying out haematological analysis.

The blood smear procedure followed onboard vessel in 2012 was the same as the procedure used successfully since 2005. The poor quality of the 2012 smears was observed in almost all samples, independent of the technologist making the smears, indicating a problem more likely associated with the materials/chemicals used. These included syringes, capillary tubes, ethylenediaminetetraacetic acid (EDTA) tubes to prevent clot formation, slides and methanol. It is not known if the clotting was linked to the batch of EDTA tubes used. In future programs, the EDTA tubes will be tested just prior to the survey to make sure that they display adequate anti-clotting properties.

### 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

immature, 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), and because there were adequate data to examine the influence of maturity level on MFO activity.

MFO enzyme activities, measured as EROD, in the liver of males (all maturity stages combined) and immature, pre-spawning and spent females are provided in Appendix C-3, Annex D, and results are summarized in Figures 6-14 and 6-15. EROD activity was greater in males (generally 20 to 40 pmol/min/mg protein) than in pre-spawning (~10 to 20 pmol/min/mg protein) or spent females (generally 10 to 20 pmol/min/mg). Activity in immature females ranged from approximately 10 to 40 pmol/min/mg.
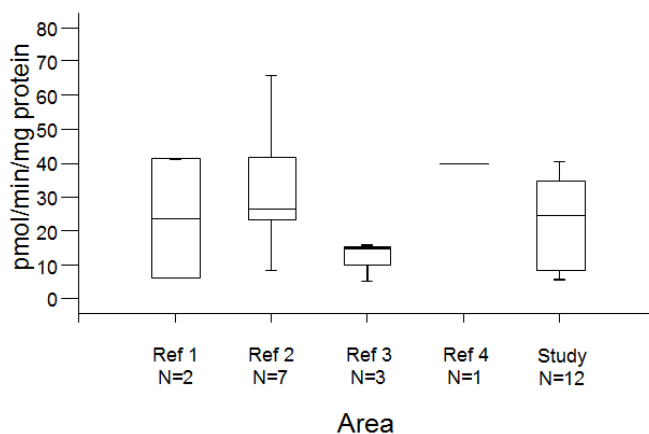


**Figure 6-14       Box Plots of EROD Activity in the Liver of Male Plaice (All Maturity Stages Combined)**

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. Asterisks indicate values falling within the quartile ±3 x interquartile spread. Open circles indicate values falling outside the quartile ±3 x interquartile spread.
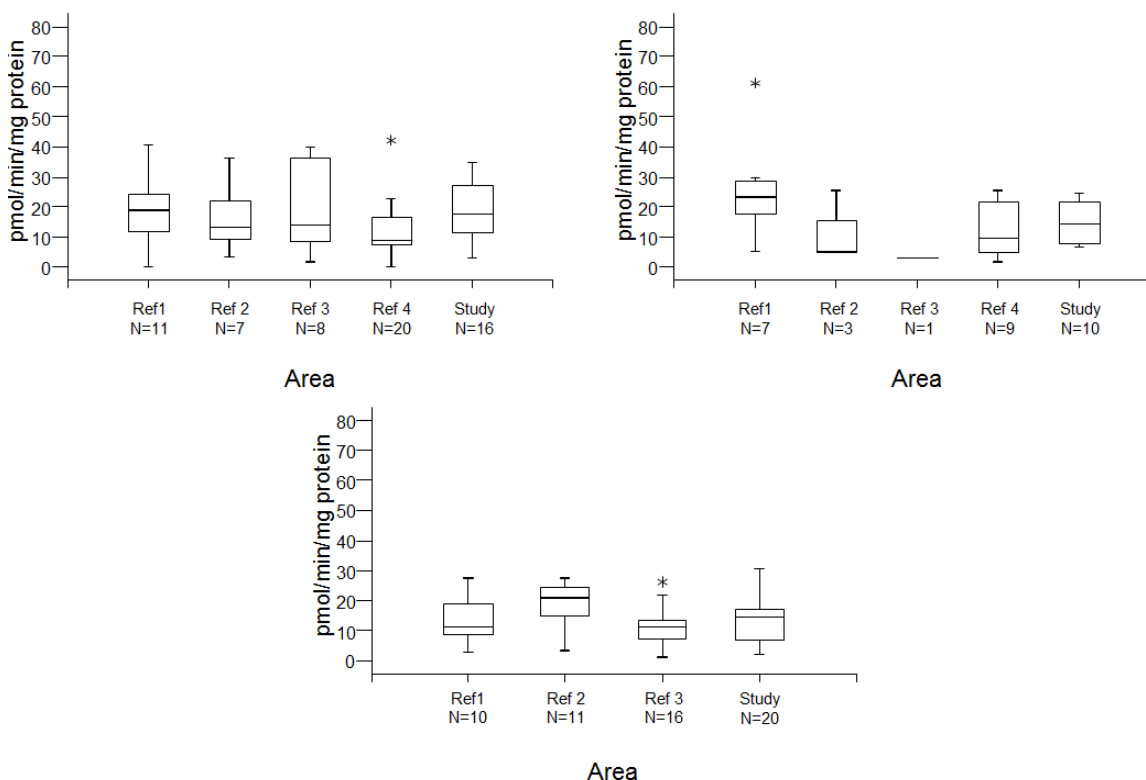
**Figure 6-15**　　**Box Plots of EROD Activity in the Liver of Immature, Pre-spawning and Spent Female Plaice**

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.

EROD activity did not differ significantly between fish from the Study Area and fish from the combined Reference Areas or among fish from the Reference Areas, regardless of gender or spawning condition (Table 6-23).

**Table 6-23**　　**Results of ANOVA Comparing MFO Activities in Male and Female Plaice (2012)**

| | *p*-value | |
|---|---|---|
| **Variable (Y)** | **Among References (AR)** | **Study versus References (SR)** |
| Males | 0.271 | 0.683 |
| Immature Females | 0.271 | 0.550 |
| Pre-Spawn Females | 0.065 | 0.214 |
| Spent Females | 0.189 | 0.602 |

Notes:　-　MFO activities were log-transformed.
　　　　-　See Appendix C-3, Annex A for maturity stage classifications.

### 6.2.4.6　Histopathology

**Liver Histopathology**

A total of 180 livers were examined, 60 from the Study Area and 30 from each of the four Reference Areas. Results were expressed as percentage of fish affected by each type of lesion/observation (or prevalence of lesion) in each Area (Table 6-24). The complete data set is provided in Appendix C-3, Annex E. Representative photographs of normal

liver, as well as a number of histological changes, are included in Appendix C-3, Annex G.

Nuclear pleomorphism was observed in two fish from Reference Area 3. One of the two cases was also associated with megalocytic hepatosis (Appendix C-3, Annex G, Photo 2).

Three cases of small 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. One case with a couple of clear cell foci (Appendix C-3, Annex G, Photo 3) was noted in a fish from Reference Area 1, one case of a very small unclassified focus surrounded by fibrotic tissue (Appendix C-3, Annex G, Photo 4) was detected in a fish from Reference Area 3, while one case of an eosinophilic focus was found in a fish from the Study Area (Appendix C-3, Annex G, Photo 5).

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

Eleven cases of inflammatory response were noted. In all cases, the inflammation was localized in a single small area of the section. The responses were rated as mild in three fish from Reference Area 1 and three fish from Reference Area 4; moderate in one fish from Reference Area 2, one fish from Reference Area 3 and two fish from the Study Area; and severe in one fish from Reference Area 4 (see Appendix C-3, Annex G, for representative photographs).

**Table 6-24     Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions (2012)**

| Hepatic Lesions | Measure | Area | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Ref 1 | Ref 2 | Ref 3 | Ref 4 | All Ref | Study | Grand Total |
| Number of Fish | | 30 | 30 | 30 | 30 | 120 | 60 | 180 |
| Nuclear Pleomorphism | Number | 0 | 0 | **2** | 0 | **2** | 0 | **2** |
| | % | 0 | 0 | 7 | 0 | 2 | 0 | |
| Megalocytic Hepatosis | Number | 0 | 0 | **1** | 0 | **1** | 0 | **1** |
| | % | 0 | 0 | 3 | 0 | 1 | 0 | |
| Eosinophilic Focus | Number | **0** | 0 | **0** | 0 | **0** | 1 | **1** |
| | % | 0 | 0 | 0 | 0 | 0 | 2 | |
| Basophilic Focus | Number | **0** | 0 | **1** | 0 | **1** | **0** | **1** |
| | % | 0 | 0 | 3 | 0 | 1 | 0 | |
| Clear Cell Focus | Number | **1** | 0 | **0** | 0 | **0** | **0** | **1** |
| | % | 3 | 0 | 0 | 0 | 0 | 0 | |
| Proliferation of Macro phage Aggregates [a] | Number | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | % | 0 | 0 | 0 | 0 | 0 | 0 | |
| Fibrillar Inclusions | Number | 0 | 0 | **1** | 0 | **1** | 0 | **1** |
| | % | 0 | 0 | 3 | 0 | 1 | 0 | |
| Biliary Duct Hyperplasia | Number | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | % | 0 | 0 | 0 | 0 | 0 | 0 | |
| Hepatocellular Carcinoma | Number | 0 | 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 | 0 | |
| Cholangiofibrosis | Number | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | % | 0 | 0 | 0 | 0 | 0 | 0 | |

| Hepatic Lesions | Measure | Area | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Ref 1 | Ref 2 | Ref 3 | Ref 4 | All Ref | Study | Grand Total |
| Hydropic Vacuolation | Number | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | % | 0 | 0 | 0 | 0 | 0 | 0 | |
| Inflammation Response [b] | Number | **3** | **1** | **1** | **4** | **9** | **2** | **11** |
| | % | 10 | 3 | 3 | 13 | 8 | 3 | |
| Hepatocellular Vacuolation | Number | 9 | 11 | 8 | 10 | 38 | 25 | 63 |
| | % | 30 | 37 | 27 | 33 | 32 | 42 | |
| Parasites | Number | 11 | 16 | 12 | 16 | 55 | 28 | 83 |
| | % | 37 | 53 | 40 | 53 | 46 | 47 | |
| Golden Rings | Number | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| | % | 0 | 0 | 0 | 0 | 0 | 2 | |

Notes:   -   [a] Defined as scores greater than 3 on a 0 to 7 relative scale.
         -   [b] Inflammation response including mild, moderate and severe scores.

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

Golden rings were detected around bile ducts in one fish from the Study Area (Appendix C-3, Annex G, Photo 8).

There were also two cases of fish, one in the Study Area and one in Reference Area 1, with hepatocytes with pronounced cytoplasmic vacuolation and nuclei pushed at the periphery of the cell (Appendix C-3 Annex G, Photo 9). Vacuoles were clear and spherical, typical of fat accumulation in the cytoplasm of hepatocytes. It is of note that this condition was not accompanied by other lesions such as pyknotic nuclei or necrosis.

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

**Gill Histopathology**

Accurate gill histopathology counts were not possible for four fish from the Reference Areas and three fish from the Study Area. Detailed histopathological studies were therefore carried out on gill tissues of 116 fish from the Reference Areas and 57 fish from the Study Area.

There were no cases of epithelial lifting in fish from any Area and the percentages of lamellae affected by the other lesions were very low (all were less than 4.2%, except for one fish from Reference Area 3, with 21.30% of lamellae exhibiting telangiectasis.

Means ±1 standard deviation of percentages of lamellae presenting each type of lesion are provided in Table 6-25. Significant differences were observed among Reference Areas for fusion, with a higher percentage of fusion in Reference Area 3 than in the other Reference Areas ($p$ = 0.003). However, there were no significant differences in the percentages of lamellae presenting each type of lesion between Reference and Study Areas ($p$ > 0.05, Table 6-26).

**Table 6-25    Occurrence of Lesions and Oedema Condition in the Gill Tissues of Plaice (2012)**

| Statistics | Area | | | | | |
|---|---|---|---|---|---|---|
| | Ref 1 | Ref 2 | Ref 3 | Ref 4 | Study | Total |
| Number of Fish | 30 | 29 | 30 | 27 | 57 | 173 |
| Distal Hyperplasia [a] | 0.294±0.71 | 0.094±0.24 | 0.175±0.38 | 0.029±0.13 | 0.089±0.48 | 0.13±0.45 |
| Tip Hyperplasia [a] | 0.089±0.14 | 0.021±0.06 | 0.094±0.16 | 0.058±0.09 | 0.058±0.19 | 0.063±0.15 |
| Basal Hyperplasia 1 [a c] | 0.325±0.79 | 0.174±0.66 | 0.303±0.83 | 0.221±0.45 | 0.123±0.4 | 0.211±0.61 |
| Basal Hyperplasia 2 [a d] | 0±0 | 0±0 | 0±0 | 0±0 | 0±0 | 0±0 |
| Fusion [a] | 0.049±0.22 | 0.01±0.06 | 0.223±0.54 | 0.008±0.04 | 0.037±0.11 | 0.061±0.26 |
| Telangiectasis [a] | 0.019±0.06 | 0.023±0.1 | 0.826±3.95 | 0.013±0.05 | 0.033±0.17 | 0.159±1.62 |
| Oedema Rating [b] | 1.07±0.96 | 1.13±1.01 | 0.66±0.77 | 1.15±0.77 | 1.07±0.92 | 1.02±0.9 |

Notes:　-　Values are means $\pm$ 1 standard deviation.
　　　　-　[a] Mean percentage of lamellae presenting the lesion.
　　　　-　[b] Mean of rating on a relative 0-3 scale.
　　　　-　[c] Basal hyperplasia 1: increase in thickness of the epithelium reaching 1/3 to 2/3 of total lamellar length.
　　　　-　[d] Basal hyperplasia 2: increase in thickness of the epithelium reaching more than 2/3 of total lamellar length.

**Table 6-26　　Results of ANOVA Comparing Gill Lesions in Plaice (2012)**

| Variable (Y) | *p*-value | |
|---|---|---|
| | Among Reference (AR) | Study versus References (SR) |
| Distal Hyperplasia | 0.143 | 0.417 |
| Tip Hyperplasia | 0.205 | 0.765 |
| Basal Hyperplasia 1 [a] | 0.766 | 0.185 |
| Basal Hyperplasia 2 [b] | No variation in this indicator | |
| Fusion | 0.003 | 0.373 |
| Telangiectasis | 0.148 | 0.473 |
| Oedema Rating | 0.123 | 0.641 |

Notes:　-　[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.

An additional statistical comparison was carried out on the number of fish exhibiting lesions between the Study Area versus the combined Reference Areas (Table 6-27), using Fisher's Exact Test. Lesions were considered "present" if occurring on any of the lamellae examined for each fish.

None of the gill lesions occurred either more or less frequently in Study Area fish compared to Reference Area fish (Fisher Exact test, *p* > 0.05 in all cases).

**Table 6-27　　Number of Plaice with Specific Types of Gill Lesions and Percentages of Fish Exhibiting the Lesions (2012)**

| Gill Lesions | Measure | Area | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ref 1 | Ref 2 | Ref 3 | Ref 4 | All Reference | Study |
| Number of Fish | | 30 | 29 | 30 | 27 | 116 | 57 |
| Distal Hyperplasia | Number | 11 | 5 | 10 | 2 | 28 | 7 |
| | % | 37 | 17 | 33 | 7 | 24 | 12 |
| Tip Hyperplasia | Number | 11 | 3 | 9 | 9 | 32 | 10 |
| | % | 37 | 10 | 30 | 33 | 28 | 18 |
| Basal Hyperplasia 1 [a] | Number | 10 | 6 | 9 | 7 | 32 | 10 |
| | % | 33 | 21 | 30 | 26 | 28 | 18 |
| Basal Hyperplasia 2 [b] | Number | 0 | 0 | 0 | 0 | 0 | 0 |
| | % | 0 | 0 | 0 | 0 | 0 | 0 |
| Fusion | Number | 2 | 1 | 5 | 1 | 9 | 6 |
| | % | 7 | 3 | 17 | 4 | 8 | 11 |
| Telangiectasis | Number | 4 | 2 | 6 | 2 | 14 | 4 |

| Gill Lesions | Measure | Area | | | | | |
|---|---|---|---|---|---|---|---|
| | | Ref 1 | Ref 2 | Ref 3 | Ref 4 | All Reference | Study |
| | % | 13 | 7 | 20 | 7 | 12 | 8 |

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

## 6.3    Summary of Findings

### 6.3.1   Biological Characteristics

There was no significant difference in gutted weight between the Reference Area composites and Study Area composites for plaice used in body burden analyses. Similarly, there were no significant differences in biological characteristics (carapace width and claw height) between Areas for crab composites used in body burden analyses.

Plaice biological characteristics (sex ratio, maturity stage, length, gutted weight, age and a variety of condition indices) were also examined within the context of fish health analyses. There were no significant differences in sex ratio and maturity stage between the Reference Areas and the Study Area. There were also no significant differences among Areas for all size- and age-related variables for male, pre-spawning and spent female plaice. However, for immature female plaice, there were significant differences between the Study Area and the Reference Areas for gutted weight versus length (a CF index equivalent) and liver weight versus gutted weight (an HSI equivalent). Immature female plaice in the Study Area were heavier (by approximately 6%) than immature females from the Reference Areas, and immature females from the Reference Areas had larger livers than immature females from the Study Area (average = 5.8 g in the Study Area versus 7.2 g in the combined Reference Areas).

### 6.3.2   Body Burden

In 2012, there were no significant differences in plaice liver between the Study Area and the Reference Areas for all frequently detected compounds (%fat, %moisture, arsenic, cadmium, copper, iron, manganese, mercury, selenium, zinc, $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$). Compounds in the $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ hydrocarbon range were again detected in liver. 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 natural, perhaps diet related, rather than petrogenic in origin. There were also no significant differences between the Study Area and the Reference Areas in trends over time (2004 to 2012). Arsenic, cadmium, copper, selenium, zinc and $>C_{21}$-$C_{32}$ concentrations all significantly increased in livers of plaice between 2004 and 2012 in the Study and Reference Areas. Manganese and $>C_{10}$-$C_{21}$ decreased significantly between 2004 and 2012, again in all Areas. Selenium concentrations increased from 2004 to 2006, and decreased from 2010 to 2012 across all Areas.

There were no significant differences in fat, moisture, mercury, arsenic and zinc content between the Study Area and the Reference Areas for plaice fillets in 2012. There were also no significant differences between the Study Area and the Reference Areas in trends over time (2004 to 2012). Fat content and zinc concentrations generally

decreased over time in fillets of fish from both Study and Reference Areas, while percent moisture in plaice fillets increased over time across both Study and Reference Areas.

In 2012, there were no significant differences in crab tissue between the Study Area and the Reference Areas for frequently detected compounds (%moisture, arsenic, boron, copper, mercury, selenium, silver, strontium and zinc). Concentrations of many compounds were lower in 2012 than in previous years, in all Areas. The only significant difference in trends over time between the Study Area and the Reference Areas was for zinc. Zinc concentration in crab tissue was slightly higher in the Study Area in 2008 and 2010 than in the Reference Area.

### 6.3.3  Taste Tests

There were no significant differences in taste test results between Study and Reference Areas 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 2012 indicated that the health of plaice, as assessed by condition indices, external and internal abnormalities, hepatic MFO enzymes, and liver and gill histopathology, was similar between the Study Area and the Reference Areas. There were no visible lesions or abnormalities on the skin and fins or on internal organs (gill, liver, gonads, digestive tract, musculature and spleen) in any of the fish examined. Hepatic basal levels of EROD activity did not differ significantly between the Study Area and the Reference Areas, regardless of gender or maturity condition (immature, pre-spawning or spent females). With respect to gill histopathology, microstructural changes, which have been associated with chemical exposure, were absent or found in less than 0.3% of secondary lamellae and lesion prevalence did not differ significantly between the Study Area and the Reference Areas. For liver histopathology, a low prevalence of hepatic histopathological changes (less than 2%), which have been associated with chemical exposure, was observed, with no significant differences in prevalence between the Study Area and the Reference Areas.

# 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 to aid in the design of the Water Quality program. In 2010, Husky Energy submitted a Water Quality monitoring program design to the C-NLOPB (Husky Energy 2010).

The Water Quality monitoring program at White Rose currently involves collection of sediment and seawater samples around White Rose and in two Reference Areas located approximately 28 km to the northeast and northwest of the *SeaRose FPSO*. 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 seawater samples or sediment samples. The ultimate goals of the modelling exercises has been to find a potential tracer for produced water and/or fine-tune the Water Quality sampling program at White Rose (details are provided in Husky Energy 2010; also see Section 1).

Because the Water Quality monitoring program at White Rose has been modified based on model results, model results for seawater and sediments are either summarized, for seawater, or provided, for sediment, before field results in the sections that follow.

## 7.2   Seawater

### 7.2.1   Modelling Study

Full model results predicting the concentration of selected produced water constituents in seawater were provided as part of the 2010 EEM report (Husky Energy 2011).

#### 7.2.1.1   Conclusions and Recommendations

Conclusions and recommendations from the seawater modelling exercise were as follows:

- 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 mid-field stations (approximately 1 to 5 km from source) should be effective for those constituents with a high probability of detection. Mid-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.

Recommendations were implemented for the 2012 field program.

## 7.2.2  Field Sampling

### 7.2.2.1  Water Sample Collection

Water collection for the 2012 EEM Program was conducted from August 21 to August 26, 2012, using the offshore supply vessel *Burin Sea*. Collection stations for the 2012 program are shown in Figure 7-1. In accordance with recommendations in Section 7.2.1, samples in the near-field were collected down-wind/current from the *SeaRose FPSO*. In 2012, those stations were located to the southeast of the *SeaRose FPSO*. Mid-field stations were added at 4 km from the *SeaRose FPSO* in the direction of the prevailing seasonal current. Station 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. Compounds analyzed included BTEX, $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ hydrocarbons, PAHs and alkyl PAHs, phenols and alkyl phenols, volatile organic acids, metals, 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, depth (CTD) recorder cast was performed 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 and ammonia were collected at stations W-5SE (middle), W-12R (surface) and 4 (middle). QA/QC samples were collected at the same stations.

### 7.2.2.2  Laboratory Processing

Water samples were processed for constituents listed in Table 7-2. In the previous EEM program (2010), most constituents were processed at RPC, Fredericton, NB. In 2012, in accordance with recommendations in Section 7.2.1, inorganic constituents were processed at Maxxam Analytics (Halifax, NS) because detection limits for most inorganic constituents of interest were lower at that analytical laboratory. TOC was also processed at Maxxam analytics in 2012. 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.
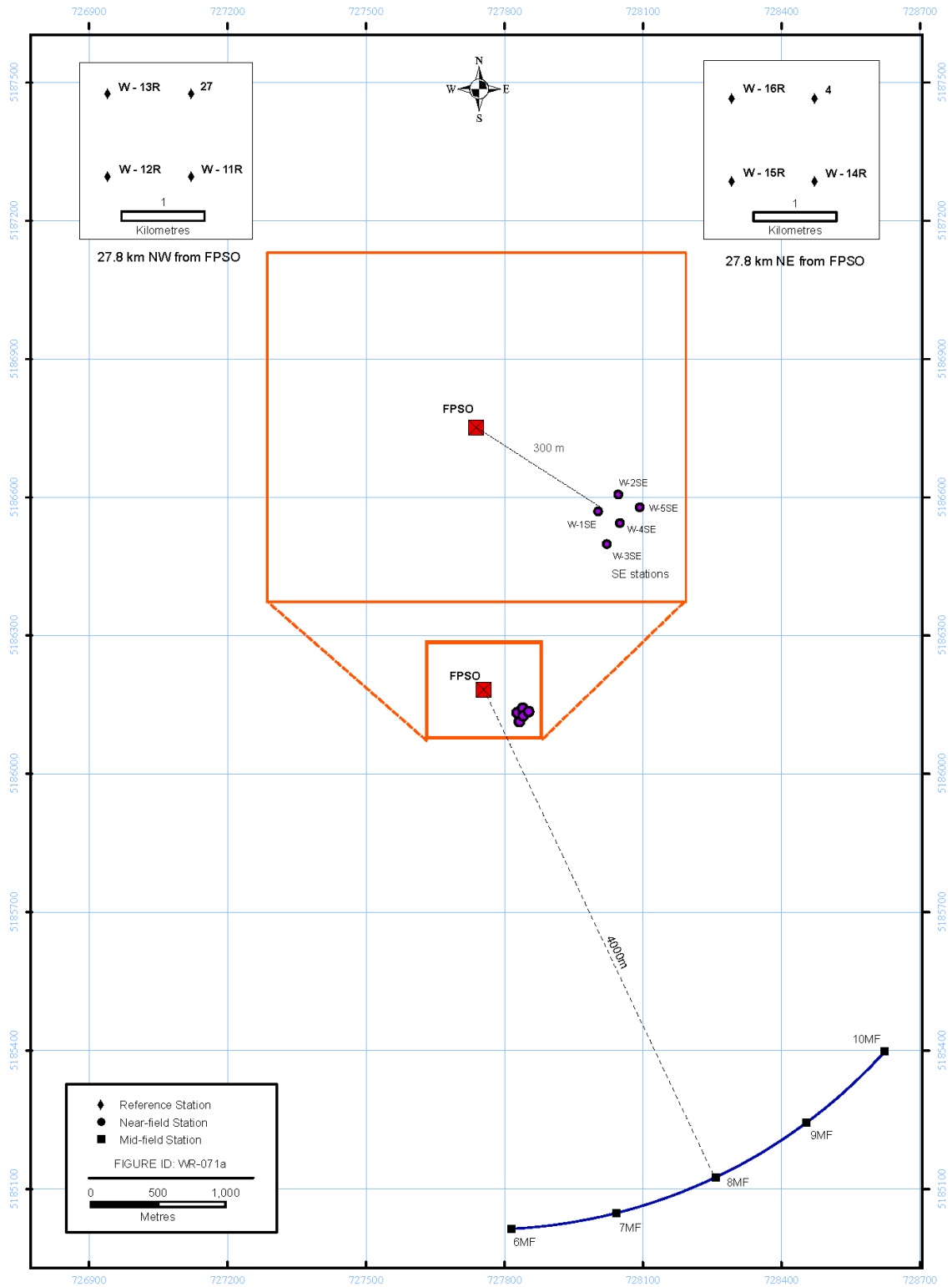
**Figure 7-1      Water Quality Stations (2012)**

**Figure 7-2        Niskin Bottle Water Samples**

**Table 7-1        Water Sample Storage**

| Analysis | Storage Container | Preservative Description and Comments | Storage Temperature | Holding Time |
|---|---|---|---|---|
| Atlantic MUST [a] | 2 – 250 ml clear glass bottles<br>2 – 40 ml vials | Sodium bisulphate<br><br>Sodium bisulphate | 4ºC | 7 days |
| PAHs & Alkyl PAHs | 1 – l L amber glass bottle | None | 4ºC | 7 days |
| Phenols & Alkyl Phenols & Volatile Organic Acids | 1 – 1 L amber glass bottle | None | 4ºC | 7 days |
| Trace Metals | 1 - 120 (or 200 mL) plastic bottle | Nitric acid | 4ºC | 6 month |
| Mercury | 1 - 100 ml amber glass | Potassium dichromate ($K_2Cr_2O_7$ in nitric acid) | 4ºC | 28 days |
| Ammonia | 1 – 100 ml amber glass bottle | Sulphuric acid | 4ºC | 28 days |
| TOC | 1 – 100 ml amber glass bottle | Sulphuric acid | 4ºC | 28 days |
| TSS | 1 L plastic bottle | None | 4ºC | 7 days |
| TIC | 1 – 200 ml plastic bottle | No preservative required. Fill to top | 4°C | 28 Days |
| XCide450 | Analysis conducted in-site in test tubes Water drawn off into bottles | Test to be conducted as soon as water sample is retrieved | none | None – test to be conducted as soon as sample is retrieved |
| SCW4453 | 1 – 125 ml plastic bottle | None | 4ºC | 14 days |

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

**Table 7-2    Water Chemistry Constituents (2010 and 2012)**

| Constituent | Unit | Detection Limit | |
|---|---|---|---|
| | | 2010 | 2012 |
| **Hydrocarbons** | | | |
| Benzene | mg/L | 0.001 | 0.001 |
| Toluene | mg/L | 0.001 | 0.001 |
| Ethylbenzene | mg/L | 0.001 | 0.001 |
| Xylenes | mg/L | 0.001 | 0.001 |
| $C_6$-$C_{10}$ (less BTEX) | mg/L | 0.01 | 0.01 |
| >$C_{10}$-$C_{21}$ | mg/L | 0.05 | 0.05 |
| >$C_{21}$-$C_{32}$ | mg/L | 0.1 | 0.1 |
| **Phenols and Alkyl Phenols** | | | |
| Phenol | µg/L | 10 | 10 |
| *o*-cresol | µg/L | 10 | 10 |
| *m,p*-cresol | µg/L | 10 | 10 |
| Total C2 Phenols | µg/L | 20 | 20 |
| Total C3 Phenols | µg/L | 20 | 20 |
| Total C4 Phenols | µg/L | 20 | 20 |
| Total C5 Phenols | µg/L | 20 | 20 |
| 4-n-hexylphenol | µg/L | 10 | 10 |
| 2,5-diisopropylphenol | µg/L | 10 | 10 |
| 2,6-diisopropylphenol | µg/L | 10 | 10 |
| 2-tert-butyl-4-ethylphenol | µg/L | 10 | 10 |
| 6-tert-butyl-2,4-dimethyphenol | µg/L | 10 | 10 |
| 4-n-heptylphenol | µg/L | 10 | 10 |
| 2,6-dimethyl-4-(1,1-dimethypropyl)phenol | µg/L | 10 | 10 |
| 4-(1-ethyl-1-methylpropyl)-2-methylphenol | µg/L | 10 | 10 |
| 4-n-octylphenol | µg/L | 10 | 10 |
| 4-tert-octylphenol | µg/L | 10 | 10 |
| 2,4-di-sec-butylphenol | µg/L | 10 | 10 |
| 2,6-di-tert-butylphenol | µg/L | 10 | 10 |
| 4-n-nonylphenol | µg/L | 20 | 20 |
| 2-methyl-4-tert-octylphenol | µg/L | 10 | 10 |
| 2,6-di-tert-butyl-4-methylphenol | µg/L | 10 | 10 |
| 4,6-di-tert-butyl-2-methylphenol | µg/L | 10 | 10 |
| **PAHs and Alkyl PAHs** | | | |
| Naphthalene | µg/L | 0.01 | 0.05 |
| Acenaphthylene | µg/L | 0.01 | 0.01 |
| Acenaphthene | µg/L | 0.01 | 0.01 |
| Fluorene | µg/L | 0.01 | 0.01 |
| Phenanthrene | µg/L | 0.01 | 0.01 |
| Anthracene | µg/L | 0.01 | 0.01 |
| Fluoranthene | µg/L | 0.01 | 0.01 |
| Pyrene | µg/L | 0.01 | 0.01 |
| Benzo(*a*)anthracene | µg/L | 0.01 | 0.01 |
| Chrysene/Triphenylene | µg/L | 0.01 | 0.01 |
| Benzo(*b*)fluoranthene | µg/L | 0.01 | 0.01 |
| Benzo(*k*)fluoranthene | µg/L | 0.01 | 0.01 |
| Benzo(*e*)pyrene | µg/L | 0.01 | 0.01 |
| Benzo(*a*)pyrene | µg/L | 0.01 | 0.01 |
| Indenopyrene | µg/L | 0.01 | 0.01 |
| Benzo(*g,h,i*)perylene | µg/L | 0.01 | 0.01 |
| Dibenzo(*a,h*)anthracene | µg/L | 0.01 | 0.01 |
| C1-Naphthalenes [a] | µg/L | 0.05 | 0.10 |
| C2-Naphthalenes [a] | µg/L | 0.05 | 0.10 |
| C3-Naphthalenes | µg/L | 0.05 | 0.10 |
| C1-Phenanthrenes | µg/L | 0.05 | 0.10 |
| C2-Phenanthrenes | µg/L | 0.05 | 0.10 |
| C3-Phenanthrenes | µg/L | 0.05 | 0.10 |
| Dibenzothiophene | µg/L | 0.05 | 0.10 |
| C1-Dibenzothiophenes | µg/L | 0.05 | 0.10 |
| C2-Dibenzothiophenes | µg/L | 0.05 | 0.10 |
| C3-Dibenzothiophenes | µg/L | 0.05 | 0.10 |
| Perylene | µg/L | 0.01 | 0.01 |
| Biphenyl | µg/L | 0.01 | 0.05 |

| Constituent | Unit | Detection Limit | |
|---|---|---|---|
| | | **2010** | **2012** |
| **Organic Acids** | | | |
| Acetic Acid | mg/L | 2 | 2 |
| Propionic Acid | mg/L | 2 | 2 |
| Iso-butyric Acid | mg/L | 2 | 2 |
| Butyric Acid | mg/L | 2 | 2 |
| Iso-valeric Acid | mg/L | 2 | 2 |
| n-valeric Acid | mg/L | 2 | 2 |
| **Radionuclides [b]** | | | |
| Radium-228 | Bq/L | 1 | NA |
| Radium-226 | Bq/L | 0.3 | NA |
| Lead-210 | Bq/L | 1 | NA |
| **Metals** | | | |
| Aluminum | µg/L | 5 | 10 |
| Antimony | µg/L | 1 | 0.5 |
| Arsenic | µg/L | 10 | 0.5 |
| Barium | µg/L | 0.1 | 1 |
| Beryllium | µg/L | 0.05 | 1 |
| Boron | µg/L | 10 | 50 |
| Cadmium | µg/L | 0.05 | 0.05 |
| Calcium | mg/L | 0.05 | 1 |
| Chromium | µg/L | 2 | 0.5 |
| Cobalt | µg/L | 0.5 | 0.10 |
| Copper | µg/L | 5 | 0.5 |
| Iron | µg/L | 10 | 5 |
| Lanthanum | µg/L | 0.2 | NA |
| Lead | µg/L | 0.05 | 0.1 |
| Lithium | µg/L | 5 | 20 |
| Magnesium | mg/L | 10 | 1 |
| Manganese | µg/L | 0.01 | 0.50 |
| Mercury | µg/L | 0.025 | 0.013 |
| Molybdenum | µg/L | 0.1 | 1.0 |
| Nickel | µg/L | 5 | 0.20 |
| Potassium | mg/L | 20 | 1 |
| Phosphorus | µg/L | NA | 50 |
| Selenium | µg/L | 10 | 0.5 |
| Silicon | µg/L | NA | 100 |
| Silver | µg/L | 0.02 | 0.05 |
| Sodium | mg/L | 0.05 | 1 |
| Strontium | µg/L | 10 | 10 |
| Sulfur | mg/L | 0.05 | 20 |
| Tellurium | µg/L | 0.5 | NA |
| Thallium | µg/L | 2 | 0.10 |
| Tin | µg/L | NA | 1.0 |
| Titanium | µg/L | NA | 10 |
| Uranium | µg/L | 0.1 | 0.05 |
| Vanadium | µg/L | 1 | 10 |
| Zinc | µg/L | 1 | 1 |
| **Other** | | | |
| Ammonia (as N) | mg/L | 0.05 | 0.05 |
| TIC | mg/L | 0.5 | 0.5 |
| TOC | mg/L | 0.5 | 5 |
| TSS | mg/L | 5 | 0.5 |
| XCide450 | mg/L | 0.5 | 0.5 |
| SCW4453 | mg/L | 1 | 0.03 |

Note: - [a] Includes 1- and 2-Chloronaphthalene.
- [b] Radionuclide sampling was discontinued in 2012 based on model results that showed that probability of detection in water samples was zero (Husky Energy 2011).

### 7.2.2.3  Data Analysis

Data analyses focused on 2012 data, with qualitative comparisons to 2010 data. Data collected during baseline (2000) are not comparable to EEM 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 2012, the Water Quality component of the White Rose EEM program used a multiple-Reference and multiple Study Area design, with two Reference Areas and one near-field and one mid-field Study Area. Boxplots of variables that occurred above laboratory detection limit in all or most cases were generated for each Area. Values below detection limit were set to ½ detection limit for plotting.

Seven comparisons were tested on frequently detected variables using ANOVA with depth and Area as factors:

- Differences in concentration between the Study Areas and the Reference Areas (SR)

- Differences in concentrations between the Study Areas (BS)

- Differences in concentration between the Reference Areas (BR)

- Differences between the near-field Study Area and the Reference Areas (NF *vs* R)

- Differences between the mid-field Study Area and the Reference Areas (MF *vs* R)

- Differences in depth gradients, overall (Depth)

- Differences in depth gradients among Areas (AD)

Analyses were performed using Systat (version 13). Variables with values less than laboratory detection limit were rank transformed before analysis. Rank transformation treats values below detection limit as tied for the lowest rank. Remaining variables were $\log_{10}$ transformed.

### 7.2.2.4  Results

Raw data and 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 beginning of the thermocline was between approximately 10 to 25 m depth in all Areas.

Arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, nickel, potassium, sodium, strontium, sulphur, uranium and TIC were detected in all samples. SCW4453 was detected in 98% of samples, TSS was detected in 91% of samples, chromium was detected in 87% of samples and zinc was detected in 76% of samples. With the exception of TIC, which varied over the narrow range of 23 to 25 $\mu$g/L, all these variables were included in quantitative analyses below.

Cadmium was detected in 52% of samples (13 out of 30 samples in the Study Areas and 15 out of 24 samples in the Reference Areas). Silicon was detected in 32% of samples (10 out of 30 samples in the Study Areas and 7 out of 24 samples in the Reference Areas). Lead was detected in 20% of samples (six samples in the Study Area and five samples in the Reference Areas). Ammonia was detected in 20% of samples (10 samples in the Study Areas, eight of these bottom samples, and one bottom sample in the Reference Areas). Iron was detected in 17% of samples (three samples in the Study Areas and six samples in the Reference Areas). Copper was detected in 9% of samples (four samples in the Study Areas and one sample in the Reference Areas). $C_6$-$C_{10}$ hydrocarbons (less BTEX) were detected in three samples from the Reference Areas. Low levels of benzene (0.001 to 0.002 $\mu$g/L) were detected in two near-field samples at the surface levels. $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ hydrocarbons, PAHs and alkyl PAHs, phenols and alkyl phenols, organic acids and XCide450 were not detected in water samples.

Boxplots by area and depth for variables with most values above the laboratory detection limit are provided in Figure 7-3. Boxplots are not provided for TIC because values varied over a very narrow range.

There was a clear and significant increasing trend in concentration with depth for most variables (Figure 7.3; Table 7-3) as in 2010 (Husky Energy 2011).
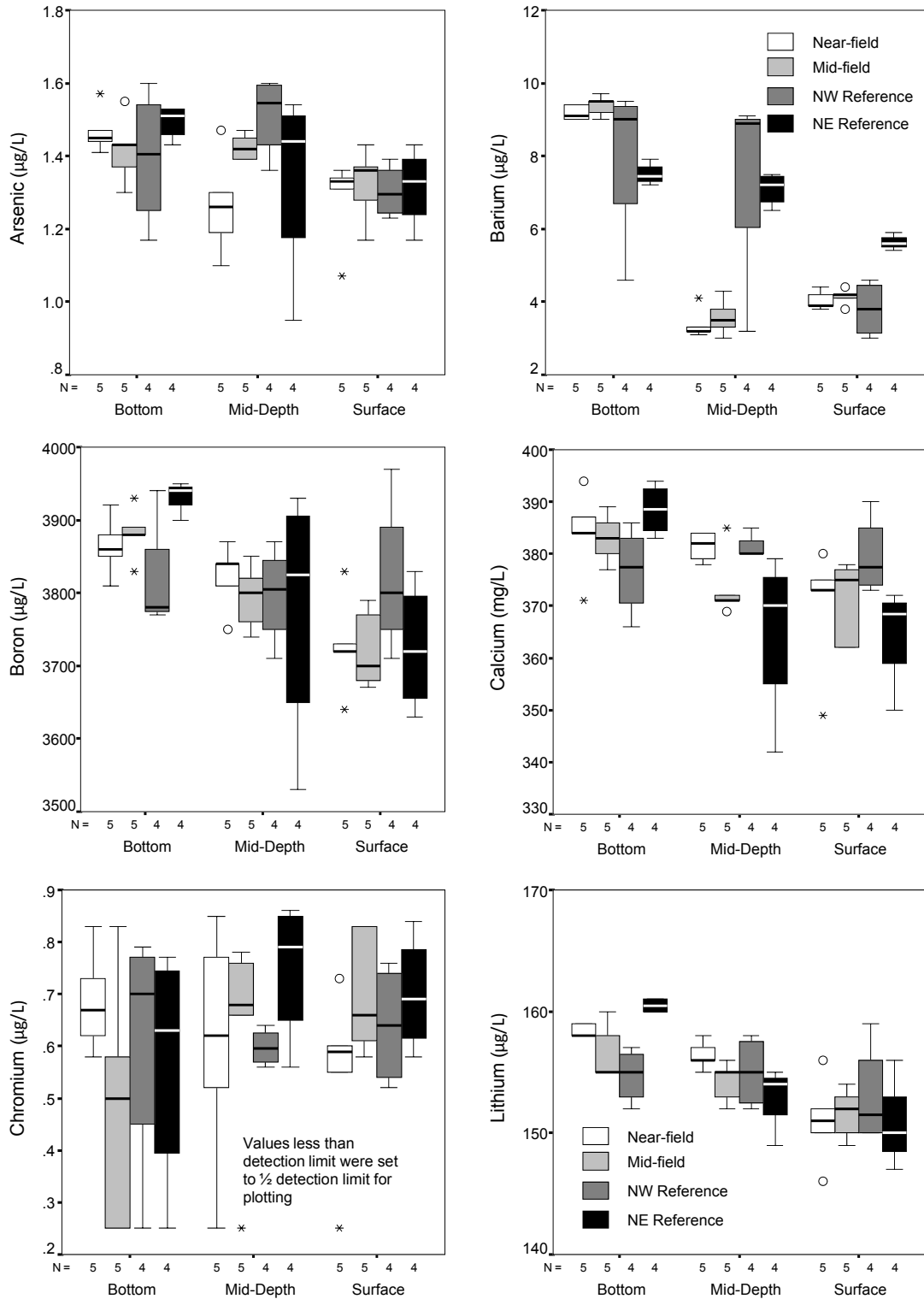
**Figure 7-3        Boxplots of Water Chemistry by Area and Depth**
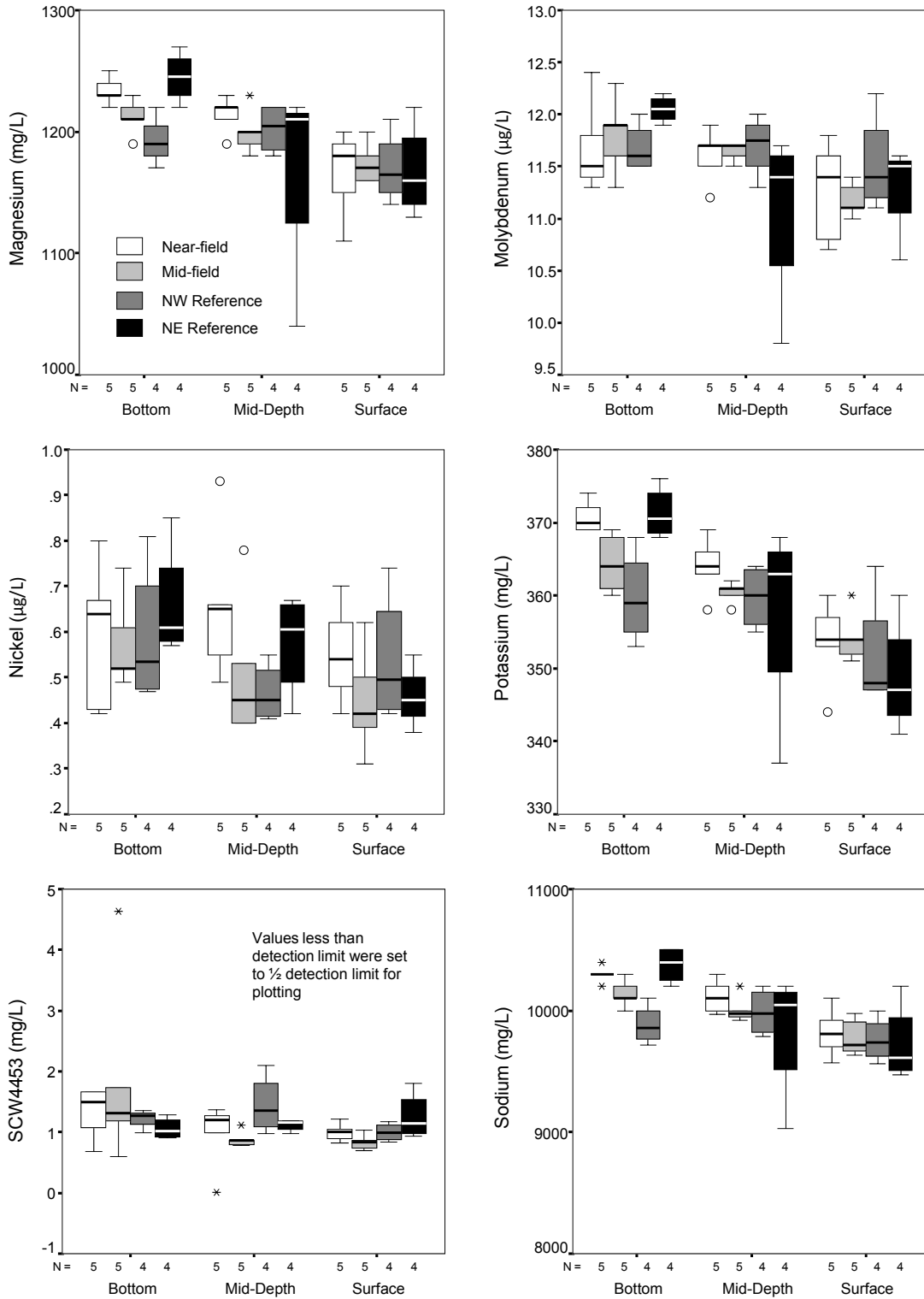
**Figure 7-3    Boxplots of Water Chemistry by Area and Depth (cont.)**
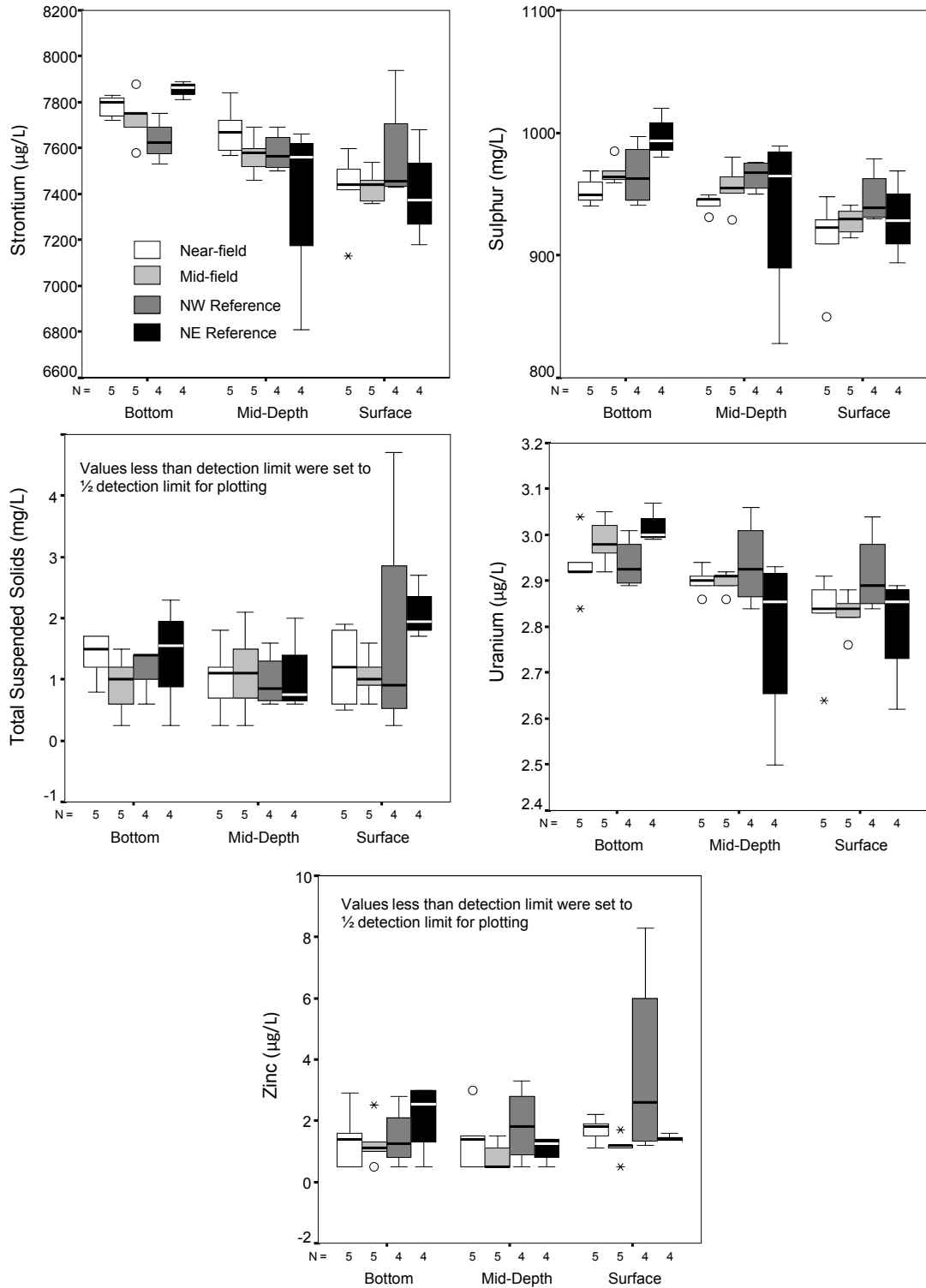
**Figure 7-3      Boxplots of Water Chemistry by Area and Depth (cont.)**

**Table 7-3      Results of ANOVA (*p*-values) Testing Differences Between Areas**

| Variable | *p*-values | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Area | Depth | AxD | SR | BR | BS | NF *vs* R | MF *vs* R |
| Arsenic | 0.603 | 0.015 | 0.188 | 0.477 | 0.282 | 0.680 | 0.414 | 0.745 |
| Barium | **<0.001** | **<0.001** | **<0.001** | **<0.001** | 0.138 | 0.863 | **<0.001** | **<0.001** |
| Boron | 0.978 | **<0.001** | 0.162 | 0.690 | 0.855 | 0.961 | 0.727 | 0.771 |
| Calcium | 0.308 | 0.002 | 0.028 | 0.642 | 0.453 | 0.094 | 0.522 | 0.170 |
| Chromium | 0.704 | 0.737 | 0.325 | 0.649 | 0.884 | 0.283 | 0.779 | 0.315 |
| Lithium | 0.637 | **<0.001** | 0.031 | 0.524 | 0.235 | 0.356 | 0.391 | 0.747 |
| Magnesium | 0.665 | **<0.001** | 0.205 | 0.329 | 0.480 | 0.750 | 0.331 | 0.552 |
| Molybdenum | 0.789 | 0.005 | 0.180 | 0.855 | 0.854 | 0.327 | 0.463 | 0.658 |
| Nickel | 0.246 | 0.051 | 0.492 | 0.881 | 0.057 | 0.502 | 0.602 | 0.778 |
| Potassium | 0.147 | **<0.001** | 0.224 | 0.077 | 0.193 | 0.439 | 0.061 | 0.331 |
| SCW4453 | 0.606 | 0.242 | 0.499 | 0.249 | 0.508 | 0.828 | 0.292 | 0.424 |
| Sodium | 0.188 | **<0.001** | 0.143 | 0.108 | 0.252 | 0.333 | 0.064 | 0.471 |
| Strontium | 0.709 | **<0.001** | 0.095 | 0.523 | 0.463 | 0.516 | 0.901 | 0.369 |
| Sulphur | 0.179 | **<0.001** | 0.420 | 0.101 | 0.158 | 0.615 | 0.107 | 0.304 |
| TSS | 0.267 | 0.411 | 0.518 | 0.398 | 0.399 | 0.112 | 0.778 | 0.105 |
| Uranium | 0.358 | **<0.001** | 0.158 | 0.906 | 0.543 | 0.094 | 0.270 | 0.360 |
| Zinc | 0.112 | 0.268 | 0.725 | 0.108 | 0.077 | 0.553 | 0.101 | 0.343 |

Notes:
- 'Area' tests for differences among the four areas, overall.
- 'Depth' tests for depth differences, overall.
- 'SR' tests for differences between the two Reference Areas and the two Study Areas.
- 'BR' tests for differences between the two Reference Areas.
- 'BS' tests for differences between the two Study Areas.
- 'NF *vs* R' tests for a difference between the near-field and the average of the Reference Areas.
- 'MF *vs* R' tests for a difference between the mid-field and the average of the Reference Areas.
- 'AxD' tests for differences in depth gradients among Areas.
  If AxD was statistically significant, subsequent tests were of the interaction with Depth (*i.e.*, for Lithium and Barium) and tested for differences in depth profiles between groups of areas of interest in the hypothesis.
- Reported *p*-values for Area, Depth, BR, SR, BS, NF *vs* R, and MF *vs* R were from models with the interaction term removed when the interaction term was not significant.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (**in bold**).

With the exception of barium, no significant differences were noted between the Study and Reference Areas in ANOVA for any variable (SR test, Table 7-3). Barium concentrations were higher in bottom samples in the near- and mid-field, and lower in mid-depth and surface samples in those two Areas compared to the Reference Areas (Figure 7-3). ANOVA by depth class confirmed that differences between Areas at each depth were significant (Table 7-4).

**Table 7-4      ANOVA by Depth Class for Barium**

| Depth Class | *p*-values | | | | |
|---|---|---|---|---|---|
| | SR | BR | BS | NF *vs* R | MF *vs* R |
| Surface | 0.037 | <0.001 | 0.716 | 0.052 | 0.109 |
| Mid-depth | <0.001 | 0.903 | 0.740 | <0.001 | <0.001 |
| Bottom | 0.022 | 0.808 | 0.838 | 0.061 | 0.040 |

In 2010, molybdenum and sulphur concentrations differed significantly between the Study Area and the Reference Areas, with concentrations lower in the Study Area. In that year, barium concentrations differed between the two Reference Areas but did not differ between the Study Area and the Reference Areas (Husky Energy 2011). Figure

7-4 plots median barium concentration in 2010 and 2012 in the Study Area (2010)[14], the combined Study Areas (2012) and the combined Reference Areas (2010 and 2012). This figure indicates that differences in median barium concentration were greater in 2012 than in 2010 and that the difference in barium concentration between the combined Study Area and the combined Reference Areas at mid-depth in 2012 (also noted in Figure 7-3 and Table 7-4) results from a decrease in levels in the Study Area compared to 2010 level. Similarly, median barium levels were lower in surface samples in 2012 than in 2010, in both the Study and Reference Areas. In bottom samples, median barium concentration in the Study Area was slightly higher in 2012 than in 2010 (9 μg/L *versus* 8 μg/L) (Figure 7-4).
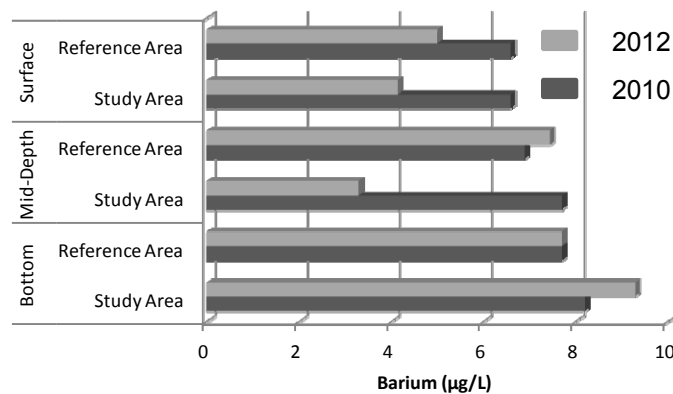


**Figure 7-4      Barium Concentration in the Combined Study and Reference Areas in 2010 and 2012**

## 7.3     Sediment

### 7.3.1   Modelling Study

As was the case for produced water constituents in seawater, DREAM (Dose Related Risks and Effects Assessment Model) was used to simulate the discharge of produced water and the resulting concentrations of constituents in sediments (see Appendix D-4 for details).

#### 7.3.1.1  Constituent Selection

Concentrations of produced water constituents from the *SeaRose FPSO* were compared to concentrations in marine sediments around White Rose to identify those constituents that would likely settle to sediments at sufficiently high concentrations to act as tracers. This exercise drew on chemical characterizations of produced water performed at White Rose from 2007 to 2010 and results of sediment chemistry obtained through the White Rose EEM programs. Of the constituents examined, iron, barium and radionuclides (Ra-226, Ra-228 and Pb-210) were identified as potential tracers and, of these, Ra-228 was modelled.

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[14] Only one Study Area, with stations located up to 1 km from the *SeaRose FPSO*, was sampled in 2010. Reference Areas remained unchanged from 2010 to 2012.

Barium was not modelled because it is discharged with drill muds (*i.e.*, there are multiple sources of barium from White Rose). Iron was excluded because the expected particle size distribution of iron oxyhydroxides that could form is unknown and knowledge of particle size distribution is required to model the deposition of constituents (see Appendix D-4 for details). Various assumptions about the particle size distribution of iron particles could have been made, but since iron is and will continue to be measured at White Rose as part of the EEM program, analysis of EEM data with a particular focus on iron in sediments was judged sufficient to assess iron as a tracer for produced water.

In the White Rose area, naturally occurring Ra-228 is detected less frequently in marine sediments than Ra-226 and Pb-210 (Husky Energy 2010). Based on this, Husky Energy (2010) concluded that, of the three radionuclides, Ra-228 was the most promising potential tracer in sediments for produced water. Radium radionuclides will most often precipitate rapidly from produced water as $Ba,RASO_4$ (Neff 2002; Jerez Vegueria *et al.* 2002; Appendix D-4) and, although there is some uncertainty about the influence of production chemicals (see Appendix D-4), the particle size distribution of $BaSO_4$, and hence $Ba,RASO_4$, in produced water is known (Rye *et al.* 2007).

### 7.3.1.2  Summary of Methods

A produced water concentration of 3 Bq/L Ra-228 was used in simulations based on the median concentration (range <0.3 to 7 Bq/L) in nine produced water samples collected at White Rose from August 2007 to April 2011. Simulations represented one year of Ra-228 deposition from produced water discharges. Maximum allowable release of produced water (28,000 $m^3$/day) was used as the release rate to generate worst-case scenario (*i.e.*, maximum) concentrations. Modelling was performed over 14 months, with discharge for the first 12 months. The last two 'discharge-free' months allowed some time for the final discharges to deposit to sediments. Current data at 23, 63 and 111 m for 2009 from a mooring near White Rose were used. Resuspension of sediments was not considered in simulations.

Concentrations in sediments after 10, 20, 30 and 40 years of discharge were calculated by multiplying output concentrations after one year by 10, 20, 30 and 40, respectively. Resulting concentrations were then scaled down to account for radioactive decay of Ra-228 (half-life: 5.75 years).

More detailed methods are provided in Appendix D-4.

### 7.3.1.3  Summary of Results and Discussion

The expected concentrations of Ra-228 in sediments after 20, 30 and 40 years of produced water release, with and without consideration of radioactive decay, are shown in Figures 7-5, 7-6 and 7-7, respectively. Concentrations of Ra-228 in sediments after 10 years of produced water release were all below the laboratory detection limit of 3 Bq/kg, with or without radioactive decay, and a figure is not provided. Concentrations below the laboratory detection limit in Figures 7-5 to 7-7 are shown in blue to merge with the background.

## Husky Energy
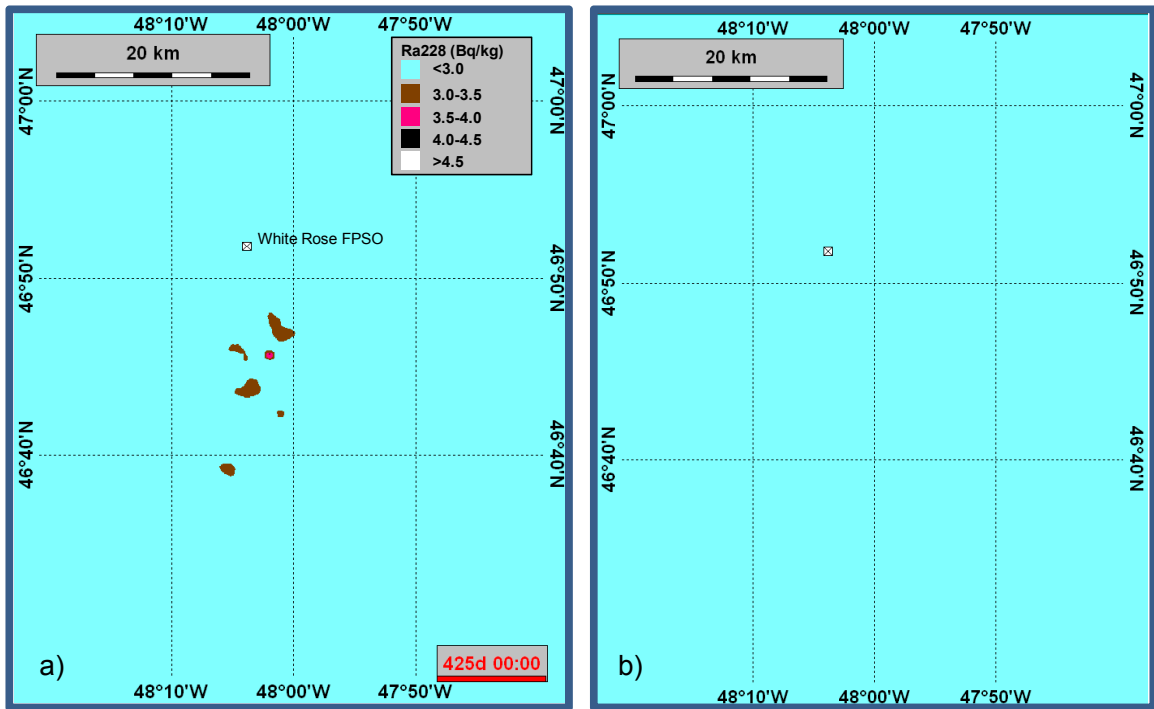


**Figure 7-5**    Expected Concentrations of Ra-228 in Sediments After 20 Years of Produced Water Release, a) without radioactive decay and b) with radioactive decay
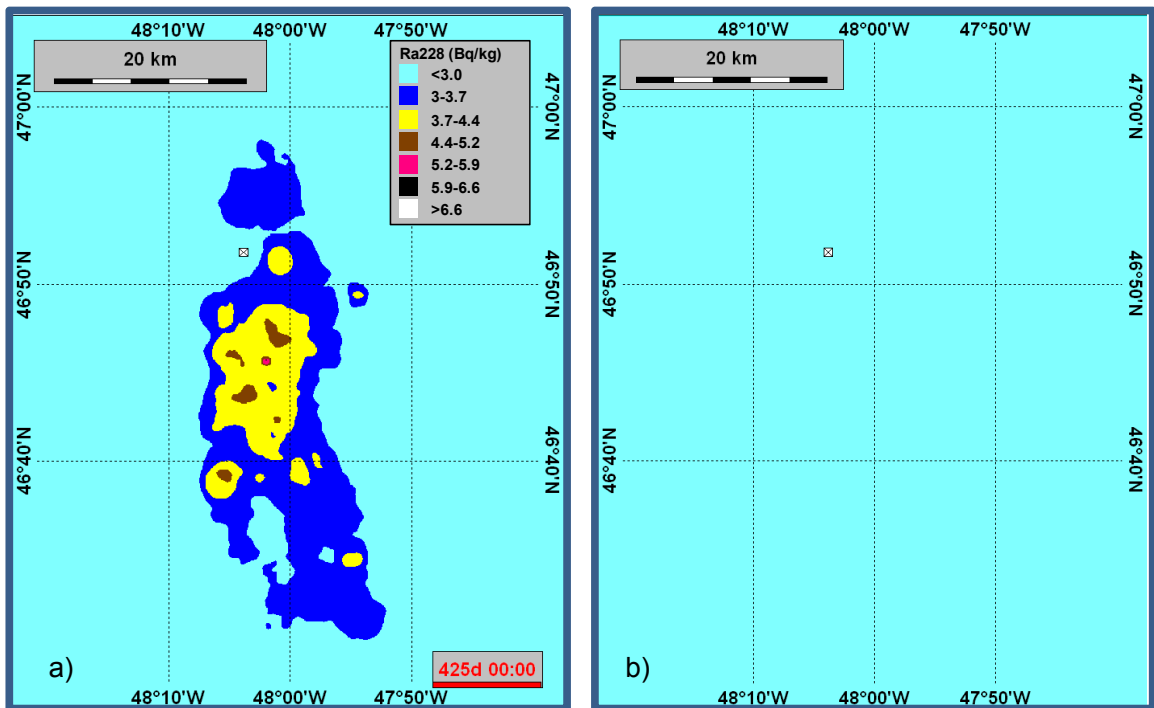


**Figure 7-6**    Expected Concentrations of Ra-228 in Sediments After 30 Years of Produced Water Release, a) without radioactive decay and b) with radioactive decay
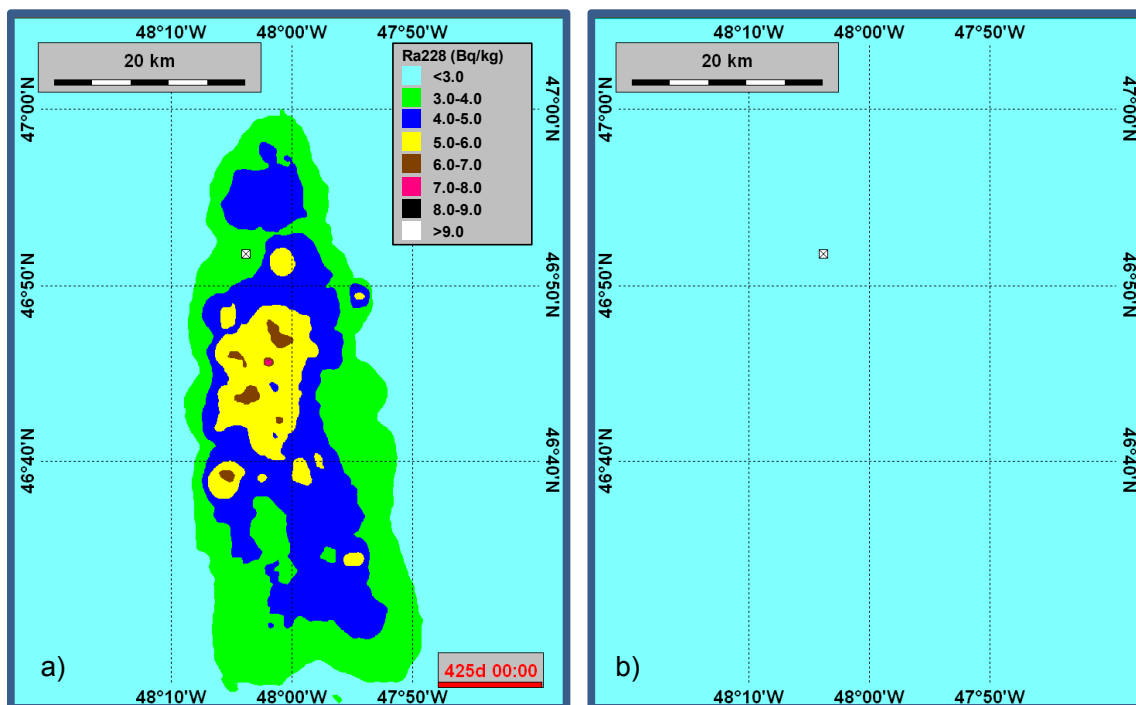
**Figure 7-7     Expected Concentrations of Ra-228 in Sediments After 40 Years of Produced Water Release a) without radioactive decay and b) with radioactive decay**

With a half-life of 5.75 years, 36%, 25% and 19% of accumulated amounts of Ra-228 are expected to remain in sediments after 20, 30 and 40 years, respectively. If scaling factors of 36%, 25% and 19% are applied to the maxima in Figures 7-5 to 7-7, maxima then become 1.62, 1.65 and 1.71 Bq/kg, respectively, and all values are below the laboratory detection limit of 3 Bq/kg.

Although not specifically modelled, results with Ra-228 are applicable to Ra-226, because Ra-228 and Ra-226 will both bind to $BaSO_4$ and median concentration of Ra-226 in White Rose produced water is 3 Bq/L, like that of Ra-228. The half-life of Ra-226 is much longer than the half-life of Ra-228 (1,601 years versus 5.75 years) and, on that time scale, radioactive decay does not need to be considered in model output (*i.e.*, Figures 7-5a, 7-6a and 7-7a can also be used to represent expected concentration of Ra-226). However, since the lowest detection limit for Ra-226 in sediments is 10 Bq/kg, concentrations of this radionuclide in sediments as a result of produced water release are also expected to be below detection limit around White Rose, even after 40 years at maximum produced water discharge.

Although below detection limit, the highest concentrations of radionuclides are expected approximately 10 km 'down current', rather than in the immediate vicinity of the *SeaRose FPSO*. Given this, it is fair to assume that other constituents within produced water would also have a higher probability of settling to the south of the *SeaRose FPSO*, although the distance at which these other constituents settle would depend on their particle size. Nevertheless, since iron is also expected to settle out of produced water at potentially detectable concentrations, examination of field data should address iron

concentration with distance from the *SeaRose FPSO*, with particular attention paid to concentrations to the south of White Rose.

Detailed results and discussion are provided in Appendix D-4.

### 7.3.1.4  Conclusions and Recommendations

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

- Radium radionuclides are not expected to be effective tracers of produced water constituents in sediments.

- Based on this, the collection and examination of sediment radionuclide data as a potential tracer for produced water was discontinued.

- Close attention should be paid to any increase in iron concentrations in sediments, particularly to the south, since modelling showed that deposition of constituents likely would be greater to the south of the *SeaRose FPSO*.

### 7.3.2  Field Sampling

### 7.3.2.1  Sediment Sample Collection and Laboratory Processing

Sediment collection and laboratory processing are described in Section 5. In addition to the sediment stations sampled as part of the Sediment Quality component of the EEM program (*i.e.*, Sediment Quality Triad stations), one sediment core was also collected for chemistry analysis at those stations sampled for water (Figure 7-1).

### 7.3.2.2  Data Analysis

Quantitative analysis of sediment data for the Water Quality portion of the White Rose EEM program focuses on iron concentration in sediments, as per recommendations in Section 7.3.1.4. Quantitative analyses on other sediment quality variables at Sediment Quality Triad stations are provided in Section 5.

The following procedures were used to determine if iron concentrations in sediments were associated with releases from the *SeaRose FPSO*. The analysis was carried out in four main steps. First, correlations between iron concentrations in sediments and distance to the *SeaRose FPSO* were computed for each year. Plots of the Spearman rank correlations over time were produced, to make it easier to visualize changes in the strength of the distance relationship. The second step involved the production of scatterplots of iron concentrations in relation to distance from the *SeaRose FPSO*, for each year of the program. The third step involved maps of iron concentration in 2012 relative to baseline concentration to better visualize the full spatial distribution of iron. The fourth step involved the use of repeated-measures regression to test for changes in mean iron concentrations across the sampling area from before (2000, 2004, 2005, 2006) to after (2008, 2010, 2012) discharge from the *SeaRose FPSO*. As was the case in Section 5, repeated-measures regression involved only those stations sampled repeatedly over all years ($n$ = 36).

Iron tends to covary with other metals in the sampling area. There was some concern that the background variations in metals concentrations might mask variations in iron that were due to discharge from the *SeaRose FPSO*. A two-step procedure was carried out in order to create a measure of iron concentrations that was independent of the concentrations of other metals. Principal components analysis (PCA) was carried out in the first step using logged concentrations of aluminum, barium, chromium, lead, manganese, strontium, uranium and vanadium. The PCA axis scores were used as summary measures of overall metals concentrations in the sediments, similar to what has been done in the assessment of metals concentrations in relation to active drill centres (Section 5). Residuals from regression of iron concentrations ($\log_{10}$) on PCA axis scores can be considered to be representative of variations in iron that are independent of concentrations of other metals. The second step was regression of iron on PCA axis scores. Residuals of iron were then examined using Spearman rank correlations, scatterplots, maps and repeated-measures regression, similar to what was done with concentrations of iron.

### 7.3.2.3  Results

Summary statistics for sediment physical and chemical characteristics at Water Quality stations are provided in Appendix D-2. Raw data for sediment physical and chemical characteristics at all sediment stations (Sediment Quality Triad and Water Quality stations) are provided in Appendix B. Sediment chemistry results at Water Quality stations were qualitatively similar to results at Sediment Quality Triad stations, with aluminum, barium, iron, lead, manganese, strontium, uranium and vanadium detected at every station[15]. In 2012, low levels of 15 PAHs were detected in sediments at station W-2SE, located 0.32 km from the *SeaRose FPSO*. In 2010, low levels of four PAHs were detected at Station 16[16], located 0.74 km from the *SeaRose FPSO*. Otherwise, PAHs have not been detected in White Rose sediments.

**Principal Components Analysis**

All metals were strongly associated (*i.e.*, $r_P$ > |0.6|) with scores on the first PCA axis (Table 7-5). The first PCA axis, therefore, was a good summary of overall concentrations of metals. Barium concentrations correlated strongly with both the first and second PCA axes. The second axis, therefore, was a summary of variations in barium that were independent of variations in overall metals concentrations. Barium is examined in detail in Section 5. Residuals of iron concentrations ($\log_{10}$) were obtained from regression against scores on the first PCA axis.

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[15] Two stations, 4 and 27, were common to both the Sediment Quality and the Water Quality programs in 2012. Four stations, 4, 8, 16 and 27, were common to both the Sediment Quality and the Water Quality programs in 2010. Therefore, summary statistics for these sets of stations are not fully independent.
[16] In 2010, station 16 acted as both an Sediment Quality Triad and a Water Quality station. Therefore, those PAHs are in summary statistics for both Sediment Quality Triad and Water Quality stations.

**Table 7-5　　Principal Components Analysis of Metals Concentrations (all Years)**

| Parameter | Principal Component | |
|---|---|---|
| | 1 | 2 |
| Aluminum | **0.78** | 0.14 |
| Barium | **0.63** | **-0.67** |
| Chromium | **0.78** | 0.33 |
| Lead | **0.71** | -0.58 |
| Manganese | **0.75** | 0.48 |
| Strontium | **0.85** | -0.45 |
| Uranium | **0.69** | 0.23 |
| Vanadium | **0.77** | 0.43 |
| Variance Explained | 56 | 20 |

### Spearman Rank Correlations

Spearman rank correlations for iron in relation to distance to the *SeaRose FPSO*, and for iron residuals, for all years, are illustrated in the Figures 7-8 and 7-9. Spearman rank correlations were not significant in 2012 for iron, or for iron residuals. Rank correlations were not significant for iron in any year (Figure 7-8). Rank correlations were significant for iron residuals when all stations were considered in 2005, and when only repeated-measures stations were considered in 2010 (Figure 7-9).
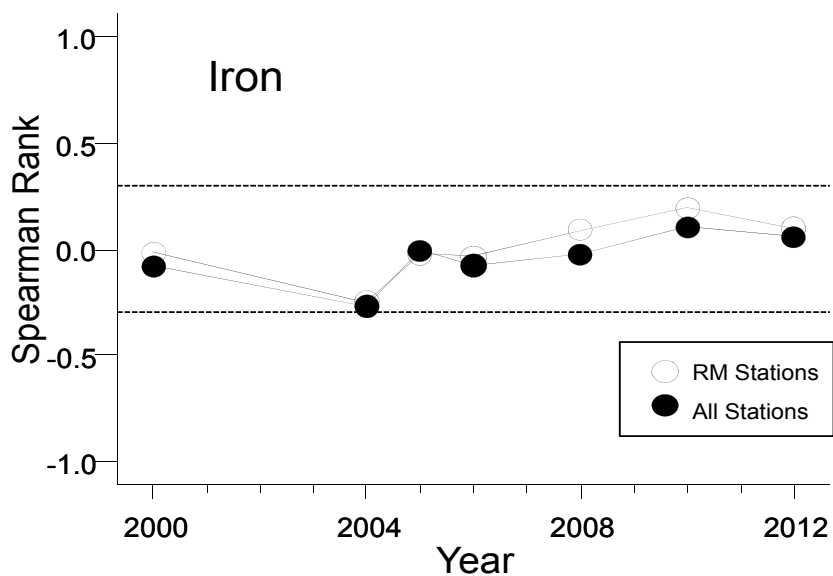


**Figure 7-8　　Spearman Rank Correlations with Distance from *SeaRose* FPSO for Iron Concentrations in Sediments**

Notes: Dotted lines indicate rank correlations of |0.3|, which were generally significant at *p* < 0.01, depending on sample size in the given year (*n* = 36 for repeated-measures stations, and varies from 44 in 2005 to 69 in 2012).
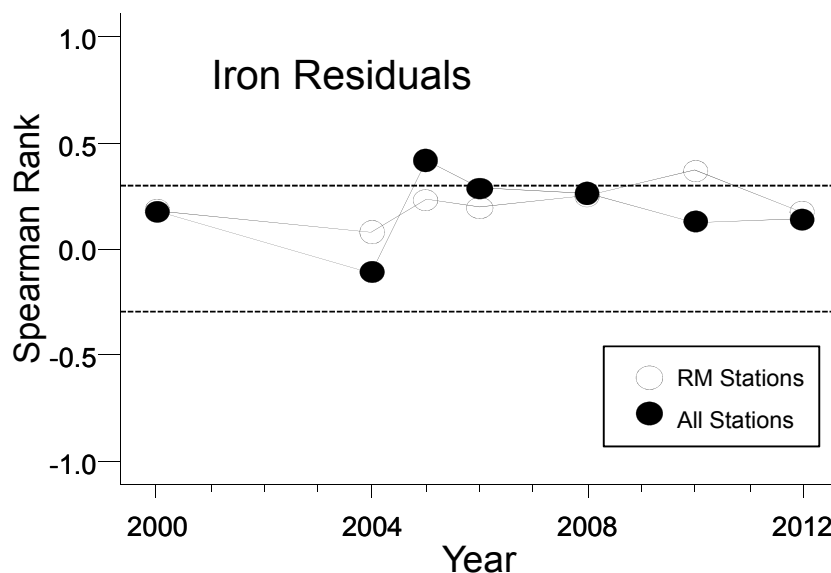
**Figure 7-9        Spearman Rank Correlations with Distance from the *SeaRose* FPSO for Iron Residuals**

Notes: Dotted lines indicate rank correlations of |0.3|, which were generally significant at *p* < 0.01, depending on sample size in the given year (*n* = 36 for repeated measures stations, and varies from 44 in 2005 to 69 in 2012).

**Scatterplots**

The relationships between iron concentrations and iron residuals and distance to the *SeaRose FPSO* are illustrated in the Figures 7-10 and 7-11. The plots indicate no increase in iron concentrations in sediments near the *SeaRose FPSO*. The plots may indicate an increase in iron concentrations in 2008, 2010 and 2012 relative to the data from prior years, with this potentially more apparent for residual iron concentrations (Figure 7-11).

**Maps**

Maps of stations with iron and iron residuals within and above the baseline background range are provided in Figures 7-12 and 7-13. Iron concentrations in Figure 7-12 are not corrected for the natural association between iron and other metals, and metals concentrations are elevated at the northeast Reference Area. Those four stations are deeper than remaining stations and this could reflect a natural tendency for metals to increase with depth. The map of iron residuals (Figure 7-13), which would correct for the natural association among metals, does not show unusually high iron at those four stations, relative to concentrations of other metals.

In general, Figure 7-13 shows a tendency for higher iron residuals between 5 and 10 km from the *SeaRose FPSO*, with more frequent enrichment to the south of the *SeaRose FPSO*. Iron residuals are not elevated at stations nearest the Central and Southern Drill Centres, where most of the drilling has occurred to date. That indicates that if the source of iron enrichment is project related, it is probably not be related to drilling.
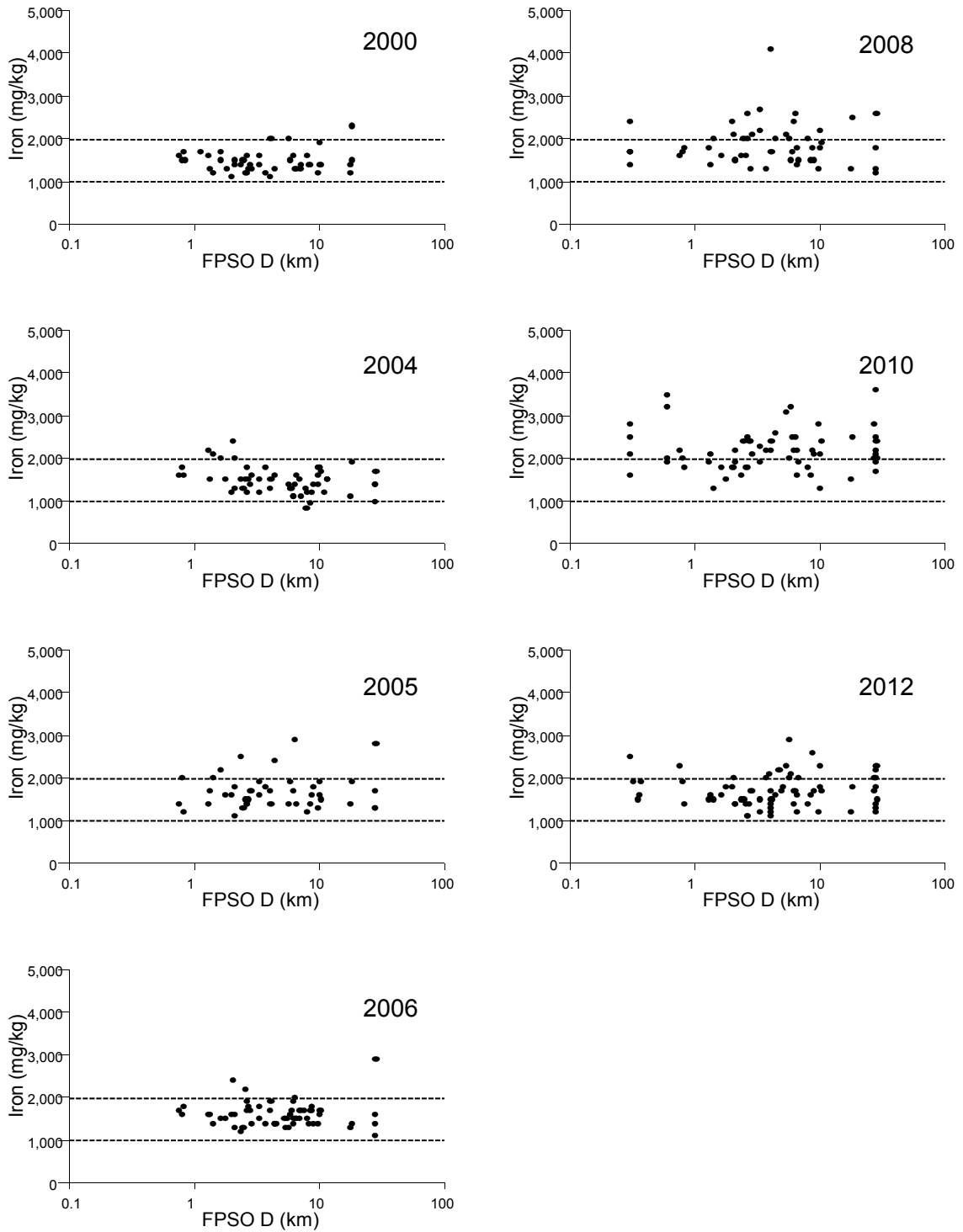
**Figure 7-10    Variation in Iron Concentrations in Sediments (mg/kg) with Distance from the *SeaRose FP*SO (all Years)**

Notes: *SeaRose FPSO* D = distance (km) to the *SeaRose FPSO*. Background iron concentrations are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).
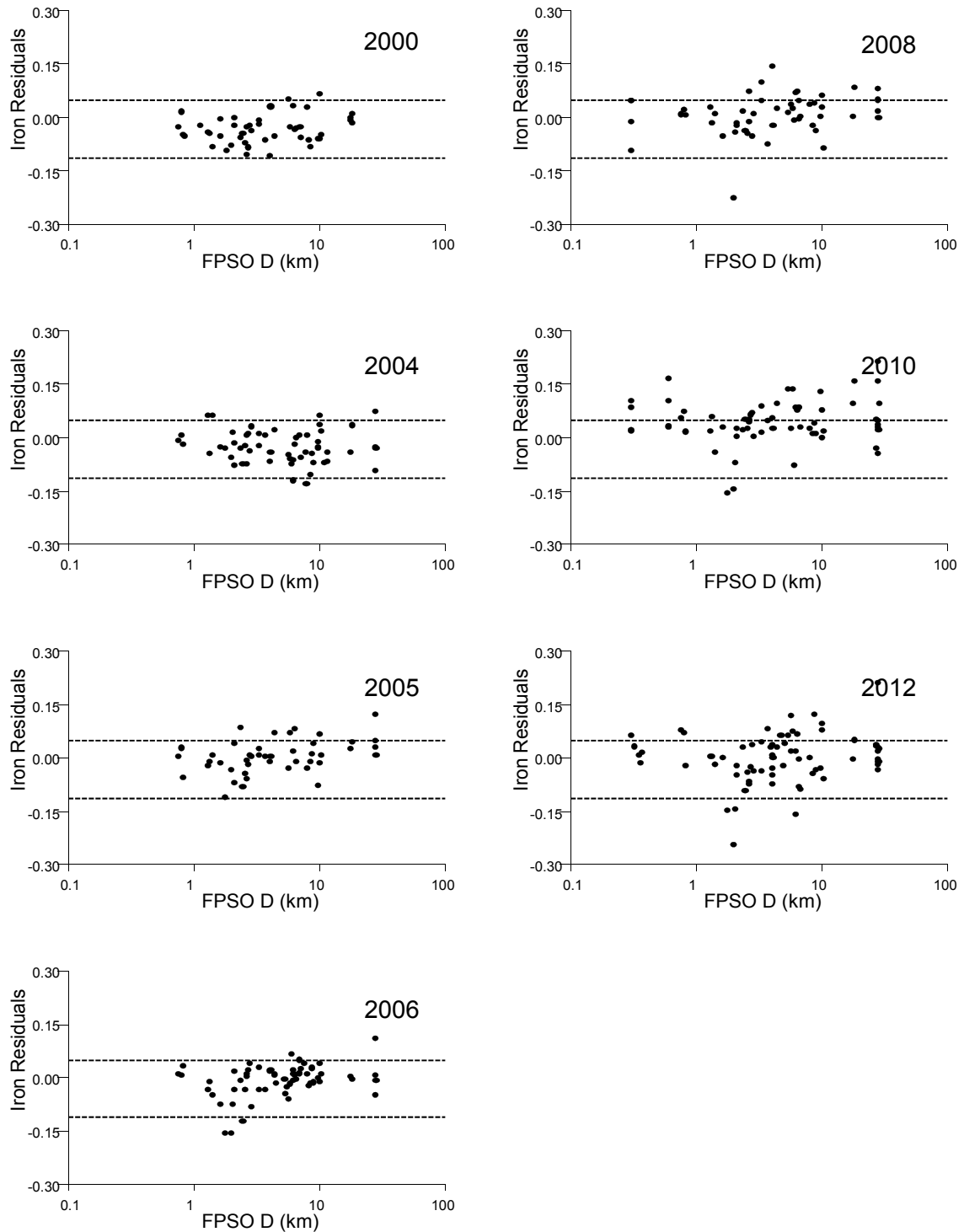
**Figure 7-11      Variation in Iron Residuals with Distance from the *SeaRose FPSO* (all Years)**

Notes: *SeaRose FPSO* D = distance (km) to the *SeaRose FPSO*. Background iron residuals are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).
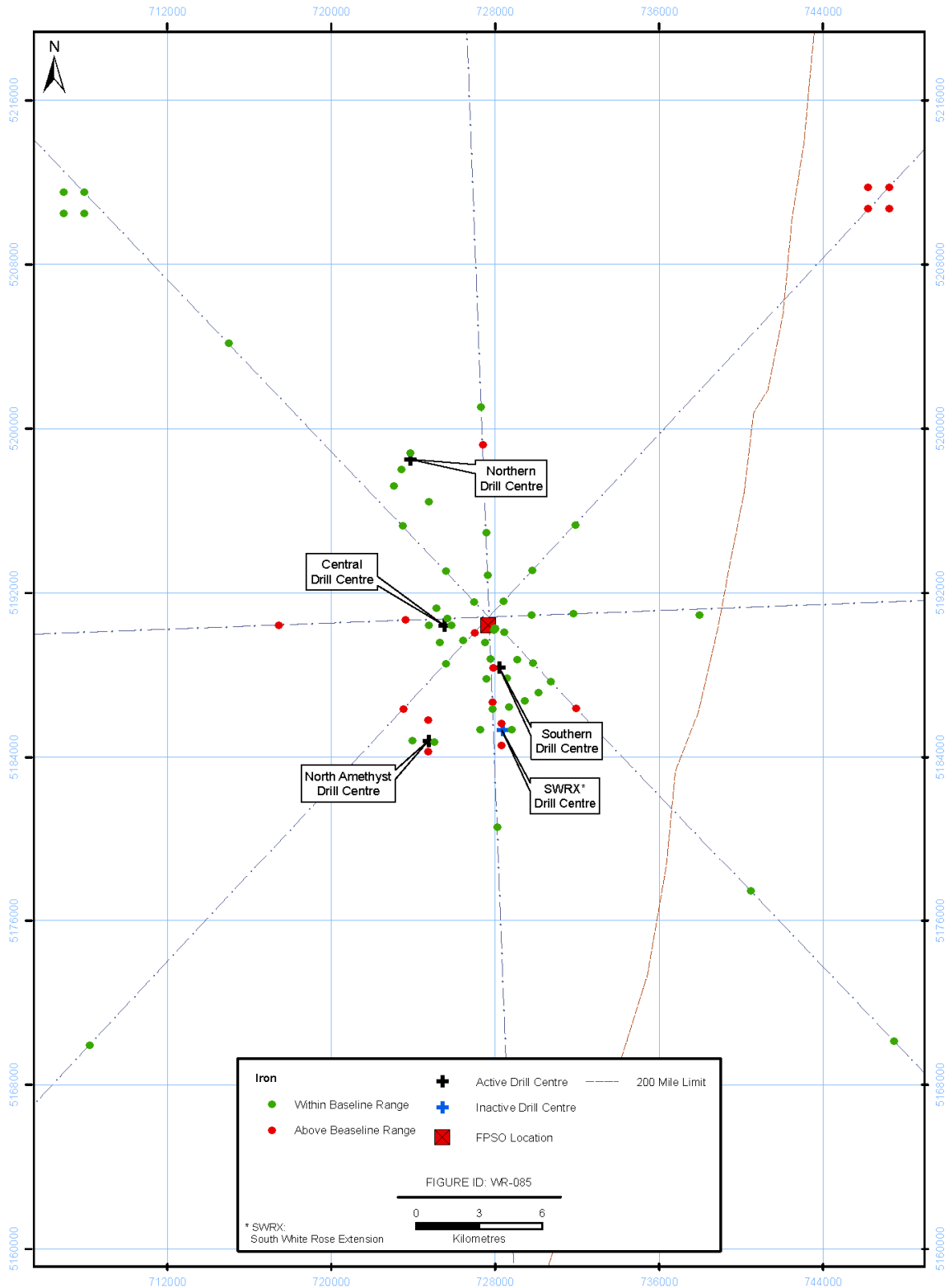
**Figure 7-12     Location of Stations with Iron Concentrations Within and Above the Baseline Range (2012)**
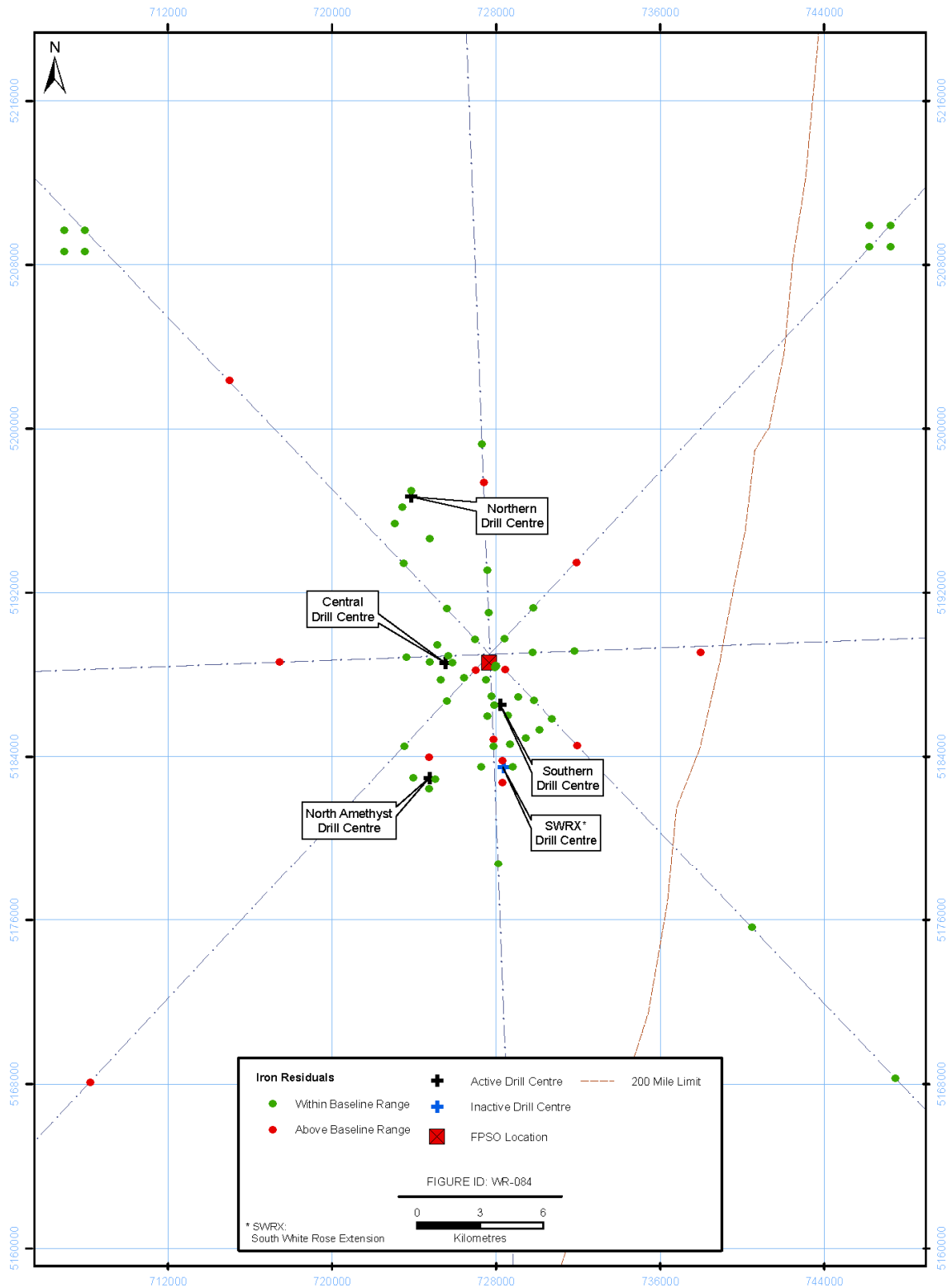
**Figure 7-13      Location of Stations with Iron Residuals Within and Above the Baseline Range (2012)**

**Repeated-Measures Regression**

Results of repeated-measures regression are provided in Table 7-2. There were no significant differences in slopes of the relations between iron or iron residuals and distance to the *SeaRose FPSO* from before to after produced water discharge began at the *SeaRose FPSO* in March, 2007. There has been a significant increase in iron concentrations in the sampling area from before to after produced water discharge began at the *SeaRose FPSO* ($p$ = 0.018), consistent with the scatterplots above. There was no change in mean iron residuals from before to after discharge began ($p$ = 0.107).

**Table 7-6     Repeated-measures Regression Testing for Changes in Iron Concentrations, and Iron Residuals over Time**

| Variable | Change in Slope from Before to After | Change in Mean from Before to After |
|---|---|---|
| Iron | 0.174 | 0.018 |
| Iron Residuals | 0.220 | 0.107 |

Notes:  -    Values are probabilities.
        -    *n* = 36

Variations in iron and iron residuals are illustrated in Figures 7-14 and 7-15. From these and analyses above, there is some evidence of enrichment of iron in sediments.
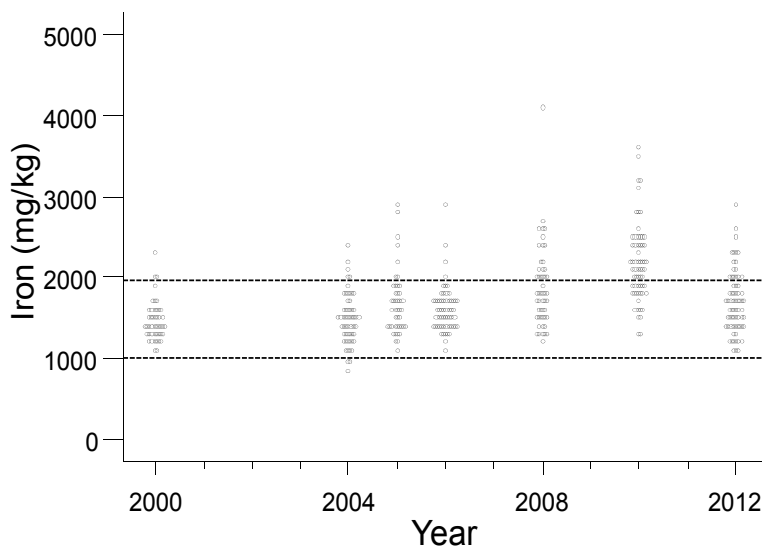


**Figure 7-14      Dot Density Plot of Iron Concentrations in Sediments (mg/kg) by Year**

Note: background iron concentrations are indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.
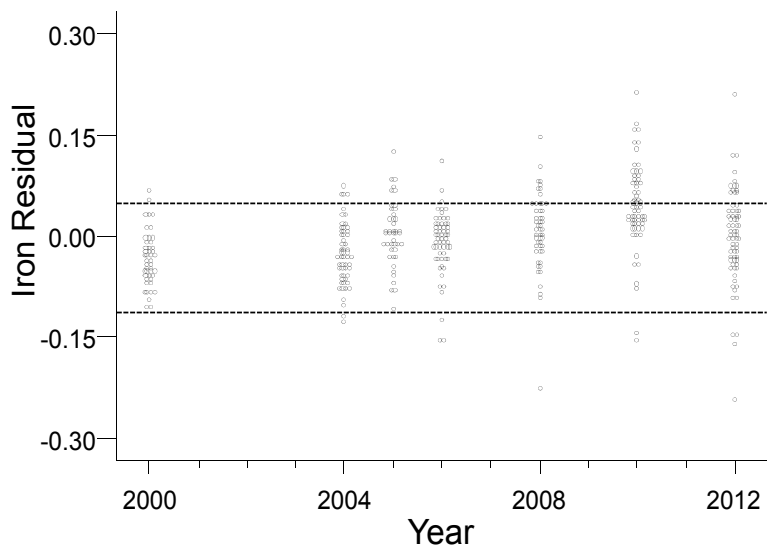
**Figure 7-15      Dot Density Plot of Iron Residuals by Year**

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

### 7.3.2.4  Sediment Fines and Total Suspended Solids in Seawater

The relationship between sediment percent fines at Water Quality stations and TSS in seawater samples was examined in response to regulator comments on the 2010 program (see Appendix A). Spearman rank correlations were calculated using 2012 data to assess any potential relationship. Data from 2010 could not be used because most TSS values in 2010 were below the laboratory detection limit of 5 mg/L. In 2012, and in keeping with Husky Energy's commitment to use lower detection limits when feasible, TSS levels were measured at a detection limit of 0.5 mg/L.

In 2012, there was no significant relationship between water column TSS concentrations and sediment percent fines at Water Quality stations, either overall ($p$ = 0.583) or between TSS at individual depths and sediment % fines ($p$ = 0.844, 0.631 and 0.260 for bottom, mid-depth and surface seawater samples, respectively). As noted previously (Section 7.2.2.4), TSS in seawater samples also did not vary significantly between the Study and Reference Areas, or among depths (Table 7-3).

## 7.4      Summary of Findings

### 7.4.1  Water

$>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ hydrocarbons, PAHs and alkyl PAHs, phenols and alkyl phenols, organic acids and XCide450 were not detected in water samples in 2012. Low levels of ammonia (median = 0.0005 mg/L) were detected in 10 (of 30) Study Area samples, eight of these bottom samples. Ammonia was detected at a level of 0.0005 mg/L in one (of 24) bottom sample in the Reference Areas. Low levels of benzene (median = 0.0015 mg/L) were detected in two (of 30) near-field Study Area samples, at the surface. Conversely, $C_6$-$C_{10}$ hydrocarbons (less BTEX) were detected in three samples from the Reference Areas at a concentration of 0.01 mg/L, but these compounds were not detected in the Study Area. Arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, nickel,

potassium, sodium, strontium, sulphur, uranium and TOC were detected in all samples, and TSS, chromium, SCW4453 and zinc were detected in most (more than 75%) samples. With the exception of TIC, which varied over a narrow range, these variables were included in quantitative analyses (ANOVA).

Except for barium, no significant differences were noted in 2012 between the Study and Reference Areas in ANOVA for any variable. Barium concentrations were lower in mid-depth and surface samples in the Study Areas compared to the Reference Areas. Conversely, concentrations were higher in bottom samples in the Study Areas than in the Reference Areas.

Examination of 2010 relative to 2012 data indicated that Area differences in median barium concentration were greater in 2012 than in 2010 and that the difference in barium concentration between the Study Areas and the Reference Areas at mid-depth in 2012 resulted from a decrease in levels in the Study Area since 2010. Similarly, median barium levels were lower in surface samples in 2012 than in 2010, in both the Study and Reference Areas. In bottom samples, median barium concentration in the Study Area was slightly higher in 2012 than in 2010 (9 µg/L versus 8 µg/L) and Reference Area concentrations remained constant (7.5 µg/L).

### 7.4.2   Sediment

#### 7.4.2.1   Modelling

Modelling results indicated that radium radionuclides are not expected to be effective tracers of produced water constituents in sediments.

However, the modelling report recommended paying attention to any increase in iron in sediments, particularly to the south, because this constituent is expected to deposit from produced water in relatively high concentration, and because modelling showed that deposition of constituents likely would be greater to the south of the *SeaRose FPSO*.

#### 7.4.2.2   Field Sampling

Qualitative examination of iron data (*i.e.*, maps) from 2012 showed a tendency for iron enrichment at distances of approximately 5 to 10 km from the *SeaRose FPSO*. That tendency was greater to the south. There was also some indication of an increase in iron from before to after produced water discharge began at the *SeaRose FPSO*. At present, the link between iron enrichment in sediments and produced water release from the *SeaRose FPSO* is not strong, but this metal may show some potential as a tracer for produced water constituents in sediments. Continued examination is warranted.

In 2012, low levels of 15 PAHs were detected in sediments at station W-2SE, located 0.32 km from the *SeaRose FPSO*.

There was no significant relationship between sediment % fines and TSS at Water Quality stations.

# 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.

### 8.1.1   Physical and Chemical Characteristics

In 2012, concentrations of $>C_{10}$-$C_{21}$ hydrocarbons and barium were elevated around all active drill centres, as they were in previous EEM years. The estimated zone of influence for $>C_{10}$-$C_{21}$ hydrocarbons from threshold models[17] in 2012 was similar than the estimated zone of influence in 2010, and less than in years prior 2010. A threshold distance (distance at which concentrations are reduced to low or background level) of 3.6 km was noted in both 2010 and 2012. Threshold distances ranging from 5.0 to 10.4 km were noted in years prior to 2010. For barium, the estimated threshold distance was 1 km, less than in previous years. Average thresholds in previous years ranged from 1.9 to 3.6 km[18].

The maximum $>C_{10}$-$C_{21}$ hydrocarbon concentration in 2012 was 510 mg/kg (at station NA1, located 0.30 km from the North Amethyst Drill Centre) and the maximum barium concentration was 4,000 mg/kg (at station 20, located 0.37 km from the Central Drill Centre). These were increases from baseline maxima (below detection limit for $>C_{10}$-$C_{21}$ hydrocarbons and 210 mg/kg for barium).

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 ranges noted from other projects.

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[17] 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.

[18] 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.

**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** | 2012 | 300 to 750 | <0.3 to 527 | 110 to 4,000 |
| | | 750 to 2,500 | 0.86 to 21.10 | 140 to 450 |
| | | 2,500 to 5,000 | <0.3 to 3.18 | 140 to 210 |
| | 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** (Suncor Energy 1998, 2001, 2002, 2003, 2005, 2007, 2009, 2011) | 2010 | 140 to 750 | <3 to 767 | 130 to 4,200 |
| | | 570 to 2,500 | <3 to 339 | 87 to 420 |
| | | 2,500 to 5,00 | <3 | 69 to 160 |
| | 2008 | 140 to 750 | <3 to 343 | 130 to 7,200 |
| | | 570 to 2,500 | <3 to 11 | 89 to 280 |
| | | 2,500 to 5,000 | <3 | 78 to 210 |
| | 2006 | 140 to 750 | 8 to 986 | 240 to 16,000 |
| | | 750 to 2,500 | <3 to 30 | 110 to 340 |
| | | 2,500 to 5,000 | <3 | 89 to 230 |
| | 2004 | 140 to 750 | 8 to 6,580 | 140 to 2,100 |
| | | 750 to 2,500 | 3 to 72 | 100 to 340 |
| | | 2,500 to 5,000 | <3 to 4 | 63 to 190 |
| | 2002 | 140 to 750 | <3 to 931 | 110 to 2,200 |
| | | 750 to 2,500 | <3 to 49 | 84 to 330 |
| | | 2,500 to 5,000 | <3 to 5 | 83 to 200 |
| | 2001 | 750 to 2,500 | <3 to 30 | 100 to 190 |
| | | 2,500 to 5,000 | <3 to 8 | 87 to 180 |
| | 2000 | 750 to 2,500 | <3 to 14 | 92 to 210 |
| | | 2,500 to 5,000 | <3 to 6 | 80 to 230 |
| | 1997 | 750 to 2,500 | <3 | 87 to 190 |
| | | 2,500 to 5,000 | <3 | 79 to 280 |
| **Gulf of Mexico (NPO-895)** (Candler *et al.* 1995) | 1993 | 50 | 134,428 | 47,437 |
| | | 200 | 80 to 11,460 | 542 to 5,641 |
| | | 2,000 | 24 | |
| **Gulf of Mexico (MAI-686)** (Kennicutt *et al.* 1996) | 1993 | 200 | 40 | 1,625 |
| | | 500 | 43 | 1,134 |
| | | 3,000 | 49 | 1,072 |
| **Gulf of Mexico (MU-A85)** (Kennicutt *et al.* 1996) | 1993 | 200 | 42.3 | 3,706 |
| | | 500 | 31.7 | 1,817 |
| | | 3,000 | 27.1 | 1,094 |
| **Gulf of Mexico (HI-A389)** (Kennicutt *et al.* 1996) | 1993 | 200 | 65 | 13,756 |
| | | 500 | 33 | 3,993 |
| | | 3,000 | 32 | 1,293 |

| Location | Year of Study | Distance from Source (m) | TPH (mg/kg) | Barium (mg/kg) |
|---|---|---|---|---|
| **North Sea (Beatrice)** (Addy *et al.* 1984) | 1982 | 250<br>750<br>3,000 | 8 to 759<br>5 to 105<br>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<br>500<br>3,000 | - | 19,000 to 96,000<br>3,700 to 9,300<br>280 to 430 |
| **North Sea (Brent)** (Massie *et al.* 1985) | 1981 | 800<br>3,200 | 41 to 61<br>33 to 43 | - |
| **North Sea (Forties)** (Massie *et al.* 1985) | 1980 | 800<br>3,200 | 9 to 78<br>16 to 55 | - |
| **Gulf of Mexico (Matagorda 622)** (Chapman *et al.* 1991; Brooks *et al.* 1990) | 1987 | 25<br>150<br>750<br>3,000 | 757 ±1,818 | 6,233<br>12,333<br>980 |
| **Santa Maria Basin (Hidalgo)** (Phillips *et al.* 1998) | 1991 | 125<br>500<br>1,000 | - | 1,250<br>975<br>1,050 |
| **Norway (Ekofisk)** (Ellis and Schneider 1997) | 1996 | 750<br>2,000<br>5,000 | - | 3,650<br>2,214<br>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<br>>500 to 2,000<br>>2,000 to 5,000 | 124 to 11,983<br>3 to 164<br>3 to 76 | 84 to 2,040<br>7 to 1595<br>8 to 729 |

Note:  -  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, 2010 and 2012 statistics.

In 2012, project effects on sediment lead and strontium concentrations were noted. Those effects have been present since 2006, but these two metals were examined separately for the first time in 2012. Threshold distances for lead have consistently decreased from a maximum 1.5 km in 2006 to a minimum 0.6 km in 2012. Threshold distances for strontium have also decreased from a maximum of 1.6 km in 2008 to a minimum of 0.6 km in 2012. There was no indication of project effects on other metals and no metal for which there are sediment quality guidelines exceeded its Interim Sediment Quality Guidelines (ISQG) (CCME 2010) (see Section 5).

In 2012, lead levels ranged from approximately 3 to 11 mg/kg near active drill centres to 2 to 4 mg/kg at more distant stations. The ISQG for lead is 30.2 mg/kg. Strontium levels ranged from approximately 60 to 170 mg/kg near active drill centres to approximately

30 to 50 mg/kg at more distant stations. There is no ISQG for strontium and, to our knowledge, there are no studies specifically addressing strontium toxicity in marine sediments. However, Neff (2007) noted that any metals from drilling muds, the likely source for both lead and strontium, would not be readily bioavailable. Maxima for lead and strontium occurred at station 20, 0.37 km from the Central Drill Centre.

Sulphur levels increased modestly at some stations less than 1 km from active drill centres, with levels ranging from approximately 0.05 to 0.11% in the immediate vicinity of drill centres to levels near the laboratory detection limit of 0.03 % at more distant stations. The relationship between sulphur and distance to the nearest active drill centre was relatively weak, with no threshold for effects. Sulphur is also a constituent of barite ($BaSO_4$), and minor increases in sediment sulphur concentrations near active drill centres have been noted in previous years. Maximum sulphur levels (0.11%) occurred at two stations in 2012: NA1, located 0.29 km from the North Amethyst Drill Centre and S5, located 0.31 km from the Southern Drill Centre.

Since the last EEM program, drilling was most active at the Central Drill Centre in 2011, and drilling was most active at the Southern and North Amethyst Drill Centre in 2012. In 2011, 649 metric tonnes of water-based mud cuttings and 429 metric tonnes of synthetic fluid-based drill mud cuttings were discharged at the Central Drill Centre. In 2012, 459 and 512 metric tonnes of water-based mud cuttings were discharged at the Southern and North Amethyst Drill Centres, respectively; and 732 and 853 metric tonnes of synthetic fluid-based drill mud cuttings were released at each of these two drill centres. Maxima for the affected variables listed above occurred at these drill centres in 2012.

There was little indication of project effects on sediment particle size (% fines and % gravel), sediment concentrations of TOC and ammonia, and redox potential. As noted above, metals other than barium, lead and strontium also appeared unaffected by project activity.

### 8.1.2   Laboratory Toxicity Tests

Sediments were generally non-toxic in 2012, as in previous EEM years.

In 2012, all samples tested for Microtox toxicity were non-toxic. Over all EEM years, only one sample (in 2010) was ever classified as toxic to Microtox.

Amphipod survival in toxicity tests in most White Rose samples has been high in EEM years. In 2012, one sample, from station N3 (0.6 km from the Northern Drill Centre), was toxic to laboratory amphipods. Sediments from the station nearest the Northern Drill Centre (N4 at 0.3 km) were not toxic. Amphipod survival was unrelated to sediment chemical characteristics (including those chemical characteristics influenced by project activity, Section 8.1.1), but survival increased with % fines in sediment.

### 8.1.3   Benthic Invertebrate Community Structure

In 2012, there was weak evidence of project effects on total benthic abundances, stronger evidence of effects on total biomass and little evidence of effects on richness. For individual taxa, there was strong evidence of project effects on Paraonidae and little evidence of project effects on Spionidae, Tellinidae and Amphipoda.

Total benthic abundances, benthic biomass and numbers of Paraonidae were related to concentrations of $>C_{10}$-$C_{32}$ hydrocarbons and barium. Total abundances and biomass, and abundances of Paraonidae were lower in sediments with high concentrations of barium and $>C_{10}$-$C_{21}$ hydrocarbons. Higher concentrations of sulphur and, to a lesser extent, strontium in sediments also tended to co-occur with lower biomass and lower abundances of Paraonidae. In addition, Paraonidae abundance was negatively correlated with concentrations of lead. All these chemical characteristics of sediment were affected by project activity (Section 8.1.1). Richness, as well as abundances of Spionidae polychaetes, Tellinidae and Amphipoda, were not correlated with any sediment physical or chemical characteristics.

The assessment of the zone of effects on benthic invertebrates relied on: 1) an examination of changes in benthic indices, or taxa abundances, with distance from the nearest active drill centre (*i.e.*, threshold models as described in Section 8.1.1); and 2) an examination of changes in benthic indices near individual drill centres (*i.e.*, maps of indices or taxon abundance within or below the baseline range). The first approach can be regarded as a whole-field approach, whereas the second approach targets effect of individual drill centres. This combined approach was adopted in 2010 because the effect of drill centres, particularly drill centres in close proximity, is not independent, which can lead to an overestimate of the zone of effects using whole-field estimates.

The relationship between total benthic abundance and distance to the nearest active drill centre was relatively weak, with no threshold distance for effects. Total abundance ranged from approximately 500 to 2,500 organisms/m$^2$ near active drill centres (*i.e.*, drill centre stations). The range at the most distant stations (more than 10 km from drill centres) was 1,200 to 3,400 organisms/m$^2$. 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, potentially indicating natural variability.

Total biomass varied from 5 to 900 g/m$^2$ near active drill centres to approximately 250 to 1,100 g/m$^2$ at the most distant stations (more than 10 km from drill centres). The relationship between total biomass and distance from the nearest active drill centre was significant in 2012, with a threshold distance for effects of approximately 1.5 km (range: 0.8 to 2.7 km). For individual drill centres, total benthic biomass was below the baseline range of values at distances of approximately 1.8 km from the Southern Drill Centre; 1.2 km from the Central Drill Centre; 0.9 km from the North Amethyst Drill Centre. Additional analyses indicated that reductions in total biomass were likely associated with reductions in the numbers of larger echinoderms near active drill centres.

Number of families per stations (*i.e.*, richness) varied between 18 and 45 in 2012, which compares well to the baseline range of between 21 and 38 families. As noted above, richness was not related to any sediment physical and chemical characteristic in 2012. Richness was also uncorrelated to distance from the nearest active drill centre. Richness was reduced at the nearest stations to the Southern and Central Drill Centres, but richness values at other stations around those drill centres were within the baseline range. From these data, there is insufficient evidence to conclude that richness was affected by project activity.

Responses of selected individual taxa at White Rose were examined to provide additional insight into the more general indices of community composition. Bray-Curtis

values and non-metric multi-dimensional scaling (NMDS) were used in a similar fashion. Of the taxa examined, Paraonidae were clearly affected by project activities, but there was little evidence of project effects on Spionidae, Tellinidae and Amphipoda.

Paraonidae abundance was strongly related to distance from the nearest active drill centre in 2012, as in previous years. Threshold distances for effects have been variable (1.6 km in 2010 to 4.1 km in 2004), but with no statistical differences among years. The threshold distance for effects in 2012 was 2.5 km (range: 1.5 to 4.3 km). Paraonidae abundances were reduced within: approximately 1.8 km from the Central Drill Centre; within approximately 0.9 km from the Southern Drill Centre and North Amethyst Drill Centre; and within approximately 0.6 km from the Northern Drill Centre. Most of these distances are below the estimated range of threshold distances for the whole-field (1.5 to 4.3 km). The combined effect of the Central and Southern Drill Centre is particularly noticeable for Paraonidae abundance, with reduced abundances apparent between the two drill centres. The proximity of these two drill centres and, consequently, their combined effect, would increase both calculated threshold distances and variability about estimates of threshold distances for the whole-field. Map results for the North Amethyst and the Northern Drill Centres, two drill centres that may not be influenced by other drill centres as much as the Central and Southern Drill Centres, indicate that effects on Paraonidae extended to between approximately 0.6 and 0.9 km.

As noted above, abundance of Spionidae, Tellinidae and Amphipoda were unrelated to any sediment physical and chemical characteristics. Abundances of these taxa were also unrelated to distance to the nearest active drill centre in 2012. Given these results, there is insufficient evidence to conclude that these taxa were affected by project activity.

Analysis of Bray-Curtis values and NMDS generally agreed with the more specific analyses of indices of community structure and taxon abundances and are not discussed further.

In summary, there were project effects on some sediment chemical characteristics and indices of benthic community at White Rose. Sediment concentrations of $>C_{10}-C_{21}$ hydrocarbons, barium, lead, strontium and sulphur were affected by project activity. Evidence of effects on total abundance, noted since 2005, was again marginal, with only a few stations affected. Benthic biomass was affected by project activity, seemingly related to decreases in the number of echinoderms near active 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. As in previous years, no effects on richness were noted. 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 active drill centres, although these responses are of general interest.

After monitoring the effects of drilling on sediment quality six times over a period of eight years, distance relationships have varied somewhat in their strength, while threshold distances have also varied somewhat from year to year, with the annual variations depending on the analyte or measure of benthic community composition. There have been no overwhelming trends to indicate that effects are getting greater in magnitude or in extent. Rather, temporal variations suggest that effects are staying the same from

year to year, or potentially getting more localized. Threshold distances for $>C_{10}$-$C_{21}$, barium, lead and strontium were generally shorter (closer to active drill centres) in 2012 than in prior EEM years.

## 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 2012, there were no significant differences between the Study and Reference Areas for all frequently detected compounds in plaice liver (%fat, %moisture, arsenic, cadmium, copper, iron, manganese, mercury, selenium, zinc, $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$). Compounds in the $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ hydrocarbon range were again detected in liver. As in previous years, additional laboratory analyses indicated that compounds in the $>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ hydrocarbon range were natural, perhaps diet related, rather than petrogenic in origin. There were no significant differences between the Study Area and the Reference Areas for any compound in trends over time (2004 to 2012). Arsenic, cadmium, copper, selenium, zinc and $>C_{21}$-$C_{32}$ concentrations all significantly increased in livers of plaice between 2004 and 2012 across all Areas. Manganese and $>C_{10}$-$C_{21}$ decreased significantly between 2004 and 2012, again in all Areas. Selenium concentrations increased from 2004 to 2006, and decreased from 2010 to 2012, across all Areas.

There were no significant differences in plaice fillet tissue between the Study Area and the Reference Areas in 2012 for frequently detected compounds (percent fat and moisture, mercury, arsenic and zinc concentrations). There were also no significant differences between the Study Area and the Reference Areas in trends over time (2004 to 2012) for any compound. Fat content and zinc concentrations generally decreased over time in fillets of fish from both Study and Reference Areas, while percent moisture in plaice fillets increased over time across both Study and Reference Areas.

In 2012, there were no significant differences in crab tissue between the Study Area and the Reference Areas for frequently detected compounds (%moisture, arsenic, boron, copper, mercury, selenium, silver, strontium and zinc). Concentrations of many compounds were lower in 2012 than in previous years, in all Areas. The only significant difference in trends over time between the Study Area and the Reference Areas was for zinc. Zinc concentration in crab tissue was slightly higher (approximately 2 mg/kg higher) in the Study Area in 2008 and 2010 than in the Reference Area.

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) at White Rose. 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 Areas 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 resource.

## 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 were examined within the context of these studies.

Female plaice outnumbered males in every Area, accounting for 86% of the 180 fish sampled. The female:male ratio was similar among the Reference Areas and between the Study Area and the combined Reference Areas.

There were no significant differences in the frequencies of various fish maturity stages between the Study Area and the Reference Areas, regardless of gender.

Assessment of biological characteristics of male fish (all maturity stages combined) and pre-spawning and spent females indicated that there were no significant differences in length, body weight, liver weight, gonad weight and age among the Reference Areas or between the Study Area and Reference Areas for these fish. In addition, comparisons on gutted body weight versus length, as well as liver and gonad weight versus gutted body weight did not result in significant differences among the Reference Areas or between the Study Area and combined Reference Areas.

For immature females, significant differences were noted between the Study and Reference Area for gutted body weight versus length and liver weight versus gutted body weight. Immature females from the Study Area were heavier (6% on average) for their length and Reference Area females had larger livers.

Overall, heterogeneity in biological characteristics 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 for all fish during the necropsies. There were no visible lesions on the skin or fins or on internal organs (gonad, digestive tract, liver, body cavity and spleen) of any fish.

### 8.2.3.3  Haematology

Blood smears collected in 2012 displayed signs of clotting and were considered of insufficient uniformity for carrying out reliable differential cell counts.

The blood smear procedure followed onboard the vessel in 2012 was the same as the procedure used successfully since 2005. The poor quality of the 2012 smears was observed in almost all samples, independent of the technologist making the smears, indicating a problem more likely associated with the materials/chemicals used. These included syringes, capillary tubes, ethylenediaminetetraacetic acid (EDTA) tubes to prevent clot formation, slides and methanol. It is not known if the clotting was linked to the batch of EDTA tubes used. In future programs, the EDTA tubes will be tested just prior to the survey to make sure that they display adequate anti-clotting properties.

### 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 immature, pre-spawning and spent females, since maturity stage can probably result in some loss of sensitivity for resolving contaminant mediated differences during spawning (*e.g.*, Whyte *et al.* 2000).

There were no significant differences in MFO activity between the Study and Reference Areas, regardless of gender or maturity stage (immature, pre-spawning and spent).

### 8.2.3.5  Histopathology

Detailed studies were carried out on liver tissues of plaice with a focus on various lesions that have been associated with chemical toxicity in field and laboratory studies (*e.g.*, Myers *et al.* 1987; Hinton *et al.* 1992; Johnson *et al.* 1993; Myers and Fournie 2002; ICES 2004; Blazer *et al.* 2007; Codi King *et al.* 2011).

Small foci of cellular alteration were detected in the liver of three fish. There was one case of clear cell foci in Reference Area 1, one case of unclassified very small focus of alteration in Reference Area 3, and one case of a single eosinophilic focus in the Study Area. It has been suggested that, for some fish, some of these types of foci are 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 or oestrogenic compounds. A few cases of foci of cellular alteration have been observed in other areas of the Grand Banks not associated with oil and gas activity during the last decade (Mathieu *et al.* 2005;

2011). This may indicate that a low prevalence of these lesions could be background in nature.

Besides these few cases of lesions that have been associated with chemical toxicity, other hepatic conditions not specifically associated with contamination were also noted.

Golden rings around bile ducts were detected in one fish from the Study Area.

Small focal inflammatory responses were observed in a total of 11 fish (nine from the Reference Areas and two from the Study Area). The condition was mild in six cases. A moderate response was recorded in four cases (one in Reference Area 2, one in Reference Area 3 and two in the Study Area), while a more pronounced response appeared in one fish from Reference Area 4. Inflammatory responses are known to appear following viral, bacterial or parasitic infections as well as tissue damage (*e.g.*, Feist *et al.* 2004). However, a level of inflammation can also be associated with normal tissue repair and maintenance processes.

Pronounced cytoplasmic vacuolation, which could be linked to fat accumulation, was observed in two fish, one from Reference Area 1 and one from the Study Area. However, this was not accompanied with other lesions such as pyknotic nuclei and necrosis. A level of fat accumulation in hepatocytes can be a normal occurrence linked to feeding. Excessive fatty accumulation, or steatosis, is also a non-specific lesion that can indicate infectious or parasitic stress. However, a high prevalence of severe steatosis in fish has also been associated with chemical contaminant exposure (*e.g.*, Grizzle 1986; Kohler *et al.* 1992; Lyons *et al.* 2004; Codi King *et al.* 2011; Ruiz *et al.* 2012).

As noted in previous years, a "patchy distribution" of hepatocellular vacuolation, not associated with degenerative changes, was observed in a similar proportion of fish from the Study and Reference Areas, and this likely linked to gonadal maturation (Timashova 1981; Bodammer and Murchelano 1990; Couillard *et al.* 1997).

Parasites were recorded in the liver of a number of fish but these did not appear to result in any other pathological changes in hepatic tissues. Parasites are generally not a result of the presence of chemical pollutants.

The observations on golden rings, mild inflammatory responses, pronounced cytoplasmic vacuolation, hepatocellular vacuolation and parasitism are of value in relation to providing general information on their presence in the area. However, it is important to note from an EEM perspective that a large number of liver lesions typically seen in fish that have been exposed to chemical contamination were generally absent or found only at a low incidence.

For gills, microstructural changes 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. The percentages of secondary lamellae affected by various lesions were very low (less than 0.5%) in all Areas and no differences between the Study and Reference Areas were observed in either the percentage of lamellae affected or the percentage of fish affected.

Overall, results of the fish health survey carried out in 2012 indicated that the health of American plaice is similar between the Study Area and the Reference Areas.

## 8.3    Water Quality Component

The Water Quality monitoring program at White Rose currently involves collection of sediment and seawater samples around the *SeaRose FPSO* and in two Reference Areas, located approximately 28 km to the northeast and northwest of the *SeaRose FPSO*. These samples are assessed for water and sediment chemistry.

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 and sediment samples. In 2010, selected soluble constituents of produced water were modelled. In 2012, modelling examined deposition of selected produced water constituents to sediments. The ultimate goals of the modelling exercises have been to find a potential tracer for produced water and/or fine-tune the Water Quality sampling program at White Rose (details are provided in Husky Energy 2010; also see Section 1). Modelling of soluble produced water constituents in 2010 resulted in the following main modifications to the program in 2012:

- Stations located at approximately 300 m from the *SeaRose FPSO* (near-field Study Area stations) were positioned at the time of sampling so that they would be down-current from the *SeaRose FPSO*.

- Mid-field Study Area stations were added at 4 km from the *SeaRose FPSO* in the direction of the prevailing seasonal current (to the southeast of the *SeaRose FPSO*).

### 8.3.1  Seawater Chemistry

Arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, nickel, potassium, sodium, strontium, sulphur, uranium and total inorganic carbon were detected in all samples, and the process chemical SCW4453, total suspended solids (TSS), chromium and zinc were detected in most (more than 75% of) samples. With the exception of total inorganic carbon, which varied over a very narrow range (23 to 25 mg/L), these variables were included in quantitative analyses. Except for barium, no significant differences were noted in 2012 between the Study and Reference Areas for any of these variables.

In 2012, barium concentrations were lower in mid-depth and surface samples in the near and mid-field Study Areas compared to the Reference Areas. Conversely, concentrations were higher in bottom samples in the Study Areas than in the Reference Areas. The largest difference in barium concentrations occurred at mid-depth, with a median level of approximately 7 µg/L in the Reference Areas versus a median level of approximately 3 µg/L in the Study Areas. In bottom samples, the median barium level was approximately 2 µg/L higher in the Study Areas than in the Reference Areas (7 µg/L versus 9 µg/L).

Because barium is a major constituent of drilling muds and it is enriched in produced water (see Appendix D-4), differences in barium concentrations noted among Areas in 2012 could partly be related to project activity. Jerez Vegueria *et al.* (2002) found no evidence of barium contamination in seawater samples near the Barcia de Campos oil

field in Brazil. Similarly, no differences among Areas in barium levels were noted at White Rose in the 2010 EEM program.

Area differences in median barium concentration were greater in 2012 than in 2010. The difference in barium concentration between the Study Areas and the Reference Areas at the surface and at mid-depth in 2012 resulted from a decrease in levels in the Study Area since 2010. In bottom samples, median barium concentration in the Study Areas was slightly higher in 2012 than in 2010 (9 µg/L versus 8 µg/L) and Reference Areas concentrations remained constant (7.5 µg/L). Beyond this, Neff (2002) reports barium levels of approximately 15 µg/L in oceanic waters. Therefore, barium levels at White Rose are within the background range[19]. Overall, in 2012, differences among Areas were small and the largest difference involved lower levels in the Study Areas compared to the Reference Areas.

$>C_{10}$-$C_{21}$ and $>C_{21}$-$C_{32}$ hydrocarbons, PAHs and alkyl PAHs, phenols and alkyl phenols, organic acids and XCide450 were not detected in water samples in 2012. Ammonia, benzene and $C_6$-$C_{10}$ hydrocarbons (less BTEX) were infrequently detected at low levels. Ammonia (median concentration = 0.0005 mg/L) was detected in 10 (of 30) Study Area samples, eight of these bottom samples. Ammonia was detected at a concentration of 0.0005 mg/L in 1 (of 24) bottom sample in the Reference Areas. Ammonia is often associated with decomposition of organic matter. Benzene (median concentration = 0.0015 mg/L) was detected in 2 (of 30) near-field Study Areas samples, at the surface. Conversely, $C_6$-$C_{10}$ hydrocarbons (less BTEX) were detected in three samples from the Reference Areas at a concentration of 0.01 mg/L.

## 8.3.2 Modelling

Constituent-based modelling was used to assess sediment concentrations of selected produced water constituents over 10, 20, 30 and 40 years of produced water release to identify potential tracers of produced water. Maximum allowable release of produced water (28,000 $m^3$/day) was used as the release rate.

One constituent, Ra-228, was selected for modelling based on its concentration in produced water relative to concentrations in sediments, but results could also be used to assess the potential concentrations of Ra-226 and the potential distribution of iron in sediments. Both of these constituents were also judged likely to settle from produced water to sediments.

Results indicated that neither Ra-228 nor Ra-226 can be expected to be effective tracers of produced water constituents in sediments. Sediment concentrations resulting from produced water discharge are expected to be below laboratory detection limit even after 40 years of deposition at maximum discharge rate.

For iron, and since modelling showed that deposition of constituents likely would be greater to the south of the *SeaRose FPSO*, attention to any increase in iron concentrations, particularly to the south, was recommended.

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[19] Barium was not measured in water samples during baseline (2000). Therefore, only literature values are available.

### 8.3.3   Sediment Iron Concentration

Based on recommendations from the modelling exercise described above, sediment iron concentrations from 2000 to 2012 at both water quality and Sediment Quality Triad stations were examined.

Qualitative examination of iron data (*i.e.*, maps) from 2012 showed a tendency for iron enrichment at distances of approximately 5 to 10 km from the *SeaRose FPSO*. That tendency was greater to the south. There was also some indication of an increase in iron from before to after produced water discharge began at the *SeaRose FPSO*. At present, the link between iron enrichment in sediments and produced water release from the *SeaRose FPSO* is not strong, but this metal may show some potential as a tracer for produced water constituents in sediments. Continued examination is warranted.

Beyond the examination of iron concentration in sediments, sediment chemistry analysis indicated the presence of 15 PAHs in sediments from Water Quality station W-2SE, located 0.32 km from the *SeaRose FPSO*. Levels were low and comparable to the concentrations of the five PAHs detected in sediments in 2010.

### 8.3.4   Sediment Fines and Total Suspended Solids in Seawater

The relationship between sediment percent fines at water quality stations and TSS in seawater samples in 2012 was examined in response to regulator comments on the 2010 program. There was no significant relationship between water column TSS concentrations and sediment percent fines at water quality stations, either overall or between TSS at individual depths (surface, mid-depth and bottom) and sediment percent fines. Beyond this, there was no evidence of TSS enrichment from White Rose in water column samples (Section 8.3.1) and no evidence of fines enrichment in sediments (Section 8.1.1).

## 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 2012 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, concentrations of $>C_{10}-C_{21}$ hydrocarbons and barium were elevated by drilling activity near drill centres. To a lesser extent, sediment lead, strontium and sulphur concentrations were also affected by drilling. Elevated concentrations of $>C_{10}-C_{21}$ hydrocarbons and barium at White Rose in 2012 remain comparable to levels observed at other developments.

The spatial extent of contamination in 2012 was consistent with original predictions on the spatial extent of the zone of influence of drill cuttings (9 km from source; Hodgins and Hodgins 2000; Section 1.5). $>C_{10}-C_{21}$ hydrocarbon contamination extended to 3.6 km from source. Barium contamination extended to 1 km from source. Lead and strontium contamination extended to 0.6 km from source, and sulphur contamination was noted at some stations within approximately 1 km from source. The threshold distance model was not significant for sulphur.

One of 53 sediment samples tested was toxic to laboratory amphipods and no sediments were toxic to luminescent bacteria (Microtox) in 2012. Amphipod toxicity occurred at station N3, located 0.6 km from the Northern Drill Centre. Sediments from the station nearest the Northern Drill Centre (N4 at 0.3 km) were not toxic. Amphipod survival was unrelated to distance to the nearest active drill centre, nor was it related to any sediment chemical characteristics (including those chemical characteristics influenced by project activity). Together, the Microtox and amphipod toxicity tests indicate that sediments at White Rose are fundamentally non-toxic.

In 2012, as in the last two EEM years, evidence of effects on total abundance was relatively weak, benthic biomass was affected by project activity and there was little evidence of project effects on richness. The taxon most affected by project activity

remains Paraonidae. As in 2010, there was little evidence of project effects on Spionidae, Tellinidae and Amphipoda abundance.

The threshold distance model was not significant for total abundance, indicating that the relationship with distance was relatively weak. The threshold distance model for total biomass was significant in 2012, with effects noted to within approximately 1.5 km from source. Effects on Paraonidae extended to approximately 2.5 km from source. An examination of the spatial extent of effects by drill centre indicated that effects from the Central and Southern Drill Centres overlapped. For total biomass, effects around the North Amethyst Drill Centre, which was probably less affected by the proximity of another drill centre, extended to approximately 0.9 km from source. For Paraonidae, effects extended to approximately 0.6 km and 0.9 km from the more isolated Northern and North Amethyst Drill Centre, respectively.

As noted in previous EEM reports, 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 0.5 km 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, Gerard *et al.* (1999) also describe a zone of approximately 0.5 km 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 environmental assessments predictions are consistent with observations of both Davies *et al.* (1984) and Gerard *et al.* (1999); highly disrupted communities can be expected near source. The environmental assessments estimated the spatial extent of effects around individual drill centres and predicted that effects on benthic communities would extend to approximately 0.5 km from any one drill centre. On a per-drill centre basis and because both literature results and results at White Rose can only be approximate, the EEM results for 2012 support EIS predictions, with effects noted from approximately 0.3 to 0.9 km from source.

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 not the condition at White Rose. In the worst case in 2012, total abundance was reduced to approximately 25% or less than the lower limit of the baseline range of variation at nine (of 18) stations near active drill centres[20], more than the three stations near drill centres noted in 2010. However, as noted above, total abundance appears to have decreased at a number of stations, some far from drill centres, in 2012. Therefore, the increase in the number of stations near drill centres with reduced abundances could be partly natural. Biomass was reduced to 25% or less of the lower limit of the baseline range at four stations near active drill centres, less than the

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

nine stations noted in 2010. Richness levels did not fall to less than 25% of the baseline range at any drill centre station in 2012, as in previous years. Overall, richness has remained within the range of values noted in the baseline year (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 2012 and in previous years have never translated into effects on the fisheries resources, as indicated by fish health assessment 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 2014 EEM program

### 8.5.1  Sediment Quality

Use of repeated-measures regression results should be omitted in future monitoring years. Repeated-measures regression is a statistically sensitive tool for assessing linear trends over time. However, the tool requires sampling of the same locations each year. The sampling field associated with the White Rose development has been increasing (and will continue to increase) in size because of the addition of new drill centres. A total of 53 sediment quality stations were sampled in 2012, with only 36 useable in repeated-measures analysis. In 2012, results based on the 36 repeated measures stations produced results that were somewhat different from those associated with the full 53-station data set from the larger sampling field. Beyond this, the 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. Repeated-measures regression analyses could therefore be removed from the set of statistical tools used to interpret the White Rose data without affecting the sensitivity of the EEM program. There would remain several other statistical tools that have been demonstrated to be informative. Those tools include (1) Spearman rank correlation of analytes and benthic indices with distance to the nearest drill centre, (2) threshold models, (3) scatterplots of response variables in relation to distance from the nearest active drill centre and dot density graphs and (4) maps illustrating sampling locations that are unusual relative to the baseline range of variation.

Because of the overlapping effects of drill centres, threshold models alone cannot be used to estimate the extent of effects on benthic communities. Graphical tools such as the plotting of distance relationships and maps illustrating sample results are required. Those analyses compliment the more quantitative analysis used in this report.

Future assessment of the benthic community at White Rose should focus on key variables (abundance, richness, biomass, numbers of numerically dominant families). It is recommended that multivariate analyses including non-metric multi-dimensional scaling and the Bray-Curtis dissimilarity measure be discontinued. Those statistical expressions of the data have not provided insight into the data (and associated effects on benthos) that have not been obvious with the simpler and more direct key variables (listed above). Therefore, a simplification of the data analysis procedures is warranted.

### 8.5.2   Commercial Fish

In 2012, 1,436 cod (2,266 kg) were caught as by-catch. Survival after processing (counting and weighing) is low. Because these fish are not required for the EEM program, it is recommended that counting and weighing of non-SARA by-catch species be discontinued in future programs. By-catch was reported in EEM reports prior to the 2010 program, but this has now been discontinued because of the changes to fishing gear and vessels (*i.e.*, catch is not comparable across years, nor is it an objective of the EEM program to examine catch or catch rates).

Use of crab pots instead of a groundfish trawl should be considered to capture crab at White Rose. Use of a groundfish trawl should continue for plaice.

In future programs, the EDTA tubes used for plaice haematology should be tested just prior to the survey to make sure that they display adequate anti-clotting properties.

### 8.5.3   Water Quality

In 2012, there was some indication (albeit weak) that iron could act as a tracer of produced water constituents in sediments. Therefore, the analysis of iron in sediments using chemistry data from both Sediment Quality Triad and water quality stations should continue in 2014.

Conversely, the process chemicals XCide 450 and SCW4453 have not proven to be effective tracers for produced water in seawater samples. These chemicals were measured in 2010 and 2012 and levels were either below detection (XCide 450) or low and similar between the Study and Reference Areas (SCW4453). SCW4453 is proprietary to Baker Petrolite. Its constituents are unknown and its detection at low concentrations in all areas would indicate that some of its constituents may be ubiquitous and not necessarily related to activities at White Rose. As such, it along with XCide 450 are poor indicators of the distribution of produced water from White Rose. Measurement of these two process chemicals in seawater samples should be discontinued.

No relationship was noted between TSS in seawater samples and fines enrichment in sediments. Nor were these two variables visibly affected by project activity. This analysis should be discontinued in future programs unless both variables are affected by project activity.

**8.6     Regulator Comments on the 2010 EEM Program**

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

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