Husky Report

White Rose

Environmental Effects Monitoring Program

2018

Volume 1 of 2

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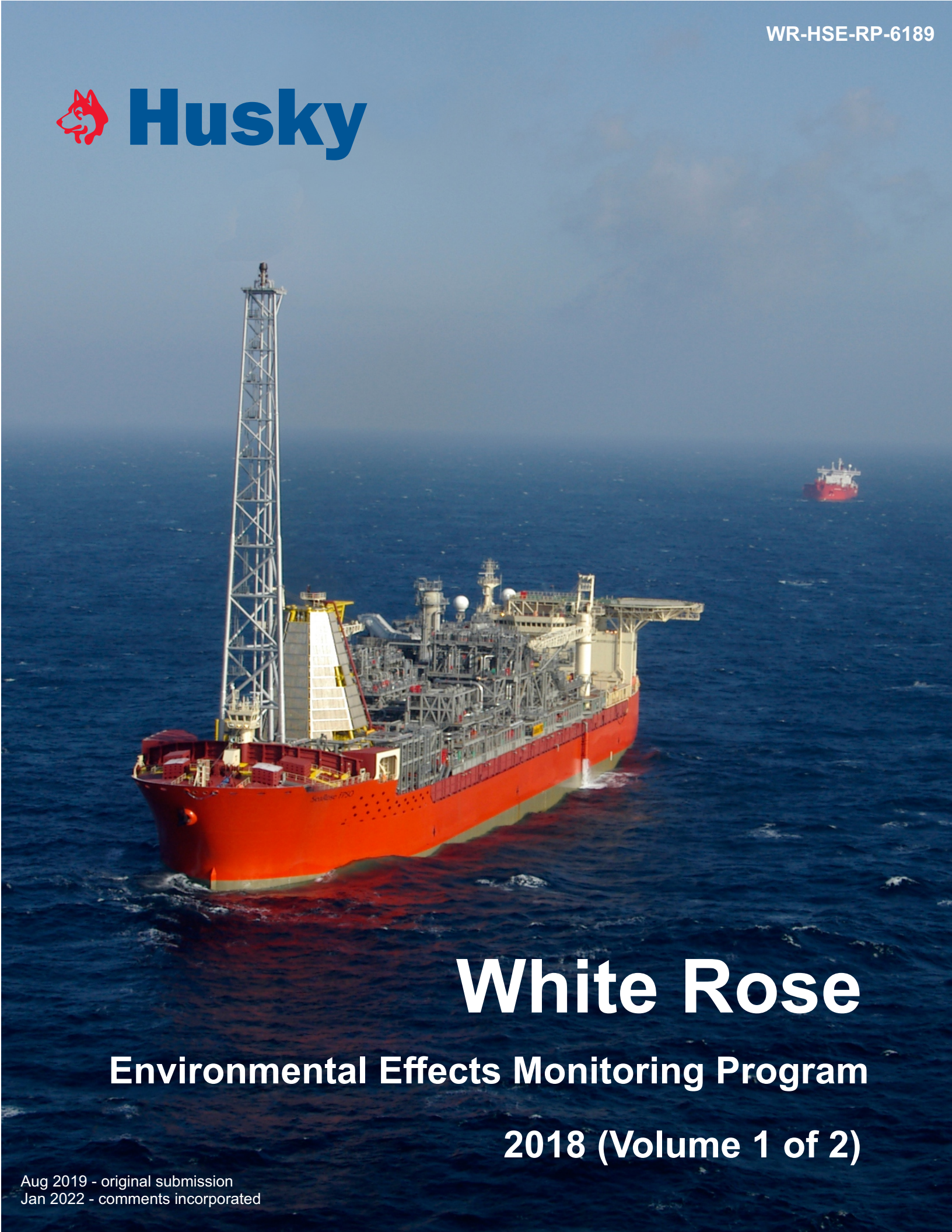

White Rose

Environmental Effects Monitoring Program

2018 (Volume 1 of 2)

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Executive Summary

The White Rose Environmental Effects Monitoring (EEM) program was designed to evaluate the environmental effects of Husky Energy's offshore oil drilling and production activities for the White Rose Development. Program design drew on the predictions and information in the White Rose Development Plan Environmental Impact Statement (EIS) and its supporting modelling studies on drill cuttings and produced water dispersion. Baseline studies to document pre-development conditions were conducted in 2000 and 2002. Those studies, 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 to support planning for the coming cycle. Comments from the regulatory community on the 2016 EEM program are provided in Appendix A1. Comments from the regulatory community for this 2018 EEM program have been incorporated into the final version and are provided into the Addendum.

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. The main components of the EEM program are sediment quality, commercial fish, and water quality.

Seabed sediments and commercial fish species from the White Rose Field have been collected in 2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016 and 2018 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 collectively 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 have been collected at White Rose in 2008, 2010, 2012, 2014, 2016 and 2018 and 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 subsequent years. 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 was used as part of the White Rose Water Quality program to iteratively improve field sampling. The 2014, 2016 and 2018 Water Quality programs included seawater sampling and sediment chemistry sampling at Water Quality stations; there was no modelling component in 2014, 2016 and 2018.

Figure 1 illustrates the components of the EEM program.

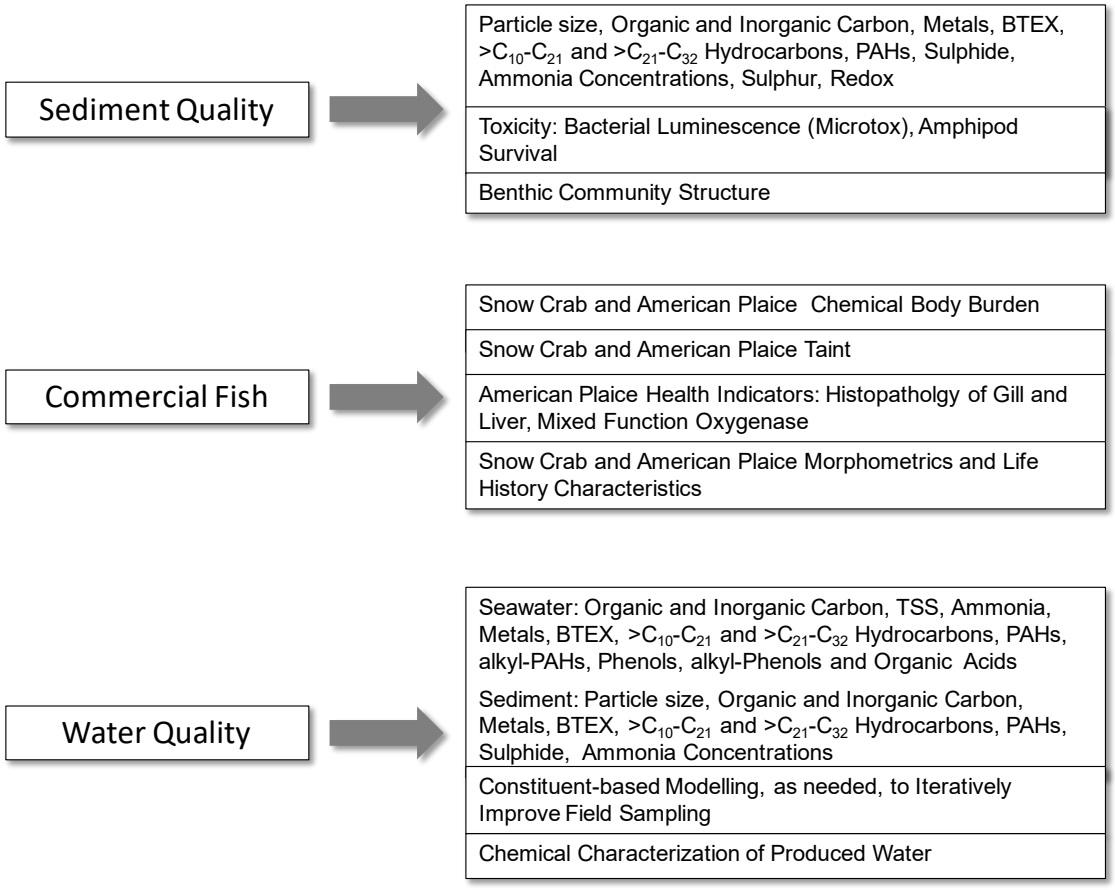

Figure 1 EEM Program Components

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

This report provides the results from the ninth round of post-operational sampling under the program conducted in the summer of 2018. The findings are interpreted in the context of results of previous sampling years and the baseline data collected pre-development.

Sediment Quality

In the summer of 2018, 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 km² 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, sediment lead, strontium, organic carbon, fines, ammonia, sulphur, metals other than barium and sulphide concentrations were also affected by drilling.

Maximum drill mud hydrocarbon (hydrocarbons in the >C_{10}-C_{21} range) and barium concentrations at White Rose in 2018 were 710 and 3,400 mg/kg, respectively. The estimated distance over which hydrocarbons concentrations were correlated with distance from active drill centres (*i.e.*, the threshold distance) extended to an average of 2.4 km in 2018, similar to the average of 2.7 noted in 2016. The distance over which barium concentrations were correlated with distance from active drill centres extended to an average of 1.0 km in 2018, similar to the average of 1.2 km noted in 2016. In general, estimated average threshold distances for both hydrocarbons and barium were greater in earlier EEM years (2004 to 2010) than they have been in more recent years.

In 2018, project effects on sediment lead and strontium were noted to an average distance of 0.8 km, and effects on organic carbon were noted to an average distance of 1.0 km. Project effects on lead have been noted since 2006 and threshold distances have been approximately 1 km. Threshold distances of approximately 1 km have also been noted for strontium in 2006, 2008 and 2012, with relationships weak or absent in other years. Project effects on organic carbon have not been noted previously.

Relationships between sediment fines, ammonia, sulphur and metals other than barium with distance to drill centres were too weak to assess thresholds. Sulphides also were elevated near drill centres, despite the lack a of distance relationship with drill centres. In all cases, effects were limited to a few stations located within approximately 1 km of drill centres. Evidence of effects on these last variables generally has been either weak or absent in EEM years. However, percent fines exhibited a threshold with distance from drill centres in 2014, and sulphide concentrations exhibited a threshold in 2006 and 2008. In all cases, threshold distances were approximately 1 km or less.

Sediments were generally non-toxic in 2018. No sample was toxic to Microtox. One sample was toxic to laboratory amphipods when compared to Reference sediments but it was not toxic when compared to laboratory control sediments; and there was no significant relationship between laboratory amphipod survival and any sediment particle size or chemistry variable. The one sample that was toxic relative to Reference sediments did have elevated levels drill mud hydrocarbon and barium concentrations. However, there were many stations with higher concentrations of hydrocarbons and barium that were not toxic to laboratory amphipods. Therefore, the link between project activity and this response in 2018 is not clear. Over all EEM years, 6 (of 352 samples) have been toxic to Microtox and 15 (of 352) samples have been toxic to laboratory amphipods, indicating that sediments at White Rose are generally non-toxic.

As in previous years, there was evidence of project effects on benthic biomass and little evidence of effects on richness. However, project effects on total abundance were weaker in 2018 than in previous years. The relationship between total abundance and distance to drill centre has been significant in most EEM years. That relationship was not significant in 2018 and only two stations near drill centres (within 0.5 km) had values for total abundance below what was noted over all stations during baseline[1]. The abundances of some polychaete worms and crustacean taxa (predominantly Paraonidae, Tanaidacea and Orbiniidae) were lower near drill centres. Conversely, the abundances of other polychaete taxa (predominantly Cirratulidae and Dorvilleidae) were higher near drill centres. Therefore, the overall effect on total abundance was minor.

[1] The baseline range (mean ± 2 standard deviations) is used to assess declines, or increases, at individual stations.

Of the taxa listed above, the polychaete family Paraonidae was the most affected by project-related activity in comparison to baseline, with decreased numbers noted to 1 to 2 km. As was the case for drill mud hydrocarbons and barium, there was an indication that the distance over which this taxon was affected was greater in earlier EEM years than in more recent years.

Overall effects on biomass were weaker in 2018 than from 2012 to 2016. Although the relationship between biomass and distance was significant in 2018, no threshold distance could be estimated. Effects on biomass in 2018 were limited to within approximately 1 km from drill centres and seven stations near drill centres had biomass values lower than what was noted in baseline. Five of these seven stations were within 0.5 km of drill centres.

As in previous years, the relationship between richness and distance to drill centres was not significant. In 2018, only two stations near drill centres (within 0.5 km) had richness values lower than what was noted in baseline.

Overall, 2018 data suggest that the majority of effects on benthos occur within 0.5 km of drill centres, with subtle and/or highly localized effects between 1 to 2 km.

After monitoring sediment quality at White Rose nine times over a period of 14 years, noted effects on sediment physical and chemical variables and benthos have varied in strength from year to year. With the addition of 2018 information, there is no compelling evidence that effects are growing in magnitude or spatial extent. The decrease in the spatial extent of effects on sediment concentrations of drill mud hydrocarbons, barium, Paraonidae abundances and biomass from earlier to later EEM years suggests that effects may be becoming more localized.

Commercial Fish

During the Summer of 2018, samples of American plaice and snow crab were collected near the White Rose Field (the Study Area) and at two Reference Areas, located approximately 28 km to the northwest and southwest of the White Rose Field. 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.

In 2018, there continues to be little evidence of project effects on metal and hydrocarbon concentrations in American plaice and snow crab tissues. Furthermore, results of taste tests demonstrated that edible tissues from the two species were not tainted, and indices of fish health for American plaice showed that the general health and condition of this species was similar between the Study and Reference Areas.

Overall, analyses of tissue chemistry, taste, and fish health revealed no compelling evidence of effects of project activities on commercial fish.

Water Quality

In the summer of 2018, water samples were collected in two Study Areas, the first (near-field) located 300 m from the *SeaRose* floating, production, storage, and offloading (*FPSO*) vessel and the second (mid-field) located 4 km to the southeast. Samples were also collected in two Reference Areas, located approximately 28 km to the northeast and northwest. Samples were processed for parameters listed in Figure 1.

There was little evidence of project-effects on overall water quality in 2018. As in previous years, some differences among Areas were noted but these differences have not been consistent over time and can better be attributed to natural variability than project-effects. Conversely, examination of individual occurrences of constituents in high concentration in produced water indicated low levels of some of these constituents at three near-field stations in 2018. These occurrences indicate that produced water may have been detected at some stations near (within 300 m of) the *SeaRose FPSO*, as in 2016. This is consistent with the prediction that effects of produced water would be localized near the point of discharge.

Conclusion

In 2018, there was evidence of project effects on fish habitat (physical and chemical characteristics), and produced water may have been detected at some near-field water quality stations. These effects are within predictions made in the White Rose EIS and there is no evidence that additional mitigation measures are required at this time.

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1.0 Introduction

1.1 Project Setting and Field Layout

Husky Energy (Husky), with its joint-venture partner Suncor Energy, is developing and operating the White Rose Field on the Grand Banks, offshore Newfoundland. The field is approximately 360 km east-southeast of St. John's, Newfoundland and Labrador, 50 km from both the Terra Nova and Hibernia fields and 46 km from the Hebron Field (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. The North Amethyst Drill Centre was excavated in 2007 and the South White Rose Extension (SWRX) Drill Centre was excavated in 2012 (Figure 1-2). Nalcor Energy is an additional partner in the North Amethyst and SWRX Drill Centres developments.

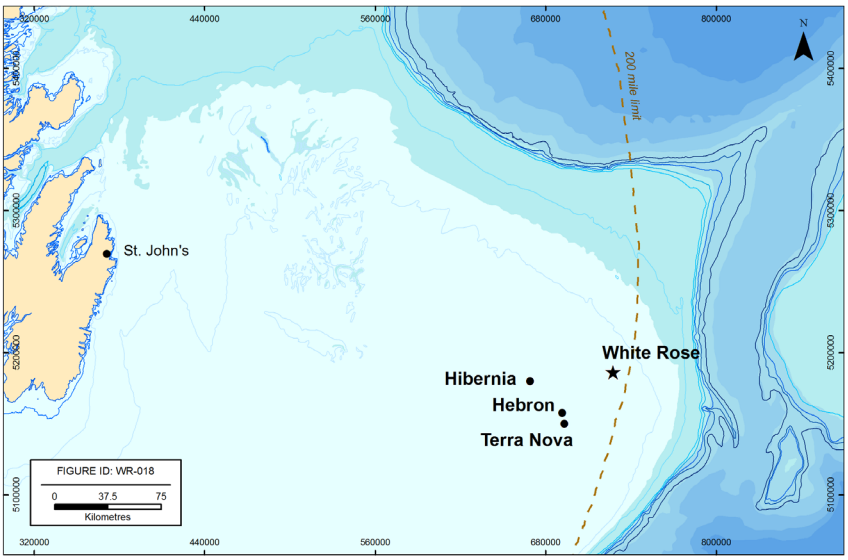

Figure 1-1 Location of the White Rose Field

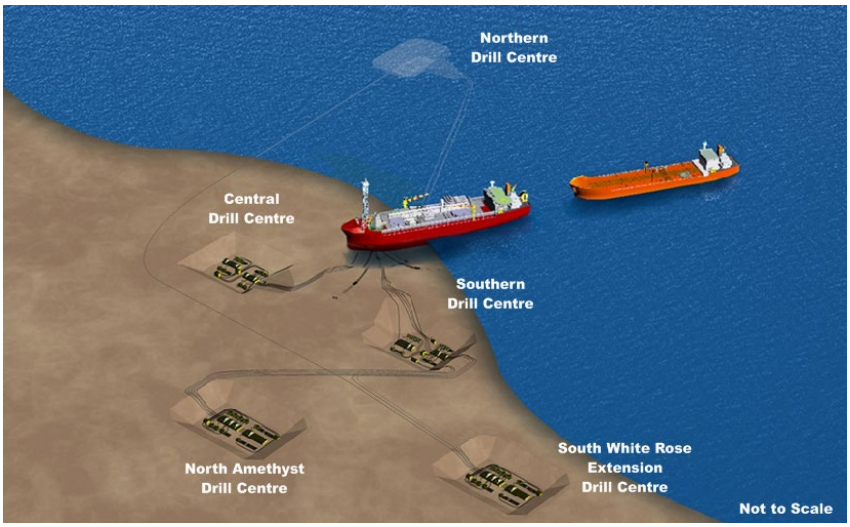

Figure 1-2 White Rose Field Layout

1.2 Project Commitments

Husky committed in its Environmental Impact Statement (EIS) (Part One of the White Rose Oilfield Comprehensive Study (Husky Oil Operations Limited 2000)) to develop and implement a comprehensive Environmental Effects Monitoring (EEM) program. This commitment was integrated into Decision 2001.01 (C-NLOPB (Canada-Newfoundland and Labrador 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 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's Environmental Protection and Compliance Monitoring Plans, prerequisites for the issuance of Operating Authorizations by the C-NLOPB, state that Husky will make the Baseline and EEM reports available to the public via Husky's corporate website.

1.3 EEM Program Design

Husky submitted an EEM program design to the C-NLOPB in May 2004, which was approved for implementation in July 2004. The design drew on information provided in the White Rose EIS (Husky Oil Operations Limited 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. Revised versions of the EEM program design document to accommodate the development of the North Amethyst Drill Centre were submitted to the C-NLOPB in July 2008 and, subsequently, in March 2014 to accommodate the SWRX Drill Centre and incorporate the 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 relative to EIS predictions and the identification of appropriate modifications to project activities.

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

- to estimate the zone of influence[2] of project contaminants;
- to test biological effects predictions made in the EIS;
- to provide feedback to Husky for project management decisions requiring modification of operations practices where/when necessary; and
- to provide a scientifically-defensible synthesis, analysis, and interpretation of data.

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

1.5 White Rose EIS Predictions

The White Rose EIS assessed the significance of environmental effects on Valued Ecosystem Components. Valued Ecosystem Components addressed within the context of the Husky EEM program are Fish and Fish Habitat and Commercial Fisheries (Husky Oil Operations Limited 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 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 of other waste streams associated with drilling and production) 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.

Effects of produced water (and other liquid waste streams) on physical and chemical characteristics of seawater were expected to be localized near the point of discharge. 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 Operations Limited 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 this document were consistent with the White Rose development EIS (Husky Oil Operations Limited 2000); based on modelling, a 500 m biological zone of influence was estimated around each well. Cumulative effects from new drill centre construction and operations were assessed as non-significant.

Predictions and the rankings used to assess effects are described in greater detail in project environmental assessments (Husky Oil Operations Limited 2000; LGL 2006). Further discussion on environmental assessment predictions are also provided in Section 8. 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.

[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.

1.6 EEM Program Components and Monitoring Variables

The White Rose EEM program is divided into three components: 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 (*Chionoecetes opilio*) and American plaice (*Hippoglossoides platessoides*) 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, as needed, 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, 2010a, 2010b, 2014).

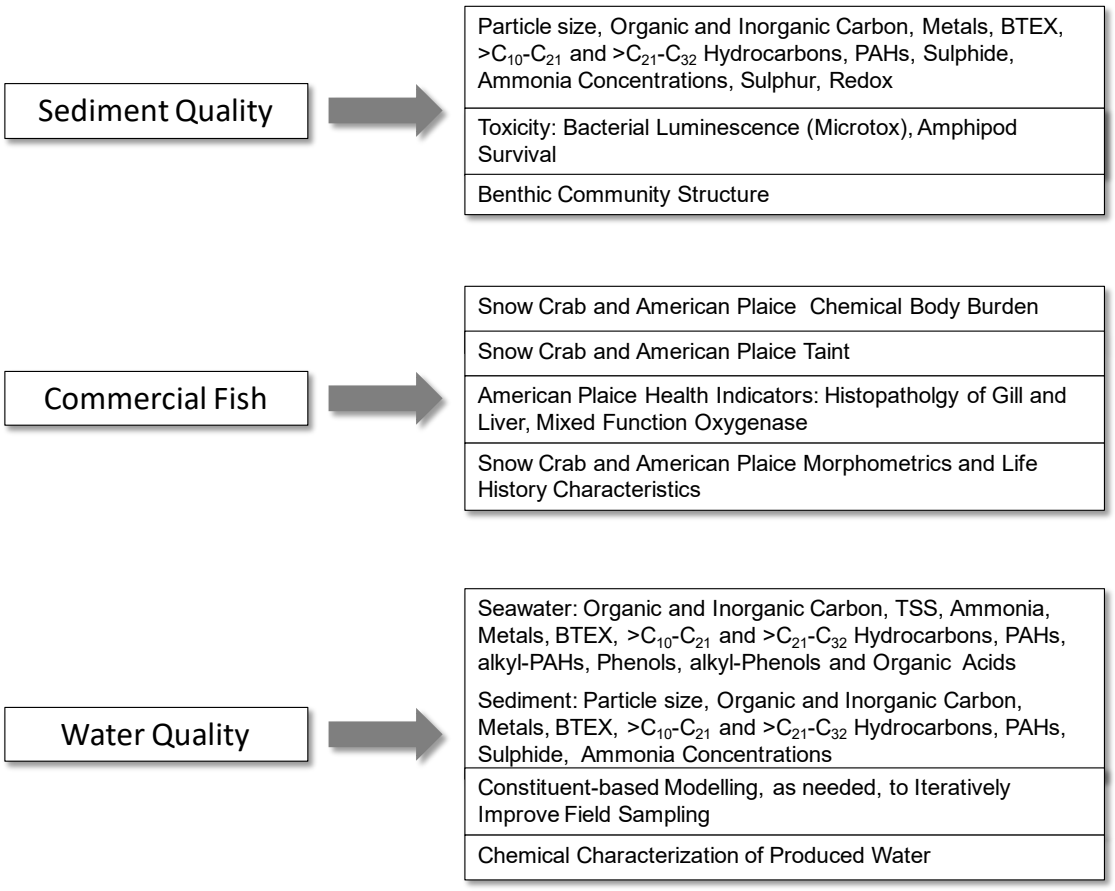

Figure 1-3 EEM Program Components

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

1.7 Monitoring Hypotheses

Monitoring, or null (H_0), hypotheses were established as part of the original White Rose EEM program design to assess effects predictions. In accordance with a recommendation from the C-NLOPB on the 2016 report (see Appendix A), these hypotheses will be replaced and re-assessed by regulatory authorities during the redesign of the White Rose EEM program[4]. In this 2018 EEM program report, the originally approved null hypotheses are addressed.

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 hypotheses are addressed in this report:

[4] A re-design is required to monitor additional potential effects associated with the White Rose Extension Project.

- 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 and Mixed Function Oxygenase (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 normally at four distant Reference Areas located approximately 28 km to the northeast, northwest, southeast, and southwest. In 2018, sampling could not be performed in the northeast and southeast Reference Areas because of intense commercial fishing activity for crab.

Water samples are collected in the vicinity of the *SeaRose* floating, production, storage and offloading (*FPSO*) vessel (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 type of 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, 2012, 2014, 2016 and 2018). 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), 53 stations were sampled from 2012 to 2018 (Figures 1-10 and 1-11, respectively). In all, 36 stations were common to all sampling programs.

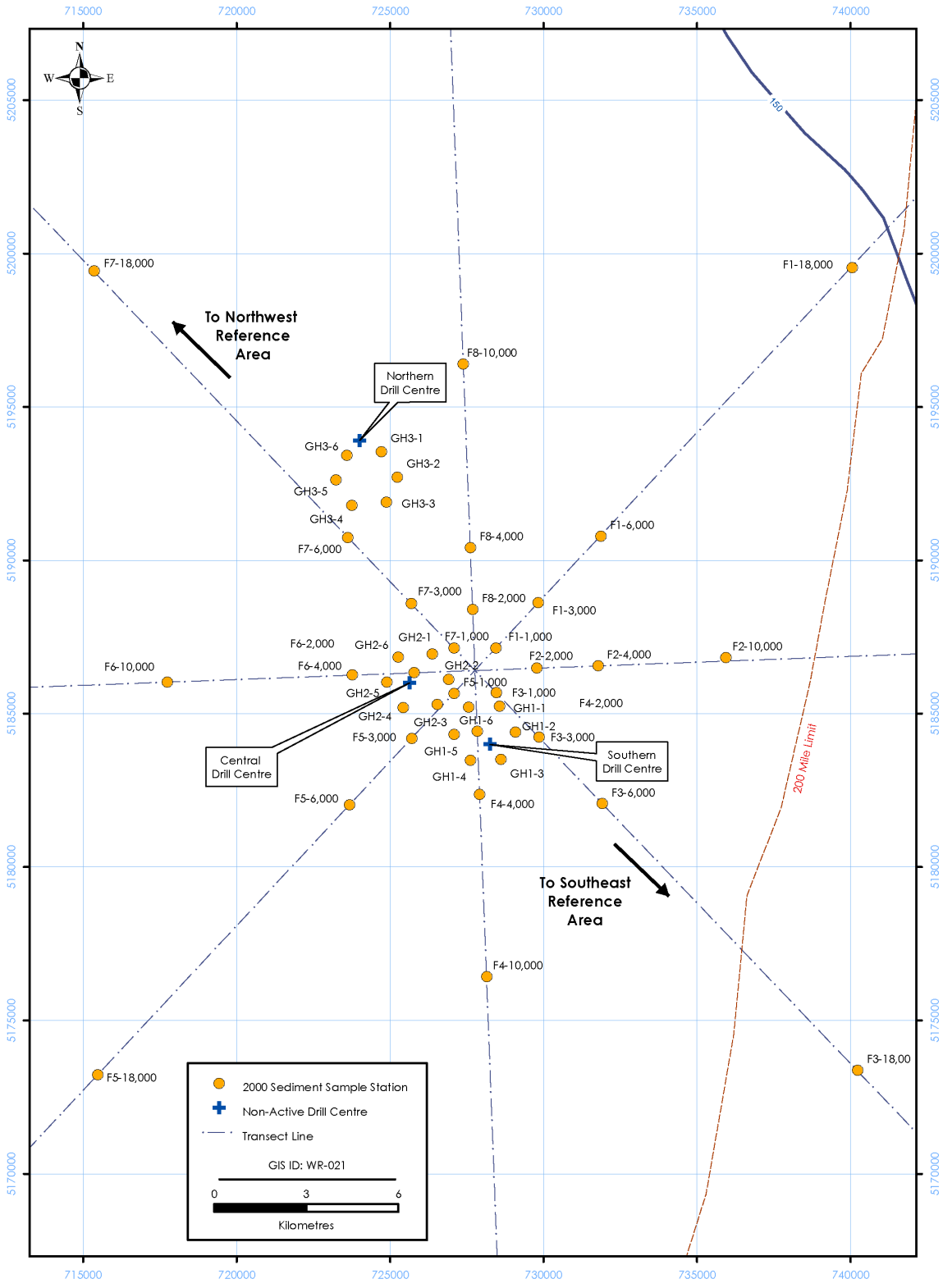

Figure 1-4 2000 Baseline Program Sediment Quality Stations

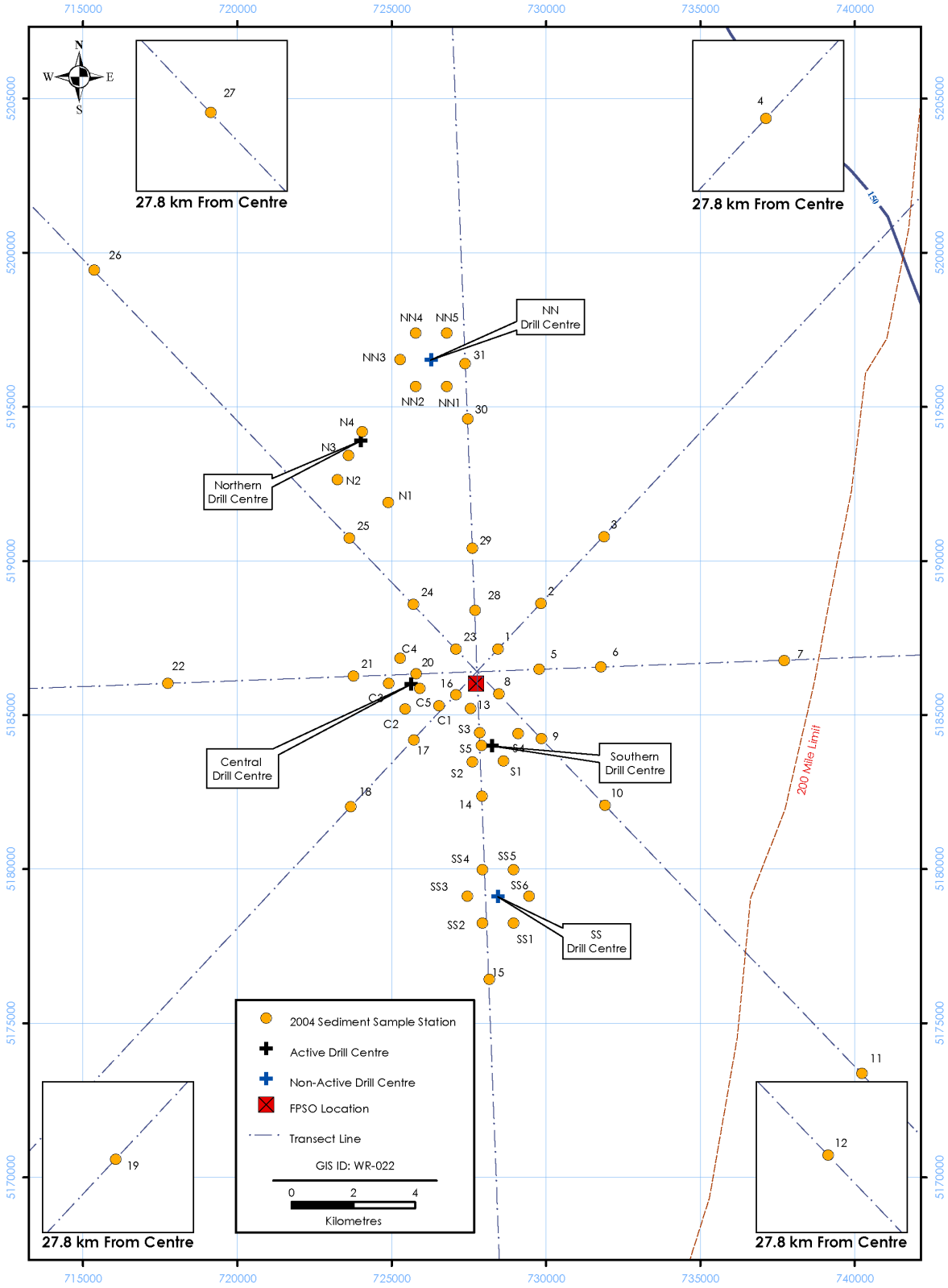

Figure 1-5 2004 EEM Program Sediment Quality Stations

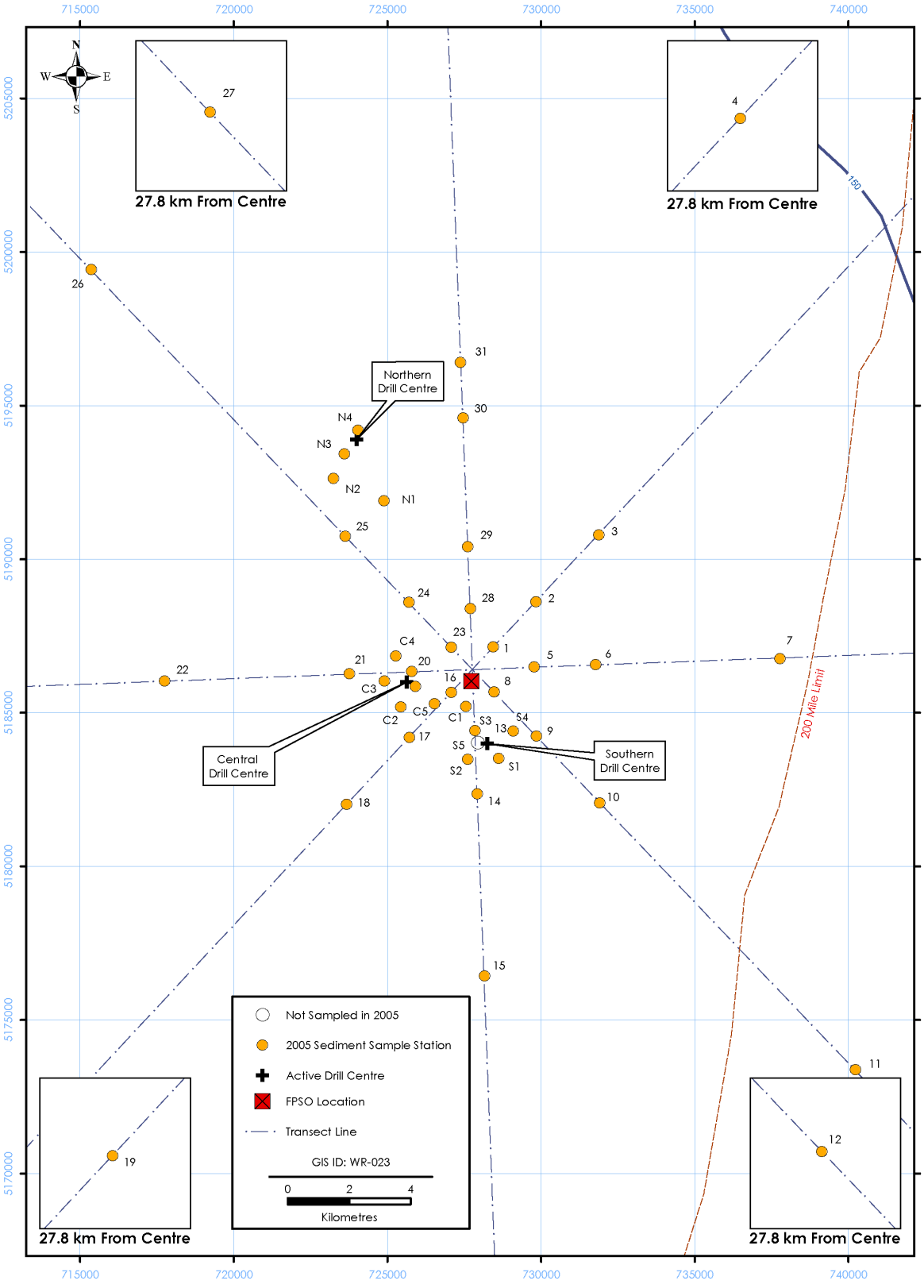

Figure 1-6 2005 EEM Program Sediment Quality Stations

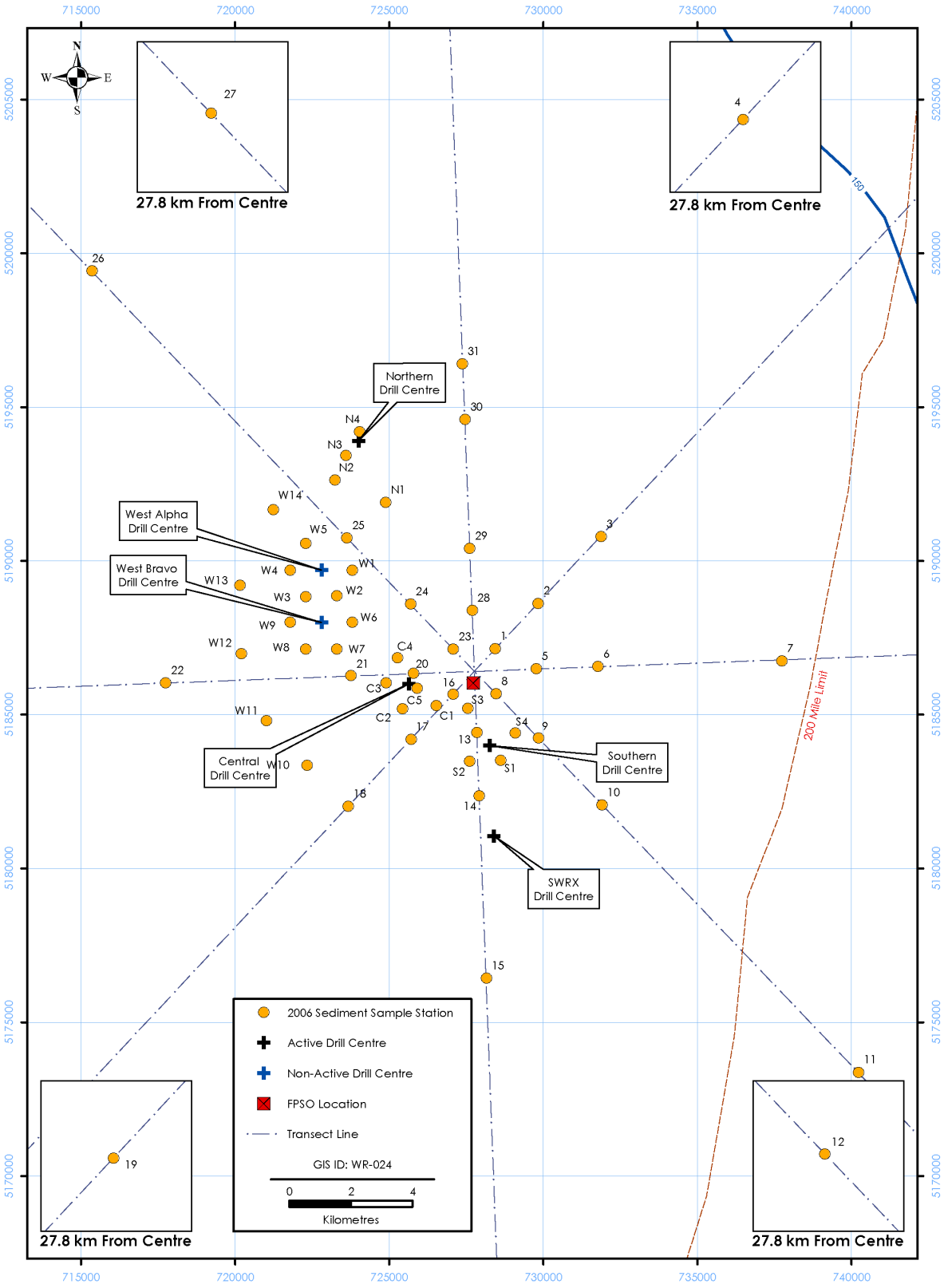

Figure 1-7 2006 EEM Program Sediment Quality Stations

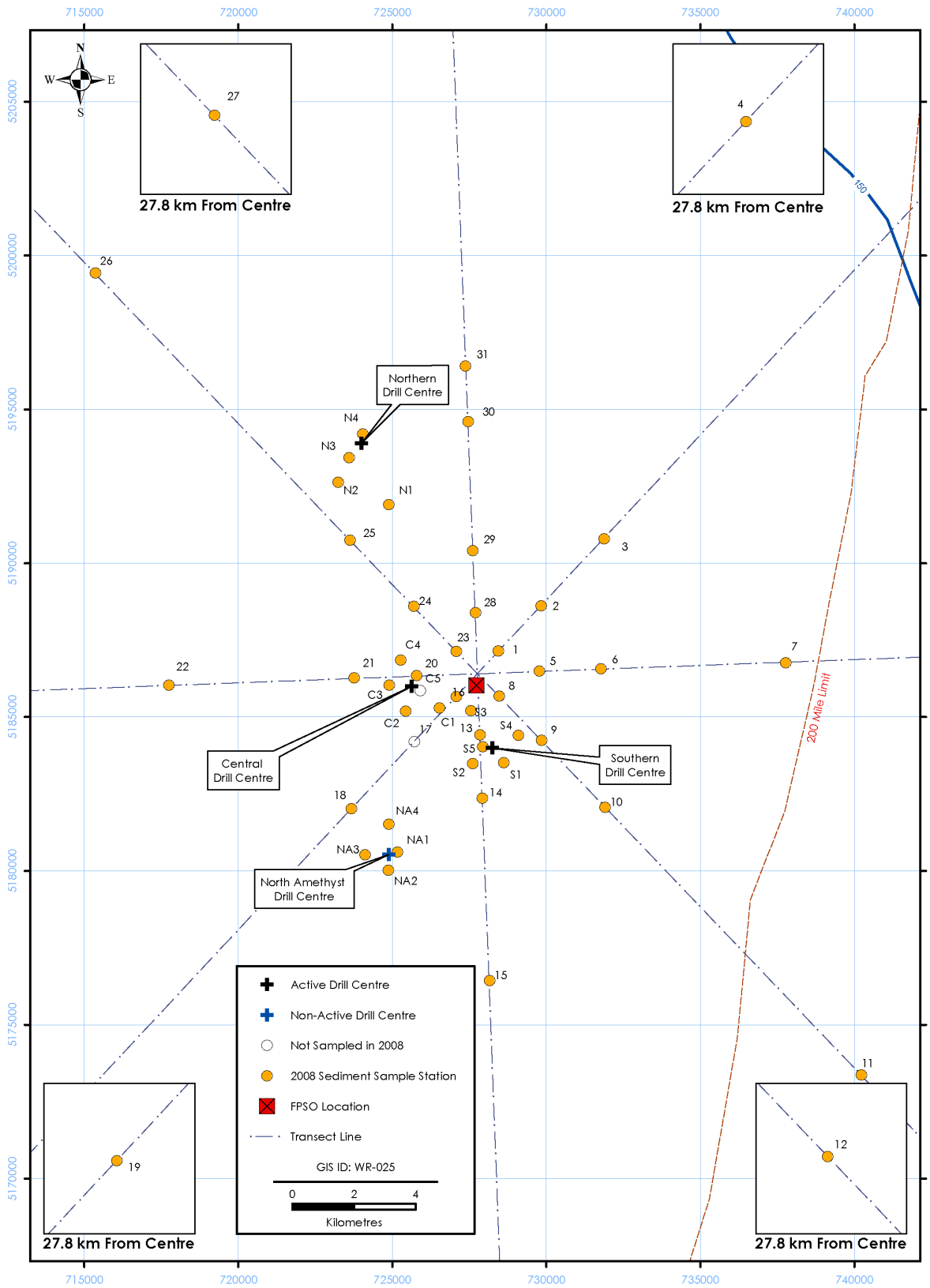

Figure 1-8 2008 EEM Program Sediment Quality Stations

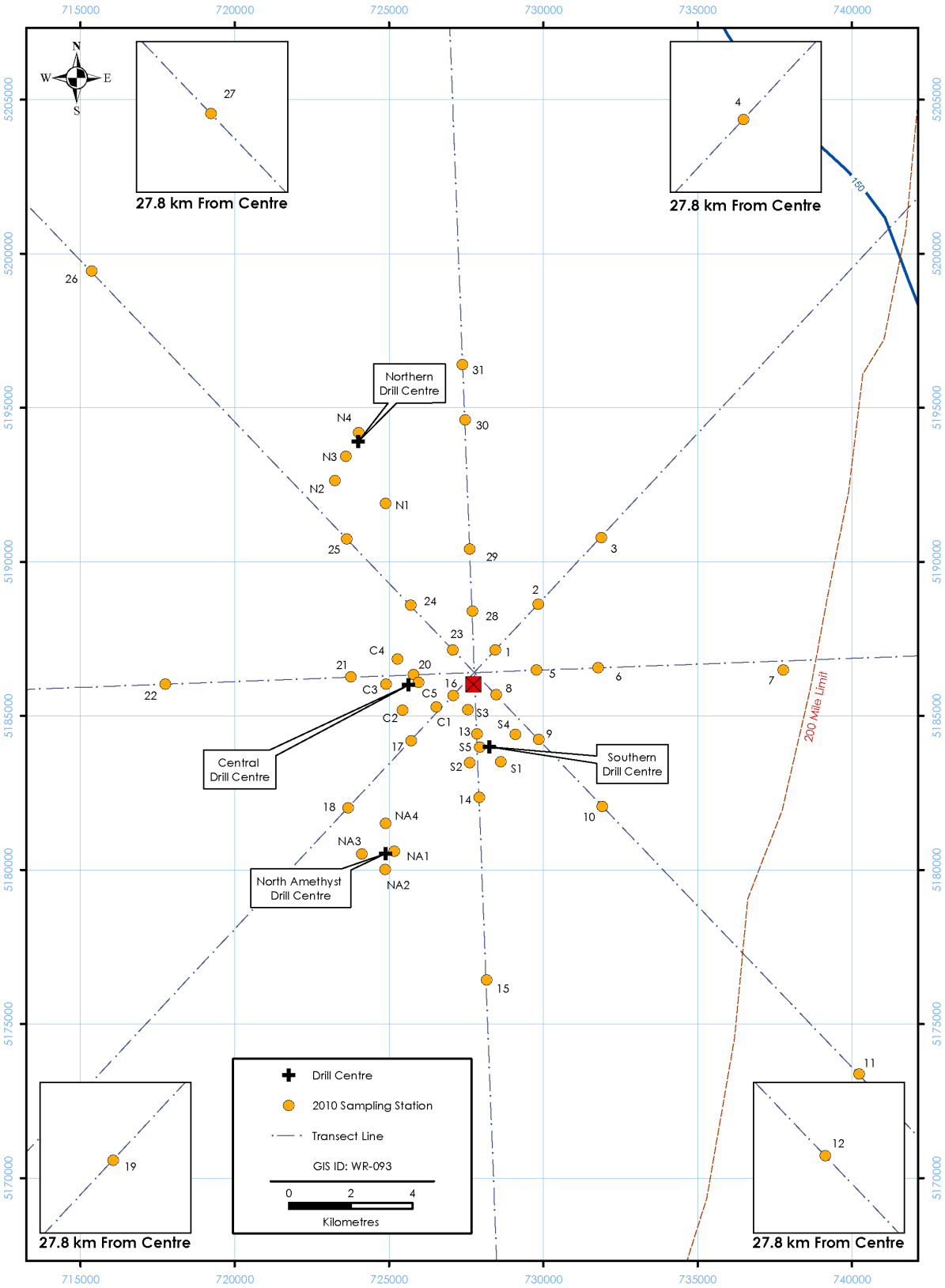

Figure 1-9 2010 EEM Program Sediment Quality Stations

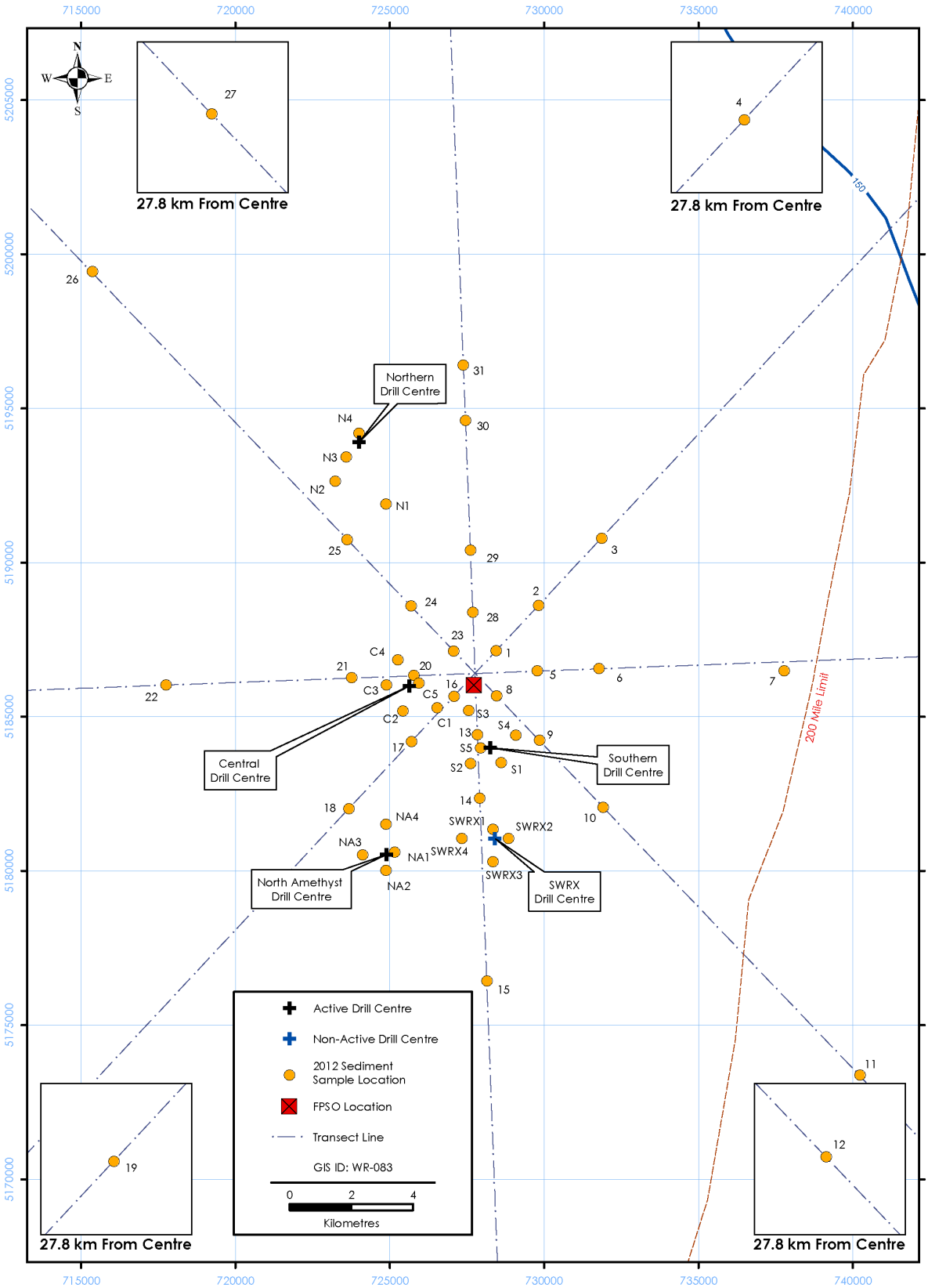

Figure 1-10 2012 EEM Program Sediment Quality Stations

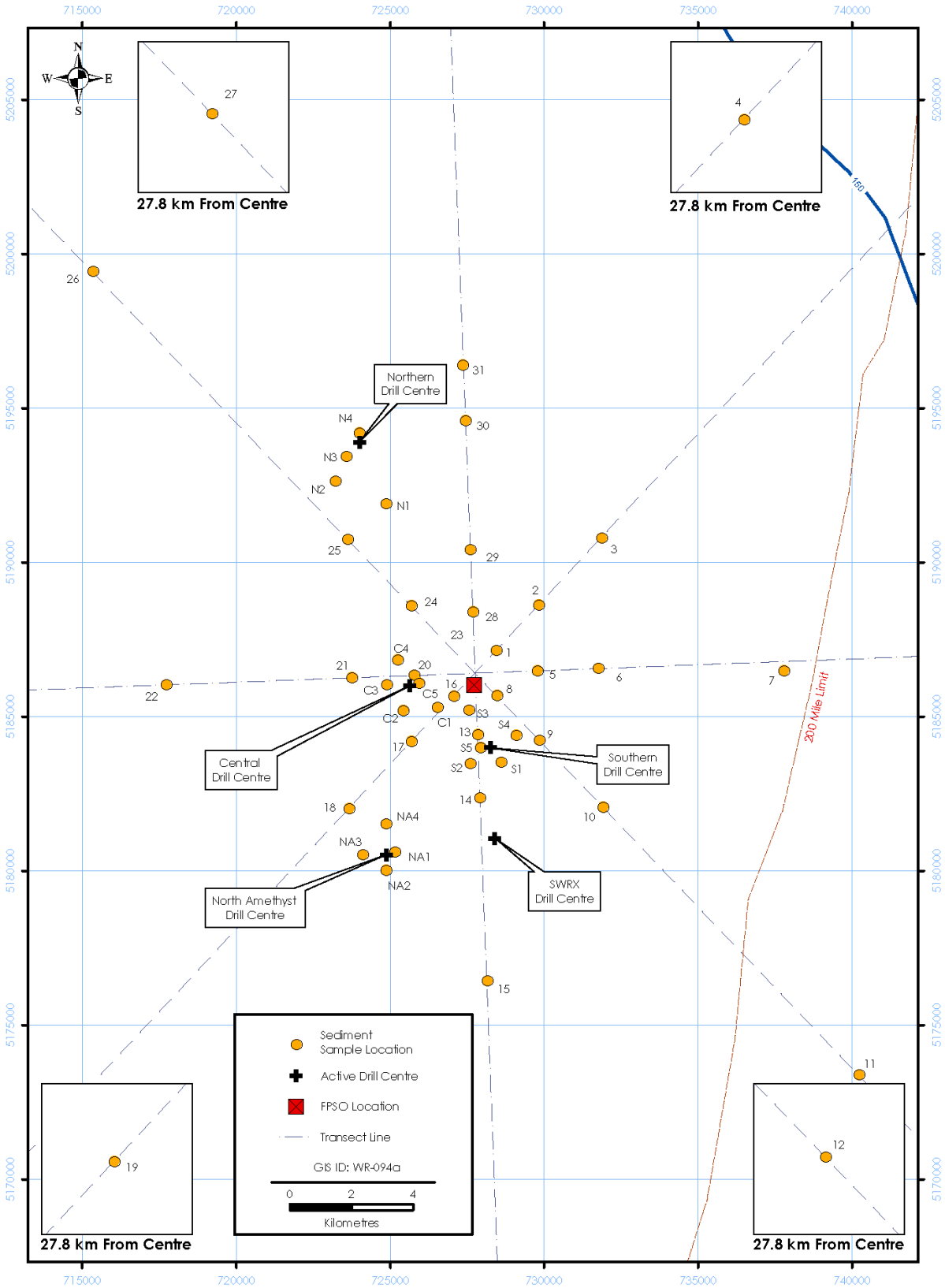

Figure 1-11 2014, 2016 and 2018 EEM Program Sediment Quality Stations

As part of EEM program design (Husky Energy 2004, 2008), seven baseline stations in the immediate vicinity of drill centres were eliminated because they were redundant. 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 and three drill centre stations located approximately 300 m from each of the Northern, Central and Southern Drill Centres. However, in 2005, one of these stations (Station S5) could not be sampled because of drilling activity at the Southern Drill Centre.

In 2004, six drill centre stations were sampled at 1 km from the proposed location of each of more northerly (NN) and more southerly (SS) drill centres to provide additional baseline data should drilling occur at these drill centres (see Figure 1-5). Since there are no immediate plans to drill at these 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, 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, 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.

In 2014, Stations C1 and C5 were moved slightly because of proximity to subsea infrastructure. All stations were moved less than 50 m from their original location.

In 2016, Stations SWRX1, SWRX2 and W-6MF were moved slightly because of proximity to subsea infrastructure. Stations W-6MF and SWRX2 were moved less than 50 m from their original location; Station SWRXI was moved 106 m from its original location.

In 2018, Stations C-5, W-7MF, and W-8MF were moved because of proximity to HGR Anchor Chain #1 / CDC-NDC Umbilical (C-5) and metocean equipment (W-7MF and W-8MF). Station C-5 was moved 116.m from its original location. Stations W-7MF and W-8MF were moved 409 m and 667 m, respectively, from their original locations. A 500 m buffer zone was required around metocean equipment.

Table 1-1 provides a summary of changes between the 2000 baseline program and the 2018 EEM program for sediment, as well as station name changes that were proposed in the EEM design document to simplify reporting of results.

Table 1-1 Table of Concordance between Baseline and 2018 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	Not Sampled in 2000
31**	F8-10,000
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

EEM Program Station Name	Corresponding Station Name during the 2000 Baseline Program
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:
- **Bold** – Repeated Measures Stations. *Italics* – Drill Centre Stations. Refer to Section 5 for details.
- 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 2008 because of drilling activity; **Although sampled in every year, Station 30 is excluded from repeated-measures analysis because it is near a delineation well and, as a result, the station is a statistical outlier in analyses. See Section 5 for details. *** Not sampled in 2005 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 1-12 to 1-20 provide transect locations for the 2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016 and 2018 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 2012, the approved White Rose safety zone was used as the boundary for fishing, and that area was expanded in 2014 and subsequent years to accommodate the SWRX Drill Centre. In 2008 and 2018, heavy commercial fishing activity for crab in Reference Areas 3 and 4 prevented sampling in those areas. In 2016, heavy commercial fishing activity for crab in Reference Area 4 prevented sampling in that area.

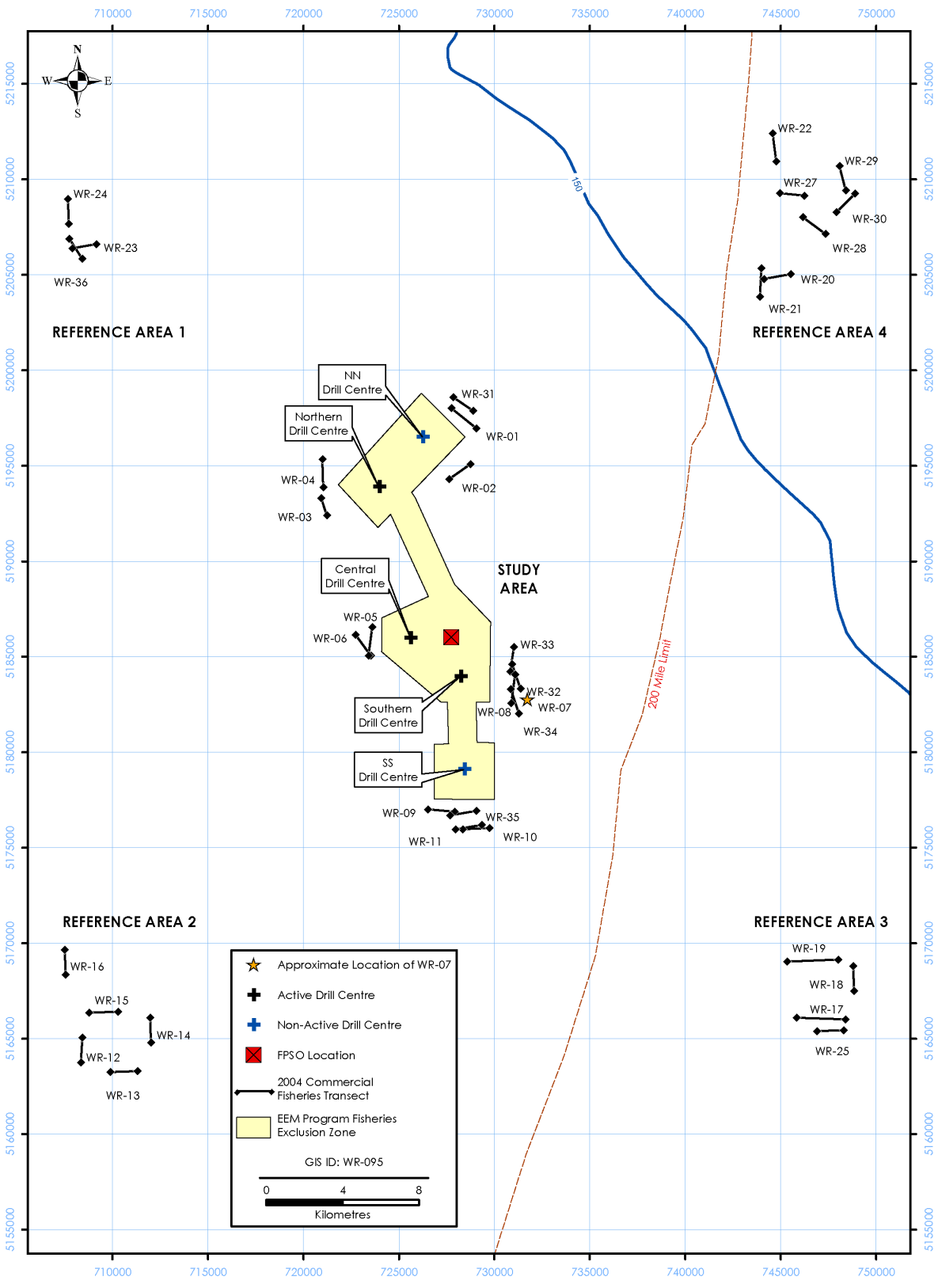

Figure 1-12 2004 EEM Program Commercial Fish Transect Locations

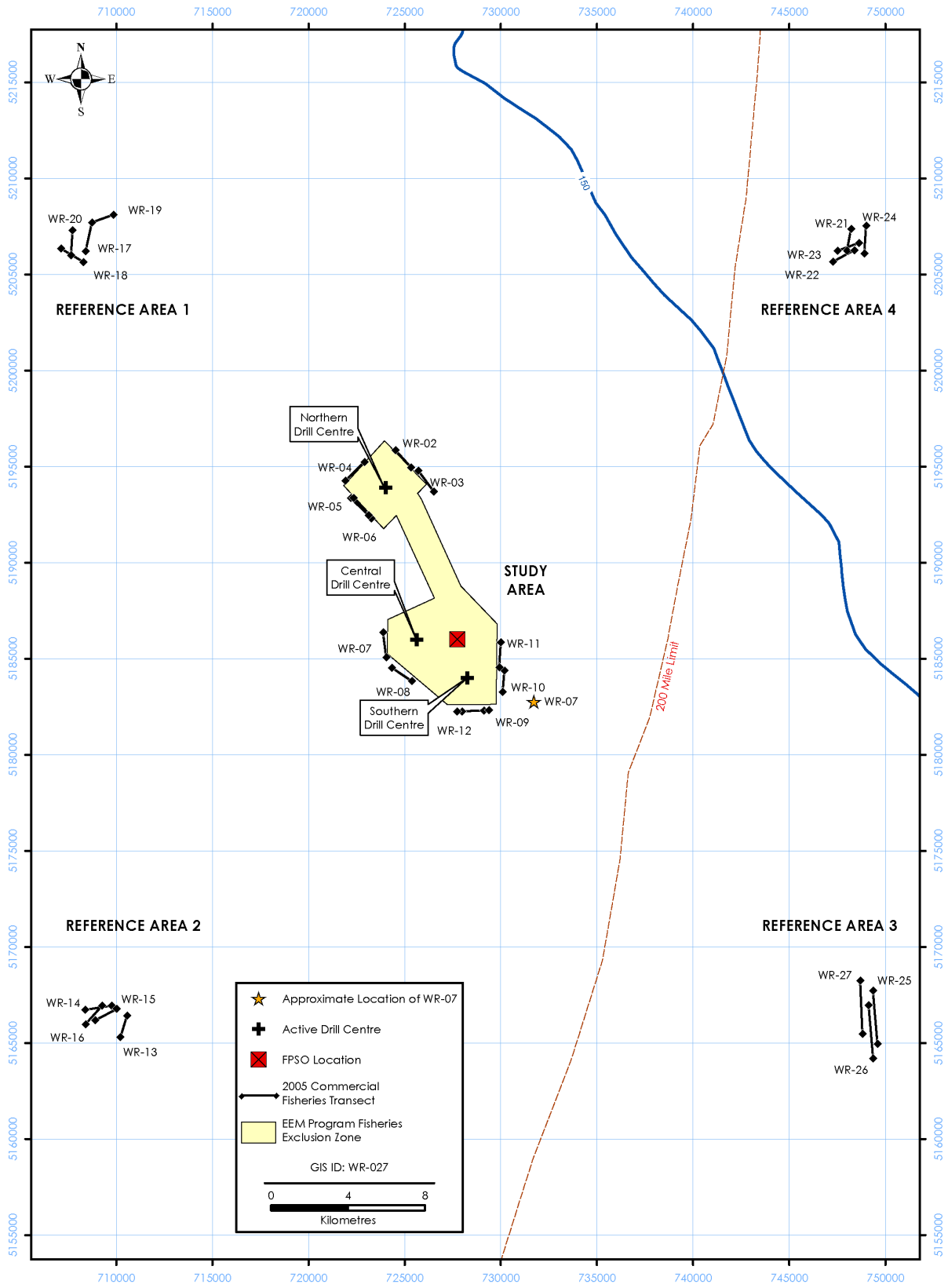

Figure 1-13 2005 EEM Program Commercial Fish Transect Locations

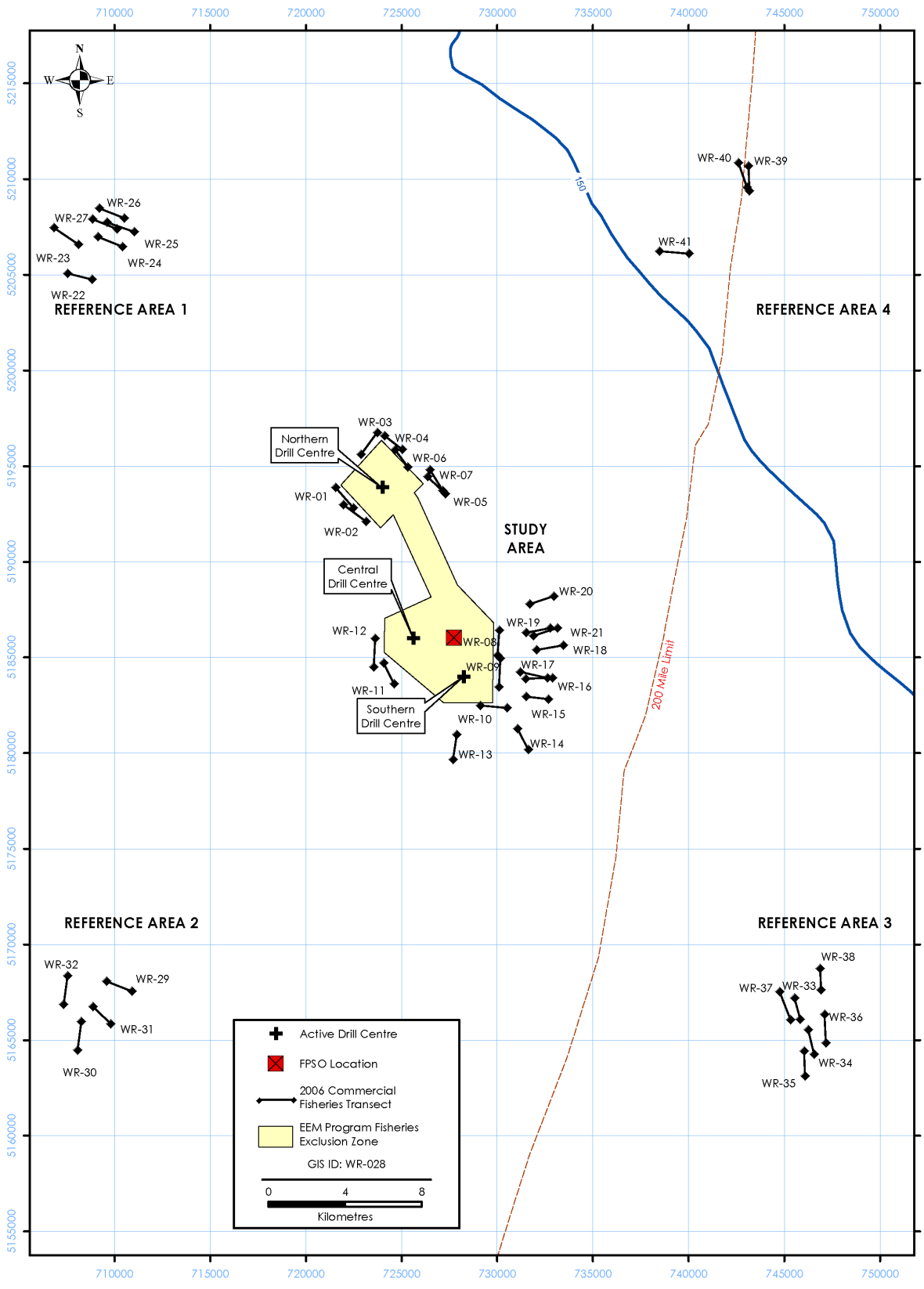

Figure 1-14 2006 EEM Program Commercial Fish Transect Locations

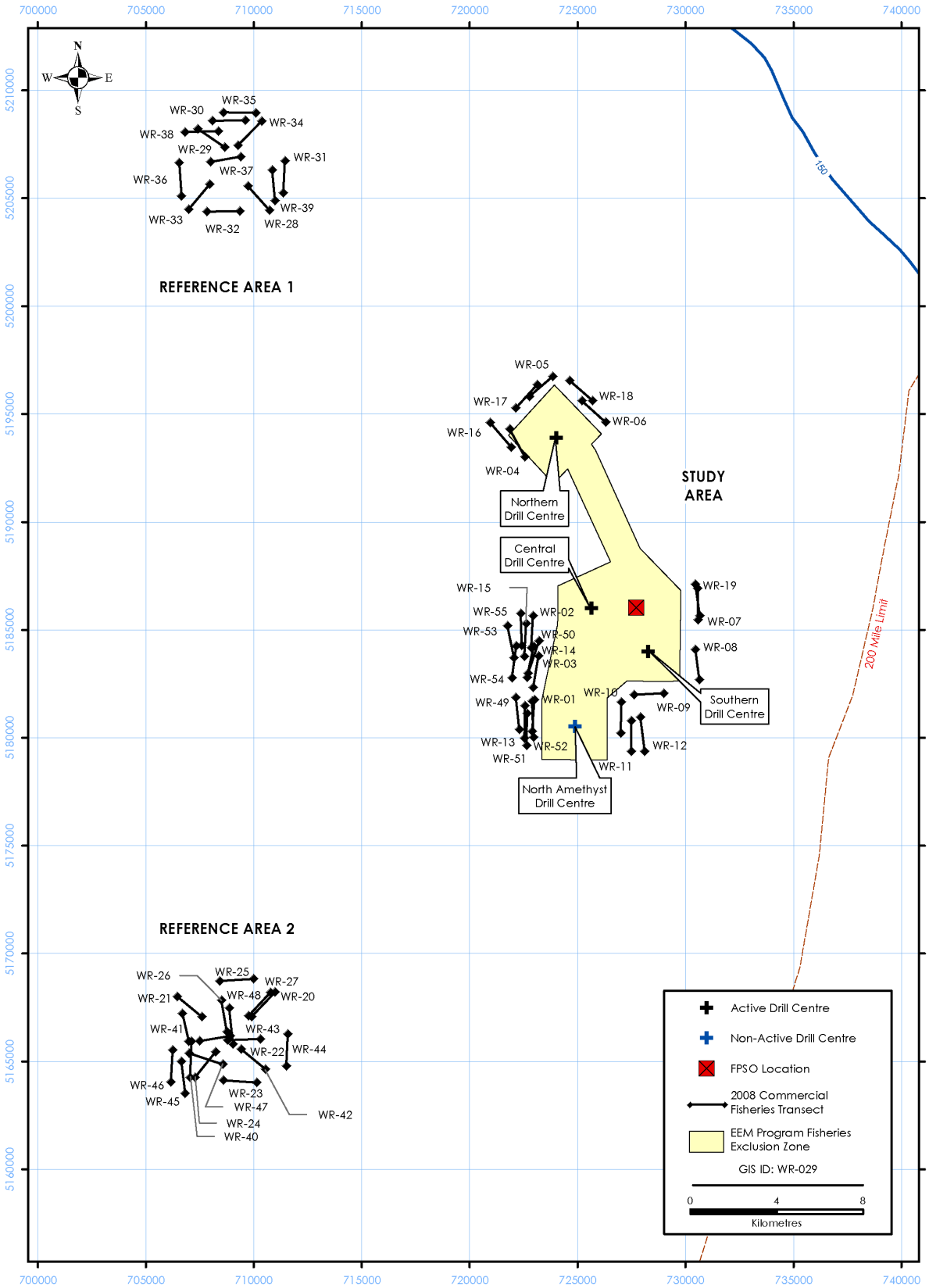

Figure 1-15 2008 EEM Program Commercial Fish Transect Locations

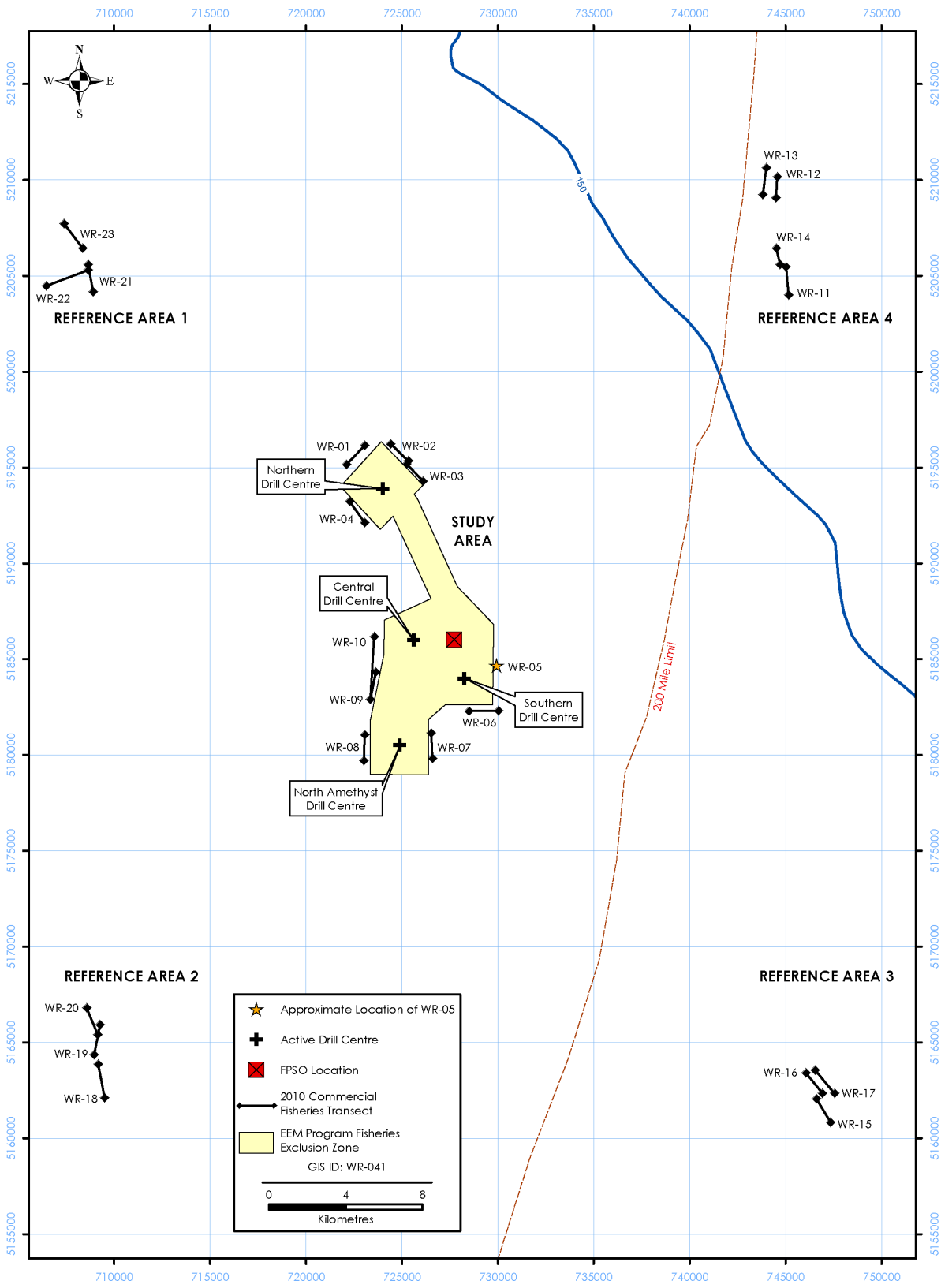

Figure 1-16 2010 EEM Program Commercial Fish Transect Locations

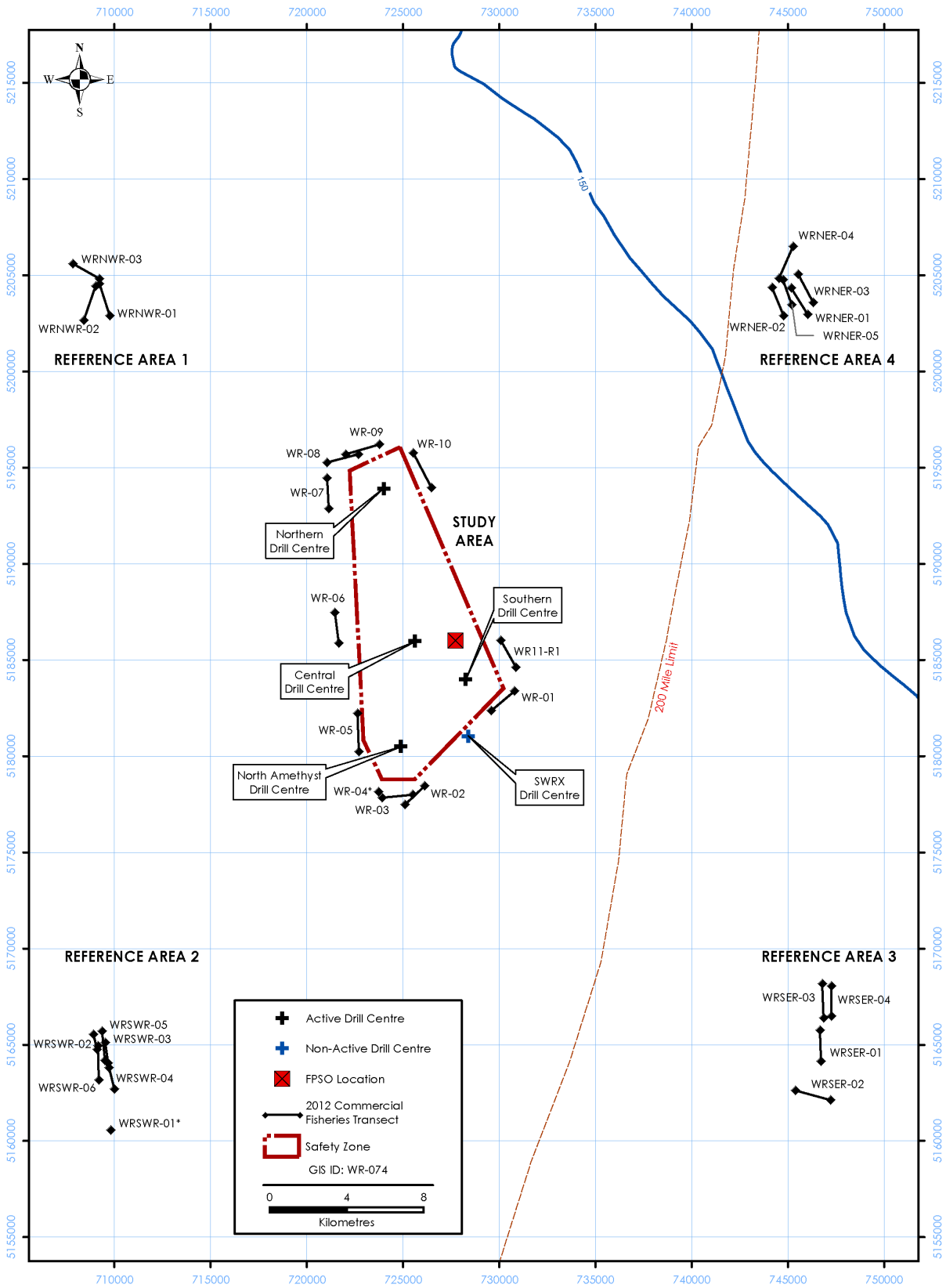

Figure 1-17 2012 EEM Program Commercial Fish Transect Locations

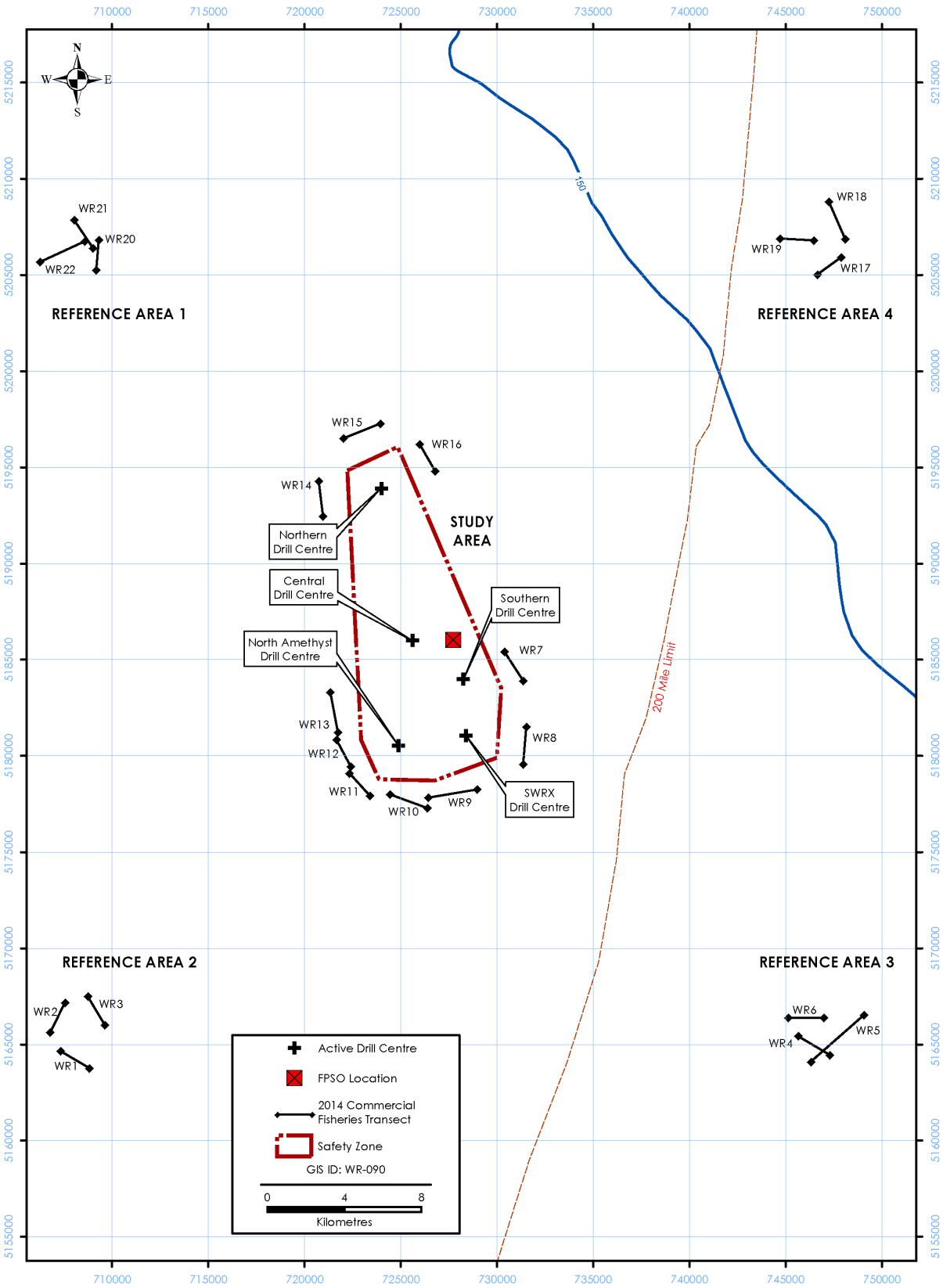

Figure 1-18 2014 EEM Program Commercial Fish Transect Locations

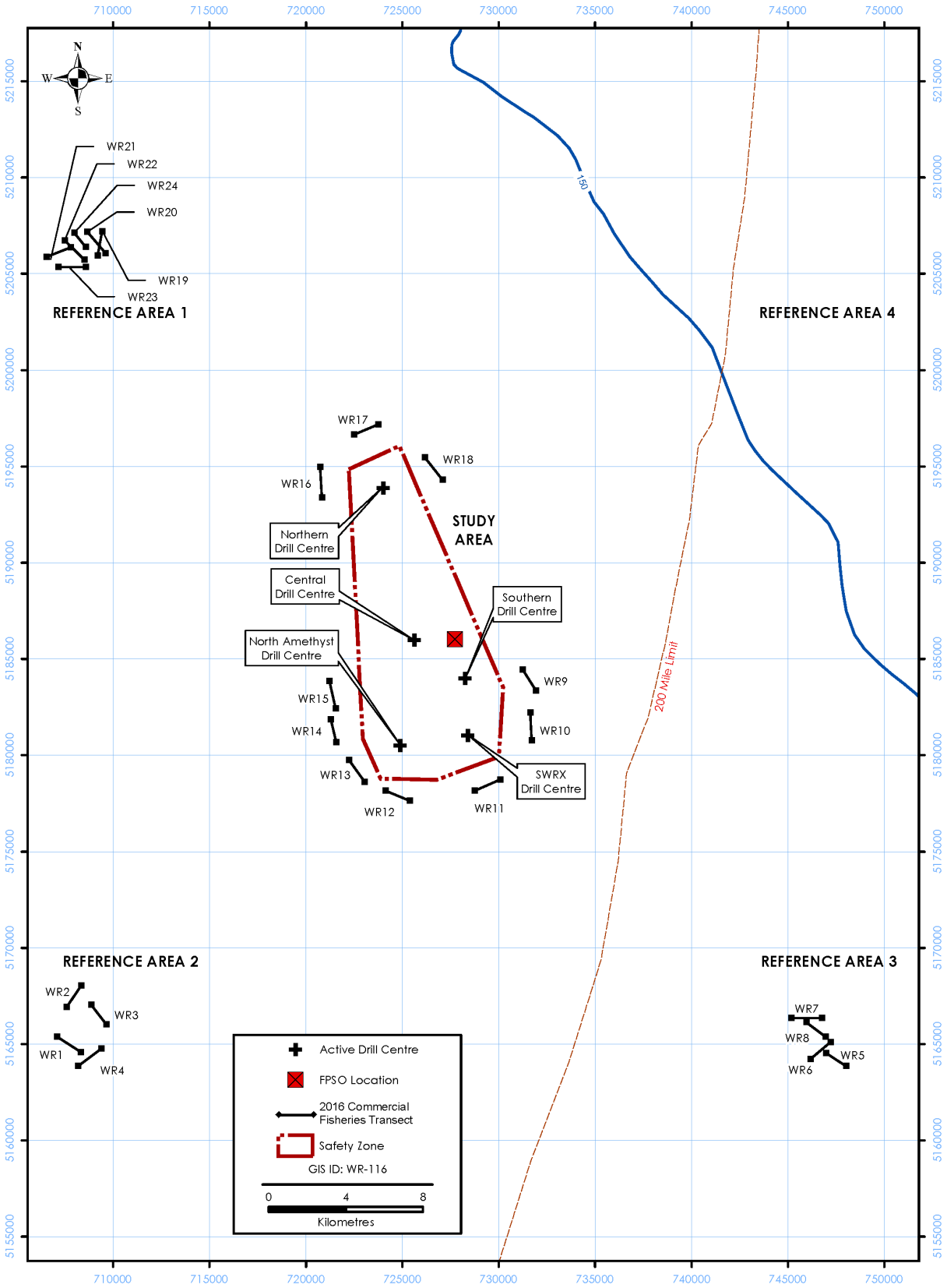

Figure 1-19 2016 EEM Program Commercial Fish Transect Locations

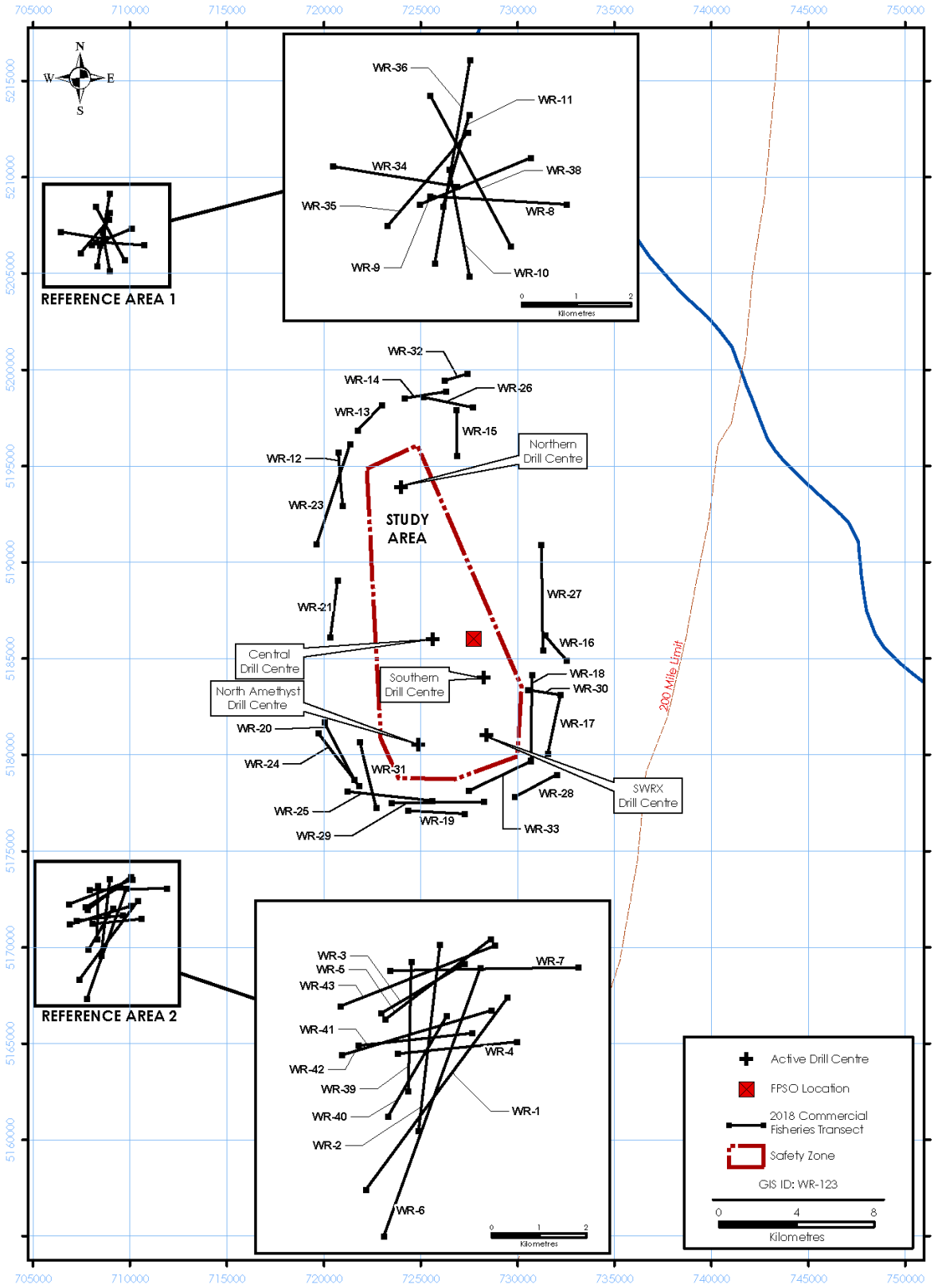

Figure 1-20 2018 EEM Program Commercial Fish Transect Location

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 1-21[5]). 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 1-22). A greater number of stations (18) was sampled in 2010, with 10 stations located near the *SeaRose FPSO* and eight stations located in Reference Areas to northwest and northeast (Figure 1-23). Modelling was used in the 2010 program to assess the probability of detection of produced water constituents in seawater given anticipated dilution and laboratory detection limits. The Water Quality program then was modified based on modelling, as well as field results. Sampling of radionuclides (sampled in seawater) was discontinued in 2012. Sampling of selected process chemicals in seawater was discontinued in 2014. From 2012 to 2018, 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 (Figures 1-24 to 1-27, respectively). 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 2010a for details).

1.8.3.2 Sediment Samples

In 2010, stations sampled for seawater were also sampled for sediment particle size and sediment chemistry, including radionuclide concentration. Thirteen 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.

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 were retained.

[5] Figure 1-20 excludes water samples collected at the two control stations sampled during baseline and subsequently excluded from the EEM sampling.

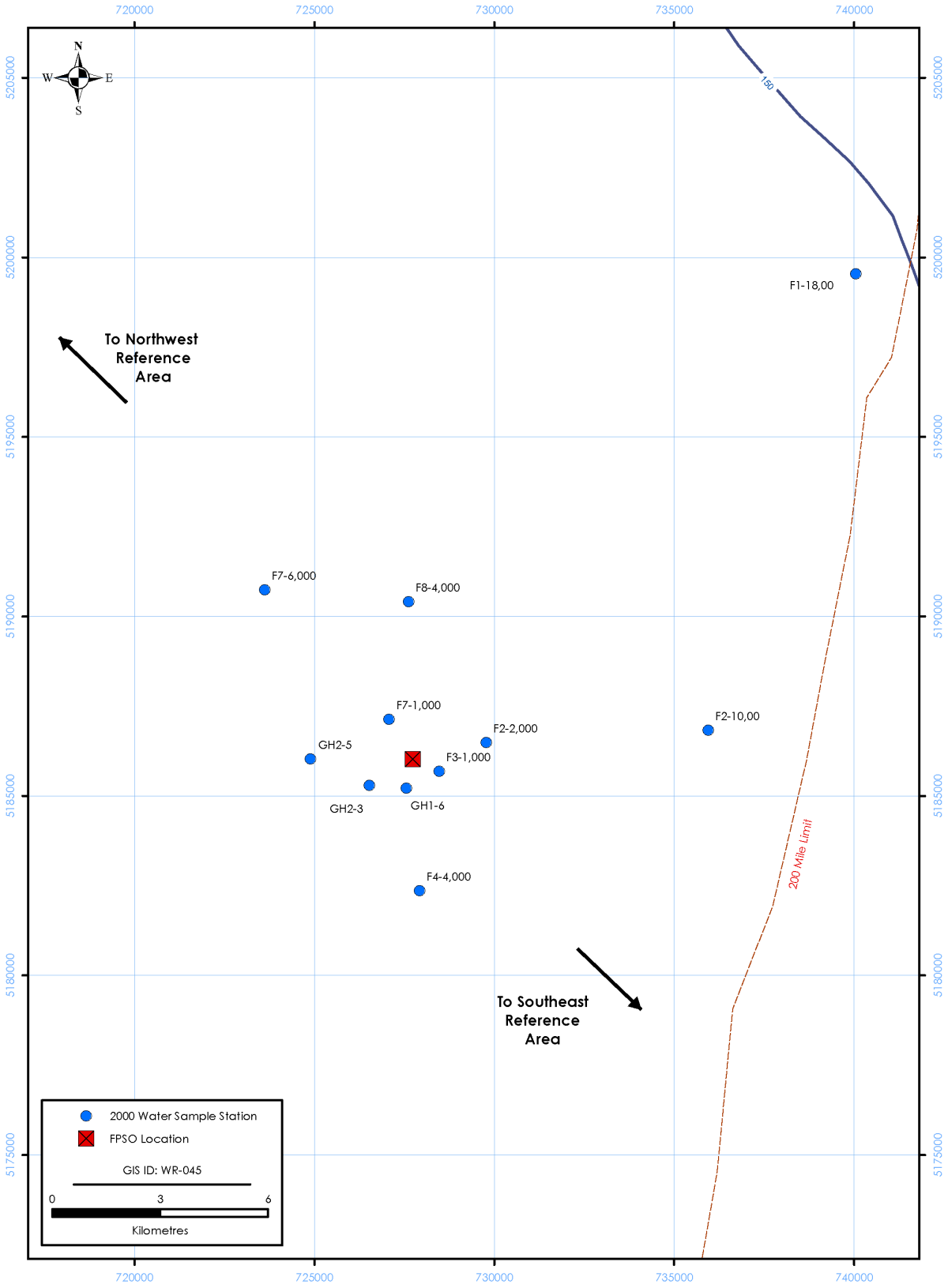

Figure 1-21 2000 Baseline Program Water Quality Stations

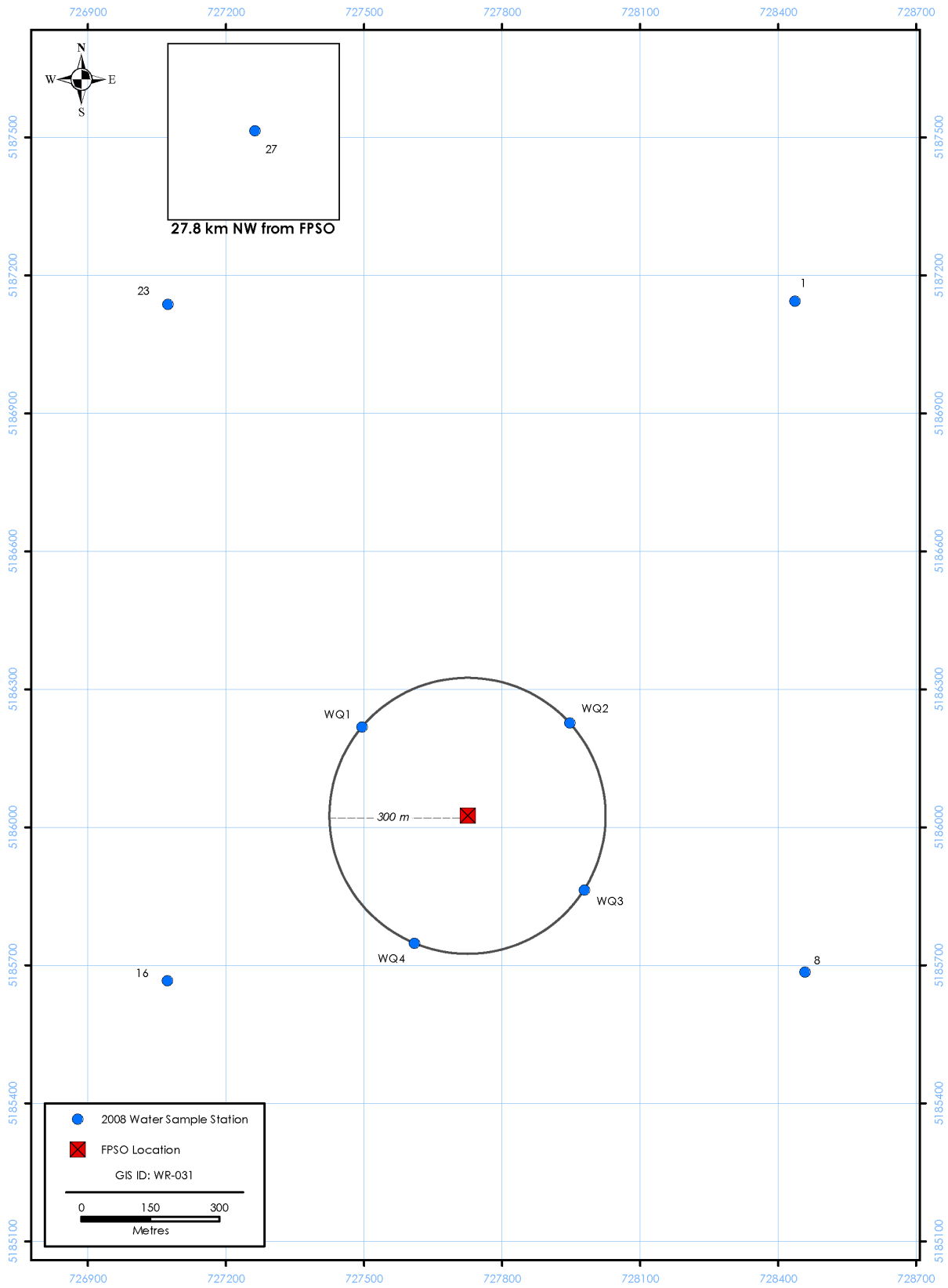

Figure 1-22 2008 EEM Program Water Quality Stations

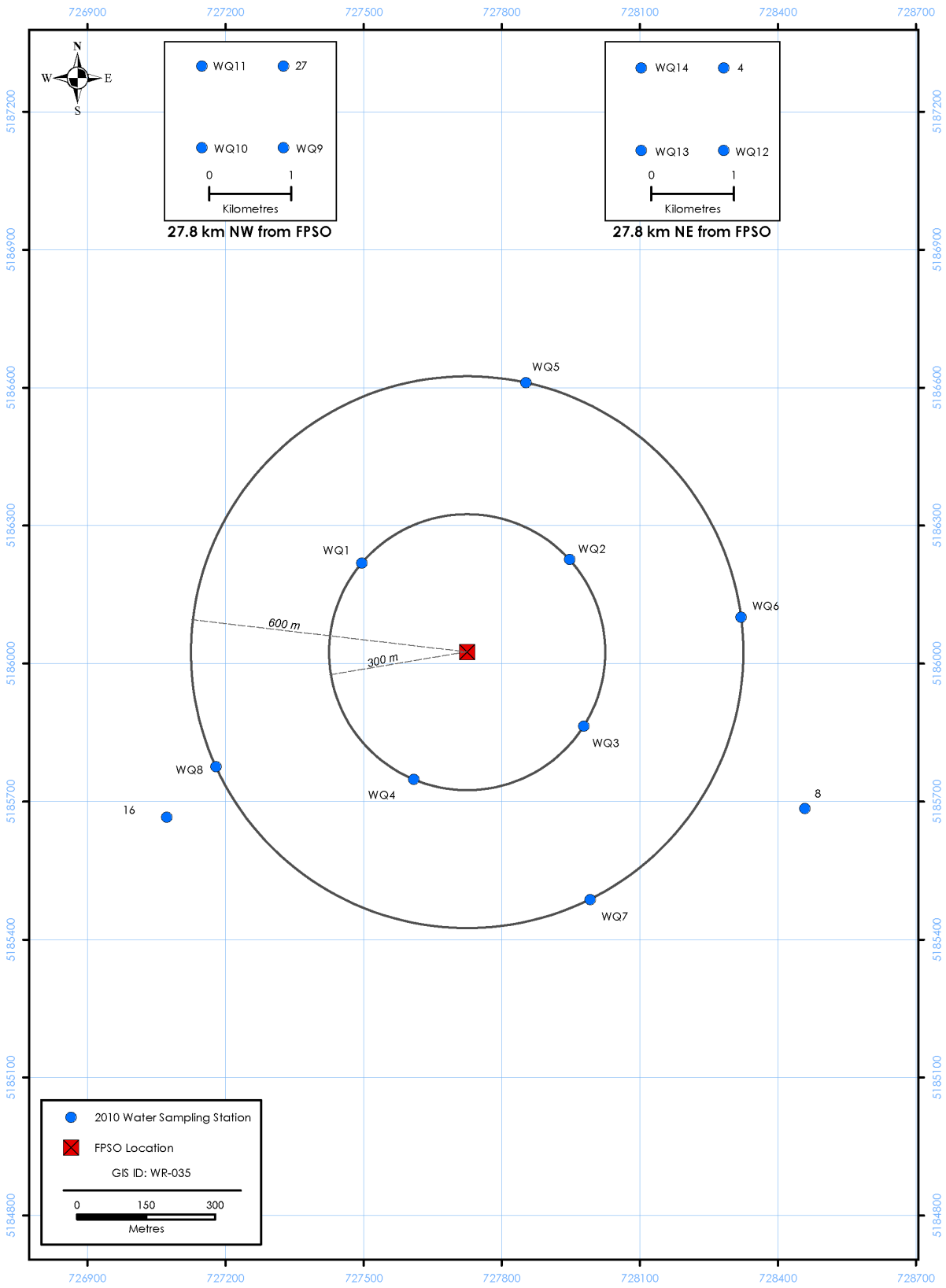

Figure 1-23 2010 EEM Program Water Quality Stations

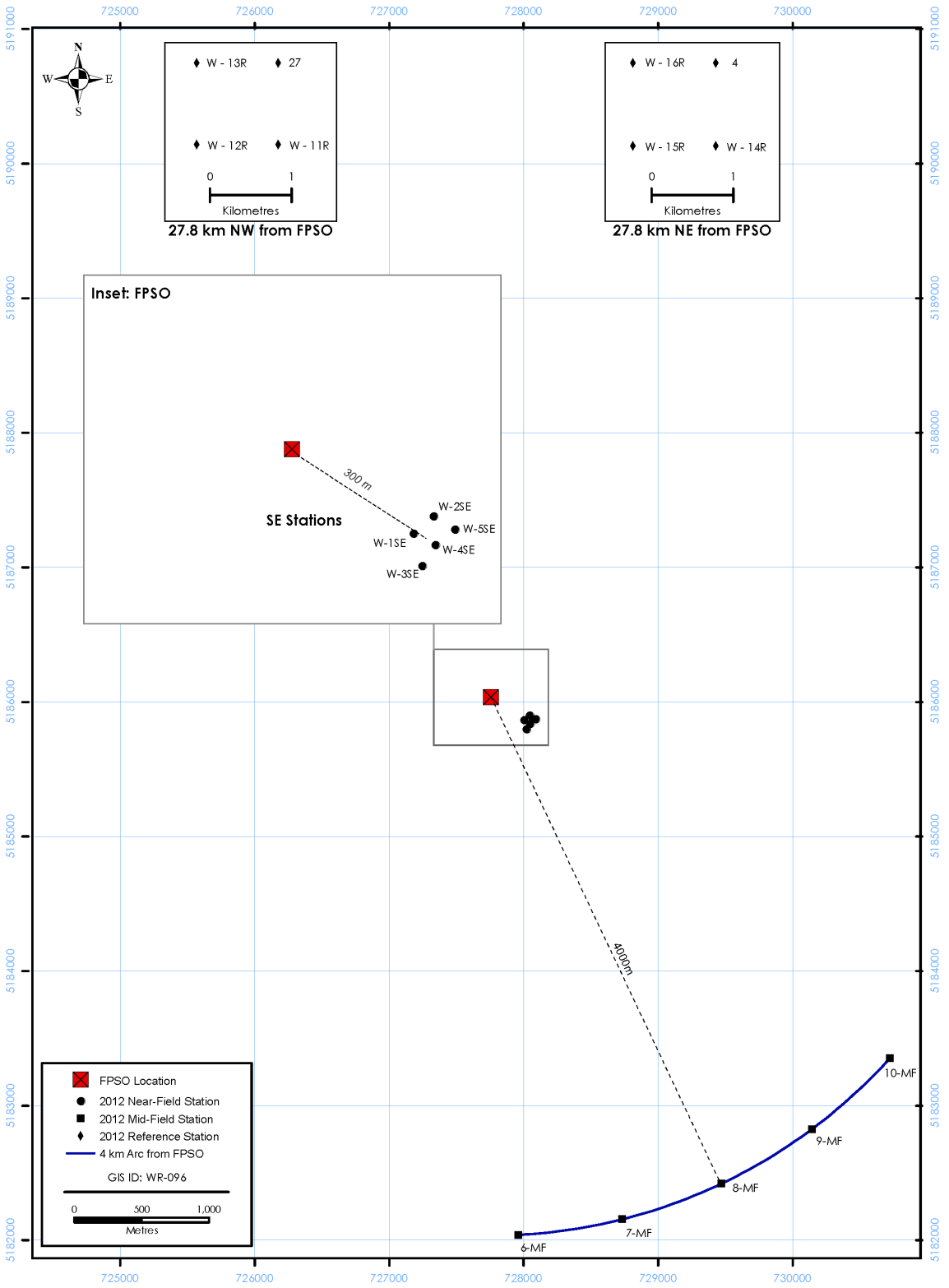

Figure 1-24 2012 EEM Program Water Quality Stations

Notes: The grey square represents an expanded view of the centre of the development. The blue line shows that mid-field stations are distributed on an arc, with each station 4,000 m from the centre of the development.

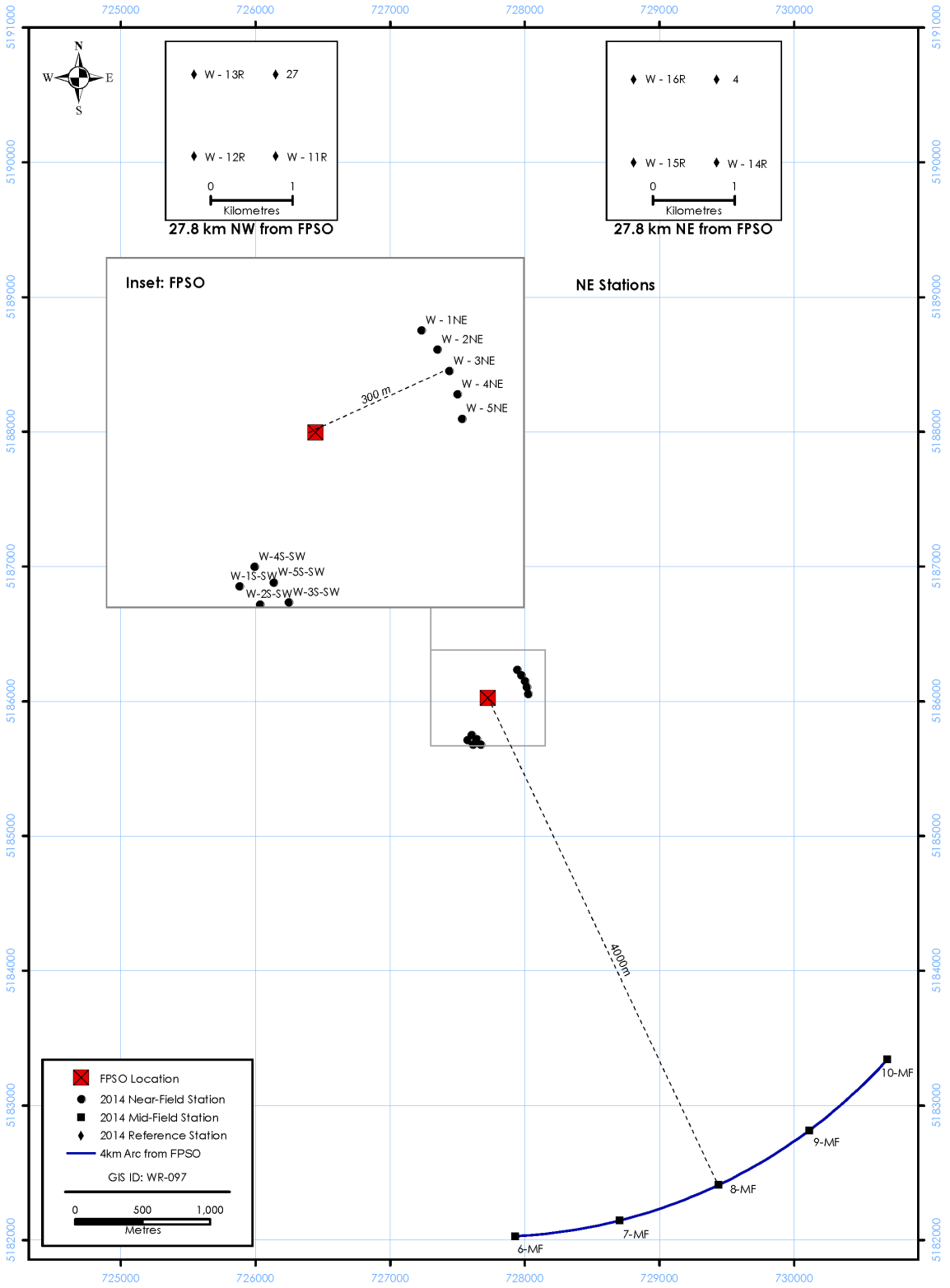

Figure 1-25 2014 EEM Program Water Quality Stations

Notes: The grey square represents an expanded view of the centre of the development. The blue line shows that mid-field stations are distributed on an arc, with each station 4,000 m from the centre of the development.

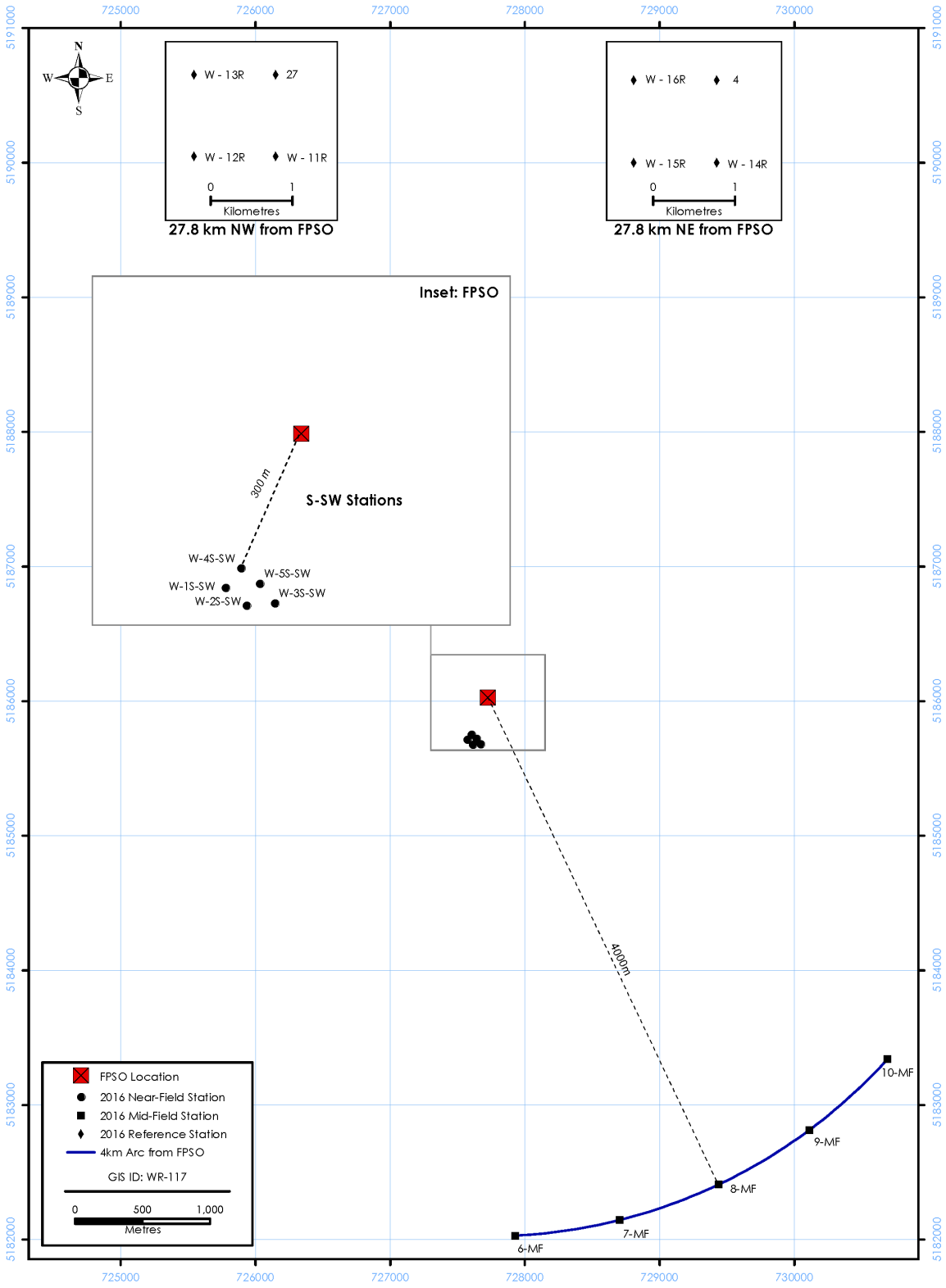

Figure 1-26 2016 EEM Program Water Quality Stations

Notes: The inset square represents an expanded view of the centre of the development. The blue line shows that mid-field stations are distributed on an arc, with each station 4,000 m from the centre of the development.

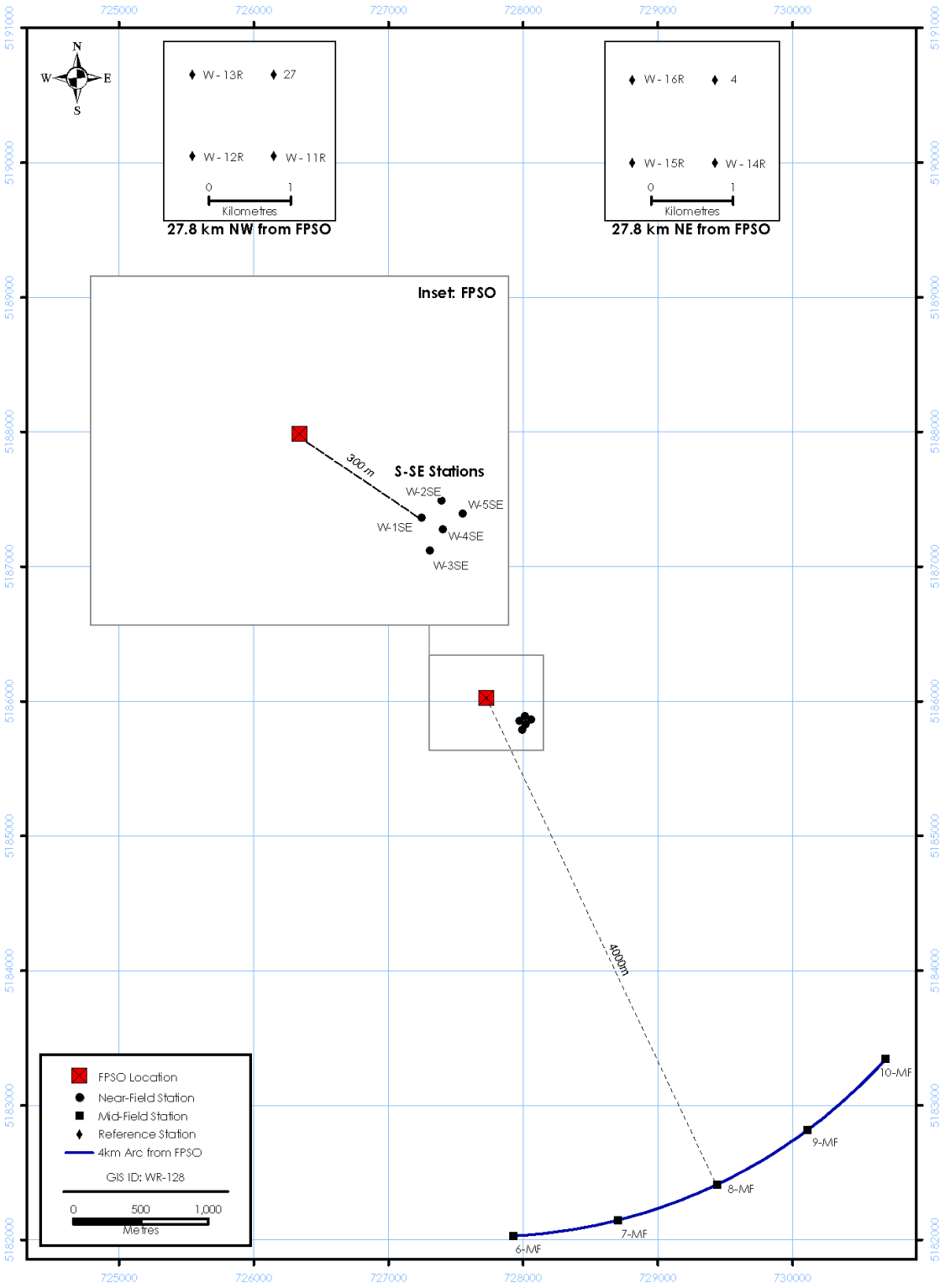

Figure 1-27 2018 EEM Program Water Quality Stations

Notes: The inset square represents an expanded view of the centre of the development. The blue line shows that mid-field stations are distributed on an arc, with each station 4,000 m from the centre of the development.

2.0 Scope

This document, *White Rose Environmental Effects Monitoring Program 2018 (Volume 1)*, provides summary results, analyses, and interpretations for the White Rose 2018 EEM program. Where applicable, results from the baseline and previous EEM programs are compared to 2018 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 2018 (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 (Section 9.0). The most useful references, as well as other standard references, are provided below.

Armsworthy, S.L., P.J. Cranford and K. Lee (Editors). 2005. *Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Technologies.* Battelle Press, Columbus, OH. xvi + 631 pp.

DeBlois, E.M., J.W. Kiceniuk, M.D. Paine, B.W. Kilgour, E. Tracy, R.D. Crowley, U.P. Williams, G.G. Janes. 2014a. Examination of body burden and taint for Iceland scallop (*Chlamys islandica*) and American plaice (*Hippoglossoides platessoides*) near the Terra Nova offshore oil development over ten years of drilling on the Grand Banks of Newfoundland, Canada. *Deep-Sea Research II*, 110: 65-83.

DeBlois, E.M., M.D. Paine, B.W. Kilgour, E. Tracy, R.D. Crowley, U.P. Williams and G.G. Janes. 2014b. Alterations in bottom sediment physical and chemical characteristics at the Terra Nova offshore oil development over ten years of drilling on the Grand Banks of Newfoundland, Canada. *Deep-Sea Research II*, 110: 13-25.

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Paine, M.D., E.M. DeBlois, B.W. Kilgour, E. Tracy, P. Pocklington, R.D. Crowley, U.P. Williams, G.G. Janes. 2014a. Effects of the Terra Nova offshore oil development on benthic macro-invertebrates over 10 years of development drilling on the Grand Banks of Newfoundland, Canada. *Deep-Sea Research II*, 110: 38-64.

Paine, M.D., M.A. Skinner, B.W. Kilgour, E.M. DeBlois, E. Tracy. 2014b. Repeated-measures regression designs and analysis for environmental effects monitoring programs. *Deep-Sea Research II*, 110: 84-91.

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).

Whiteway, S.A., M.D. Paine, T.A. Wells, E.M. DeBlois, B.W. Kilgour, E. Tracy, R.D. Crowley, U.P. Williams and G.G. Janes. 2014. Toxicity assessment in marine sediments for the Terra Nova environmental effects monitoring program (1997 - 2010). *Deep-Sea Research II*, 110: 26-37.

3.0 Abbreviations, Acronyms, and Units of Measure

The following abbreviations, acronyms and units of measure are used in this report.

Abbreviations	Definition
°C	degrees Celsius
#/m²	number [of organisms] per square metre
AIC	Akaike Information Criterion
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
Bq/g	Becquerel per gram
BTEX	benzene, toluene, ethylbenzene and xylenes
CCME	Canadian Council of Ministers of the Environment
cm	centimetre
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
CTD	conductivity, temperature, depth
DFO	Fisheries and Oceans Canada
DISTLM	distance-based linear model
EEM	environmental effects monitoring
EIS	Environmental Impact Statement
EPCMP	Environmental Protection and Compliance Monitoring Plan
EROD	7-ethoxyresorufin O-deethylase
FPSO	floating, production, storage and offloading vessel
g	gram
g/kg	gram per kilogram
g/m²	gram per square metre
H_0	null hypothesis
HOIMS	Husky Operational Integrity Management System
IC_{50}	50% inhibitory concentration
ISQG	Interim Sediment Quality Guidelines
kg	kilogram
km	kilometre
km²	square kilometre
L	litre
L/s	litre per second
m	metre
m²	square metre
m³	cubic metre
MFO	Mixed Function Oxygenase
mg	milligram
mg/kg	milligram per kilogram
mg/L	milligram per litre
mL	millilitre
mm	millimetre
mV	millivolts
NE	northeast
NW	northwest
nMDS	non-Metric Multidimensional Scaling

Abbreviations	Definition
PAH	polycyclic aromatic hydrocarbon
PCA	Principal Component Analysis
PERMANOVA	permutational multivariate analysis of variation
ppm	parts per million
QA/QC	quality assurance/quality control
RM	repeated-measure
SD	standard deviation
SIMPER	similarity percentage
SWRX	South White Rose Extension
TIC	total inorganic carbon
TOC	total organic carbon
TSS	total suspended solids
µg/L	microgram per litre
WRRS	White Rose Reference Station [sediment]

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 associated with these operations.

Husky's *Environmental Protection and Compliance Monitoring Plans* (EPCMPs) describe the environmental protection measures and compliance monitoring requirements applicable to Husky's drilling- and production-related operations. The EPCMPs are prepared to align with the C-NLOPB's *Environmental Protection Plan Guidelines* (National Energy Board *et al.* 2011), *Offshore Waste Treatment Guidelines* (National Energy Board *et al.* 2010), *Drilling and Production Guidelines* (C-NLOPB and Canada-Nova Scotia Offshore Petroleum Board 2011), and other applicable regulatory requirements. The EPCMP has its basis in the *Husky Operational Integrity Management System* (HOIMS) and is responsive to the C-NLOPB's regulatory approval process and other relevant regulatory requirements.

The purpose of this section is to provide context for the interpretation of the results from the EEM program provided in Chapters 5, 6, and 7.

4.2 Project Activities

Activities associated with the White Rose Development Project to date fall into five 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;
- A new drill centre at SWRX was excavated in 2012. In 2013, a gas injection flowline from the Northern Drill Centre was tied-in directly to the SWRX Drill Centre. In 2014, the SWRX Drill Centre was tied back to the existing production, water injection and gas lift flowlines from the North Amethyst Drill Centre and the Southern Drill Centre;
- drilling operations including development, and delineation drilling in the White Rose Field (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).

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 November of 2005. In May 2010, White Rose started producing from the North Amethyst Drill Centre. Production from the SWRX drill centre began in June, 2015. Since the last EEM in October 2016, the *SeaRose FPSO* was shut down for maintenance from September 6 to 25, 2017, and from May 24 to June 19, 2018, during which time there was no production-related discharge.

4.3 Drilling and Completions Operations

Husky uses both water-based drill muds and synthetic fluid-based drill muds in its drilling programs. Water-based drill 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.

HOIMS and Husky's *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 reduce the waste generated from Husky's Atlantic Region operations; and
- handle waste from Husky's Atlantic Region operations in an environmentally responsible manner.

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

- White Rose Waste Management Plan;
- *SeaRose* Waste Management Procedure;
- internal reviews of waste manifesting procedures; and
- management of key contractors.

4.3.1 Drilling Mud and Completion Fluids Discharges

There was no drilling activity within the White Rose Field between October 2015 and May 2016.

Table 4-1 provides the volumes of drill cuttings and water-based drill muds discharged during development drilling activities by year and drill centre since the last EEM program in 2016. The months during which drilling activities took place are also indicated. Total drill cuttings and water-based drill mud discharges at each drill centre since the beginning of drilling are also summarized in Table 4-1.

Table 4-2 provides the volumes of drill cuttings and synthetic fluid-based drill muds discharged during development drilling activities by year and drill centre since the last EEM program in 2016. The months during which drilling activities took place are also indicated. Total drill cuttings and synthetic fluid-based drill mud discharges at each drill centre since the beginning of drilling are also summarized in Table 4-2.

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 provides the volumes of completion fluids discharged during well completions by year and drill centre since the last EEM program. The months during which these activities took place are also indicated. Total completion fluid discharges at each drill centre since the beginning of drilling are also summarized in Table 4-3.

Table 4-1 Cuttings and Water-based Mud Discharges

Year	Drill Centre	Months with Drilling Activiy												Total Cuttings Discharged (mt)	Total Muds Discharged (m³)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
2016	Northern													N/A	N/A
	Central													N/A	628
	Southern													N/A	N/A
	NADC**													584	1743
	SWRX***													865	2,056
	EEM Program							F		SW					
2017	Northern													N/A	N/A
	Central													N/A	N/A
	Southern													N/A	N/A
	NADC**													793	1,798
	SWRX***													2,720	3,669
2018	Northern													N/A	N/A
	Central													2,355	2,280
	Southern													N/A	N/A
	NADC**													N/A	N/A
	SWRX***													N/A	N/A
	EEM Program							F	SW						

Total Discharge at Northern Drill Centre since the beginning of drilling	1,335	1,182
Total Discharge at Central Drill Centre since the beginning of drilling	9,168	11,155
Total Discharge at Southern Drill Centre since the beginning of drilling	4,219	6,102
Total Discharge at NADC** since the beginning of drilling	7,135	18,739
Total Discharge at SWRX*** since the beginning of drilling	4,684	12,527
Total Field Discharge since the beginning of drilling	26,540	49,705

Notes:
- * NADC – North Amethyst Drill Centre.
- ** SRWX – South White Rose 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.
- mt = metric tonne
- m^3 = cubic metre
- N/A = no drilling activity in that particular drill centre

Table 4-2 Cuttings and Synthetic-based Mud Discharges

Year	Drill Centre	Months with Drilling Activiy												Total Cuttings Discharged (mt)	Total Solids Discharged (mt)	Total Base Oil Discharged (m³)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
2016	Northern													N/A	N/A	N/A
	Central													637	174	47
	Southern													N/A	N/A	N/A
	NADC**													940	249	64
	SWRX***													1,541	364.8	103
	EEM Program							F		SW						
2017	Northern													N/A	N/A	N/A
	Central													N/A	N/A	N/A
	Southern													N/A	N/A	N/A
	NADC**													229	12	11
	SWRX***													3,522	1,076	305
2018	Northern													N/A	N/A	N/A
	Central													1,849	631	162
	Southern													N/A	N/A	N/A
	NADC**													668	247	61
	SWRX***													N/A	N/A	N/A
	EEM Program							F	SW							

Total Discharge at Northern Drill Centre since the beginning of drilling	1,636	3,145	330
Total Discharge at Central Drill Centre since the beginning of drilling	8,025	13,441	1,703
Total Discharge at Southern Drill Centre since the beginning of drilling	4,778	10,071	1,418
Total Discharge at NADC** since the beginning of drilling	7,553	11,039	1,049
Total Discharge at SWRX*** since the beginning of drilling	7,481	4,017	704
Total Field Discharge since the beginning of drilling	29,473	41,713	5,204

Notes:
- * NADC – North Amethyst Drill Centre.
- ** SWRX – South White Rose Extension 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.
- mt = metric tonne
- m^3 = cubic metre
- N/A = no drilling activity in that particular drill centre

Table 4-3 Completion Fluid Discharges

Year	Drill Centre	Months with Drilling Activiy												Total Completion Fluids Discharged (m³)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2016	Northern													N/A
	Central													628.4
	Southern													N/A
	NADC**													N/A
	SWRX***													588
	EEM Program						F				SW			
2017	Northern													N/A
	Central													N/A
	Southern													N/A
	NADC**													475
	SWRX***													2,212
2018	Northern													N/A
	Central													2795.1
	Southern													N/A
	NADC**													433.5
	SWRX***													N/A
	EEM Program							F	SW					

Total Discharge at Northern Drill Centre since the beginning of drilling	385
Total Discharge at Central Drill Centre since the beginning of drilling	7,217
Total Discharge at Southern Drill Centre since the beginning of drilling	4,314
Total Discharge at NADC** since the beginning of drilling	5,481
Total Discharge at SWRX*** since the beginning of drilling	3,262
Total Field Discharge since the beginning of drilling	20,659

Notes:
- * NADC – North Amethyst Drill Centre.
- ** SWRX – South White Rose Extension 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.
- m³ = cubic metre
- N/A = no drilling activity in that particular drill centre

4.3.2 Other Discharges from Drilling Operations

Between October 2016 and September 2018, a total of 154.5 m³ of bilge water from drilling operations was 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 EPCMPs. In total, 2.3 kg of hydrocarbons were released to the marine environment from bilge water. Deck drainage is another waste stream that can typically be discharged providing the hydrocarbon content is 15 ppm or less. The Henry Goodrich MODU does not discharge deck drainage.

Water, ethylene glycol and control fluid (*i.e.*, blowout preventer fluid) are routinely discharged during function testing of a seabed blowout preventer. In total, over the reporting period between October 2016 and September 2018, 505.5 m³ of blowout preventer fluid was discharged. Approximately 26%, or 134.5 m³, represents glycol and control fluid.

4.4 *SeaRose FPSO* Production Operations

The primary points of hydrocarbon discharge to the marine environment from the *SeaRose FPSO* are the bilge, the slops tanks, and produced water. 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 *SeaRose FPSO* EPCMP. Between October 2016 and September 2018, a total of 2230.6 m³ of water was released from the slops tanks, representing 9.75 kg (average 3.05 ppm) of 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 *SeaRose FPSO* EPCMP: a 24-hour volume-weighted mean less than 44 ppm; and a volume-weighted 30-day rolling average less than 30 ppm. Between October 2016 and September 2018, 5,934,811 m³ of produced water was released, representing 102,309 kg (average for end-of month 30-day rolling average was 17.19 ppm) of 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 2016 and September 2018, the average residual chlorine concentration prior to release was 0.30 ppm.

4.5 Supply Vessel Operations

All offshore facilities and operations are supported by Offshore Supply Vessels. Normal vessel operations involve discharge of both treated sewage and bilge water. Bilge water from vessels is treated such that it contains 15 ppm or less of dispersed oil and is released in accordance with the *International Convention for the Prevention of Pollution from Ships* (MARPOL 73/78) requirements.

5.0 Sediment Component

5.1 Methods

5.1.1 Field Collection

The Sediment Component of the 2018 EEM Program was conducted from August 8 to 15, 2018, using the offshore supply vessel *Atlantic Osprey*. 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 1-11 (Section 1), with the 2018 station locations provided again in Figure 5-1. Differences in sampling locations among years are described in Section 1. More details on the baseline survey and the Year 1, 2, 3, 4, 5, 6, 7 and 8 EEM programs can be found in Husky Energy (2001, 2005, 2006, 2007, 2009, 2011, 2013, 2017, 2019). Geographic coordinates, station depth and distances to drill centres for EEM stations sampled in 2018 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
EEM Program Year 7	October 31 to November 4, 2014
EEM Program Year 8	September 2 to September 7, 2016
EEM Program Year 9	August 8 to 15, 2018

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 m² (0.0995 m²) of seabed (Figures 5-2 and 5-3). Station depth was measured using the ship sounder at each station before deploying the corer. Sediment oxidation/ reduction potential (redox) was measured on each sediment core before sample collection. 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, total organic and total inorganic carbon, metals, benzene, toluene, ethylbenzene, and xylenes (BTEX), $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), sulphur, sulphide, ammonia and moisture. Toxicity variables included bacterial luminescence and amphipod survival. Benthic community variables included total abundance, biomass and richness, and abundances of selected individual taxa.

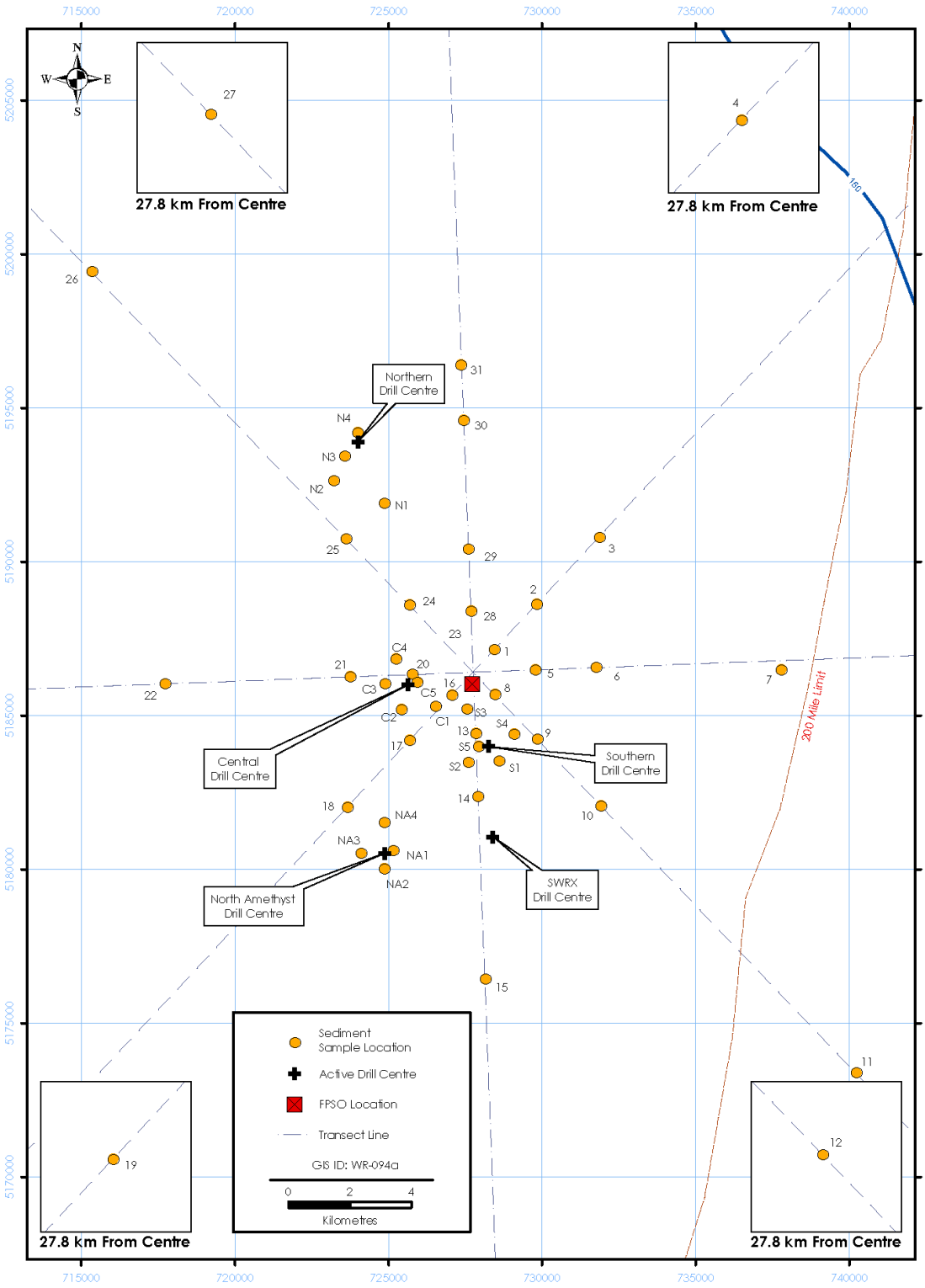


Figure 5-1 2018 Sediment Quality Triad Stations

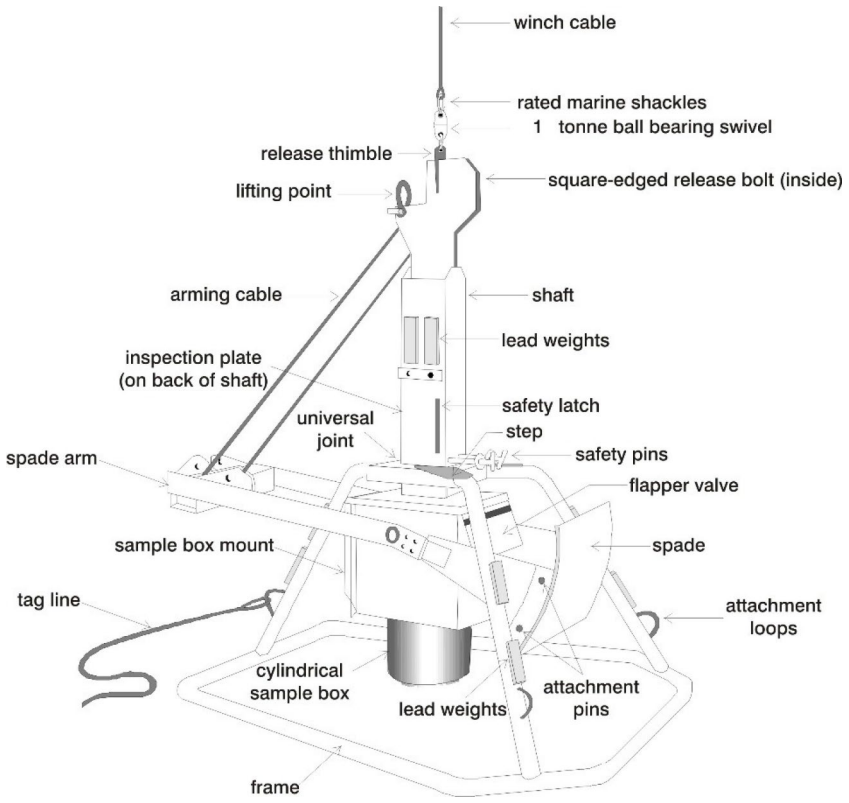


Figure 5-2 Sediment Corer Diagram

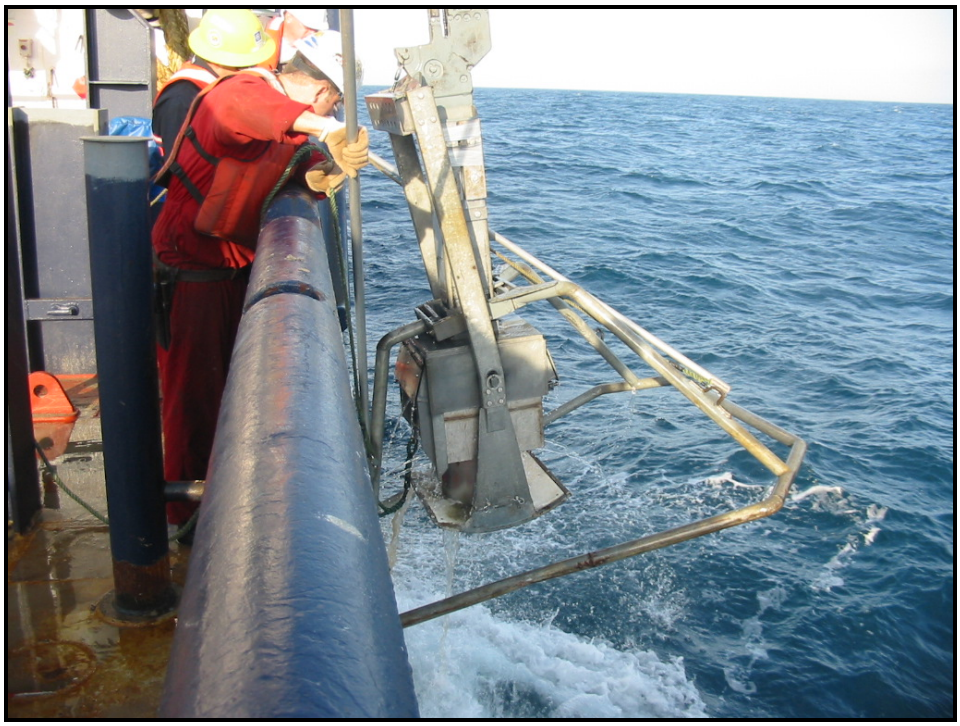


Figure 5-3 Sediment Corer

Sediment samples collected for physical and chemical analyses were a composite from the top layer of three cores per station. Sediment was sampled at the surface of the cores and at least 2 cm away from the corer walls (*i.e.*, over an area of approximately 0.078 m²) and down to a depth of approximately 2 to 3 cm. Most samples were collected with a stainless-steel spoon and then stored in pre-labelled 120 mL or 250 mL glass jars at -20°C. Sediment samples collected for sulphide analysis were stored in a 120 mL glass jar at 4°C. Two 10 mL sediment samples for BTEX were collected by syringe and deposited into two individual vials pre-filled with 10 mL methanol. Sediment samples collected for toxicity analysis 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 bag (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[6]. These samples were mixed with approximately 1 L of 10% buffered formalin. Benthic invertebrate counts from these two samples were later pooled for analysis.

The following Quality Assurance/Quality Control (QA/QC) protocols were implemented for collection of samples. Field duplicates were collected for sediment chemistry at five randomly selected stations (Stations 19, 29, C1, C3, and NA1). Duplicates were collected for analysis of BTEX, $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, PAHs, metals, ammonia, sulphur, sulphides, and organic and inorganic carbon. For sample handling, core samples were immediately covered with clean, plastic-lined metal covers and moved to a clean 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 or from the boat. Processed samples were transferred to cold storage within one hour of collection. Once ashore, samples to be analyzed by Maxxam were transferred to the Maxxam Laboratory in St. John's for shipment to the Maxxam laboratory in Halifax. Samples to be analyzed by Avalon Laboratories, Arenicola Marine and the Stantec Materials Lab were transferred to cold storage at Stantec and then shipped to the respective laboratories. Where applicable, samples were delivered to laboratories within the prescribed sample holding time.

5.1.2 Laboratory Analysis

5.1.2.1 Physical and Chemical Characteristics

Sediment particle size analysis was conducted by Stantec, in St. John's, Newfoundland and Labrador, following the Wentworth particle size classification scale (Table 5-2, also see Appendix B-2 for the method summary). Sediment chemistry analysis was conducted by Maxxam Analytics, in Halifax, Nova Scotia. The full suite of chemical parameters is provided in Table 5-3 along with the laboratory detection limits. Methods summaries for chemistry analyses are provided in Appendix B-3.

[6] 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 Scale)	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 collectively referred to as "fines".

Within the hydrocarbons, BTEX are aromatic organic compounds that are detected in the C_6-C_{10} range, commonly referred to as the gasoline range. The >C_{10}-C_{21} range 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. 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. When complex hydrocarbon mixtures are separated by chromatography, the more unique compounds such as the *n*-alkanes separate as individual peaks. Isoalkanes, on the other hand, are such a diverse group with so little difference in physical characteristics that they tend not to separate into distinct peaks in the chromatogram but rather, form a “hump” in the chromatogram (e.g., Figure 5-4). This hump is often referred to as the Unresolved Complex Mixture. 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}. In Figure 5-4, most of the components of PureDrill IA35-LV form an Unresolved Complex Mixture that starts around the retention time of 3 minutes and ends around a retention time of 5 minutes.

Table 5-3 Sediment Chemistry Variables (2000, 2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016 and 2018)

Variables	Method	Laboratory Detection Limit									Units
		2000	2004	2005	2006	2008	2010/2012	2014	2016	2018	
Hydrocarbons											
Benzene	Calculated	0.03	0.03	0.03	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	0.04	0.03	0.03	mg/kg
Ethylbenzene	Calculated	0.03	0.03	0.03	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	0.05	0.05	0.05	mg/kg
C_6-C_{10} (less BTEX)	Calculated	3	3	3	4	3	3	3	3	3	mg/kg
>C_{10}-C_{21}	GC/FID	0.3	0.3	0.3	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	0.3	0.3	0.3	mg/kg
PAHs											
1-Chloronaphthalene	GC/FID	NA	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
2-Chloronaphthalene	GC/FID	NA	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
1-Methylnaphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
2-Methylnaphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Acenaphthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Acenaphthylene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Benz[*a*]anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Benzo[*a*]pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Benzo[*b*]fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Benzo[*ghi*]perylene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Benzo[*k*]fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Chrysene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Dibenz[*a,h*]anthracene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Fluoranthene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Fluorene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Indeno[1,2,3-*cd*]pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Naphthalene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Perylene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Phenanthrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Pyrene	GC/FID	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	0.01	mg/kg
Carbon											
Carbon	LECO	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.2	g/kg
Organic Carbon	LECO	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.2	g/kg
Inorganic Carbon	By Diff	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.5	0.2	g/kg
Metals											
Aluminum	ICP-MS	10	10	10	10	10	10	10	10	10	mg/kg
Antimony	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Arsenic	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Barium	ICP-MS	5	5	5	5	5	5	5	5	5	mg/kg
Beryllium	ICP-MS	5	2	2	2	2	2	2	2	2	mg/kg
Cadmium	GFAAS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Chromium	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Cobalt	ICP-MS	1	1	1	1	1	1	1	1	1	mg/kg

Variables	Method	Laboratory Detection Limit									Units
		2000	2004	2005	2006	2008	2010/2012	2014	2016	2018	
Copper	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Iron	ICP-MS	20	50	50	50	50	50	50	50	50	mg/kg
Lead	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Lithium	ICP-MS	5	2	2	2	2	2	2	2	2	mg/kg
Manganese	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Mercury	CVAA	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.01	mg/kg
Molybdenum	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Nickel	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Selenium	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Strontium	ICP-MS	5	5	5	5	5	5	5	5	5	mg/kg
Thallium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	mg/kg
Tin	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Uranium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	mg/kg
Vanadium	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Zinc	ICP-MS	2	5	2	5	5	5	5	5	5	mg/kg
Other											
Ammonia (as N)	COBAS	NA	0.25	0.3	0.3	0.3	0.3	0.3	0.3	0.3	mg/kg
Sulphide	SM4500	NA	2	0.2	0.2	0.2	0.2	0.2	0.5	0.5	mg/kg
Sulphur	LECO	NA	0.02	0.02	0.002	0.01	0.03	0.03	0.01	0.01	%
Moisture	Grav.	0.1	0.1	0.1	1	1	1	1	1	1	%

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 will vary among analytically laboratories. They may also vary from year to year if instruments are checked for precision and accuracy as part of QA/QC procedures.
- Laboratory detection limits for hydrocarbons in 2000, 2004, 2005, 2012, 2014 and 2016 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.
- NA = Not Analyzed.
- GC/FID = Gas Chromatography/Flame Ionization Detection
- GFAAS = Glass Furnace Atomic Absorption Spectroscopy
- ICP-MS = Inductively Coupled Plasma/Mass Spectrometer
- CVAA = Cold Vapour Atomic Absorption

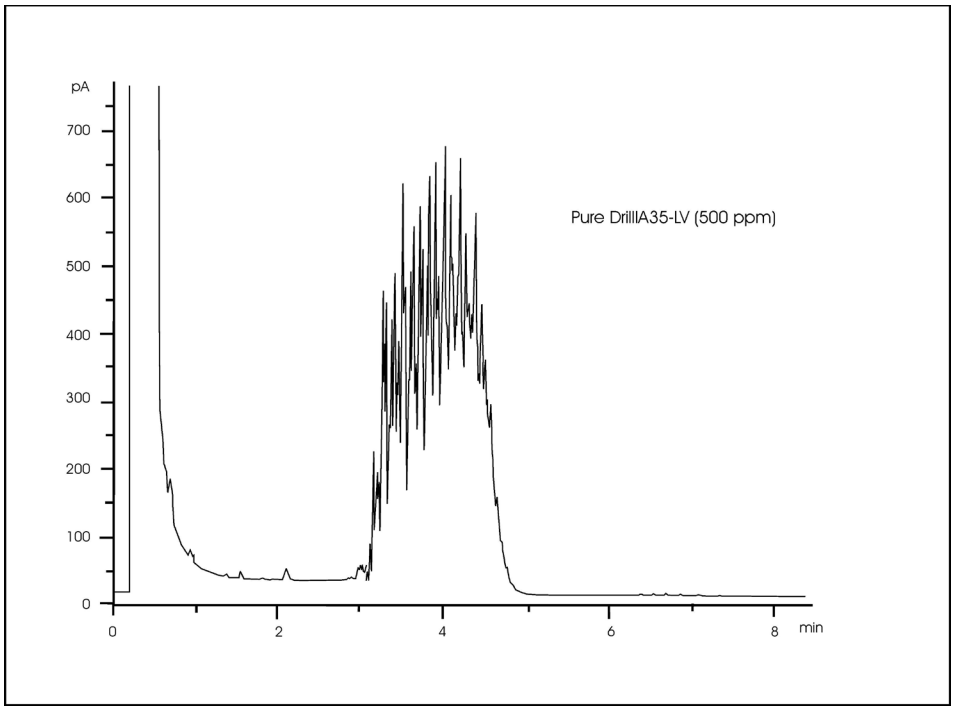


Figure 5-4 Gas Chromatogram Trace for PureDrill IA35-LV

5.1.2.2 Toxicity

Analytical Methods

Sediment toxicity analyses were conducted at Avalon Laboratories in St. John's, Newfoundland and Labrador. Sediment samples were examined using the amphipod survival bioassay and the bacterial luminescence assay. 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 and guidance from Environment Canada using the marine amphipod *Rhepoxynius abronius* collected 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, and monitor seasonal and batch sensitivity to a specific toxicant.

Amphipod toxicity tests were initiated within the six weeks holding period recommended by Environment Canada (1998).

The bacterial luminescence test (Microtox) was performed with *Aliivibrio fishcheri*. This bacterium emits light as a result of normal metabolic activities. This assay was conducted according to the Environment Canada (2002) Reference Method and

guidance from Environment Canada 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 from 2004 to 2018 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).

Both Environment Canada (1998) and Environment Canada (2002) require measurement of pore water pH, salinity and ammonia. However, based on recommendations from Environment Canada ensuing from discussions on the 2014 EEM report, these measurements were replaced with measurement of sediment ammonia, sulphides and redox potential (see Appendix B-4 and B-5 for details).

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. This endpoint was calculated using the Dunnett's Multiple Comparison Test using the CETIS computer program (©2001-2010 Tidepool Scientific, LLC). The statistical endpoint for the Microtox 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}[7] value.

Avalon Laboratories conducted amphipod toxicity tests using two separate reference samples: negative control sediment that came from the source site for the amphipods; and a composite sample made up of sediment from four reference stations (Stations 4, 12, 19, 27). Using two reference samples to define toxicity reduces an already very low risk of false positives. The amphipod survival test results for sediments were considered toxic if mean survival was reduced by more than 30% as compared to the negative control sediment and the result was statistically significantly different from survival in the negative control sediment.

Amphipod survival was also compared to White Rose Reference Station sediment (a composite sample from Stations 4, 12, 19 and 27). In this test, amphipod survival results for sediments were considered toxic if survival was reduced by more than 20% as compared to survival in composite reference sediment and the result was significantly different from survival in the composite reference.

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

Amphipod toxicity test results were then examined for the potential influence of sediment ammonia, sulphide and redox potential, as described in Appendix B-4.

The Reference Method for Determining the Toxicity of Sediment Using Luminescent Bacteria in a Solid-Phase Test (Environment Canada 2002) was used to assess Microtox toxicity. In this test, sediments with levels of silt/clay (*i.e.*, fines) greater than 20% are considered 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.

As was the case for the amphipod tests, Microtox toxicity test results were examined for the potential influence of sediment ammonia, sulphide and redox potential, as described in Appendix B-5.

5.1.2.3 Benthic Community Structure

All 2018 benthic invertebrate samples were provided whole to Arenicola Marine Limited (Wolfville, Nova Scotia). The two core samples collected at each station were processed separately but data were pooled for data analysis (see Section 5.1.3.3).

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. When they were present, barnacles 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 ranging from 99.3 to 100% were achieved (*i.e.*, the first sorter recovered 99.3% to 100% 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-6). All organisms were identified by Patricia Pocklington, a specialist in marine benthic invertebrate taxonomy.

Benthic invertebrate samples from 2004 to 2018 were also processed by Arenicola Marine Limited. Benthic invertebrate samples from 2000 were processed by Envirosphere Limited. Methods and the level of taxonomy were similar to those used for the 2004 to 2018 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 (since operations began; from 2004 to present) 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[8] for sediment chemistry. Drill centres were considered active if any drilling had occurred there in the past.

As indicated in Husky'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. When no baseline data are available, values observed at stations greater than 10 km from drill centres since the variable began to be measured until 2014[9] are used instead.

Based on regulatory feedback from Fisheries and Oceans Canada (see Appendix A in the 2016 EEM Program Report, Husky Energy 2018), Station 31 was excluded from all statistical analyses as it is a clear outlier in terms of chemistry (hydrocarbons and barium in particular). Station 31 is located 4.2 km from the nearest development drill centre, but the station is located near the site of a delineation well drilled in 2007.

5.1.3.1 Physical and Chemical Characteristics

Data were first screened to identify and exclude variables that frequently occurred below detectable concentrations. In most cases, variables with greater than 25% of test results below laboratory detection limits were not included in statistical analyses. The variables selected for detailed analysis in 2018 included $>C_{10}$-C_{12} hydrocarbons, barium, sediment particle size (% fines), ammonia, sulphide, sulphur, organic carbon, redox potential and

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

[9] The year 2014 is used as a cut-off because sufficient numbers are available to assess background for the variables in question and because thresholds would change from program to program if the dataset was consistently updated to include the current sample year.

a summary measure of concentration of metals other than barium (derived from a principal component analysis (PCA) of metals data). More than 25% of results were below laboratory detection limit for sulphide; however, this variable was included. Also, because the metals PCA indicated that lead and strontium behaved differently from other metals, these two metals were examined separately. The rationale for selecting these variables is provided below.

Synthetic-based drill muds have elevated concentrations of $>C_{10}$-C_{21} hydrocarbons. Barium, as barium sulphate (barite), is a constituent of both water-based and synthetic-base drill muds. Sediment particle size (particularly % fines) and organic carbon 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.

Sulphur, as sulphate in barite, is also an important constituent of drill muds. Ammonia and sulphide levels are typically high, and redox levels are low, in sediments where decomposition or degradation of natural or synthetic organic matter is extensive. Ammonia and sulphides, as well as particle size, are also important confounding factors that need to be considered in the interpretation of toxicity test results (Tay *et al.* 1998); and these variables, as well as organic carbon content, are known to affect benthic communities (Pearson and Rosenberg 1978). 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. These tools are described below.

Spearman rank correlations (Tool 1) were used to statistically test for associations between distance from the nearest active drill centre (indicated as Min D in graphics) and concentration of the subset of variables selected for detailed analysis. Correlations were assessed for all stations (n = 52 in 2018) and for only those stations tested in repeated-measures regression (n = 35; see Tool 5 below). The latter correlations were assessed predominantly to aid in interpretation of repeated-measures regression results. Because sample size differs between the two datasets, results of each set of analyses did at times indicate different trends over time.

Threshold models (Tool 2), including all stations (n = 52), were constructed in order to estimate the spatial extent (threshold distance) of influence of active drill centres. These models assessed the distance over which variables were correlated with distance. Threshold models were only tested on variables that were demonstrated with Spearman rank correlations to be significantly correlated with distance from the nearest active drill centre.

The third tool (Tool 3) involved visual inspection of response variable data for all stations 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. Station 31 was shown on scatterplots for $>C_{10}$-C_{21} hydrocarbons and barium (*i.e.*, n = 53) since those were the variables most affected by delineation drilling near that station. Station 31 was excluded (*i.e.*, n = 52) from other scatterplots. As noted above, the station was not included in analyses.

Maps (Tool 4) of 2018 data for all stations were generated to indicate concentrations within and exceeding the variability observed in baseline (2000), or background variability (stations located at more than 10 km from drill centres) if baseline data were unavailable. These maps were used to visually assess the effects of individual drill centres on variables that were demonstrated with Spearman rank correlations to be significantly correlated with distance from the nearest active drill centre.

Repeated-measures regression (Tool 5) was used to test for spatial and temporal variation at those stations that have been repeatedly sampled since baseline (n = 35, excluding Station 31). 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 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 and concentration (*i.e.*, the slope of the relationship may get steeper over time, indicating an increase in concentrations adjacent to active drill centres). For Tools 2 and 5, data were $\log_{10}$-transformed to satisfy assumption of normality, homogeneity of variance and linearity.

5.1.3.2 Toxicity

No analyses of results for Microtox were conducted in 2018 because no sample was toxic to Microtox. Analyses have also not been performed in previous years because there have always been very few samples assessed as toxic to Microtox.

The relationship between amphipod survival, distance to the nearest active drill centre and the other variables brought forward for analysis was tested using Spearman rank correlations.

5.1.3.3 Benthic Community Structure

Univariate Analyses

In 2018, as in previous years, benthic community structure analysis focused on three summary indices:

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

Abundances of four taxa were also analyzed. These analyses were secondary to analyses of indices of benthic community structure 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).

As with the sediment chemistry and amphipod toxicity results, the objective of the detailed analysis of the benthic community data was to test for evidence of effects from active drill centres. Five univariate statistical tools were used to explore the spatial variations of the selected indices of benthic community structure: Spearman rank correlations (Tool 1), threshold models (Tool 2), graphical display of data (Tool 3), maps (Tool 4), and repeated-measures regression (Tool 5). Analyses followed the methods detailed in Section 5.1.3.1; except that maps were generated for all summary indices, even if Spearman rank correlations with distance to drill centres were not significant. For individual taxa, only those taxa that showed significant correlations with distance were examined using maps, as was done for sediment physical and chemical characteristics.

Multivariate Analyses

As recommended in the 2014 EEM report (Husky Energy 2017), within year multivariate analyses (specifically, non-Metric Multidimensional Scaling (nMDS)) were undertaken in the 2016 and 2018 reports. Multiyear analyses including both 2016 and 2018 using nMDS were also included in this (2018) report based on recommendations in the 2016 EEM report (Husky Energy 2019).

All multivariate statistical and graphical analyses of taxonomic abundance were based on square root-transformed Bray-Curtis similarity matrices. To assess variation in benthic infauna assemblages, permutational multivariate analysis of variance (PERMANOVA) was used by conducting 4,999 random permutations for each dataset (Anderson *et al.* 2008). The percent contribution of species or groups to the observed dissimilarity among distance groups from nearest active drill centres was determined using similarity percentage (SIMPER) analyses (Clarke and Warwick 2001). Data are presented for taxa that contributed to approximately ≥5% of the observed dissimilarity among distance groups from nearest active drill centres.

To examine correlations between sediment physical/chemical variables and the benthic invertebrate assemblage data, step-wise distance-based linear models (DISTLM) with an Akaike Information Criterion (AIC) selection process (Anderson *et al.* 2008) were used. All physical/chemical variables assessed in the EEM program, as well as station depth, were included in these analyses. Prior to conducting DISTLM step-wise multivariate multiple regression analyses, sediment physical/chemical variables were $\log_{10}$-transformed and screened to identify highly correlated variables (Pearson correlation coefficients > |0.8|), which could bias model selection (Anderson *et al.* 2008). The reduced model results were then compared to the results of the model incorporating all variables. Exclusion of the correlated variables (reduced model) did not alter the statistical interpretations; therefore, the statistical results reported are based on the full model that considered all potential variables. All multivariate statistical analyses were performed using PRIMER with PERMANOVA+ (ver. 6.1.11, PRIMER-E Ltd, Plymouth, UK).

All statistical methods are described in greater detail in Appendix B-7.

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 that occurred above the laboratory detection limit from 2000 to 2018, and Table 5-4 provides those statistics for 2018. Table 5-4 excludes Station 31, located near the site of a delineation well. Toluene was detected at levels close to the laboratory detection limit at one station in 2005 and was not detected in other years. Hydrocarbons in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} ranges have been detected in sediments since 2004, but were not detected in 2000, the baseline year. Among the PAHs, pyrene, benzo(*b*)-, benzo(*j*)-, and benzo(*k*)- fluoranthene were each detected at one Sediment Quality Triad station in 2018. All the fluoranthenes were detected at Station 1, located 1.3 km from the *SeaRose* FPSO. Pyrene was detected at Station 31. In other sampling years, PAHs were only detected at Sediment Quality Triad stations in baseline (at one station) and in 2010 (at five stations). In all cases, including 2018, PAH concentrations were low and near the laboratory detection limit. Commonly detected metals in all ten sampling years were aluminum, barium, chromium, iron, lead, manganese, strontium, uranium and vanadium.

As in previous years, sediments collected in 2018 were predominantly sand, with gravel-sized materials comprising up to 9.1% of the sediment (Table 5-4). Organic carbon content was low, with an average of 0.9 g/kg and a maximum of 1.6 g/kg at Station C-5. Sediment percent fines (*i.e.*, silt and clay fractions combined) content was also low with an average of 1.5% and a maximum value of 3.6% at Station 4.

Sediment concentrations of metals for which there is a sediment quality guideline were below their Interim Sediment Quality Guidelines (ISQG) (Canadian Council of Ministers of the Environment (CCME) 2001, 2015; see Table 5-4). Adverse biological effects are rarely expected to occur below ISQG (CCME 2001, 2015). Concentrations of $>C_{10}$-C_{21} hydrocarbons averaged 32.9 mg/kg, with a maximum of 710 mg/kg at Station 20. Barium concentrations averaged 388 mg/kg with a maximum of 3,400 mg/kg at Station C-5.

Table 5-4 Summary Statistics for Detected Sediment Variables (2018)

Variable	Units	ISQG	*n*	*n* > LDL	Min	Max	Mean
$>C_{10}$-C_{21} hydrocarbons	mg/kg	-	52	52	0.36	710	32.93
$>C_{21}$-C_{32} hydrocarbons	mg/kg	-	52	52	0.5	20	1.67
Benzo(*b*)fluoranthene	mg/kg	-	1	1	<0.017	0.017	NA
Benzo(*j*)fluoranthene	mg/kg	-	1	1	<0.013	0.013	NA
Benzo(*k*)fluoranthene	mg/kg	-	1	1	<0.016	0.016	NA
Inorganic carbon	g/kg	-	1	1	<0.3	0.3	NA
Organic carbon	g/kg	-	52	52	0.51	1.6	0.91
Aluminum	mg/kg	-	52	52	6800	11000	8429
Barium	mg/kg	-	52	52	110	3400	388
Chromium	mg/kg	52.3	52	52	2.4	29	3.72
Copper	mg/kg	18.7	1	1	<2.3	2.3	NA
Iron	mg/kg	-	52	52	1100	2300	1448
Lead	mg/kg	30.2	52	52	2	9.3	3.03
Lithium	mg/kg	-	4	4	<2.1	2.7	NA
Manganese	mg/kg	-	52	52	21	63	34
Mercury	mg/kg	0.13	1	1	<0.011	0.011	NA
Molybdenum	mg/kg	-	1	1	<3.5	3.5	NA
Nickel	mg/kg	-	1	1	<40	40	NA
Strontium	mg/kg	-	52	52	31	140	53
Thallium	mg/kg	-	2	2	<0.11	0.11	NA

Variable	Units	ISQG	*n*	*n* > LDL	Min	Max	Mean
Uranium	mg/kg	-	52	52	0.16	0.29	0.20
Vanadium	mg/kg	-	52	52	4.2	8.1	5.19
Zinc	mg/kg	124	1	1	<5.7	5.7	NA
Ammonia	mg/kg	-	52	52	3	17	5.30
Sulphide	mg/kg	-	8	8	<0.5	21.8	NA
Sulphur	%	-	52	52	0.025	0.14	0.04
% Clay	%	-	52	52	0.35	1.18	0.62
% Fines	%	-	52	52	0.7	3.6	1.46
% Gravel	%	-	52	52	0	9.1	1.26
% Sand	%	-	52	52	89.3	98.8	97
% Silt	%	-	52	52	0.07	2.63	0.84
Redox	mV	-	52	52	152	239	191

Notes:
- Station 31 is excluded.
- ISQG = Interim Sediment Quality Guidelines.
- LDL = Laboratory Detection Limit.
- NA = Not Available. When more than 25% of values were below the laboratory detection limit, a mean is not calculated in this table.

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

As in previous years, concentrations of >C_{10}-C_{21} hydrocarbons in 2018 were significantly and negatively correlated (*i.e.*, decreased) with distance from the nearest active drill centre (ρ_s = -0.942, p < 0.001, All stations; ρ_s = -0.921, p < 0.001, repeated-measures stations[10]) (Figure 5-6).

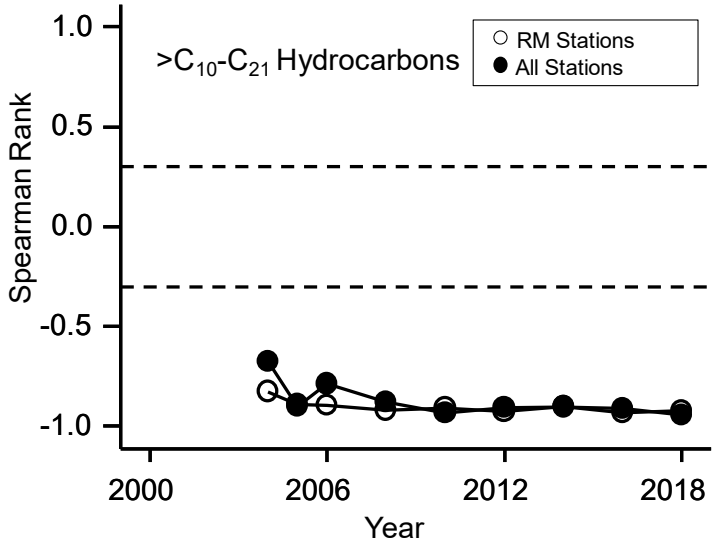


Figure 5-6 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for >C_{10}-C_{21} Hydrocarbons

Notes: Station 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. Significance levels from specific statistical tests are reported in text.

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; see Appendix B-7 for details on threshold model methods and results). In 2018, the

[10] Refer to Table 1-1, Section 1for repeated-measures (RM) stations

threshold distance was estimated to be 2.4 km (Table 5-5). Based on confidence limits in Table 5-5, the estimated threshold in 2018 is lower than those recorded prior to 2010 and, with the exception of 2014, similar to estimates in more recent years (the 2018 estimate is lower than the 2014 estimate). 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 (km)
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)
2014	5.8 (3.5, 9.5)
2016	2.7 (1.9, 3.9)
2018	2.4 (1.8, 3.23)

Notes: - 95% confidence limits are provided in brackets.
- n = 52 in 2018 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 active drill centres in 2018 (Figures 5-7 and 5-8). $>C_{10}$-C_{21} hydrocarbons were also enriched at Station 31, located near the site of a delineation well (White Rose K-03) (Figure 5-8).

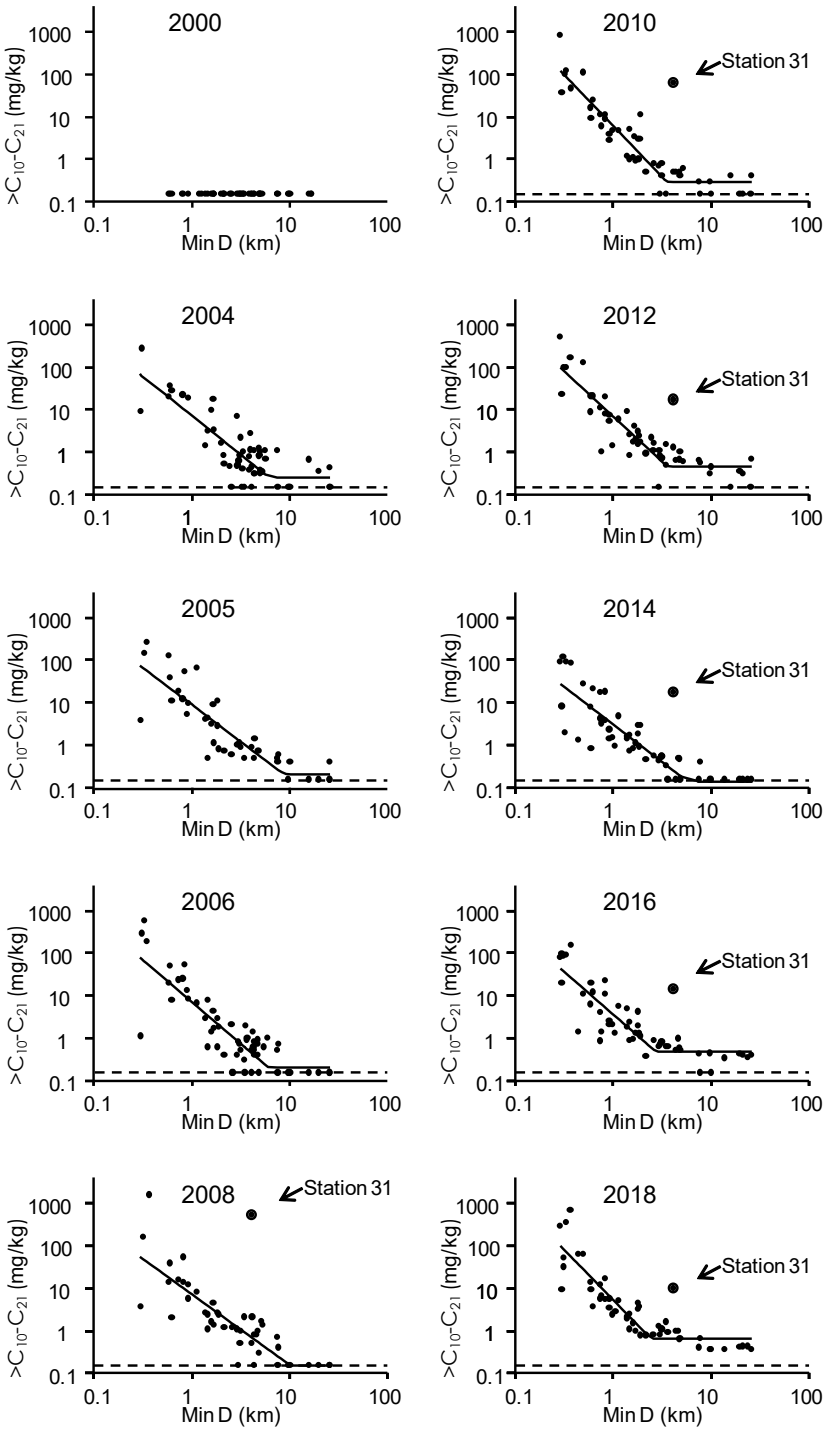


Figure 5-7 Variations in >C_{10}-C_{21} Hydrocarbon Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. The ½ of the detection limit is indicated in each graph by a horizontal dotted line (0.15 mg/kg), to indicate the levels observed in the baseline year (2000). Here and in similar figures, threshold models are plotted when these were significant. Station 31 is identified in this figure because it was a clear outlier for >C_{10}-C_{21} hydrocarbons. Therefore, it was excluded from all analyses (see Section 5.1.3.

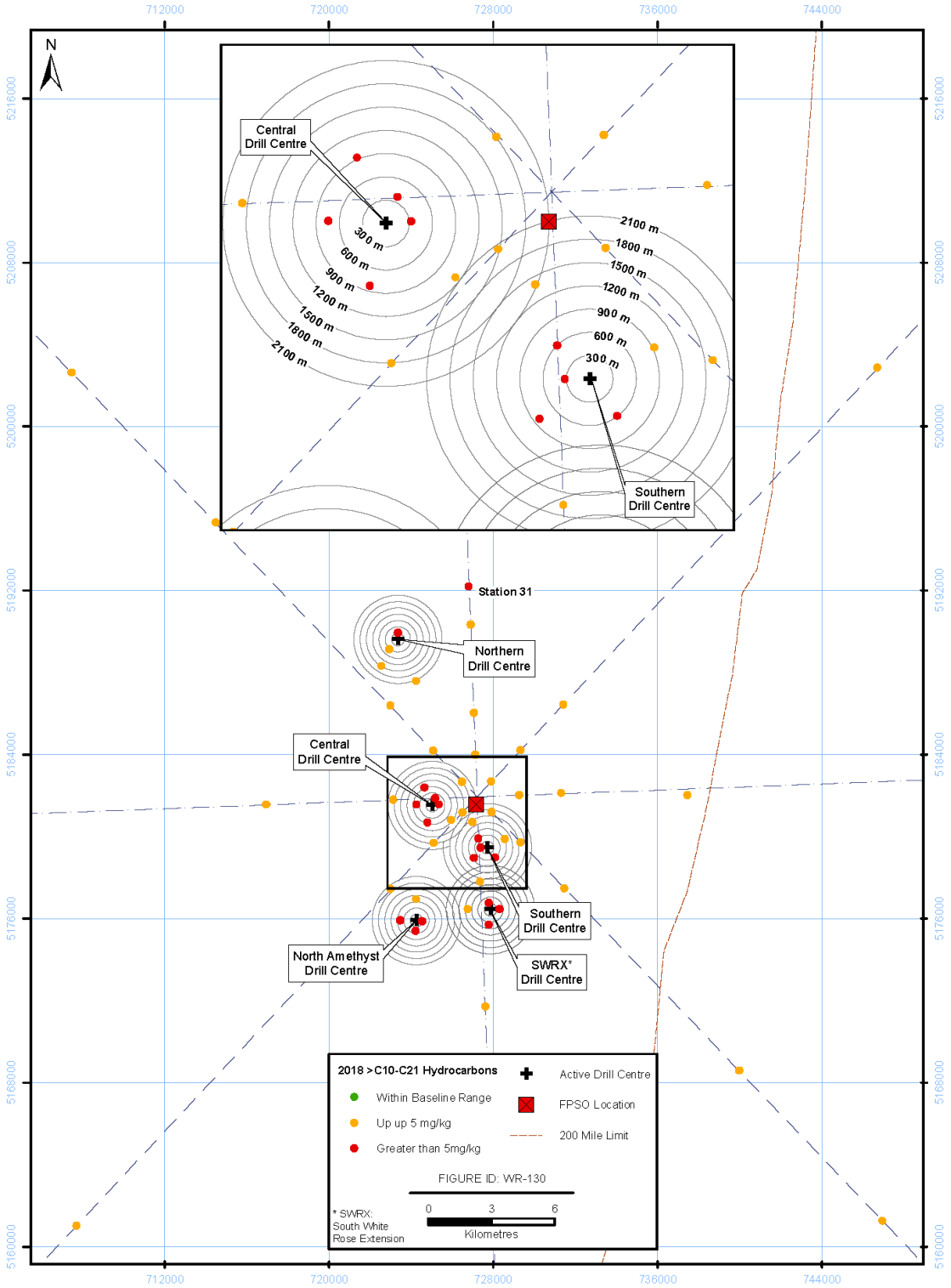


Figure 5-8 Location of Stations with >C_{10}-C_{21} Hydrocarbon Values within the Baseline Range (not detected), Stations Showing Mild Enrichment up to 5 mg/kg, and Stations with Values Greater than 5 mg/kg (2018)

Note: Station 31 is identified in this figure because it was excluded from analyses.

Repeated-measures regression indicated no change over time in the relationship between distance and concentrations of >C_{10}-C_{21} hydrocarbons for repeated-measures stations (p = 0.374; Table 5-6), and no changes in area-wide concentrations over time (p = 0.311). This conclusion applies to the time period from 2004 to present (*i.e.*, EEM years). Concentrations of >C_{10}-C_{21} hydrocarbons were non-detectable in 2000, and generally have been at detectable concentrations since 2004 (Figures 5-7 and 5-9).

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

Trend Over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.374	0.311	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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018. The Before to After contrast cannot be performed for >C_{10}-C_{21} hydrocarbons since all concentrations were below detection limit during baseline.

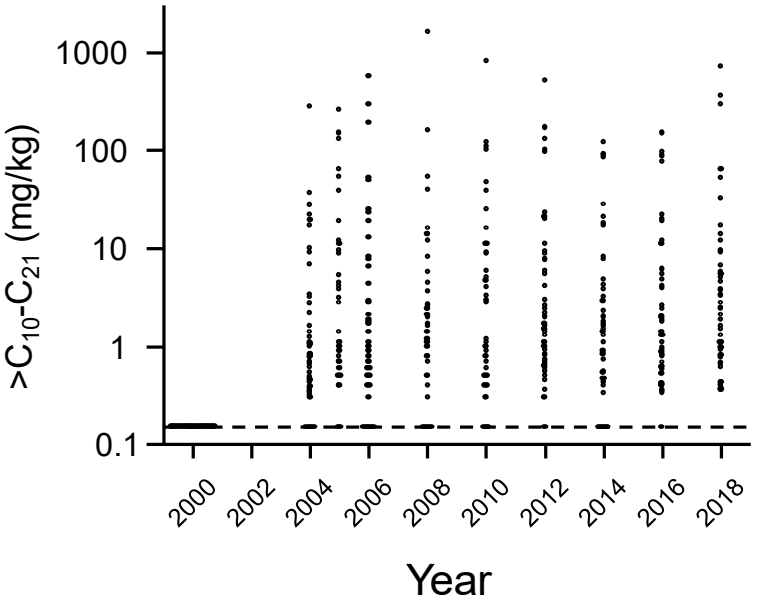


Figure 5-9 Dot Density Plot of >C_{10}-C_{21} Hydrocarbon Values by Year

Note: The horizontal dotted line indicates ½ the detection limit (0.15 mg/kg), to indicate the levels observed in the baseline year (2000).

5.2.1.2 Barium

Like >C_{10}-C_{21} hydrocarbons, barium produced a significant negative Spearman rank correlation with distance to active drill centres in 2018 (ρ_s = -0.840, p < 0.001, All stations; ρ_s = -0.779, p < 0.001, repeated-measures stations), as in previous years (Figure 5-10).

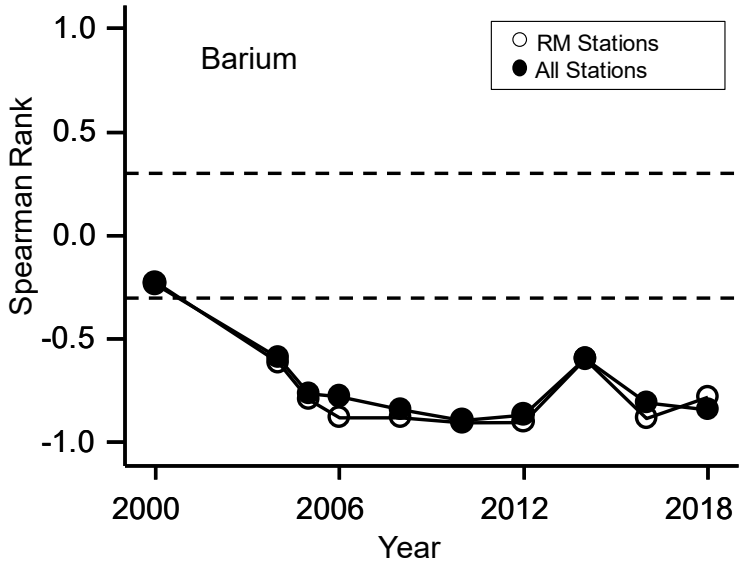


Figure 5-10 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Barium

Notes: Station 31 was excluded. *n* = 52 for All Stations. *n* = 35 for Repeated-Measures (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. Significance levels from specific statistical tests are reported in text.

The threshold model in 2018 was again significant ($p < 0.001$). The estimated threshold distance in 2018 was 1.0 km (Table 5-7; also see Appendix B-7). Based on confidence limits in Table 5-7, the estimated threshold in 2018 is lower than those estimated prior to 2012 and similar to estimates from more recent years. Figure 5-11 provides a graphic representation of threshold models.

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

Year	Threshold Distance (km)
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 to 1.2)
2014	1.0 (0.8 to 1.4)
2016	1.2 (0.9 to 1.6)
2018	1.0 (0.8 to 1.3)

Notes: - 95% confidence limits are provided in brackets.
- *n* = 52 in 2016 with Station 31 excluded.

As indicated in Figure 5-11, 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 (mean + 2 SDs) was used as a “benchmark” against which to judge spatial variation in the sampling area in Figures 5-11 and 5-12. Barium was enriched to levels exceeding 202 mg/kg at some stations around drill centres (Figure 5-12). Barium was also enriched at Station 31, located near the site of a delineation well (White Rose K-03).

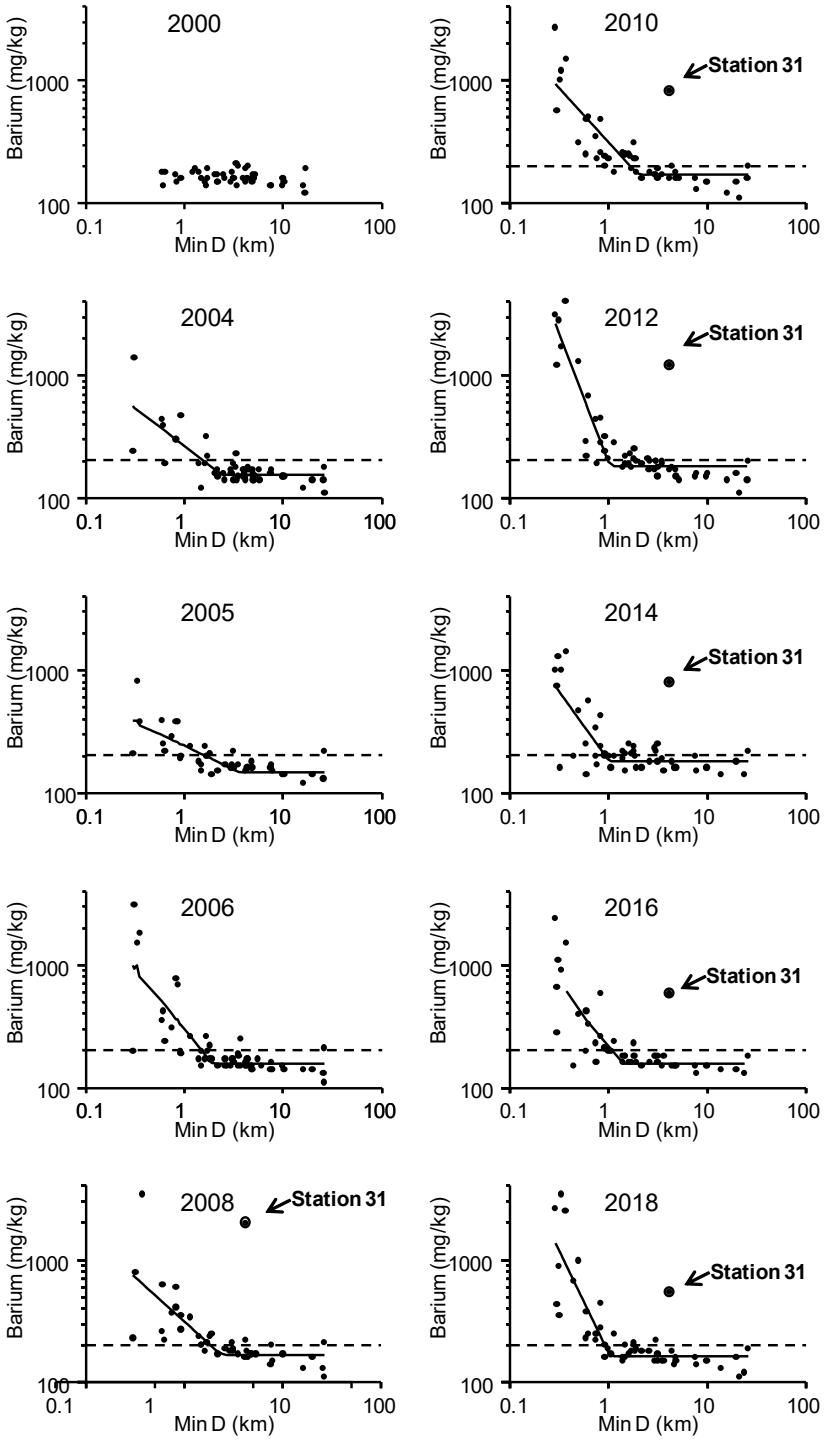


Figure 5-11 Variations in Barium Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. 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). Here and in similar figures, threshold models are plotted when these were significant. Station 31 is identified in this figure because it was a clear outlier for barium. Therefore, the station was excluded from all analyses (see Section 5.1.3).

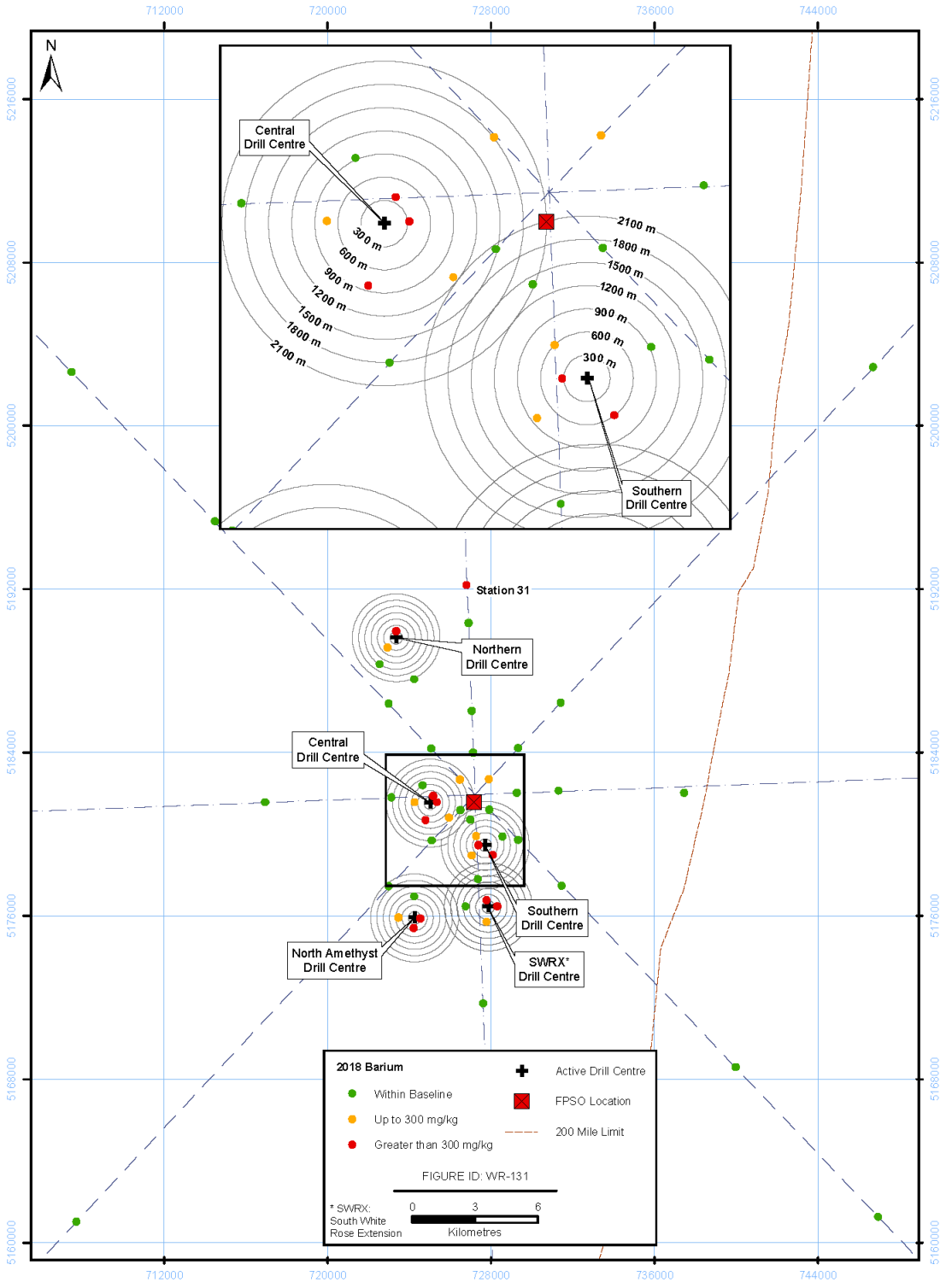


Figure 5-12 Location of Stations with Barium Levels Within the Baseline Range (up to 202 mg/kg), Stations Showing Mild Enrichment up to 300 mg/kg, and Stations with Values Greater than 300 mg/kg (2018)

Note: Station 31 is identified in this figure because it was excluded from analyses.

Repeated-measures regression indicated no change over time in the slope of the relationship between barium concentration and distance to the nearest active drill centre in EEM years for repeated-measures stations (p = 0.217; Table 5-8). There was also no change over time in average barium concentration in EEM years (p = 0.164; also see Figure 5-13). Slopes differed from before to after drilling operations began (p < 0.001). Concentrations of barium in year 2000 averaged 168 mg/kg, with no significant correlation between barium concentrations and distance from drill centres (*e.g.*, Figure 5-10[11]). Conversely, distance correlations have been strong for barium since drilling began. Overall average barium concentrations have been higher since drilling operations began in 2004 (p < 0.001; also see Figure 5-13).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.217	0.164	<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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

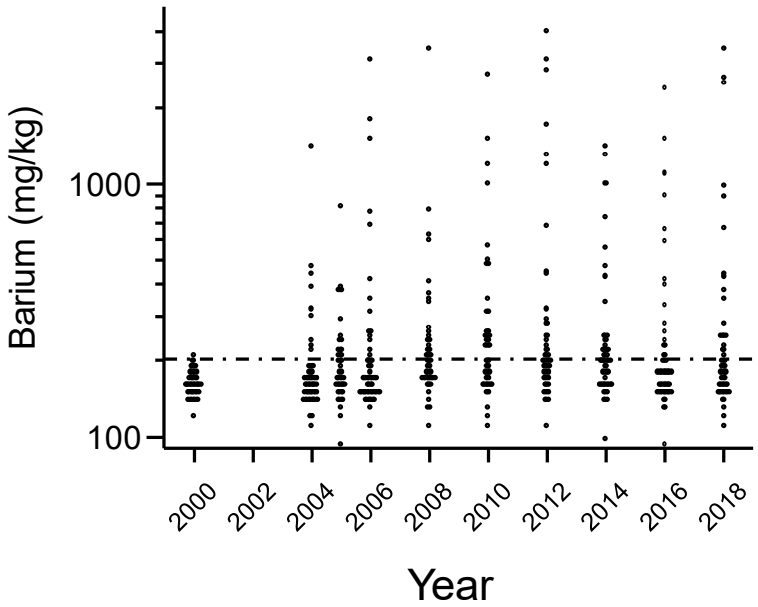


Figure 5-13 Dot Density Plot of Barium Values by Year

Note: A concentration of 202 mg/kg is indicated by a horizontal line, as based on the mean values + 2 SDs using data from the baseline year (2000).

[11] Although slopes from Spearman rank correlations (Figure 5-10 and other similar figures) are not the same as slopes from repeated-measures regression (the former is non-parametric, the latter is parametric), Figure 5-10 (and other similar figures) can often be used to better understand repeated-measures regression results.

5.2.1.3 Fines

Percent of sediment as fines (*i.e.*, silt and clay) varied between 0.7% and 3.6% across the sampling area in 2018; and the variable was significantly correlated with distance to drill centres for All stations (ρ_s = -0.431, p = 0.002) but not for repeated-measures stations (ρ_s = -0.266, p > 0.05) (Figure 5-14). The plot of Spearman rank correlations over time in Figure 5-14 indicates that the relation between fines and distance from the nearest active drill centre typically has not been strong.

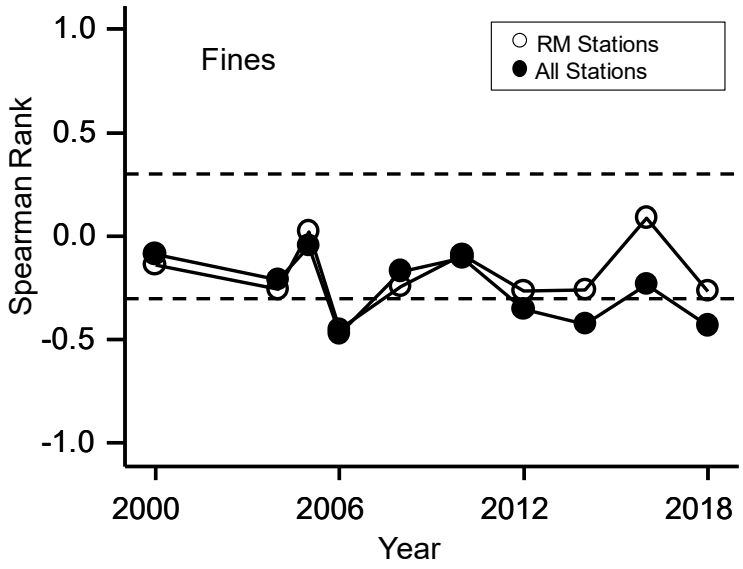


Figure 5-14 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Fines

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (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. Significance levels from specific statistical tests are reported in text.

Figure 5-15 provides a graphical representation of percent fines with distance from nearest active drill centres. Despite the significant spearman rank correlation when all stations were considered, the threshold model was not able to estimate a reliable threshold for these stations (Appendix B-7). However, Figure 5-15 does indicate potential mild enrichment at stations near (within approximately 0.5 km from) drill centres. Potential enrichment near drill centres was also noted in other EEM years, particularly since 2010, and the threshold model for fines was significant in 2014 (Figure 5-15).

In 2018, fines were enriched to levels exceeding the baseline range near the drill centres. Fines were also enriched at Station 31, the site of an exploration well, and at six stations more distant from drill centres (Figure 5-16).

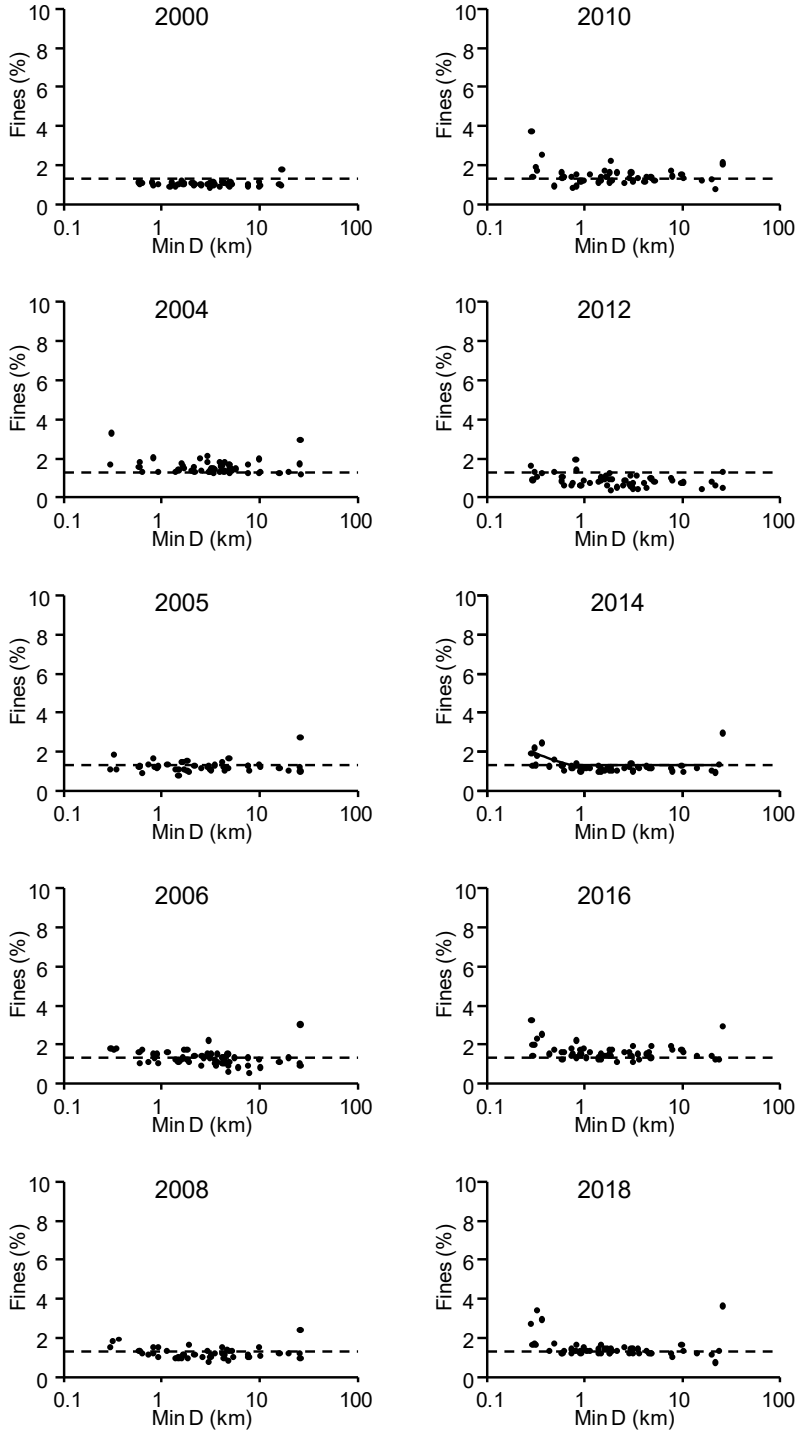


Figure 5-15 Variations in Percent Fines with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. A concentration of 1.3% is indicated in each graph by a horizontal line, based on the mean values + 2 SDs in 2000 (baseline). Here and in similar figures, threshold models are plotted when these were significant.

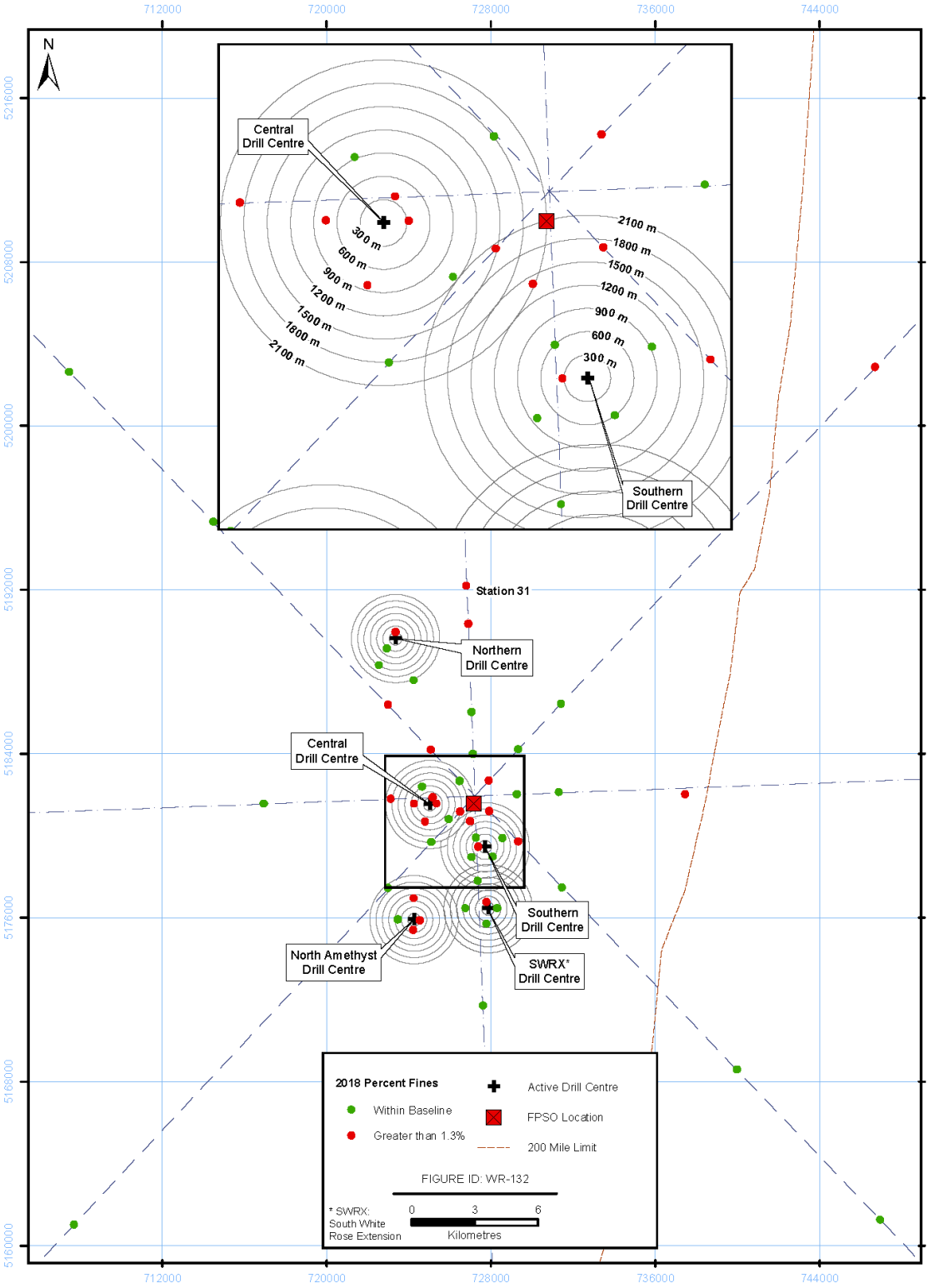


Figure 5-16 Location of Stations with Percent Fines Concentrations (2018) Within and Above the Baseline Range

Station 31 is identified in this figure because it was excluded from analyses.

Repeated-measures regression (Table 5-9) indicated that there was no significant change over time in the slope of the relationship between fines and distance from the nearest active drill centre for repeated-measures stations in EEM years (p = 0.371). There were also no significant differences in slopes from before to after drilling (p = 0.071). However, there was a significant difference in percent fines across the sampling area from before to after drilling operations (p < 0.001) with fines levels generally lower before drilling began (Figure 5-17).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.371	0.819	0.071	<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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

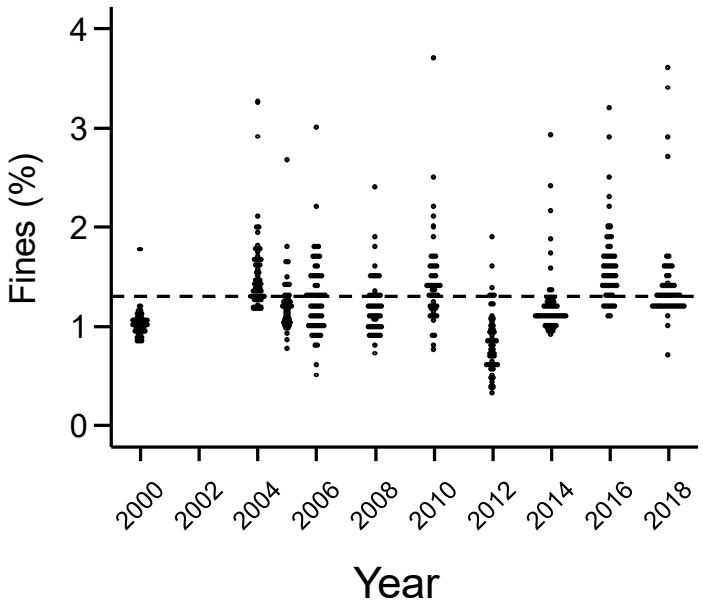


Figure 5-17 Dot Density Plot of Percent Fines by Year

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

Overall, percent fines were generally at or above pre-drilling levels, except in 2012, when percent fines were generally at or below pre-drilling levels (Figures 5-15 and 5-17).Other than at stations within approximately 0.5 km from drill centres, the more general increase in 2018 and prior EEM years is diffuse in nature and not conclusively linked to drilling activity.

5.2.1.4 Organic Carbon

Organic carbon was significantly correlated with distance from the nearest active drill centre in 2018 (ρ_s = -0.578, p < 0.001, All Stations; ρ_s = -0.376, p = 0.03, repeated-measures stations) (Figure 5-18).

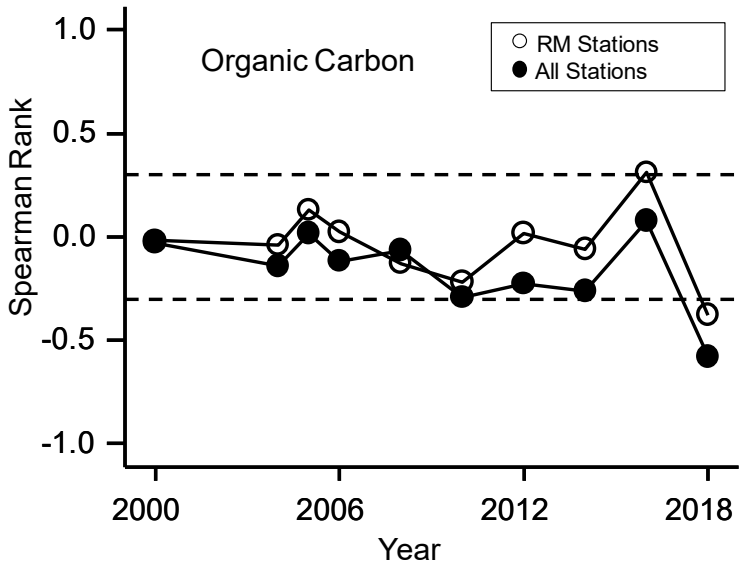


Figure 5-18 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Organic Carbon

Notes: Station 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. Significance levels from specific statistical tests are reported in text.

The threshold model for organic carbon was significant (p < 0.001) in 2018 (Appendix B-7). The estimated threshold distance in 2018 was 1.0 km (95% confidence limits = 0.70 to 1.4 km). The threshold model was not significant in previous years (Figure 5-19). Although a statistically significant threshold was noted in 2018, the vast majority of stations were below the upper limit of the baseline range (1.0 g/kg) (Figures 5-19 and 5-20). Six stations located at approximately 0.3 km from the nearest active drill centre had values which ranged between 1.1 and 1.6 g/kg. Other than this, Station 3, located approximately 7.5 km from the nearest drill centre, had an organic carbon concentration of 1.1 g/kg (Figures 5-19 and 5-20).

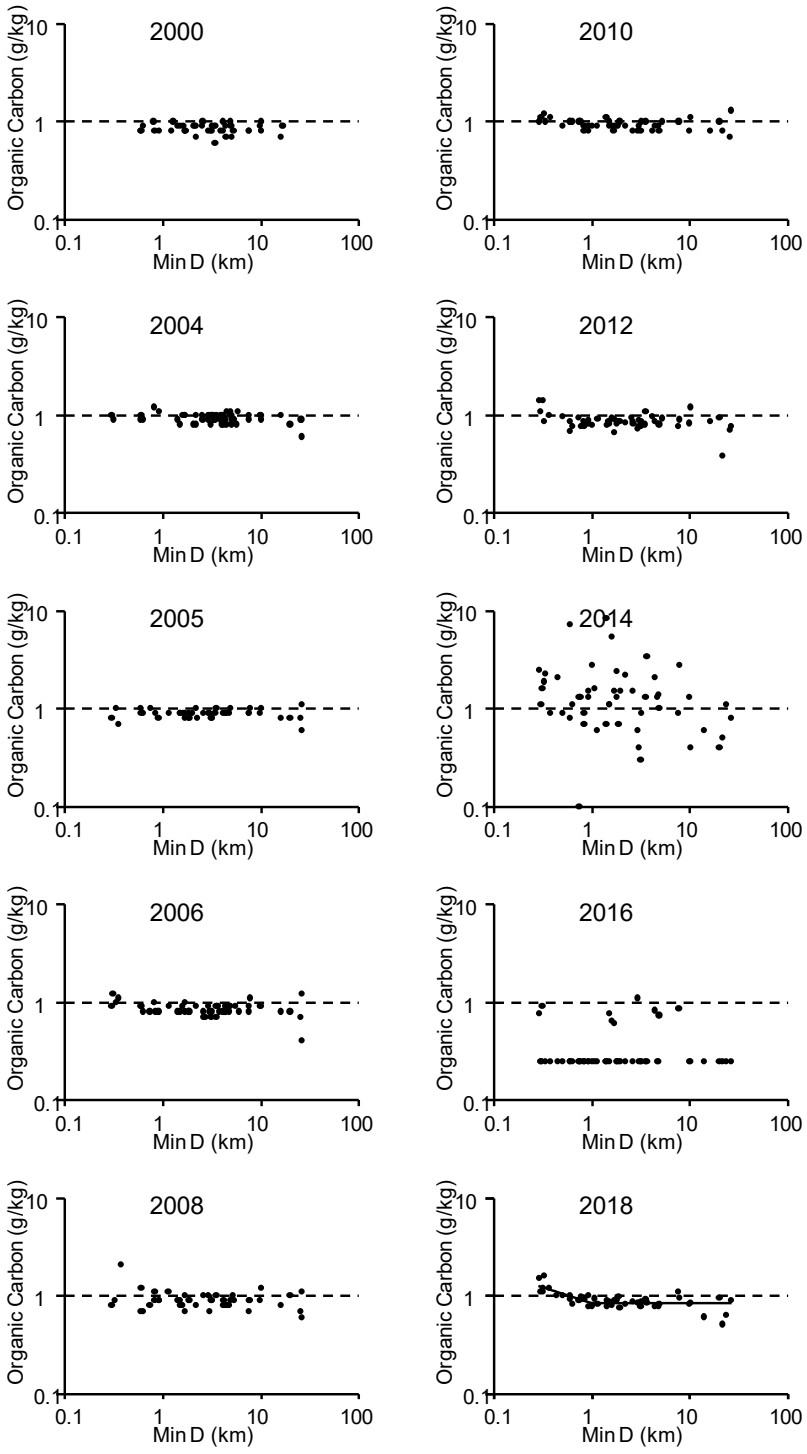


Figure 5-19 Variations in Organic Carbon with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. 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). Differences between 2014 and remaining years in Figure 5-19 relate to a difference in the analytical method used (see Husky Energy 2015 for details).

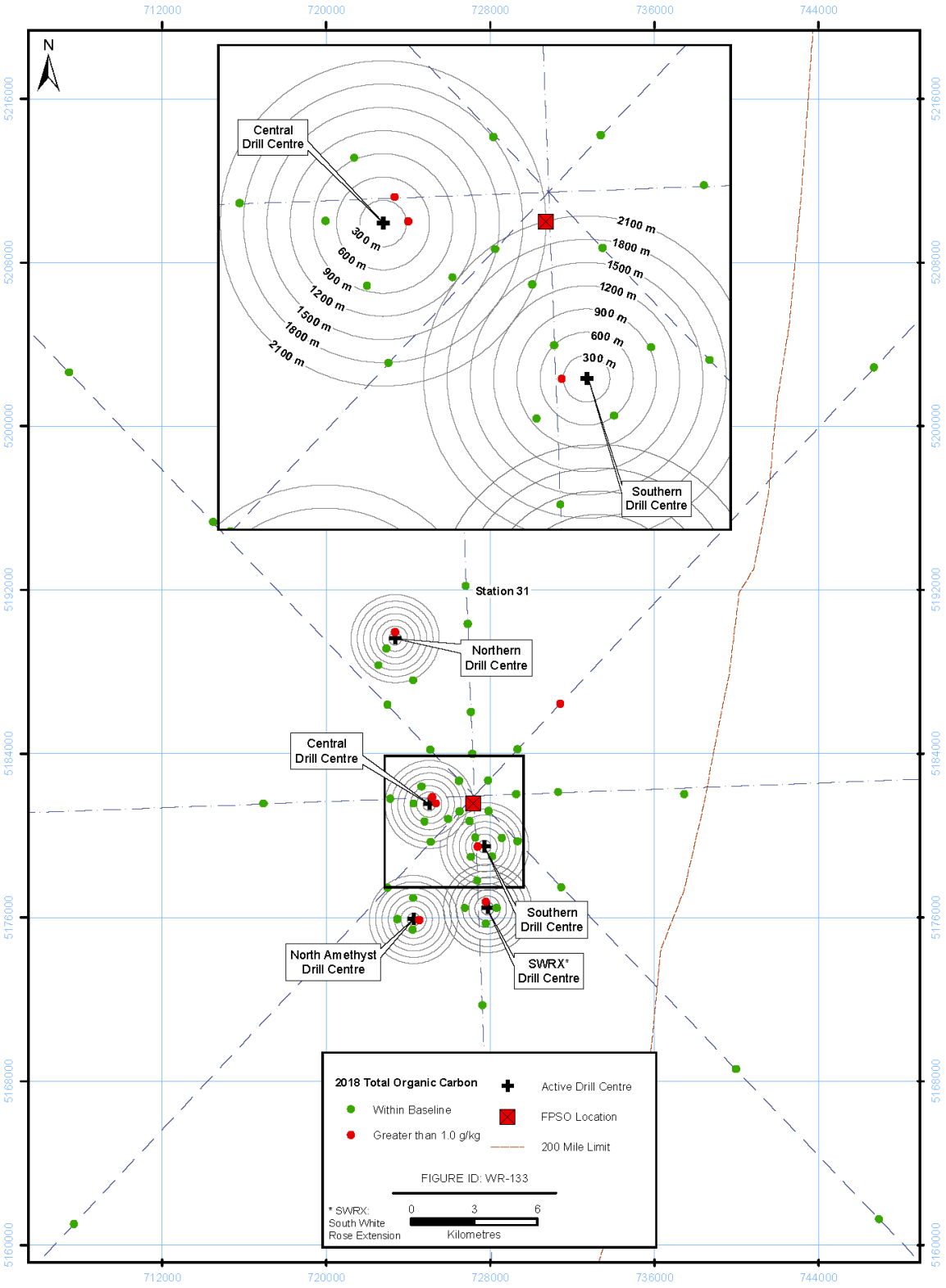


Figure 5-20 Location of Stations with Organic Carbon Concentrations (2018) Within and Above the Baseline Range

Station 31 is identified in this figure because it was excluded from analyses.

Repeated-measures regression (Table 5-10) indicated that the slope of the relationship between organic carbon and distance from the nearest active drill centres did not vary linearly in EEM years for repeated-measures stations (p = 0.869). There was also no change in slopes from before to after drilling (p = 0.342). Mean values significantly varied over time since operations began (*i.e.*, from 2004 to 2018). However, this result was due to the influence of 2014 and 2016 data anomalies. Differences in the distribution of organic carbon values in 2014 were due to a difference in the acid used to extract carbon at the commercial laboratory in that year, while more than 80% of organic carbon values in 2016 were less than the laboratory detection limit of 0.5 g/kg.

Table 5-10 Repeated-measures Regression Testing for Changes in Percent Total Organic Carbon over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.869	<0.001	0.342	0.802

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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

A dot density plot of organic carbon concentration by year is provided in Figure 5-21. Seven samples in 2018 were above the baseline range.

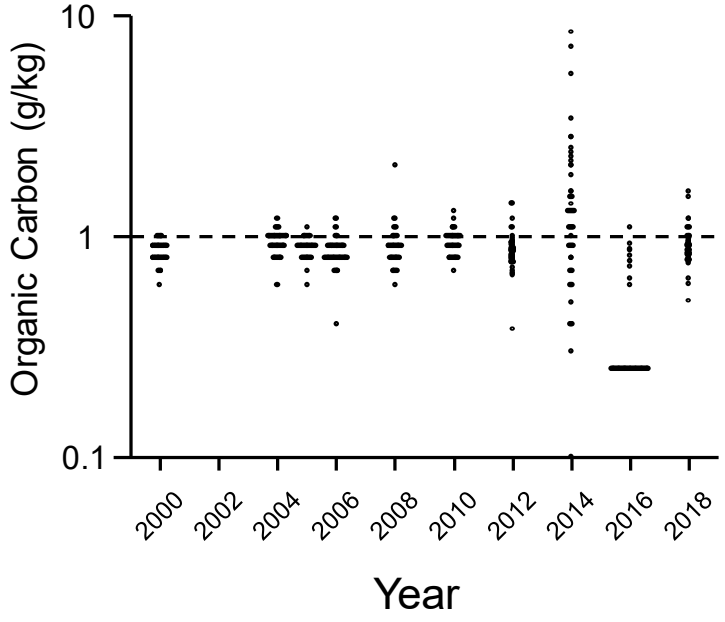


Figure 5-21 Dot Density Plot of Total Organic Carbon by Year

Note: A concentration of 1 g/kg is indicated in each graph by a horizontal line, based on the mean values + 2 SDs in the baseline year (2000). Differences between 2014 and remaining years in Figure 5-19 relate to a difference in the analytical method used (see Husky Energy 2015 for details).

5.2.1.5 Ammonia

Ammonia concentrations were generally less than 10 mg/kg in EEM years. The maximum value in 2018 was 17 mg/kg, observed at Station NA1. Ammonia concentrations were significantly and negatively correlated (*i.e.*, decreased) with distance from the nearest active drill centre in 2018 (ρ_s = -0.404, p = 0.003, All stations). However, the relationship was not significant when only repeated-measures stations were considered (ρ_s = -0.060, p > 0.05; Figure 5-22). Despite the significant Spearman rank correlation when all stations were considered, the threshold model was not able to estimate a reliable threshold (Appendix B-7). Other than at stations within approximately 0.5 km from drill centres, a relationship between ammonia concentrations and distance to the nearest active drill centre was not readily apparent in Figure 5-23.

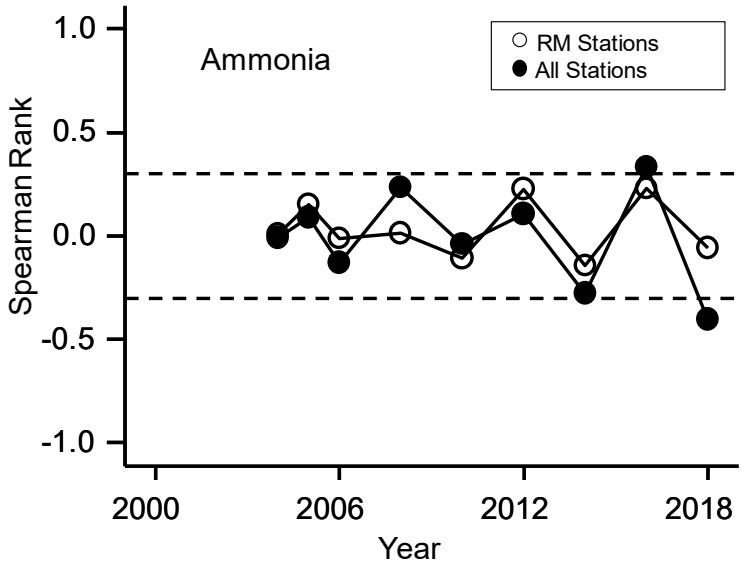


Figure 5-22 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Ammonia

Notes: Station 31 was excluded. n = 52 for All Stations n = 35 for Repeated-Measures (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. Significance levels from specific statistical tests are reported in text. Ammonia was not measured in the 2000 baseline survey.

Ammonia concentrations exceeded the background range at a single station in 2018 (Figures 5-23 and 5-24)[12]. Repeated-measures regression (Table 5-11) indicated that there was no change in the slope of the relationship between ammonia and distance in EEM years for repeated-measures stations (p = 0.399), but there was significant change over time in average concentrations across the sampling area (p < 0.001, Table 5-11). Concentrations generally decreased over time (Figure 5-25).

[12] Ammonia was not sampled in baseline. An ammonia concentration of 12.2 mg/kg was used as an estimate of the upper level of the background range. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (n = 43).

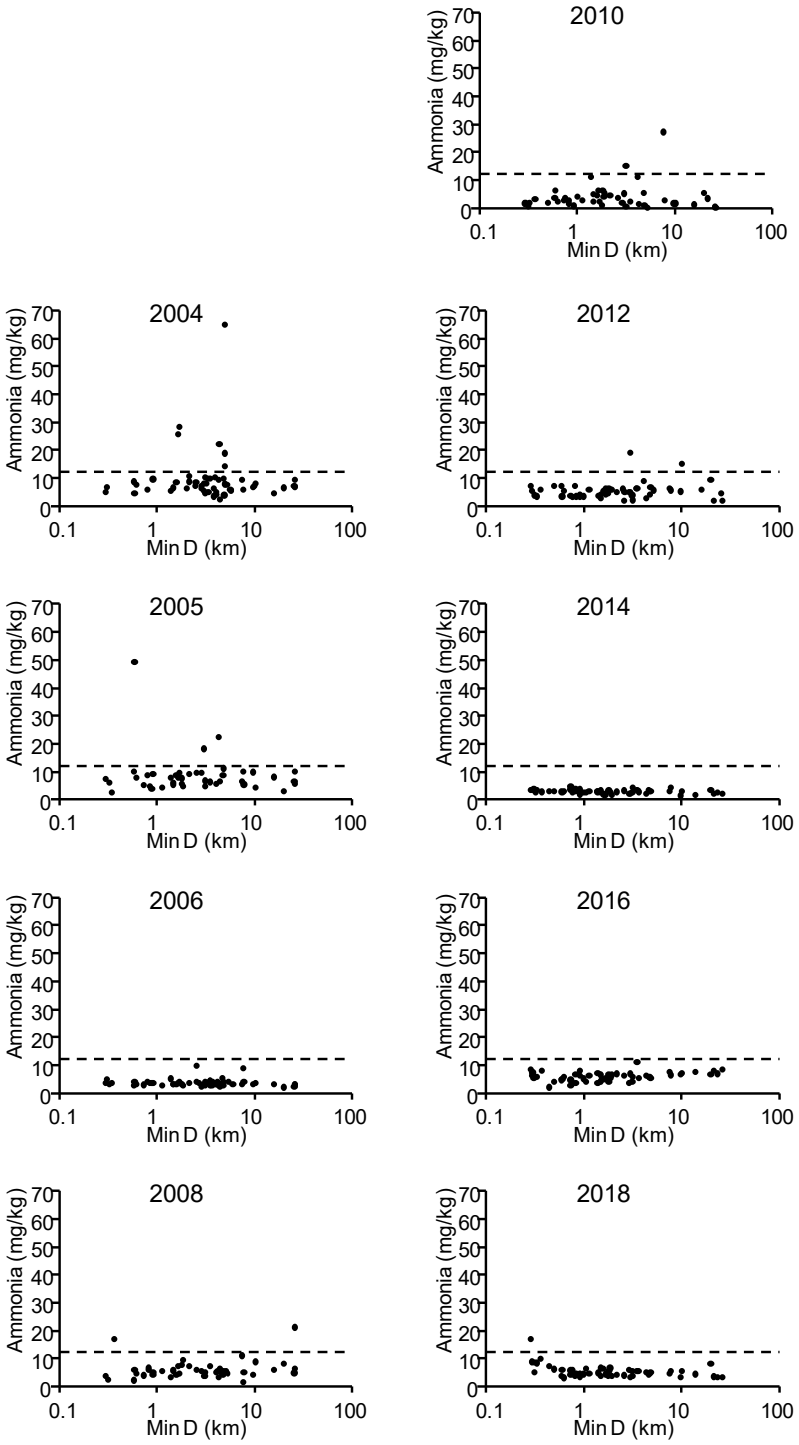


Figure 5-23 Variations in Ammonia Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre. Ammonia was not measured the 2000 baseline survey. An ammonia concentration of 12.2 mg/kg was used as an estimate of the upper level of the background range. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (*n* = 43).

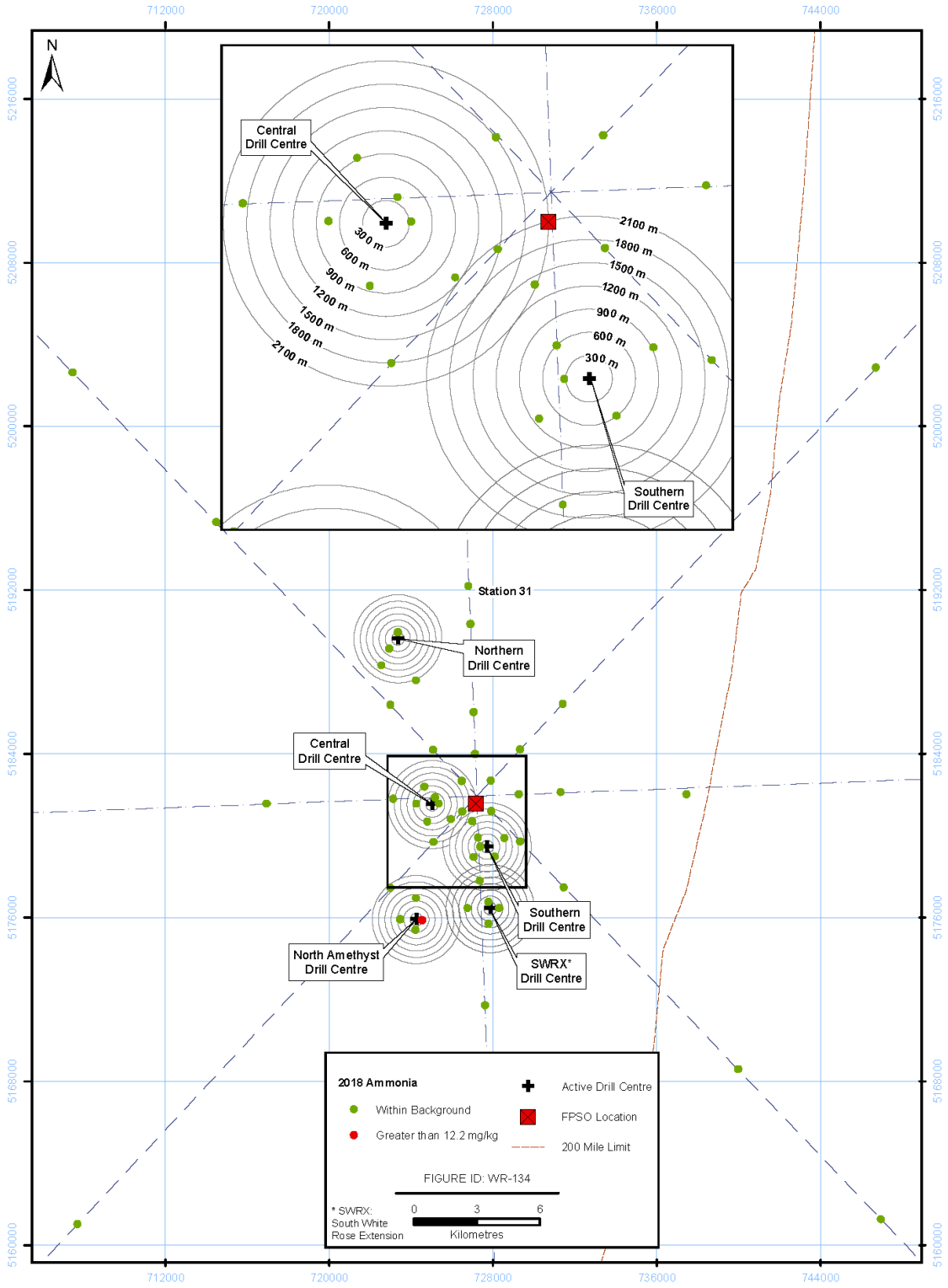


Figure 5-24 Location of Stations with Ammonia Concentrations (2018) Within and Above the Background Range

Station 31 is identified in this figure because it was excluded from analyses.

Table 5-11 Repeated-measures Regression Testing for Changes in Ammonia Concentrations over Time

Trend over Time		Before to After	
Slope	Mean	Slope	Mean
0.399	<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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018. The Before and After contrast cannot be tested for ammonia because it was not measured in baseline.

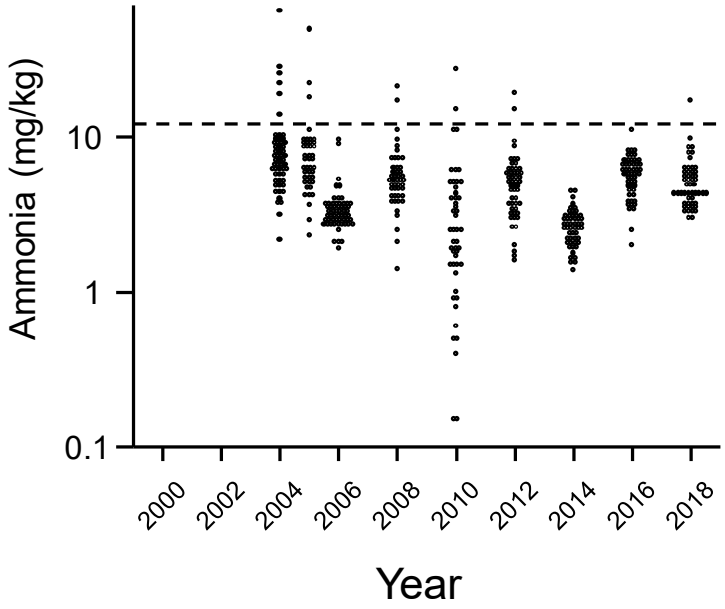


Figure 5-25 Dot Density Plot of Ammonia Concentrations by Year

Note: A concentration of 12.2 mg/kg is indicated by a horizontal line, based on the mean values + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (*n* = 43).

5.2.1.6 Sulphide

In 2018, 33% of sulphide values were below the laboratory detection limit. An increase in detection limit from 0.2 mg/kg to 0.5 mg/kg in 2016 and 2018 (see Table 5-3) may have contributed to these results. In spite of the large number of values below laboratory detection limit, sulphide results are examined here because distance effects have been noted in the past and the variable is known to influence toxicity test results and benthic communities. The large number of values below detection will bias inter-annual comparisons of absolute concentrations. Therefore, these comparisons are not presented. However, examinations of correlation coefficients and regression slopes versus distance to the nearest active drill centre are still valid.

Sulphide concentrations were not related to distance to the nearest drill centre in 2018 (ρ_s = -0.190, p > 0.05, all stations; ρ_s = -0.034, p >0.05 repeated-measures stations) (Figure 5-26).

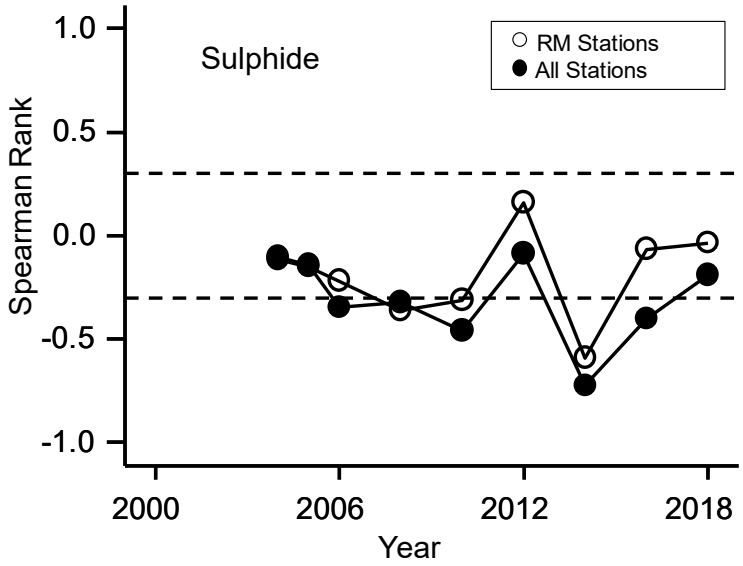


Figure 5-26 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Sulphide

Notes: Station 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. Significance levels from specific statistical tests are reported in text.
Sulphide was not measured in the 2000 baseline survey.

Figure 5-27 provides a graphical representation of sulphide concentrations with distance from nearest active drill centres. In 2018, three stations within 0.5 km from drill centres had sulphides elevated above background within 0.43 km from drill centres, which is generally consistent with results observed in most years since 2006.

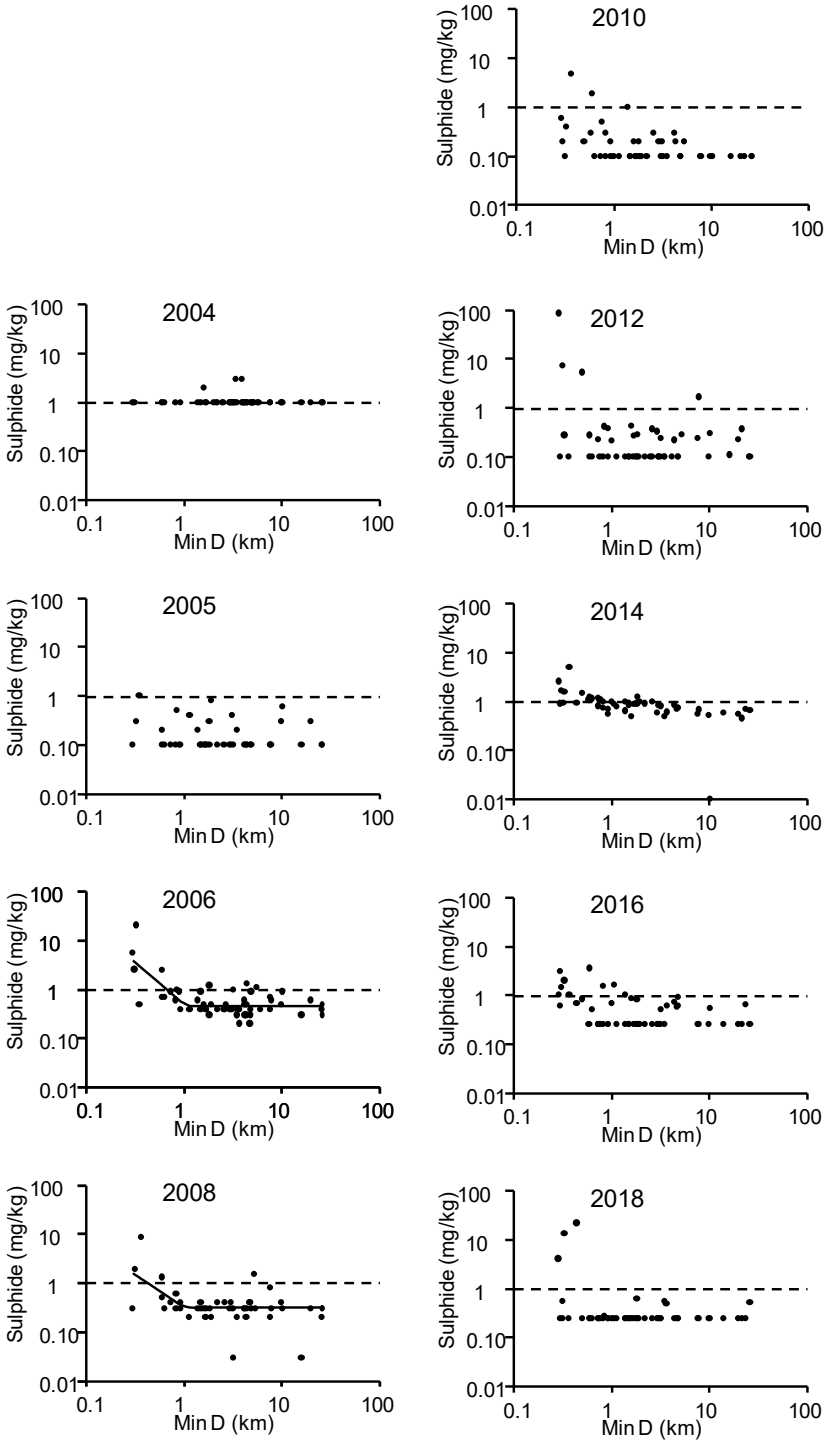


Figure 5-27 Variations in Sulphide with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre. Sulphide was not measured in the 2000 baseline survey. A sulphide concentration of 0.98 mg/kg was used as an estimate of the upper limit of the background range. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (*n* = 43). Here and in similar figures, threshold models are plotted when these were significant.

Repeated-measures regression (Table 5-12) indicated that there was significant change in the slope relationship between sulphide concentrations and distance in EEM years for repeated-measures stations (p = 0.032). For these stations, there was no relationship between sulphide concentrations and distance in 2005, 2006, 2012, 2016 or 2018. Slopes were significant and negative in 2008, 2010, and 2014 (Figure 5-26).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.032	NA	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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018. The Before to After contrast cannot be performed for sulphides because these were not measured during baseline.
- In 2018, 83% of sulphide values were below the laboratory detection limit. As such, inter-annual comparisons of means would be biased and were excluded from analyses. Examination of regression slopes of sulphide concentration versus distance to the nearest active drill centre are still valid as they test changes in relationships as opposed to absolute concentrations.

A dot density plot of sulphide values by year is provided in Figure 5-28.

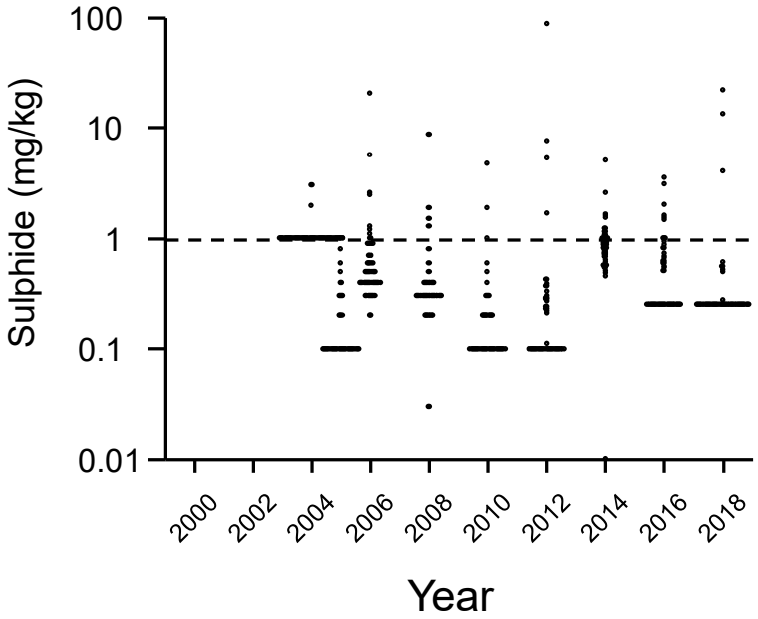


Figure 5-28 Dot Density Plot of Sulphide Concentrations by Year

Note: Sulphide was not measured in baseline. A concentration of 0.98 mg/kg is indicated in each graph by a horizontal line, based on the mean values + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (n = 43).

5.2.1.7 Sulphur

Sulphur and distance to the nearest active drill centre were significantly and negatively correlated in 2018 (ρ_s = -0.654, p < 0.001, All stations; ρ_s = -0.383, p = 0.02 repeated-measures stations) (Figure 5-29). Despite this significant correlation, the threshold model was not able to estimate a reliable threshold (Appendix B-7).

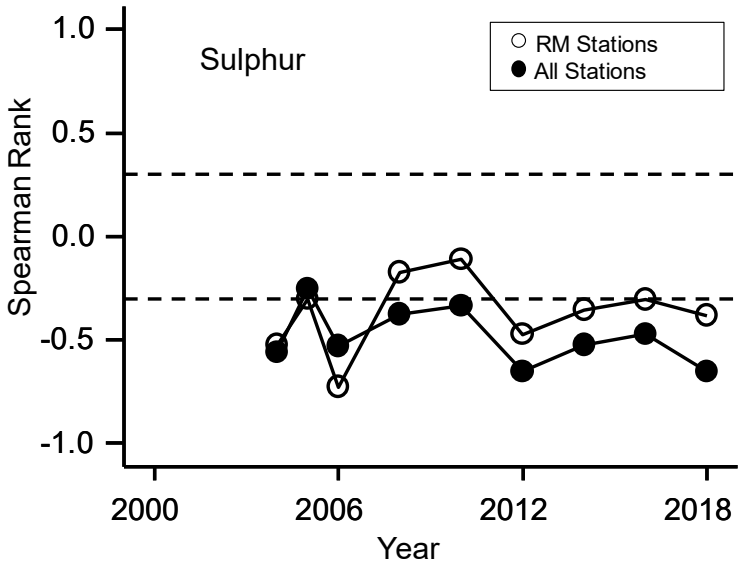


Figure 5-29 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Sulphur

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (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. Significance levels from specific statistical tests are reported in text.

Figure 5-30 provides a graphical representation of sulphur concentrations with distance from nearest active drill centres. In 2018, six stations within 0.5 km from drill centres had concentrations elevated above background (Figure 5-31).

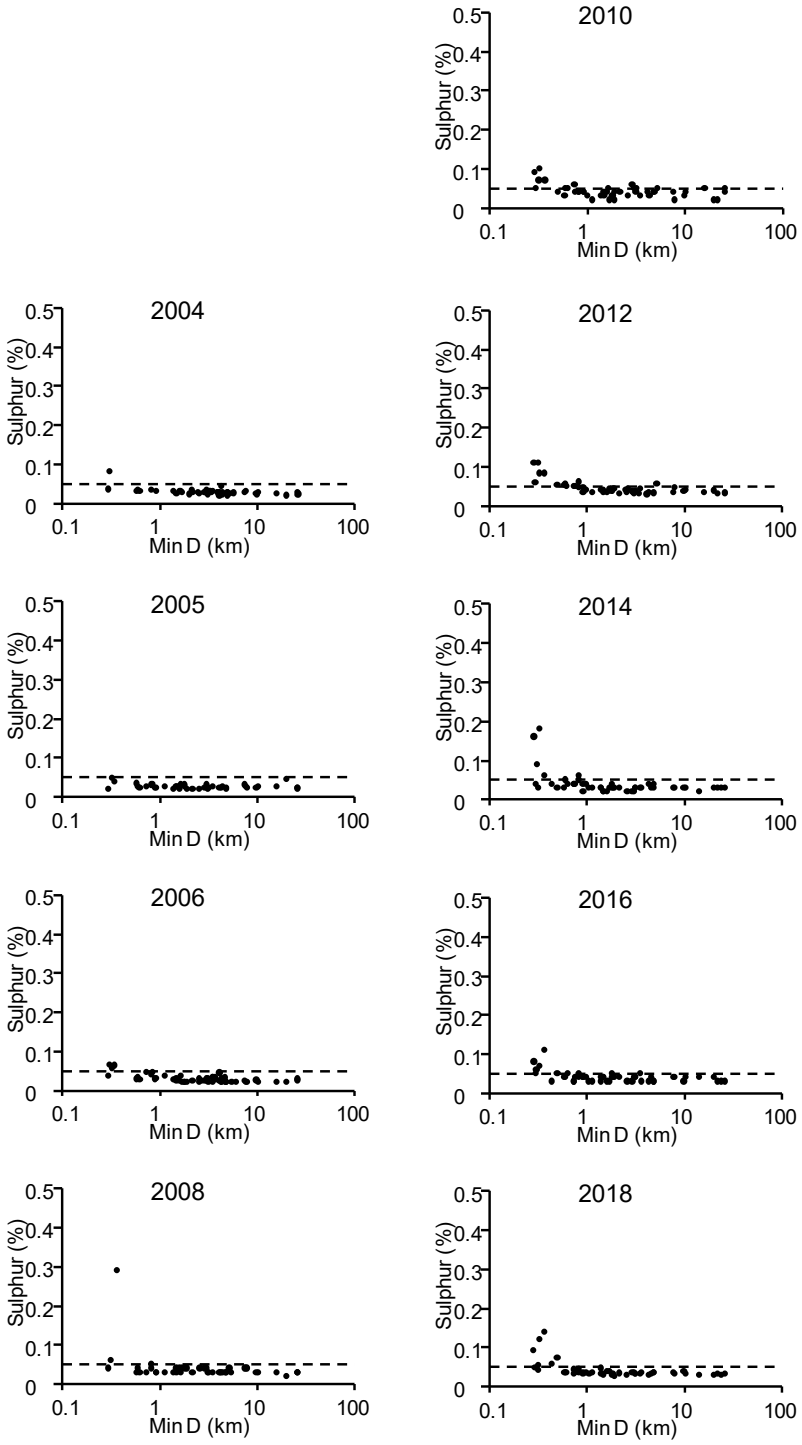


Figure 5-30 Variations in Sulphur Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Note: Min D = distance (km) to the nearest active drill centre. Sulphur was not measured in the 2000 baseline survey. A concentration of 0.05%, representing the upper limit of the background range, is indicated in each graph by a horizontal line. This was based on the mean value + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (*n* = 43).

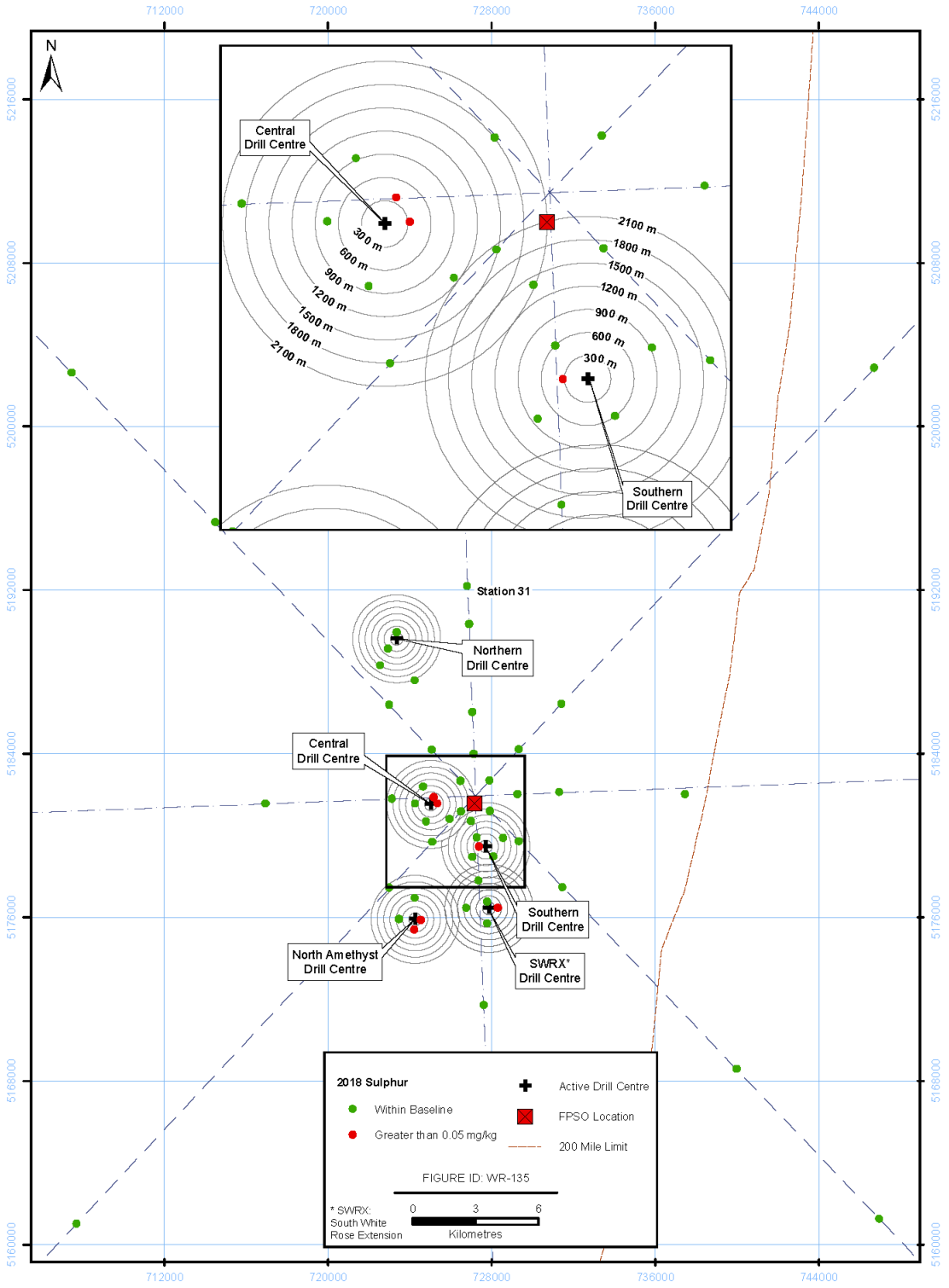


Figure 5-31 Location of Stations with Sulphur (2018) Within and Above the Background Range

Station 31 is identified in this figure because it was excluded from analyses.

Repeated-measures regression (Table 5-13) indicated that there was no change in the slope of the relationship between sulphur and distance from active drill centres in EEM years for repeated-measures stations (p = 0.449). There was a significant linear change in average sulphur concentrations in the overall sampling area (p < 0.001). The dot density graph of percent sulphur (Figure 5-32) illustrates that mean values in sediments have been higher from 2008 to 2018 than in prior EEM 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**
0.449	<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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018. The Before to After contrast cannot be performed for sulphur because sulphur was not measured in baseline.

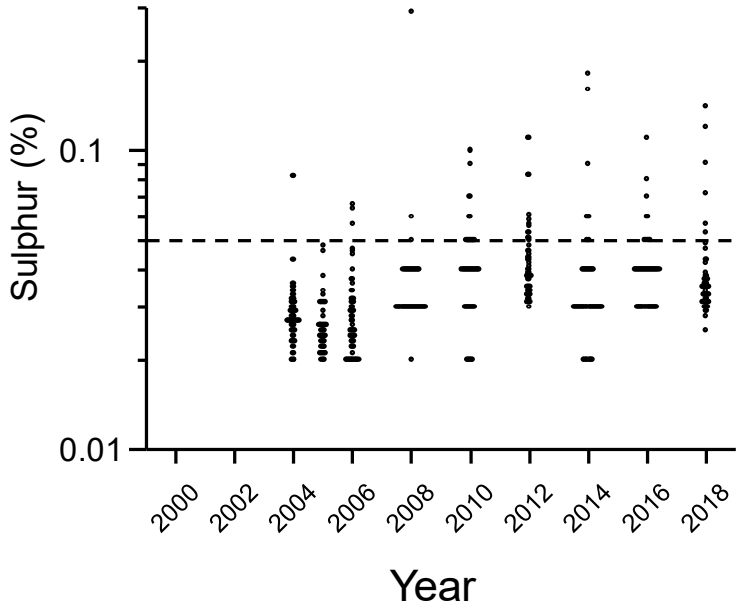


Figure 5-32 Dot Density Plot of Sulphur Concentrations by Year

Note: A concentration of 0.05% is indicated in each graph by a horizontal line, based on the mean values + 2 SDs for stations with a Min D greater than 10 km from 2004 to 2014 (n = 43).

5.2.1.8 Metals Other than Barium

Analysis of sediment chemistry data in previous years has demonstrated that metal concentrations co-vary (increase and decrease in concentration together). Rather than analyze the spatial-temporal variations of individual metals, one option, since the metals co-vary, is to produce a proxy variable that reflects the increasing and decreasing concentrations of metals. A PCA was carried out to produce a proxy 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 (*i.e.*, proxy 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 strongly 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 proxy 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 Component Loadings (Correlations) of Metals Concentrations

Variable	Principal Component	
	1	2
Aluminum	0.371	0.305
Chromium	**0.641**	0.170
Iron	**0.900**	0.254
Lead	**0.562**	**-0.744**
Manganese	**0.853**	0.36
Strontium	**0.668**	**-0.678**
Uranium	**0.681**	-0.090
Vanadium	**0.84**	0.208
Percent Variance Explained	50.2	17.2

Notes: - $|r| \geq 0.6$ in **bold.** $n = 52$, with Station 31 excluded.

Metals PC1

Metals PC1 scores were correlated with distance from the nearest active drill centre in 2018 when all stations were considered ($\rho_s = -0.298$, $p = 0.03$) but not when assessing repeated-measures stations ($\rho_s = -0.142$, $p > 0.05$; Figure 5-33). Despite the significant Spearman rank correlation when all stations were considered, the threshold model was not able to estimate a reliable threshold.

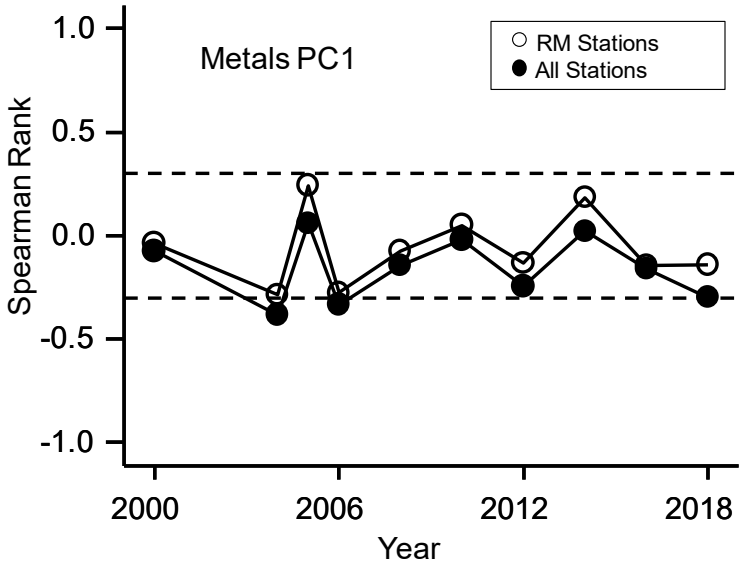


Figure 5-33 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Metals PC1

Notes: Station 31 was excluded. *n* = 52 for All Stations *n* = 35 for Repeated-Measures (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. Significance levels from statistical tests are reported in text.

Figure 5-34 provides a graphical representation of Metals PC1 scores with distance from active drill centres. Metals PC1 scores were above background average at two stations (Stations 20 and C5) adjacent to the Central Drill Centre (Figures 5-34 and 5-35).

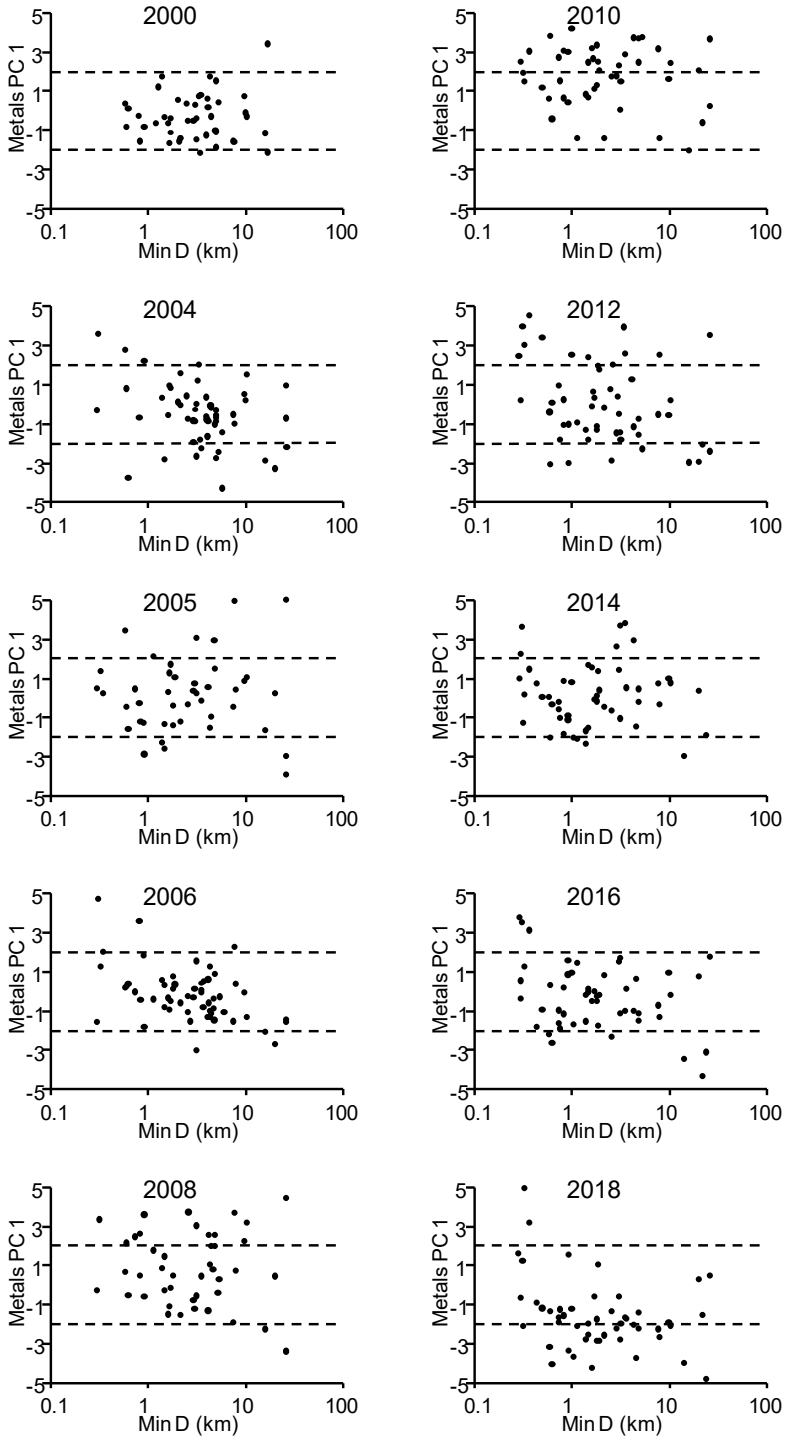


Figure 5-34 Variations in Metals PC1 Scores with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Background PC1 scores (-2.67 and 1.98) are indicated by a horizontal line, based on the mean values ± 2 SDs using data from 2000.

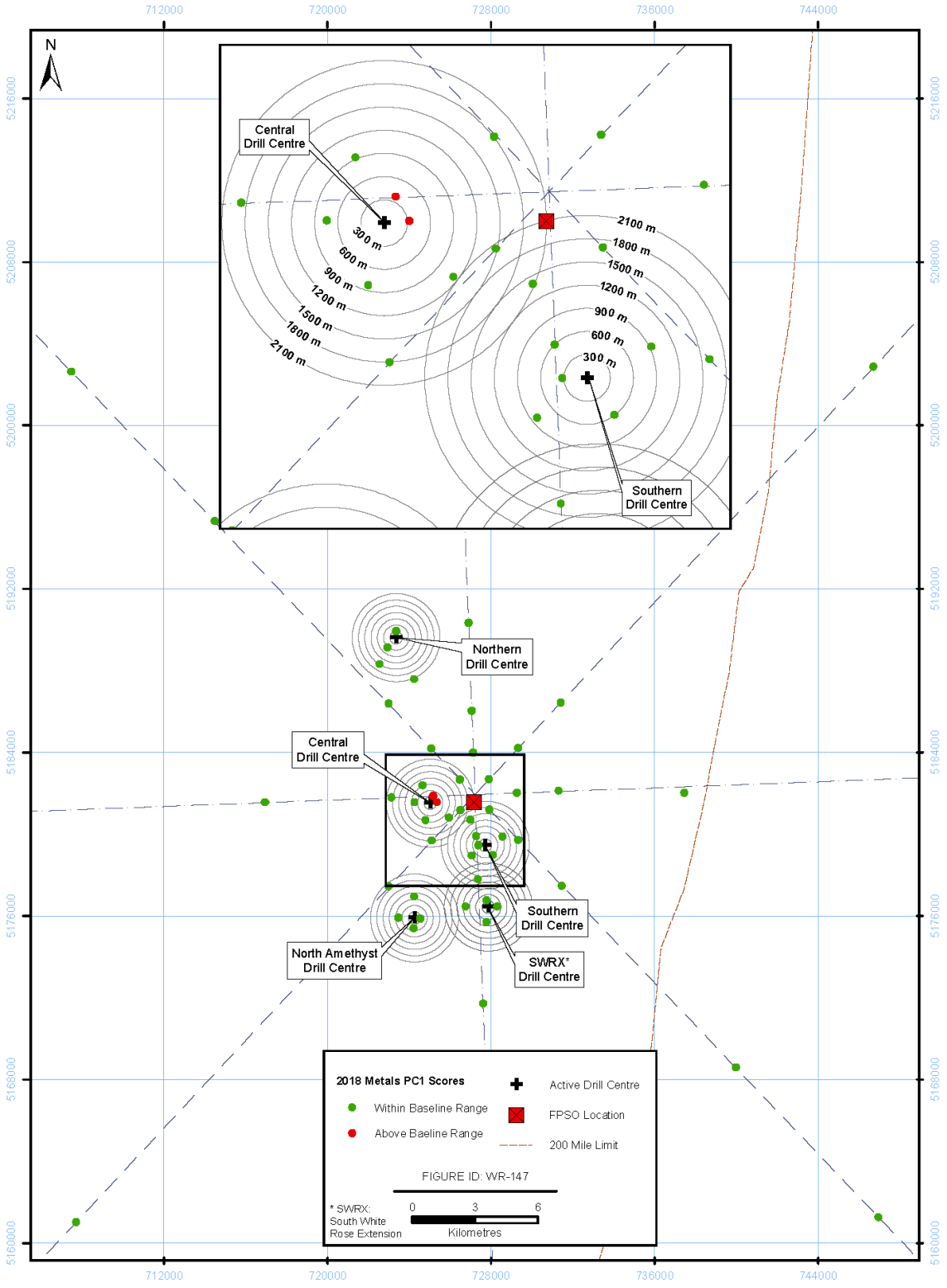


Figure 5-35 Location of Stations with Metals PC1 (2018) Within and Above the Baseline Range Map for Metals PC1

Station 31 is not shown in this figure because it was excluded from PCA.

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 in EEM years for repeated-measures stations (p = 0.193), and no change in slope from before to after drilling began (p = 0.389). There were significant variations in the average PC1 axis scores in the overall sampling area (p = 0.001) driven by the higher scores in 2008 and the lower scores in 2018 (Figure 5-36). However, no difference was noted from before drilling to after drilling began (p = 0.839).

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**
0.193	0.001	0.389	0.839

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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

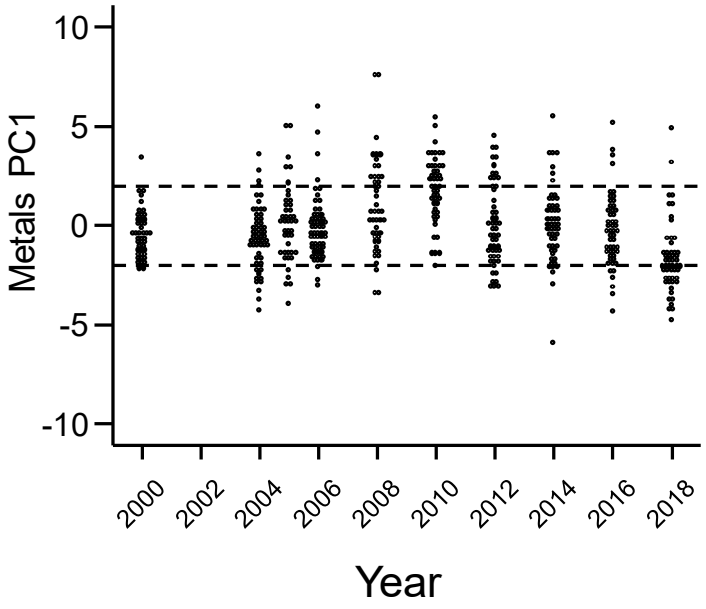


Figure 5-36 Dot Density Plot of Metals PC1 Scores by Year

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

The dot density graph of scores (Figure 5-36) illustrates that Metals PC1 scores in 2018 were generally below the baseline range of variation for scores in 2000.

Lead

Lead concentrations in sediments were negatively correlated with distance to the nearest active drill centre in 2018 (ρ_s = -0.517, p < 0.001, All stations; ρ_s = -0.376, p = 0.03, repeated measures stations) (Figure 5-37). A threshold distance explained significant variation in distance relationships from 2006 to 2018 (Figure 5-38; Appendix B-7), with threshold distances typically near 1 km (Table 5-16). In 2018, lead was enriched above the baseline range around the Central, North Amethyst and Southern Drill Centres (Figure 5-39).

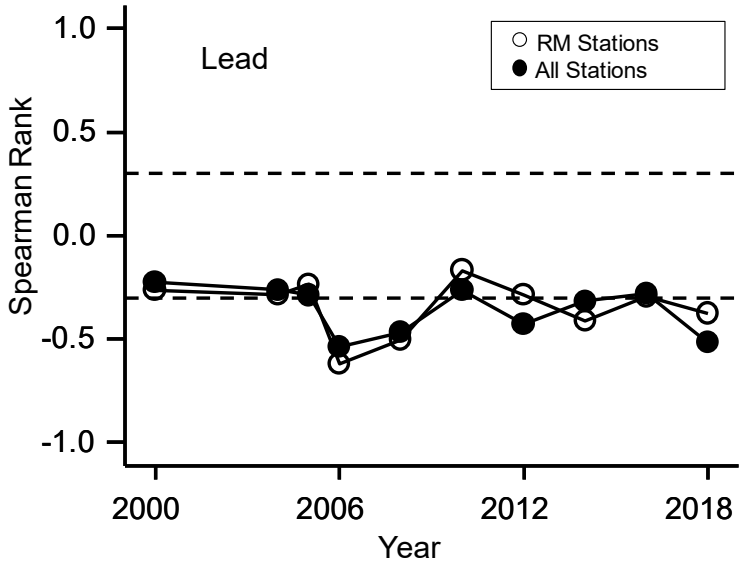


Figure 5-37 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Lead

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (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. Significance levels from specific statistical tests are reported in text.

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

Year	Threshold Distance (km)
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)
2014	0.6 (0.4, 1.0)
2016	1.4 (0.3, 6.1)
2018	0.84 (0.6, 1.2)

Notes: - 95% confidence limits are provided in brackets.
- n = 52 in 2018 with Station 31 excluded.

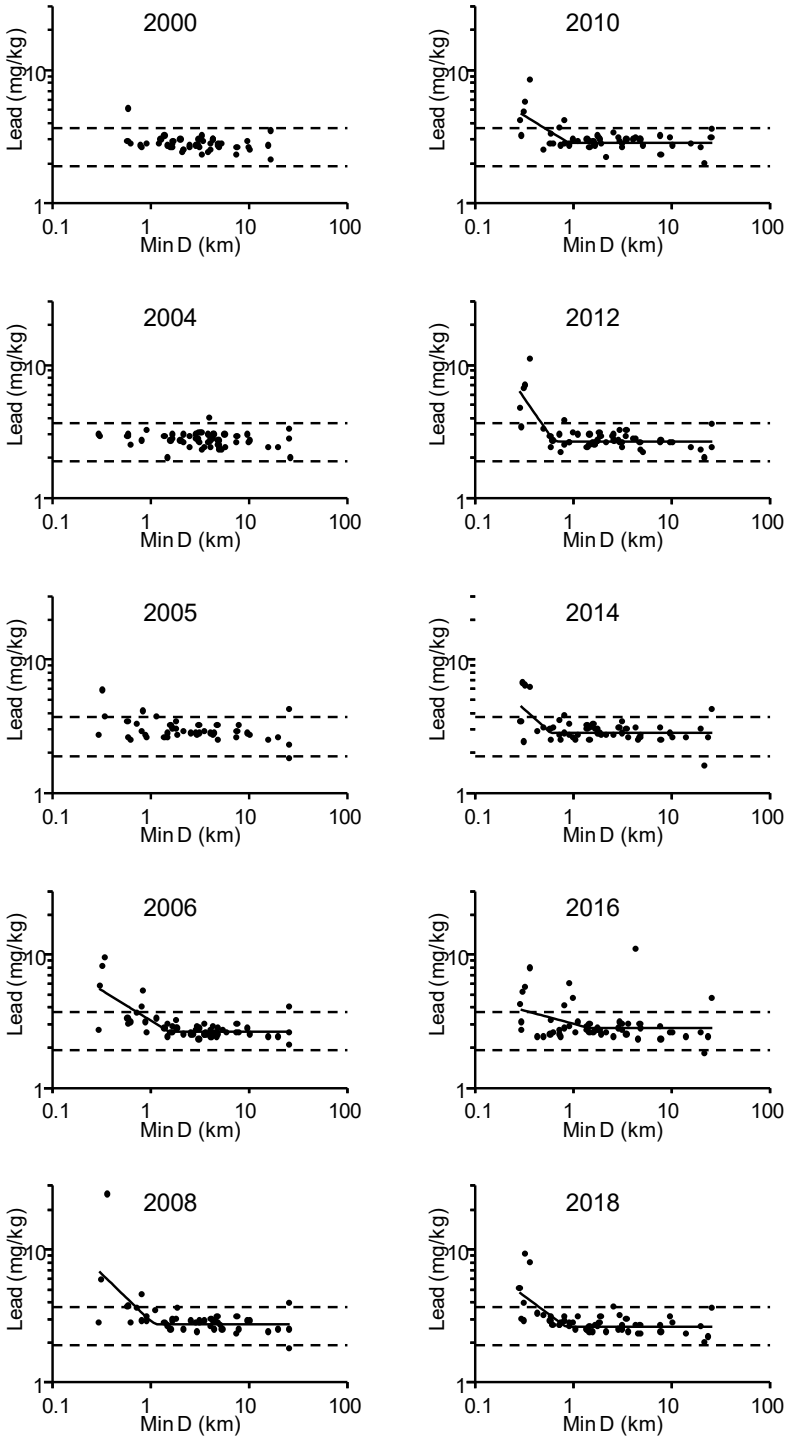


Figure 5-38 Variations in Lead with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Background concentrations of 2.1 and 3.7 mg/kg are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline), respectively. Here and in similar figures, threshold models are plotted when these were significant.

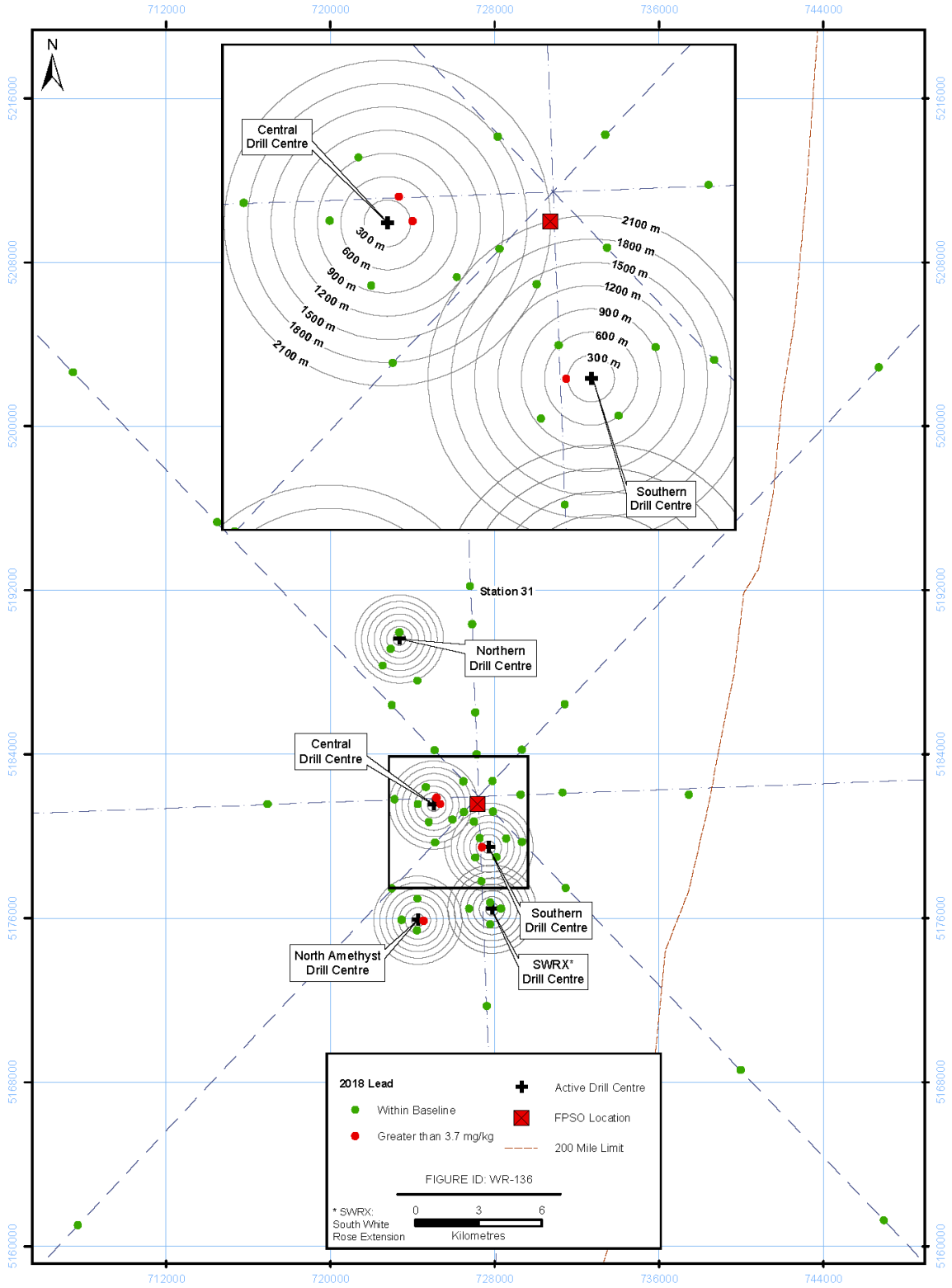


Figure 5-39 Location of Stations with Lead (2018) Within and Above the Baseline Range

Station 31 is identified in this figure because it was excluded from analyses.

Repeated-measures regression (Table 5-17) indicated that there was no change in the slope of the relationship between lead concentration in sediment and distance to the nearest active drill centre in EEM years for repeated-measures stations (p = 0.218), and no change in slope from before to after drilling began (p = 0.117). There was also no change in average lead concentration in the overall sampling area during active drilling (p = 0.243), but average lead concentration did vary significantly from before to after drilling began (p = 0.046). The central tendency for lead concentrations remained relatively similar from survey to survey but, in EEM years, there was a larger number of stations (near active drill centres) that had elevated concentrations of lead (Figures 5-38 and 5-40).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.218	0.243	0.117	0.046

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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

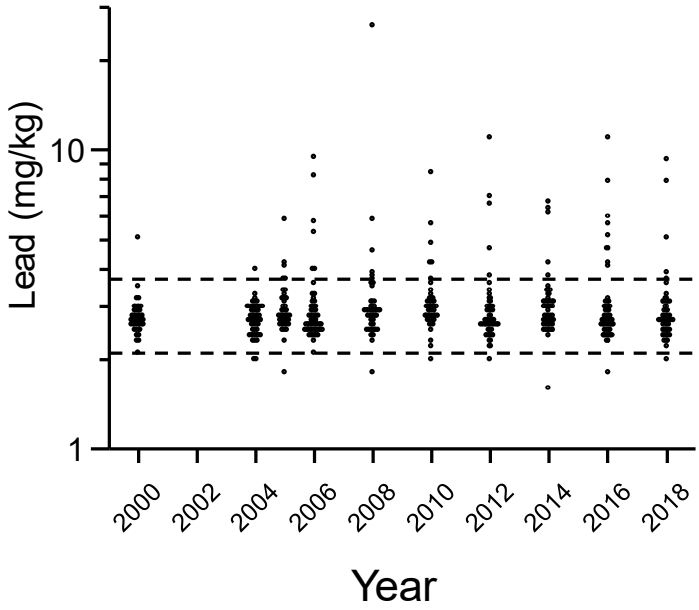


Figure 5-40 Dot Density Plot of Lead by Year

Note: Background concentrations of 2.1 and 3.7 mg/kg are indicated by the horizontal lines, based on the mean value ± 2 SDs using data from 2000.

Strontium

Strontium concentrations in sediments were significantly and negatively correlated with distance to the nearest active drill centre in 2018 (ρ_s = -0.515, p < 0.001, All stations; ρ_s = -0.443, p < 0.01, repeated-measures stations) (Figure 5-41). The threshold model in 2018 was significant (p < 0.001; Appendix B-7). Thresholds for strontium were also significant in 2006, 2008 and 2012, with threshold distances typically near 1 km (Table 5-18; Figure 5-42). In 2018, strontium was enriched above the baseline range around the Central, North Amethyst, SWRX, and Southern Drill Centres. Strontium was also enriched at Stations 30 and 31, and at Reference Station 4 (Figure 5-43).

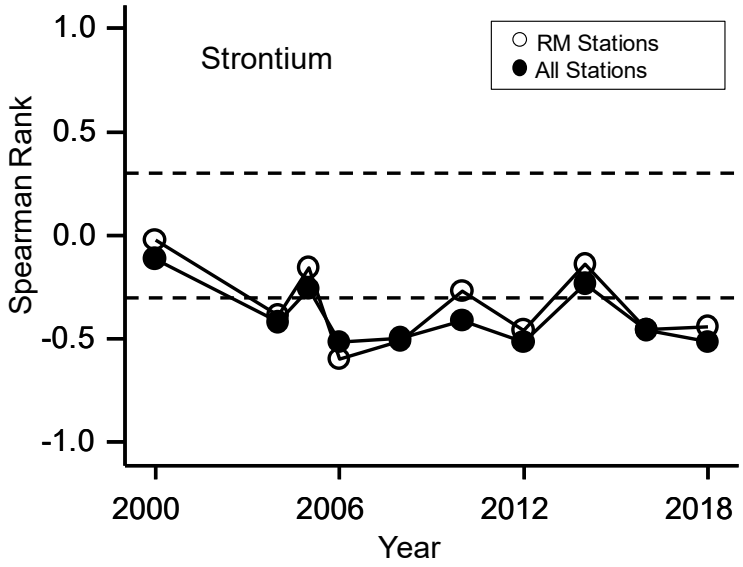


Figure 5-41 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Strontium

Notes: Station 31 was excluded. n = 52 for All Stations n = 35 for Repeated-Measures (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. Significance levels from specific statistical tests are reported in text.

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)
2014	No threshold
2016	No threshold
2018	0.8 (0.6, 1.1)

Notes:
- 95% confidence limits are provided in brackets.
- n = 52 in 2018 with Station 31 excluded.

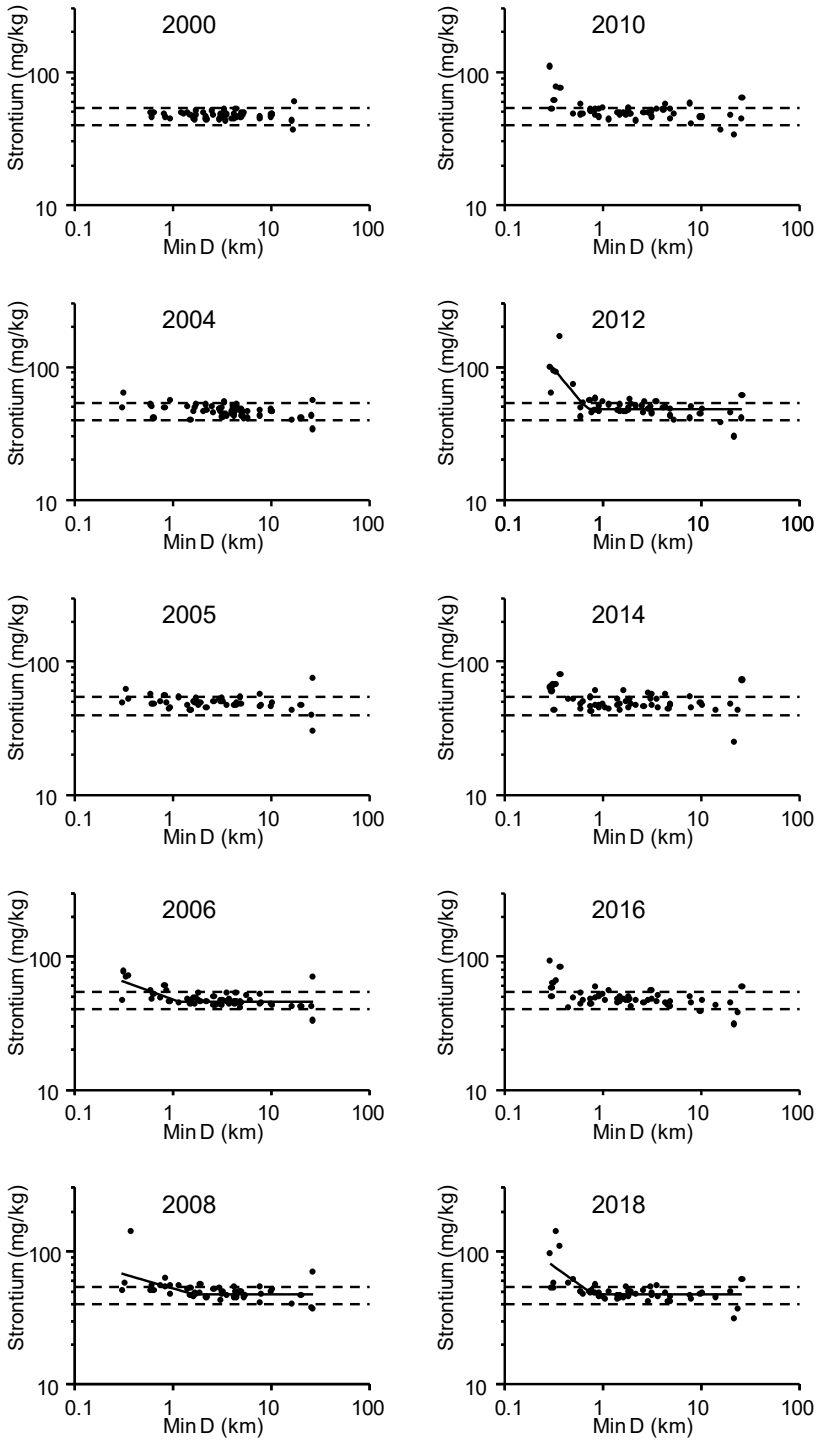


Figure 5-42 Variations in Strontium with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Background concentrations of 40 and 54 mg/kg are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline), respectively. Here and in similar figures, threshold models are plotted when these were significant.

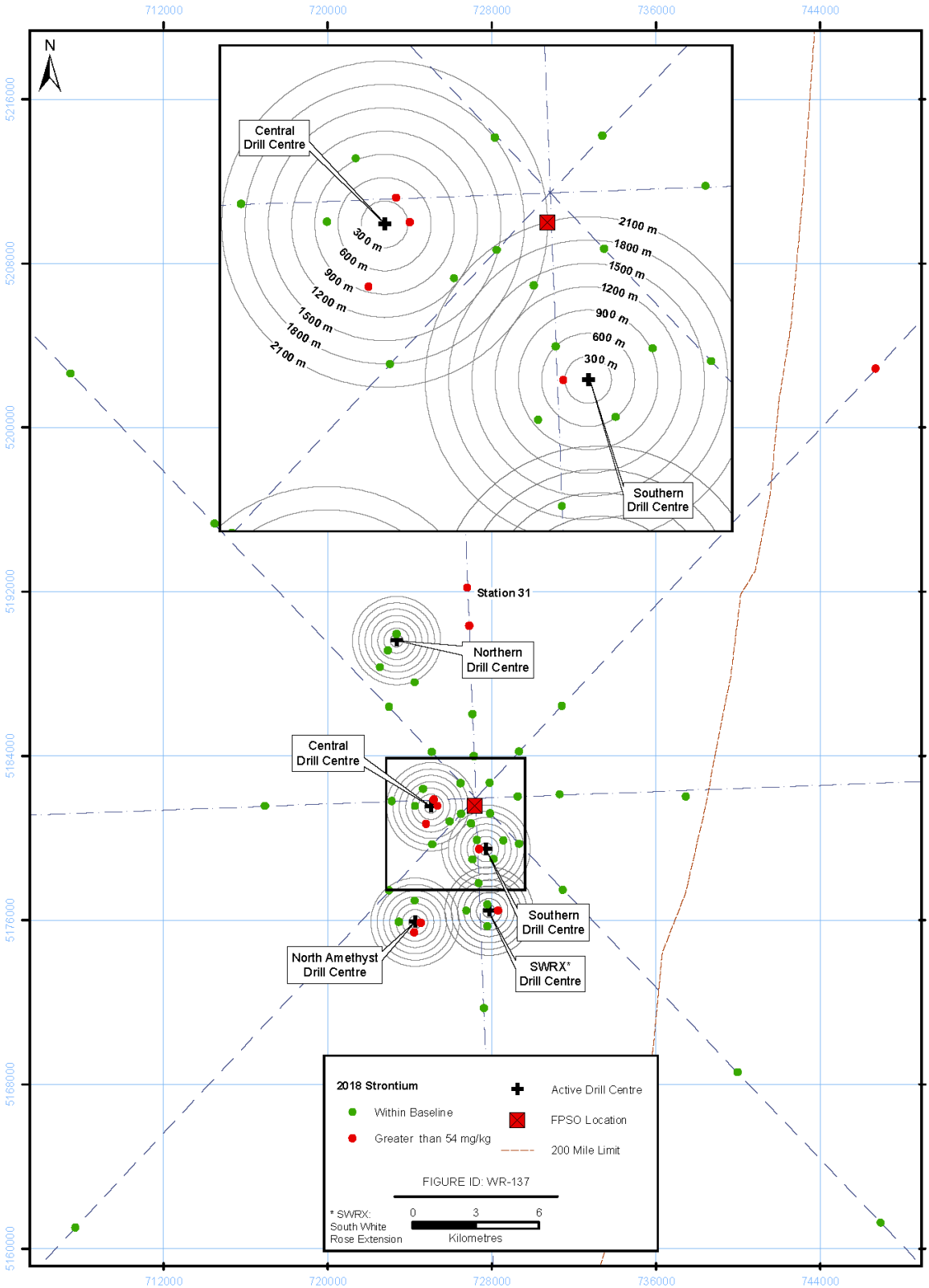


Figure 5-43 Location of Stations with Strontium (2018) Within and Above the Baseline Range

Station 31 is identified in this figure because it was excluded from analyses.

Repeated-measures regression (Table 5-19) indicated no change in the slope of the relationship between strontium concentration and distance to the nearest active drill centre in EEM years for repeated-measures stations (p = 0.075). However, slopes did vary significantly from before to after drilling (p = 0.009). Slopes were generally steeper in EEM years (*e.g.*, Figures 5-41 and 5-42). Overall strontium concentrations in the sampling area did not significantly vary in EEM years (p = 0.054, Figure 5-44), but strontium concentrations were generally higher in EEM years than in baseline (p = 0.001, Figure 5-44). Figure 5-44 illustrates that the central tendency for strontium concentrations remained similar from survey to survey but, in EEM years, there was a larger number of stations (near active drill centres) that had high concentrations of strontium (Figure 5-42).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.075	0.054	0.009	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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

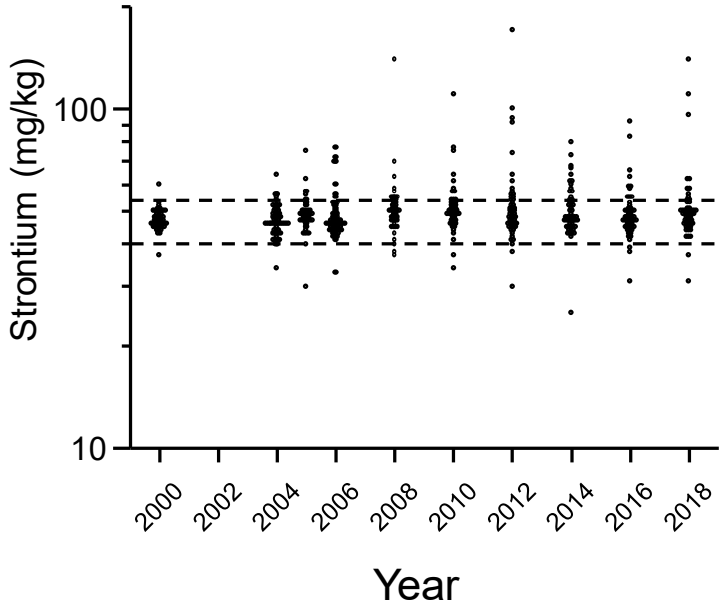


Figure 5-44 Dot Density Plot of Strontium by Year

Note: Background concentrations of 40 and 54 mg/kg 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 152 and 239 mV in 2018 and was not significantly correlated with distance from the nearest active drill centre (ρ_s = -0.003, p > 0.05, All stations; ρ_s = -0.020, p >0.05, repeated-measures stations) (Figure 5-45).

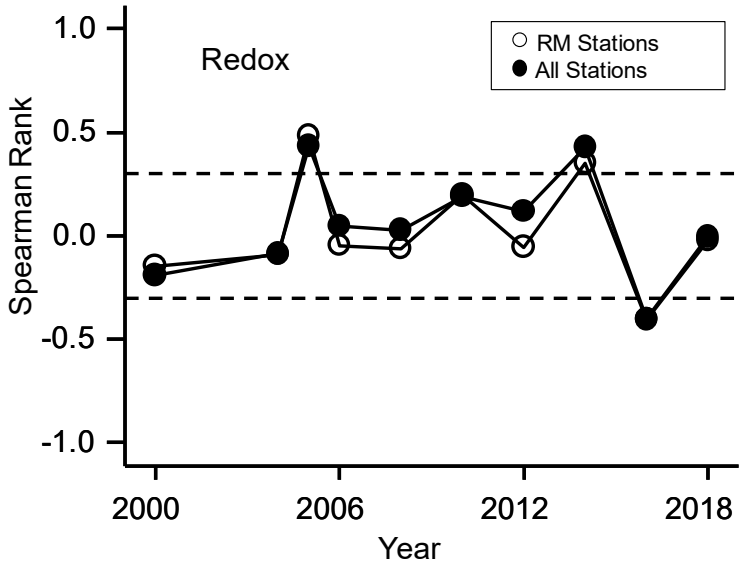


Figure 5-45 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Redox Potential

Notes: Station 31 was excluded. n = 52 for All Stations. n = 35 for Repeated-Measures (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. Significance levels from specific statistical tests are reported in text.

Figure 5-46 provides a graphical representation of redox levels with distance from active drill centres.

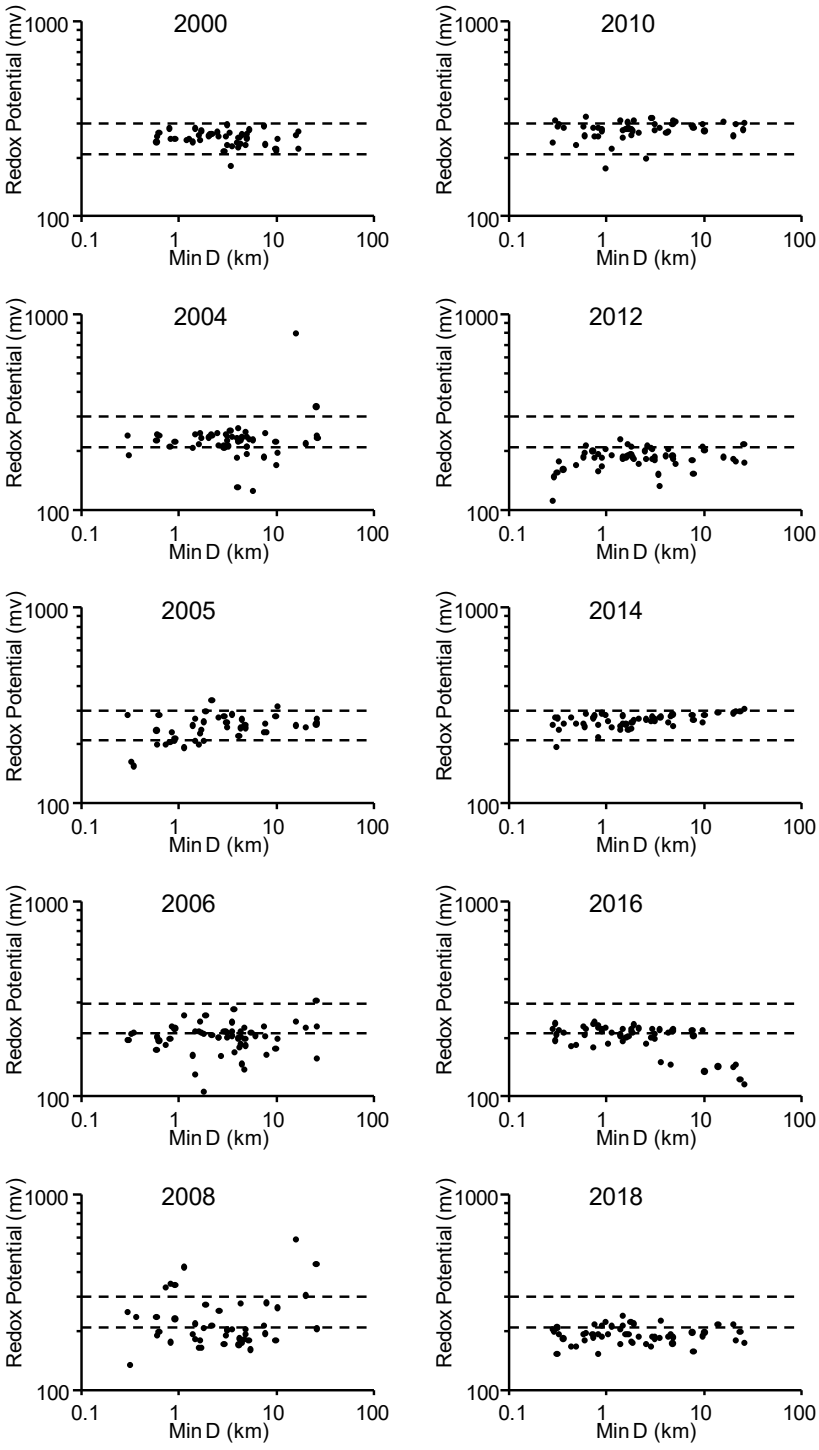


Figure 5-46 Variations in Redox Potential with Distance from the Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Background redox potential levels are indicated by a horizontal line, based on the mean values ± 2 SDs (209 and 299 mV) using data from 2000.

Repeated-measures regression (Table 5-20) demonstrated that the slope of the relationship between redox potential in sediment and distance to the nearest active drill centre varied in EEM years (p = 0.007; also see Figure 5-45); but there was no change in EEM years in mean redox potential across the sampling area (p = 0.149). However, there was a significant change in mean redox potential from before to after drilling (p < 0.001), with redox potential often lower in EEM years (Figure 5-47).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.007	0.149	0.813	<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 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

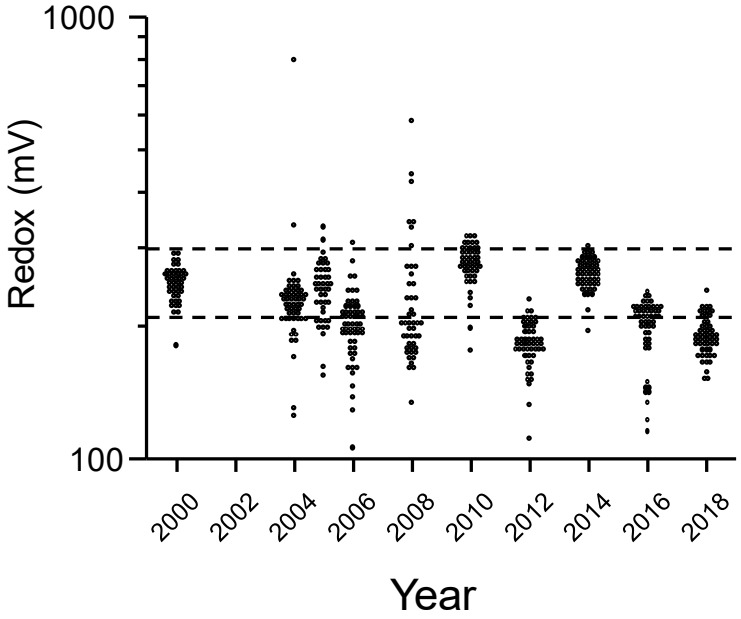


Figure 5-47 Dot Density Plot of Redox Potential by Year

Note: Background concentrations of 209 and 299 mV are indicated by the horizontal lines, based on the mean value ± 2 SDs using data from 2000.

The dot density graph illustrates that redox values were generally lower in 2018 than in the baseline year, and that 2018 levels were comparable to levels noted in 2012. Levels generally lower than baseline were also noted in 2006 and 2016. However, all sediments since baseline have been oxic (>100 mV).

5.2.2 Toxicity

In 2018, no samples were toxic to Microtox. Examination of sediment ammonia and sulphide levels, and sediment redox potential in the laboratory at the time of testing in 2018 indicated that these variables were within the tolerance and application limits for the Microtox test (Appendix B-5). In previous years, one sample was toxic to Microtox in 2010; three samples were toxic in 2014; and two samples were toxic to Microtox in 2016. Overall, sediments at White Rose generally have been non-toxic to Microtox.

One sediment sample (from Station S2) was considered toxic to laboratory amphipods in 2018 when compared to Reference sediments; but it was not toxic when compared to control sediments (Appendix B-4). Examination of sediment ammonia and sulphide levels as well as sediment redox potential in the laboratory at the time of testing in 2018 indicated that these variables were within the tolerance and application limits for the amphipod test.

Station S2 is located 0.8 km from the nearest active drill centre and 2018 chemistry data indicated that sediments at that station were above baseline concentrations for barium (280 mg/kg) and >C_{10}–C_{21} hydrocarbons (5.5 mg/kg). However, there were many stations with higher barium and >C_{10}-C_{21} hydrocarbon concentrations that were not toxic to amphipods; and no significant correlations were noted between percent amphipod survival and any sediment particle size or chemistry variable (all $p > 0.05$; Table 5-21).

Table 5-21 Spearman Rank Correlations (ρ_s) Between Amphipod Survival *versus* Distance from the Nearest Active Drill Centre and Sediment Physical and Chemical Characteristics (2018)

Variable	Spearman Rank Correlation (ρ_s) with Amphipod Survival
Distance from nearest active drill centre	0.148
>C_{10}–C_{21} hydrocarbons	0.011
Barium	-0.123
% Fines	-0.169
Organic Carbon	0.071
Ammonia	0.043
Sulphide	0.141
Sulphur	-0.153
Metals PC1	-0.024
Lead	-0.136
Strontium	0.025
Redox	0.063

Notes: - *$p \leq 0.05$; **$p \leq 0.01$.
- n = 52 in 2018 with Station 31 excluded.

In previous years, no sample was toxic to laboratory amphipods in 2000, 2004, 2010, and 2016. Sediments from three stations were toxic in 2006; sediments from eight stations were toxic in 2008; sediments from one station were toxic in 2012; and sediments from two stations were toxic in 2014. The 2018 data, and toxicity data from previous years, suggest little change over time. Overall, sediments at White Rose have been predominantly non-toxic to laboratory amphipods. Variation in amphipod survival was somewhat higher in 2005, 2006 and 2008, and was similar in 2018 to what was observed in 2000 (baseline), 2004, and from 2010 to 2016 (Figure 5-48).

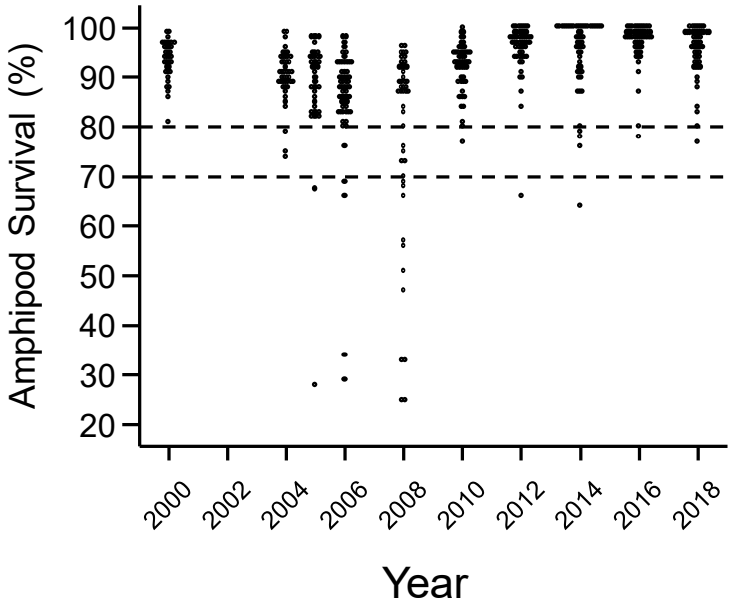


Figure 5-48 Dot Density Plot of Laboratory Amphipod Survival by Year

Note: The horizontal lines denote 70% and 80% survival. Values above 70% indicate a non-toxic response relative to control sediments. Values above 80% indicate a non-toxic response relative to Reference sediments.

5.2.3 Benthic Community Structure

5.2.3.1 General Composition

Raw data for benthic community structure in 2018 are provided in Appendix B-6. A total of 103 families were identified from 106 samples collected from 53 stations in 2018. As in prior years, Polychaeta were numerically dominant, accounting for 75% of total numbers, while Bivalvia (6%), Amphipoda (3%) and Tanaidacea (4%) were sub-dominant numerically, and Cnidaria, Gastropoda, Cumacea, Decapoda, Echinodermata, and Hemichordata were found in trace numbers (1% or less)[13].

[13] *n* = 52 in 2018 with Station 31 excluded.

5.2.3.2 Univariate Analyses

Total Abundance

In 2018, total abundance of all benthic invertebrates varied between approximately 1,100 organisms per m² to over 9,000 per m² across the sampling area. The relationship between total abundance and distance from the nearest active drill centre was not significant in 2018 (ρ_s = 0.032, p > 0.05, all stations; ρ_s = -0.329, p > 0.05, repeated-measures stations; Figure 5-49). Significant distance relationships for all stations were noted in 2005, 2006, 2008, 2012 and 2014 (Figure 5-49).

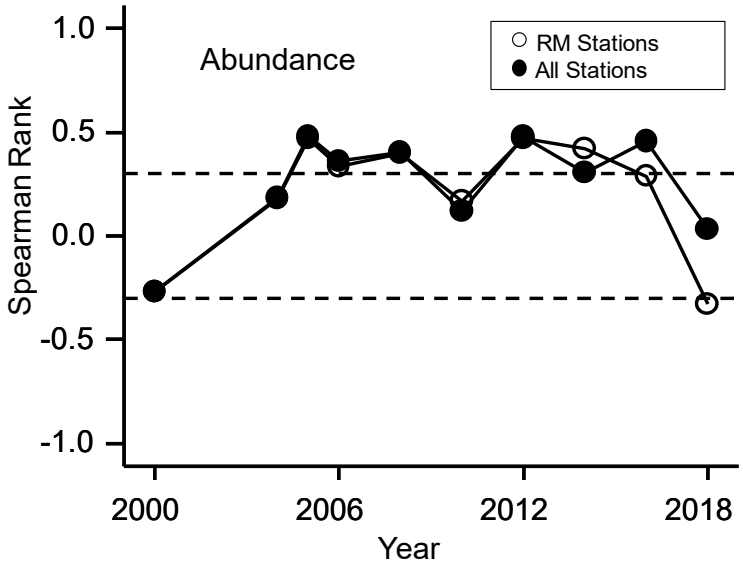


Figure 5-49 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Benthic Abundance

Notes: Station 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. Significance levels from specific statistical tests are reported in text.

The relationships between total abundance and distance to the nearest active drill centre since 2000 are illustrated in Figure 5-50. As indicated in the figure, 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 m². Those values were also used as “benchmarks” against which to judge spatial variations in the sampling area in 2018 (Figure 5-51), as well as variations over time (Figure 5-52).

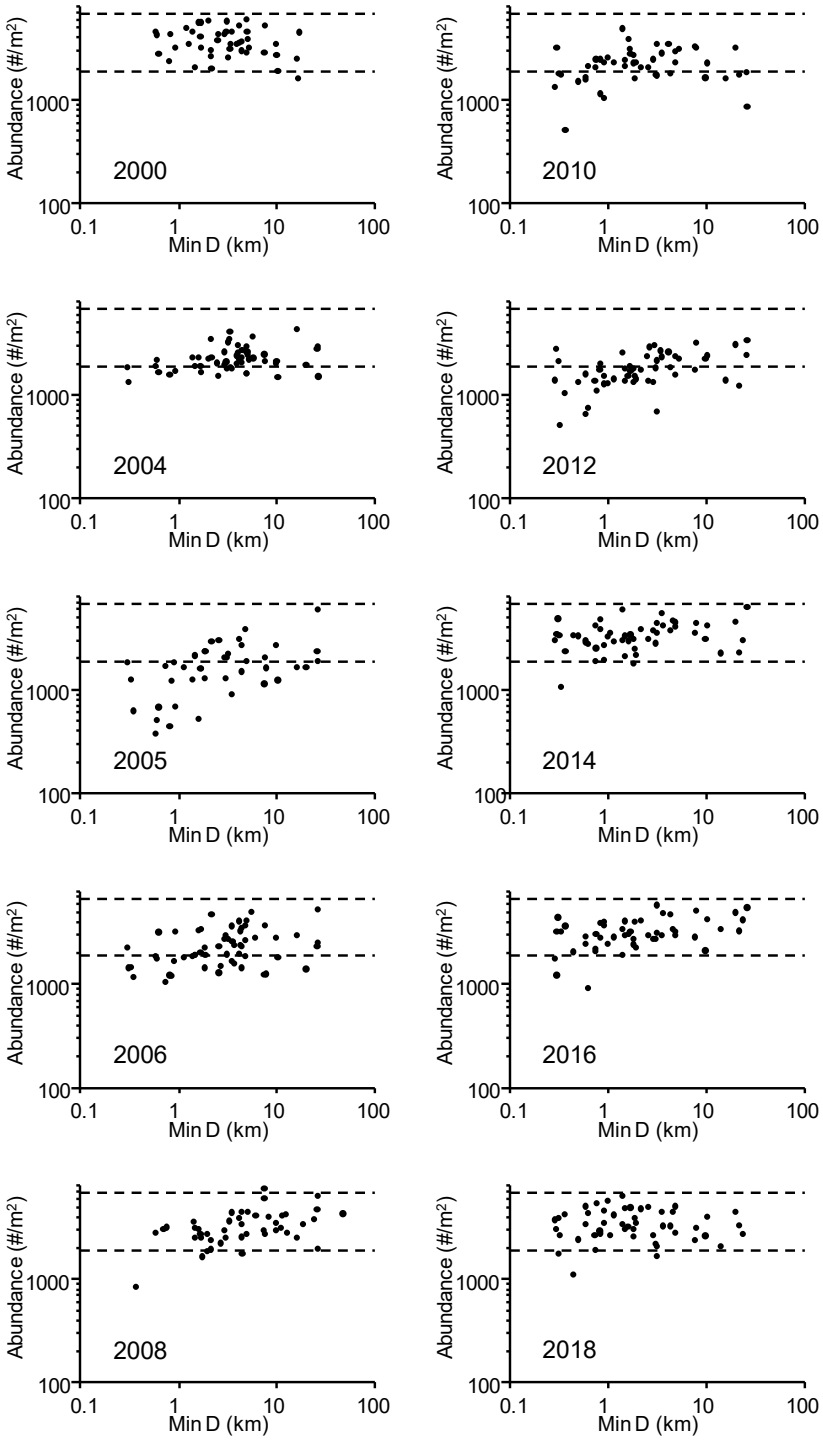


Figure 5-50 Variation in Total Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 1,885 and 6,776 individuals per m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

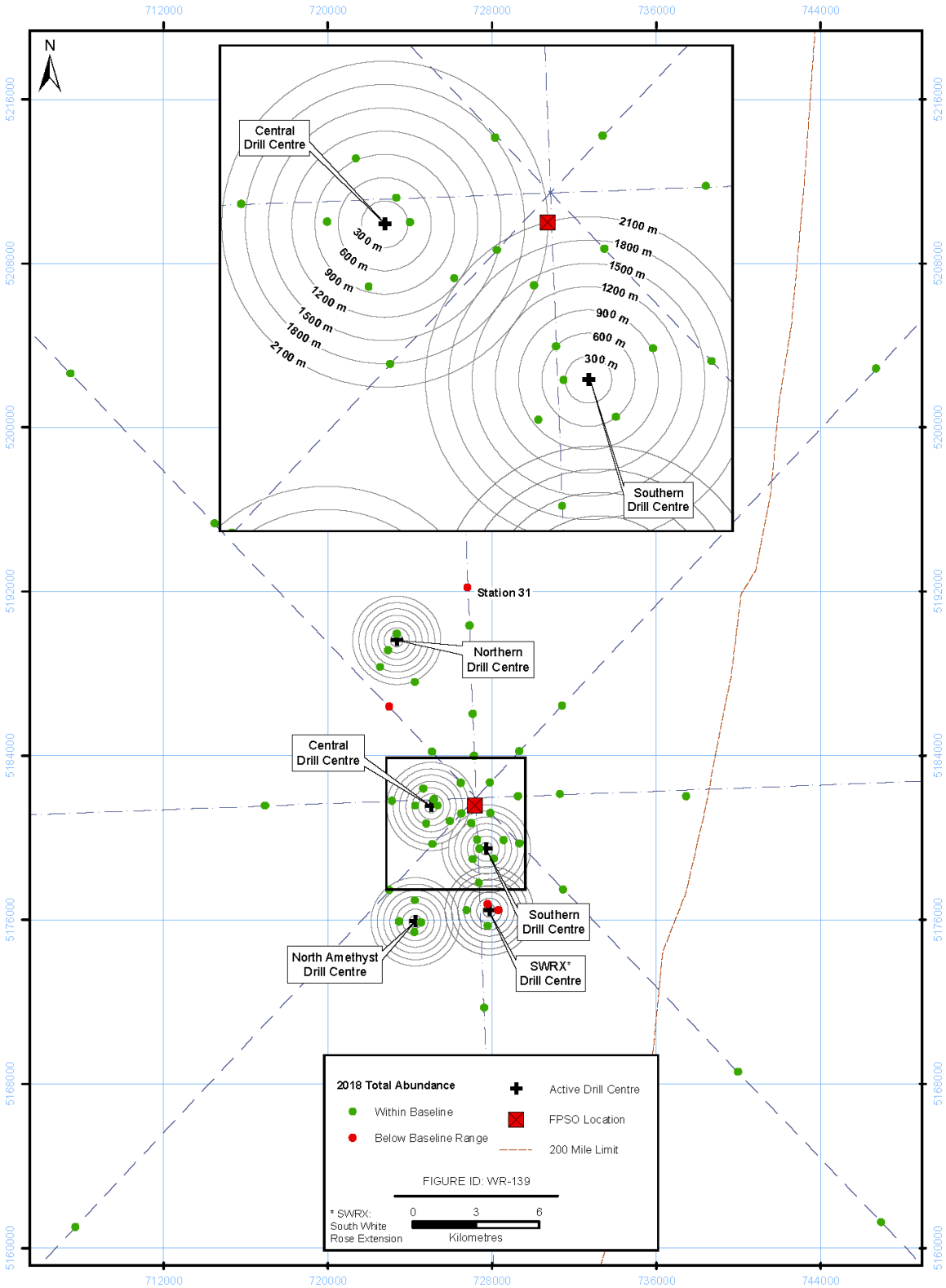


Figure 5-51 Location of Stations with Total Abundance Values Within and Below the Baseline Range (2018)

Station 31 is identified in this figure because it was excluded from analyses.

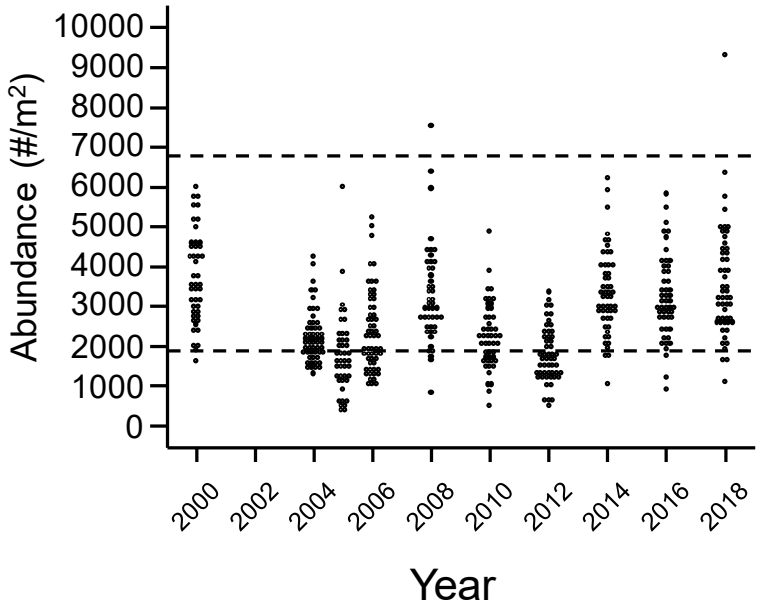


Figure 5-52 Dot Density Plot of Total Benthic Abundance by Year

Note: Values of 1,885 and 6,776 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

In 2018, two stations near the SWRX Drill Centre had abundance values lower than the baseline range (Figure 5-51). Abundance was also lower than the baseline range at Station 31 and at Station 25 (located 3.2 km south of the Northern Drill Centre).

Repeated-measures regression (Table 5-22) demonstrated that the relationship between abundance and distance from nearest active drill centre significantly varied over time in EEM years (p = 0.010) as well as from before to after drilling (p = 0.007). There was no distance trend before drilling; distance trends generally became positive, with lower abundance near drill centres after drilling began. However, that trend was more prominent in some EEM years, with distance relationships weak and not significant in 2018 (see Figure 5-49). There was also a decreasing trend in overall numbers in EEM years (p < 0.001) and between Before to After drilling (p = 0.012), although that trend reversed in 2014 with the abundance in almost all samples since 2014 at levels comparable to baseline (Figure 5-52). Overall, 2018 results for abundance generally are similar to those noted in baseline (see Figures 5-49, 5-50, and 5-52).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.010	<0.001	0.007	0.012

Notes:
- Values are probabilities.
- n = 35.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

Total Biomass

In 2018, total biomass varied from approximately 3.5 to 500 g/m² within 500 m of active drill centres and from approximately 50 to 600 g/m² at stations more than 10 km from drill centres. Variations in total biomass were significantly related to distance from active drill centres in 2018 for all stations (ρ_s = 0.389, p < 0.01) but not for repeated-measures stations (ρ_s = 0.269, p < 0.05, Figure 5-53). The data did not allow for precise estimation of a threshold (Appendix B-7). A threshold could be estimated for biomass in 2012 and 2014 (Figure 5-54).

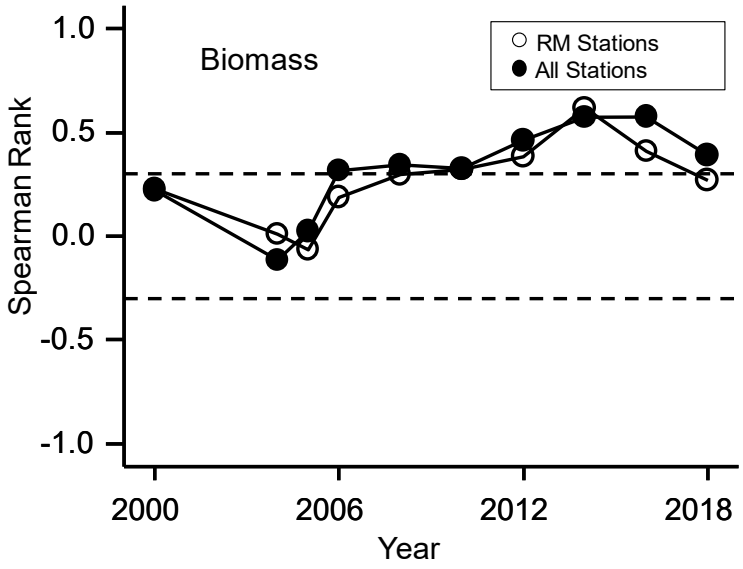


Figure 5-53 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Benthic Biomass

Notes: Station 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. Significance levels from specific statistical tests are reported in text.

As indicated in Figure 5-54, 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/m² in 2000 (*i.e.*, mean from year 2000 ± 2 SDs). Those values also were used to judge spatial variation in the sampling area in 2018 (Figure 5-55) and over time (Figure 5-54).

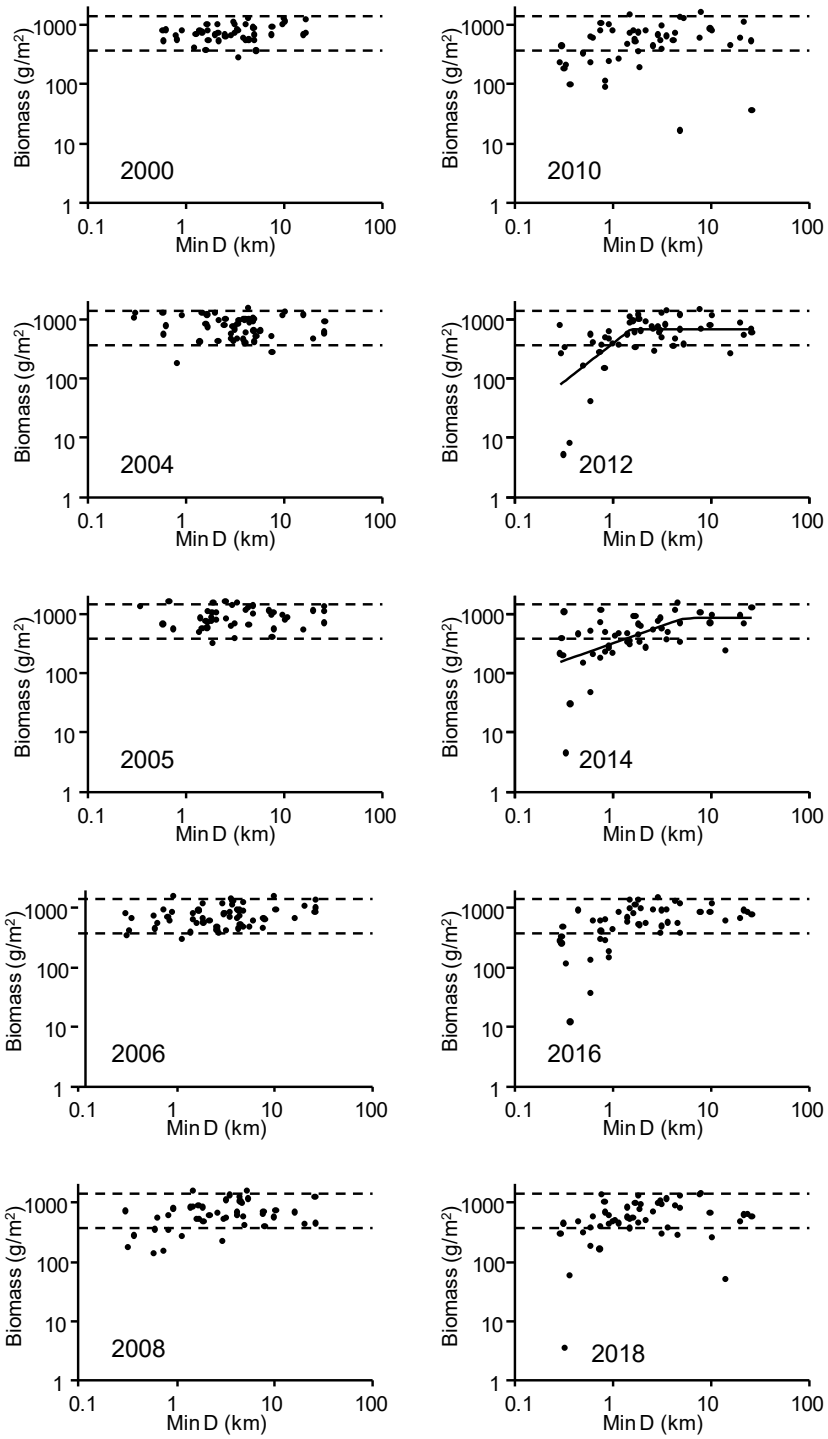


Figure 5-54 Variation in Total Benthic Biomass (g/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 367 and 1,400 g per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline), Here and in similar figures, threshold models are plotted when these were significant.

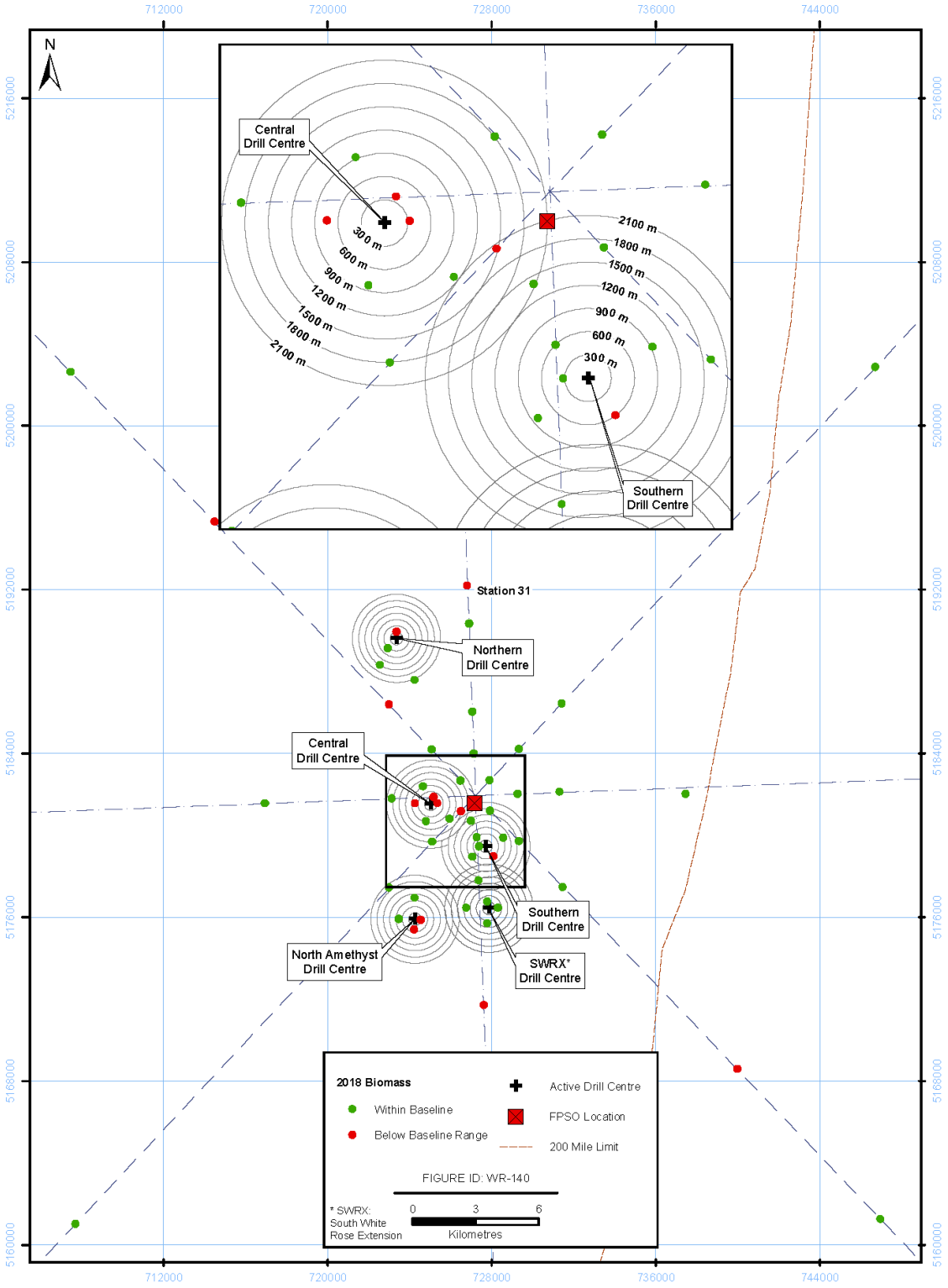


Figure 5-55 Location of Stations with Total Biomass Values Within and Below the Baseline Range (2018)

Station 31 is identified in this figure because it was excluded from analyses.

Biomass was below the baseline range near all drill centres except SWRX in 2018. Biomass was also below baseline range at a five more distant stations, including Station 31 (Figure 5-55).

Repeated-measures regression (Table 5-23) indicated that there was a significant linear trend over time in the slope of the distance relationship for biomass in EEM years for repeated-measures stations (p = 0.033). Slopes generally became increasingly positive over time (see Figure 5-53). There was also a significant difference in the slope of the relationship from before to after drilling (p = 0.046), with slopes more positive in EEM years than in baseline. Mean biomass was generally greater before drilling than during drilling (p = 0.001; Figure 5-56). Mean biomass also varied among EEM years (p = 0.001), with relatively higher biomass prior to 2008 within progressive declines since then (Figure 5-56).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.033	0.001	0.046	0.001

Notes:
- Values are probabilities.
- n = 35.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

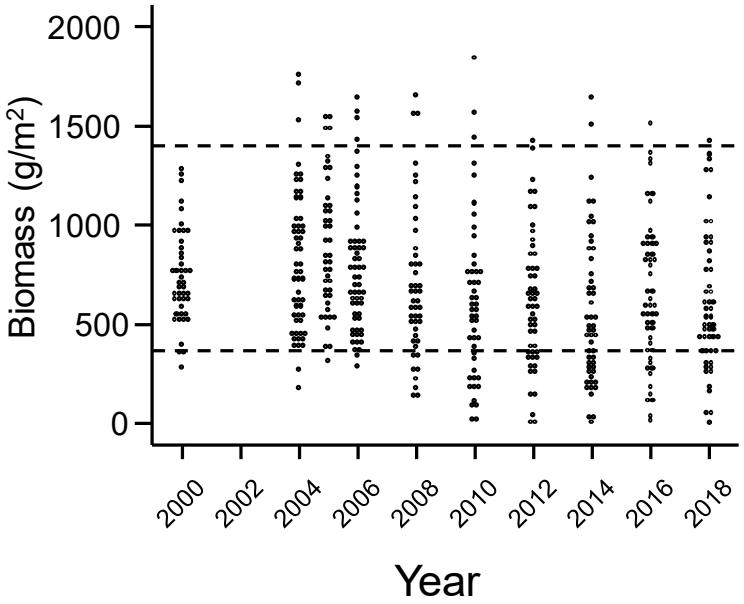


Figure 5-56 Dot Density Plot of Total Benthic Biomass by Year

Note: Values of 367 and 1,400 g per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

As indicated previous reports, reductions in biomass near drill centres are related, in part, to reductions in the number of larger echinoderms. In 2018, 14 stations with biomass below the baseline range also had reduced echinoderm abundance relative to remaining stations (mean = 7 at these 14 stations versus 35 echinoderms/m² at remaining stations). Of these 14 stations, the majority (11 of 14) were less than 2.2 km from the nearest drill centre. To date, the strongest effect on biomass occurred in 2014 (see Figure 5-53 with the highest Spearman rank correlation and Figure 5-56 with more values below the background range).

Richness

Number of families per station (*i.e.*, richness) varied between 19 and 44 in 2018, compared to the baseline range of between 22 and 38 families. Richness was not significantly correlated with distance to the nearest active drill centre in 2018 (ρ_s = 0.070, p > 0.05, All stations; ρ_s = -0.281, p > 0.05, repeated-measures stations), or in other years (Figure 5-57). Figure 5-58 provides graphical representations of the relationship between richness and distance to active drill centres. In 2018, richness was reduced to below the baseline range at Station 31 and at two stations near drill centres; one near Central drill centre and one near SWRX drill centre (Figure 5-59).

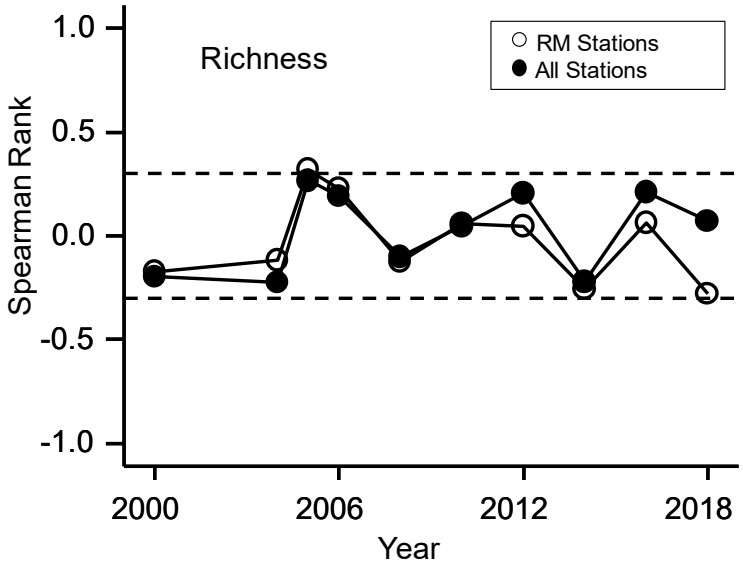


Figure 5-57 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Taxa Richness

Notes: Station 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. Significance levels from specific statistical tests are reported in text.

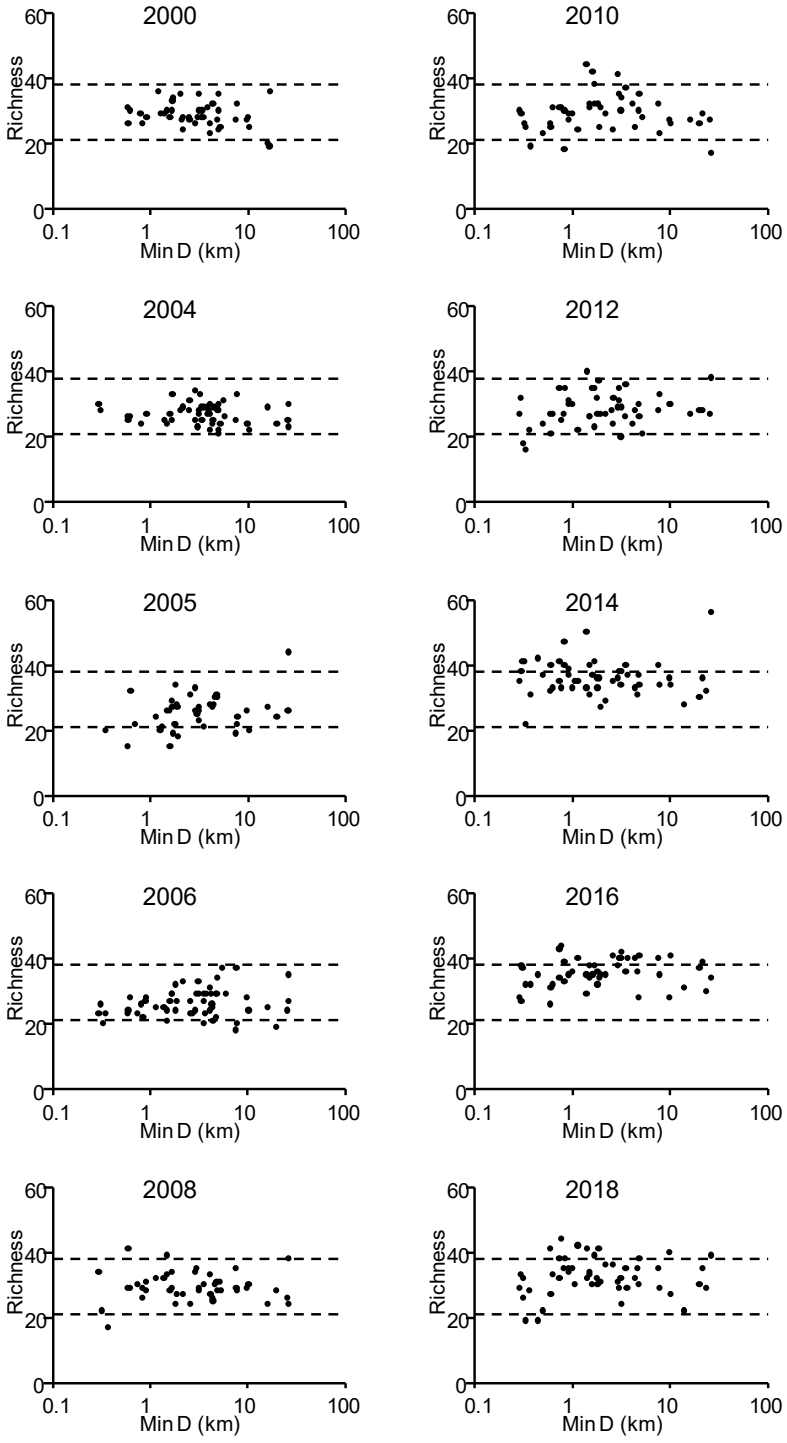


Figure 5-58 Variation in Taxa Richness with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values for number of families (22 and 38) are indicated by a horizontal line, based on the mean values ± 2 SDs using data from 2000.

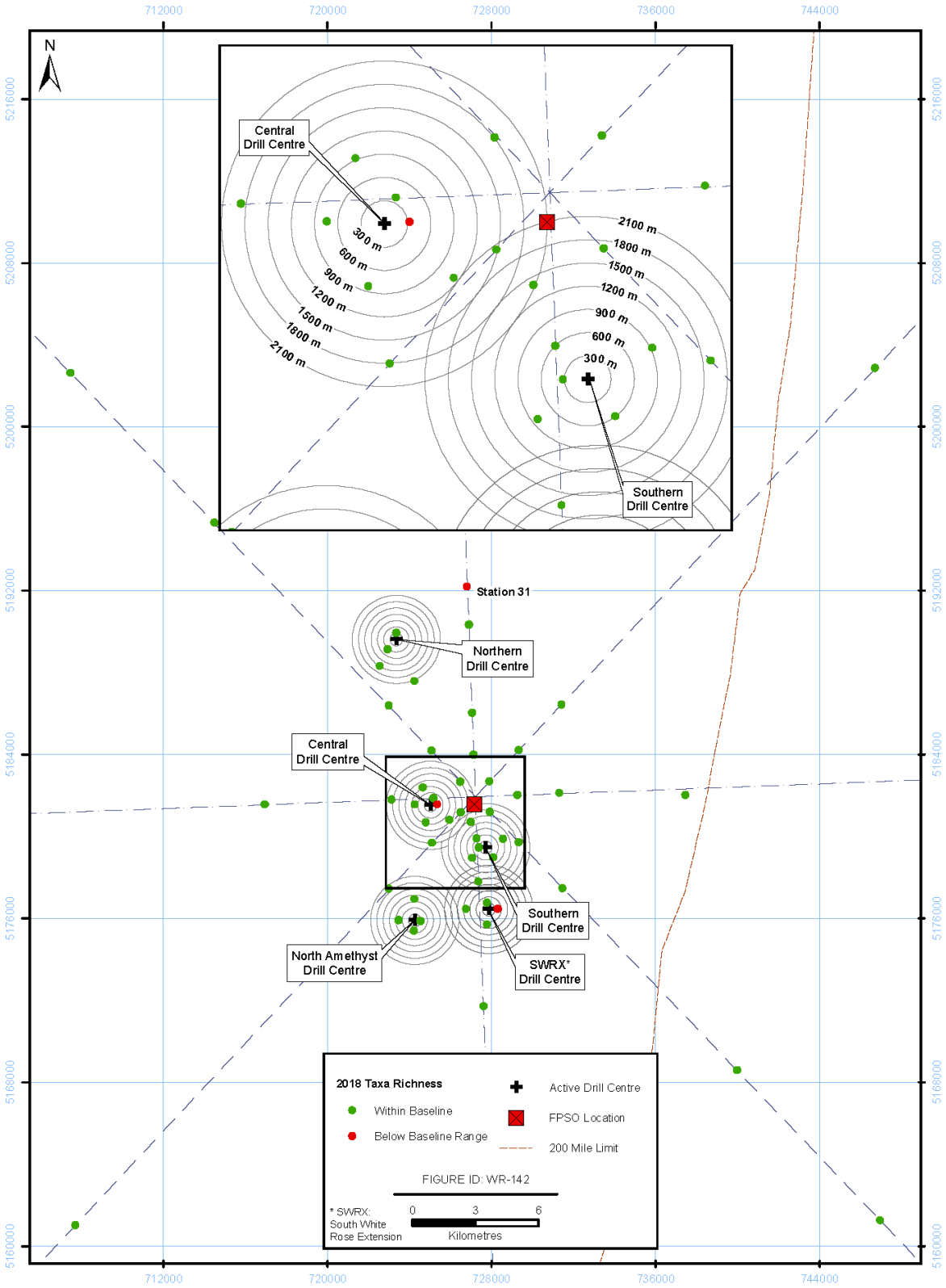


Figure 5-59 Location of Stations with Richness Values Within and Below the Baseline Range (2018)

Station 31 is identified in this figure because it was excluded from analyses.

Repeated-measures regression (Table 5-24) indicated that the slope of the relationship between number of families and distance from the nearest active drill centre has significantly varied over time in EEM years for repeated-measures stations (p = 0.030; see Figure 5-57). However, the relationship from before to after drilling has not changed significantly (p = 0.074). There was a significant trend in mean number of taxa in EEM years (p < 0.001), with richness generally increasing over time (Figure 5-60). Mean number of taxa did not differ significantly between EEM years and the baseline year (p = 0.530; Figure 5-60).

Table 5-24 Repeated-measures Regression Testing for Changes in Taxa Richness over Time

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.030	<0.001	0.074	0.530

Notes:
- Values are probabilities.
- n = 35.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

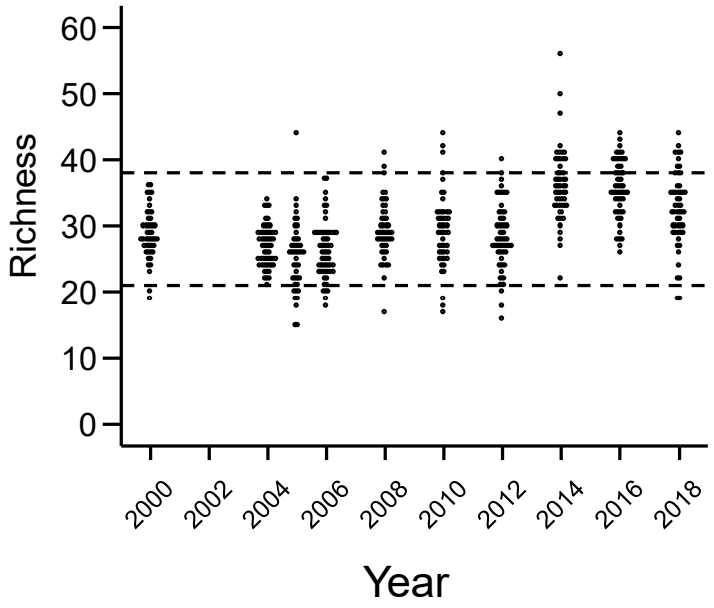


Figure 5-60 Dot Density Plot of Taxa Richness by Year

Note: Values for number of families (22 to 38) are indicated by horizontal lines, based on the mean values ± 2 SDs using data from 2000.

Results indicate that there has been no overall reduction in the number of taxa (richness) in the sampling area and, in fact, there has been a progressive increase in richness since 2005, with the greatest increase noted in the period from 2014 to 2018 (Figure 5-60).

Paraonidae Abundance

Paraonidae abundances have been strongly related to distance from active drill centres (Figure 5-61), with abundances lower near drill centres in most EEM years and in 2018 (ρ_s = 0.763, p < 0.001, All stations; ρ_s = 0.581, p < 0.001, repeated-measures stations). Threshold models were significant for Paraonidae abundance for all years from 2004 to 2018 (Table 5-25). Threshold distances have been somewhat variable (1.2 km in 2016 to 4.1 km in 2004) but confidence limits have generally overlapped (Table 5-25).

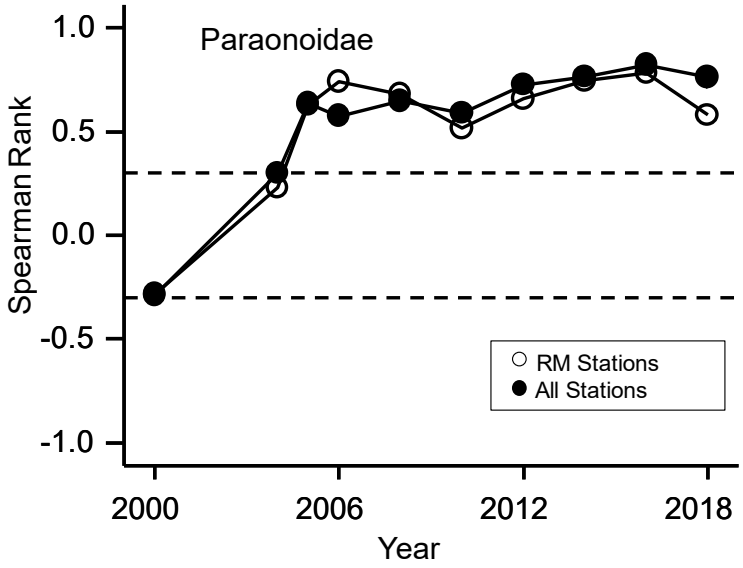


Figure 5-61 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Paraonidae Abundances

Notes: Station 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. Significance levels from specific statistical tests are reported in text.

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

Year	Threshold Distance (km)
2004	4.1 (2.0 to 8.6)
2005	2.6 (1.5 to 4.5)
2006	2.8 (1.9 to 4.2)
2008	3.8 (2.1 to 6.9)
2010	1.6 (1.0 to 2.7)
2012	2.5 (1.5, 4.3)
2014	1.5 (0.5 to 3.0)
2016	1.2 (0.6 to 2.1)
2018	1.6 (1.3 to 2.1)

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

Figure 5-62 provides a graphical representation of the relationship between Paraonidae abundance and distance to active drill centres. As indicated in the figure, the “normal range” of variation for Paraonidae abundance across the sampling area was computed from the 2000 baseline data. Values ranged from 130 to 1,671 per m² in 2000. The lower range of 130 individuals per m² was used as a “benchmark” against which to judge spatial variations in the sampling area in 2018 (Figure 5-63) as well as variations over time (Figure 5-64).

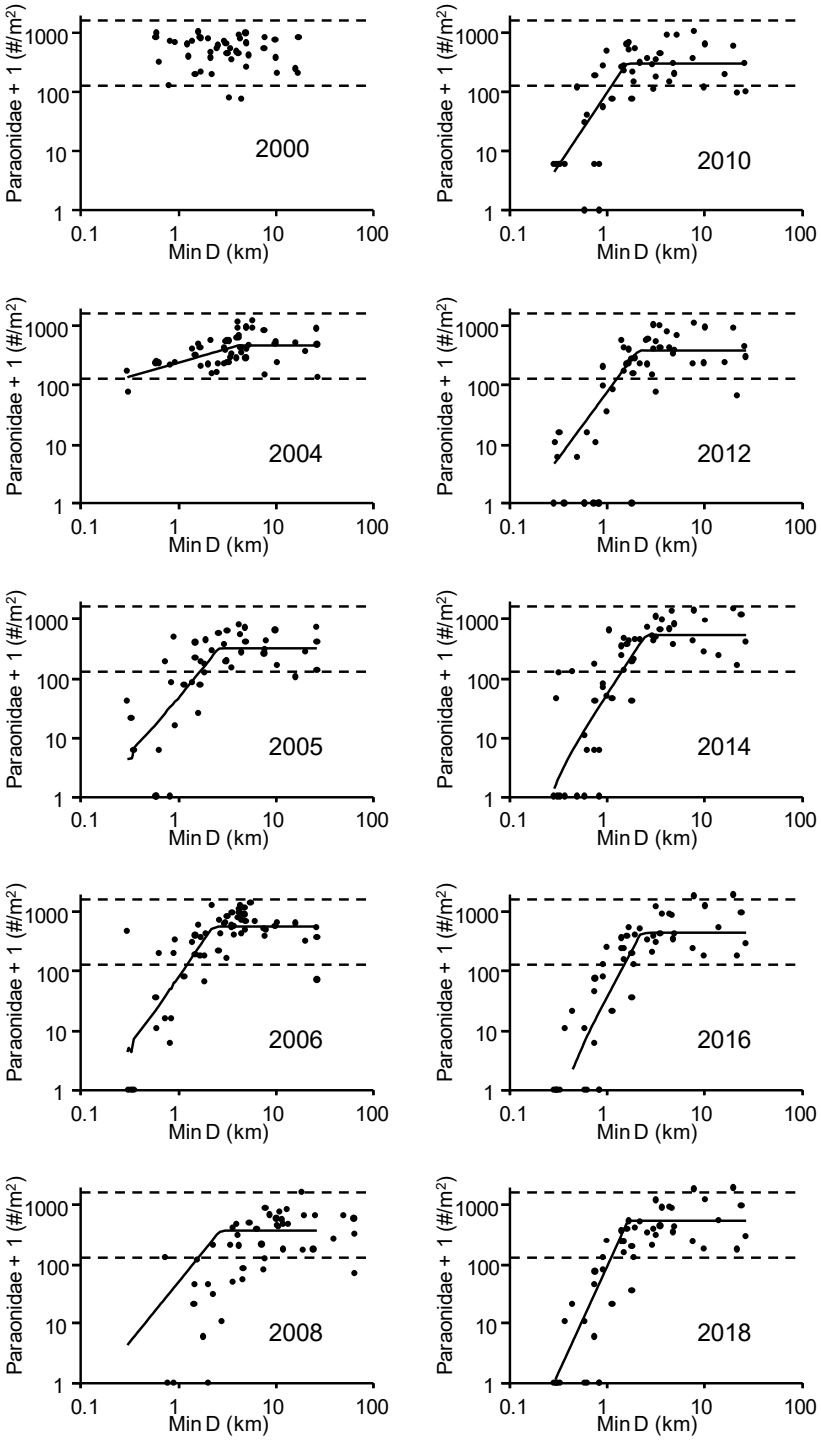


Figure 5-62 Variation in Paraonidae Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 130 and 1,671 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline). One (1) was added to all Paraonidae abundances because some abundances were zero and that value cannot be plotted on a log scale. Here and in similar figures, threshold models are plotted when these were significant.

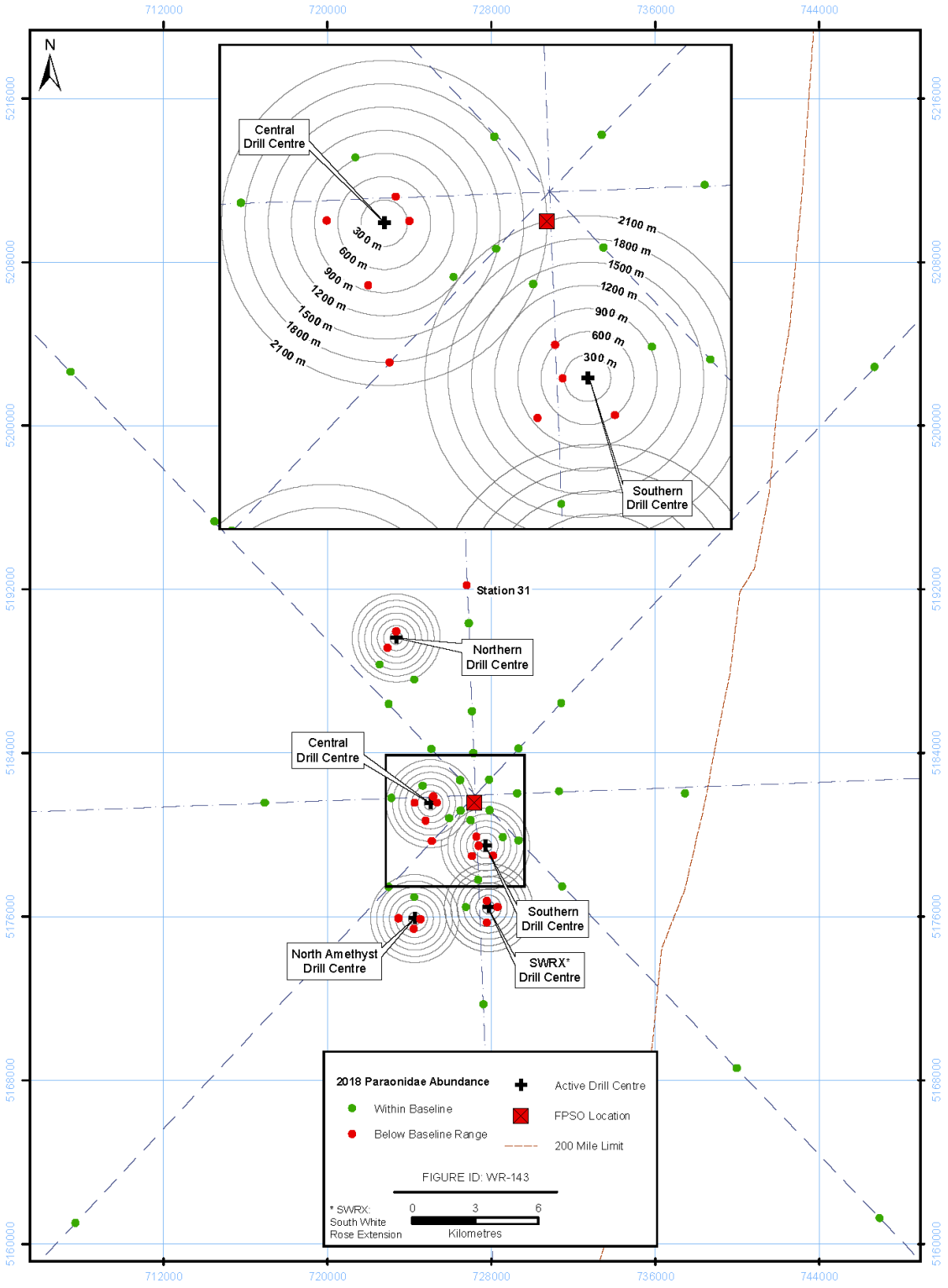


Figure 5-63 Location of Stations with Paraonidae Abundance Values Within and Below the Baseline Range (2018)

Station 31 is identified in this figure because it was excluded from analyses.

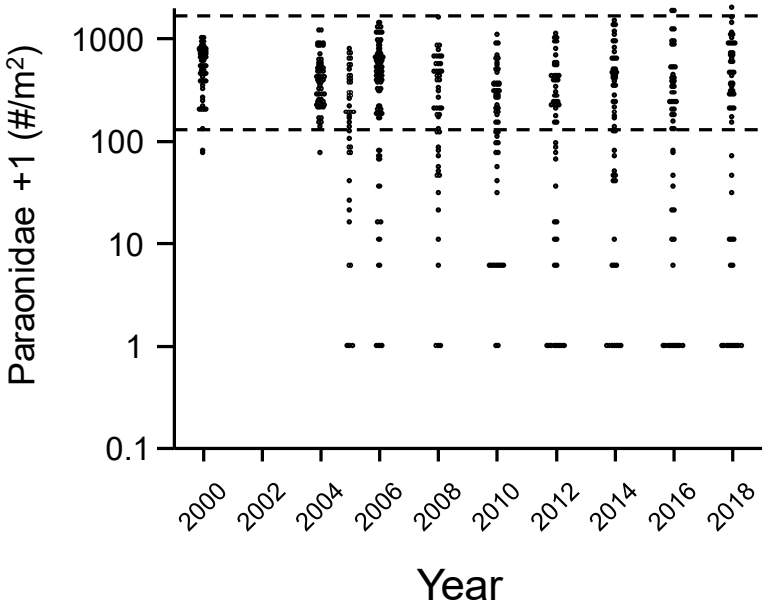


Figure 5-64 Dot Density Plot of Paraonidae Abundance by Year

Note: Values of 130 and 1,671 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

Paraonidae abundances were reduced at several stations around all drill centres in 2018 (Figure 5-63). Paraonidae abundances were also reduced at Station 31.

Repeated-measures regression (Table 5-26) indicated there was a significant linear trend over time in the slope of the relationship between distance and Paraonidae abundance in EEM years for repeated-measures stations (increase in the slope, $p < 0.001$; also see Figure 5-61). There was also a difference in the slope from before to after drilling (higher slope in EEM years, $p < 0.001$); a linear decrease over time in mean Paraonidae abundances in EEM years ($p < 0.001$); and overall lower numbers of Paraonidae from before to after drilling ($p < 0.001$), with effects caused by the low abundances near active drill centres (*e.g.*, Figure 5-62).

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

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

Notes:
- Values are probabilities.
- $n = 35$.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

Spionidae Abundance

Spionidae abundances varied between 185 and 2,140 individuals per m², averaging just over 970 per m² in 2018. Variation in abundances of Spionidae polychaetes in 2018 was not significantly correlated with distance to the nearest active drill centre (ρ_s = -0.135, p > 0.05, All stations; ρ_s = -0.308, p > 0.05, repeated-measures stations) (Figure 5-65). Figure 5-66 provides a graphical representation of the relationship between Spionidae abundance and distance to active drill centres.

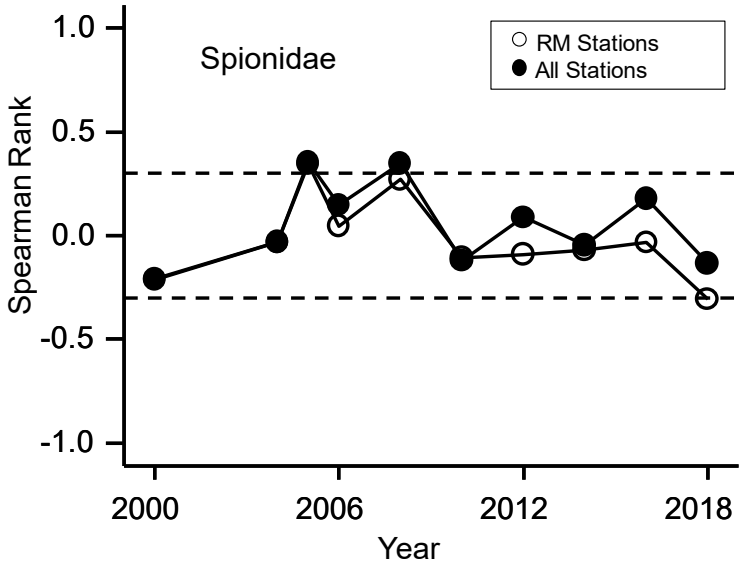


Figure 5-65 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Spionidae Abundances

Notes: Station 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. Significance levels from specific statistical tests are reported in text.

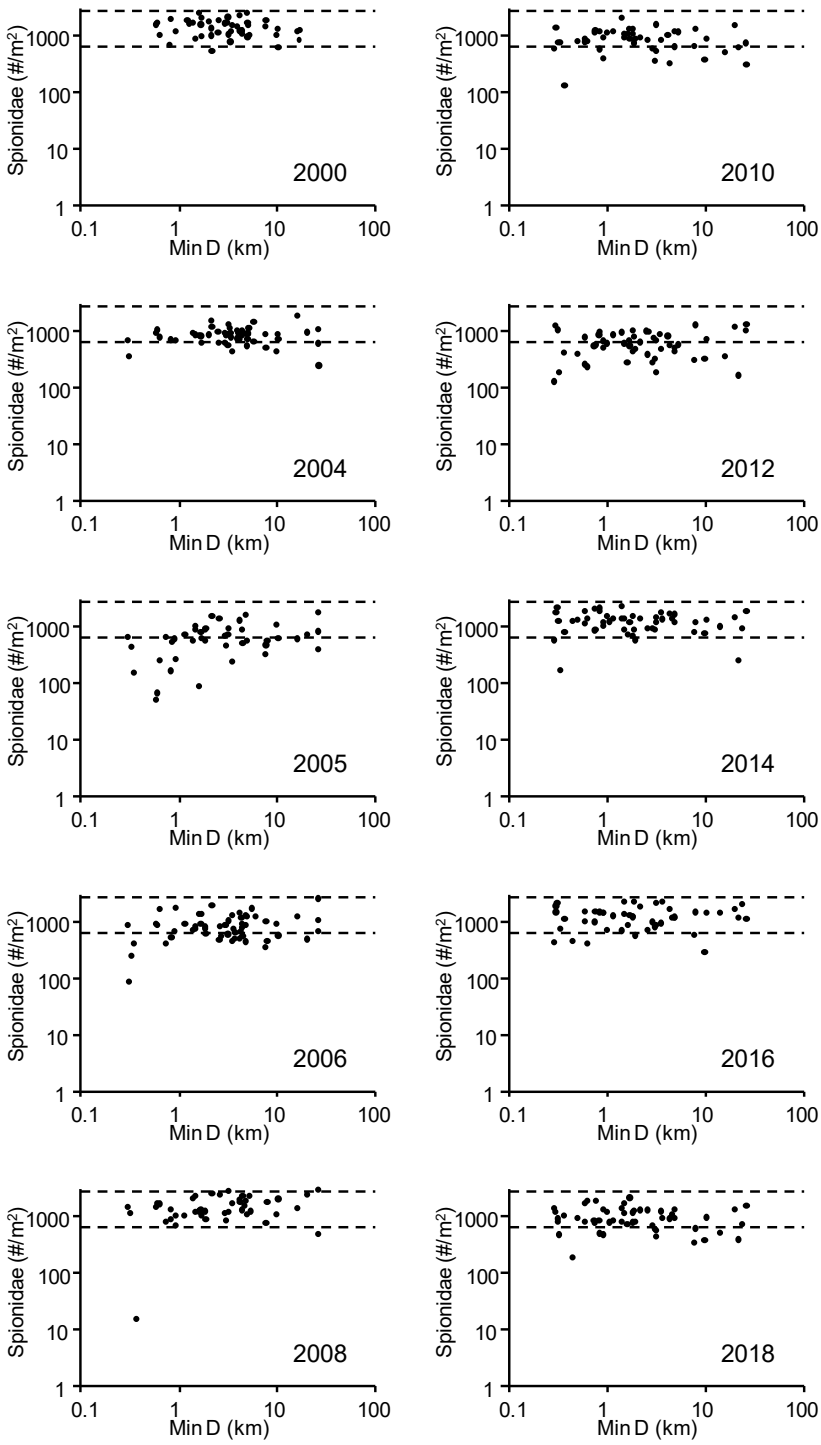


Figure 5-66 Variation in Spionidae Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 640 and 2,700 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

Repeated-measures regression (Table 5-27) indicated a significant change in the slope of the relationship between Spionidae abundance and distance from the nearest active drill centre in EEM years for repeated-measured stations ($p < 0.001$), yet no difference in slope from before to after active drilling operations ($p = 0.374$). Slopes in earlier EEM years were more positive; slopes since 2010 have been similar to baseline (*e.g.*, Figure 5-65). There was no difference in mean Spionidae abundance across the sampling area from before to after active drilling ($p = 0.103$; Figure 5-67). In contrast, reduced abundances in 2005, 2010 and 2012 combined with the relative increase in abundances in since 2014 were likely the drivers for the significant difference in mean abundances in EEM years ($p < 0.001$; see Figure 5-67).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
<0.001	<0.001	0.374	0.103

Notes:
- Values are probabilities.
- $n = 35$.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

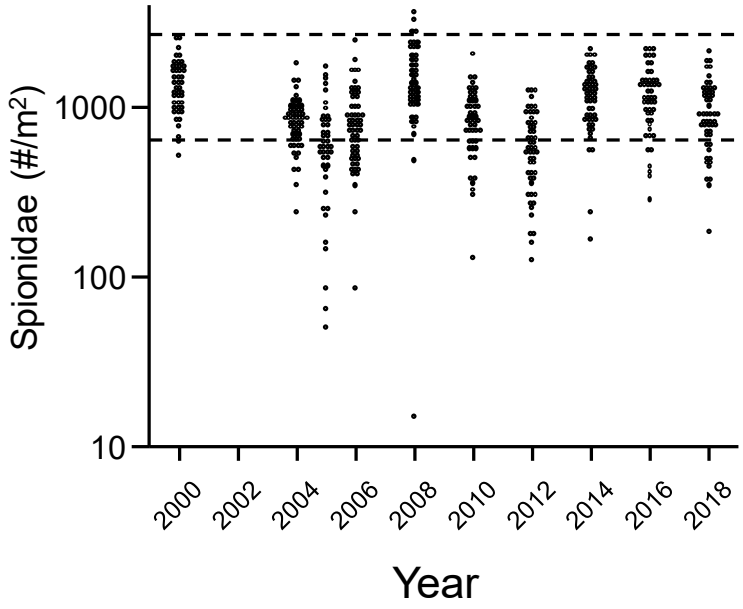


Figure 5-67 Dot Density Plot of Spionidae Abundance by Year

Note: Values of 640 and 2,700 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

Tellinidae Abundance

Tellinidae abundances varied between 0 and 80 individuals per m², with an area-wide average of approximately 147 per m² in 2018. In 2018, Tellinidae abundances were not significantly correlated with distance to the nearest active drill centre (ρ_s = 0.008, p > 0.05, All stations; ρ_s = 0.154, p > 0.05, repeated-measures stations). The correlation between Tellinidae abundance and distance to active drill centres was significant from 2008 to 2014. In 2016, the relationship was also significant when all stations were considered (Figure 5-68).

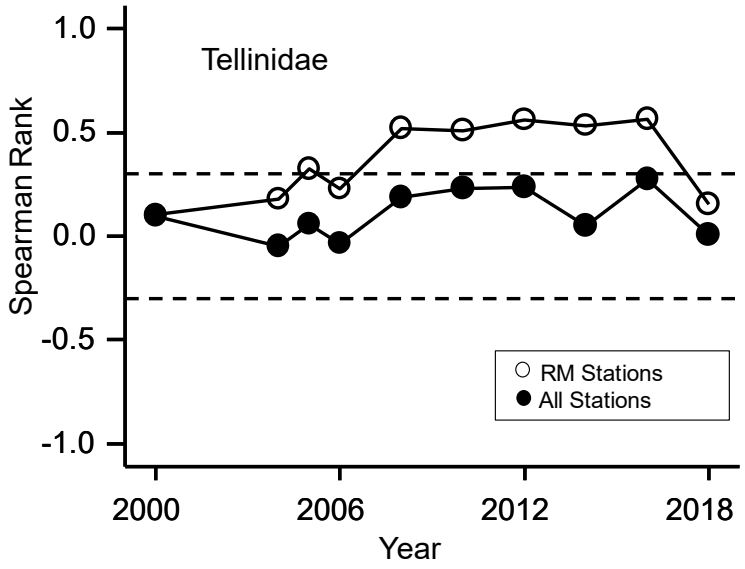


Figure 5-68 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Tellinidae Abundance

Notes: Station 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. Significance levels from specific statistical tests are reported in text.

Figure 5-69 provides a graphical representation of the relationship between Tellinidae abundance and distance to active drill centres. In 2018, Tellinidae abundances were reduced at virtually all stations, regardless of distance from drill centres. Similar results were seen in 2012.

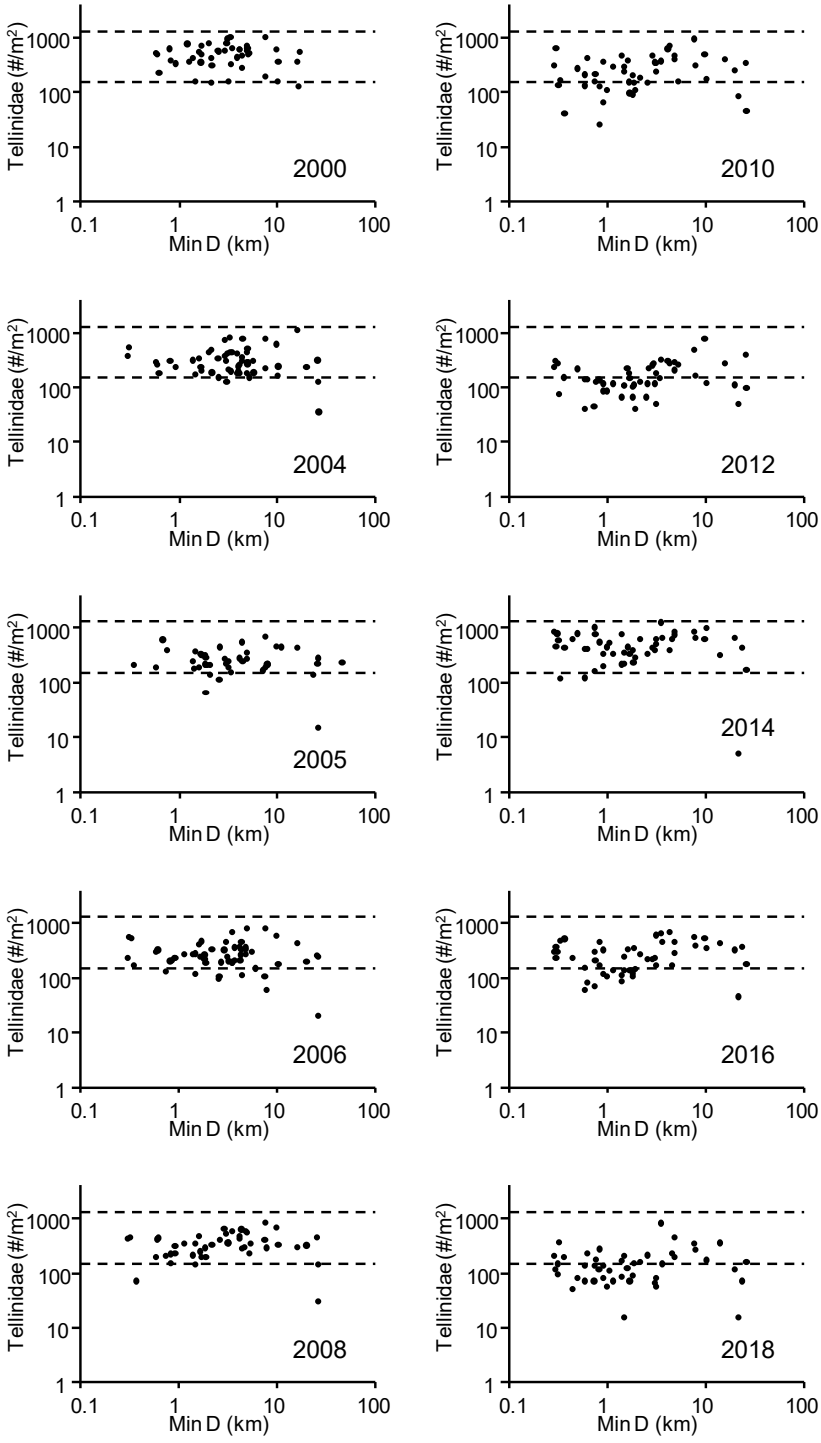


Figure 5-69 Variation in Tellinidae Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 151 and 1,303 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

Repeated-measures regression (Table 5-28) indicated that the slope of the relationship between Tellinidae abundance and distance to the nearest active drill centre was different between EEM years and baseline for repeated-measures stations (p = 0.024), yet the slope of the relationship did not significantly vary during EEM years (p = 0.759). In general, the slope of the relationship between Tellinidae abundances and distance was more positive in EEM years relative to baseline. However, the slope of the relationship in 2018 was similar to that noted in baseline (Figure 5-68). Mean numbers of Tellinidae varied significantly over time in EEM years (p = 0.011) as well as between baseline and EEM years (p < 0.001), with numbers generally lower in EEM years (Figure 5-70).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
0.759	0.011	0.024	<0.001

Notes:
- Values are probabilities.
- n = 35.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

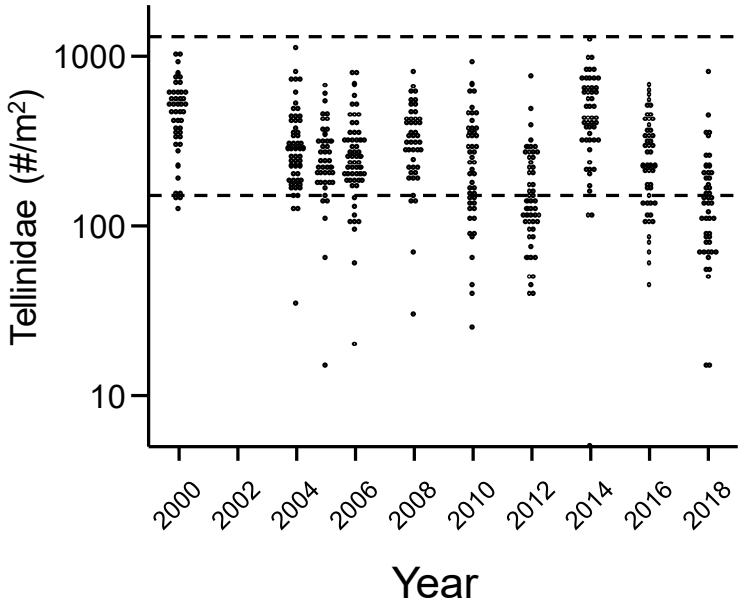


Figure 5-70 Dot Density Plot of Tellinidae Abundance by Year

Note: Values of 151 and 1,303 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

Amphipod Abundance

Amphipod abundances varied between 10 and 390 individuals per m², with an area-wide average of approximately 111 per m² in 2018. In 2018, amphipod abundance was not correlated with distance to nearest active drill centre (ρ_s = -0.083, p > 0.05, All stations; ρ_s = -0.276, p > 0.05, repeated-measures stations; Figure 5-71).

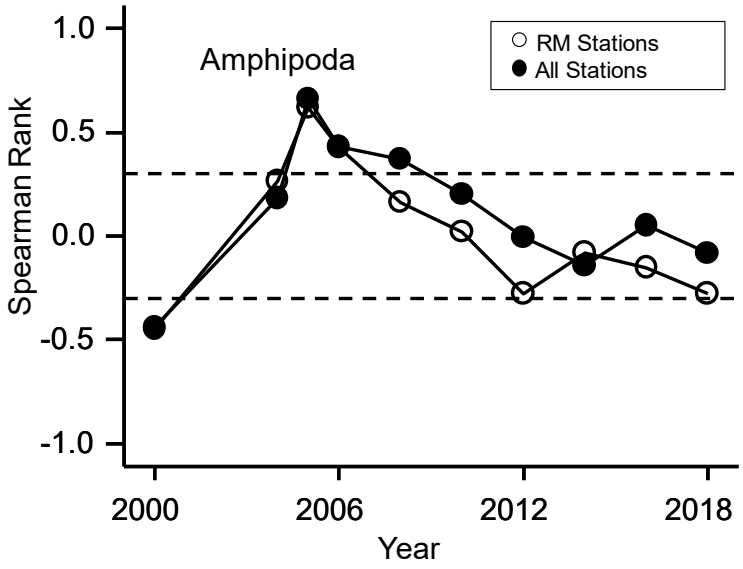


Figure 5-71 Centre for Amphipoda Abundance

Notes: Station 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. Significance levels from specific statistical tests are reported in text.

Figure 5-72 provides a graphical representation of the relationship between amphipod abundance and distance to active drill centres. As indicated in the figure, the “normal range” of variation for amphipod abundance across the sampling area was computed from the 2000 baseline data. Values ranged from 44 to 313 per m² in 2000. The lower range of 44 individuals per m² was used as a “benchmark” against which to variations over time (Figure 5-73).

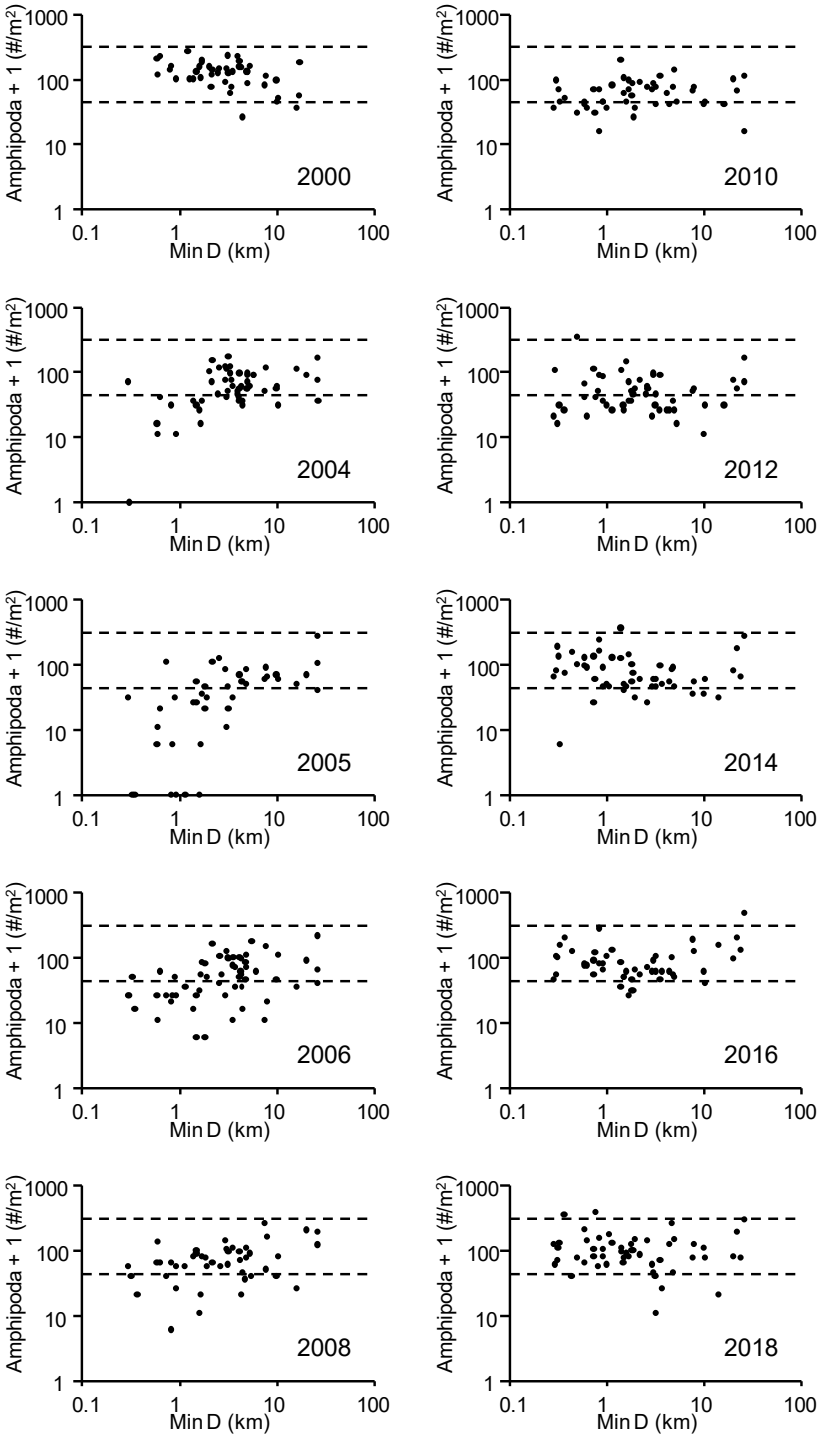


Figure 5-72 Variation in Amphipoda Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Min D = distance (km) to the nearest active drill centre, except in 2000 (baseline), where Min D is distance to the nearest future drill centre. Values of 44 and 313 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

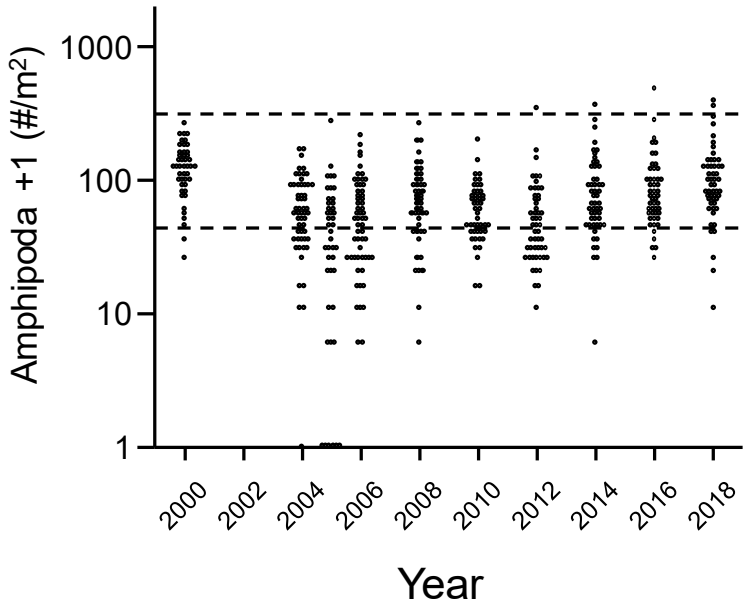


Figure 5-73 Dot Density Plot of Amphipoda Abundance by Year

Note: Values of 44 and 313 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

Repeated-measures regression indicated that slopes of the relationship between amphipod abundance and distance to the nearest drill centre varied linearly in EEM years ($p < 0.001$; a decrease in strength, see Figure 5-71), and from before to after drilling ($p < 0.001$, Table 5-29) for repeated-measures stations. The slope of the distance relationship was modestly negative during in baseline (see Figure 5-71) and tended to be more positive in earlier EEM years, reflecting somewhat reduced numbers of amphipods near drill centres. The linear change in slopes over time in EEM years indicates that effects near drill centres (if any) decreased over time. There were significant variations in mean abundance over time ($p < 0.001$ for both mean terms), with numbers generally lower in EEM years, and with numbers since 2014 showing increases (Figure 5-73).

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

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

Notes:
- Values are probabilities.
- $n = 35$.
- The Trend over Time contrast tests for trends over time since operations began (*i.e.*, from 2004 to 2018).
- The Before to After contrast tests for differences between year 2000 (baseline) and the mean in the period including 2004 to 2018.

Correlations Between Univariate Measures of Benthic Community Structure and Environmental Descriptors

In 2018, none of the indices of benthic community composition were significantly related to redox potential. Total abundance, and the abundances of Spionidae and Tellinidae, were not significantly related to any environmental descriptor (Table 5-30).

Table 5-30 Spearman Rank Correlations (ρ_S) of Indices of Benthic Community Composition with Environmental Descriptors (2018)

Environmental Descriptor	Index of Invertebrate Community Composition						
	Total Abundance	Biomass	Richness	Paraonidae Abundance	Spionidae Abundance	Tellinidae Abundance	Amphipoda Abundance
$>C_{10}$-C_{21}	-0.107	-0.370**	-0.098	**-0.785*** **	0.045	-0.018	0.113
Barium	-0.061	-0.302*	-0.070	**-0.758*** **	0.148	-0.038	0.142
% Fines	0.052	-0.240	0.039	-0.348*	0.148	0.026	0.091
Organic Carbon	-0.048	-0.215	-0.132	**-0.533*** **	0.140	0.257	0.100
Ammonia	-0.038	-0.224	-0.312*	-0.223	0.078	0.209	-0.086
Sulphide	-0.162	-0.064	-0.251	-0.241	-0.104	0.158	0.044
Sulphur	-0.079	-0.239	-0.042	**-0.613*** **	0.016	0.155	0.011
Metals PC1	0.067	-0.081	-0.024	-0.355**	0.053	-0.011	-0.082
Lead	-0.004	-0.128	-0.027	**-0.556*** **	0.015	-0.007	0.105
Strontium	0.015	-0.180	-0.053	**-0.476*** **	0.136	0.055	0.092
Redox	0.183	-0.261	0.092	0.093	0.269	0.045	0.066
Laboratory Amphipod survival	-0.194	-0.111	-0.331*	0.012	-0.149	0.065	-0.050
Water Depth	-0.114	0.207	0.135	0.112	-0.050	0.070	-0.319**

Notes:
- *p < 0.05; **p < 0.01; ***p < 0.001 (**in bold**).
- Sulphides were excluded from the above comparisons because too many values were below laboratory detection limit.
- n = 52 with Station 31 excluded.

Biomass declined significantly with increasing sediment concentrations of $>C_{10}$-C_{21} hydrocarbons and barium. Paraonidae abundance significantly decreased with increasing sediment fines, $>C_{10}$-C_{21} hydrocarbon, barium, Metals PC1, lead, strontium, sulphur, and organic carbon concentrations (Table 5-30). Richness decreased with increasing ammonia concentrations. Amphipod abundance decreased with increasing water depth; and laboratory amphipod survival significantly declined with increasing taxa richness.

5.2.3.3 Multivariate Analyses

Significant differences in benthic invertebrate community structure (*i.e.*, based on multivariate assessment of taxa abundance) relative to distance from nearest active drill centres were detected among samples collected during 2018 sampling (PERMANOVA Pseudo-$F_{5,46}$ = 7.01; P(perm) < 0.001, Table 3-4, Appendix B-7).

Specifically, station groups less than 500 m, 500 to 1,000 m, and 1,000 to 2,000 m from active drill centres were significantly different from other groups (Figure 5-74; P(perm) < 0.05, Appendix B-7 Table 3-5), while stations at more than 2,000 m were statistically indistinguishable.

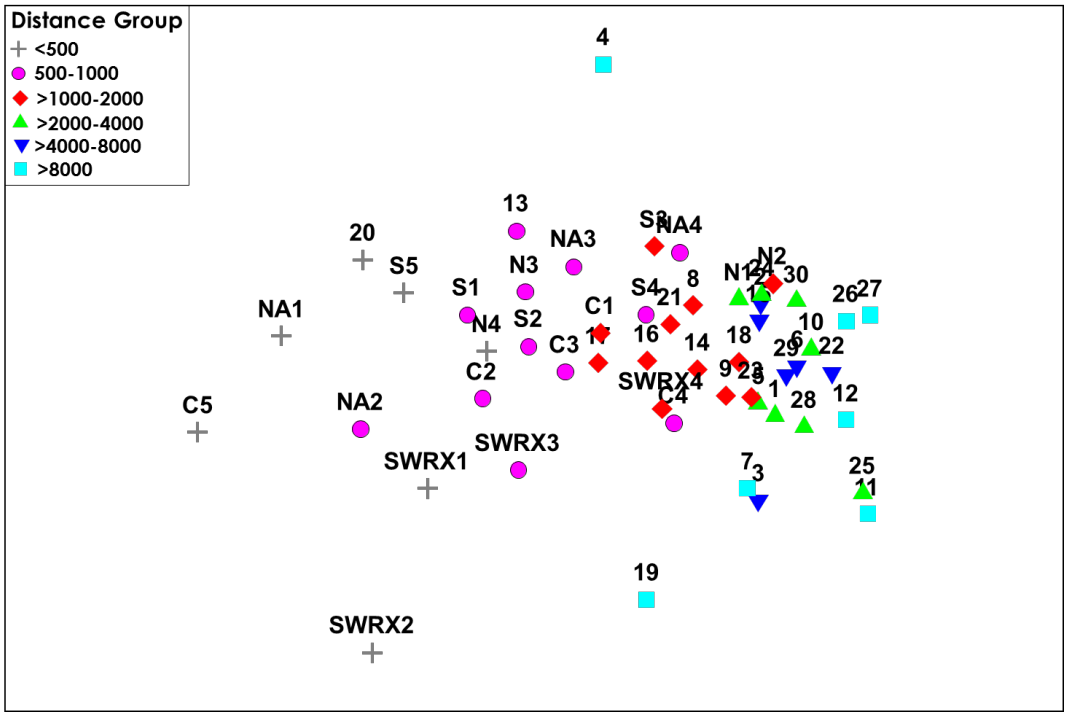


Figure 5-74 nMDS Scatterplot Based on Bray-Curtis Similarities of Benthic Infauna Assemblage Matrix Sampled in 2018 Grouped by Distance

Notes: *n* = 52 with Station 31 excluded. Stress = 0.11. Stress values are a measure of goodness-of-fit between the calculated similarity values and the distance between sample points. Stress values <0.1 have no real prospect for misinterpretation while values >0.2 are close to being arbitrarily placed and should be interpreted with a high degree of caution (Clarke and Warwick 2001).

Further multivariate analyses detected significant relationships between the benthic community structure and sediment physical and chemical variables. When sediment physical and chemical variables were considered sequentially using step-wise multivariate multiple regression (distance-based linear models; DISTLM), the resulting model explained 51% of the variation in the benthic assemblages (Table 5-31). The individual sediment physical and chemical variable contributing most to this variation was >C_{10}-C_{21} hydrocarbons (35%). The subsequent addition of the variables (in order of cumulative contribution to cumulative R^2) ammonia, water depth, barium, strontium and percent fines. The remaining variables percent gravel, percent sand, redox potential, organic carbon, sediment concentrations of organic carbon, lead, zinc and Metals PC1 scores did not significantly improve the multivariate model[14].

[14] Distance to the nearest active drill centre was also not included as it is an aggregate variable.

Table 5-31 Results of DISTLM Multivariate Multiple Stepwise Regression of Predictor Variables on Bray-Curtis Similarities of 2018 Benthic Infauna Assemblage Matrix

Variable	*p*	Sequential Proportion of Variance Explained	Cumulative R^2
>C_{10}-C_{21} Hydrocarbons	**<0.001*** **	0.346	0.346
Ammonia	0.001**	0.042	0.388
Depth	0.010*	0.035	0.423
Barium	0.011*	0.030	0.453
Strontium	0.007**	0.031	0.484
% Fines	0.029*	0.024	0.508

Notes: - *p < 0.05; **p < 0.01; ***p < 0.001 (**in bold**).
- n = 52 with Station 31 excluded.
- Further model diagnostics and graphics on the relationship between benthic community structure and selected variables are provided in Appendix B-7.

Ten taxa contributed to a total of 61% of the variation in community structure between samples within 500 m of the nearest active drill centre and those greater than 8,000 m away, as determined by SIMPER analyses. The polychaete family Paraonidae (14.8%) was most influential, followed by Cirratulidae polychaetes (8.5%) and Tanaidacea crustaceans (6.2%). The remaining taxa that contributed to 5% or more of the observed differences between these two distance groups were from the polychaete families Dorvilleidae (6%) and Orbiniidae (5.4%).

The mean abundance of Paraonidae within 500 m of the nearest active drill centre was 0.1 individuals per m² versus 754 individuals per m² at stations greater than 8,000 m away (Table 5-32). Similar trends of increasing abundance with distance from drill centres for Orbiniidae and Tanaidacea. Cirratulidae and Dorvilleidae had greater abundances at stations closest to drill centres (Table 5-32).

Table 5-32 Mean Abundance of Key Benthic Infauna Taxa by Distance Group (2018)

Distance Groups	*n*	Mean Abundance (individuals per m²)				
		Paraonidae	Cirratulidae	Tanaidacea	Dorvilleidae	Orbiniidae
<500	7	0.102	352	3.24	144	0.303
500 to 1,000	12	36.1	594	44.4	17.5	56.3
>1,000 to 2,000	12	413	333	142	2.66	211
>2,000 to 4,000	8	690	29.9	149	0.706	212
>4,000 to 8,000	6	695	15.7	262	2.50	167
>8,000	7	754	130	202	0.757	97.8

Notes: - n = 52, with Station 31 excluded.

Multiyear comparison of benthic invertebrate community structure (*i.e.*, taxa abundances from 2016 and 2018) found significant differences among samples relative to distance from nearest active drill centres and year of sampling but no significant interaction between levels of distance or year (Table 5-33; Figure 5-75). These results indicate that while benthic invertebrate community structure significantly differed between 2016 and 2018, relationships with distance from nearest active drill centres were statistically indistinguishable between these two sampling events (Figure 5-75) (*i.e.,* distance effects in 2018 were not stronger, or weaker, than in 2016).

Table 5-33 Results of Two-way PERMANOVA Testing Main Effects of Location and Year on Bray-Curtis Similarities of Benthic Infauna Assemblage Matrix (2016 and 2018)

Source	df	MS	Pseudo-F	P(perm)	Unique Perms
Distance	5	4523	12.80	<0.001***	4965
Year	1	14905	42.19	<0.001***	4985
Distance x Year	5	148	0.42	0.9988	4959
Residual	88	353			
Total	99				

Notes: - *n* = 50 per year with Stations 31, NA2, and SWRX4 excluded for continuity of comparison between 2016 and 2018 data sets. In 2016, benthic invertebrate samples from Stations NA2 and SWRX4 returned anomalous results with low abundances and biomass. In 2018, Station 31 was excluded based on regulatory feedback. Further explanations and model details are provided in Appendix B-7.

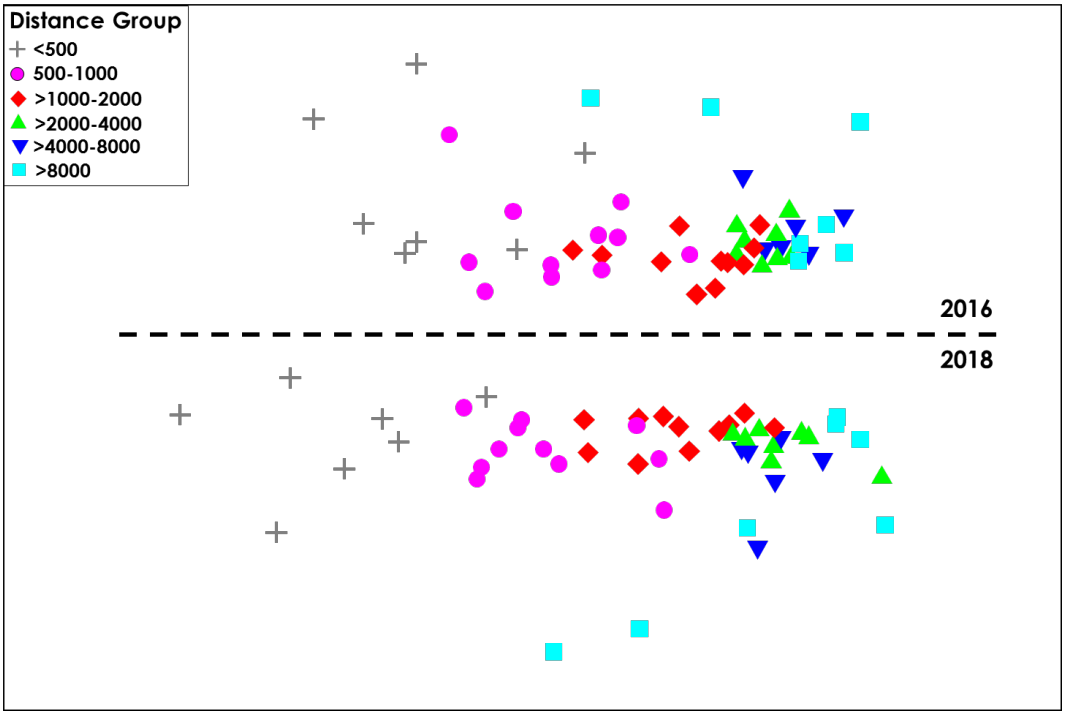


Figure 5-75 nMDS Scatterplot Based on Bray-Curtis Similarities of Benthic Infauna Assemblage Matrix Sampled in 2016 and 2018 Grouped by Distance

Notes: *n* = 50 per year with Stations 31, NA2, and SWRX4 excluded. Stress = 0.16. Stress values are a measure of goodness-of-fit between the calculated similarity values and the distance between sample points. Stress values <0.1 have no real prospect for misinterpretation while values >0.2 are close to being arbitrarily placed and should be interpreted with a high degree of caution (Clarke and Warwick 2001).

5.3 Summary of Results

5.3.1 Whole-Field Response

Hydrocarbons in the >C_{10}-C_{21} range and barium in sediments were clearly influenced by drilling operations in 2018, with concentrations elevated up to estimated threshold distances of 2.4 km and 1.0 km from the nearest active drill centre, respectively. Significant threshold distances (*i.e.*, the distance at which values return to background values) have been detected in all sampling years for >C_{10}-C_{21} hydrocarbons and barium since drilling began. The average threshold distance for >C_{10}-C_{21} hydrocarbons has varied from 5.9 to 10.4 km from 2004 to 2008, and from 2.7 to 5.8 km from 2010 to 2018. Average threshold distances for barium also tended to be greater in earlier EEM years; 1.9 to 3.6 km from 2004 to 2010 versus approximately 1 km since 2012.

Remaining sediment chemical and physical characteristics showed either no or highly localized project-related alterations. Sediment lead, strontium and organic carbon concentrations also exhibited a threshold relationship with distance from drill centres in 2018. Sediment lead concentrations were elevated to 0.8 km from drill centres. Elevated lead levels from 0.6 to 1.4 km of drill centres have been noted since 2006. Sediment strontium concentrations were also elevated to 0.8 km in 2018. No thresholds for strontium were noted in the last two sampling years, but thresholds ranging from approximately 0.6 to 1.6 km were also noted in 2006, 2008 and 2012. Sediment organic carbon concentrations were elevated to 1.0 km in 2018 and no threshold has been noted in previous EEM years.

There was some evidence of effects on percent fines and concentrations of ammonia, sulphur and overall metals (as assessed through Metals PC1) at a few stations within 1 km of drill centres in 2018, but relationships with distance to drill centres were too weak to assess thresholds. Sulphides also were elevated at a few stations near drill centres, in spite of the lack of a statistically significant distance relationship. Finally, there was no evidence of effects on sediment redox potential in 2018. Evidence of effects on these last variables generally has been either weak or absent in EEM years. However, percent fines exhibited a threshold with distance from drill centres in 2014, and sulphide concentrations exhibited a threshold in 2006 and 2008. In all cases, threshold distances were approximately 1 km or less.

Sediments were generally non-toxic in 2018. No samples were toxic to Microtox. One sample was toxic to laboratory amphipods when compared to Reference sediments, but it was not toxic when compared to laboratory control sediment; and there were no significant correlations between laboratory amphipod survival and any sediment particle size or chemistry variable

In 2018, there was evidence of project effects on benthic biomass, and little evidence of effects on total abundance and richness. Univariate analysis of abundances of individual taxa provided evidence of project effects on Paraonidae. Multivariate analyses of 2018 data confirmed that Paraonidae was the taxon most affected by project activity, and also indicated project-effects on Cirratulidae, Tanaidacea, Dorvilleidae and Orbiniidae.

The relationship between total benthic abundance and distance to active drill centres was weaker in 2018 than in previous years and not significant. However, total abundance was reduced at two stations in the immediate vicinity of the SWRX drill centre (see Section 5.3.2 on effects of individual drill centres).

The relationship between total biomass and distance from active drill centres was somewhat weaker than those observed in 2012 and 2014 when threshold for effects of 1.5 and 5.5 km, respectively, were noted. No threshold could be estimated in 2018, and effects were generally limited to approximately 1 km from drill centres. As indicated in previous reports, reductions in biomass near drill centres are related, in part, to reductions in the number of larger echinoderms.

Richness was predominantly unaffected by project activity in 2018, as in previous years. However, two stations had reduced richness in the immediate vicinity of drill centres (see Section 5.3.2 on effects of individual drill centres).

Paraonidae abundance has been strongly related to distance from active drill centres, with threshold distances significant in every EEM year. The threshold distance for Paraonidae in 2018 was estimated at 1.6 km. As was the case for $>C_{10}$-C_{21} hydrocarbons and barium, there was an indication that threshold distances were larger in early EEM years (approximately 3 to 4 km from 2004 to 2008) and approximately 1 to 2.5 km from 2010 to 2018.

Univariate analysis indicated that benthic biomass and abundances of Paraonidae were correlated to sediment concentrations of $>C_{10}$-C_{21} hydrocarbons and barium. Biomass and abundances of Paraonidae were lower in sediments with elevated concentrations of $>C_{10}$-C_{21} hydrocarbons and barium. Higher concentrations of sulphur, lead, organic carbon, strontium, metals, and percent fines also co-occurred with lower abundances of Paraonidae. Richness declined with increasing ammonia concentrations. Multivariate assessment of taxa abundance identified correlations between sediment $>C_{10}$-C_{21} hydrocarbons and barium concentration and benthic community structure and also identified changes in community structure with varying sediment ammonia, water depth, strontium and percent fines. Overall, these and prior analyses indicate that $>C_{10}$-C_{21} hydrocarbons and barium are the best indicators of the presence of drill muds in sediment and the strongest correlates to the benthic community response.

5.3.2 Effects of Individual Drill Centres

Maps of response variables outside the baseline (2000) or background (>10 km from nearest active drill centre) range were used to qualitatively assess the spatial distribution of effects around individual drill centres, with a focus on benthic invertebrate responses. For the most part, only drill centre stations (*i.e.*, stations labeled with a drill centre prefix) are used in this exercise. Other stations are considered when they are located within 2 km of any one drill centre. In total, 32 stations are considered.

Total abundance in 2018 was reduced below the baseline range at two stations around the SWRX drill centre. Stations SWRX1 and SWRX2 had reduced total abundance. These stations are within 0.5 km of the SWRX Drill Centre.

Total benthic biomass in 2018 was below the baseline range at one to three stations around the Central, North Amethyst, Southern and Northern Drill Centres. Stations C5, 20, and C3 had reduced biomass around the Central Drill Centre. Stations NA1 and NA2 had reduced biomass around the North Amethyst Drill Centre. Station S1 had reduced biomass around the Southern Drill Centre and Station N4 had reduced biomass around the Northern Drill Centre. With the exception of Stations C3 and S1, these stations are located within 0.5 km of drill centres. Station C3 is located 0.74 km from the Central Drill Centre and Station S1 is located 0.6 km from the Southern Drill Centre.

Richness was reduced to below the baseline range at one station around each of the Central and SWRX Drill Centres. Richness was reduced at Station C5, located 0.33 km from the Central Drill Centre. Richness was also reduced at Station SWRX3, located 0.74 km from the SWRX Drill Centre.

Paraonidae abundance was reduced to below the baseline range at approximately half the stations around drill centres (17 out of the 32 stations considered here). Stations C5, 20, C3, C2 and 17 had reduced Paraonidae around the Central Drill Centre. Stations NA1, NA2 and NA3 had reduced Paraonidae abundance around the North Amethyst Drill Centre. Stations SWRX1, SWRX2 and SWRX3 had reduced Paraonidae abundance around the SWRX Drill Centre. Stations S5, 13, S1 and S2 had reduced Paraonidae abundance around the Southern Drill Centre and Stations N4 and N3 had reduced Paraonidae abundance around the Northern Drill Centre. Most of these stations are within 0.5 km from drill centres. Stations C3, C2, NA3 and SWRX3 are within 1 km of drill centres; and Station 17 is 1.81 km from the Central Drill Centre.

Overall, 2018 data suggest that the majority of effects on benthos occur within 0.5 km of drill centres, with more subtle and/or highly localized effects between 1 to 2 km. This is supported by the 2018 multivariate assessment, which showed that stations beyond 2 km of drill centres were indistinguishable from each other.

In terms of magnitude of effect in 2018, and examining only the stations nearest the drill centres, mean $>C_{10}$-C_{21} hydrocarbon concentrations were highest at the North Amethyst Drill Centre and they were also relatively high at the Central Drill Centre (Table 5-34). Mean barium concentrations were also relatively high at the North Amethyst and Central Drill Centres. The maximum $>C_{10}$-C_{21} hydrocarbon and barium concentrations occurred at Station C5 located 0.33 km from the Central Drill Centre; although concentrations were also relatively high at Station NA1 located 0.29 km from the North Amethyst Drill Centre were also relatively high.

Total benthic invertebrate abundance was reduced to less than 75% of the baseline range at one station around the SWRX Drill Centre. Biomass was reduced to less than 75% of the baseline range at two stations around the Central Drill Centre and one station around the Southern Drill Centre. Richness was not reduced at any station. Paraonidae abundance was reduced to less than 75% of the baseline range of three stations around each of the Central, North Amethyst, Southern and SWRX Drill Centres and at two stations around the Northern Drill Centre.

Table 5-34 Values at Drill Centre Stations for Selected Variables

Station	Distance to Drill Centre (km)	Barium (mg/kg)	$>C_{10}$-C_{21} (mg/kg)	Fines (%)	Abundance (#/m²)	Biomass (g/m²)	Richness	Paraonidae (#/m²)
Central Drill Centre								
C1	1.14	250	5	1.3	4155	438	42	150
C2	0.83	440	17	1.6	2750	675	38	10
C3	0.74	250	5.6	1.4	2650	161	38	10
C4	0.92	160	5.7	1.2	3470	611	35	285
C5	0.33	3400	360	3.4	2680	4	19	0
Mean	**0.79**	**900**	**78.7**	**1.78**	**3141**	**378**	**34**	**91**
Minimum	**0.33**	**160**	**5.0**	**1.2**	**2650**	**4**	**19**	**0**
Maximum	**1.14**	**3400**	**360.0**	**3.4**	**4155**	**675**	**42**	**285**
Northern Drill Centre								
N1	2.18	180	0.77	1.3	4740	496	36	1440
N2	1.49	160	1.1	1.2	4870	509	33	910
N3	0.63	250	3.7	1.3	4330	576	33	30
N4	0.30	430	9.2	1.6	3045	289	33	0
Mean	**1.15**	**255**	**3.7**	**1.35**	**4246**	**467**	**34**	**595**
Minimum	**0.30**	**160**	**0.8**	**1.2**	**3045**	**289**	**33**	**0**
Maximum	**2.18**	**430**	**9.2**	**1.6**	**4870**	**576**	**36**	**1440**
North Amethyst Drill Centre								
NA1	0.29	2600	290	2.7	3725	296	29	0
NA2	0.50	980	64	1.7	2400	304	22	5
NA3	0.76	250	6.6	1.3	5420	1356	44	70
NA4	1.00	190	2.4	1.5	5740	479	35	210
Mean	**0.64**	**1005**	**90.8**	**1.8**	**4321**	**609**	**33**	**71.25**
Minimum	**0.29**	**190**	**2.4**	**1.3**	**2400**	**296**	**22**	**0**
Maximum	**1.00**	**2600**	**290.0**	**2.7**	**5740**	**1356**	**44**	**210**
Southern Drill Centre								
S1	0.60	380	9.6	1.2	3380	184	27	0
S2	0.83	280	5.5	1.3	2900	1017	35	0
S3	1.40	160	1.9	1.4	6360	817	41	900
S4	0.92	200	3.4	1.3	4575	431	34	635
S5	0.31	890	52	1.7	3890	438	32	5
Mean	**0.81**	**430**	**24.1**	**1.5**	**3420**	**396**	**34**	**99**
Minimum	**0.31**	**160**	**1.9**	**1.2**	**2900**	**184**	**27**	**0**
Maximum	**1.40**	**890**	**52.0**	**1.7**	**6360**	**1017**	**41**	**900**
SWRX Drill Centre								
SWRX1	0.32	350	32	1.6	1740	434	26	0
SWRX2	0.44	670	64	1.3	1100	477	19	0
SWRX3	0.74	220	12	1.2	1905	384	32	0
SWRX4	1.06	170	2.8	1.3	2620	488	30	170
Mean	**0.64**	**293**	**25**	**1.5**	**1780**	**509**	**32**	**22**
Minimum	**0.32**	**170**	**2.8**	**1.2**	**1100**	**384**	**19**	**0**
Maximum	**1.06**	**670**	**64.0**	**1.6**	**2620**	**488**	**32**	**170**

Notes: - Shading indicates values 75% below the baseline range for benthic invertebrates. For total abundance, biomass, richness and Paraonidae abundance, values 75% below the baseline ranges were below 1,413 #/m², 275 g/m², 17 and 97 #/m², 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 Atlantic Champion* between June 27 and July 5, 2018. Collection dates for the baseline program and subsequent 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
2014 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	June 26 to June 28, 2014
2016 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 15, 2016
2018 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	June 27 to July 5, 2018

Notes: - Since the location of Reference Areas sampled from 2004 to 2018 differs from locations sampled in 2000 and 2002, data from Reference Areas collected during baseline cannot be compared to EEM Reference Area data (see Husky Energy 2004 for details).

Details on the collection and processing of 2000, 2002, 2004, 2005, 2006, 2008, 2010, 2012, 2014, and 2016 samples are presented in Husky Energy (2001, 2003, 2005, 2006, 2007, 2009, 2011, 2013, 2015, 2019). Locations of transects for sample collection are provided in Figure 6-1 and Appendix C-1[15]. In 2018, sampling in Reference Areas 3 and 4 was not possible because of intense commercial fishing activity in that area for crab. Therefore, additional transects were performed in Reference Areas 1 and 2 to provide the necessary number and weight of plaice and crab for use in this EEM program.

[15] Trawl by-catch data are no longer provided in Appendix C-1 for comparison with previous years because a commercial trawl has been used since 2010. This results in substantially less by-catch than the previous DFO Campelen trawl (2000-2008).

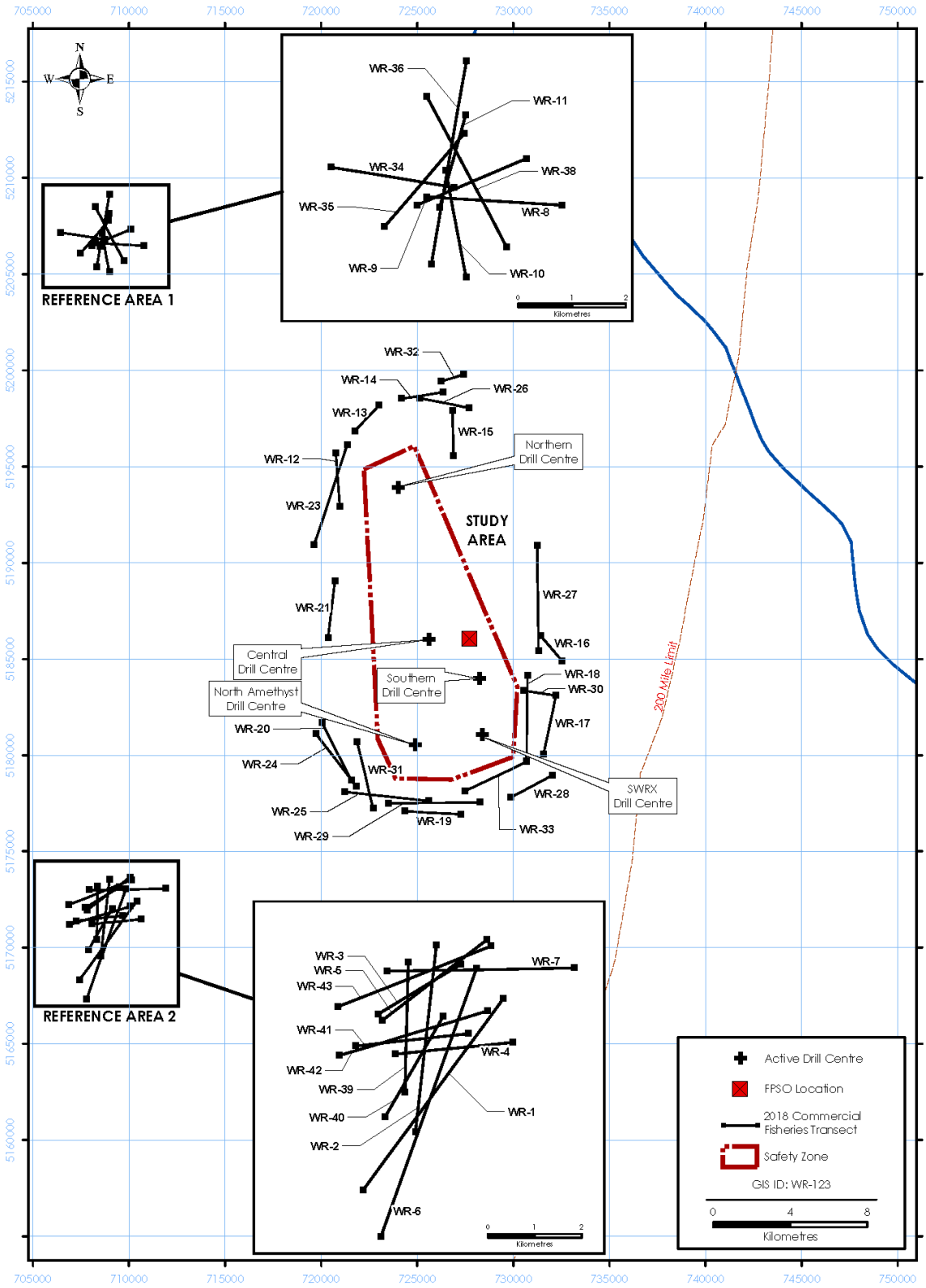


Figure 6-1 2018 EEM Program Transect Locations

Sampling for the 2018 program was conducted under an experimental fishing license (NL4673-18) issued to Stantec. A total of 135 plaice and 98 crab from the White Rose Study Area were retained for analysis in 2018; a total of 186 plaice and 123 crab were retained from Reference Areas. Plaice and crab that were not retained were released with as little damage as possible. Three striped (or Atlantic) wolffish (*Anarhichas lupus*, a federally listed species at risk) were collected in separate trawls (two around the White Rose Safety Zone, one in Reference Area 1); all were released uninjured.

As in previous years, preliminary processing of samples was done on-board the vessel. Plaice and crab that had suffered obvious trawl damage were discarded. Only plaice larger than 300 mm in length and crab larger than 60 mm in carapace width were retained for analysis. Tissue samples for subsequent taste analysis on shore (*i.e.*, top fillet for plaice and left legs for crab) were frozen at -20°C. For body burden analysis, bottom fillets and liver (left half only) for plaice and right legs for crab were frozen at -20°C. For fish health analysis, gill, liver (right half) and otolith samples from plaice were preserved (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.

The following procedures were used for collection of fish health samples. Fish were killed by severing the spinal cord. Each fish was assessed visually for any parasites and/or abnormalities observed 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). Fish were dissected and sex and maturity stage were determined by visual examination according to procedures used by the Department of Fisheries and Oceans in the Newfoundland Region (Annex A, Appendix C-3). Liver and gonad were weighed. The first gill arch on the right and top side of the fish was removed and placed in 10% buffered formalin for histological processing. The entire liver was excised and bisected, and the right half was retained for fish health analysis. A three to five millimeter thick slice was cut from the centre portion of the right half of the liver (along the longitudinal axis) and placed in Dietrich fixative for histological processing and the remainder of the right half was frozen on dry ice until return to port when it was placed in a -80 °C freezer for MFO analysis. A pair of otoliths was removed for ageing. Throughout the dissection process, any internal parasites and/or abnormal tissues were recorded and preserved in 10% buffered formalin for subsequent identification.

6.1.1.1 Sampling Quality Assurance/Quality Control

The following sampling QA/QC protocols were implemented to reduce the potential for introducing contamination to samples from the vessel, from handling, or from samples from other transects. For each transect, the deck of the survey vessel was washed with degreaser then flushed with seawater prior to sample collection and handling of samples on deck. The fishing deck was flushed continuously with clean seawater 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 -20°C freezer within one hour of collection, where applicable. Additional QA/QC measures also included use of trained and experienced technical staff as well as use of calibrated equipment for taking weight and

length measurements. In 2018, cod fillets purchased from a commercial source were used as a "field blank" to identify potential on-board contamination. One commercial fillet was exposed to the work space for the duration of processing of each the trawl (field blanks are only processed for chemistry if results from sample tissues indicate potential onboard contamination).

6.1.2 Laboratory Analysis

6.1.2.1 Allocation of Samples

Plaice were used for body burden analysis, taste tests and fish health assessment. Plaice bottom fillets and liver tissues were composited to generate 10 individual body burden samples for fillet and liver for the Study Area and 12 composites for the Reference Areas. When sufficient tissue was available, tissues from individual fish were 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, by design, were conducted on individual fish rather than composite or randomly assigned samples (see Table 6-2).

Table 6-2 Plaice Selected for Body Burden, Taste and Health Analyses (2018)

Transect No.	Area	No. of Fish Retained	Body Burden Composite Identifier # (# fish used for composites (fillet and liver)	Taste Test (wt. (g) of Top Fillets)	Fish Health (No. of Fish)
WR12	Study Area	15	1 (15 fish)	612	6
WR13	Study Area	15	2 (15 fish)	606	6
WR14	Study Area	15	3 (15 fish)	589	6
WR15	Study Area	15	4 (15 fish)	590	6
WR16	Study Area	10	5 (10 fish)	601	6
WR17	Study Area	10	6 (10 fish)	600	6
WR18	Study Area	15	7 (15 fish)	612	6
WR19	Study Area	15	8 (15 fish)	630	6
WR20	Study Area	15	9 (15 fish)	570	6
WR21	Study Area	10	10 (10 fish)	593	6
Study Area Total		**135**	**10**	**6003**	**60**
WR1 & WR2	Reference Area 2	21	11 (21 fish)	882	10*
WR3	Reference Area 2	15	12 (15 fish)	449	10
WR4	Reference Area 2	15	13 (15 fish)	435	10
WR39	Reference Area 2	15	14 (15 fish)	490	10
WR40	Reference Area 2	15	15 (15 fish)	450	10
WR41	Reference Area 2	15	16 (15 fish)	430	10
WR8	Reference Area 1	15	17 (15 fish)	495	10
WR9	Reference Area 1	15	18 (15 fish)	515	10
WR10	Reference Area 1	15	19 (15 fish)	505	10
WR11	Reference Area 1	15	20 (15 fish)	510	10
WR34	Reference Area 1	15	21 (15 fish)	490	10
WR35	Reference Area 1	15	22 (15 fish)	502	
Reference Area Total		**186**	**12**	**6153**	**120**

Note: - A much as feasible, tissue weights for taste tests were selected to generate relatively constant weights over all composites within the Study Area or over each of the Reference Areas.

-* Fish from trawl WR1 only were used.

Crab were used for body burden and taste analyses. Only hard-shell crab were tested. Tissue from right legs was composited to generate 10 body burden samples for the Study Area and 12 composite samples for the Reference Areas (see 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 was allocated to the triangle test and the hedonic scaling test and then randomly assigned to panelists (see Section 6.1.2.3 for details on taste tests).

Table 6-3 Crab Selected for Body Burden and Taste Analysis (2018)

Transect No.	Area	No. of Crab	Body Burden Composite Identifier # (# of crab used for composites: right legs)	Taste Tests (wt. (g) of Crab, Left Legs)
WR13 & WR23	Study Area	7	1 (7 crab)	639
WR14 & WR 15	Study Area	10	2(10 crab)	488
WR26	Study Area	12	3 (12 (crab)	462
WR32	Study Area	12	4 (12 crab)	1060
WR18 & WR30	Study Area	7	5 (7 crab)	733
WR27	Study Area	6	6 (6 crab)	347
WR19	Study Area	6	7 (6 crab)	340
WR33	Study Area	12	8 (12 crab)	992
WR24 & WR31 & WR20	Study Area	20	9 (20 crab)	1127
WR21	Study Area	6	10 (6 crab)	871
Study Area Total		**98**	**10**	**7059**
WR3	Reference Area 2	12	11 (12 crab)	487
WR6	Reference Area 2	11	12 (11 crab)	532
WR7	Reference Area 2	16	13 (16 crab)	822
WR43	Reference Area 2	7	14 (7 crab)	370
WR4 & WR5	Reference Area 2	11	15 (11 crab)	427
WR39 & WR41 &WR42	Reference Area 2	12	16 (12 crab)	517
WR10	Reference Area 1	24	17 (24 crab)	665
WR11	Reference Area 1	6	18 (6 crab)	560
WR35	Reference Area 1	6	19 (6 crab)	462
WR38	Reference Area 1	6	20 (6 crab)	643
WR8 & WR9	Reference Area 1	6	21 6 crab)	868
WR34 & WR36	Reference Area 1	6	22 (6 crab)	597
Reference Area Total		**123**	**12**	**6950**

Note: - A much as feasible, tissue weights for taste tests were selected to generate relatively constant weights over all composites within the Study Area or over each of the Reference Areas.

6.1.2.2 Body Burden

Samples of plaice fillet and liver as well as crab leg were delivered frozen to Maxxam Analytics (Halifax, Nova Scotia) and processed for the variables listed in Table 6-4. Analytical methods for these tests are provided in Appendix C-2.

Table 6-4 Body Burden Variables (2000, 2002, 2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016, and 2018)

Variables	Method	Laboratory Detection Limits							Units
		2000	2002	2004 & 2005	2006	2008, 2010 & 2012	2014	2016 & 2018	
Hydrocarbons									
>C_{10}-C_{21}	GC/FID	15	15	15	15	15	15	15	mg/kg
>C_{21}-C_{32}	GC/FID	15	15	15	15	15	15	15	mg/kg
PAHs									
1-Chloronaphthalene	GC/MS	NA	NA	0.05	0.05	0.05	0.05	0.05	mg/kg
2-Chloronaphthalene	GC/MS	NA	NA	0.05	0.05	0.05	0.05	0.05	mg/kg
1-Methylnaphthalene	GC/MS	0.05	0.05	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	0.05	0.05	mg/kg
Acenaphthene	GC/MS	0.05	0.05	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	0.05	0.05	mg/kg
Anthracene	GC/MS	0.05	0.05	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	0.05	0.05	mg/kg
Benzo[*a*]pyrene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*b*]fluoranthene	GC/MS	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*ghi*]perylene	GC/MS	0.05	0.05	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	0.05	0.05	mg/kg
Chrysene	GC/MS	0.05	0.05	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	0.05	0.05	mg/kg
Fluoranthene	GC/MS	0.05	0.05	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	0.05	0.05	mg/kg
Indeno[1,2,3-*cd*]pyrene	GC/MS	0.05	0.05	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	0.05	0.05	mg/kg
Perylene	GC/MS	0.05	0.05	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	0.05	0.05	mg/kg
Pyrene	GC/MS	0.05	0.05	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	2.5	2.5	mg/kg
Antimony	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.35	0.5	mg/kg
Arsenic	ICP-MS	0.5	0.5	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	1.5	1.5	mg/kg
Beryllium	ICP-MS	1.5	1.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Boron	ICP-MS	1.5	1.5	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	0.05	0.05	mg/kg
Chromium	ICP-MS	0.5	0.5	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	0.2	0.2	mg/kg
Copper	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Iron	ICP-MS	5	5	15	15	15	0.1	15	mg/kg
Lead	ICP-MS	0.18	0.18	0.18	0.18	0.18	0.25	0.18	mg/kg
Lithium	ICP-MS	0.5	0.5	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	0.5	0.5	mg/kg
Mercury	CVAA	0.01	0.01	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	0.5	0.5	mg/kg
Nickel	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.1	0.5	mg/kg
Selenium	ICP-MS	0.5	0.5	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	0.1	0.12	mg/kg
Strontium	ICP-MS	1.5	1.5	1.5	1.5	1.5	0.15	1.5	mg/kg
Thallium	ICP-MS	0.02	0.02	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	0.5	0.5	mg/kg
Uranium	ICP-MS	0.02	0.02	0.02	0.02	0.02	0.10	0.02	mg/kg
Vanadium	ICP-MS	0.5	0.5	0.5	0.5	0.5	1.0	0.5	mg/kg
Zinc	ICP-MS	0.5	0.5	0.5	1.5	1.5	0.5	1.5	mg/kg

Variables	Method	Laboratory Detection Limits							Units
		2000	2002	2004 & 2005	2006	2008, 2010 & 2012	2014	2016 & 2018	
Other									
Percent Lipids/Crude Fat	AOAC922.06	0.1	0.5	0.5	0.5	0.5	0.5	0.5	%
Moisture	Gravimetry	0.1	0.1	0.1	0.1	1	0.10	1	%

Notes:
- NA = Not Analyzed.
- GC/FID = Gas Chromatography/Flame Ionization Detection.
- GC/MS = Gas Chromatography/Mass Spectrometer.
- ICP-MS = Inductively Coupled Plasma/Mass Spectrometer.
- CVAA = Cold Vapour Atomic Absorption.

6.1.2.3 Taste Tests

Plaice and crab samples were delivered frozen to the Marine Institute of Memorial University for sensory evaluation, using triangle and hedonic scaling taste test procedures (after Botta 1994). Since no procedures have been established to compare multiple Reference Areas to one Study Area, samples were selected from each of the sampled 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. Samples were then 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) 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.

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:

_____

_____

_____

_____

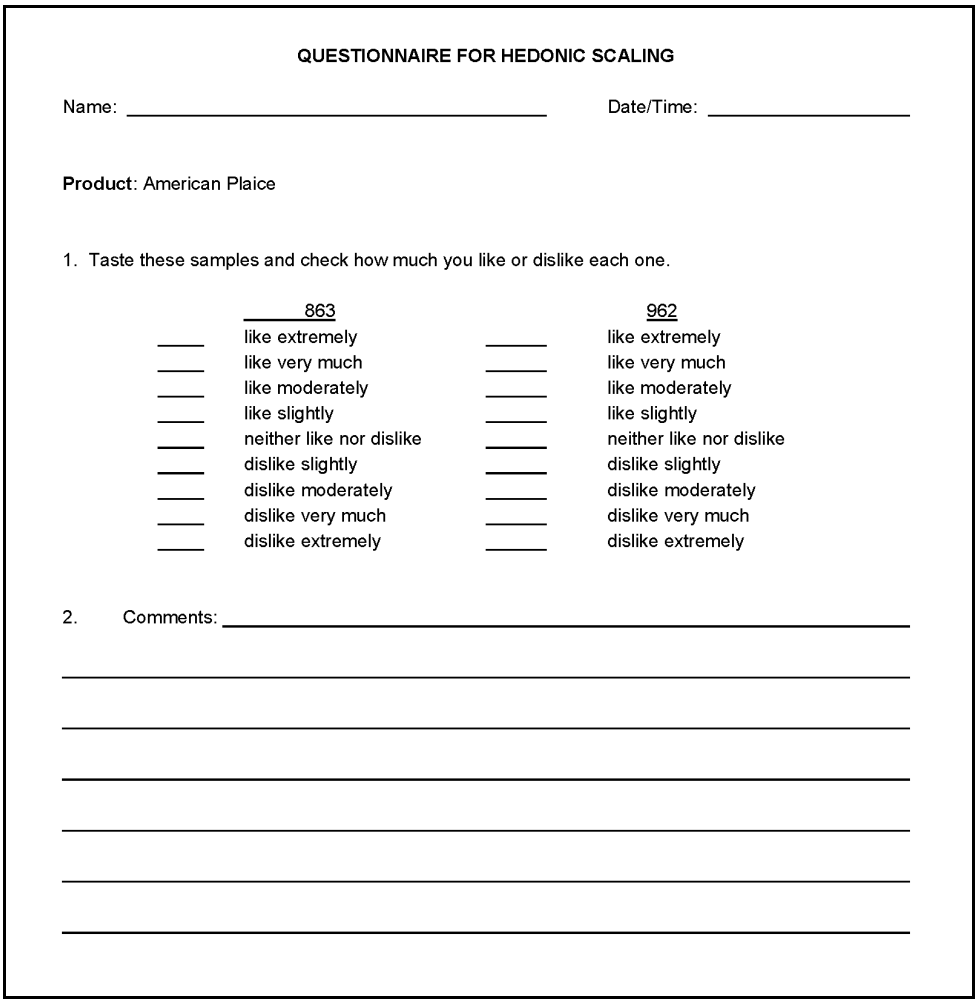
_____

_____

_____

_____

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.

	863		962
____	like extremely	_____	like extremely
____	like very much	_____	like very much
____	like moderately	_____	like moderately
____	like slightly	_____	like slightly
____	neither like nor dislike	_____	neither like nor 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

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).

6.1.2.4 Fish Health Indicators

MFO induction was assessed in liver samples as 7-ethoxyresorufin-O-deethylase (EROD) activity according to the fluorometric method of Pohl and Fouts (1980) as modified by Porter *et al*. (1989). Liver and gill samples were processed for histological analysis using standard histological methods (Lynch *et al.* 1969). Details on these methods are provided in Appendix C-3.

6.1.3 Data Analysis

6.1.3.1 Overview

The commercial fish component of the White Rose EEM program uses a multiple-reference design, usually with four Reference Areas and one Study Area. In 2018, two of the four Reference Areas were sampled (Reference Areas 1 and 2) because intense commercial fishing activity prevented sampling in Reference Areas 3 and 4. Multi-reference designs are common in environmental monitoring programs when a single Study Area of interest (*i.e.*, one production area) exists (Underwood 1993). The goal of these "asymmetrical" designs is to assess for potential environmental effects at a Study Area relative to the average of several representative Reference Areas. Using multiple reference areas better estimates the natural variability in environmental conditions of the larger region, thus providing a more accurate benchmark against which to compare environmental conditions at the Study Area.

6.1.3.2 Biological Characteristics

Biological characteristics (*i.e.*, 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. Additional analyses on plaice were performed in the context of the Fish Health Assessment (described below). Formal comparisons among years were not conducted.

Plaice

Composite mean gutted weights of plaice were compared among Areas using asymmetrical ANOVA (see Section 6.1.3.1) to test for differences in size among Reference Areas and between Reference and Study Areas for chemistry composites.

Differences in maturity stages between the Study and Reference Areas for fish used in Fish Health Assessment were assessed with Fisher's Exact Test. Biological characteristics and condition of these fish were compared among Areas. Total length, gutted weight and age were analyzed using asymmetrical 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 asymmetrical ANCOVA, which compares regression intercepts or adjusted means among Areas. Differences among Reference Areas and between the Reference and Study Areas were tested.

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)[16].

[16] The shell condition index used for White Rose is the index used by Fisheries and Oceans Canada in Newfoundland offshore surveys.

Shell condition was examined qualitatively. Asymmetrical ANOVA was used to test for significant differences in carapace width and claw height between the Reference and Study Areas.

6.1.3.3 Body Burden

Plaice

Spatial Variations in 2018

Body burden variables that were statistically analyzed were those that were frequently detected[17]. For liver tissue, this included fat content, concentrations of eight metals (arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc) and concentrations of $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons. These variables occurred above laboratory detection limit in all samples.

Fewer variables were frequently detected in plaice fillet tissue than in liver tissue. Variables analyzed in fillets were concentrations of arsenic, mercury, and zinc.

Asymmetrical ANOVA was used to compare body burden data among Areas. Concentrations were corrected for moisture content[18] and $\log_{10}$-transformed prior to analysis.

Variations in Temporal Trends

Differences in temporal trends in plaice liver variables were tested using a two-way asymmetrical ANOVA of composite tissue concentrations from 2004 to 2018[19] (Table 6-5). Due to missing data from Reference Area 3 in 2008, Reference Area 4 in 2008 and 2016 and Reference Areas 3 and 4 in 2018, Reference Areas were pooled into two groups to prevent loss of denominator degrees of freedom in the orthogonal study design. Reference Areas 1 and 4 were pooled into one group (North Reference Area) while Reference Areas 2 and 3 were pooled into another (South Reference Area). 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).

[17] Variables with greater than 25% of samples with test results below laboratory detection limits were not included in statistical analyses.

[18] Concentrations were standardized to approximate dry weights using: Corrected concentration = Original wet weight concentration/(1-Moisture Content). True dry weights would involve drying the samples prior to chemistry analysis, which was not conducted.

[19] Data from 2000 were not included in analyses because Reference Area data were collected in different locations during that year (see Husky Energy 2004 for details on baseline collections).

Table 6-5 Asymmetrical ANOVA Used for Comparison of Body Burden Variables Among Years (2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016, and 2018)

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)	8	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	8	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 (= Error)	8	Natural variance in concentrations among Reference Areas within years

Note: - df = degrees of freedom.

Concentrations were corrected for moisture content and $\log_{10}$-transformed prior to analysis. Moisture content was unavailable for thirteen of seventeen composite liver samples in 2008, and for four of twenty-two composite liver samples in 2012. Missing moisture values were replaced with the mean of remaining values in each of those years.

Crab

Spatial Variations in 2018

Crab leg body burden variables analyzed were concentrations of eight frequently detected metals (arsenic, boron, copper, mercury, selenium, silver, strontium, and zinc). Values less than laboratory detection limits were set at ½ laboratory detection limits prior to statistical analysis.

Asymmetrical ANOVA was used to compare body burden data among Areas. Concentrations were corrected for moisture content and $\log_{10}$-transformed prior to analysis.

Variations in Temporal Trends

Differences in temporal trends in crab tissue variables were tested using a two-way asymmetrical ANOVA of composite tissue concentrations from 2004 to 2018[20] (Table 6-5), as described above. 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 above, concentrations were corrected for moisture content and $\log_{10}$-transformed prior to analysis.

[20] As with plaice, data from baseline were not included in these analyses because Reference Area data were collected in different locations.

6.1.3.4 Taste Tests

The triangle and hedonic scaling test procedures (Botta 1994) were used to compare Study Area samples to combined Reference Area samples.

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

Mixed Function Oxygenase Activity

Asymmetrical ANOVA was used to compare MFO activity in immature and pre-spawning females. MFO values were $\log_{10}$-transformed for analyses. Data for male fish were examined qualitatively because of low sample size.

Histopathology

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

Liver Histopathology

Fisher's Exact Test was used to compare the frequency of nuclear pleomorphism, macrophage aggregates, inflammatory response, hepatocellular vacuolation, and parasites between the Study Area and the combined Reference Areas. The low incidence of all the other hepatic lesions prevented statistical comparisons.

Gill Histopathology

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.

6.2 Results

6.2.1 Biological Characteristics

6.2.1.1 Plaice

Summary statistics for composite mean gutted weights of plaice used in body burden analyses are provided in Table 6-6.

Table 6-6 Summary Statistics for Plaice Composite Mean Gutted Weight (g) (2018)

Area	*n*	Min	Max	Mean	SD
Reference Area 1	6	531	663	605	43
Reference Area 2	6	376	588	488	74
Both References	12	376	663	547	84
Study Area	10	454	699	548	84

Notes: - *n* = number of composites per Area. Refer to Table 6-2 for number of fish per composite.
- SD = standard deviation.

Variations in mean gutted weight within composites did not differ between the Study and Reference Areas (p = 0.972, Table 6-7). However, mean gutted weight within composites differed between the two Reference Areas (p = 0.012), with mean gutted weight higher in Reference Area 1 than in Reference Area 2 (Figure 6-5).

Table 6-7 Results of Asymmetrical ANOVA Comparing Plaice Composite Mean Gutted Weight (g) Among Areas (2018)

Source	SS	df	MS	F-Ratio	*p*
Reference *vs* Study	6.52	1	6.52	0.00123	0.972
Among Reference	41282.34	1	41282.34	7.81	0.012*
Error	100375.72	19	5282.93		

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

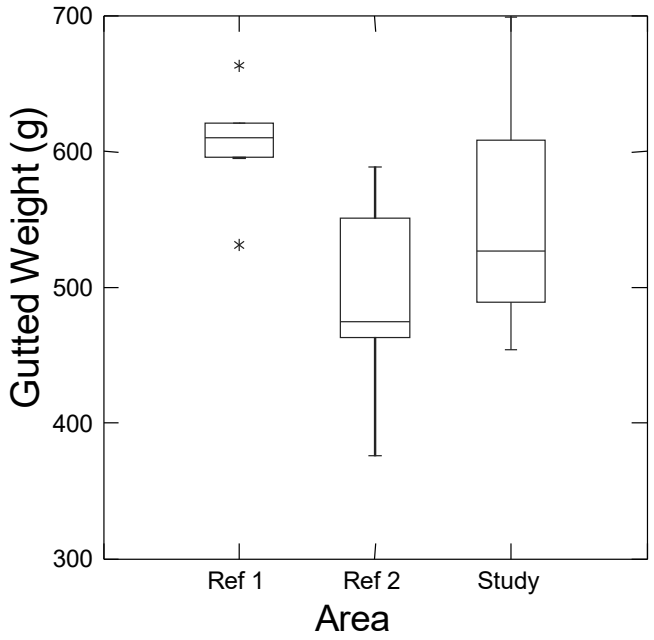


Figure 6-5 Box Plot of Plaice Gutted Weight (g)

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 and condition of individual plaice is undertaken within the context of Fish Health Assessment. More relevant information is provided below, with details in Appendix C-3.

Female plaice outnumbered males in all Areas (Table 6-8), accounting for 95% of the 180 fish processed. Sex ratios did not differ significantly between the combined Reference Areas (F:M≈14:1) and the Study (F:M≈59:1) Area (p = 0.275; Fisher's Exact Test).

Table 6-8 Numbers of Female and Male Plaice (2018)

Area	Females		Males		Total
	Number	%	Number	%	Number
Reference 1	59	98.3	1	1.7	60
Reference 2	53	88.3	7	11.7	60
All Reference Areas	112	93.3	8	6.7	120
Study Area	59	98.3	1	1.7	60
All Areas	171	95.0	9	5.0	180

Notes: - All References = Sum of the three Reference Areas.
- All Areas = sum of the Reference and Study Areas.

Most females examined (79%) were mature (i.e., all maturity stages except F-500), and very few (1%) of the mature females were spent (maturity stage F-560) (Table 6-9). Sufficient numbers of immature and pre-spawning females were available to perform statistical analyses on these two groups. Frequencies of immature (maturity stage F-500) and pre-spawning females (maturity stages F-510 to F-540) did not vary significantly between the combined Reference Areas and the Study Area (Fisher's Exact test, p = 1.00).

Table 6-9 Frequency of Maturity Stages of Female Plaice (2018)

Area	Immature F-500 [a]		Maturing to spawn this year F-510 to F-540 [a]		Spent this year F-560 [a]		Total Number
	Number	%	Number	%	Number	%	
Reference 1	14	24	45	76	0	0	59
Reference 2	10	19	41	77	2	4	53
All References	24	21	86	77	2	2	112
Study Area	12	20	47	80	0	0	59
All Areas	36	21	133	78	2	1	171

Notes: - [a] Maturity stages were defined per procedures used by DFO (Appendix C-3, Annex A);
- All References = Sum of the two Reference Areas;
- All Areas = sum of the Reference and Study Areas

Since female fish undergo physical and physiological changes during their reproductive period, it can be informative to carry out comparisons of biological characteristics and condition within maturity stages, when numbers permit. In 2018, sufficient numbers of immature (stage F-500) and pre-spawning females (stages F-510 to F-540) were caught to allow comparison.

Biological characteristics and condition of immature females (expressed as means ± standard deviations (SDs)) from the Reference and Study Areas are summarized in Table 6-10. Across all Areas, immature females varied in length from 32 to 47 cm, in gutted weight from 244 to 788 g, and in age from 5 to 11 years. The regression analogue of condition factor (gutted weight over length analyzed using ANCOVA) differed

significant between the Study and Reference Areas (Table 6-11) and was greater by 13% in the Study Area. In contrast, gutted weight and age were significantly different between Reference Areas (Table 6-11) with fish in Reference Area 2 lighter and younger than fish in Reference Area 1 (Table 6-10).

Table 6-10 Mean Biological Characteristics and Condition of Immature Female Plaice (2018)

Statistics	Area			
	Ref 1	Ref 2	Study	Total
Number of Fish	**14**	**10**	**12**	**36**
Length (cm)	38.3 ± 3.7	35.4 ± 1.6	37.8 ± 4.2	37.3 ± 3.6
Weight (g)	542 ± 147	414 ± 72	543 ± 181	507 ± 152
Gutted Weight (g)	420 ± 133	323 ± 50	426 ± 140	395 ± 124
Liver Weight (g)	7.9± 3.5	6.4 ± 2.1	6.7 ± 3.0	7.1 ± 3.0
Gonad Weight (g)	10.7 ± 7.7	9.9 ± 5.7	8.0 ± 3.0	9.6 ± 5.9
Age (years)	8.3 ± 1.3	6.7 ± 1.3	8.4 ± 1.5	7.9 ± 1.5
Condition Factor[a]	0.7 ± 0.1	0.7 ± 0.0	0.8 ± 0.1	0.7 ± 0.1
HSI[b]	1.9 ± 0.7	2.0 ± 0.6	1.6 ± 0.4	1.8 ± 0.6
GSI[c]	2.5 ± 1.0	3.0 ± 1.7	2.0 ± 0.7	2.4 ± 1.2

Notes: - [a] Condition Factor = 100 × gutted weight/length³.
- [b] HSI = hepatosomatic index = 100 × liver weight/gutted weight.
- [c] GSI = gonadosomatic index = 100 × gonad weight/gutted weight.
- Values are means ± 1 SD.

Table 6-11 Results of Asymmetrical ANCOVA Comparing Biological Characteristics and Condition of Immature Female Plaice (2018)

Variable (Y)	Covariable (X)	*p*-value	
		Among Reference (AR)	Study versus References (SR)
Length		0.093	0.484
Gutted Weight		0.039*	0.275
Age		0.010**	0.117
Gutted Weight	Length	1.000	0.032*
Liver Weight	Gutted Weight	0.485	0.121
Gonad Weight[a]	Gutted Weight	0.416	0.678

Notes: - Results were based on log-transformed values of *Y* and *X* variables.
- **p* ≤ 0.05; ***p* ≤ 0.01; ****p* ≤ 0.001 (in **bold**).
[a] Due to the significantly lower gutted weight of fish from Reference Area 2, a subset of fish with comparable weight ranges were selected for analyses to avoid violation of assumption of parallel slopes among Areas (Quinn and Keough, 2002).

Biological characteristics and condition of pre-spawning females (expressed as means ± SD) from the Reference and Study Areas are summarized in Table 6-12.

Table 6-12 Biological Characteristics and Condition of Pre-spawning Female Plaice (2018)

Statistics	Area			
	Ref 1	Ref 2	Study	Total
Number of Fish	**45**	**41**	**47**	**133**
Length (cm)	44.1 ± 4.5	41.3 ± 3.6	43.2 ± 4.4	42.9 ± 4.3
Weight (g)	885 ± 316	693 ± 180	827 ± 327	805 ± 294
Gutted Weight (g)	699 ± 262	567 ± 159	673 ± 262	649 ± 240
Liver Weight (g)	13.8 ± 7.3	10.0 ± 5.2	13.7 ± 6.5	12.6 ± 6.6
Gonad Weight (g)	27.6 ± 14.7	40.1 ± 29.8	33.0 ± 33.7	33.4 ± 27.6
Age (years)	9.5 ± 1.2	8.8 ± 1.2	9.3 ± 1.1	9.2 ± 1.2
Condition Factor[a]	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1	0.8 ± 0.1
HSI[b]	1.9 ± 0.7	1.8 ± 0.8	2.0 ± 0.6	1.9 ± 0.7
GSI[c]	3.9 ± 1.8	7.2 ± 4.9	4.8 ± 3.4	5.2 ± 3.8

Notes: - [a] Condition factor = 100 × gutted weight/length³.
- [b] HSI = hepatosomatic index = 100 × liver weight/gutted weight.
- [c] GSI = gonadosomatic index = 100 × gonad weight /gutted weight.
- DFO maturity stages F-510, F-520, F-530 and F-540 were combined for these analyses.
- Values are means ± 1 SD.

Across all Areas, pre-spawning females varied in length from 33.5 to 56.5 cm, in gutted weight from 300 to 1,548 g, and in age from 6 to 13 years. No significant differences were found between Study and Reference Areas for any of the variables examined for pre-spawning females (Table 6-13). In contrast, length, gutted weight, age, and gonad weight (as a function of gutted weight) were significantly different between Reference Areas, with Reference Area 2 fish shorter, lighter, younger, and with much heavier gonads than Reference Area 1 fish (Tables 6-12).

Table 6-13 Results of Asymmetrical ANCOVA Comparing Biological Characteristics and Condition of Pre-spawning Females Plaice (2018)

Variable (Y)	Covariable (X)	*p*-value	
		Among Reference (AR)	Study versus References (SR)
Length		0.004**	0.481
Gutted Weight		0.007**	0.376
Age		0.003**	0.373
Gutted Weight	Length	0.481	0.319
Liver Weight	Gutted Weight	0.151	0.076
Gonad Weight	Gutted Weight	**<0.001*** **	0.108

Notes: - ANCOVA were based on log-transformed values of *Y* and *X* variables.
- DFO maturity stages F-510, F-520, F-530 and F-540 were combined for these analyses.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

6.2.1.2 Crab

Shell condition index values for crab collected in 2018 and used for body burden analyses are provided in Table 6-14. The majority of the crab collected in the Study Area and in Reference 1 had moulted in 2018. The majority of crab in Reference Area 2 had moulted in 2017 (Table 6-14).

Table 6-14 Frequency (%) of Index Values Indicating Year Since Moult in Crab (2018)

Index Value	Year of Moult	Area			
		Ref 1	Ref 2	All Ref	Study
1,2	2018	67%	36%	50%	52%
6	2017	6%	54%	33%	25%
3,4	2016 or earlier	30%	10%	18%	24%
Total Crabs (*n*)		54	69	123	98

Notes: - Index values 1 and 2: recent moult.
- Index value 6: one year since moult.
- Index values 3 and 4: two or more years since moult.
- Percentages do not add up precisely to 100% because of rounding error.

Summary statistics for composite means for carapace width and claw height are provided in Table 6-15. Neither crab carapace width nor claw height differed significantly between the Reference and Study Areas ($p > 0.05$; Table 6-16). In contrast, mean carapace width and claw height varied significantly between the Reference Areas ($p \leq 0.05$; Table 6-16), with both carapace width and claw height larger in Reference Area 1 than in Reference Area 2 (Table 6-15).

Table 6-15 Summary Statistics for Biological Characteristics of Crab Based on Composite Mean Carapace Width and Claw Height (2018)

Variable	Area	*n*	Min	Max	Mean	SD
Carapace width (mm)	Reference Area 1	6	84.7	104.0	95.9	6.7
	Reference Area 2	6	75.3	86.0	80.0	3.9
	Both References	12	75.3	104.0	87.9	9.8
	Study Area	10	77.6	106.5	89.6	9.1
Claw height (mm)	Reference Area 1	6	18.2	23.0	20.5	1.9
	Reference Area 2	6	12.5	16.1	14.4	1.4
	Both References	12	12.5	23.0	17.5	3.5
	Study Area	10	12.7	24.3	18.8	3.5

Note: - SD = standard deviation.

Table 6-16 Results of Asymmetrical ANOVA Comparing Crab Biological Characteristics Among Areas (2018)

Variable	Source	Type III SS	df	Mean Squares	F-Ratio	*p*-value
Carapace Width	Study *vs* Reference	15.68	1	15.68	0.28	0.600
	Among Reference	756.29	1	756.29	13.74	**0.001*** **
	Error	1045.91	19	55.05		
Claw Height	Study *vs* Reference	9.88	1	9.88	1.36	0.258
	Among Reference	109.64	1	109.64	15.10	**0.001*** **
	Error	137.98	19	7.26		

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, 2012, 2014, 2016, and 2018, and raw data for 2018 are provided in Appendix C-2. Arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc were detected frequently in all years. Concentrations of these eight metals, fat content, and concentrations of $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons were analyzed quantitatively.

Hydrocarbons in the >C_{10}-C_{21} and >C_{21}-C_{32} range have been detected in all years and have shown no resemblance to drill fluid or petroleum hydrocarbons (J. Kiceniuk, pers. comm.; Maxxam Analytics, pers. comm.), and similar compounds also have been consistently observed in liver tissue at the nearby Terra Nova site (Suncor Energy 2017). As in previous years, additional Gas Chromatography/ Mass Spectrometer analysis of four liver samples in 2018 (see Appendix C-2) indicated that there was no indication of drill fluid or petroleum hydrocarbons in those samples (see Appendix C-2).

Spatial Variations in 2018

The results of asymmetrical ANOVA are presented in Table 6-17, and the spatial variations in variable concentrations are illustrated in the box plots in Figure 6-6. Liver concentrations of >C_{10}-C_{21} hydrocarbons varied significantly between the two Reference Areas, with concentrations higher in Reference Area 1 than in Reference Area 2 ($p \leq 0.05$, Table 6-17; Figure 6-6). Liver concentrations of cadmium, selenium and >C_{10}-C_{21} hydrocarbons varied significantly between the Reference Areas and the Study Area ($p \leq 0.05$, Table 6-17; Figure 6-6). Differences in mercury concentrations between the Reference Areas and the Study Area were also near significant ($p = 0.051$, Table 6-17). Concentrations of cadmium, mercury and selenium were lower in the Study Area than in the Reference Areas. Concentrations of >C_{10}-C_{21} hydrocarbons were higher in the Study Area although, as noted, concentrations of >C_{10}-C_{21} hydrocarbons also differed between the two Reference Areas (Figure 6-6).

Table 6-17 Results of Asymmetrical ANOVA Comparing Plaice Liver Body Burden Variables among Areas (2018)

Variable	*p*-values	
	Among Reference	**Reference *vs* Study**
Fat	0.871	0.527
Arsenic	0.587	0.238
Cadmium	0.269	0.016*
Copper	0.707	0.192
Iron	0.119	0.174
Manganese	0.250	0.071
Mercury	0.324	0.051
Selenium	0.819	0.002**
Zinc	0.962	0.063
>C_{10}-C_{21}	**<0.001*** **	**<0.001*** **
>C_{21}-C_{32}	0.169	0.097

Notes:
- Values are probabilities of no difference among areas, or no difference among or between the Areas.
- Variables were corrected for moisture content and $\log_{10}$-transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- A statistical outlier was noted for cadmium; a high cadmium value was noted for one composite sample from the Study Area (see Figure 6-6). Removal of this outlier changed results for the Reference vs Study Comparison from not-significant to significant. Results provided are with the outlier excluded.

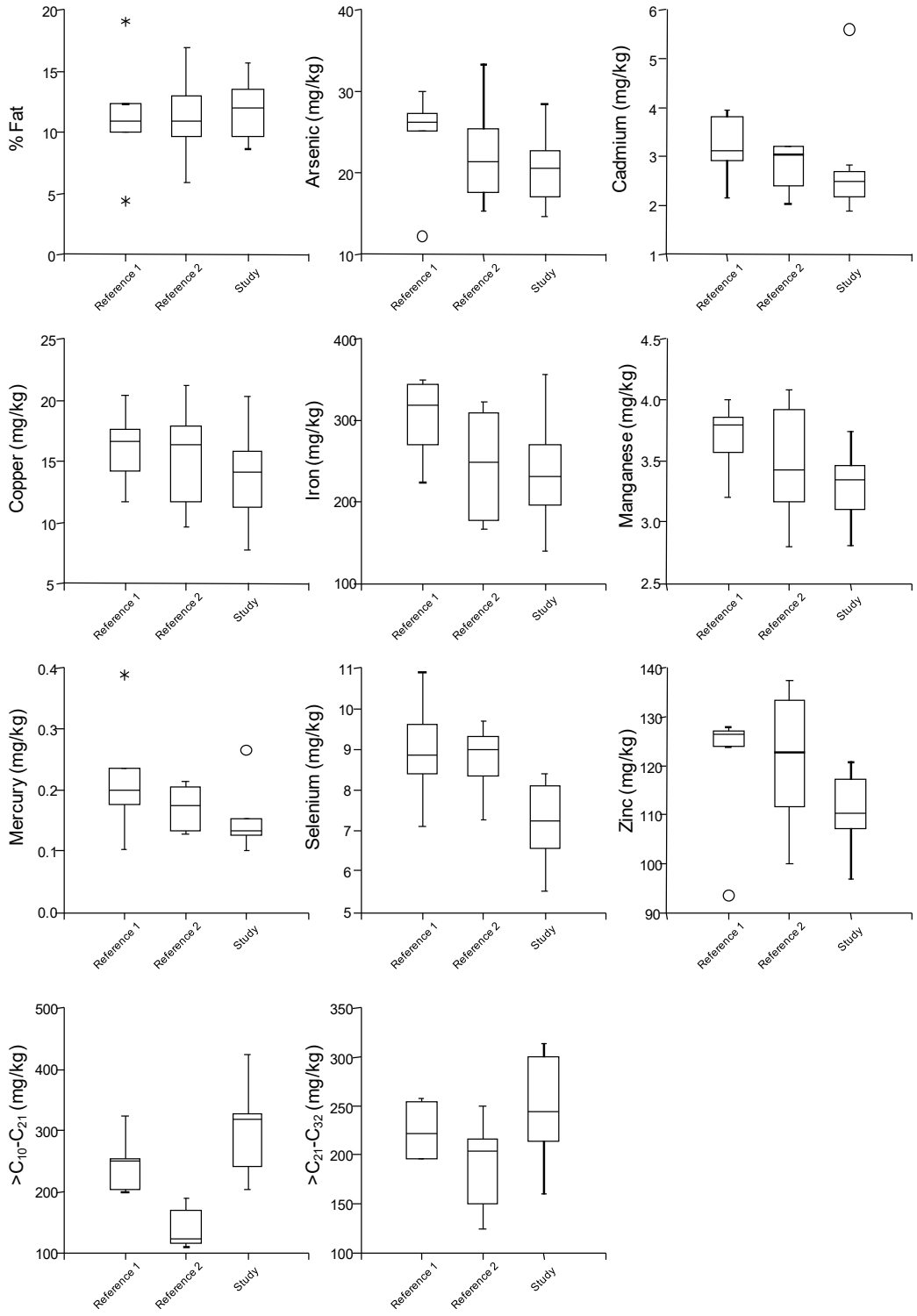


Figure 6-6 Box Plots of Variable Concentrations in Plaice Livers in Reference and Study Areas (2018)

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. Variables were corrected for moisture content.

Variations in Temporal Trends

Variations in mean concentrations of frequently detected variables in plaice livers between 2004 and 2018 are illustrated in Figure 6-7. A significant area-wide linear trend was noted for all variables except >C_{10}-C_{21} hydrocarbons (Table 6-18). Percent fat generally decreased over time, in all areas. Remaining variables exhibiting linear trends generally increased over time, in all Areas (Figure 6-7). The linear trend differed between the Reference and Study Areas for copper only (p = 0.048, Table 6-18). Copper concentrations generally increased from 2014 to 2016, in all Areas. However, the increase to 2016 was slightly more pronounced in the Study Area (as determined by the slope of the linear relationships). This was largely driven by relatively high copper concentrations in Study Area liver in 2014 and 2016. In 2018, concentrations in the Study Area were similar to those in the Reference Areas (Figure 6-7; also see Table 6-17).

Table 6-18 Results of Asymmetrical ANOVA Testing for Differences in Average Plaice Liver Body Burden Variables and Temporal Trends Between the Reference and Study Areas (2004 to 2018)

Variable	Linear		Quadratic	
	Area-Wide Trend	Difference Between Reference and Study	Area-Wide Trend	Difference Between Reference and Study
Fat	**<0.001*** **	0.397	**<0.001*** **	0.868
Arsenic	**<0.001*** **	0.886	**<0.001*** **	0.389
Cadmium	**<0.001*** **	0.715	0.692	0.897
Copper	**<0.001*** **	0.048*	**<0.001*** **	0.301
Iron	**<0.001*** **	0.792	0.562	0.857
Manganese	**<0.001*** **	0.439	**<0.001*** **	0.440
Mercury	**<0.001*** **	0.488	0.053	0.246
Selenium	**<0.001*** **	0.981	0.017*	0.775
Zinc	**<0.001*** **	0.733	0.043*	0.168
>C_{10}-C_{21}	0.511	0.499	<0.001***	0.102
>C_{21}-C_{32}	**<0.001*** **	0.947	**<0.001*** **	0.388

Notes:
- Values are probabilities of no temporal trend or no difference in temporal trends.
- Variables were corrected for moisture content and $\log_{10}$-transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- A statistical outlier was noted for zinc (a low value of 18.4 mg/kg wet (or 52.6 mg/kg corrected for moisture content) in one composite samples from Reference Area 2 in 2012). Removal of this outlier changed the significance of the area-wide term from not-significant to significant. Results presented are those with the statistical outlier excluded.

Area-wide quadratic trends (increase followed by a decrease or vice versa; see Figure 6-7) were significant for all variables except cadmium, iron and mercury. In general, metals concentrations were high in 2014 and 2016 relative to prior or subsequent years, in all areas. Fat concentrations were relatively high in 2006 relative to other years, in all areas. >C_{10}-C_{21} hydrocarbon concentrations were low from 2006 to 2014, relative to years prior or subsequent years; and >C_{21}-C_{32} hydrocarbon concentrations were lowest in 2004, 2006, and 2018, and higher in intervening years (Figure 6-7). These changes occurred in all areas with no significant difference between the Reference and the Study Areas (Table 6-18).

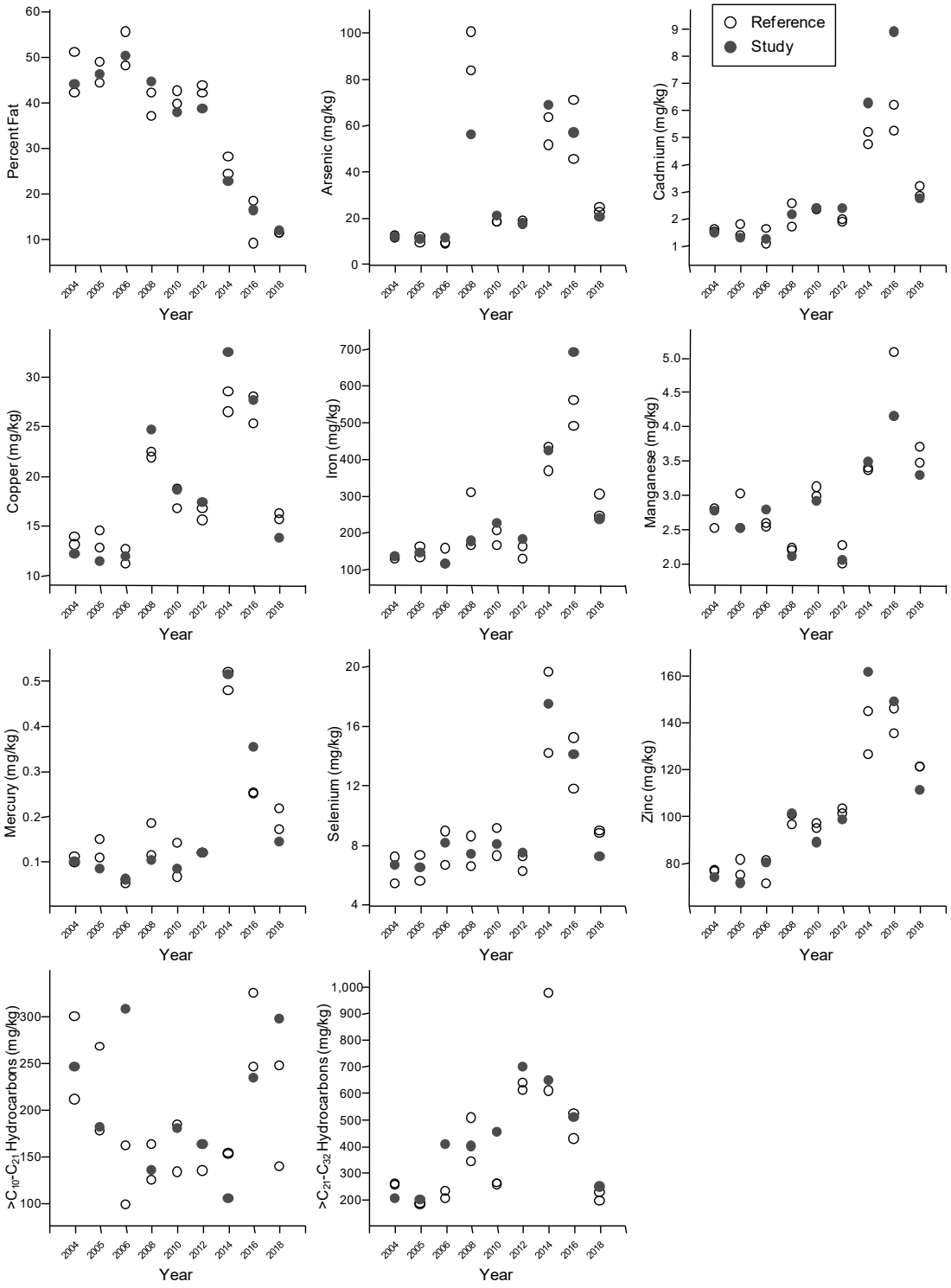


Figure 6-7 Variations in Area Means of Detectable Metals and Hydrocarbons in Plaice Liver Composites from 2004 and 2018

Note: Values shown are annual averages within Areas. Black circles are Study Area averages; open circles are averages for each Reference Area. Variables were corrected for moisture content.

Fillets

Summary statistics for concentrations of detected substances in 2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016, and 2018, and raw data for 2018 are provided in Appendix C-2. Arsenic, mercury, and zinc were detected frequently in plaice fillet tissue in all years. These metals were analyzed quantitatively.

Aluminum, boron, copper, iron, lead, nickel, selenium, and strontium were detected in some samples in some years (Appendix C-2). Compounds in the $>C_{10}$-C_{21} and/or $>C_{21}$-C_{32} hydrocarbon range were sometimes detected in Reference Areas. However, chromatograms for these samples did not indicate the presence of drill muds or petrogenic compounds (J. Kiceniuk, pers. comm.). PAHs were only detected in 2014, in seven samples from the Reference Areas and in two samples from the Study Area. Details are provided in Appendix C-2.

Spatial Variations in 2018

In 2018, significant differences were noted between Reference Areas fillet concentrations of arsenic and mercury ($p \leq 0.05$, Table 6-19), with lower values for both variables in Reference Area 2 (Figure 6-8). Arsenic concentrations were higher in the Study Area compared to Reference Areas overall ($p = 0.002$, Table 6-19). However, arsenic concentrations were similar between the Study Area and Reference Area 1 (Figure 6-8).

Table 6-19 Results of Asymmetrical ANOVA Comparing Plaice Fillet Body Burden Variables among Areas (2018)

Variable	*p*-values	
	Among Reference	**Study *vs* Reference**
Arsenic	0.005**	0.002**
Mercury	0.046*	0.493
Zinc	0.886	0.522

Notes:
- Values are probabilities of no difference among Areas, or between Reference and Study Areas.
- Variables were corrected for moisture content and $\log_{10}$-transformed prior to analysis.
- One statistical outlier for arsenic from Reference Area 2 was noted (see Figure 6-8). Removal of the outlier changed the significance of both the Among Reference and Study vs Reference terms from not-significant to significant. Results presented for arsenic are with the outlier excluded.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

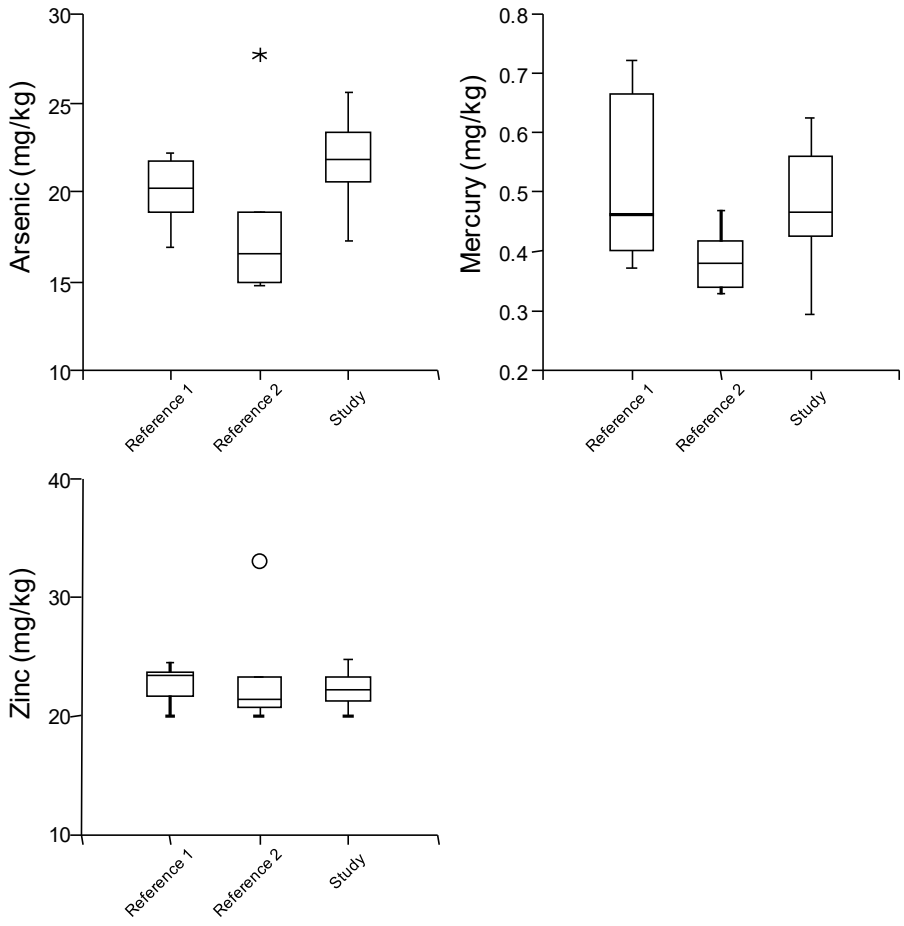


Figure 6-8 Box Plots of Variable Concentrations in Plaice Fillets in Reference and Study Areas (2018)

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. Variables were corrected for moisture content.

Variations in Temporal Trends

Significant linear area-wide trends were seen for fillet arsenic, mercury and zinc concentrations ($p \leq 0.05$, Table 6-20), with a general increase over time in both the Study and Reference Areas (Figure 6-9). Significant area-wide quadratic trends (in this case, a decrease followed by an increase) were also seen for all variables ($p \leq 0.05$, Table 6-20; Figure 6-9). There was no difference between the Reference and Study Areas in either linear or quadratic trends ($p > 0.05$).

Table 6-20 Results of Asymmetrical ANOVA Testing for Differences in Average Fillet Body Burden Variables and Temporal Trends Between the Reference Areas and the Study Areas (2004 to 2018)

Variable	Linear		Quadratic	
	Area-Wide Trend	Difference Between Reference and Study	Area-Wide Trend	Difference Between Reference and Study
Arsenic	**<0.001*** **	0.417	**0.001*** **	0.118
Mercury	<0.001***	0.235	0.002**	0.317
Zinc	<0.001***	0.930	**<0.001*** **	0.923

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

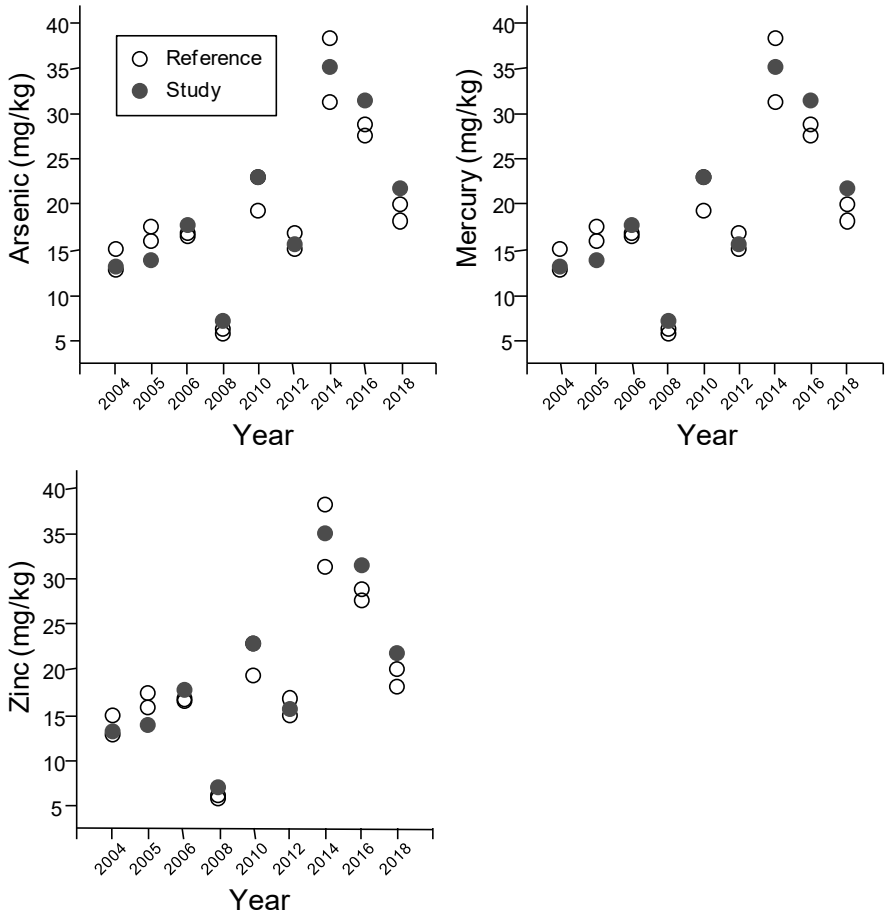


Figure 6-9 Variations in Arsenic, Mercury and Zinc Concentrations in Plaice Fillets from 2004 to 2018

Note: Values shown are annual averages within Areas. Black circles are Study Area averages; open circles are averages for each Reference Area. Variables were corrected for moisture content.

6.2.2.2 Crab

Summary statistics for concentrations of detected substances in crab claw composites in 2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016, and 2018 are provided in Appendix C-2, as are raw data for 2018. Arsenic, boron, copper, mercury, selenium, silver, strontium, and zinc were detected frequently in crab claw tissue across all years. These metals were analyzed quantitatively.

Iron was detected in all tissues in 2014, when it was measured at a lower detection limit (Table 6-4). PAHs were also detected in 2014, in three samples in Reference Areas and in three samples from the Study Area; and, again in that year, compounds in the $>C_{21}$-C_{32} hydrocarbon range bearing no resemblance to drill fluids or petrogenic compounds were detected in two samples from the Reference Areas and four samples from the Study Area. Aluminum, cadmium, cobalt, and lead were detected sporadically across all years (Appendix C-2).

Spatial Variations in 2018

Concentrations of boron, copper, mercury, selenium and zinc varied significantly among Reference Areas in 2018 ($p \leq 0.05$, Table 6-21; Figure 6-10). Concentrations of boron, copper and mercury also varied significantly between the Study Area and the Reference Areas ($p \leq 0.05$, Table 6-21). Boron concentrations were generally higher in the Study Area than in the Reference Areas (Figure 6-10). Though not apparent from Figure 6-10, copper concentrations were lower and mercury concentrations were higher in the Study Area compared to the Reference Areas overall. However, for boron, copper and mercury, Study Area concentrations were similar to concentrations in Reference Area 1 (Figure 6-10).

Table 6-21 Results of Asymmetrical ANOVA Comparing Crab Body Burden Variables among Areas (2018)

Variable	*p*-value	
	Among Reference	**Study *vs* Reference**
Arsenic	0.110	0.369
Boron	**<0.001*** **	**<0.001*** **
Copper	0.002**	0.013*
Mercury	**<0.001*** **	0.004**
Selenium	**0.001*** **	0.071
Silver	0.340	0.596
Strontium	0.558	0.528
Zinc	**<0.001*** **	0.085

Note: - Values are probabilities of no difference among or between the Areas.
- Variables were corrected for moisture content and $\log_{10}$-transformed prior to analysis.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

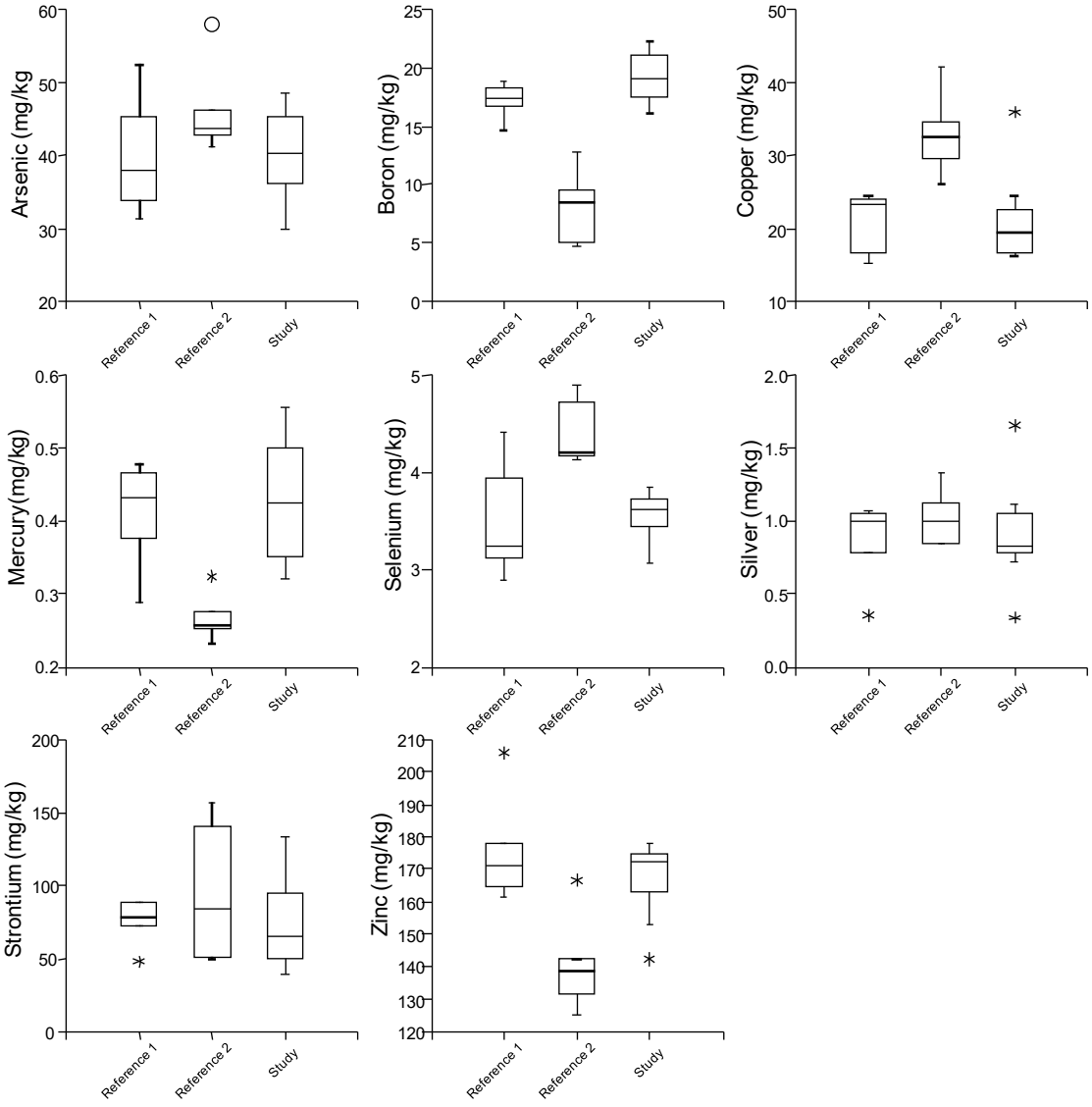


Figure 6-10 Box Plots of Variable Concentrations in Crab Claw in Reference and Study Areas (2018)

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. Variables were corrected for moisture content.

Variations in Temporal trends

Significant area-wide linear trends were noted for arsenic, copper, selenium, and zinc ($p \leq 0.05$, Table 6-22). Although not readily apparent from plots of areas means (Figure 6-11), there was a general increase over time for all four variables, with no significant differences in linear trends between the Study and Reference Areas for these or any other variable (Table 6-22). Quadratic trends (in this case a decrease followed by an increase) were stronger (Table 6-22) and more apparent (Figure 6-11) than linear trends. There was a significant area-wide quadratic trend for all variables (Table 6-22). For arsenic, the quadratic trend differed between the Study and Reference Areas ($p = 0.031$, Table 6-22). In general, the decrease and subsequent increase for arsenic was less pronounced in the Reference Areas than the Study Area. There were no other significant differences in quadratic trends between the Study and Reference Areas.

Table 6-22 Results of Asymmetrical ANOVA Testing for Differences in Average Crab Body Burden Variables and Temporal Trends Between the Reference Areas and the Study Areas (2004 to 2018)

Variable	Linear		Quadratic	
	Area-Wide Trend	Difference Between Reference and Study	Area-Wide Trend	Difference Between Reference and Study
Arsenic	0.038*	0.066	**<0.001*** **	0.031*
Boron	0.553	0.309	0.028*	0.278
Copper	0.002**	0.188	**<0.001*** **	0.119
Mercury	0.356	0.936	0.018*	0.409
Selenium	0.002**	0.461	**<0.001*** **	0.375
Silver	0.778	0.662	**<0.001*** **	0.498
Strontium	0.438	0.520	0.039*	0.468
Zinc	0.017*	0.997	**<0.001*** **	0.588

Notes:
- Values are probabilities of no trend, or no difference in temporal trends.
- Variable concentrations were corrected for moisture content and $\log_{10}$-transformed prior to the analyses.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

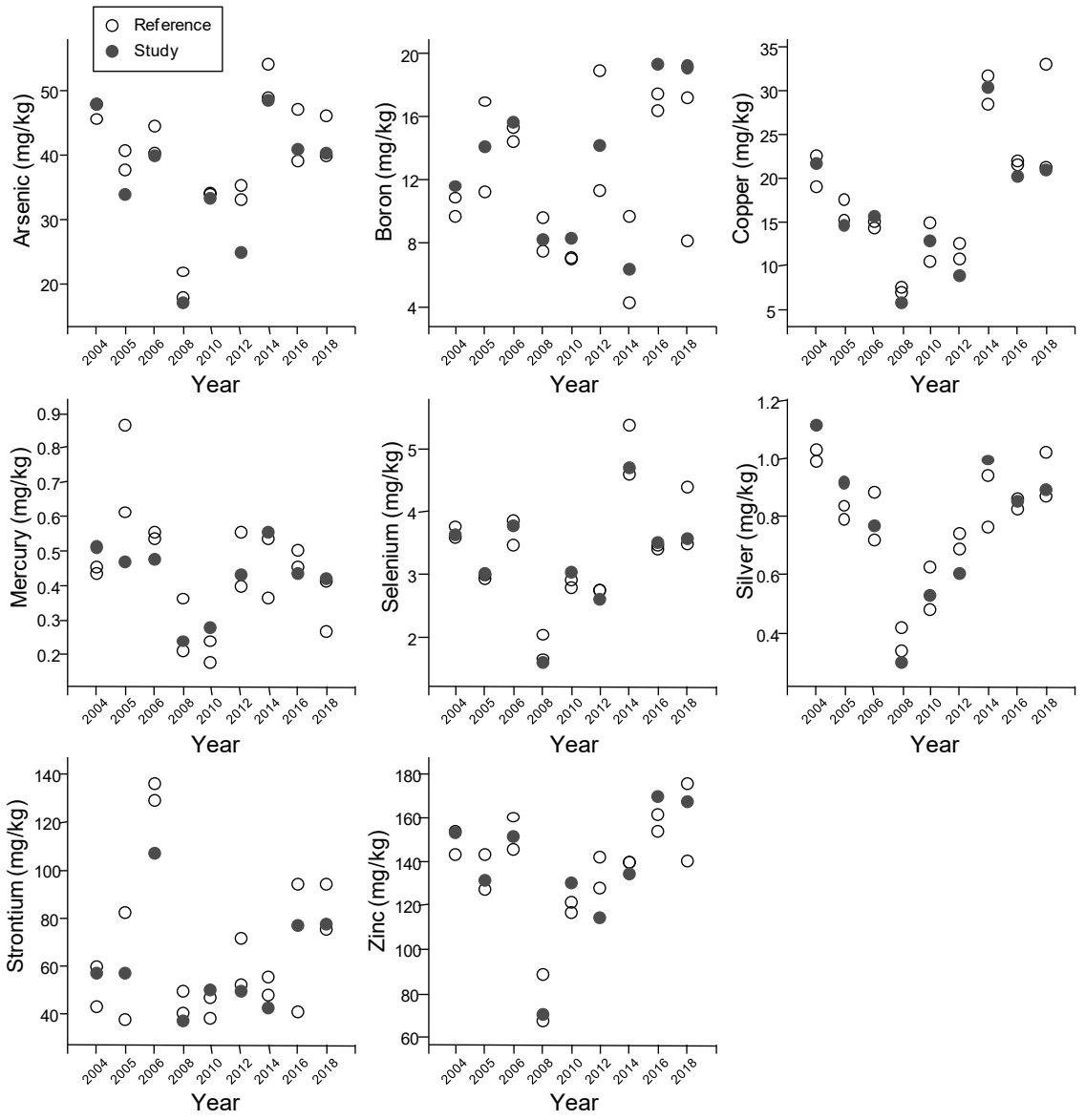


Figure 6-11 Variation in Area Means of Detectable Variable Concentrations in Crab Claw Composites from 2004 to 2018

Note: Values shown are annual averages within Areas. Black circles are Study Area averages; open circles are averages for each Reference Area. Variables were corrected for moisture content.

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 2018 in either the triangle or hedonic scaling tests. Panelists for the triangle test were successful in discriminating 7 out of 24 samples. These results were not significant (p > 0.05, Appendix C-4). ANOVA statistics for hedonic scaling are provided in Table 6-23. The results were not significant (p = 0.92) 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 6-25 and 6-26, and Appendix C-4), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 6-23 ANOVA for Taste Preference Evaluation of Plaice by Hedonic Scaling (2018)

Source of Variation	SS	df	MS	F	*p*-value
Between Groups	0.02	1	0.02	0.01	0.92
Within Groups	94.96	46	2.06		
Total	94.98	47			

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

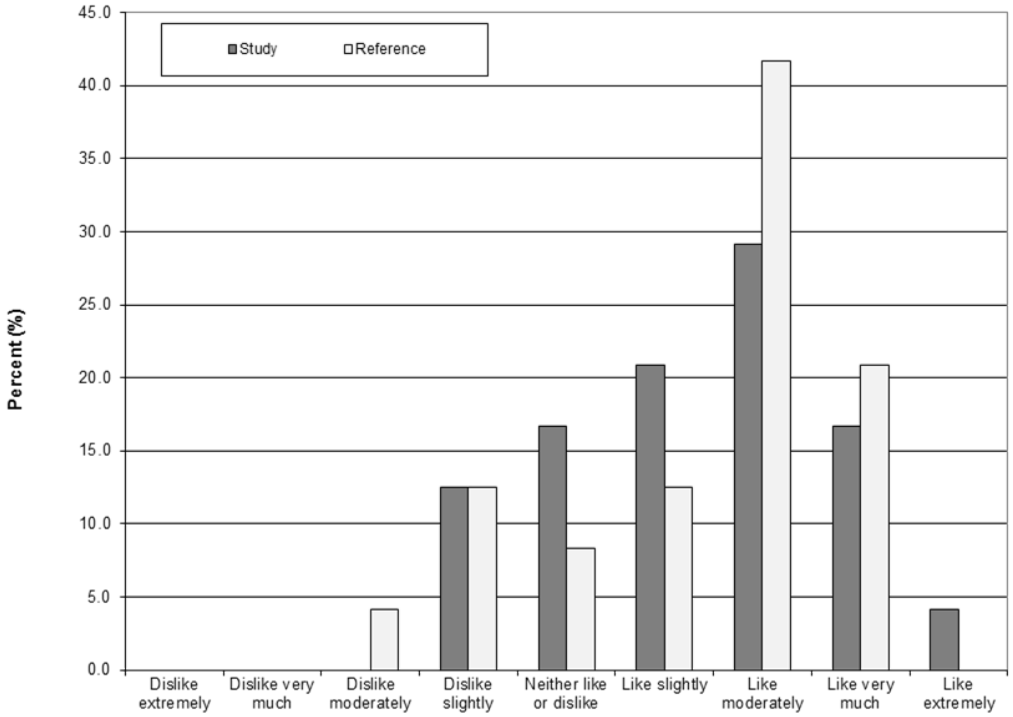


Figure 6-12 Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2018)

Table 6-24 Summary of Comments from the Triangle Taste Test for Plaice (2018)

Reference Area	Study Area
Correctly identified as odd sample	**Correctly identified as odd sample**
	Very little difference if any. Chose 849 [Study Area], but not a big difference
	827 [Study Area] was milder in flavour
	827 [Study Area] is milder in taste
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
None, but less fishy odour	Very little difference
492 [Reference Area] had a slightly less desirable flavour	Almost tasteless
492 [Reference Area] had a slightly better taste that the other 2 samples	807 [Study Area] - different odour
827 [Study Area] and 492 [Reference Area] had similar taste, a bit salty. 677 [Reference Area] had a different odour and taste	

Note: - Comments are transcribed exactly from participant input except that the text for “reference” and “study” was inserted. These were blind taste tests and therefore panelists were unaware of the source of samples.

Table 6-25 Summary of Comments from the Hedonic Scaling Taste Test for Plaice (2018)

Preferred Reference Area	Preferred Study Area
No real difference observed	No real difference observed
I think the 739 [Study Area] sample tasted metallic	902 [Reference Area] tasted first - very bland but strange aftertaste. 739 [Study Area] tasted second - more mild of a flavour
Sample 902 [Reference Area] has a more preferred intense flavour	
The taste of 902 [Reference Area] was very good. Didn't smell fishy at all and the taste wasn't too strong. I'm not a huge fan of fish and I enjoyed it. I liked 739 [Study Area] just as much. Didn't notice a difference between 902 [Reference Area] and 739 [Study Area]	The taste of 902 [Reference Area] was very good. Didn't smell fishy at all and the taste wasn't too strong. I'm not a huge fan of fish and I enjoyed it. I liked 739 [Study Area] just as much. Didn't notice a difference between 902 [Reference Area] and 739 [Study Area]
I ticked "moderately" for both, but I liked 713 [Reference Area] slightly more	I ticked "moderately" for both, but I liked 713 [Reference Area] slightly more
713 [Reference Area] tasted like nothing. 193 [Study Area\ pretty much no taste	713 [Reference Area] tasted like nothing. 193 [Study Area\ pretty much no taste
Both tasted the same. Kind of bland	Both tasted the same. Kind of bland
I liked 562 [Study Area] *slightly* more. Good flavour in both	I liked 562 [Study Area] *slightly* more. Good flavour in both
227 [Reference Area] has more "fish' taste, which I like. I think they have a similar smell	562 [Study Area] appears to be slightly sweeter than 227 [Reference Area]
Just smells like the salt sea - not overpowering. Fine	Just smells like the salt sea - not overpowering. Fine
Not much difference, Sample 227 [Reference Area] had a slightly more favourable flavour	Not much difference, Sample 227 [Reference Area \ had a slightly more favourable flavour
962 [Reference Area] had a little more desirable flavour - little sweeter	Milder in flavour
If the flavouring was altered with chemicals, I'd rather have a blander fish and add my own flavouring at home*	
I only liked both moderately but would choose 962 [Reference Area] sample	I only liked both moderately but would choose 962 [Reference Area] sample
Easy to eat; very mild tasting	Easy to eat; very mild tasting

Note: - Comments are transcribed exactly from participant input except that the text for “reference” and “study” was inserted. These were blind taste tests and therefore panelists were unaware of the source of samples.
- When there was no preference for either samples, comments are repeated in both columns.

6.2.3.2 Crab

Panelists for the triangle test were successful in discriminating 14 out of 24 samples. These results were significant (p > 0.05, Appendix C-4). However, there was no preference for any Area in the hedonic scaling test (p = 0.59, Table 6-26, also see Figure 6-13). From ancillary comments (Tables 6-28 and 6-29, and Appendix C-4), there were no consistent comments identifying abnormal or foreign odour or taste. Together, these results do not indicate taint in White Rose crab samples.

Table 6-26 ANOVA for Taste Preference Evaluation of Crab by Hedonic Scaling (2018)

Source of Variation	SS	df	MS	F	*p*-value
Between Groups	0.52	1	0.52	0.29	0.59
Within Groups	81.96	46	1.78		
Total	82.48	47			

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

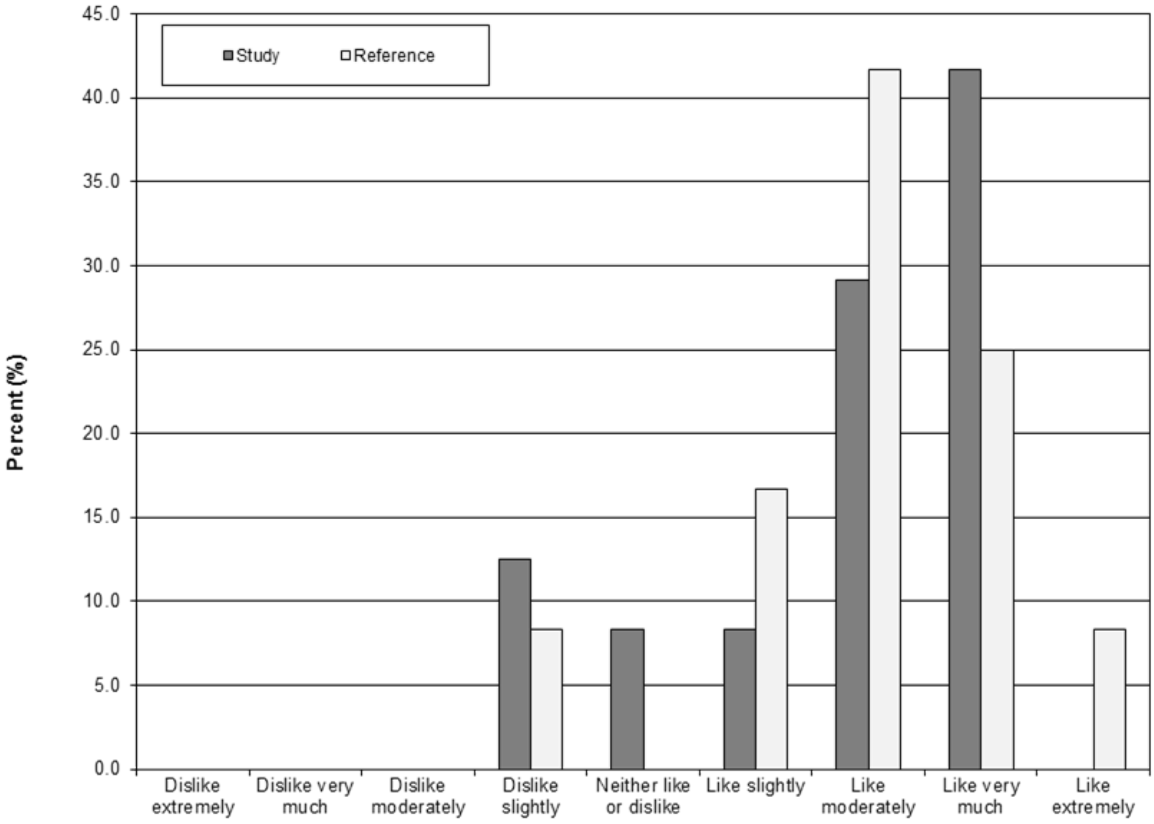


Figure 6-13 Crab Frequency Histogram for Hedonic Scaling Taste Evaluation (2018)

Table 6-27 Summary of Comments from the Triangle Taste Test for Crab (2018)

Reference Area	Study Area
Correctly identified as odd sample	**Correctly identified as odd sample**
Quite distinct and flavourful	269 [Reference Area] not much odor on any sample. 983 [Study Area] tastes sweeter
#485 [Reference Area] had a sweeter flavour and smelled differently than the others	More bland
Really couldn't tell any difference. Had to pick one	661 [Reference Area] taste like crab; 223 [Reference Area] smooth taste
	421 [Study Area] seems less salty and more moist
	421 [Study Area] salty and tangy. 661 [Reference Area] similar but tang not as frequent / strong. 223 [Reference Area] tastes like 661 [Reference Area]. 421 [Study Area] must be the different one. All were delicious though
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
130 [Reference Area] smells different	671 [Study Area] - no odor
269 [Reference Area] and 983 [Study Area] sweeter	671 [Study Area] and 141 [Reference Area] much sweeter in taste
223 [Reference Area] was less flavourful	870 [Study Area] had a slightly off flavour. 641 [Study Area] / 485 [Reference Area] were more desirable
I couldn't taste a lot of difference. 661 [Reference Area] seemed slightly blander	Sample 485 [Reference Area] contains a little bit of crab shell
	641 [Study Area] was slightly less flavourful (and smells lighter too) than the other 2

Note: - Comments are transcribed exactly from participant input except that the text for “reference” and “study” was inserted. These were blind taste tests and therefore panelists were unaware of the source of samples.

Table 6-28 Summary of Comments from Hedonic Scaling Taste Tests for Crab (2018)

Preferred Reference Area	Preferred Study Area
814 [Study Area] had a less desirable flavour. Almost an off flavour associated with it.	814 [Study Area\ had more of a fresh crab flavour whereas 300 [Reference Area] was more neutral or bland in terms of taste
Flavour was sweeter (300 [Study Area])	300 [Reference Area] seemed sweeter
871 [Study Area] not as aromatic, more bland flavour	871 [Study Area] had a sweeter crab taste. 467 [Reference Area] more bland
467 [Reference Area] tastes sweeter	No difference between the two
Tried 467 [Reference Area] first. It had a slightly more natural flavour. 871 [Study Area] second, did not really taste like much	I really enjoyed the taste of 433 [Study Area]. I liked it; sweeter and tasted like traditional crab
Something "greasy" in 871 [Study Area] and not as sweet as 467 [Reference Area]/ 871 [Study Area] more "tangy" or strong than 467 [Reference Area]	Found 710 [Study Area] to be slightly more flavourful
#433 [Study Area] is a bit blander than #564 [Reference Area]. 564 [Reference Area\ is "crabbier" tasting	
I preferred the smell of 564 [Reference Area]. They both taste good	
564 [Reference Area] has a sweet taste as opposed to 433 [Study Area]	
No difference between the two	
Not much difference but 248 [Reference Area] seems to have more odor	

Preferred Reference Area	Preferred Study Area
Not much difference in flavour	
I preferred 248 [Reference Area]. Sample 710 [Study Area] is more "soupy" and I think I feel sth "hard" inside {maybe not totally fractionized?). 248 [Reference Area] is definitely better and more neat	

Note: - Comments are transcribed exactly from participant input except that the text for “reference” and “study” was inserted. These were blind taste tests and therefore panelists were unaware of the source of samples.
- When there was no preference for either samples, comments are repeated in both columns.

6.2.4 Fish Health

6.2.4.1 Gross Pathology

No visible abnormalities were observed 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).

6.2.4.2 Mixed Function Oxygenase 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. Results of immature and pre-spawning females are examined further below because sample size permitted statistical analysis.

Significant differences in EROD activity were found between Reference Areas for pre-spawning females (p = 0.024) with EROD activity in Reference Area 1 (29.2 ± 15.8 pmol/min/mg protein, n = 45) significantly greater than in Reference Area 2 (22.6 ± 13.6 pmol/min/mg protein, n = 41; Figure 6-14; Table 6-29).

No significant differences were found between Reference Areas for immature females (p = 0.181; Figure 6-14; Table 6-29). Similarly, no significant differences were found between the Study and Reference Areas for immature or pre-spawning females (p = 0.728 and 0.065, respectively; Table 6-29).

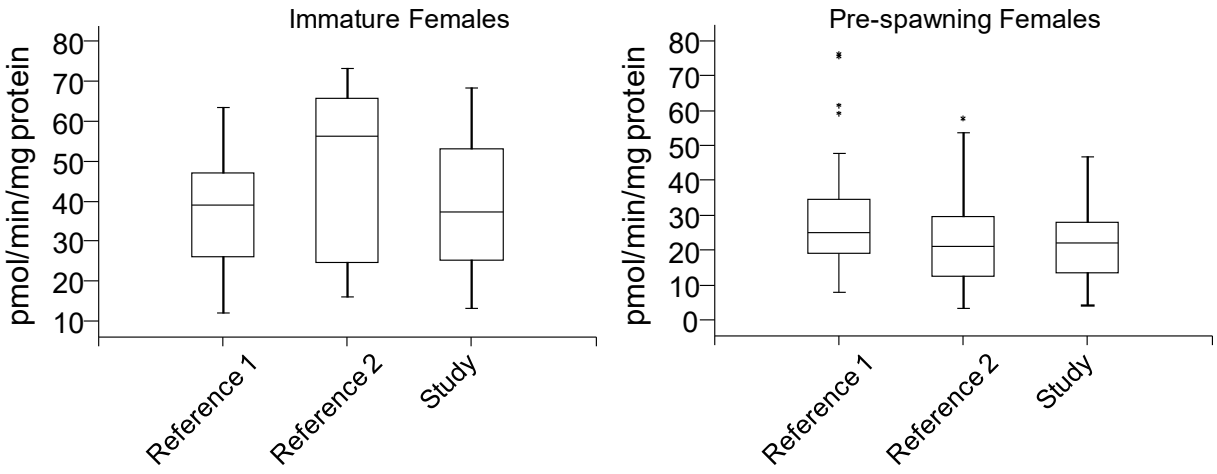


Figure 6-14 Box Plots of EROD Activity in the Liver of Immature (F-500) and Pre-spawning (F-510 to F-540) Female Plaice

Note: 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, if present, would indicate values falling outside the quartile ± 3 x interquartile spread.
See Appendix C-3, Annex A for DFO maturity stage classifications.

Table 6-29 Results of Asymmetrical ANOVA Comparing MFO Activities in Female Plaice (2018)

Variable (Y)	p-value	
	Among Reference	Study vs Reference
Immature Females	0.181	0.728
Pre-Spawn Females	0.024*	0.065

Note: -See Appendix C-3, Annex A for maturity stage classifications.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

6.2.4.3 Histopathology

Liver Histopathology

A total of 180 livers were examined, 60 each from the Study Area, Reference Area 1 and Reference Area 2. Results were expressed as the percentage of fish affected by each type of lesion/observation (or prevalence of lesion) in each Area (Table 6-30). The complete data set is provided in Appendix C-3, Annex E. Representative photographs of normal liver as well as several histological changes are included in Appendix C-3, Annex G.

Nine cases of nuclear pleomorphism were detected in each Reference Area and 12 cases were detected in the Study Area. One case of megalocytic hepatosis was detected in each Area. No cases of focus of cellular alteration or fibrillar inclusions were observed. Proliferation of macrophage aggregates was detected in 57 fish, in 23 fish from the Study Area, and in 19 and 15 fish from Reference Areas 1 and 2, respectively. Inflammatory response was detected in 142 fish, in 48 fish from the Study Area, and in 48 and 46 fish from Reference Areas 1 and 2, respectively. Twenty-seven cases of hepatocellular vacuolation were detected, in 8 fish from the Study Area and 9 and 10 fish

from Reference Areas 1 and 2, respectively. Finally, parasites were detected in 32 fish from the Study Area, and in 26 and 25 fish from References Areas 1 and 2, respectively. Although such liver conditions are of interest, they are generally not a result of the presence of chemical pollutants.

Table 6-30 Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions (2018)

Hepatic Lesions	Measure	Area				
		Ref 1	Ref 2	All Ref	Study	Grand Total
Number of Fish	Number	60	60	120	60	180
Nuclear Pleomorphism	Number	9	9	18	12	30
	%	15	15	15	20	16.67
Megalocytic Hepatosis	Number	1	1	2	1	3
	%	1.67	1.67	1.67	1.67	1.67
Focus of Cellular Alteration	Number	0	0	0	0	0
	%	0	0	0	0	0
Proliferation of Macrophage Aggregates [a]	Number	19	15	34	23	57
	%	31.67	25	28.33	38.33	31.67
Fibrillar Inclusions	Number	0	0	0	0	0
	%	0	0	0	0	0
Inflammatory Response [b]	Number	48	46	94	48	142
	%	80	76.67	78.33	80	78.89
Hepatocellular Vacuolation	Number	9	10	19	8	27
	%	15	16.67	15.83	13.33	15
Parasites	Number	26	25	51	32	83
	%	43.33	41.67	42.5	53.33	46.11
Golden Rings	Number	0	0	0	0	0
	%	0	0	0	0	0

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

Statistical analyses were conducted on nuclear pleomorphism, macrophage aggregates, inflammatory response, hepatocellular vacuolation, and parasites only since the low incidence of all the other hepatic lesions prevented statistical comparisons. Overall, there were no significant differences in liver conditions between fish from the Study and Reference Areas (Fisher Exact test, all p's > 0.05).

Gill Histopathology

Gill sections were examined for the presence of various lesions associated with chemical toxicity and detailed results are provided in Appendix C-3. Means ± standard deviation of percentages of gill lamellae with each type of lesion are provided in Table 6-31.

Table 6-31 Mean Percent Occurrence of Lesions in Gill Tissues (2018)

Statistics	Area			
	Reference 1	Reference 2	Study	Total
Number of Fish	58	56	54	168
Distal Hyperplasia[a]	0.0002 ± 0.0008	0.0003 ± 0.0015	0.0003 ± 0.0014	0.00025 ± 0.00131
Tip Hyperplasia[a]	0 ± 0	0.0002 ± 0.0007	0.0002 ± 0.0013	0.00013 ± 0.00087
Basal Hyperplasia 1[ab]	0.0002 ± 0.0008	0.0001 ± 0.0005	0.0006 ± 0.0017	0.000286 ± 0.00115
Basal Hyperplasia 2[ac]	0.00011 ± 0.0008	0.0003 ± 0.0016	0.0002 ± 0.0011	0.00022 ± 0.00120
Fusion[a]	0.0001 ± 0.0005	0.0005 ± 0.0022	0.0004 ± 0.0022	0.00033 ± 0.00178
Telangiectasis[a]	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Parasites	0.00004 ± 0.0003	0.0001 ± 0.0001	0.0001 ± 0.0005	0.00008 ± 0.00050

Note: -Values are means ± 1 standard deviation.
-[a] Mean percentage of lamellae presenting the lesion.
-[b] Basal hyperplasia 1: increase in thickness of the epithelium reaching ⅓ to ⅔ of total lamellar length.
-[c] Basal hyperplasia 2: increase in thickness of the epithelium reaching more than ⅔ of total lamellar length.

Statistical comparisons between the Study Area and the combined Reference Areas were carried out on the number of fish exhibiting lesions (Table 6-32) using Fisher's Exact Test. Lesions were considered "present" if they occurred on any of the lamellae examined for each fish. Statistical analysis was not conducted on telangiectasis because low incidence prevented statistical comparisons. With the exception of basal hyperplasia (⅓ to ⅔), none of the gill lesions occurred either more or less frequently in Study Area fish compared to Reference Area fish (Fisher Exact Test, all *p*'s > 0.05 in all cases). Basal hyperplasia (⅓ to ⅔) occurred more frequently in Study Area fish (Fisher Exact Test $p = 0.0295$). It occurred in 15% of fish from the Study Area versus 4% of fish from the Reference Areas (Table 6-32).

Table 6-32 Number and Percentage of Plaice with Specific Types of Gill Lesions (2018)

Gill Lesions	Measure	Area			
		Reference 1	Reference 2	Mean Reference	Study
Number of Fish	Number	58	56	57	54
Distal Hyperplasia	Number	3	3	3	3
	%	5.17	5.36	5.26	5.56
Tip Hyperplasia	Number	0	4	2	2
	%	0.00	7.14	3.51	3.70
Basal Hyperplasia 1[a]	Number	4	1	2.5	8
	%	6.90	1.79	4.39	14.81
Basal Hyperplasia 2[b]	Number	2	4	3	2
	%	3.45	7.14	5.26	3.70
Fusion	Number	1	4	2.5	2
	%	1.72	7.14	4.39	3.70
Telangiectasis	Number	0	0	0	0
	%	0.00	0.00	0.00	0.00
Parasites	Number	1	1	1	3
	%	1.72	1.79	1.75	5.56

Note: -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 ⅓ to ⅔ of total lamellar length.
-[b] Basal hyperplasia 2: increase in thickness of the epithelium reaching more than ⅔ of total lamellar length.

6.3 Summary of Results

6.3.1 Biological Characteristics

There were no significant differences between the Reference Areas and the Study Area for plaice mean gutted weight and measures of crab size (carapace width and claw height) for plaice and crab used in body burden analyses. However, plaice mean gutted weight and crab size (carapace width and claw height) were larger in Reference 1 than in Reference Area 2.

Additional differences among Areas were examined within the context of fish health analyses. Very few male plaice (9) and spent females (2) were caught. A total of 36 and 133 immature and pre-spawning females were caught, respectively; and the frequency of immature and pre-spawning females did not vary significantly between the Reference Areas and the Study Area.

Sufficient numbers of immature and pre-spawning females were caught to allow comparison among Areas for length, age, gutted weight and regression analogues of Fulton's condition factor and the HSI and GSI. No significant differences were noted between the Reference Areas and the Study Area for most biological characteristics of immature females. However, gutted weight (corrected for length - the analogue of Fulton's condition factor) was higher in the Study Area than in the Reference Area. In contrast, gutted weight and age for immature females were significantly different between the Reference Areas, with fish from Reference Area 1 larger and older. Similarly, there were no significant differences between the Reference Areas and the Study Area for biological characteristics of pre-spawning females; and length, gutted weight, age and gonad weight (as a function of gutted weight - analogue of the HSI) were higher in Reference Area 1 relative to Reference Area 2.

6.3.2 Body Burden

Compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon range were again detected in all plaice liver samples in 2018. As in previous years, additional Gas Chromatography/Mass Spectrometer analysis did not indicate the presence of drill fluid or petroleum hydrocarbons in those samples.

In 2018, most frequently detected compounds in plaice liver (% fat, arsenic, copper, iron, manganese mercury, silver, zinc, and $>C_{21}$-C_{32} hydrocarbons) did not vary significantly in concentration between the Study and Reference Areas. However, concentrations of cadmium and selenium were lower in the Study Area than in the Reference Areas; and concentrations of $>C_{10}$-C_{21} hydrocarbons were higher in the Study Area. Difference between the two Reference Areas for $>C_{10}$-C_{21} hydrocarbons were also noted, with concentrations in Reference Area 1 higher than in Reference Area 2.

There were no significant differences between the Study Area and the Reference Areas in linear or quadratic trends over time (2004 to 2018)[21] for most frequently detected compounds in plaice liver. However, a difference in linear trend over time between the Study and Reference Areas was noted for copper. Copper concentrations generally

[21] A linear trend would indicate a consistent increase or a consistent decrease over time. A quadratic trend would indicate an increase following by a decrease, or vice versa, over time.

increased to 2016, in all Areas. However, the increase was slightly more pronounced in the Study Area (as determined by the slopes of the linear relationships). The difference was largely driven by relatively high copper concentrations in Study Area liver in 2014 and 2016. As noted above, copper concentrations in the Study Area were similar to those in the Reference Areas in 2018.

In 2018, mercury and zinc concentrations in plaice fillets did not vary significantly between the Study and Reference Areas. Arsenic concentrations varied significantly and were higher in the Study Area compared to the Reference Areas, overall. However, Arsenic concentrations were similar between the Study Area and Reference Area 1. Across years, there were no significant differences between the Reference and Study Areas in either linear or quadratic trends.

For crab tissue in 2018, concentrations of boron, copper and mercury varied significant between the Study Area and the Reference Areas. Boron and mercury concentrations were generally higher and copper concentrations were generally lower in the Study Area compared to the Reference Areas, overall. However, in all cases, Study Area concentrations were similar to concentrations in Reference Area 1; and concentrations of all three variables, and that of selenium and zinc, differed significantly between the two Reference Areas. Across years, there was a significant difference in quadratic trends between the Study and Reference Areas for arsenic in crab tissue. Like all other tested metals, arsenic concentrations in crab tissue decreased from 2004 to 2008-2012, and then increased, in all Areas. However, the trend for arsenic was slightly more pronounced in the Study Area than in the Reference Areas.

6.3.3 Taste Tests

There were no significant differences in taste test results between Study and Reference Areas for plaice and, from ancillary comments, there were no consistent comments identifying abnormal or foreign odour or taste.

For crab, panelists for the triangle test were successful in discriminating between samples from the Study and Reference Area. However, there was no preference for either Area in the hedonic scaling test and; from ancillary comments from both tests, there were no consistent comments identifying abnormal or foreign odour or taste. Together, these results do not indicate taint in White Rose crab samples.

6.3.4 Fish Health Indicators

There were no visible lesions on the skins, fins, or internal organs of any plaice.

There were no significant differences in EROD activity between the Reference Areas and the Study Area for both immature and pre-spawning females. However, for pre-spawning females, there was a difference in EROD activity between the two Reference Areas, with EROD activity greater in Reference Area 1 than in Reference Area 2. Low numbers prevented comparison between Areas for males and other female maturity groupings.

Sufficient incidences of lesions allowed statistical comparison among Areas for nuclear pleomorphism, macrophage aggregates, inflammatory response, hepatocellular vacuolation and parasite counts. There were no significant differences in these liver conditions between the Study and Reference Areas.

For gill histopathology, with the exception of basal hyperplasia, no significant differences were found between the Study and Reference Areas for any of the studied conditions. However, more fish from the Study Area exhibited basal hyperplasia than fish from the Reference Areas (15% in the Study Area compared to 4% in the Reference Areas).

7.0 Water Quality Component

7.1 Background

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

Because the Water Quality monitoring program at White Rose has been modified based on modelling, the model results for produced water discharge are summarized before seawater and sediment 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).

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

- 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 water current direction (*i.e.*, down-current) at the time of sampling (*i.e.*, stations 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 first implemented for the 2012 field program and continue to be implemented.

7.2.2 Field Study

7.2.2.1 Water Sample Collection

Water collection for the 2018 EEM Program was conducted from August 13 to August 14, 2018, using the offshore supply vessel *Atlantic Osprey*. Collection stations for the 2018 program are shown in Figure 7-1. In accordance with recommendations in Section 7.2.1, samples in the Near-field were collected down-current from the *SeaRose FPSO*. In 2018, those stations were located to the southeast of the *SeaRose FPSO*. Station coordinates and distance to the *SeaRose FPSO* are provided in Appendix D-1.

Water samples were collected at 10 m below surface ("surface"), 40 m below surface ("mid-depth"), and 10 m above bottom ("bottom") using a string of three Teflon-lined, 10 L Niskin-X bottle water samplers. All stations were sampled for physical and chemical characteristics. Compounds analyzed included benzene, toluene, ethylbenzene, and xylenes (BTEX), $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, polycyclic aromatic 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) and ammonia. 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.

The following Quality Assurance/Quality Control (QA/QC) protocols were implemented for collection of samples. Field duplicates were collected for water chemistry at four stations. Sampling personnel were supplied with new latex gloves for each station. Samples were decanted from the Niskin samplers into the labelled jars. Processed samples were transferred to cold storage within one hour of collection. Once ashore, samples to be analyzed by RPC were transferred to cold storage at Stantec and then shipped to RPC; samples to be analyzed by Maxxam were delivered to the Maxxam Laboratory in St. John's for shipment to the Maxxam laboratory in Halifax. Samples were delivered to laboratories within prescribed sample holding time.

7.2.2.2 Laboratory Processing

Water samples were processed for constituents listed in Table 7-2. In the 2010 EEM program, most constituents were processed at RPC, Fredericton, NB. From 2012 to 2018, inorganic constituents (trace metals, mercury) were processed at Maxxam Analytics (Halifax, NS) because detection limits for most inorganic constituents of interest were lower at that analytical laboratory, as per recommendations in Section 7.2.1. TIC/TOC/TSS and ammonia were also processed at Maxxam Analytics from 2012 to 2018. The remaining constituents were processed at RPC. Details on analytical methods for RPC and Maxxam Analytics are provided in Appendix D-2.

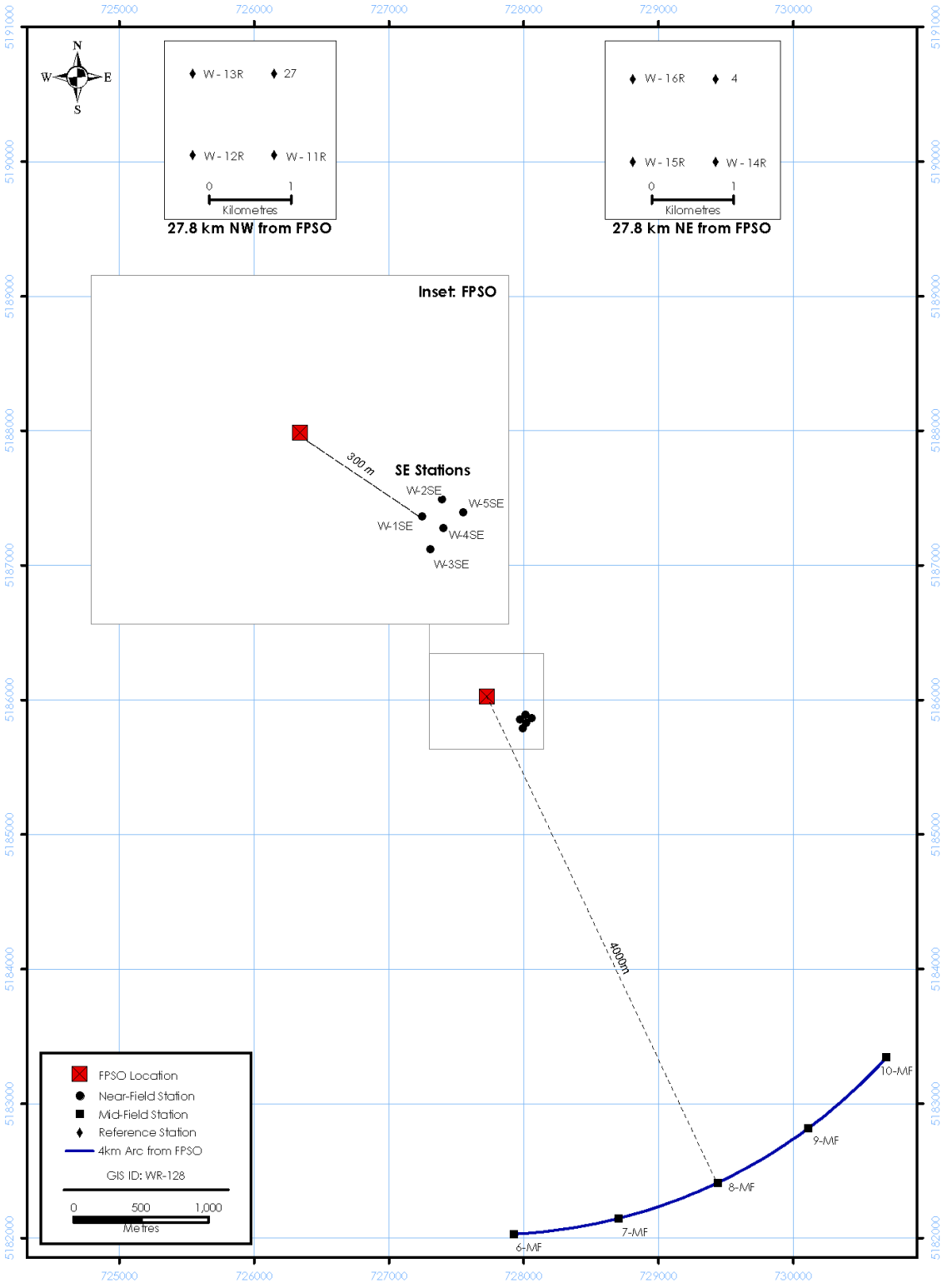


Figure 7-1 Water Quality Stations 2018

Notes: The inset represents an expanded view of the centre of the development. The blue line shows that mid-field stations are distributed on an arc, with each station 4,000 m from the *SeaRose FPSO*.

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 2 – 40 mL vials	Sodium bisulphate Sodium bisulphate	4ºC	7 days
PAHs & Alkyl PAHs	1 – 1 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 mL (or 200 mL) plastic bottle	None	4ºC	6 months
Mercury	1 - 100 mL amber glass bottle	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	4°C	7 days
TIC	1 – 200 mL plastic bottle	No preservative required. Fill to top	4°C	28 Days

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

Table 7-2 Water Chemistry Constituents (2010, 2012, 2014, 2016 and 2018)

Constituent	Unit	Detection Limit				
		2010	2012	2014	2016	2018
Hydrocarbons						
Benzene	mg/L	0.001	0.001	0.001	0.001	0.001
Toluene	mg/L	0.001	0.001	0.001	0.001	0.001
Ethylbenzene	mg/L	0.001	0.001	0.001	0.001	0.001
Xylenes	mg/L	0.001	0.001	0.001	0.001	0.001
C_6-C_{10} (less BTEX)	mg/L	0.01	0.01	0.01	0.01	0.01
>C_{10}-C_{21}	mg/L	0.05	0.05	0.05	0.05	0.05
>C_{21}-C_{32}	mg/L	0.1	0.1	0.1	0.1	0.1
Phenols and Alkyl Phenols						
Phenol	µg/L	10	10	10	10	10
o-cresol	µg/L	10	10	10	10	10
m,p-cresol	µg/L	10	10	10	10	10
Total C2 Phenols	µg/L	20	20	20	20	20
Total C3 Phenols	µg/L	20	20	20	20	20
Total C4 Phenols	µg/L	20	20	20	20	20
Total C5 Phenols	µg/L	20	20	20	20	20
4-*n*-hexylphenol	µg/L	10	10	10	10	10
2,5-diisopropylphenol	µg/L	10	10	10	10	10
2,6-diisopropylphenol	µg/L	10	10	10	10	10
2-*tert*-butyl-4-ethylphenol	µg/L	10	10	10	10	10
6-*tert*-butyl-2,4-dimethyphenol	µg/L	10	10	10	10	10
4-*n*-heptylphenol	µg/L	10	10	10	10	10
2,6-dimethyl-4-(1,1-dimethypropyl)phenol	µg/L	10	10	10	10	10
4-(1-ethyl-1-methylpropyl)-2-methylphenol	µg/L	10	10	10	10	10
4-*n*-octylphenol	µg/L	10	10	10	10	10
4-*tert*-octylphenol	µg/L	10	10	10	10	10
2,4-di-*sec*-butylphenol	µg/L	10	10	10	10	10
2,6-di-*tert*-butylphenol	µg/L	10	10	10	10	10
4-*n*-nonylphenol	µg/L	20	20	20	20	20
2-methyl-4-*tert*-octylphenol	µg/L	10	10	10	10	10
2,6-di-*tert*-butyl-4-methylphenol	µg/L	10	10	10	10	10
4,6-di-*tert*-butyl-2-methylphenol	µg/L	10	10	10	10	10

Constituent	Unit	Detection Limit				
		2010	2012	2014	2016	2018
PAHs and Alkyl PAHs						
Naphthalene	µg/L	0.01	0.05	0.05	0.05	0.05
1-Methylnapthalene	µg/L	NA	NA	0.05	0.05	0.05
2-Methylnapthalene	µg/L	NA	NA	0.05	0.05	0.05
Acenaphthylene	µg/L	0.01	0.01	0.01	0.01	0.01
Acenaphthene	µg/L	0.01	0.01	0.01	0.01	0.01
Fluorene	µg/L	0.01	0.01	0.01	0.01	0.01
Phenanthrene	µg/L	0.01	0.01	0.01	0.01	0.01
Anthracene	µg/L	0.01	0.01	0.01	0.01	0.01
Fluoranthene	µg/L	0.01	0.01	0.01	0.01	0.01
Pyrene	µg/L	0.01	0.01	0.01	0.01	0.01
Benzo(*a*)anthracene	µg/L	0.01	0.01	0.01	0.01	0.01
Chrysene/Triphenylene	µg/L	0.01	0.01	0.01	0.01	0.01
Benzo(*b*)fluoranthene	µg/L	0.01	0.01	0.01	0.01	0.01
Benzo(*k*)fluoranthene	µg/L	0.01	0.01	0.01	0.01	0.01
Benzo(*e*)pyrene	µg/L	0.01	0.01	0.01	0.01	0.01
Benzo(*a*)pyrene	µg/L	0.01	0.01	0.01	0.01	0.01
Indenopyrene	µg/L	0.01	0.01	0.01	0.01	0.01
Benzo(*g,h,i*)perylene	µg/L	0.01	0.01	0.01	0.01	0.01
Dibenzo(*a,h*)anthracene	µg/L	0.01	0.01	0.01	0.01	0.01
C1-Naphthalenes [a]	µg/L	0.05	0.10	0.10	0.10	0.10
C2-Naphthalenes [a]	µg/L	0.05	0.10	0.10	0.10	0.10
C3-Naphthalenes	µg/L	0.05	0.10	0.10	0.10	0.10
C1-Phenanthrenes	µg/L	0.05	0.10	0.10	0.10	0.10
C2-Phenanthrenes	µg/L	0.05	0.10	0.10	0.10	0.10
C3-Phenanthrenes	µg/L	0.05	0.10	0.10	0.10	0.10
Dibenzothiophene	µg/L	0.05	0.10	0.10	0.10	0.10
C1-Dibenzothiophenes	µg/L	0.05	0.10	0.10	0.10	0.10
C2-Dibenzothiophenes	µg/L	0.05	0.10	0.10	0.10	0.10
C3-Dibenzothiophenes	µg/L	0.05	0.10	0.10	0.10	0.10
Perylene	µg/L	0.01	0.01	0.01	0.01	0.01
Biphenyl	µg/L	0.01	0.05	0.05	0.05	0.05
Organic Acids						
Acetic Acid	mg/L	2	2	2	2	2
Propionic Acid	mg/L	2	2	2	2	2
Iso-butyric Acid	mg/L	2	2	2	2	2
Butyric Acid	mg/L	2	2	2	2	2
Iso-valeric Acid	mg/L	2	2	2	2	2
n-valeric Acid	mg/L	2	2	2	2	2
Metals						
Aluminum	µg/L	5	10	10	10	10
Antimony	µg/L	1	0.5	0.5	0.5	0.5
Arsenic	µg/L	10	0.5	0.5	0.5	0.5
Barium	µg/L	0.1	1	1	1	1
Beryllium	µg/L	0.05	1	1	1	1
Boron	µg/L	10	50	50	50	50
Cadmium	µg/L	0.05	0.05	0.05	0.05	0.05
Calcium	mg/L	0.05	1	1	1	1
Chromium	µg/L	2	0.5	0.5	0.5	0.5
Cobalt	µg/L	0.5	0.1	0.1	0.1	0.1
Copper	µg/L	5	0.5	0.5	0.5	0.5
Iron	µg/L	10	5	5	10	2
Lanthanum	µg/L	0.2	NA	NA	NA	NA
Lead	µg/L	0.05	0.1	0.1	0.1	0.1
Lithium	µg/L	5	20	20	20	20
Magnesium	mg/L	10	1	1	1	1
Manganese	µg/L	0.01	0.5	0.5	0.5	0.5
Mercury	µg/L	0.025	0.013	0.013	0.013	0.013
Molybdenum	µg/L	0.1	1	1	1	1
Nickel	µg/L	5	0.2	0.2	0.2	0.2
Potassium	mg/L	20	1	1	1	1
Phosphorus	µg/L	NA	50	50	50	50
Selenium	µg/L	10	0.5	0.5	0.5	0.5
Silicon	µg/L	NA	100	100	1000	1000

Constituent	Unit	Detection Limit				
		2010	2012	2014	2016	2018
Silver	µg/L	0.02	0.05	0.05	0.05	0.05
Sodium	mg/L	0.05	1	1	1	5[b]
Strontium	µg/L	10	10	10	10	10
Sulphur	mg/L	0.05	20	20	20	20
Tellurium	µg/L	0.5	NA	NA	NA	NA
Thallium	µg/L	2	0.1	0.1	0.1	0.1
Tin	µg/L	NA	1	1	1	1
Titanium	µg/L	NA	10	10	10	10
Uranium	µg/L	0.1	0.05	0.05	0.05	0.05
Vanadium	µg/L	1	10	10	10	10
Zinc	µg/L	1	1	1	1	1
Other						
Unionized Ammonia	mg/L	NA	0.0001	0.0001	0.0001	0.0001
Total Inorganic Carbon (TIC)	mg/L	0.5	0.5	0.5	0.5	0.5
Total Organic Carbon (TOC)	mg/L	0.5	5	5	5	0.5
Total Suspended Solids (TSS)	mg/L	5	0.5	0.5	1	1

Note: - [a] Includes 1- and 2-Chloronaphthalene.
- [b] The increase in detection limit for sodium in 2018 is inconsequential because sodium levels are much higher than the 2018 detection limit of 5 mg/L.

7.2.2.3 Data Analysis

General Water Quality

Data analyses focused on 2018 data, with qualitative comparisons to results from 2010 to 2016. 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 (2010a).

Frequently Detected variables

In 2018, 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 frequently detected variables [22] were generated for each Area.

Overall Area differences were tested on frequently detected variables using ANOVA with Depth and Area as factors. When no significant Area x Depth interaction was detected, the ANOVA was repeated excluding the Area x Depth interaction term from the model, with levels of significance for the factors Area and Depth reported as such. If overall Area differences were significant, then Study versus Reference (SR), Between Study (BS), Between Reference (BR), Near-field versus Reference (NF *vs* R) and Mid-field versus Reference (MF *vs* R) contrasts were examined. Statistical outliers (studentized residual > |4|) were retained in ANOVA if their removal did not change results from significant to not-significant, or vice versa. Otherwise, discussion is provided on results with and without outliers.

Variables were $\log_{10}$ transformed for ANOVA. Values below detection limit were set to ½ detection limit for plotting and ANOVA.

[22] Variables that occurred above detection limit in more than 75% of overall cases.

Infrequently Detected Variables

Percent occurrence of infrequently detected variables in the Study Areas (Near-field and Mid-field combined) and the Reference Areas (NE and NW Reference Areas combined) was plotted and qualitatively compared. When occurrence was more frequent in Study Area samples, the Study Area (Near-field or Mid-field) with higher occurrence was identified.

Produced Water Constituents

Concentrations of produced water constituents were compared to concentrations of seawater constituents at Reference Area stations to generate an estimate of expected enrichment resulting from release of produced water. Individual stations were then examined for produced water constituents with expected concentrations on release more than 10 times seawater concentrations. The concentration of produced water constituents was obtained from produced water chemical characterizations obtained on January 30, 2017 and July 9, 2018.

Statistical analyses were performed using Systat (version 13) and Excel 2007.

7.2.2.4 Results

General Water Quality

Raw data and summary statistics for variables measured in seawater samples (Table 7-2) are provided in Appendix D-2. Conductivity, temperature, depth profiles are provided in Appendix D-3. The upper limit of the thermocline was between 10 and 15 m at most stations. Exceptions were Stations W4-SE and W5-SE in the Near-field and Stations W6-MF and W8-MF in the Mid-field. At these stations, the upper limit of the thermocline was between 20 and 30 m. The lower limit of the thermocline was generally between 50 and 60 m at most stations, except in the NW Reference Area. At those stations, the lower limit of the thermocline was shallower, at approximately 40 m. Therefore, most mid-depth samples (40 m depth) were collected within the thermocline, but some samples collected in the NW Reference Area may have been collected near the lower limit of the thermocline.

Frequently Detected Variables

In 2018, arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, organic and inorganic carbon, potassium, sodium, strontium, sulphur, uranium and zinc were detected in all samples; aluminum was above detection limit in 96% of samples. With the exception of inorganic carbon, which varied over the narrow range of 28 and 29 mg/L, all these variables were included in quantitative analyses for 2018.

Boxplots by Area and Depth for variables with most values above the laboratory detection limit are provided in Figure 7-2. Boxplots are not provided for inorganic carbon because values varied over a very narrow range. One extreme value for sodium (17,300 mg/L from the surface sample at Station W6-MF) was excluded from the boxplot[23]. This extreme value, and other values indicated in red in Figure 7-2 were excluded from ANOVA (see below for further information).

[23] Inclusion of that value influenced the scale of the figure and obscured visualization of variability for remaining data.

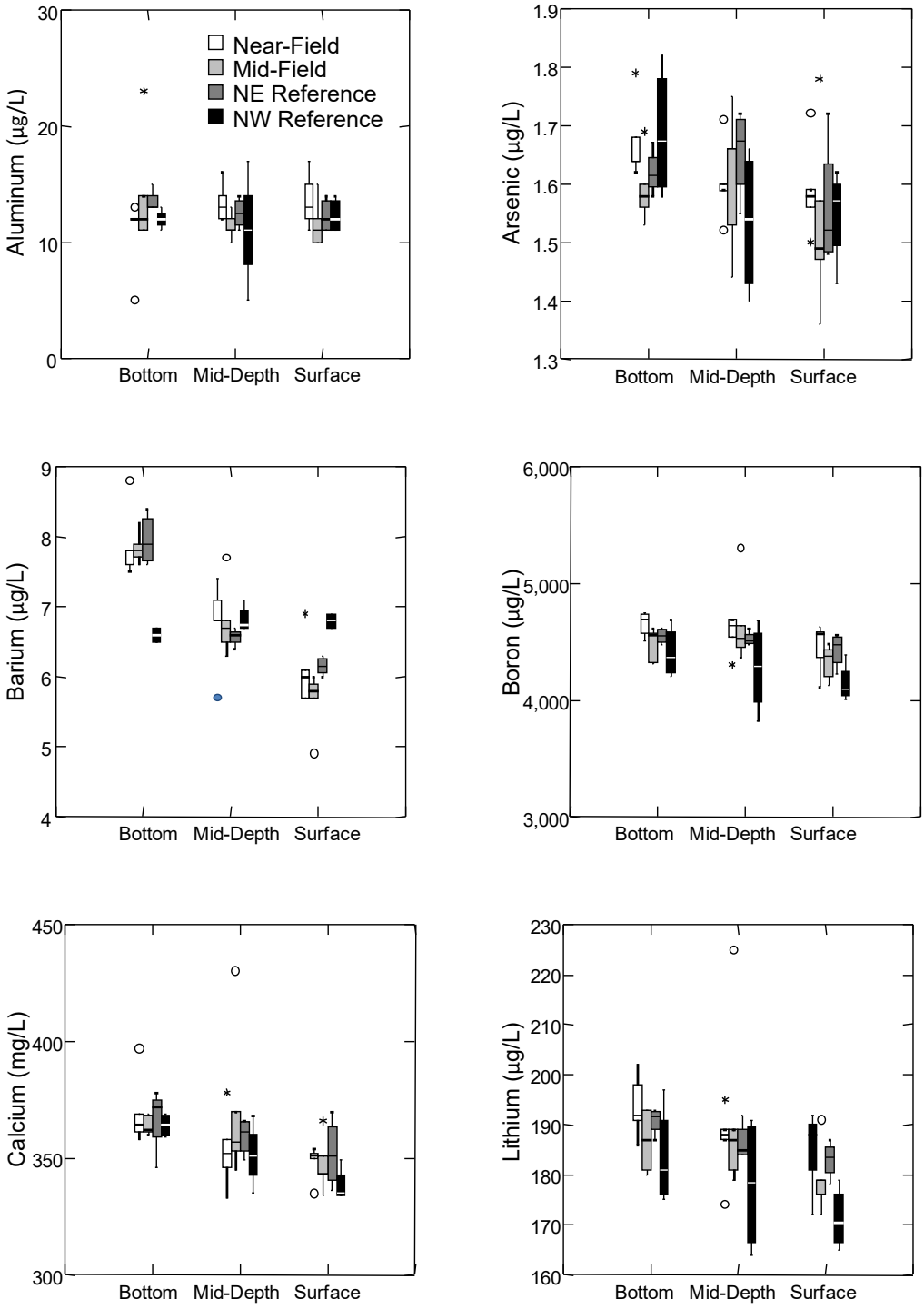


Figure 7-2 Boxplots of Water Chemistry by Area and Depth for 2018

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. Values indicated in red identify those data that were excluded from ANOVA results presented in Table 7-3. Values indicated in blue identify those data excluded from ANOVA results presented in Table 7-4.

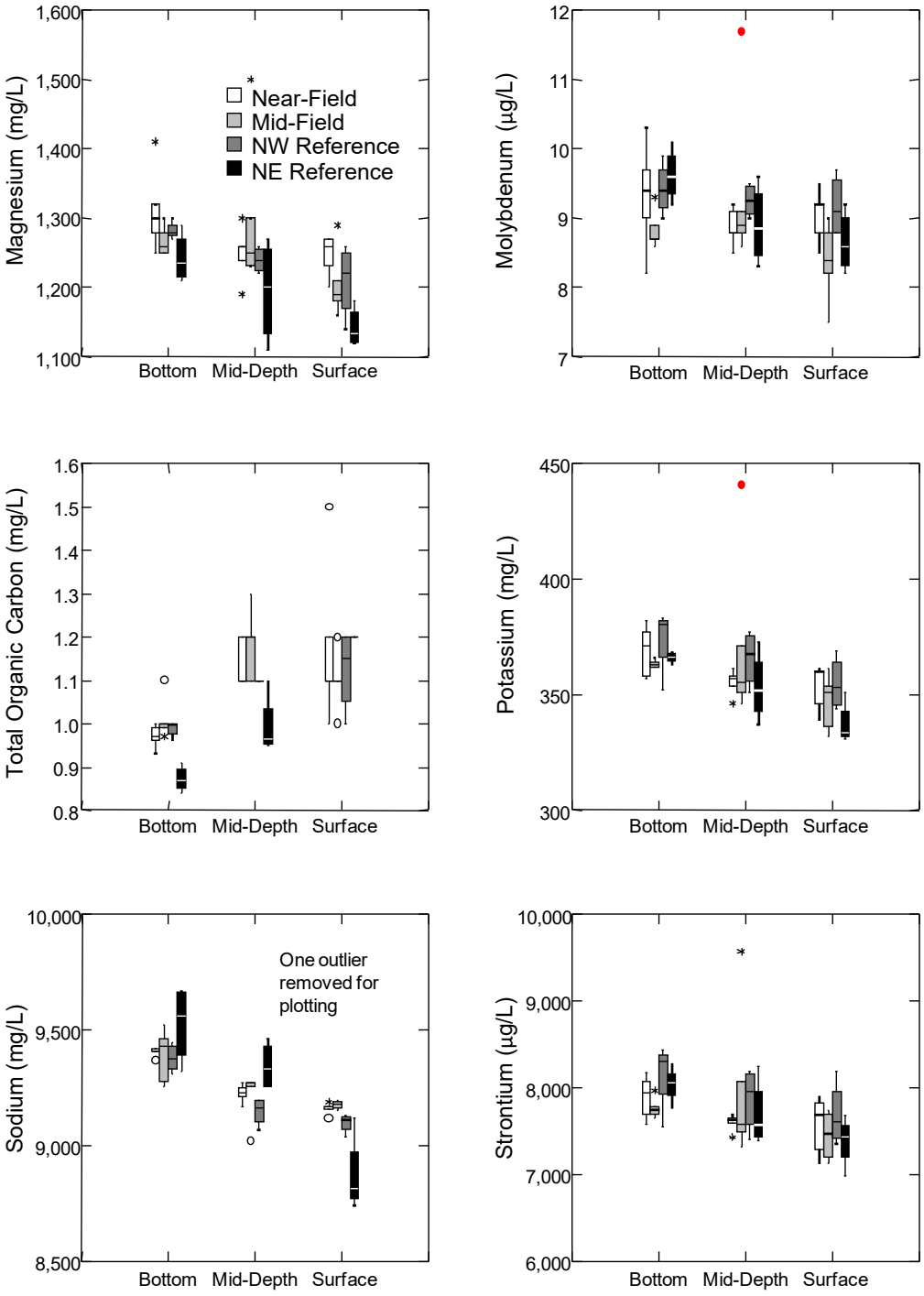


Figure 7-2 Boxplots of Water Chemistry by Area and Depth for 2018 (cont.)

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. Values indicated in red identify those data that were excluded from ANOVA results presented in Table 7-3. Values indicated in blue identify those data excluded from ANOVA results presented in Table 7-4.

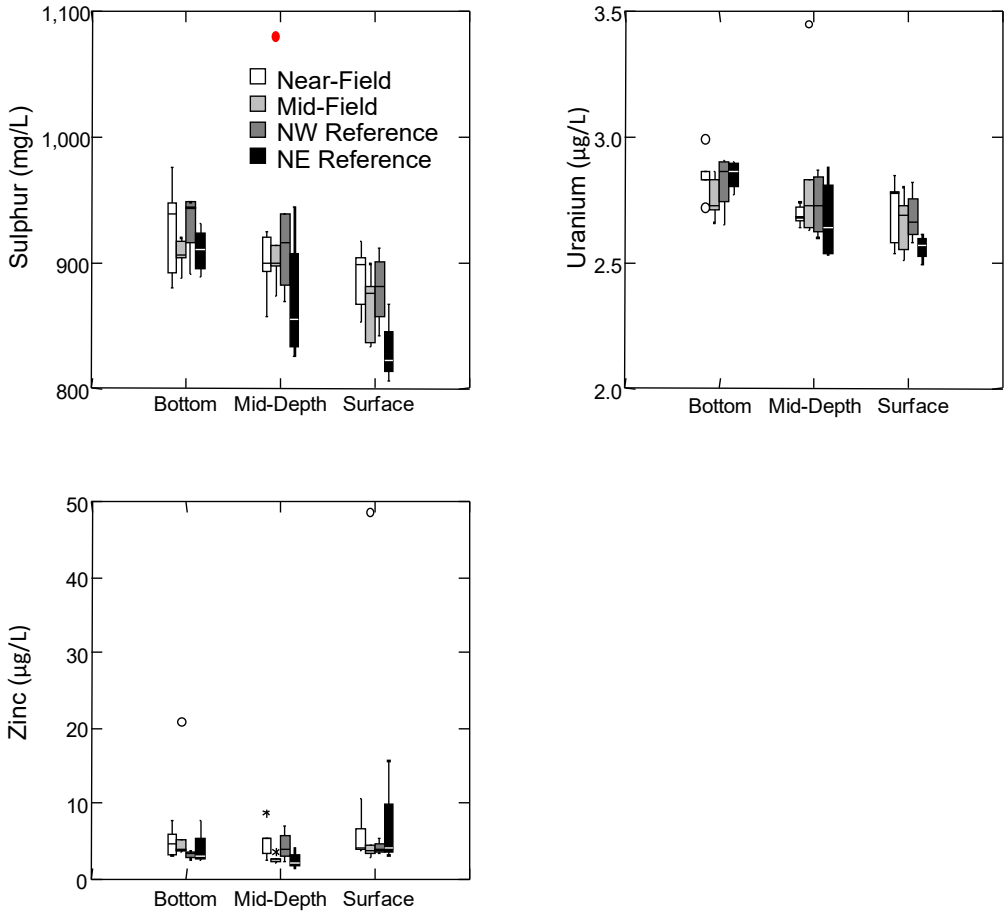


Figure 7-2 Boxplots of Water Chemistry by Area and Depth for 2018 (cont.)

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. Values indicated in red identify those data that were excluded from ANOVA results presented in Table 7-3. Values indicated in blue identify those data excluded from ANOVA results presented in Table 7-4.

Results of ANOVA comparing the concentration of frequently detected variables among Areas are provided in Table 7-3.

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

Variable	*p*-values							
	Area	Depth	AxD	**SR**	**BS**	**BR**	**NF *vs* R**	**MF *vs* R**
Aluminum	0.723	0.854	0.264					
Arsenic	0.549	0.037*	0.564					
Barium	0.650	**<0.001*** **	**<0.001*** **					
Boron	0.004**	0.014*	0.715	0.042*	0.070	0.004**	0.007**	0.492
Calcium	0.374	**0.001*** **	0.683					
Lithium	0.012*	0.009**	0.766	0.088	0.099	0.005**	0.020*	0.617
Magnesium	0.002**	**<0.001** **	0.422	0.011*	0.157	0.015*	0.004**	0.178
Molybdenum	0.010*	0.010**	0.187	0.036*	0.033*	0.251	0.579	0.004**
TOC	0.063	**<0.001*** **	0.006**					
Potassium	0.022*	**<0.001*** **	0.559	0.757	0.430	0.021*	0.852	0.490
Sodium	0.385	**<0.001*** **	**<0.001*** **					
Strontium	0.466	0.004**	0.644					
Sulphur	0.008**	**<0.001*** **	0.492	0.382	0.263	0.014*	0.174	0.922
Uranium	0.680	0.004**	0.362					
Zinc	0.445	0.073	0.499					

Notes:
- Shaded cells indicate that the test was not performed because Area differences were not significant.
- TOC = total organic carbon
- 'Area' tests for differences among the four areas, overall. Additional tests were performed when significant Area differences were noted.
- 'Depth' tests for depth differences, overall.
- 'AxD' tests for differences in depth gradients among Areas.
- 'SR' tests for differences between the Study Areas and the Reference Areas.
- 'BS' tests for differences between the Near-field and the Mid-field Study Areas (i.e. Between Study)
- 'BR' tests for differences between the two Reference Areas (i.e. Between Reference).
- 'NF *vs* R' tests for differences between the Near-field Study Area and the Reference Areas.
- 'MF *vs* R' tests for differences between the Mid-field Study Area and the Reference Areas.
- Reported *p*-values for Area and Depth 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**).
- Statistical outliers we noted for a number of variables in the analysis model including the AxD interaction, but none of these outliers changed the significance of AxD term from significant to not significant, or vice versa, for any variable, except sodium. For sodium, the extreme value of 17,300 mg/L noted at the surface at Station W6-MF influenced results; with exclusion of that sample, the AxD term became significant. Results reported for sodium in Table 7-3 exclude the extreme value. This outlier for sodium is discussed further below in the Section dealing with produced water constituents.
- In the ANOVA with the interaction term AxD removed, statistical outliers were noted for molybdenum, potassium and sulphur. For these variables, the Area term became significant with removal of the mid-depth sample collected at Station W10-MF. Values for these variables were relatively high at that station and depth (see Figure 7-2). Results for molybdenum, potassium and sulphur presented in Table 7-3 exclude the mid-depth sample from Station W10-MF. Based on a comparison of concentrations in Reference Areas in 2018 versus those in produced water, molybdenum, potassium and sulphur are not enriched in produced water. Therefore, these high values cannot reasonably be attributed to produced water.

As in previous years, concentrations for a number of variables were influenced by depth (significant Depth terms in Table 7-3). Significant differences among Areas were noted for boron, lithium, magnesium, molybdenum, potassium and sulphur. For all these variables except molybdenum, differences among areas were driven by low values in the NE Reference Area rather than unusually high values in either of the Study Areas. For potassium and sulphur, significant differences occurred only between the two Reference Areas (significant BR contrast in Table 7-3), with potassium and sulphur concentrations generally lower in the NE Reference Area than in the NW Reference Area. The largest differences for boron and lithium also occurred between the References Areas (compare *p*-values for the BR contrast with *p*-values for remaining contrasts). As was the case for potassium and sulphur, boron and lithium concentrations were lower in the NE Reference Area than in the NW Reference Area. However, in this case, concentrations were also higher in the near-field compared to Reference Areas (NF *vs* R contrast in Table 7-3). These differences were predominantly between the near-field and the NE Reference Area stations; with values similar among near-field, mid-field and NW Reference Area stations (the BS contrast is not significant in Table 7-3, and SR, NF *vs* R and MF *vs* R contrasts excluding the NE Reference were also not significant (*p*-values > 0.5 in all cases)).

For magnesium, differences between near-field and Reference Area stations were more pronounced than differences between the two Reference Areas (compare the NF *vs* R contrast to the BR contrast). However, in this case as well, differences between near-field stations and NW Reference Area stations were not significant. That magnesium concentrations at near-field stations were marginally higher accentuated the difference between those concentrations and the lower concentrations in the NE Reference Area.

Unlike boron, lithium, magnesium, potassium and sulphur, Area differences for molybdenum were driven by low concentrations in the mid-field Study Area (MF *vs* R contrast, Table 7-3; with the contrasts remaining significant at $p < 0.05$ after removal of the NE Reference Area values; also see Figure 7-2). Median molybdenum concentration was 8.8 μg/L at mid-field stations, versus a median of 9.2 μg/L at Reference Area stations (medians were 9.2 μg/l and 9.4 μg/L in the NE and NW Reference Areas, respectively).

Area comparisons for barium, total organic carbon and sodium were performed for each depth class because of the significant Area X Depth interaction for these variables in Table 7-3. Results are provided in Table 7-4.

Table 7-4 Results of ANOVA (*p*-values) by Depth Class for Barium, Organic Carbon and Sodium

Variable	Depth	*p*-values					
		Area	SR	BS	BR	NF *vs* R	MF *vs* R
Barium	Surface	0.005**	0.004**	0.088	0.037*	0.090	0.002**
	Mid-Depth	0.031*	0.384	0.011*	0.119	0.030*	0.344
	Bottom	**<0.001*** **	**0.001*** **	0.823	**<0.001*** **	0.004**	0.007**
TOC	Surface	0.546					
	Mid-Depth	0.002**	**0.001*** **	0.183	0.018*	0.015*	**0.001*** **
	Bottom	**<0.001*** **	0.002**	0.082	**<0.001*** **	0.046*	**0.001*** **
Sodium	Surface	**0.001*** **	**<0.001*** **	0.504	**<0.001*** **	**<0.001*** **	**<0.001*** **
	Mid-Depth	0.039*	0.458	0.710	0.006**	0.674	0.429
	Bottom	0.194					

Notes
- Shaded cells indicate that the test was not performed because Area differences were not significant.
- TOC = total organic carbon
- 'Area' tests for differences among the four areas, overall. Additional tests were performed when significant Area differences were noted.
- 'SR' tests for differences between the Study Areas and the Reference Areas.
- 'BS' tests for differences between the Near-field and the Mid-field Study Areas (i.e. Between Study)
- 'BR' tests for differences between the two Reference Areas (i.e. Between Reference).
- 'NF *vs* R' tests for differences between the Near-field Study Area and the Reference Areas.
- 'MF *vs* R' tests for differences between the Mid-field Study Area and the Reference Areas.
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- A statistical outlier was noted for barium at Station W1-SE at mid-depth and exclusion of the outlier changed the significance of the Area term for that Depth from not significant to significant. Results reported in Table 7-4 for barium exclude the statistical outlier. Discussion on the potential relevance of this outlier is provided in the section dealing with potential produced water constituents.

Area differences for barium occurred at all depths (Table 7-4). At the surface and at the bottom, there were again differences between the two Reference Areas (BR term, Table 7-4), with barium concentrations lower at bottom depths and higher at surface depths in the NE Reference Area relative to the NW Reference Area (Figure 7-2). As was the case for most of the variables discussed above, the SR, NF *vs* R and MF *vs* R contrasts excluding the NE Reference Area yielded non-significant results ($p > 0.05$). However, at mid-depth, barium concentrations were higher in the near-field than they were at mid-depth at Reference stations; and this difference held with exclusion of the NE Reference Area. At mid-depth, median barium concentration was 7.0 ug/L at near-field stations, versus a median of 6.7 ug/L at mid-depth Reference Area stations (mid-depth medians were 6.8 μg/l and 6.6 μg/L in the NE and NW Reference Areas, respectively).

Area differences for organic carbon occurred at mid-depth and at the bottom (Table 7-4). In both cases, Area differences between the Reference Areas were strong (BR term, Table 7-4) and the SR, NF *vs* R and MF *vs* R contrasts excluding the NE Reference Area yielded non-significant results (p's > 0.05) in most cases. However, the MF *vs* R contrast remained significant ($p = 0.042$) at mid-depth with exclusion of the NE Reference Area. Organic carbon concentrations were generally higher at mid-depth in the mid-field than they were in Reference Areas. At mid-depth, median organic carbon concentration was 1.2 mg/L at mid-field stations versus a mid-depth median of 1.1 mg/L at Reference Area stations (mid-depth medians were 1.0 and 1.1 mg/L in the NE and NW Reference Areas, respectively).

For sodium, Area differences occurred at the surface and at mid-depth (Table 7-4). At mid-depth, those differences occurred only between the two Reference Areas (the only significant mid-depth term in Table 7-4 is the BR term). At the surface, differences occurred among all Areas except between the near-field and mid-field Study Area. With exclusion of either the NE or NW Reference Areas from contrasts, all Study versus Reference contrast remained significant ($p < 0.05$). At the surface, sodium concentrations were generally higher at near-field and mid-field Study Area stations than at Reference Area stations. At the surface, median sodium concentration was 9,170 mg/L at Study Area stations versus 9,070 mg/L at Reference Area stations (surface medians were 9,170 mg/L and 9,180 mg/L in the near and mid-field Study Areas, respectively; surface medians were 8,815 mg/L and 9,110 mg/L in the NE and NW Reference Areas, respectively).

In summary, the NE Reference Area differed from remaining Areas with concentrations of many variables lower in that Area than in the NW Reference Area or the near-field and mid-field Study Areas. Other than this difference, molybdenum concentrations were lower in the mid-field Study Area than in the Reference Areas; barium concentrations were higher at mid-depth in the near-field than at mid-depth in Reference Areas; organic carbon concentrations were higher at mid-depth in the mid-field than they were in Reference Areas; and sodium concentrations were higher in the near- and mid-field Study Areas than they were in the Reference Areas. Unlike the consistent differences seen for the NE Reference Area, there were no consistent Study/Reference Area differences, and those differences that did occur were slight. Study/Reference differences ranged from 1% for sodium to 8% for organic carbon, with differences of 4% for both molybdenum and barium.

Differences among Areas have been noted in previous years and most differences within year can be reasonably attributed to natural variability. In 2010, molybdenum and sulphur concentrations were lower in the Study Area (Husky Energy 2011). In 2012, 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 (Husky Energy 2013). In 2014, barium concentrations were lower at mid-depth in the near- and mid-field; and concentrations were higher in near-field surface samples, relative to other samples at similar depths (Husky Energy 2015). In 2016, and as was the case for the NE Reference Area in 2018, differences were noted between the mid-field and remaining areas (including the near-field); and strontium concentrations were generally lower in the near-field than in Reference Areas (Husky Energy 2019). Over the years, barium has shown the more frequent differences among Areas. However, these differences were slight and have not been consistent, with Study Area concentrations higher or lower in some years and at some depths compared to Reference Area concentrations.

Infrequently Detected Variables

The following variables (in order of decreasing occurrence) were not included in quantitative analyses because they were detected in 1 to <75% of the samples: suspended solids, phosphorous, nickel, iron, unionized ammonia, lead, copper, chromium, cadmium and fluoranthene. Other variables noted in Table 7-2 were not detected in water samples.

Suspended solids, phosphorous, nickel and iron occurred in more than 30% of samples (Figure 7-3). Of these, nickel occurred more frequently in Study Area samples, and it occurred more frequently in the near-field than in the mid-field. In the mid-field, the frequency of occurrence for nickel was 47%, similar to the frequency of occurrence in Reference Areas. In the near-field, nickel occurred in 73% of samples. With more than 50% of cases below detection limit, median nickel concentration in the mid-field and in the NE and NW Reference Areas were all below the detection limit of 0.2 µg/L. The median in the near-field was 0.3 µg/L. The maximum nickel concentration in the near-field was 13 µg/L and occurred at the surface at Station W5-SE. Remaining values above detection limit in the mid-field ranged from 0.2 to 1.2 µg/L, similar to values noted in the other Areas (Appendix D-2). Suspended solids occurred more frequently in Reference Area samples (Figure 7-3).

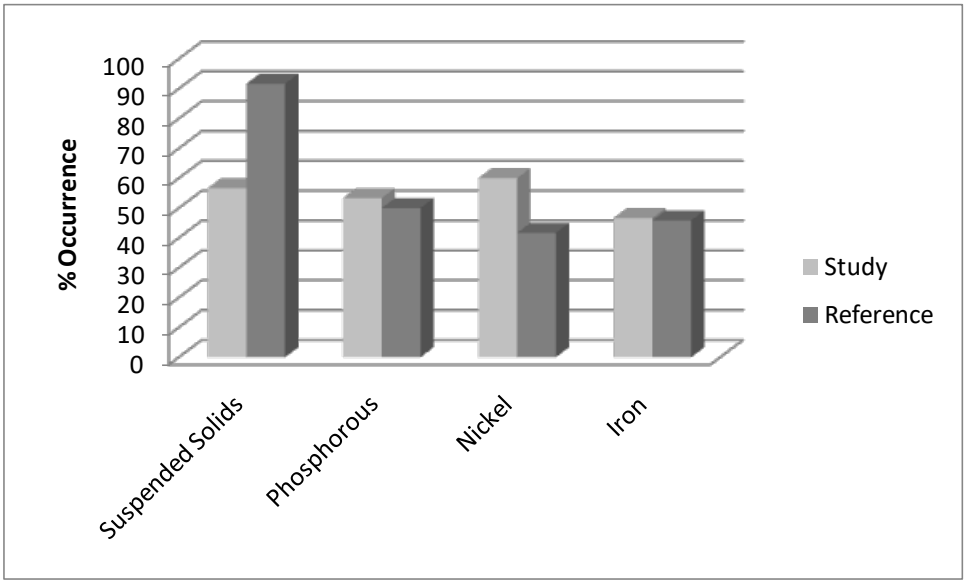


Figure 7-3 Percent Occurrence by Area of Variables that Occurred Above Laboratory Detection Limit in 30 to <75% of Samples

Note: Figure 7-3 combines the near- and mid-field Study Areas, as well as the NE and NW Reference Areas. When Study/Reference differences occurred, more detail is provided in the text.

Remaining variables were detected in less than 30% of samples (*i.e.*, 1 to 8 of 54 samples). Unionized ammonia was detected in seven samples, five in the mid-field and two in the near-field. Lead was detected in six samples, two in the mid-field, two in the near-field and one in each of the Reference Areas. Cadmium was detected in three samples, one in the mid-field and two in the near-field. Chromium was detected in three samples, one in each of the Reference Areas and one in the mid-field. Copper was detected in three samples, one in the NW Reference Area and two in the near-field. Fluoranthene was detected in one sample from the near-field. For metals and ammonia, these types of sporadic occurrences in the Study and/or Reference Areas have been noted in previous years, with no consistency within Areas among years.

Produced Water Constituents in Seawater

This section focuses on co-occurrence of potential produced water constituents at the station level. Previous sections examined Area differences in general.

Examination of seawater and produced water chemistry indicates that the following variables, in order of decreasing relative concentration in produced water, could be enriched in seawater as a result of produced water discharge: iron, barium, ammonia[24], copper, fluoranthene, strontium, lithium, arsenic and sodium. This is based on observed concentrations in produced water that were more than 10 times those noted in reference area seawater; and excludes those variables that were not detected in either the Near- or Mid-field Study Areas. Nickel, which was noted relatively frequently in near-field Study Area samples, is not particularly enriched in produced water. Its concentration in produced water is only six times that of 2018 Reference Area samples. In context, enrichment factors for copper, ammonia, barium and iron are 232, 920, 1176 and 6510 times that of 2018 Reference Area samples, respectively.

Fluoranthene and a relatively high concentration of iron (16.1 μg/L) were detected at mid-depth at Station W4-SE. The fluoranthene concentration in that sample was low (0.01 μg/L, just above the laboratory detection limit of <0.01 μg/L). Nevertheless, its presence in that sample, its absence in any other sample, coupled with a high iron concentration suggests the presence of produced water. The highest concentration of iron (20.1 μg/L) and copper (1.17 μg/L) were detected at the surface at Station W3-SE, again suggesting the presence of produced water.

Ammonia was also detected in five near-field samples and two mid-field samples and it was not detected in Reference Areas (also see the previous Section dealing with Infrequently detected variables). However, most of these detections did not coincide with the detection of iron (the constituent most likely to be enriched in produced water relative to seawater). The exception is the surface sample at Station W5-SE, which had detected levels of ammonia and a relatively high iron concentration (12.8 μg/L). The surface sample at Station W5-SE also had the highest nickel concentration (13 μg/L). Although the concentration of nickel in produced water is relatively low, this high concentration coupled with results for ammonia and iron may suggest the presence of produced water at the surface at Station W5-SE.

Remaining variables: arsenic, barium, lithium, strontium and sodium occurred in all samples, including those from the Reference Area. In general, values in the Near and Mid-Field Study Area were within the range of Reference Area concentrations (Appendix D-2), and no clear pattern emerges from an examination of maxima. As noted above, there was one extreme value for sodium (17,300 mg/L) at the surface at Station W6-MF. However, concentrations of other produced water constituents were not remarkably high in that sample.

Across years, possible evidence of produced water at some near-field stations was also noted in 2016.

[24] Calculations of the concentration of ammonia in produced water relative to that of seawater was based on total ammonia. Estimates of unionized ammonia would be irrelevant for produced water, since pH and temperature would affect the relative concentration of unionized ammonia immediately on release to seawater.

7.3 Produced Water Constituents in Sediment

7.3.1 Modelling Study

Full model results predicting the concentration of selected produced water constituents in sediments were provided as part of the 2012 EEM report (Husky Energy 2013).

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 could settle to sediments at sufficiently high concentrations to act as tracers. Based on this, accumulation of Ra-228 was modelled, with results applicable to other potential tracers in produced water (see Husky Energy 2013 for details).

7.3.1.2 Conclusions and Recommendations

The following conclusions were drawn from the modelling study:

- Radium radionuclides are not expected to be effective tracers of produced water constituents in sediments[25].
- Close attention should be paid to any increase in iron concentrations in sediments, particularly to the south, since modelling showed that deposition of produced water constituents likely would be greater to the south of the *SeaRose FPSO*.

7.3.2 Field Study

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). Results from sediments collected at Sediment Quality Triad stations and sediments collected at Water Quality stations were combined for use in this portion of the program.

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 7.3.1.2. 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

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

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 2018 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 over time both in terms of changes in mean concentration across all sampling locations [*i.e.*, an increase or decrease in concentration that is similar across all stations from before produced water discharge (2000, 2004, 2005, 2006) to after (2008, 2010, 2012, 2014, 2016, and 2018)], or a change in the nature of the relationship between distance to the *SeaRose FPSO* and concentration (*i.e.*, the slope of the relationship may get steeper over time, indicating an increase in concentrations adjacent to the *SeaRose FPSO*). As was the case in Section 5, repeated-measures regression involved only those stations sampled repeatedly over all years (n = 35).

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 conducted 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 $\log_{10}$ 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). The second step was regression of iron concentrations ($\log_{10}$) on PCA axis scores. Residuals from regression of iron concentrations on PCA axis scores can be considered to be representative of variations in iron that are independent of concentrations of other metals. 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[26]. In 2018, low levels of 13 PAHs were detected at three stations. All 13 PAHs were detected at Station W2-SE[27]; 10 PAHs were detected at Station W4-SE[28]; and two PAHs were detected at Station W1-SE[29]. In 2014, a low-level of one PAH was

[26] Two stations, 4 and 27, were common to both the Sediment Quality and the Water Quality programs from 2012 to 2018. 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.

[27] Acenaphthene, anthracene, benzo(*a*)anthracene, benzo(*b*)fluoranthene, benzo(*g,h,i*)perylene, benzo(*j*)fluoranthene, benzo(*k*)fluoranthene, chrysene, fluoranthene, fluorene, indeno(1,2,3-*cd*)pyrene, phenanthrene and pyrene were detected at Station W2-SE.

[28] Acenaphthene, anthracene, benzo(*a*)anthracene, benzo(*a*)pyrene, benzo(*b*)fluoranthene, benzo(*g,h,i*)perylene, chrysene, fluoranthene, phenanthrene and pyrene were detected at Station W4-SE.

[29] Phenanthrene and pyrene were detected at Station W1-SE.

detected in sediments at Station W-15R (a reference station), located approximately 28 km from the *SeaRose FPSO*. In 2012, low levels of 15 PAHs were detected at Station W-2SE, located 0.32 km from the *SeaRose FPSO*. In 2010, low levels of four PAHs were detected at Station 16[30], located 0.74 km from the *SeaRose FPSO*. Otherwise, PAHs have not been detected in White Rose sediments in other EEM years.

Principal Components Analysis

All metals except aluminum were strongly associated (*i.e.*, r_P > |0.6|) with scores on the first PCA axis (Table 7-5). Therefore, the first PCA axis was a good summary of overall concentrations of metals. Barium concentrations correlated strongly with both the first and second PCA axes; therefore, the second axis was a summary of variations in barium that were independent of variations in overall metals concentrations. Barium is examined in detail in Section 5.

Table 7-5 Principal Component Analysis Component Loadings (Correlations) of Metals Concentrations (All Years)

Parameter	Principal Component	
	1	2
Aluminum	0.36	0.407
Barium	**0.671**	**-0.627**
Chromium	**0.624**	0.366
Lead	**0.737**	-0.533
Manganese	**0.715**	0.504
Strontium	**0.837**	-0.449
Uranium	**0.674**	0.202
Vanadium	**0.765**	0.416
Variance Explained	47.0	20.6

Note: - **Bold** indicates component loading (correlation) greater than 0.6 or -0.6.

Spearman Rank Correlations

Spearman rank correlations for iron concentrations in relation to distance to the *SeaRose FPSO*, and for iron residuals, for all years, are illustrated in Figures 7-4 and 7-5, respectively. Spearman rank correlations were not significant for iron in 2018 (ρ_s = 0.096, p > 0.05, All stations; ρ_s = 0.852, p > 0.05, repeated-measures stations). Rank correlations were not significant for iron in any year (Figure 7-4).

In contrast, rank correlations were significant for iron residuals when all stations or repeated-measures stations were considered in 2018 (ρ_s = 0.266 p < 0.05, All stations; ρ_s = 0.338, p < 0.05, repeated-measures stations; Figure 7-5).

[30] In 2010, Station 16 acted as both a Sediment Quality Triad and a Water Quality station. Therefore, those PAHs are in summary statistics for both Sediment Quality Triad and Water Quality stations.

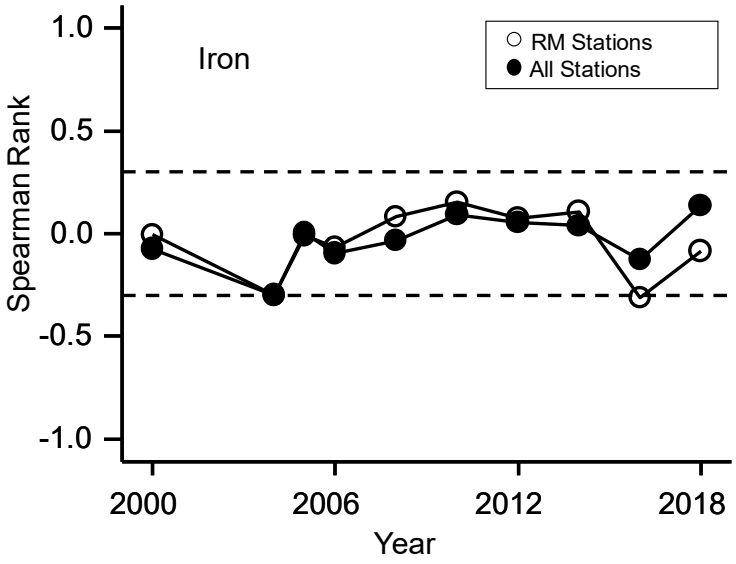


Figure 7-4 Spearman Rank Correlations with Distance from *SeaRose FPSO* for Iron Concentrations in Sediments

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 ($n = 35$ for repeated-measures (RM) stations, and varies from 44 to 68 depending on EEM year for all stations).

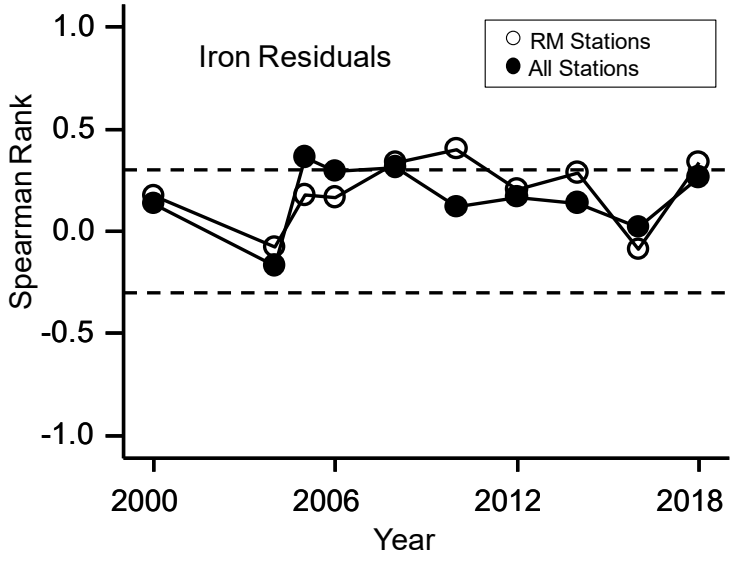


Figure 7-5 Spearman Rank Correlations with Distance from the *SeaRose FPSO* for Iron Residuals

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 ($n = 35$ for repeated-measures (RM) stations, and varies from 44 to 68 depending on EEM year for all stations).

Scatterplots

The relationships between iron concentrations and iron residuals and distance to the *SeaRose FPSO* are illustrated in the Figures 7-6 and 7-7, respectively. The plots indicate no increase in iron concentrations in sediments near the *SeaRose FPSO*.

Maps

Maps of stations with iron concentrations and iron residuals within and above the baseline background range are provided in Figures 7-8 and 7-9, respectively. Figure 7-8 shows that iron concentration was elevated at four stations, with no pattern with respect to distance from the *SeaRose* FPSO. The map of iron residuals (Figure 7-9), which corrects for the natural association among metals, shows high iron relative to concentrations of other metals at nine stations, again with no patterns with respect to distance from *SeaRose* FPSO (Figure 7-9).

In 2012, there was 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* (Husky Energy 2013). This increase in iron residuals between 5 and 10 km from the *SeaRose FPSO* was less apparent in 2014 (Figure 7-7), but higher iron residual values did tend to occur more frequently to the northwest of the *SeaRose FPSO* (Husky Energy 2017). In 2016, this trend continued within 2 and 10 km of the *SeaRose FPSO*, predominantly to the east and southeast (Figure 7-7). This trend did not appear to be repeated with 2018 data (Figures 7-7 and 7-9).

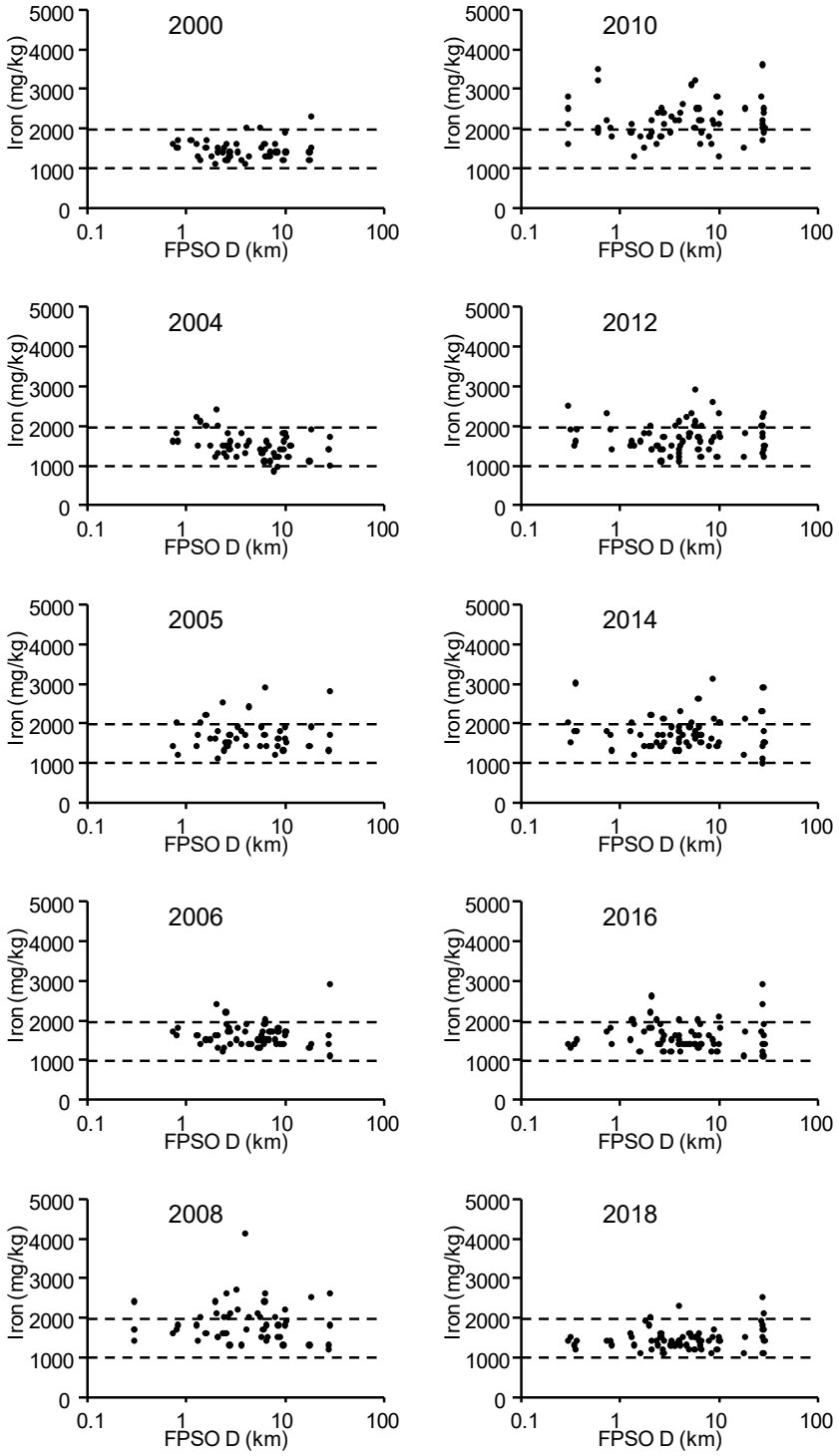


Figure 7-6 Variation in Iron Concentrations in Sediments (mg/kg) with Distance from the *SeaRose FP*SO (FPSO D) (all Years)

Notes: *SeaRose FPSO* D = distance (km) to the *SeaRose FPSO*. Background iron concentrations are indicated by horizontal lines (992 mg/kg and 1,970 mg/kg, respectively), based on the mean values ± 2 SDs from 2000 (baseline).

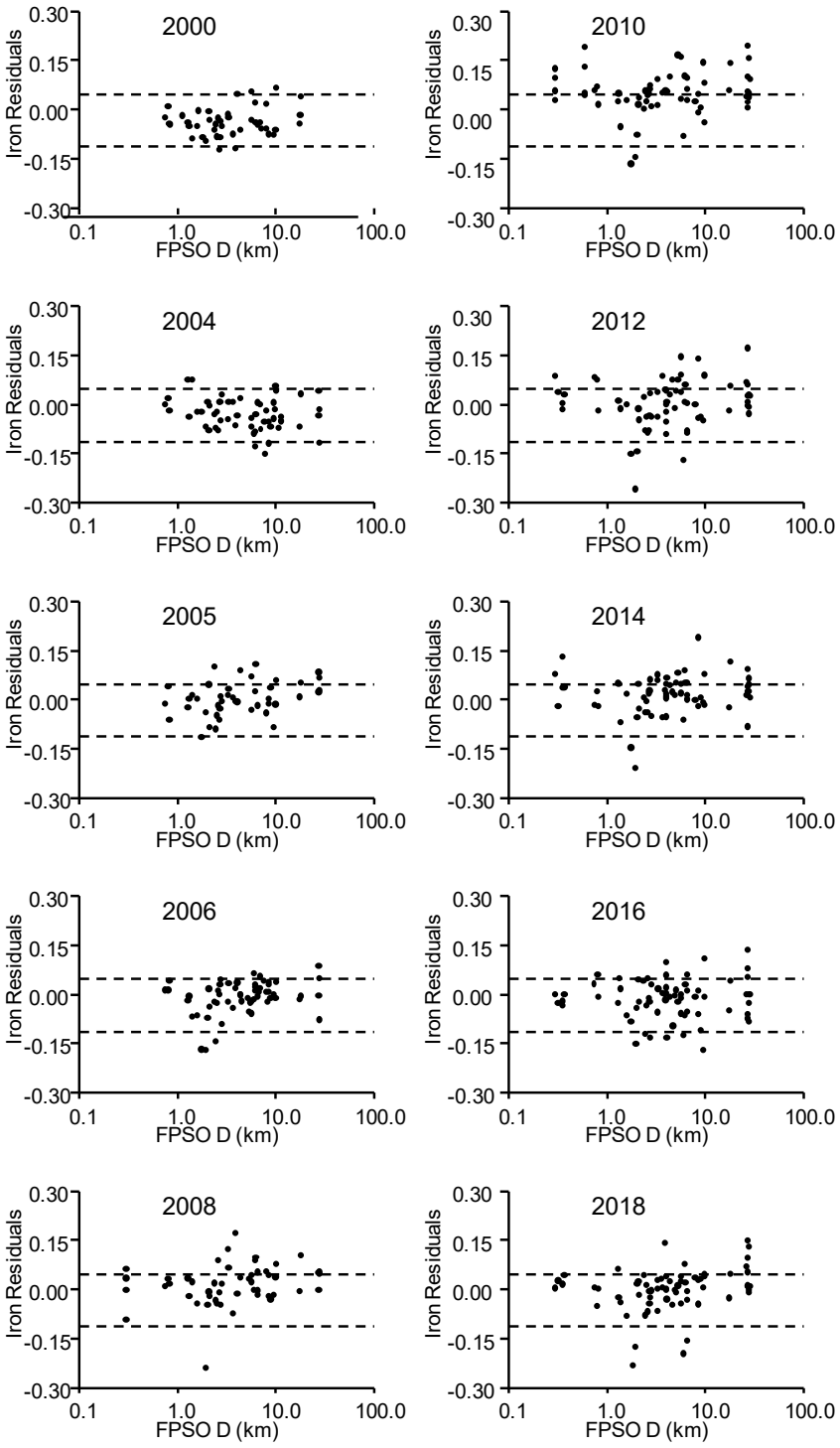


Figure 7-7 Variation in Iron Residuals with Distance from the *SeaRose FPSO* (FPSO D) (all Years)

Notes: *SeaRose FPSO* D = distance (km) to the *SeaRose FPSO*. Background iron residuals are indicated by horizontal lines (-0.113 and 0.047, respectively), based on the mean values ± 2 SDs from 2000 (baseline).

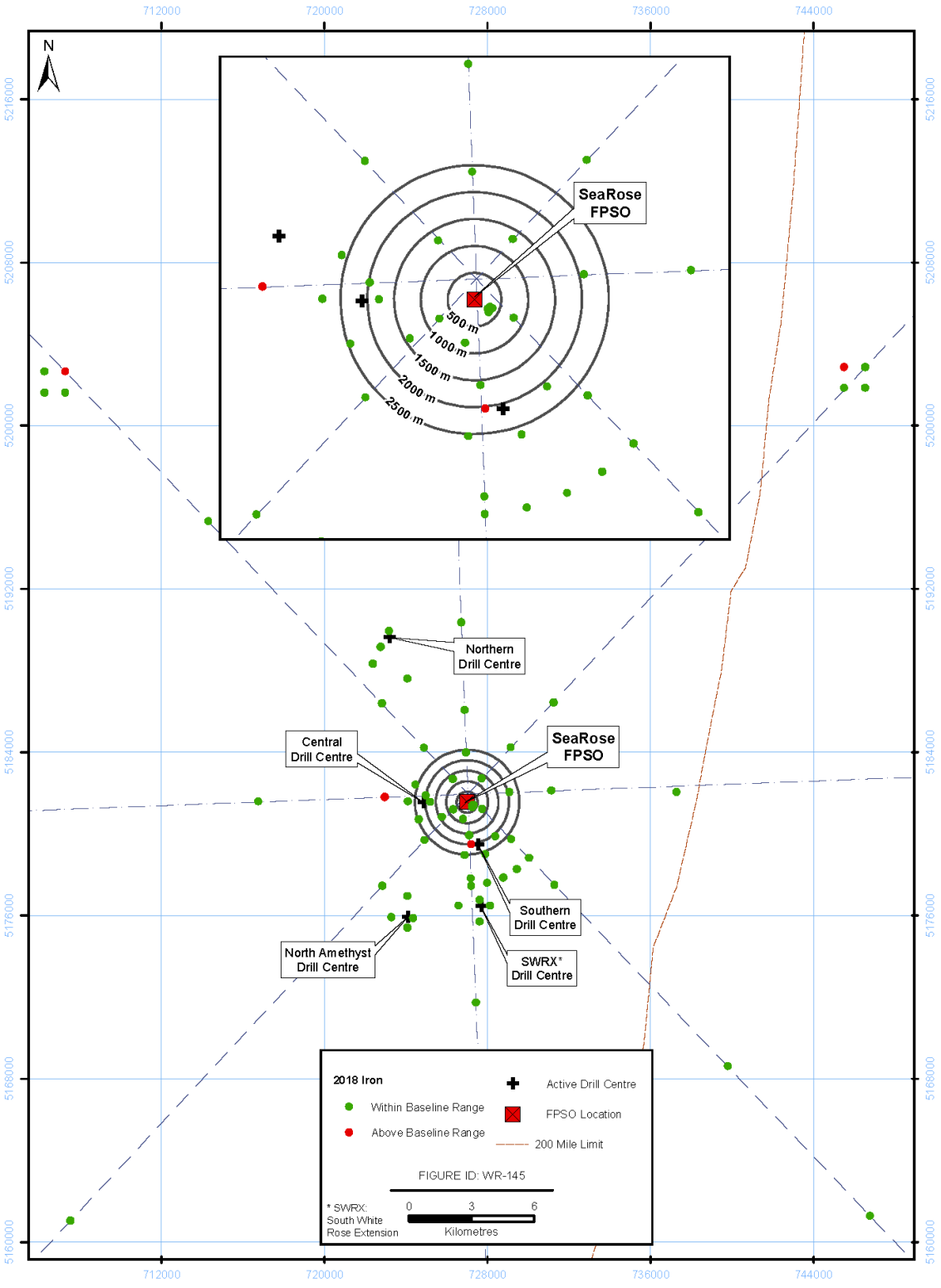


Figure 7-8 Location of Stations with Iron Concentrations Within and Above the Baseline Range (2018)

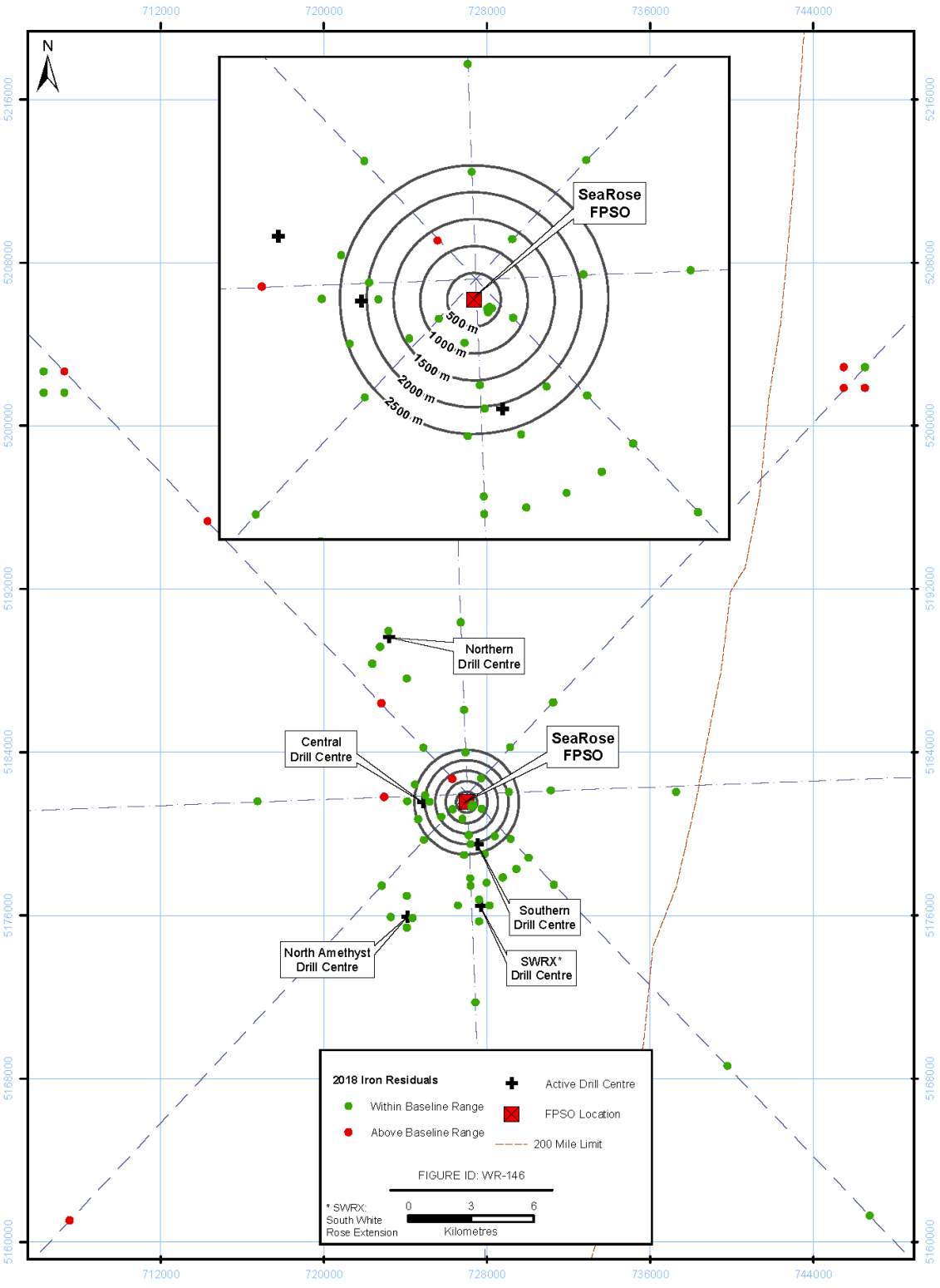


Figure 7-9 Location of Stations with Iron Residuals Within and Above the Baseline Range (2018)

Repeated-Measures Regression

Results of repeated-measures regression are provided in Table 7-6. For repeated-measures stations, there was no change over time in the slope of the relationship between iron concentrations or iron residuals and distance to the *SeaRose FPSO* in EEM years or since produced water discharge began at the *SeaRose FPSO* (in March 2007) (Table 7-6; Figures 7-6 and 7-7). Significant differences were noted for mean iron concentrations in EEM years ($p < 0.001$; Table 7-6) with higher concentrations in 2008 and 2010, followed by declines from 2012 onwards (Figure 7-10). In contrast, no significant change in the mean values of iron residuals were noted over this same period. Finally, no significant change in mean iron or iron residuals occurred from before to after release of produced water (Table 7-6, Figure 7-11).

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

Trend over Time		Before to After	
Slope	**Mean**	**Slope**	**Mean**
Iron Concentrations			
0.187	< 0.001	0.351	0.142
Iron Residuals			
0.142	0.149	0.144	0.149

Notes: - The trend over time term tests trends over EEM years (2004 to 2018); the Before to After term tests for differences from before to after release of produced water (before and after 2007).
- Values are probabilities.
- n = 35 with Station 31 excluded.

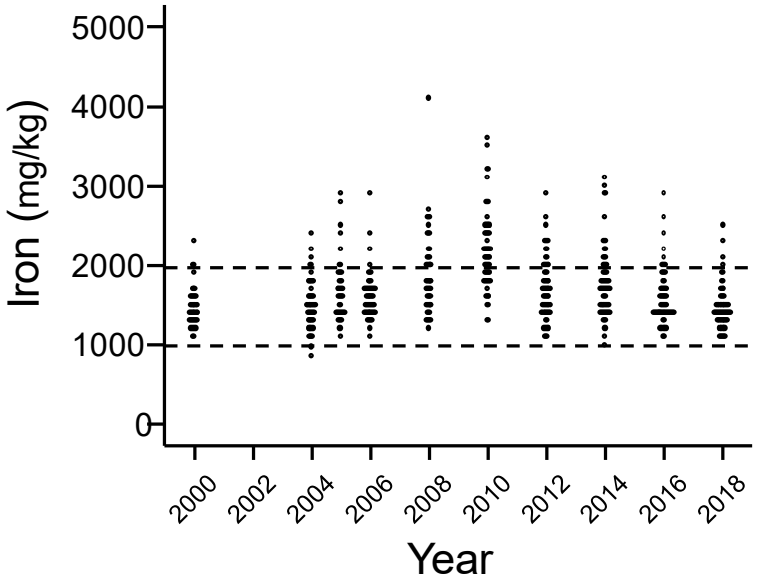


Figure 7-10 Dot Density Plot of Iron Concentrations in Sediments (mg/kg) by Year

Note: Background iron concentrations are indicated by horizontal lines (992 mg/kg and 1,970 mg/kg, respectively), based on the mean values ± 2 SDs using data from 2000.

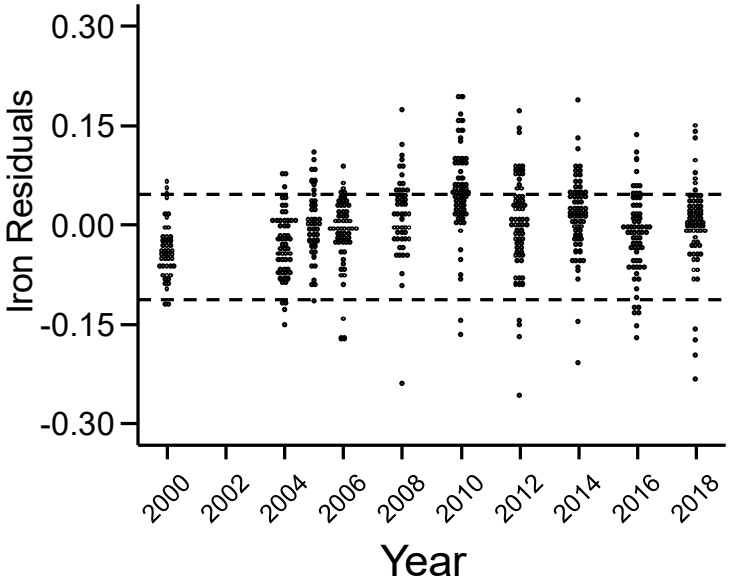


Figure 7-11 Dot Density Plot of Iron Residuals by Year

Note: Background iron residuals are indicated by horizontal lines (-0.113 and 0.047, respectively), based on the mean values ± 2 SDs using data from 2000.

From Figures 7-10 and 7-11 and analyses above, evidence of enrichment of iron in sediments is weak and change, if any, since the release of produced water has been subtle.

7.4 Summary of Results

7.4.1 Water

The following variables were detected in all seawater samples: arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, total organic and inorganic carbon, potassium, sodium, strontium, sulphur, uranium and zinc. Aluminum was above detection limit in 96% of samples. With the exception of inorganic carbon, which varied over the narrow range of 28 and 29 mg/L, all these variables were included in quantitative analyses for 2018. Variables detected in 1% to 75% of the samples were examined qualitatively. $>C_{10}$-C_{21} hydrocarbons, $>C_{21}$-C_{32} hydrocarbons, phenols and alkyl phenols and organic acids were not detected in any water samples.

Significant differences among sampling Areas (Near-field, Mid-field and NE and NW Reference Areas) were noted for barium, boron, lithium, magnesium, molybdenum, organic carbon, potassium, sodium and sulphur. In general, results pointed to more frequent differences between the NE Reference Area and remaining Areas, with concentrations in the NW Reference Area similar to those in the Study Areas. Other than the differences attributable to the NE Reference Area, molybdenum concentrations were lower in the mid-field Study Area than in the Reference Areas; barium concentrations were higher at mid-depth in the near-field than at mid-depth in Reference Areas; organic carbon concentrations were higher at mid-depth in the mid-field than they were in Reference Areas; and sodium concentrations were higher in the near- and mid-field Study Areas than they were in the Reference Areas. Unlike the consistent differences

seen for the NE Reference Area, there were no consistent Study/Reference Area differences, and differences that did occur were slight. Study/Reference differences ranged from 1% for sodium to 8% for organic carbon, with differences of 4% for both molybdenum and barium.

Among the infrequently detected variables, nickel occurred more frequently at levels above laboratory detection limits in near-field Study Area samples. It occurred in 73% of near-field samples versus in approximately 50% of samples in remaining Areas. Suspended solids occurred more frequently at levels above laboratory detection limit in the Reference Areas. There were sporadic occurrences of other constituents and some produced water constituents may have been detected at Stations W3-SE, W4-SE and W5-SE located 300 m down-current from the *SeaRose FPSO*; as determined by the presence of various combinations of ammonia, copper, fluoranthene and/or iron and, possibly, nickel at these stations.

7.4.2 Sediment

In 2018, there was little evidence that iron was enriched by produced water discharge. In previous years, there was a tendency for iron to be enriched between approximately 5 and 10 km from the *SeaRose* FPSO, although the trend has always been too weak to draw firm conclusions about the potential influence of produced water.

8.0 Discussion

8.1 Sediment Quality Component

Examination of sediment quality is standard in many EEM programs (*e.g.*, Hurley and Ellis (2004); 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 collectively 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 drill centre 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

Hydrocarbons in the $>C_{10}$-C_{21} range and barium in sediments were influenced by drilling operations in 2018, with concentrations elevated up to estimated threshold distances[31] of 2.4 and 1.0 km from the nearest active drill centre, respectively. Significant threshold distances have been detected for $>C_{10}$-C_{21} hydrocarbons and barium in all years since drilling began. The average threshold distance for $>C_{10}$-C_{21} hydrocarbons has varied from 5.9 to 10.4 km from 2004 to 2008, and from 2.4 to 5.8 km from 2010 to 2018. Confidence intervals around the average threshold estimates for $>C_{10}$-C_{21} hydrocarbons for 2016 and 2018 did not overlap with those for 2004 to 2008, indicating a significant reduction in threshold distance in 2016 and 2018 compared to those earlier years. The threshold distances for barium also tended to be greater in earlier EEM years: 2 to 3.6 km from 2004 to 2010 versus approximately 1 km since 2012. Confidence intervals around the 2018 estimate for barium did not overlap with those around estimates from 2004 to 2010, indicating a significant reduction in the threshold distance in 2018, relative to years prior 2012. Results for both $>C_{10}$-C_{21} hydrocarbon and barium concentrations indicate a decrease in the spatial extent of sediment contamination at White Rose in 2018.

A summary of $>C_{10}$-C_{21} hydrocarbon and barium concentrations for various distance classes in baseline and in each EEM year at White Rose is provided in Table 8-1. The maximum $>C_{10}$-C_{21} hydrocarbon concentration in 2018 was 710 mg/kg (at Station 20, located 0.37 km from the Central Drill Centre) and the maximum barium concentration was 3,400 mg/kg (at Station C5, located 0.33 km from the Central Drill Centre). Over all EEM years, the highest $>C_{10}$-C_{21} hydrocarbon concentration (1,600 mg/kg) was noted in 2008 at Station 20 and the highest barium concentration (4,000 mg/kg) was noted in 2012, also at Station 20.

[31] *i.e.*, the distance at which values return to background values.

Table 8-1 $>C_{10}$-C_{32} Hydrocarbon and Barium Concentrations in Sediments with Distance from Drill Centres in Baseline (2000) and EEM Years

Year	Distance from Drill Centres (m)	$>C_{10}$-C_{21} (mg/kg)	Barium (mg/kg)
2000	500 to 1000	<0.3	140 to 180
	>1000 to 2000	<0.3	140 to 190
	>2000 to 4000	<0.3	140 to 210
	>4000 to 8000	<0.3	140 to 200
	>8000	<0.3	120 to 190
2004	<500	8.99 to 275	240 to 1400
	500 to 1000	19.2 to 37	190 to 470
	>1000 to 2000	1.4 to 17.3	120 to 320
	>2000 to 4000	<0.3 to 6.85	140 to 230
	>4000 to 8000	<0.3 to 2.73	140 to 180
	>8000	<0.3 to 0.66	110 to 180
2005	<500	3.8 to 260	210 to 810
	500 to 1000	5.3 to 130	190 to 390
	>1000 to 2000	0.5 to 64	140 to 240
	>2000 to 4000	0.5 to 1.1	150 to 220
	>4000 to 8000	0.4 to 1.4	150 to 180
	>8000	<0.3 to 0.4	93 to 220
2006	<500	1.1 to 570	200 to 3100
	500 to 1000	7.7 to 52	190 to 770
	>1000 to 2000	0.6 to 7.7	150 to 260
	>2000 to 4000	<0.3 to 2.1	150 to 250
	>4000 to 8000	<0.3 to 1.4	140 to 170
	>8000	<0.3	110 to 210
2008	<500	3.6 to 1600	230 to 3400
	500 to 1000	2 to 54	220 to 630
	>1000 to 2000	1.1 to 8.1	180 to 340
	>2000 to 4000	<0.3 to 2.1	170 to 210
	>4000 to 8000	<0.3 to 2.1	140 to 220
	>8000	<0.3	110 to 210
2010	<500	38 to 810	570 to 2700
	500 to 1000	2.8 to 110	200 to 500
	>1000 to 2000	0.9 to 11	180 to 310
	>2000 to 4000	<0.3 to 0.8	160 to 190
	>4000 to 8000	<0.3 to 0.6	130 to 200
	>8000	<0.3 to 0.4	110 to 200
2012	<500	23 to 510	1200 to 4000
	500 to 1000	1 to 130	190 to 1300
	>1000 to 2000	0.84 to 9.3	180 to 280
	>2000 to 4000	<0.3 to 2.2	150 to 210
	>4000 to 8000	0.56 to 1.3	140 to 180
	>8000	<0.3 to 0.69	110 to 200
2014	<500	1.3 to 120	160 to 1400
	500 to 1000	0.84 to 28	140 to 560
	>1000 to 2000	0.74 to 4.8	150 to 250
	>2000 to 4000	<0.3 to 0.56	150 to 250
	>4000 to 8000	<0.3 to 0.48	150 to 200
	>8000	<0.3	98 to 220
2016	<500	1.4 to 150	150 to 2400
	500 to 1000	0.84 to 22	160 to 590
	>1000 to 2000	0.88 to 5.4	160 to 240
	>2000 to 4000	0.36 to 0.87	150 to 180
	>4000 to 8000	<0.3 to 0.96	130 to 150
	>8000	<0.3 to 0.43	93 to 180

Year	Distance from Drill Centres (m)	$>C_{10}$-C_{21} (mg/kg)	Barium (mg/kg)
2018	<500	9.2 to 710	350 to 3400
	500 to 1000	2.4 to 64	160 to 980
	>1000 to 2000	0.79 to 5	150 to 250
	>2000 to 4000	0.77 to 1.6	150 to 220
	>4000 to 8000	0.4 to 0.97	140 to 180
	>8000	0.36 to 0.43	110 to 190

Notes: - Station 31, near an exploration well, was excluded from these statistics.
- Previous reports have indicated that $>C_{10}$-C_{21} hydrocarbon and barium levels at White Rose are comparable to those noted at other developments (see for instance, Husky Energy 2019). For brevity, the Table 8-1 has been modified from previous reports show statistics for White Rose only, since the information on other developments has been presented numerous times. Distance classes in this table also have been modified from those presented in prior years to match those used in the multivariate assessment on benthos.

Remaining sediment chemical and physical characteristics showed either no or highly localized project-related alterations in 2018. Sediment lead, strontium and organic carbon concentrations exhibited a threshold relationship with distance from drill centres. Sediment lead concentrations were elevated to 0.8 km from drill centres. Elevated lead levels from 0.6 to 1.4 km of drill centres have been noted since 2006. Sediment strontium concentrations were also elevated to 0.8 km in 2018. No thresholds for strontium were noted in most years prior to 2018, but thresholds ranging from approximately from 0.6 to 1.6 km were noted in 2006, and 2012. Sediment organic carbon concentrations were elevated to 1.0 km in 2018, and no threshold has been noted in previous EEM years.

Maxima for lead, strontium and organic carbon in 2018 (9.3 mg/kg, 140 mg/kg and 1.6 mg/kg, respectively) all occurred at Station C5. Over all years, sediment lead concentrations have ranged from 1.6 mg/kg to 26 mg/kg, and all concentrations have been below the ISQG of 32 mg/kg [32]. Sediment strontium and organic carbon concentrations respectively have ranged from 25 to 170 mg/kg and from 0.4 to 2.1 mg/kg[33] over all years.

There was some evidence of effects on sediment fines, ammonia, sulphur and overall metals concentrations (as assessed through Metals PC1) at a few stations within 1 km of drill centres in 2018, but relationships with distance to drill centres were too weak to determine thresholds. Sulphides also were elevated at a few stations near drill centres, despite the lack of a statistically significant distance relationship. Evidence of effects on all these last variables generally has been either weak or absent in EEM years. However, percent fines exhibited a threshold with distance from drill centres in 2014, and sulphide concentrations exhibited a threshold in 2006 and 2008. In all cases, threshold distances were approximately 1 km or less.

Near drill centres, maximum fines, ammonia, sulphur and sulphides (3.4 mg/kg, 17 mg/kg. 0.14 mg/kg and 21.8 mg/kg, respectively) and overall metals (as assessed

[32] Based on ISQG, lead concentrations noted at White Rose would not be expected to induce biological effects.
[33] These statistics exclude organic carbon data from 2014, which were obtained using a different analytical method than that used in other years.

through metals PC1[34]) occurred at Stations C5, NA1, 20, SWRX1, C5[35] respectively in 2018[36]. Over all years, fines, ammonia, sulphur and sulphide concentrations have ranged up to 3.7%, 64.6 mg/kg, 0.29 mg/kg and 86.9 mg/kg, respectively.

There was no evidence of effects on sediment redox potential in 2018.

8.1.2 Laboratory Toxicity Tests

Sediments were generally non-toxic in 2018. No sample was toxic to Microtox. One sample was toxic to laboratory amphipods when compared to Reference sediments, but it was not toxic when compared to laboratory control sediment; and there was no significant correlations between laboratory amphipod survival and any sediment particle size or chemistry variable. The one sample (from Station S2) that was toxic relative to Reference sediments did have elevated levels $>C_{10}$-C_{21} hydrocarbons and barium concentrations. However, there were many stations with higher concentration of $>C_{10}$-C_{21} hydrocarbons that were not toxic to laboratory amphipods. Therefore, the link between project activity and this response is not clear.

Over all EEM years, 6 (of 352 samples) have been toxic to Microtox and 15 (of 352) samples have been toxic to laboratory amphipods, indicating that sediments at White Rose are generally non-toxic.

8.1.3 Benthic Invertebrate Community Structure

As in previous years, there was evidence of project effects on benthic biomass and little evidence of effects on richness. However, the relationship between total benthic abundance and distance to active drill centres was weaker in 2018 than in previous years and not significant. In 2018, total abundance was reduced at only two stations near drill centres (details on effects by drill centre are provided below). Multivariate analysis indicated that the most affected taxa were the polychaetes Paraonidae, Cirratulidae, Dorvileidae and Orbiniidae, and the crustacean Tanaidacea. Paraonidae, Cirratulidae, Orbiniidae and Tanaidacea were also among the most affected taxa in 2016 (the first year the multivariate analysis on benthos was conducted). The abundances of Paraonidae, Tanaidacea and Orbiniidae were lower near drill centres in 2018; and the abundances of Cirratulidae and Dorvilleidae were higher near drill centres. Because abundances of some taxa decreased, and abundances of others increased, the overall effect on total abundance was minor.

The relationship between total biomass and distance from active drill centres was weaker in 2018 than from 2012 to 2016. No threshold could be estimated in 2018, and effects were generally limited to approximately 1 km from drill centres. As indicated in previous reports, reductions in biomass near drill centres are related, in part, to reductions in the number of larger echinoderms.

[34] Metals PC1 is an aggregate variable summarizing concentrations of metals for ease of communication and interpretation.
[35] Maximum fines and maximum Metals both occurred at Station C5.
[36] The overall maximum fines (3.6 mg/kg) occurred at Station 4, a reference station, and is unlikely a result of White Rose. Sediment fines content has been relatively high at Station 4 in all years.

Richness was predominantly unaffected by project activity in 2018. However, two stations near drill centres had reduced richness (details on effects by drill centre are provided below).

As in prior years, univariate analysis of abundances of individual taxa provided evidence of project effects on Paraonidae; and multivariate analyses of 2018 data confirmed that Paraonidae was the taxon most affected by project activity. Paraonidae abundance has been strongly related to distance from active drill centres, with threshold distances significant in every EEM year. The threshold distance for effects on Paraonidae in 2018 was estimated at 1.6 km. As was the case for $>C_{10}$-C_{21} hydrocarbons and barium, there was an indication that threshold distances for Paraonidae abundance were larger in earlier EEM years (approximately 3 to 4 km from 2004 to 2008 and approximately 1 to 2.5 km from 2010 to 2016; although confidence intervals for these threshold estimates overlapped).

Benthic biomass and abundances of Paraonidae were negatively correlated with sediment concentrations of $>C_{10}$-C_{21} hydrocarbons and barium. Biomass and abundances of Paraonidae were lower in sediments with high concentrations of $>C_{10}$-C_{21} hydrocarbons and barium. Higher concentrations of sulphur, lead, organic carbon, strontium, metals (as assessed through Metals PC1), and percent fines also co-occurred with lower abundances of Paraonidae. Richness decreased with increasing ammonia concentrations, and amphipod abundance decreased with increasing water depth. Multivariate analysis confirmed correlations between sediment $>C_{10}$-C_{21} hydrocarbons and barium concentration and benthic community structure, and also identified changes in community structure with varying sediment ammonia, water depth, strontium and percent fines. These and some of the correlations noted for univariate measures could be natural. However, the association between $>C_{10}$-C_{21} hydrocarbon and barium concentrations, the two main indices of drill cuttings in sediment, and benthic responses confirms that responses were project-related.

In addition to an examination of change in benthic indices or abundances of individual taxa with distance from active drill centres as a group (as done above), the White Rose EEM program also relies on an examination of changes near individual drill centres. The first approach can be regarded as a whole-field approach, whereas the second approach targets the effect of individual drill centres. This combined approach allows for the efficient assessment of effects of individual drill centres as well as potential cumulative effects from multiple drill centres.

Near drill centres, total abundance was reduced to below the baseline range at stations SWRX1 and SWRX2 in 2018. These stations are within 0.5 km of the SWRX Drill Centre.

Total benthic biomass was below the baseline range at one to three stations around the Central, North Amethyst, Southern and Northern Drill Centres. Stations C5, 20, and C3 had reduced biomass around the Central Drill Centre. Stations NA1 and NA2 had reduced biomass around the North Amethyst Drill Centre. Station S1 had reduced biomass around the Southern Drill Centre and Station N4 had reduced biomass around the Northern Drill Centre. With the exception of Stations C3 and S1, these stations are located within 0.5 km of drill centres. Station C3 is located 0.74 km from the Central Drill Centre and Station S1 is located 0.6 km from the Southern Drill Centre.

Richness was reduced to below the baseline range at Station C5, located 0.33 km from the Central Drill Centre. Richness was also reduced at Station SWRX3, located 0.74 km from the SWRX Drill Centre.

Paraonidae abundance was reduced to below the baseline range at approximately half the stations around drill centres. Stations C5, 20, C3, C2 and 17 had reduced Paraonidae around the Central Drill Centre. Stations NA1, NA2 and NA3 had reduced Paranonidae abundance around the North Amethyst Drill Centre. Stations SWRX1, SWRX2 and SWRX3 had reduced Paraonidae abundance around the SWRX Drill Centre. Stations S5, 13, S1 and S2 had reduced Paraonidae abundance around the Southern Drill Centre and Stations N4 and N3 had reduced Paraonidae abundance around the Northern Drill Centre. Most of these stations are within 0.5 km from drill centres. Stations C3, C2, NA3 and SWRX3 are within 1 km of drill centres; and Station 17 is 1.81 km from the Central Drill Centre.

Overall, 2018 data suggest that the majority of effects on benthos occur within 0.5 km of drill centres, with more subtle and/or highly localized effects between 1 to 2 km. This is consistent with the 2018 multivariate assessment, which showed that stations beyond 2 km of drill centres were indistinguishable from each other.

After monitoring the effects of drilling on sediment quality nine times over a period of 14 years, distance relationships for sediment physical and chemical variables and benthos have varied in strength, and threshold distances have also varied somewhat from year to year. To date, there is no indication that effects are getting greater in magnitude or in spatial extent. The reduction in threshold distances for sediment $>C_{10}$-C_{21} hydrocarbons and barium concentrations and Paraonidae abundances; and the weaker relationship between benthic biomass and distance to drill centres from earlier to later EEM years suggests that effects may be getting more localized.

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 commercial 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; DeBlois *et al.* 2014a). At White Rose, American plaice liver and fillet and snow 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 usually examined for body burden. In 2018, sampling in Reference Areas 3 and 4 was not possible because of intense commercial fishing activity for crab in those areas. Therefore, additional transects were performed in Reference Areas 1 and 2 to provide the necessary number and weight of plaice and crab for use in this EEM program.

Compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon range were again detected in all plaice liver samples in 2018. As in previous years, additional Gas Chromatography/Mass Spectrometer analysis did not indicate the presence of drill fluid or petroleum hydrocarbons in those samples. It has previously been speculated that these compounds are natural and perhaps diet related.

Most of the frequently detected analytes in plaice liver did not vary significantly in concentration between the Study and Reference Areas in 2018. Unaffected analytes included % fat, arsenic, copper, iron, manganese, mercury, silver, zinc and $>C_{21}$-C_{32} hydrocarbons. However, concentrations of cadmium and selenium were lower in the Study Area than in the Reference Areas; and concentrations of $>C_{10}$-C_{21} hydrocarbons were higher in the Study Area. Difference in plaice liver between the two Reference Areas for $>C_{10}$-C_{21} hydrocarbons were also noted, with concentrations in Reference Area 1 higher than in Reference Area 2.

When they occurred, differences in plaice liver between the Study Area and the Reference Areas generally were slight. Mean cadmium concentrations were 2.7 mg/kg, 3.2 mg/kg and 2.8 mg/kg in the Study Area and in Reference Areas 1 and 2, respectively (with an overall Reference mean of 3.0 mg/kg)[37]. Mean selenium concentrations were 7.2 mg/kg, 8.9 mg/kg and 8.8 mg/kg in the Study Area and in Reference Areas 1 and 2, respectively (with an overall Reference mean of 8.85) mg/kg). The difference in $>C_{10}$-C_{21} hydrocarbon concentrations among Areas was somewhat larger. Mean $>C_{10}$-C_{21} hydrocarbon concentrations were 297 mg/kg, 247 mg/kg and 139 mg/kg in the Study Area and in Reference Areas 1 and 2, respectively (with an overall Reference mean of 193 mg/kg). As noted above, $>C_{10}$-C_{21} hydrocarbons were not petrogenic in origin and are more likely diet related. In addition, the difference $>C_{10}$-C_{21} hydrocarbon concentrations between the Study and Reference Areas has not been consistent over time. Across years (2004 to 2018), copper is the only analyte in plaice liver samples that has shown a difference between the Study and the Reference Areas. Copper concentrations generally increased in 2014 and 2016, in all Areas. However, the increase was slightly more pronounced in the Study Area (as determined by the slopes of the linear relationships). In 2018, copper concentrations in liver were similar between the Study and Reference Areas.

Mercury and zinc concentrations in plaice fillets did not vary significantly between the Study and Reference Areas in 2018. Arsenic concentrations varied significantly and were higher in the Study Area compared to the Reference Areas, overall. However, Arsenic concentrations were similar between the Study Area and Reference Area 1. Mean arsenic concentrations were 21.8 mg/kg, 20.1 mg/kg and 18.2 mg/kg in the Study Area and in Reference Areas 1 and 2, respectively (with an overall Reference mean of 19.2 mg/kg). The difference in arsenic concentration between Areas in 2018 has not been consistent over time (2004 to 2018); nor were there any significant differences in trends over time for fillet mercury and zinc concentrations.

For crab tissue in 2018, concentrations of boron, copper and mercury varied significant between the Study Area and the Reference Areas. Boron and mercury concentrations were generally higher and copper concentrations were generally lower in the Study Area compared to the Reference Areas, overall. However, in all cases, Study Area concentrations were similar to concentrations in Reference Area 1, and concentrations of these variables differed between the two Reference Areas. Mean boron concentrations were 19.2 mg/kg, 17.2 mg/kg and 8.1 mg/kg in the Study Area and in Reference Areas 1 and 2, respectively (with an overall Reference mean of 12.7 mg/kg)

[37] Concentrations in this Section and Section 6 are corrected for moisture content. For consistency with prior years, summary statistics in Appendix C-2 are reported in wet weight (uncorrected for moisture content).

[38]. Mean copper concentrations were 20.9 mg/kg, 21.2 mg/kg and 32.9 mg/kg in the Study Area and in Reference Areas 1 and 2, respectively (with an overall Reference mean of 27.1 mg/kg). Mean mercury concentrations were 0.42 mg/kg, 0.41 mg/kg and 0.27 mg/kg in the Study Area and in Reference Areas 1 and 2, respectively (with an overall Reference mean of 0.34 mg/kg).

The differences between the Study and Reference Areas noted in crab claw for boron, copper and mercury in 2018 have not been consistent over time. Across years (2004 to 2018), arsenic is the only analyte in crab claw samples that has shown a difference between the Study and the Reference Areas. Overall arsenic values declined in earlier years followed by relative increases in all Areas, but the decline was more pronounced in the Study Area. As noted above, arsenic concentrations in crab tissue were similar between the Study and Reference Areas in 2018.

Concentrations of metals in plaice and crab tissues at White Rose have been generally similar between the Study and Reference Areas or, when differences occurred, they have been slight and/or have not persisted over time. To date, there is little evidence of metals contamination in tissues of plaice and crab originating from White Rose project activity. In 2018, differences were noted between the two Reference Areas for a number of analytes. These differences have not been noted in prior years and analyte concentrations in either of the Reference Areas, as well as in the Study Area, were within the range of values noted in other years. Overall, differences among these areas can reasonably be attributed to natural variability.

8.2.2 Taste Tests

In 2018, there were no significant differences in taste test results between Study and Reference Areas for plaice and, from ancillary comments, there were no consistent comments identifying abnormal or foreign odour or taste. For crab, panelists for the triangle test were successful in discriminating between samples from the Study and Reference Area. However, there was no preference for any Area in the hedonic scaling test and; from ancillary comments from both tests, there were no consistent comments identifying abnormal or foreign odour or taste. Together, these results do not indicate taint in White Rose plaice or crab samples.

8.2.3 Fish Health Indicators

Cellular and sub-cellular bioindicator responses along with observations on 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 Special Publication Series 1992; Adams 2002; Tillitt and Papoulias 2003; Schlenk *et al.* 2008; Morales-Caselles *et al.* 2009; Santana *et al.* 2018). However, it is recognized that biomarker endpoints can display some natural variability and the focus should be on the prevalence of observations (a weight-of-evidence approach), which allows for a comprehensive evaluation of fish health and provides a good indication of environmental quality for assessment purposes (Giltrap *et al.* 2017).

[38] Two boron concentrations were below the laboratory detection limit in Reference Area 2. Values below detection were set to half detection limit calculation of the mean.

8.2.3.1 Biological Characteristics and Condition of Fish

Information on fish biological 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.

In total, 171 females and 9 males were collected during the survey. No analyses were carried out for males as too few were captured. For females, seventy eight percent (78%) were pre-spawning, 21% were immature and 1% were spent. The frequency of pre-spawning and immature females did not differ between the Study and Reference Areas. As was the case for males, no analyses were performed on spent females as only 2 were captured.

No differences were noted between the Study and Reference Areas for all biological characteristics measured on pre-spawning females. These included length, gutted weight, age, gutted weight (as a function of length), liver weight (as a function of gutted weight) and gonad weight (as a function of gutted weight). However, length, gutted weight, age and gonad weight (as a function of gutted weight) differed between the two Reference Areas. Pre-spawning females from Reference Area 2 were shorter, lighter, younger, and had heavier gonads relative to body weight compared to Reference Area 1.

For immature females, gutted weight as a function of length (the regression analogue of Condition Factor) differed between the Study and Reference Areas, with values greater in the Study Area than in the Reference Areas. Gutted weight and age differed between the two Reference Areas. Immature females from Reference Area 2 were lighter and younger than those from Reference Area 1.

Overall, the differences observed in biological characteristics of fish from the three Areas could be attributed to normal inter-site variability linked to non-pollutant factors such as the reproductive status of the fish (*e.g.*, Mayer *et al.* 1989; Barton *et al.* 2002; Maddock and Burton 1999).

8.2.3.2 Gross Pathology

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

8.2.3.3 Mixed Function Oxygenase Activity

Since basal levels of MFO enzymes can vary seasonally between males and females of the same species (*e.g.*, Walton *et al.* 1983; Mathieu *et al.* 1991), results were analyzed separately for each sex. Within the females, data were also analyzed separately for pre-spawning, and immature females, since maturity stage can result in some loss of sensitivity for resolving contaminant mediated differences in female fish during spawning (*e.g.*, Whyte *et al.* 2000), and because there were adequate numbers to examine the influence of maturity level on MFO activity. However, statistical analysis was not performed on males and spent females because the low numbers of fish.

There were no significant differences in hepatic EROD activity between the Study and Reference Areas for pre-spawning and immature females. There were also no significant differences between the two Reference Areas for immature females. However, EROD values were significantly lower in Reference Area 2 than in Reference Area 1 for pre-spawning females.

This significant difference might be due to the reproductive status of the fish, since fish from Reference Area 2 had larger gonads relative to body weight than fish from Reference Area 1, likely indicating a more advanced developmental stage and stronger influence of 17β-Estradiol on the activity of EROD (Whyte *et al.* 2000; Wunderlich *et al.* 2015). Age has also been shown to influence EROD activity in fish; however, the main age-related factors that influence the induction of CYP1A (a sub-family of cytochrome P450-dependent monooxygenases that includes EROD) in adult fish are the amount of time that the fish has had to accumulate contaminants and the reproductive status of the fish (Whyte *et al*. 2000). As previously mentioned, it is likely that the effects of gonad development influenced the EROD activity of the fish; although the effects of contaminants on EROD activity in pre-spawning females from the two Reference Areas cannot be completely ruled out. Nevertheless, that these noted differences were due to natural causes is supported by the lack of statistical differences in histological lesions specifically related to hydrocarbon exposure between Reference Areas (see Section 8.2.3.4).

8.2.3.4 Histopathology

Detailed histopathological studies were carried out on liver tissues of American plaice with observations on various lesions that have been commonly associated with chemical toxicity (*e.g.*, Myers and Fournie, 2002; Feist *et al.* 2004). Since gender and maturity status do not influence liver histopathology, all males and females from the same area were pooled for analysis. Of the liver lesions noted, nuclear pleomorphism, macrophage aggregates, inflammatory response, hepatocellular vacuolation and parasites occurred with sufficient frequency to perform statistical analysis; and there were no significant differences between the Study and Reference Areas for any of these. Other than these, one case of megalocytic hepatosis was noted in each of the sampling areas.

As in the case of liver histopathology, since gender and maturity status do not influence gill histopathology, all males and females from the same area were pooled for analysis. With the exception of basal hyperplasia, which was noted more frequently in Study Area fish, none of the gill lesions noted occurred either more or less frequently in Study Area fish compared to Reference Area fish.

Basal hyperplasia was noted in 15% of fish from the Study Area versus 4% of fish from the Reference Areas. The epithelium of the gills is a major site for the uptake of soluble chemical substances (Stentiford *et al.* 2003). As such, considerable attention has been given to their response to hydrocarbons (Solangi and Overstreet 1982; Mallat 1985; Khan 1995; Stentiford *et al.* 2003). The predominant effects of hydrocarbons upon gill tissues seem to be tissue hypertrophy and/or hyperplasia (Haensly *et al.* 1982). However, hyperplasia of the gills seems to be a generalized response to wide variety of stressors such as other xenobiotics including ammonia and ammonium hydroxide (Smith and Piper 1975), pesticides (Jauch 1979), metals (Bilinski and Jonas 1973), pulp and paper mill effluents (Khan *et al.* 1994), water pH (Daye and Garside 1976), parasites (Eller 1975), amoebic disease (Munday *et al.* 2001), bacterial infections (reviewed in

Mallat 1985), and other stressors. Hyperplasia and other alterations of the gill induced by irritants have been considered as part of a generalized systemic response to stressors (Mallat 1985). Hyperplasia lesions have been found to be temporary and gills may recover their normal histological status once the stressor is removed (Solangi and Overstreet 1982).

8.2.3.5 Overall Fish Health

As in previous years, the results of the fish health survey carried out in 2018 indicated that the overall health of American plaice is similar between the Reference Areas and the White Rose Study Area. The increase in basal hyperplasia in the gills of American plaice from the Study Area is difficult to attribute to hydrocarbon exposure since hyperplasia could be caused by a wide variety of stressors. Moreover, the lack of significant differences in all the other markers described in the present study, including EROD activity between the Study and Reference Areas seem to point to the possibility that gill hyperplasia may be due to factors other than hydrocarbon exposure. Concerning the difference in EROD activity in pre-spawning females between Reference Areas, it is likely that the difference is due to the effects of gonadal development, which is further supported by the difference in gonad weight (as a function of gutted weight) between the two areas and the lack of difference in histological lesions that can be specifically associated to hydrocarbon exposure.

8.3 Water Quality Component

The Water Quality monitoring program at White Rose involves collection of sediment and seawater samples in two Study Areas and in two Reference Areas, located approximately 28 km to the northeast and northwest of the *SeaRose FPSO*.

Samples are assessed for seawater and sediment chemistry.

8.3.1 Seawater Chemistry

The following variables were detected in all seawater samples: arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, organic and inorganic carbon, potassium, sodium, strontium, sulphur, uranium, and zinc. Aluminum was above detection limit in 96% of samples. With the exception of inorganic carbon, which varied over the narrow range of 28 and 29 mg/L, all these variables were included in quantitative analyses for 2018. Variables detected in 1% to 75% of the samples were examined qualitatively. $>C_{10}$-C_{21} hydrocarbons, $>C_{21}$-C_{32} hydrocarbons, phenols and alkyl phenols and organic acids were not detected in any water samples.

Significant differences among sampling Areas (Near-field, Mid-field and NE and NW Reference Areas) were noted for barium, boron, lithium, magnesium, molybdenum, organic carbon, potassium, sodium and sulphur. In general, results pointed to more frequent differences between the NE Reference Area and remaining Areas, with concentrations in the NW Reference Area similar to those in the Study Areas. Other than the differences attributable to the NE Reference Area, molybdenum concentrations were lower in the mid-field Study Area than in the Reference Areas; barium concentrations were higher at mid-depth in the near-field than at mid-depth in Reference Areas; organic carbon concentrations were higher at mid-depth in the mid-field than they were in Reference Areas; and sodium concentrations were higher in the near- and mid-field

Study Areas than they were in the Reference Areas. Unlike the consistent differences seen for the NE Reference Area, there were no consistent Study/Reference Area differences, and those differences that did occur were slight. Study/Reference differences ranged from 1% for sodium to 8% for organic carbon, with differences of 4% for both molybdenum and barium.

Differences among Areas have been noted in previous years and most differences within year can be reasonably attributed to natural variability. In 2010, molybdenum and sulphur concentrations were lower in the Study Area (Husky Energy 2011). In 2012, 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 (Husky Energy 2013). In 2014, barium concentrations were lower at mid-depth in the near- and mid-field; and concentrations were higher in near-field surface samples, relative to other samples at similar depths (Husky Energy 2015). In 2016, and as was the case for the NE Reference Area in 2018, differences were noted between the mid-field and remaining areas (including the near-field); and strontium concentrations were generally lower in the near-field than in Reference Areas (Husky Energy 2019). Over the years, barium has shown the more frequent differences among Areas. However, these differences were slight and have not been consistent, with Study Area concentrations higher or lower in some years and at some depths compared to Reference Area concentrations.

Among the infrequently detected variables, nickel occurred more frequently at levels above laboratory detection limits in near-field Study Area samples in 2018. It occurred in 73% of near-field samples versus in approximately 50% of samples in remaining Areas. The higher occurrence of nickel in near-field samples may have resulted from produced water input (also see the paragraph below). However, the concentration of nickel in produced water is relatively low compared to that of other constituents. Nickel has not occurred more frequently in the near-field Study Area in prior years and no sources of nickel have been identified at White Rose[39]. Suspended solids occurred more frequently at levels above laboratory detection limit in the Reference Areas.

In addition to an examination of general trends, as done above, the White Rose EEM program also examines individual occurrences of potential produced water constituents in seawater samples. This examination indicated that the produced water constituents ammonia, copper, fluoranthene, iron and, possibly, nickel[40] may have been detected at some stations within 300 m of the *SeaRose FPSO*. Possible evidence of produced water at some near-field stations was also noted in 2016[41]. In all cases, occurrences of potential produced water constituents were sporadic.

8.3.2 Sediment Iron Concentration

Modelling results indicated that iron concentrations potentially could be enriched in sediments as a result of produced water discharge (Husky Energy 2013). In 2018, there was little evidence of iron enrichment. In previous years, there was a tendency for iron to

[39] Husky reviewed the suite of drilling and production chemicals used at the field and nickel was not listed as a constituent on any of the Safety Data Sheets available for these chemicals.
[40] As noted above, nickel concentrations are not remarkably high in produced water. Therefore, attributing it to produced water input is more tenuous than for the other variables.
[41] Naphthalene, 1- and 2-methylnaphthalene, benzene, toluene, zinc, iron, and strontium were the potential produced water constituents detected in 2016.

be enriched between approximately 5 and 10 km from the *SeaRose* FPSO, although the trend has always been too weak to draw firm conclusions about the potential influence of produced water.

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 2018 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 indicated that there would 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 predicted, concentrations of $>C_{10}$-C_{21} hydrocarbons and barium were elevated by drilling activity near drill centres. To a lesser extent, sediment lead, strontium organic carbon, fines, ammonia, sulphur and metals other than barium were also affected by drilling.

The spatial extent of contamination in 2018 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 2.4 km from source. Barium contamination extended to 1.0 km from source. Both lead and strontium contamination extended to 0.8 km, and organic carbon contamination extended to 1.0 km. No threshold distance could be quantified for remaining affected

variables; levels for these were elevated at a few stations within approximately 1 km from source[42].

Sediments were generally non-toxic in 2018. No sample was toxic to Microtox. One sample was toxic to laboratory amphipods when compared to Reference sediments, but it was not toxic when compared to laboratory control sediment; and the link between project activity and toxicity in that sample was not clear. Taken together, the Microtox and amphipod toxicity tests continue to indicate that sediments at White Rose are predominantly non-toxic.

Overall, effects on indices of benthic community structure were relatively weak compared to other years. Total abundance and richness were each reduced at only two stations near drill centres in 2018. Evidence of project effects on richness has always been weak or absent. Evidence of effects on total abundance has been stronger in prior years. Effects on biomass were weaker in 2018 than from 2012 to 2016, with effects limited to approximately 1 km from drill centres.

Of the individual taxa, the polychaete family Paraonidae remains the most affected, with lesser effects noted on the polychaetes Cirratulidae, Dorvilleidae and Orbiniidae, and the crustacean Tanaidacea. The threshold distance for effects on Paraonidae in 2018 was estimated at 1.6 km.

Examination of effects by drill centre stations (*i.e.*, the four to five stations immediately surrounding each drill centre) suggest that the majority of effects on benthos occurred within 0.5 m of drill centres, with more subtle and/or highly localized effects between 1 to 2 km. This is consistent with the 2018 multivariate assessment, which showed that stations beyond 2 km of drill centres were indistinguishable from each other.

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, Gerrard *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.

Ratings of effects size to benthic communities 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. In general, this is not the condition at White Rose. In 2018, total abundance was reduced to less than 75% of the lower limit of the baseline range of variation at one station near active drill centres[43]. Biomass was

[42] When thresholds cannot be fit to the data, estimates are qualitative rather than quantitative.
[43] See Section 5 for a list of drill centre stations where values were reduced to below 75% of the baseline range.

reduced to less than 75% of the lower limit of the baseline range at three stations near active drill centres. Finally, although reductions in richness were noted at two stations, values did not fall below 75% of the baseline range at any station.

As noted in Husky's response to regulator comments on the 2014 EEM program, potential effects on benthic communities were assessed within the valued ecosystem component of Fish and Fish Habitat. In general, both the White Rose (Husky Oil Operations Limited 2000) and North Amethyst (LGL 2006) environmental assessments predictions are consistent with observations of both Davies *et al.* (1984) and Gerrard *et al.* (1999); highly disrupted communities can be expected near source. According to effect size criteria noted above, benthic communities at White Rose are not highly disrupted, although indices of benthic community structure were reduced to less than 75% of the baseline range at four drill centre stations, located at distances ranging from 0.3 to 0.7 km a drill centre. More subtle changes in community structure were noted to 2 km.

Sediment contamination and effects on benthos noted in 2018 and in previous years have not 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.

There was little evidence of project-related effects on water quality overall. As in previous years, some differences among Areas were noted but these differences have not been consistent over time and can better be attributed to natural variability than project-effects. Conversely, some compounds known to be in high concentration in produced water were detected sporadically and at low concentrations at three Near-field stations. Since these stations were located 300 m down current of the *SeaRose FPSO*, produced water constituents may have been detected in 2018. There was also evidence that produced water constituents were detected in 2016 (Husky Energy 2019).

The White Rose environmental assessment (Husky Oil Operations Limited 2000) predicted that changes to physical and chemical characteristics of seawater as a result of liquid discharge would be localized near discharge source. The sporadic occurrence of low levels of potential produced water constituents at Near-field stations is consistent with these predictions. The findings also confirm that the revised White Rose Water Quality Monitoring design (Husky Energy 2010b), with adaptive sampling in the near-field, is effective.

8.5 Conclusion

In 2018, there was evidence of project-related effects on fish habitat (physical and chemical characteristics), and produced water may have been detected at some near-field water quality stations. However, these effects are consistent with predictions made in the White Rose EIS and there is no evidence that additional mitigation measures are required at this time.

8.6 Consideration for the 2020 EEM Program

Multivariate assessment of benthic community structure identified Paraonidae as the most affected taxon in 2016 and 2018. Cirratulidae, Orbiniidae and Tanaidacea were also among the most affected taxa in both those years. The current univariate analyses on individual taxa examines changes in the abundance of Paraonidae, Spionidae, Tellinidae and Amphipoda. However, evidence of effects on the last three taxa has been inconsistent or weak. Univariate analyses for the 2020 program should examine changes in the abundances of Paraonidae, Cirratulidae, Orbiniidae and Tanaidacea. The multivariate analysis should continue to help identify if these taxa remain relevant.

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10.0 Addendum

Comments on Husky 2018 EEM Report: Volume 1

Canada-Newfoundland and Labrador Offshore Petroleum Board

Page iii of xvi: The statement "Therefore, the link between project activity and this response in 2018 is not clear" might be better stated as "There was no detectable correlation between project activity and sediment toxicity at the one location which demonstrated amphipod toxicity relative to reference samples" but the Husky's words are acceptable.

Noted. However, there were elevated concentrations of drill mud hydrocarbons and barium at the one toxic station. The point being made is that higher levels of these two constituents happened elsewhere and those samples were not toxic. This makes it difficult to draw a link between drill mud hydrocarbons and barium and toxicity.

Page iv of xvi: The statement "Of the taxa listed above, the polychaete family Paraonidae was the most affected by project-related activity, with decreased numbers noted to 1 to 2 km" should include the words "in comparison to baseline."

The text will be changed as indicated.

Page iv of xvi: Should the statement "Only two stations near drill centres (within 0.5 km) had richness values lower than what was noted in baseline" start with "In 2018"?

Yes. 'In 2018,' will be added to the beginning of the sentence.

Page 4 of 232: Figure 1-3 should be in or adjacent to section 1.6 rather than follow the introductory paragraph to section 1.7. and divide that paragraph from the hypotheses it discusses.

Agreed. Figure 1-3 will be moved as indicated.

Page 41 of 232: Table 4-1 – the last two columns appear to be labelled erroneously with the labels "Total Cuttings Discharged (mt) Since the Beginning of Drilling" and "Total Muds Discharged (m^3) Since the Beginning of Drilling" respectively. The amounts appear to be for the year rather than "Since the Beginning of Drilling" since we know that mud and cuttings were discharged at the Southern Drill Centre from 2003 to 2006. Husky should relabel these columns correctly. There is no additional information required as the cumulative amounts are provided beneath the table.

The last two columns will be relabelled:
'Total Cuttings Discharged (mt) by Year Since the Last EEM Program'
'Total Muds Discharged (m3) by Year Since the Last EEM Program'

Page 42 of 232: Table 4-2 – see comments on Table 4-1

The last three columns will be edited as per above 'by Year' will be added; 'Since the Beginning of Drilling' will be changed to 'Since the Last EEM Program'.

Page 43 of 232: Table 4-3 – see comments on Table 4-1

The last column will be edited as per above 'by Year' will be added; 'Since the Beginning of Drilling' will be changed to 'Since the Last EEM Program'.

Fisheries and Oceans Canada

General Comments

The program continues to be comprehensive for sediment, commercial fish, and water quality components. Procedures followed are clear and the results, for the most part, are well interpreted and explained. Note is made of elevated levels of several contaminates near drill centres and localized effects on macrofauna are unlikely to have significant ecological effects on fisheries in the area. Continued monitoring should establish if effects remain localized to drill centres.

Noted and thank you.

Specific Comments

Section 5.1.1: Field Collection (page 48, paragraph 2, sentence 2) – should list the stations where duplicate samples were collected or refer to a table of station names and locations with the duplicate stations indicated.

The sentence will be changed to 'Field duplicates were collected for sediment chemistry at five randomly selected stations (Stations 19, 29, C1, C3, and NA1).

Section 5.1.2.1: Physical and Chemical Characteristics (page 49, paragraph 2) – "Most of the components of PureDrill IA35-LV form an Unresolved Complex Mixture 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 Unresolved Complex Mixture for PureDrill IA35-LV looks to range from 2.5 min to approximately 4.9 min. This should be stated.

The paragraph will be changed as follows in agreement with retention times noted by Fisheries and Oceans Canada, and to better indicate that Figure 5-4 is an example of a chromatogram for PureDrill IA35-LV.

'Gas chromatography is used to assess concentrations of hydrocarbons in the C_6-C_{32} range. When complex hydrocarbon mixtures are separated by chromatography, the more unique compounds such as the *n*-alkanes separate as individual peaks. Isoalkanes, on the other hand, are such a diverse group with so little difference in physical characteristics that they tend not to separate into distinct peaks in the chromatogram but rather, form a "hump" in the chromatogram (e.g., Figure 5-4). This hump is often referred to as the Unresolved Complex Mixture. 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}. In Figure 5-4, most of the components of PureDrill IA35-LV form an Unresolved Complex Mixture that starts around the retention time of 3 minutes and ends around a retention time of 5 minutes'.

Section 5.1.3: Data Analysis (last paragraph, page 56) – 'Based on regulatory feedback from Fisheries and Oceans Canada (see Appendix A in the 2016 EEM Program Report, Husky Energy 2018), Station 31 was excluded from all statistical analyses as it is a clear outlier in terms of chemistry (hydrocarbons and barium in

particular). Station 31 is located 4.2 km from the nearest drill centre, but the station is located near the site of a delineation well drilled in 2007." The statement above originated from a comment by DFO on the 2016 EEM that Station 31 should be excluded from toxicity analysis and benthic indices since it was removed from chemical and physical analysis. Although DFO stands by the above statement, Station 31 still remains under the influence of developmental drilling and should continue to be monitored and reported on for any effects attributed to the project over time.

Station 31 will continue to be monitored under the current EEM program design. Husky Energy's revised EEM program design document recommends deletion of Station 31 along with other stations that have provided minimal or redundant information. That document and the associated power analysis for stations deletions are currently under regulatory review.

Section 5.2.1.1: $>C_{10} - C_{21}$ Hydrocarbons (first paragraph, page 65) – *P* value of 0.371 does not match what is in Table 5-6.

Thank you. The *P* value of 0.371 in the text will be changed to 0.374.

Section 5.2.1.6: Sulphide (first sentence, page 81) – first sentence should read, "In 2018, 33% of sulphide values were below the laboratory detection limit".

'In 2016' will be changed to 'In 2018'.

Section 5.2.2: Toxicity (page 105) – is there a reason that Station S2 was toxic although there were stations with higher hydrocarbons and barium? There is no explanation given.

With one station toxic to laboratory amphipods and no sample toxic to Microtox, our conclusion is that sediments at White Rose were predominantly non-toxic. In general, we look for a potential link between a toxic response and project activities. The two best indicators of project activity are sediment concentrations of $>C_{10}$-C_{21} hydrocarbons and barium and, as noted, there were many sediments from stations with higher concentrations of these two compounds that were not toxic to laboratory amphipods. Sediment fines, organic carbon, ammonia, sulphide, sulphur, and metals concentrations were not visibly elevated at Station S2. Although Station S2 had the lowest redox value among the 53 stations tested, the sediment was still toxic at 152 mV. Lower redox could indicate potential decomposition of organic matter which could, in turn, affect toxicity test results. Any decomposition of organic matter could be related to project activity or it could be natural. Chemistry results in general better support the idea that toxicity at Station S2 was due to natural factors; there is little evidence that toxicity was related to project activities. It is of note that Station S2 was toxic only when compared to Reference Sediments and was not toxic when compared to Laboratory Control Sediments.

Section 6.1.1.1: Sampling Quality Assurance/Quality Control (top of page 143) – it is mentioned that cod fillets purchased from a commercial source were used as a "field blank" to identify potential on-board contamination. One commercial fillet was exposed to the work space for the duration of processing each trawl. There is no other mention of this field blank in the analysis or in the Certificate of Analysis in the appendices. Was this field blank analysed?

The intent is to analyze field blanks only if results warrant (*i.e.*, we suspect onboard contamination). As there was no such indication in 2018 (as opposed to the 2016 EEM program (Husky Energy 2019)), the field blanks were not analyzed. We will add the following in parentheses at the end of the last sentence in Section 6.1.1.1:

"(field blanks are only processed for chemistry if results from sample tissues indicate potential onboard contamination)."

Section 6.2.1.1: Plaice (Table 6-7) – What does the superscript a mean in the table under *F*-Ratio for Reference vs Study?

This is a typo and will be removed.

Section 6.2.2.1: Plaice /Fillets/Spatial Variation in 2018 (page 162) – $p = 0.026$ does not match what is stated in Table 6-19.

The text *P* value of 0.026 will be corrected to 0.002.

Environment and Climate Change Canada

General Comments

It is noted that ECCC reviewed and commented on the **Proposed Revisions to the White Rose Environmental Effects Monitoring Program to Monitor Potential Effects of Discharges from the West White Rose Platform** [June 28, 2019] which proposed changes to sampling locations and test methods. Now that the EEM Program 2018 report is complete, have the results been considered in the development of the proposed changes to the EEM program?

For example, the Proposed Revisions to the White Rose Environmental Effects Monitoring Program [June 28, 2019] include replacing "*… the 29 km reference stations with existing stations 11 and 26, located approximately 18 km to the northwest and southeast of the centre of the development… Based on previous EEM results for White Rose and the location of reference stations elsewhere (see Section 5), 18 km stations will be sufficient to provide reference conditions for White Rose*" (page 19).

The EEM Program 2018 report states that, based on the results of seawater chemistry, "*Significant differences among sampling areas (Near-field, Mid-field, and NW and NW Reference Areas) were noted for barium, boron, lithium, magnesium, molybdenum, organic carbon, potassium, sodium and Sulphur. In general, results pointed to more frequent differences between the NE Reference Area and remaining Areas, with the concentrations in the NW Reference Area similar to those in the Study Areas*" (Section 7.4, page 206 and Section 8.3.1, page 218).

Page 193 states that "*…the NE Reference Area differed from remaining Areas with concentrations of many variables lower in that Area than in the NW Reference Area or the near-field and mid-field Study Areas… Unlike the consistent differences seen for the NE Reference Area, there were no consistent Study/ Reference Area differences…*

Differences among Areas have been noted in previous years and most differences within year can be reasonably attributed to natural variability."

Has the removal of a reference sampling area to the northeast, as identified in the proposed revisions to the EEM program, been considered in light of these results? In other words, do the results of the 2018 program support the removal of the Reference Area that is consistently different from the Study Area?

The draft EEM redesign document remains under regulatory review. Any modification to the draft document will be made based on regulatory feedback associated with that document. That said, the results from the 2018 EEM program did not vary substantially from results noted in previous EEM years.

With respect to the specific comments above about how the 2018 Water Quality results might influence the design document, those results support moving the Reference Areas nearer to the Study Area. Water Quality results are expected to be highly variable and sampling areas that are 29 km apart increases the potential for large natural differences among areas, as noted in 2018. The new proposed Reference Areas, 18 km from the Study Area, are still beyond the predicted zone of influence of liquid discharges and should provide a better means of assessing potential effects in the Study Area. Albeit natural variability could, and probably will, occur.

With respect to the final comment from Environment Canada and Climate Change (the final paragraph above), the NE Reference Area has not been consistently different from the Study and NW Reference Areas. If it had been, then replacement of the area would be even further supported. The control-impact design used in the White Rose Water Quality program requires comparison between like-areas, as much as feasible. There was no evidence of consistent natural differences among areas in 2012 and 2014. In 2016, many constituents differed between the Mid-Field Study Area and remaining areas. These differences again pointed to natural variability (Husky Energy 2019). These differences also support the statement above that natural variability will occur, even if stations are closer together (the Mid-Field Study Area is 4 km from the Near-Field Study Area). Therefore, the proposal to move the Reference Areas to 18 km could reduce, but not eliminate, natural variability. Examination of results identifies if data point to natural variability in any sampling area or potential project effects in the Study Area.

Overall, 2018 results support moving the 29 km Reference Areas for Water Quality to 18 km.