White Rose
Environmental Effect Monitoring Program
2020
Volume 1 of 2

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** On January 1, 2021, Husky and Cenovus combined to form a resilient integrated energy leader. Husky is now part of the Cenovus group of companies. Original report submitted as Husky Energy and all references to Husky remain throughout this Version 02.*

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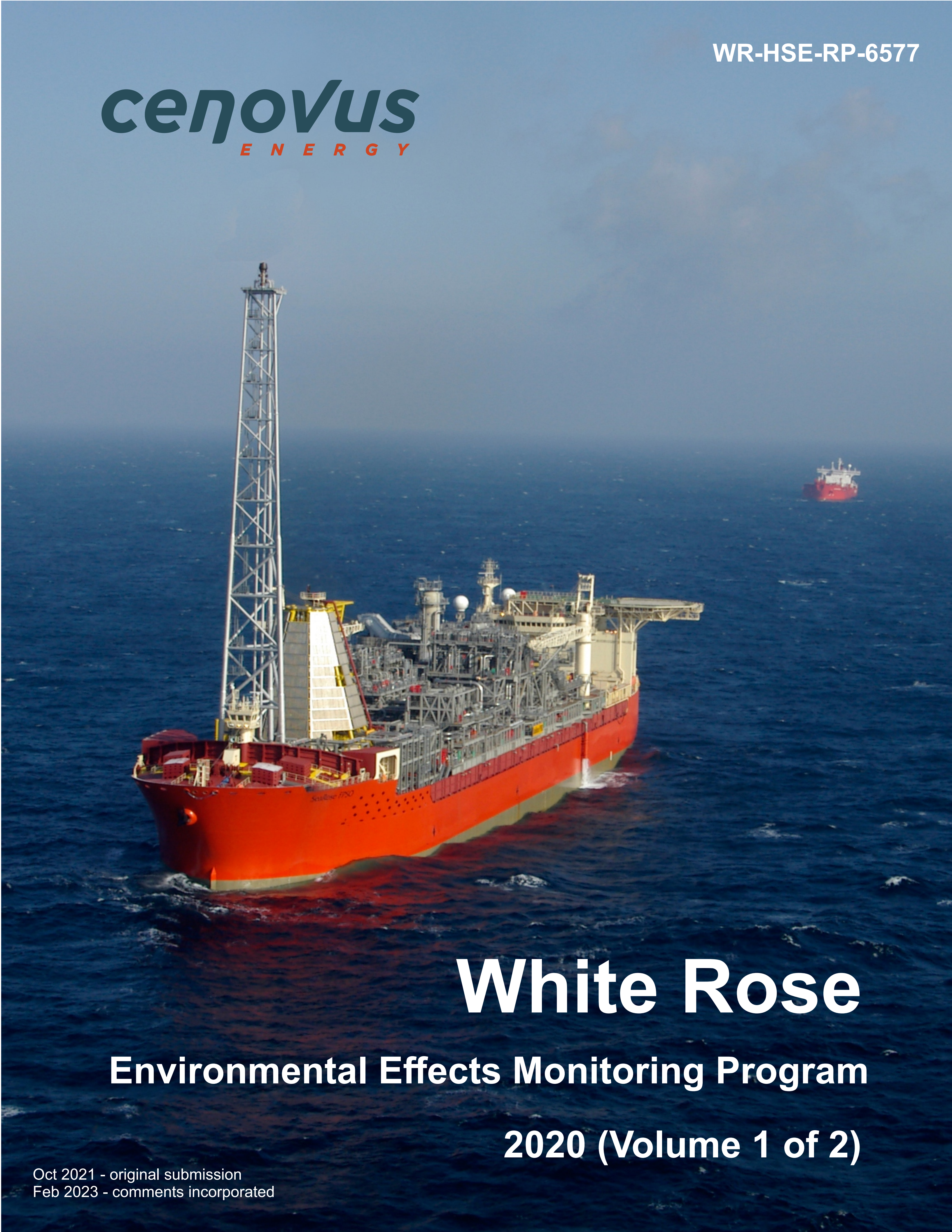

White Rose

Environmental Effects Monitoring Program

2020 (Volume 1 of 2)

Oct 2021 - original submission
Feb 2023 - comments incorporated

Executive Summary

The White Rose Environmental Effects Monitoring (EEM) program was designed to evaluate the environmental effects of Husky's offshore oil drilling and production activities for the White Rose Development. The original program design drew on predictions and information in the White Rose Development Plan Environmental Assessment (EA) and its supporting dispersion modelling studies for drill cuttings and produced water[1]. Baseline studies to document pre-development conditions were conducted in 2000 and 2002. Those studies, combined with stakeholder, expert, and regulatory agency consultations, initiated the detailed design phase of the program. Beyond this, the EEM program was modified to accommodate further development drilling at the White Rose Field; and modifications to the program have issued from regulatory review of program results.

The purpose of the EEM program is to assess the effect prediction related to fish and fish habitat made in the original EA for White Rose (Husky Oil Operations Limited 2000) and in the subsequent EA aimed at field expansion (LGL 2006). Both EAs used a weight-of-evidence approach to assess residual effects of the various project activities on fish and fish habitat; and both predicted that overall effects on fish and fish habitat would be not significant. To assess this prediction, the EEM program also uses a weight-of-evidence approach based on an examination of sediment quality and water quality, as components of fish habitat, and potential effects on selected species of past or present commercial fisheries importance.

Seabed sediments and commercial fish species from the White Rose Field have been collected from 2004 to 2020. 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 flatfish species) and snow crab (a 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.

The Water Quality Component of the EEM program was initiated after first release of produced water at the *SeaRose* FPSO. Seawater samples have been collected from 2008 to 2020 and processed for chemistry and total suspended solids. The sampling program in 2008 was preliminary, with fewer stations and variables analyzed in that year than in subsequent years. In 2010, the Water Quality Component of the EEM program included seawater sampling and sediment sampling for chemistry and particle size at water quality stations, as well as a produced water modelling exercise to assess potential concentrations of produced water constituents in seawater samples. The 2012 Water Quality Component of the EEM program included seawater and sediment sampling at water quality stations and a modelling exercise to assess potential concentrations of produced water constituents in sediments. From 2014 to 2020, the Water Quality Component of the EEM program included seawater sampling and sediment chemistry sampling at water quality stations.

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[1] Drill cuttings and produced water are the main discharges to the marine environment from development and production operations, respectively.

Figure 1 illustrates the variables measured and tests performed within each component of the EEM program.

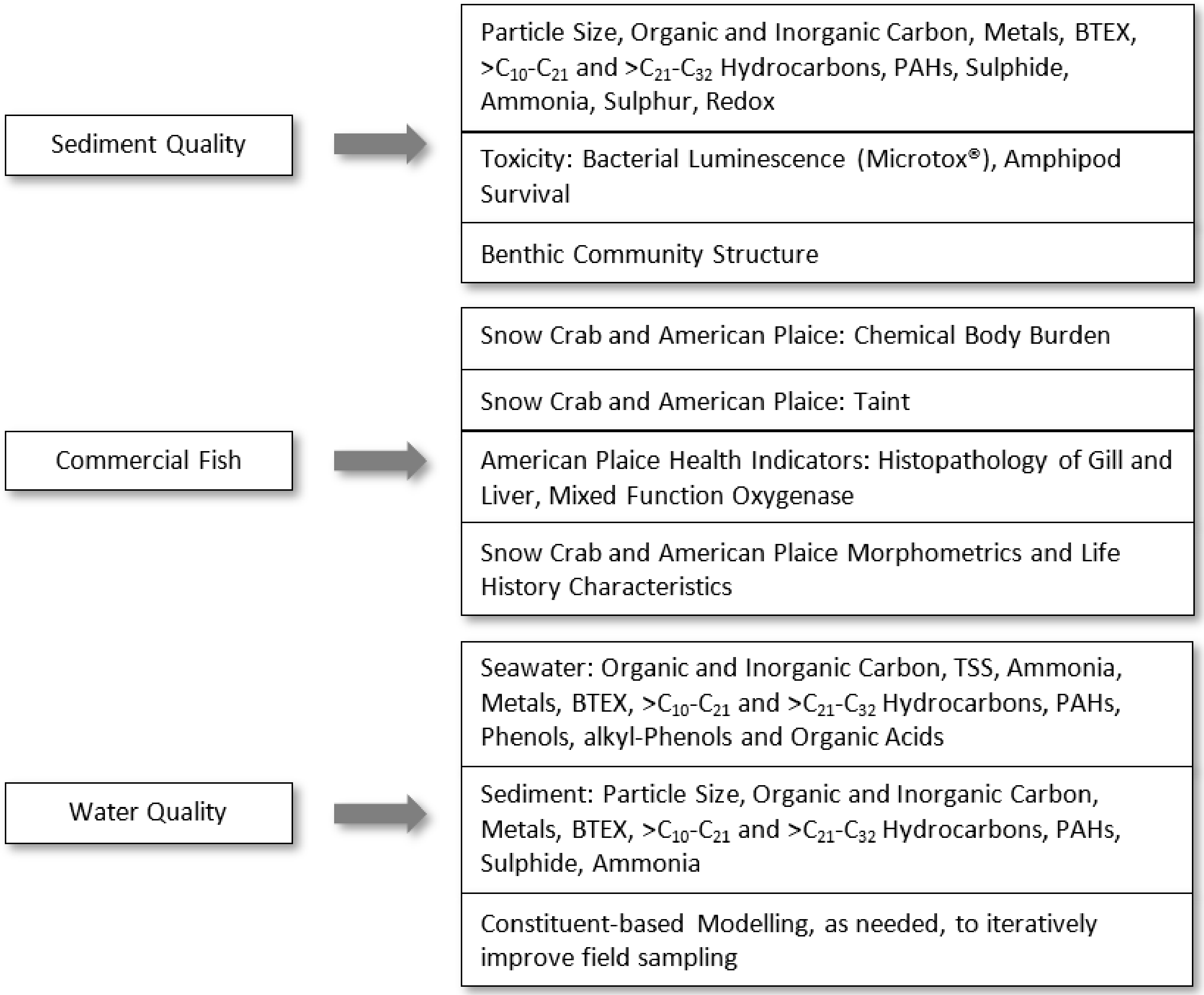

Figure 1 EEM Program Components

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

This report provides the results from the tenth round of post-operational sampling under the program conducted in the fall of 2020. The findings are interpreted in the context of results of previous sampling years, general effects predictions from the EAs and the overall EA prediction of no significant effect on fish and fish habitat.

Sediment Quality

The expected spatial extent of sediment contamination from drilling discharges was predicted through a modelling exercise associated with the White Rose EAs. That exercise indicated that drill cuttings and associated alterations to sediment physical and chemical characteristics could extent to 9 km from discharge source. As predicted, sediment alterations in physical and chemical characteristics have occurred. Concentrations of >C_{10}-C_{21} hydrocarbons and barium (main constituents of drill muds) were elevated as a result of drilling activity near drill centres in 2020. To a lesser extent, sediment particle size (percent fines) and concentrations of organic carbon, ammonia, lead, strontium, and sulphur were also affected by drilling. All alterations were within the predicted 9 km radius from discharge source. The concentrations of >C_{10}-C_{21} hydrocarbons and barium (the two most affected variables over all EEM programs) decreased with distance from source to 2.5 km and 1.1 km from source in 2020, respectively. These values were similar to those noted in 2018. In general, the estimated distance over which hydrocarbon and barium concentrations were correlated with distance from drill centres was greater in earlier EEM years (2004 to 2010) than in more recent years; indicating some level of recovery from the more intense drilling that occurred earlier during project development.

No sample was toxic using the Microtox or laboratory amphipods toxicity tests in 2020. The Microtox and amphipod toxicity tests continue to indicate that sediments at White Rose are predominantly non-toxic. There were no predictions specific to toxicity in the White Rose EAs.

Both EAs associated with the development identified that benthic community disruption would occur near source, and both predicted no significant effect on fish and fish habitat as a result of these disruptions. To provide insight into effects on benthos, the EEM program targets specific benthic community indices. Overall, examination of 2020 data suggest that for most benthic indices (as well as for selected individual taxa), the majority of effects occurred within 0.5 to 1 km of drill centres, with more subtle and/or highly localized effects between 1 to 2 km. These results are consistent with EA predictions and with those noted in previous years. Results for biomass were inconclusive in 2020, with an indication of depressed biomass at many stations outside the immediate vicinity of drill centres. This more wide-spread decrease in biomass suggested natural variation over and above project-effects. Assessment of the magnitude of effects on the benthic community indicated that disruptions were not large relative to commonly accepted criteria (*i.e.,* a highly disrupted benthic community would be indicated if total abundance was near zero and the number of taxa present was severely depressed). At White Rose, total abundance was reduced to values lower than those noted during baseline collections at three stations near drill centres in 2020, and reductions at these stations were slight (less than 25% lower than the baseline range). There was no evidence that the number of taxa (*i.e.,* benthic community richness) was affected.

Commercial Fish

Sediment contamination and effects on benthos noted in 2020 and in previous years have not translated into effects on fisheries resources, as indicated by results of fish health assessments 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. EEM results from 2020, as well as those from previous years, continue to support the EA prediction of no significant effects to fish.

Water Quality

The White Rose EA predicted that changes to physical and chemical characteristics of seawater as a result of liquid discharge would be localized near discharge source. In 2020, there was little evidence of project-related alterations 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. There was also no evidence that produced water constituents were detected in seawater samples in 2020.

Conclusion

Results from the 2020 EEM program for White Rose indicate that environmental effects at White Rose are consistent with those anticipated in the White Rose EAs and the overall EA prediction of no significant effect on fish and fish habitat. There is no evidence that additional mitigation measures are required at this time.

Acknowledgements

Project management for the White Rose EEM program was executed by Ellen Tracy at Stantec Consulting Ltd. (St. John’s, Newfoundland and Labrador). Participants in the commercial fish survey included Doug Rimmer and Kristian Greenham from Stantec Consulting Ltd., and Mirelle Caouette-Houle and Shanshan Liu from Oceans Ltd. (St. John’s, Newfoundland and Labrador). Participants in the sediment and water survey included Doug Rimmer, Tony Parr, Catie Young, Kristian Greenham, Ralph MacLean, and Justin Bath from Stantec Consulting Ltd. Fugro Geosurveys (Shane Sullivan and Trevor Lewis) provided geopositional services for sediment and water collections. Benthic invertebrate sorting, identification and enumeration was led by Joe Kene of Stantec Consulting Ltd’s Benthic Lab (Guelph, Ontario). Chemical analyses of tissues were conducted by Bureau Veritas (formerly Maxxam Analytics) (Halifax, Nova Scotia). Chemical analyses of sediments and seawater were conducted by Bureau Veritas and RPC (Fredericton, New Brunswick). Sediment toxicity tests were conducted by Avalon Laboratories (St. John's, Newfoundland and Labrador). Sediment particle size analysis was conducted by Stantec Consulting Ltd. Fish and shellfish taste tests were performed at the Marine Institute of Memorial University (St. John’s, Newfoundland and Labrador). Laboratory analyses for fish health indicators were supervised by Dr. Juan Perez Casanova of Oceans Ltd. Sediment quality and fish body burden and health data were analyzed by Dr. Marc Skinner (Stantec Consulting Ltd.), with technical review by Dr. Elisabeth DeBlois (Elisabeth DeBlois Inc., St. John’s, Newfoundland and Labrador). Water quality data analysis was performed by Dr. Elisabeth DeBlois, with technical review by Dr. Marc Skinner. Consolidation of text within each section was done by Dr. Elisabeth DeBlois. The Introduction Sections (the Executive Summary and Sections 1 through 3) and the Discussion were written by Dr. Elisabeth DeBlois. Section 4 was updated by Steve Bettles at Cenovus Energy. Editing and report consolidation was performed by Ellen Tracy (Stantec Consulting Ltd.). Karen Williams and Megan Blackwood (Stantec Consulting Ltd.) provided administrative and graphics support, respectively. Ellen Tracy, Marc Skinner and Mary Murdoch reviewed the report from a quality control perspective at Stantec Consulting Ltd. The report was prepared and finalized under the direction of Steve Bettles (Cenovus Energy).

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1.0 Introduction

1.1 Project Setting and Field Layout

On January 1, 2021, Husky Energy merged with Cenovus Energy under the Cenovus Energy name. Any subsequent references to Husky throughout refer to Husky Oil Operations Limited, a wholly-owned subsidiary of Cenovus Energy, 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.

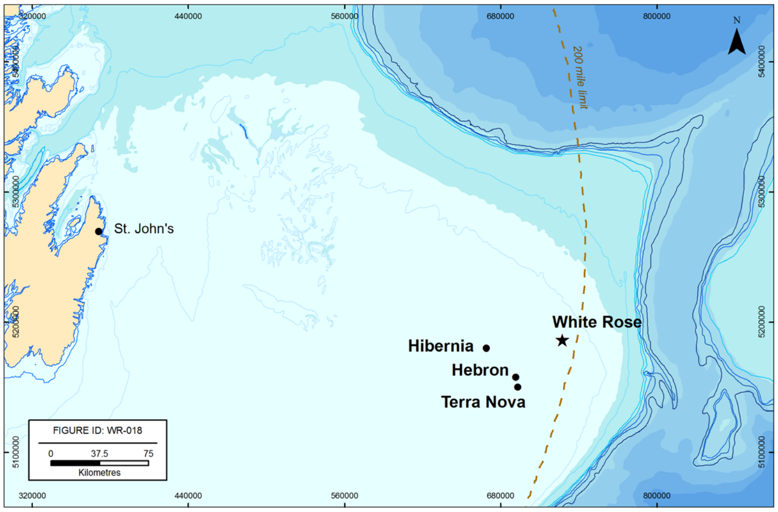

Figure 1-1 Location of the White Rose Field

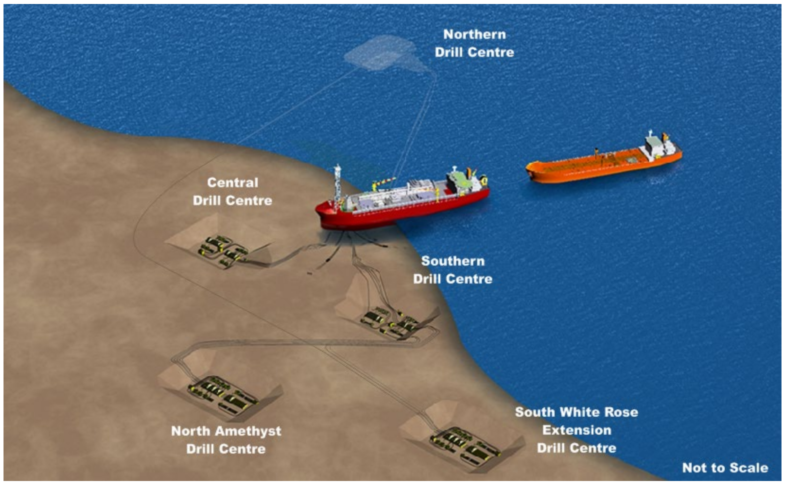

Figure 1-2 White Rose Field Layout

1.2 Project Commitments

Husky committed in its Environmental Assessment (EA) (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 (Canada-Newfoundland Offshore Petroleum Board 2001) as a condition of project approval.

Also, as noted in Condition 38 of Decision 2001.01 (Canada-Newfoundland Offshore Petroleum Board 2001), Husky 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* (EPCMPs), 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 Cenovus's corporate website[2].

1.3 EEM Objective and Program Design

The purpose of the EEM program is to assess the effect prediction on fish and fish habitat made in the EA to determine if additional measures are required to mitigate any effect. The two White Rose EAs (Husky Oil Operations Limited 2000; LGL 2006) provided a review of available information on the potential effects of various project activities and then used weight-of-evidence and professional judgment to assess the overall effects of White Rose on fish and fish habitat. Residual effects of the various project activities on fish and fish habitat were assessed as adverse but negligible to low in magnitude in both EA documents; and the overall effect on fish and fish habitat was assessed as not significant. To verify this EA prediction, the White Rose EEM program includes monitoring of two commercial fish species, and sediment and water quality, as components of fish habitat. Measured environmental variables, or tests, within each component (see Section 1.4) were not all specifically addressed in the EAs. Environmental variables or tests in the EEM program were selected to provide early warning of potential effects on fish and fish habitat (see the original EEM program design document (Husky 2004) for details on variable and test selection). Like the EAs, the EEM program adopts a weight-of-evidence approach, here coupled with an analysis of results within the individual components to assess overall effects on fish and fish habitat. Further discussion on EA predictions relative to EEM findings are provided the discussion section of this report (Section 8).

Husky submitted an EEM program design to the C-NLOPB in May 2004, which was approved for implementation in July 2004. The EEM study design drew on information provided in the original White Rose EA (Husky Oil Operations Limited 2000), dispersion modelling for drill cuttings and produced water[3], a baseline characterization program carried out in 2000 and 2002 (Husky 2001, 2003), stakeholder consultations, and consultations with experts and regulatory agencies. The EEM program was revised in 2008 to accommodate the development of the North Amethyst Drill Centre; and it was revised again in 2012 to accommodate the development of the SWRX Drill Centre and to

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[2] http://www.cenovus.com/operations/offshore.html - Environmental Performance

[3] Drill cuttings and produced water are the main discharges to the marine environment from development and production operations, respectively.

incorporate a Water Quality monitoring component. Effects predictions relating to development and operations at the North Amethyst and SWRX Drill Centres were provided in LGL (2006).

1.4 EEM Program Components and Monitoring Variables

As noted in Section 1.3, the White Rose EEM program is divided into three components: Sediment Quality, Commercial Fish, and Water Quality (Figure 1-3).

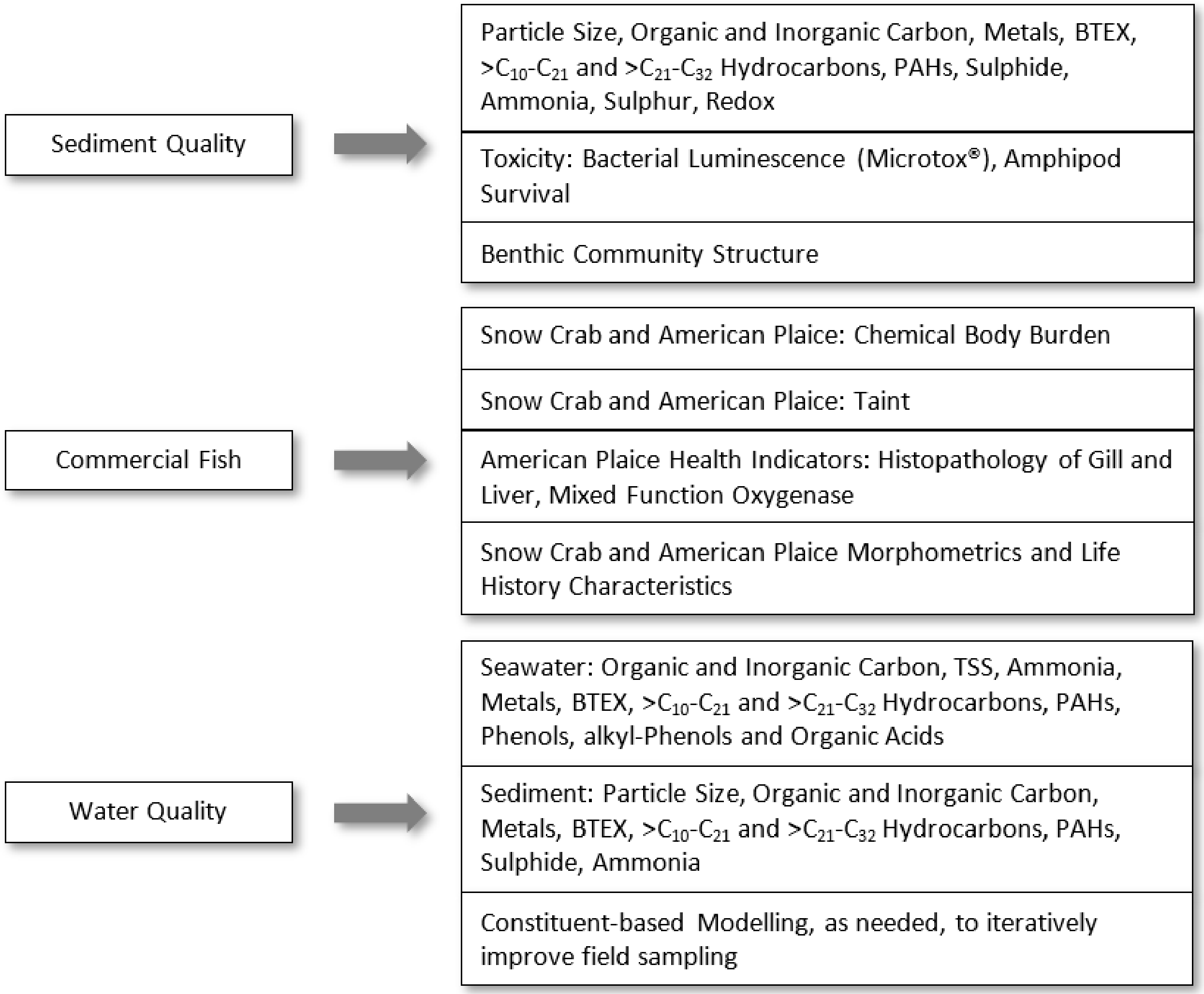

Figure 1-3 EEM Program Components

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

Assessment of Sediment Quality includes measurement of alterations in chemical and physical characteristics, measurement of sediment toxicity and assessment of benthic invertebrate 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).

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 in sediments 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 which constituent might have a higher chance of being detected and where these might occur.

1.5 Monitoring Hypotheses

For the purpose of the EEM program, testable hypotheses that drew on information provided in the EAs were developed. These monitoring, or null (H_0), hypotheses were established as part of the original White Rose EEM program design. In accordance with a recommendation from the C-NLOPB on the 2016 report, these hypotheses will be replaced and/or re-assessed by regulatory authorities during the redesign of the White Rose EEM program[4]. In this 2020 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 EA. Therefore, rejection of a null hypothesis does not necessarily invalidate EA predictions. The following hypotheses are addressed in this report:

- 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.

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

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).

1.6 EEM Sampling Designs

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[5].

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).

1.6.1 Modifications to the Sediment Sampling Design

There are some differences between sediment stations sampled for baseline (2000) and for EEM programs (2004 to 2020). 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 2020 (Figure 1-10). In all, 36 stations were common to all sampling programs.

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[5] Sampling in all Reference Areas has not been possible in some EEM years because of intense fishing activity.

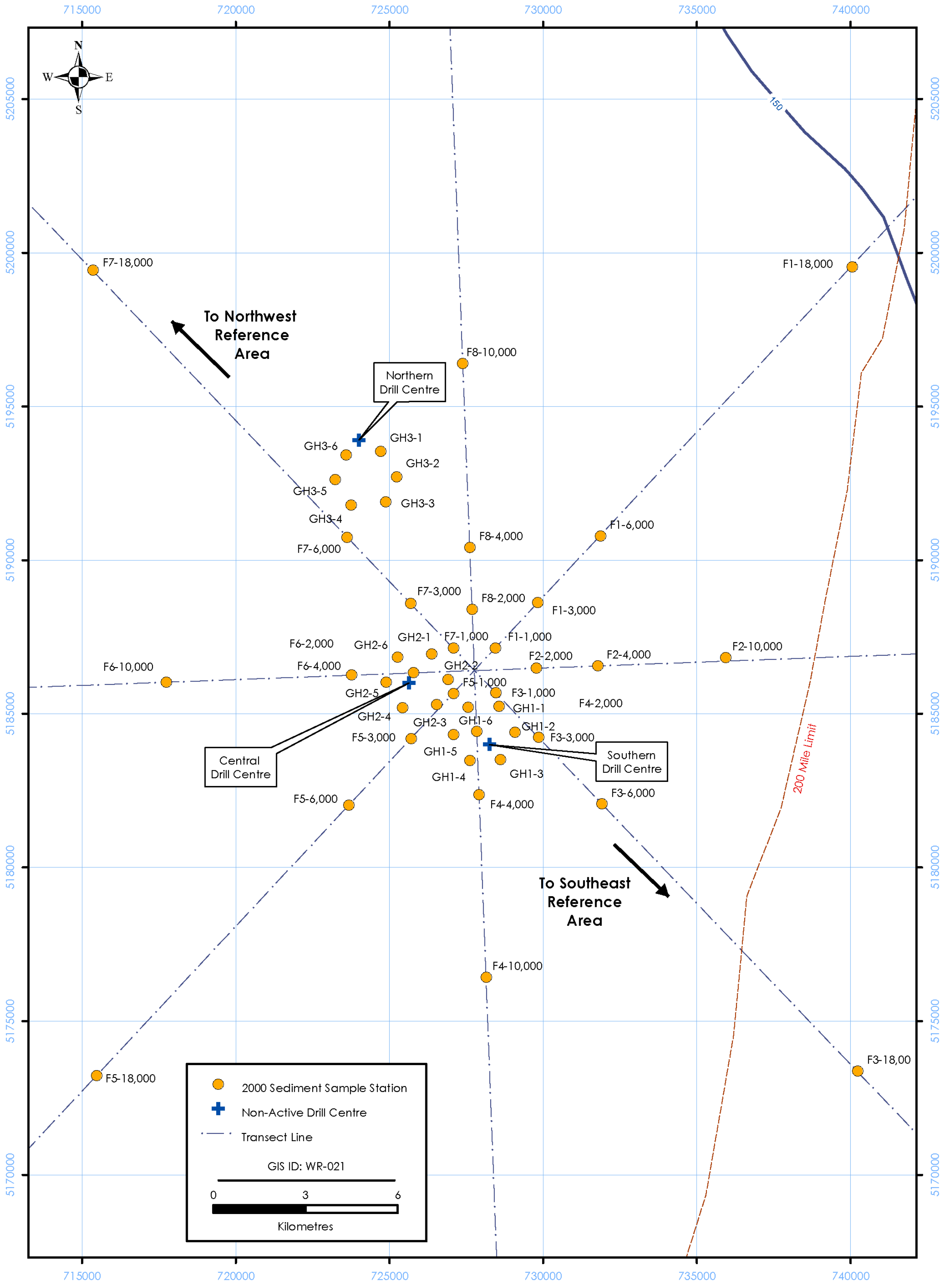

Figure 1-4 **2000 Baseline Program Sediment Quality Stations**

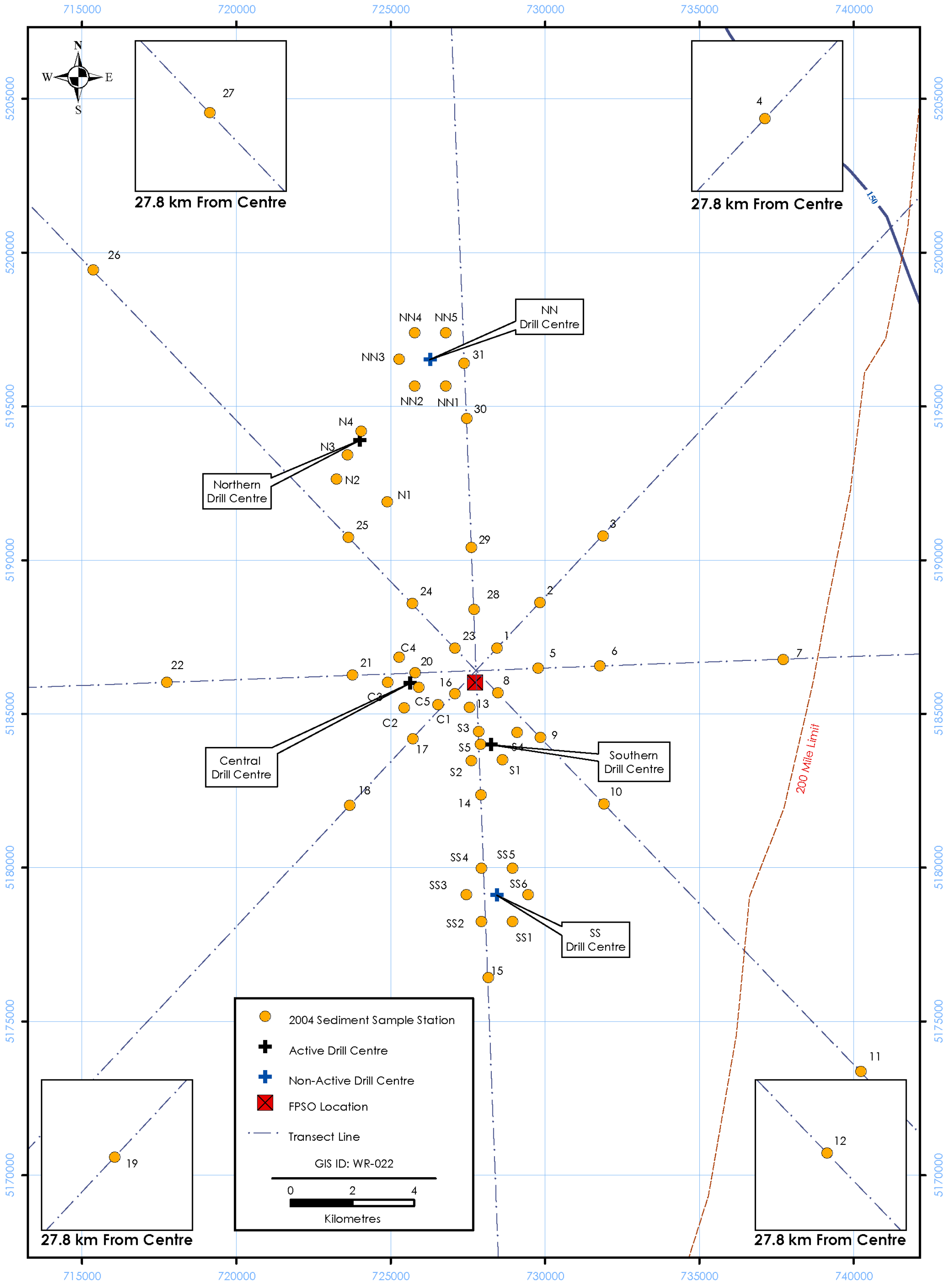

Figure 1-5 2004 EEM Program Sediment Quality Stations

Note" 'proposed FPSO location (*SeaRose FPSO* on location in August 2005). NN and SS drill centres were proposed but never developed.

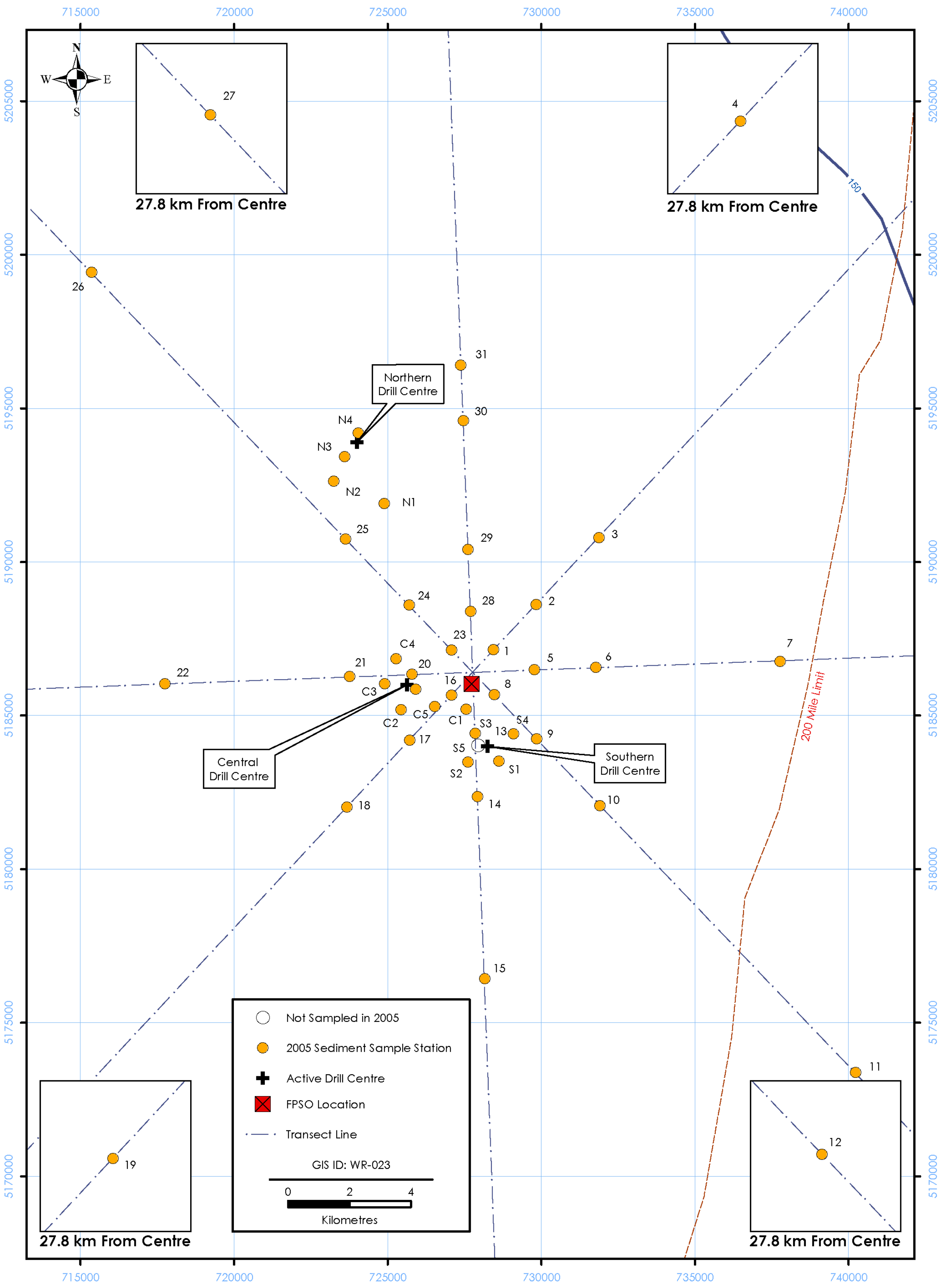

Figure 1-6 2005 EEM Program Sediment Quality Stations

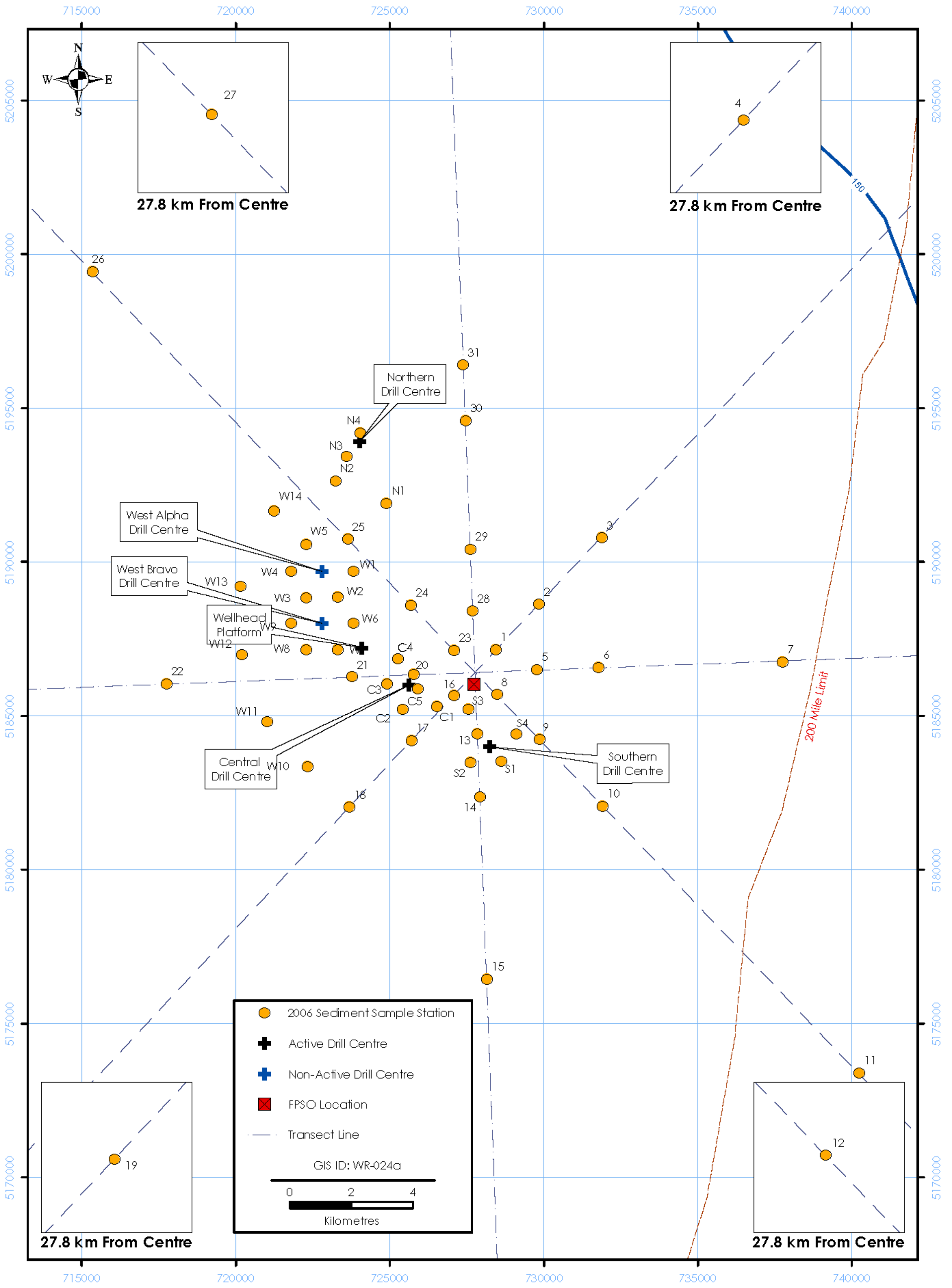

Figure 1-7 2006 EEM Program Sediment Quality Stations

Note West Alpha and West Bravo drill centres were proposed but never developed

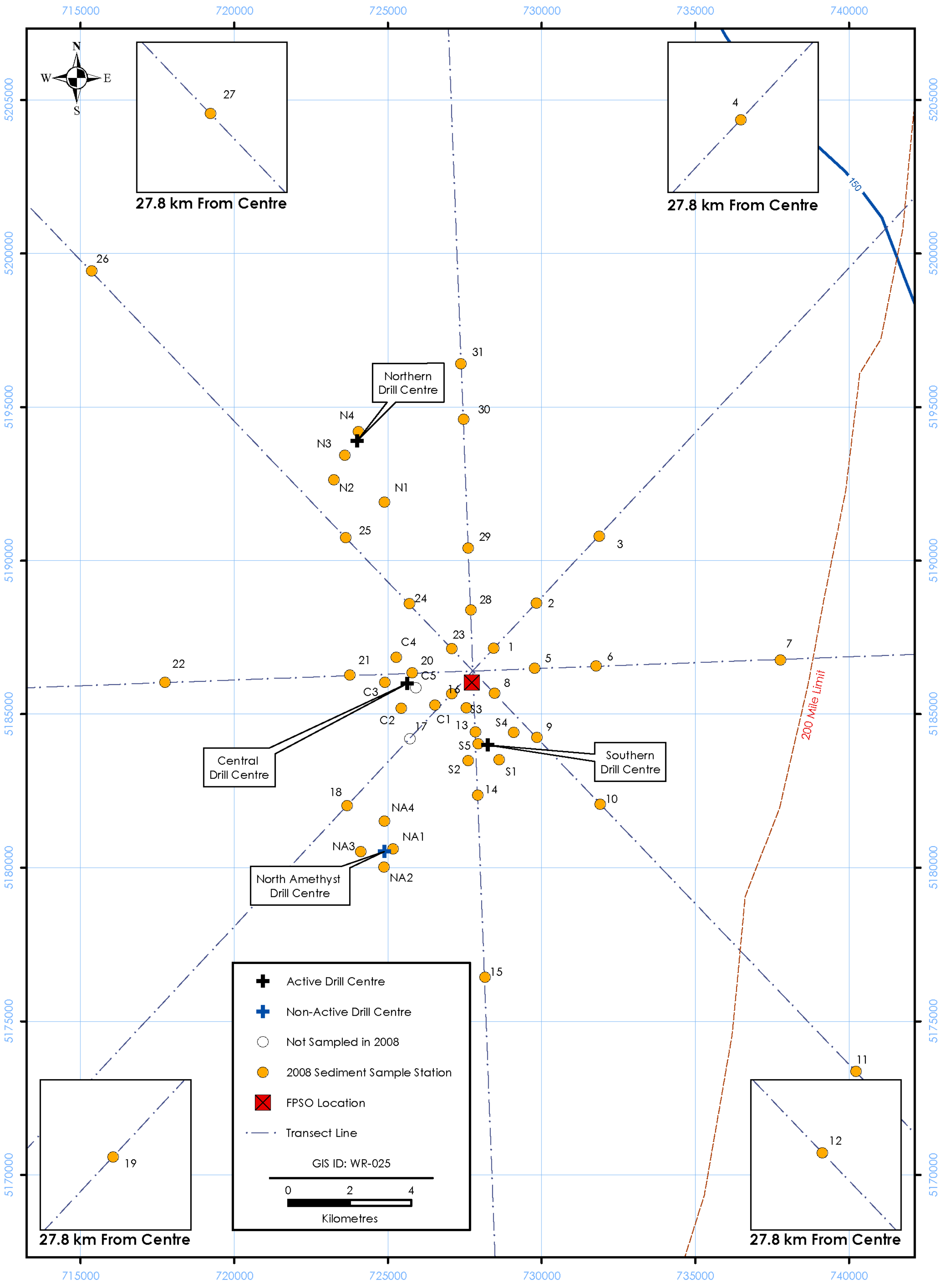

Figure 1-8 **2008 EEM Program Sediment Quality Stations**

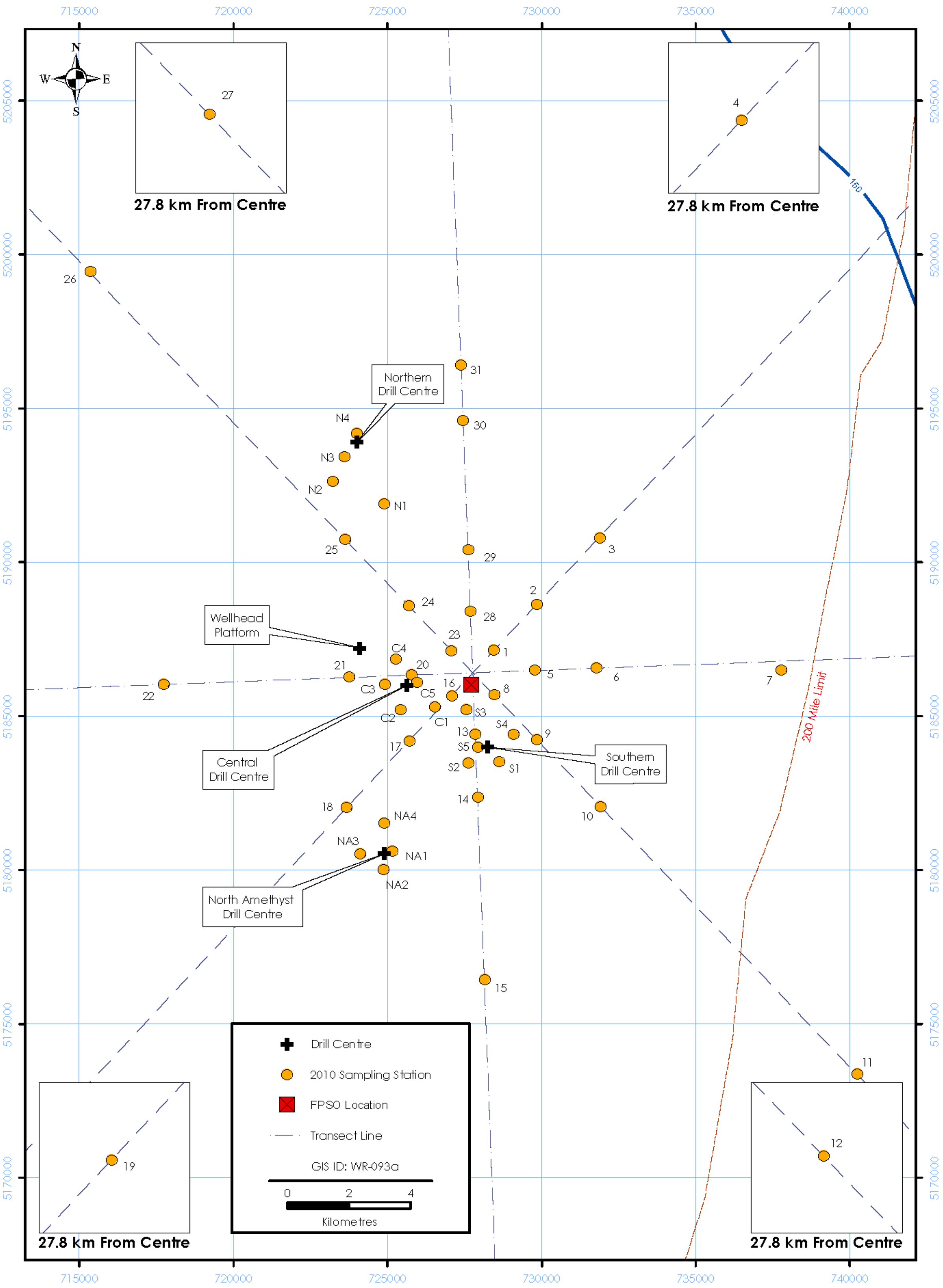

Figure 1-9 2010 EEM Program Sediment Quality Stations

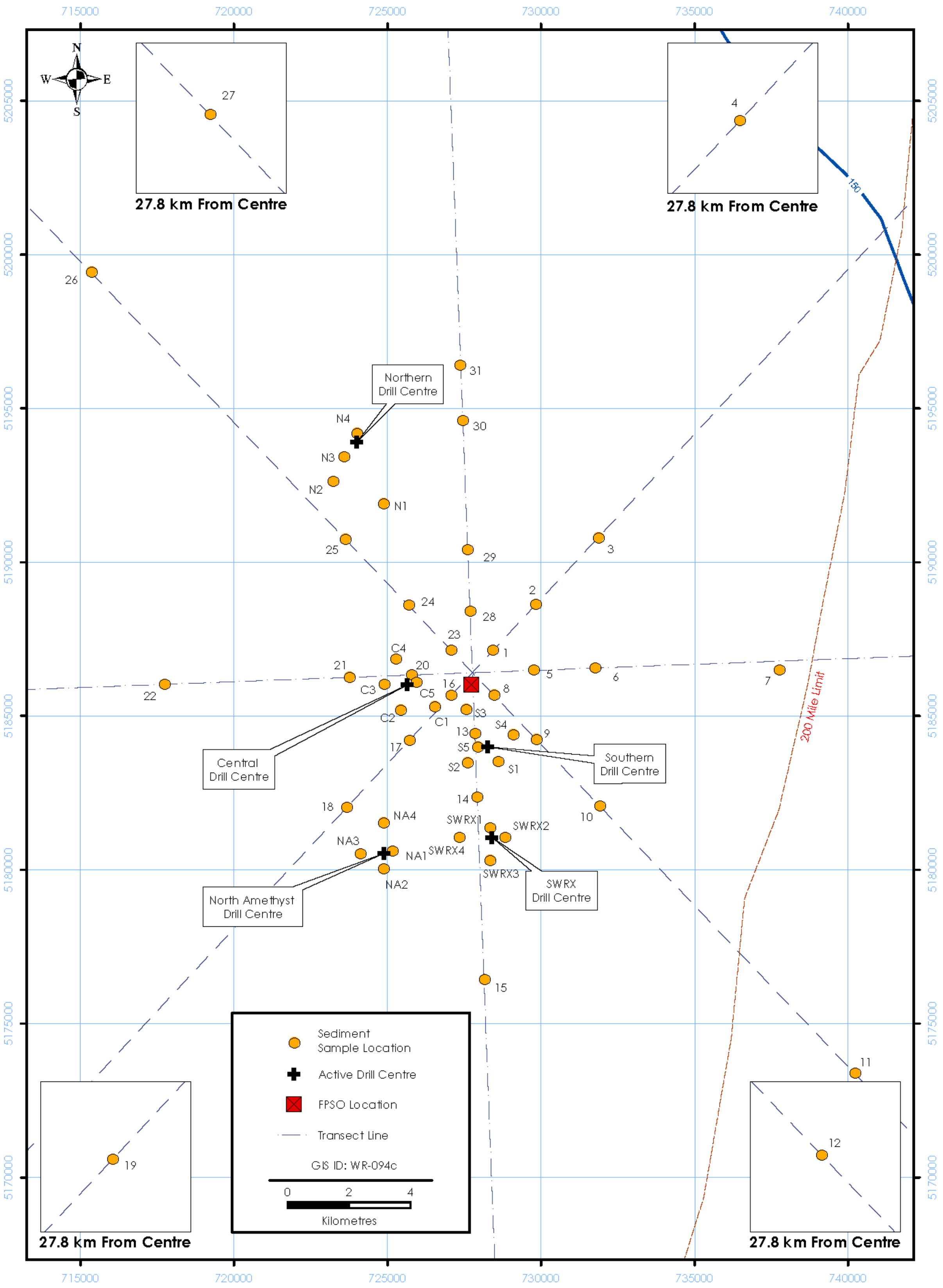

Figure 1-10 2012, 2014, 2016, 2018, and 2020 EEM Program Sediment Quality Stations

As part of EEM program design (Husky 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 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 were 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). These too were never developed and were not sampled in subsequent programs.

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.

Station moves for Stations W7-MF and W-9MF were retained in 2020 because metocean equipment remained on location. No other station moves occurred in 2020.

Table 1-1 provides a summary of changes between the 2000 baseline program and the 2020 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 2020 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

EEM Program Station Name	Corresponding Station Name during the 2000 Baseline Program
S1	GH1-3
S2	GH1-4
S3	GH1-6
S4	GH1-2
*S5****	Not Sampled in 2000
NA1	Not Sampled in 2000
NA2	Not Sampled in 2000
NA3	Not Sampled in 2000
NA4	Not Sampled in 2000
SWRX1	Not Sampled in 2000
SWRX2	Not Sampled in 2000
SWRX3	Not Sampled in 2000
SWRX4	Not Sampled in 2000

Notes:
- **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 31 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.

1.6.2 Modifications to the Commercial Fish Sampling Design

For American plaice and snow crab, sampling for the baseline program (2000 and 2002) occurred near White Rose and in one Reference Area located 85 km to the northwest. For the EEM program, this Reference Area was replaced with four Reference Areas located approximately 28 km northwest, northeast, southwest, and southeast of the development. Figures 1-11 to 1-20 provide transect locations for the 2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016, 2018 and 2020 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.

Plaice and crab were caught using a DFO Campelen trawl from baseline to the 2008 EEM program; and they were caught using a commercial trawl from 2010 to the present. In 2020, crab were also caught using crab pots because of low catch rates using only the trawl in the previous (2018) EEM program.

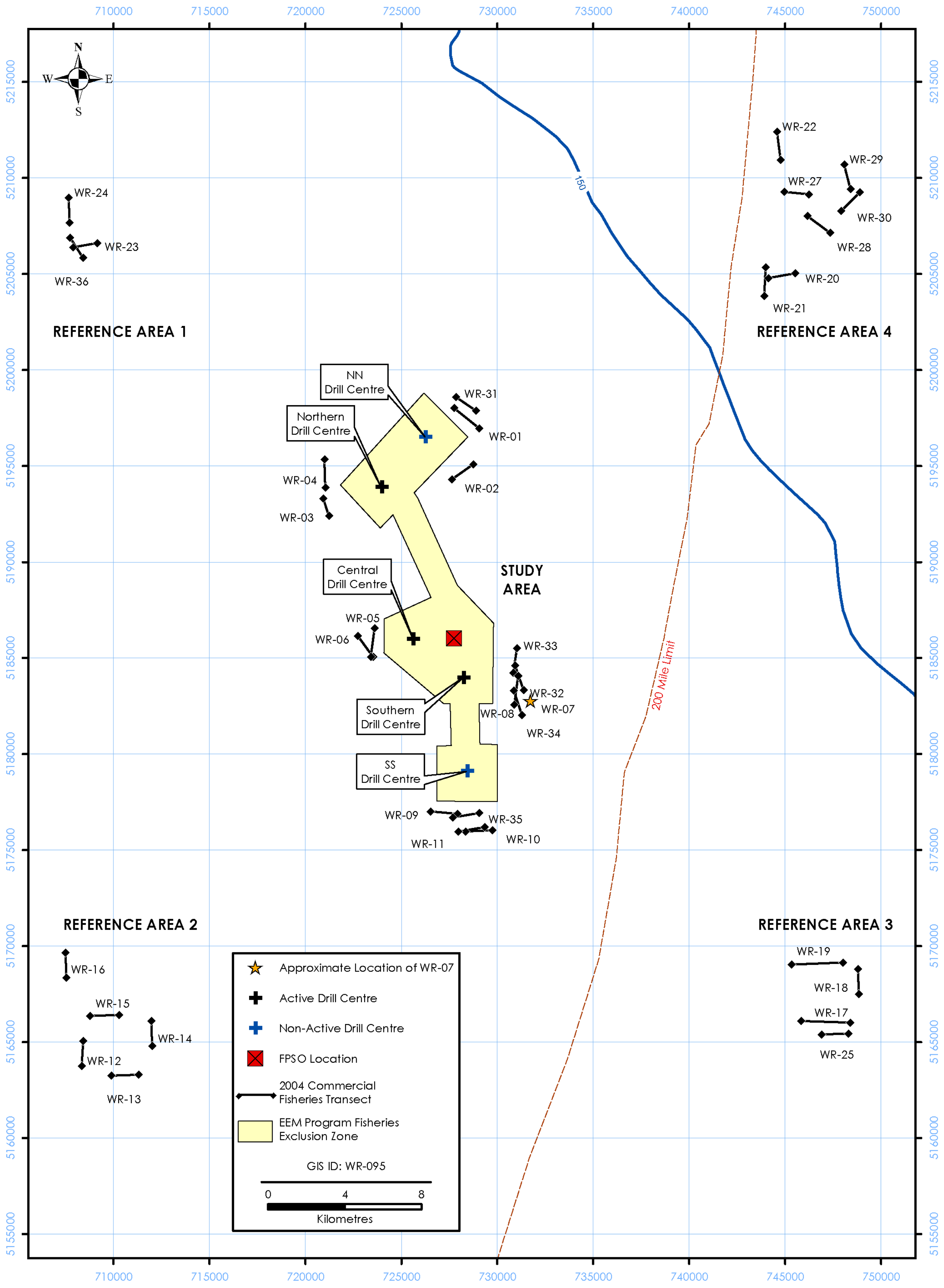

Figure 1-11 2004 EEM Program Commercial Fish Sampling Locations

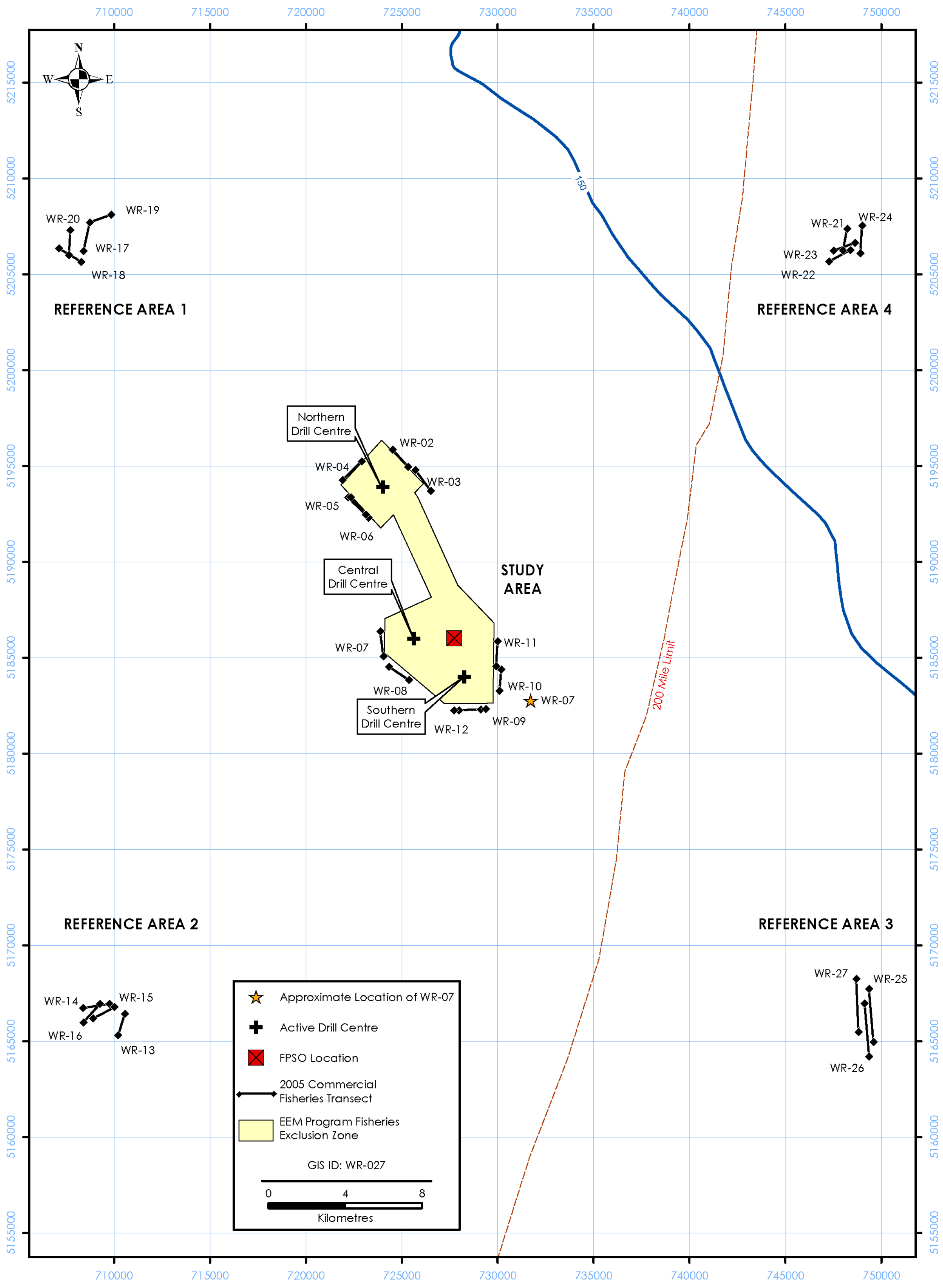

Figure 1-12 2005 EEM Program Commercial Fish Sampling Locations

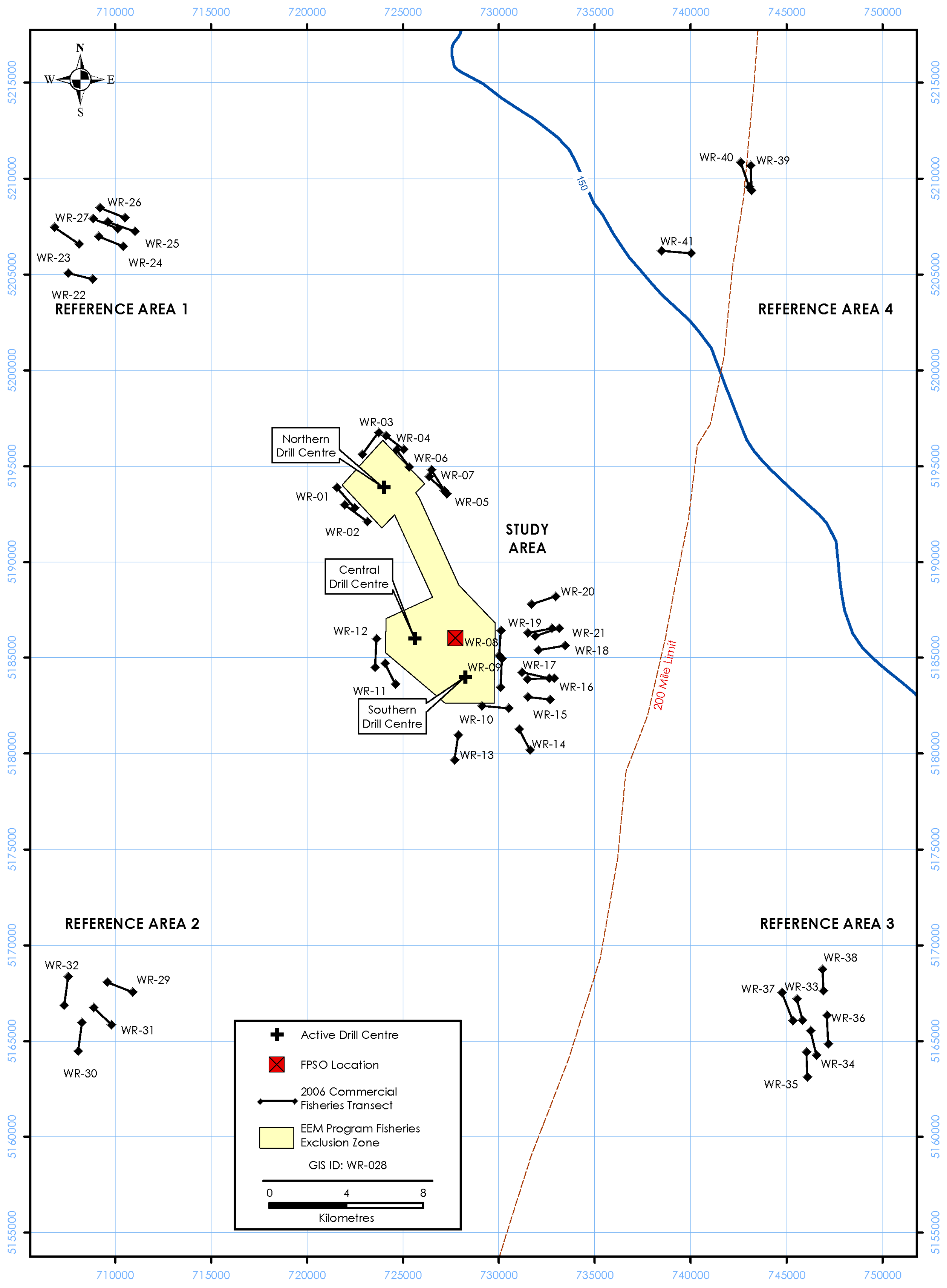

Figure 1-13 **2006 EEM Program Commercial Fish Sampling Locations**

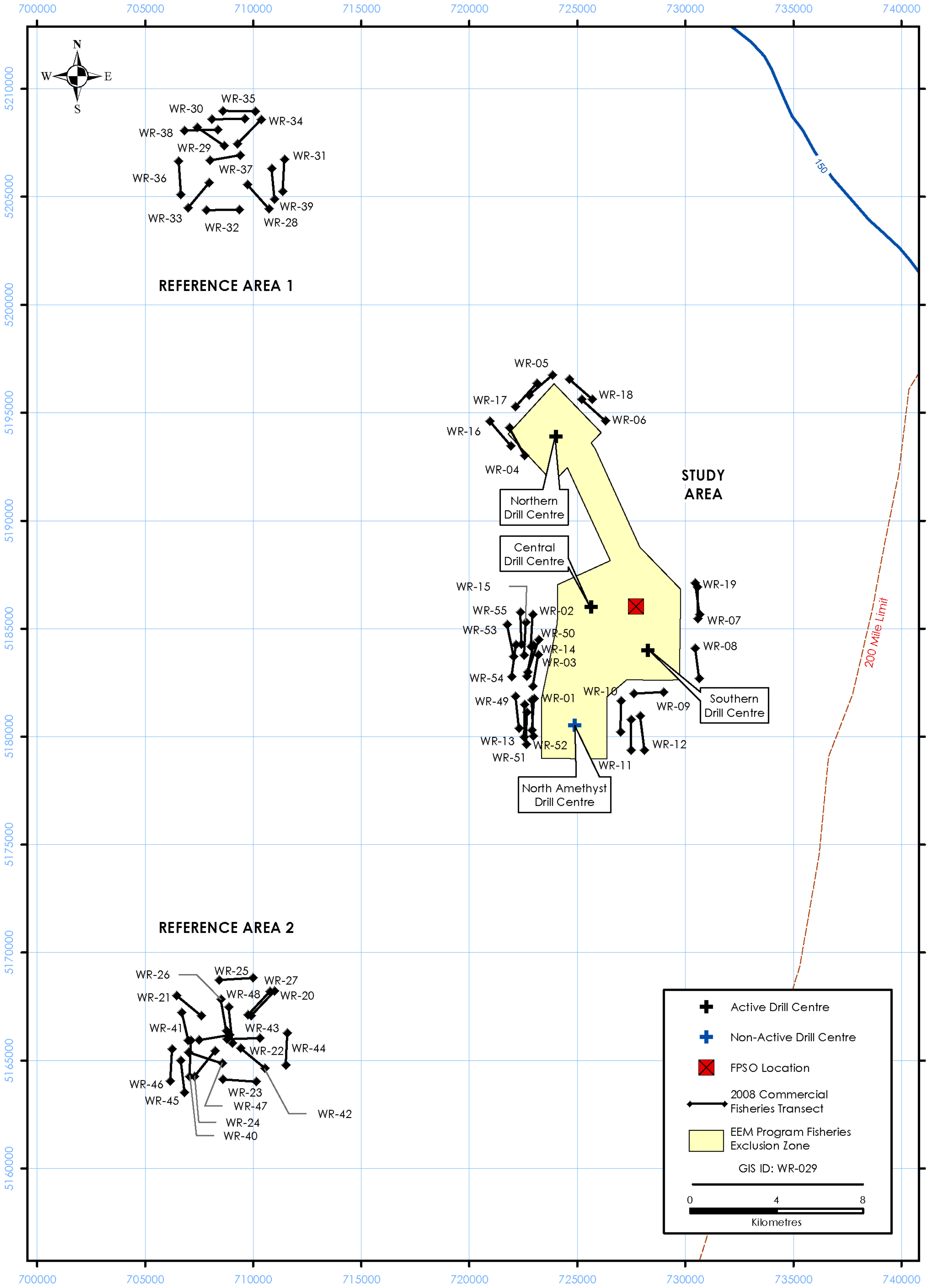

Figure 1-14 2008 EEM Program Commercial Fish Sampling Locations

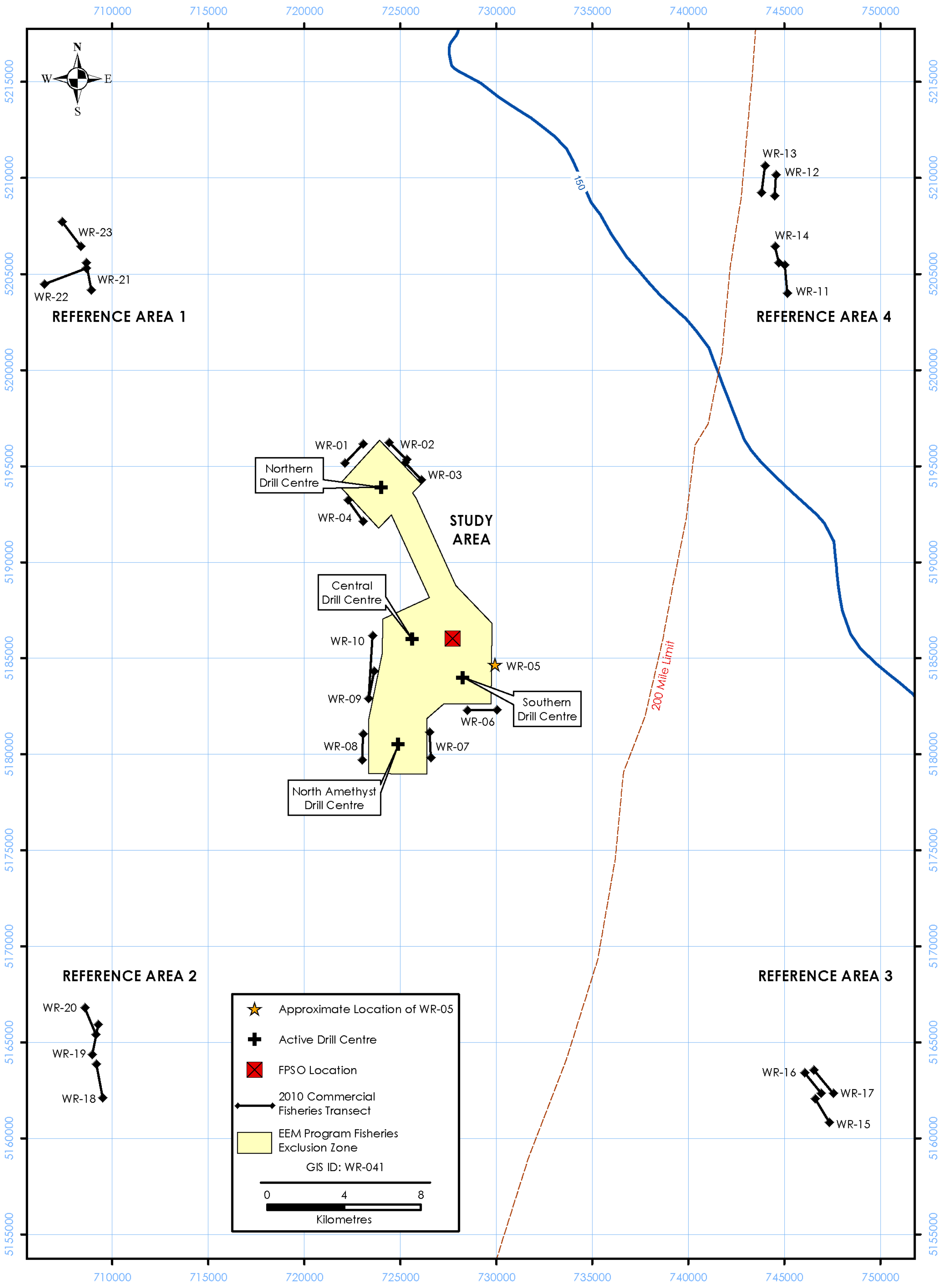

Figure 1-15 2010 EEM Program Commercial Fish Sampling Locations

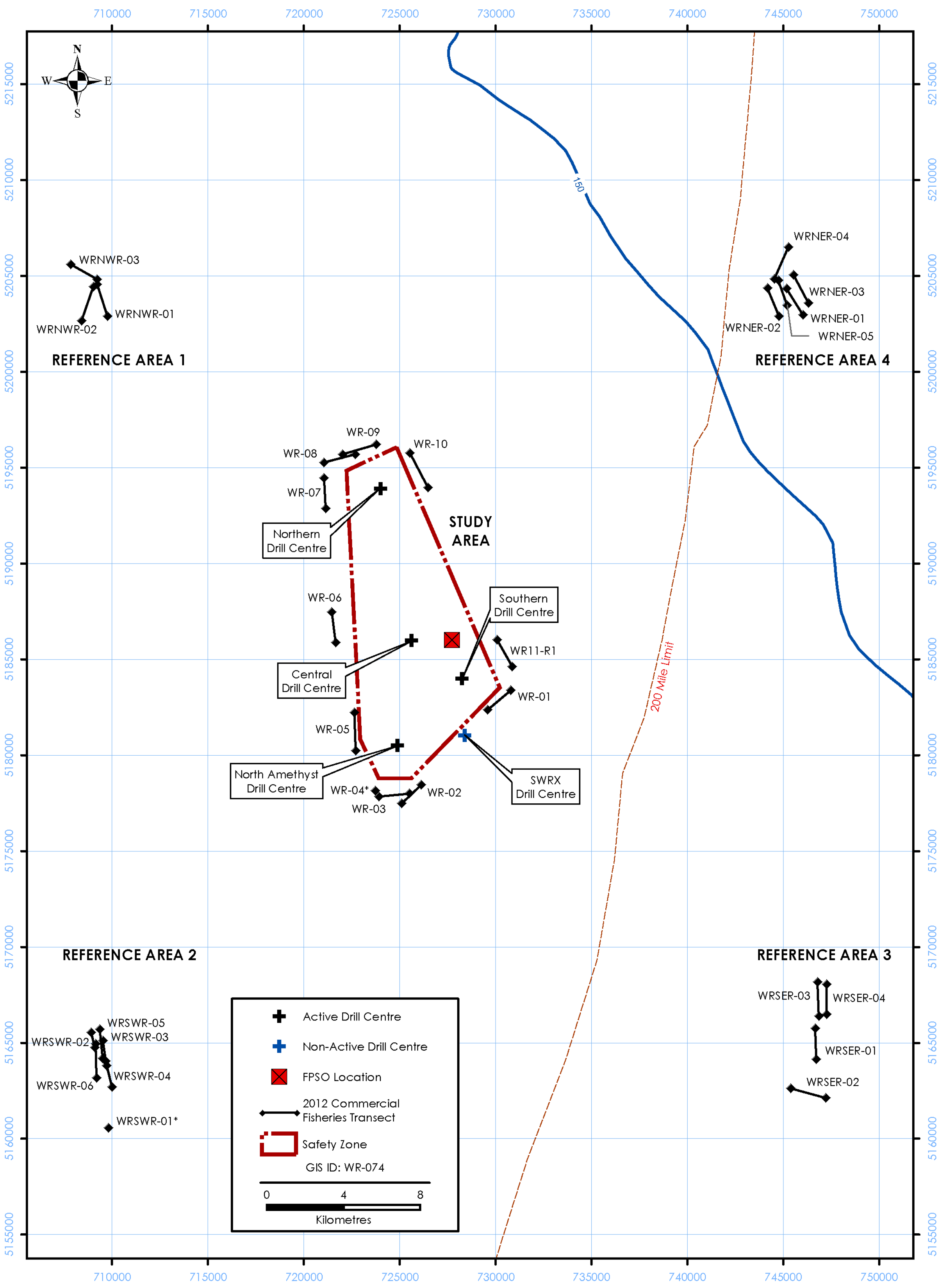

Figure 1-16 2012 EEM Program Commercial Fish Sampling Locations

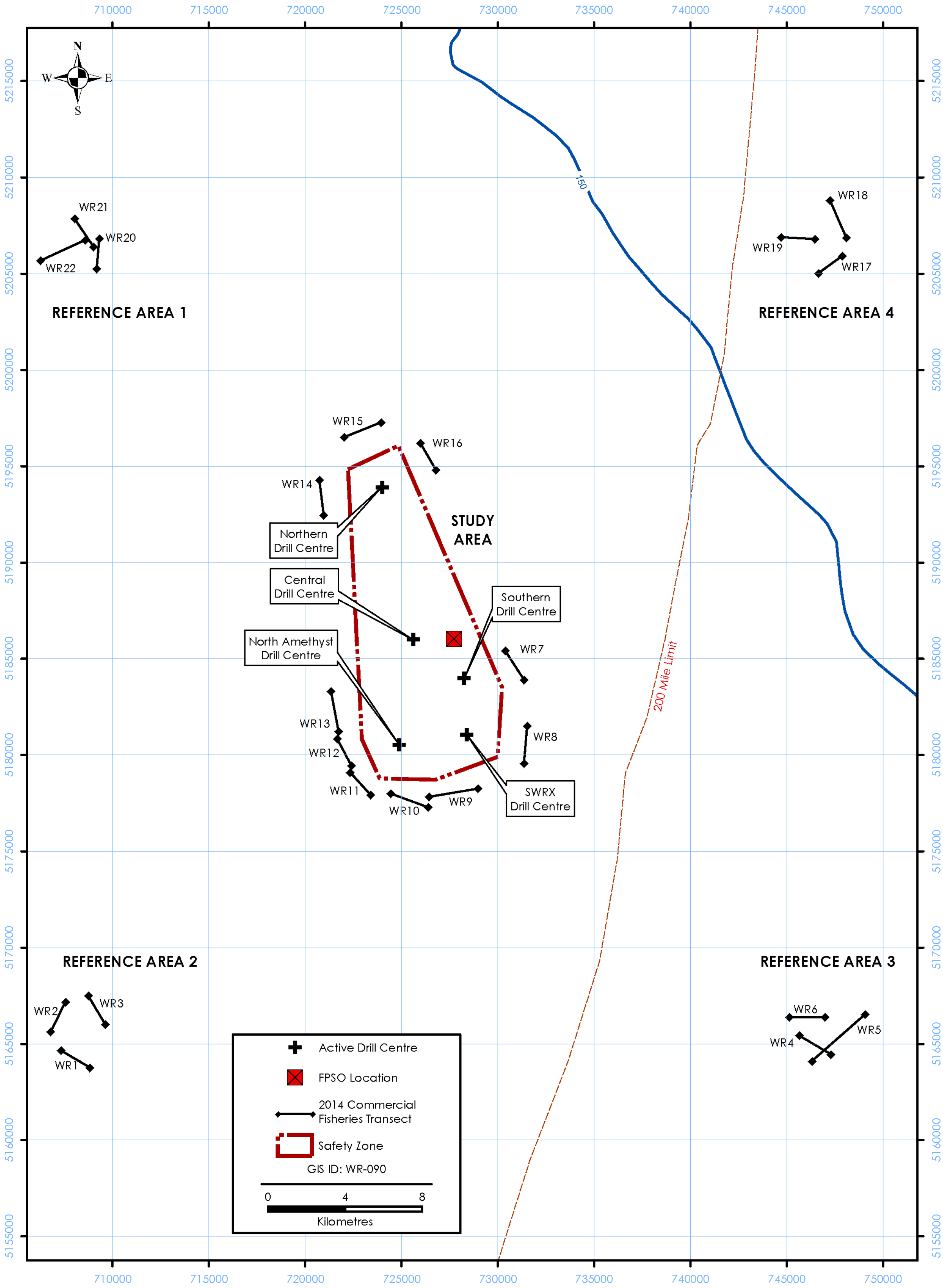

Figure 1-17 2014 EEM Program Commercial Fish Sampling Locations

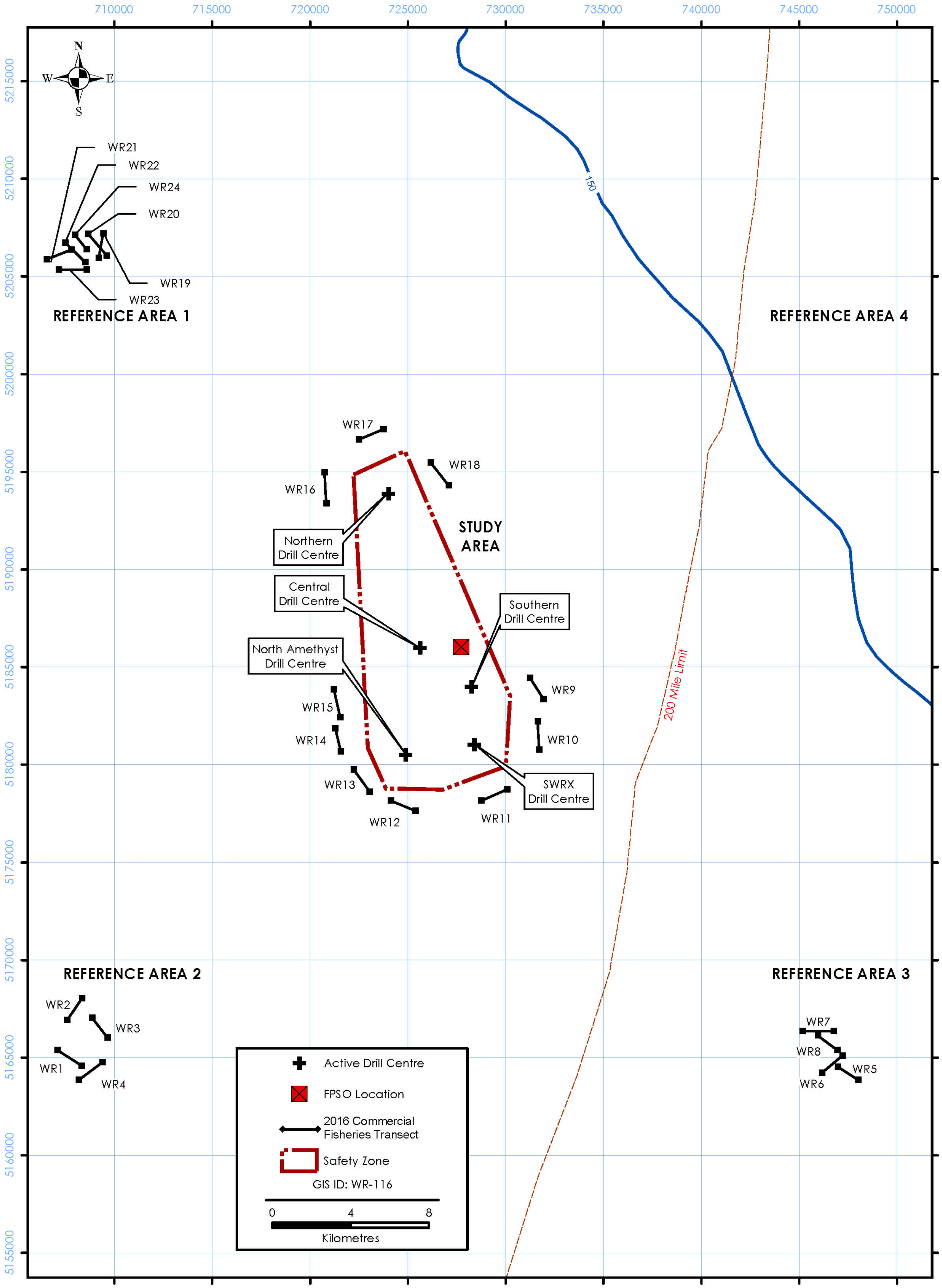

Figure 1-18 2016 EEM Program Commercial Fish Sampling Locations

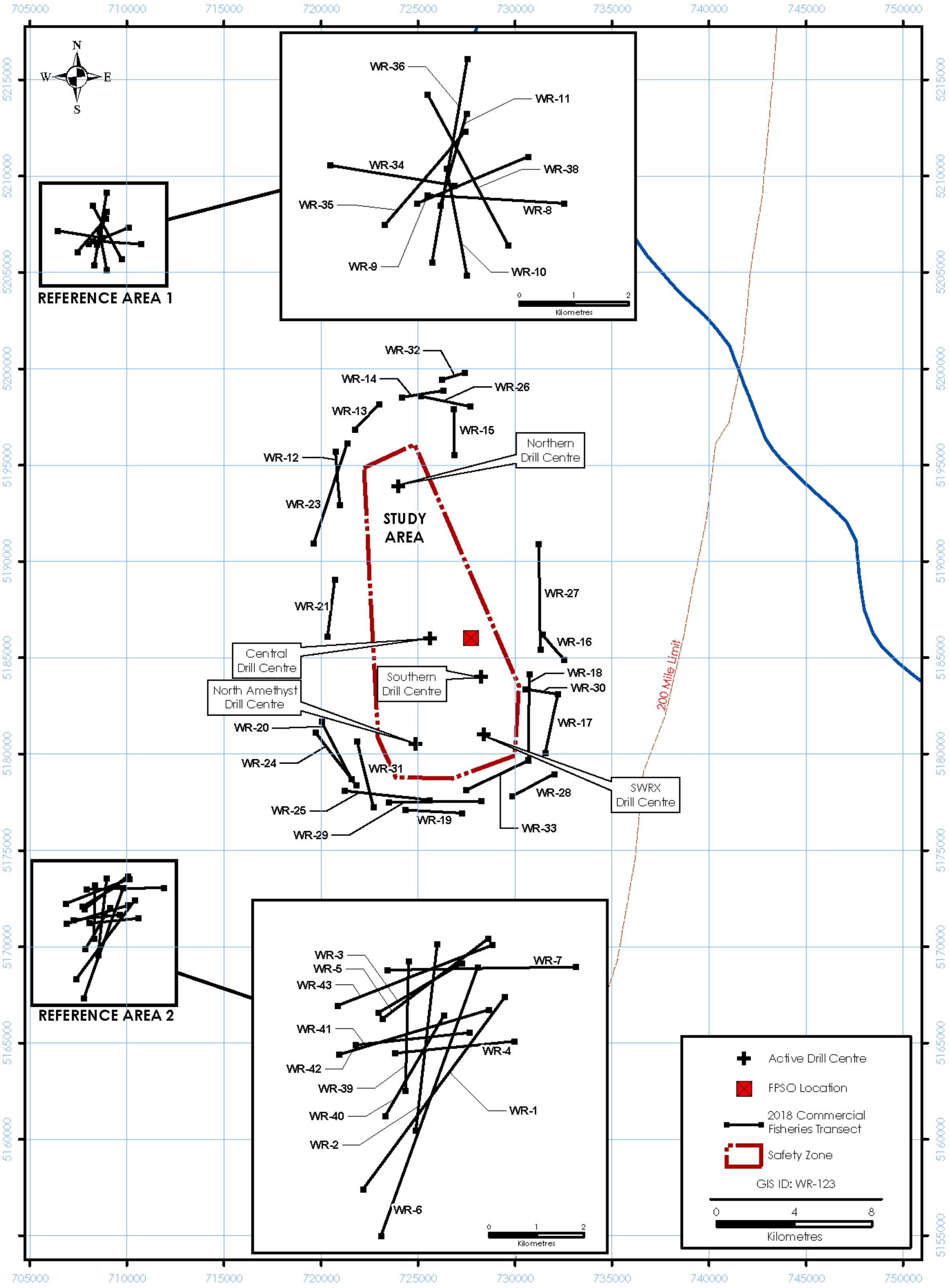

Figure 1-19 2018 EEM Program Commercial Fish Sampling Locations

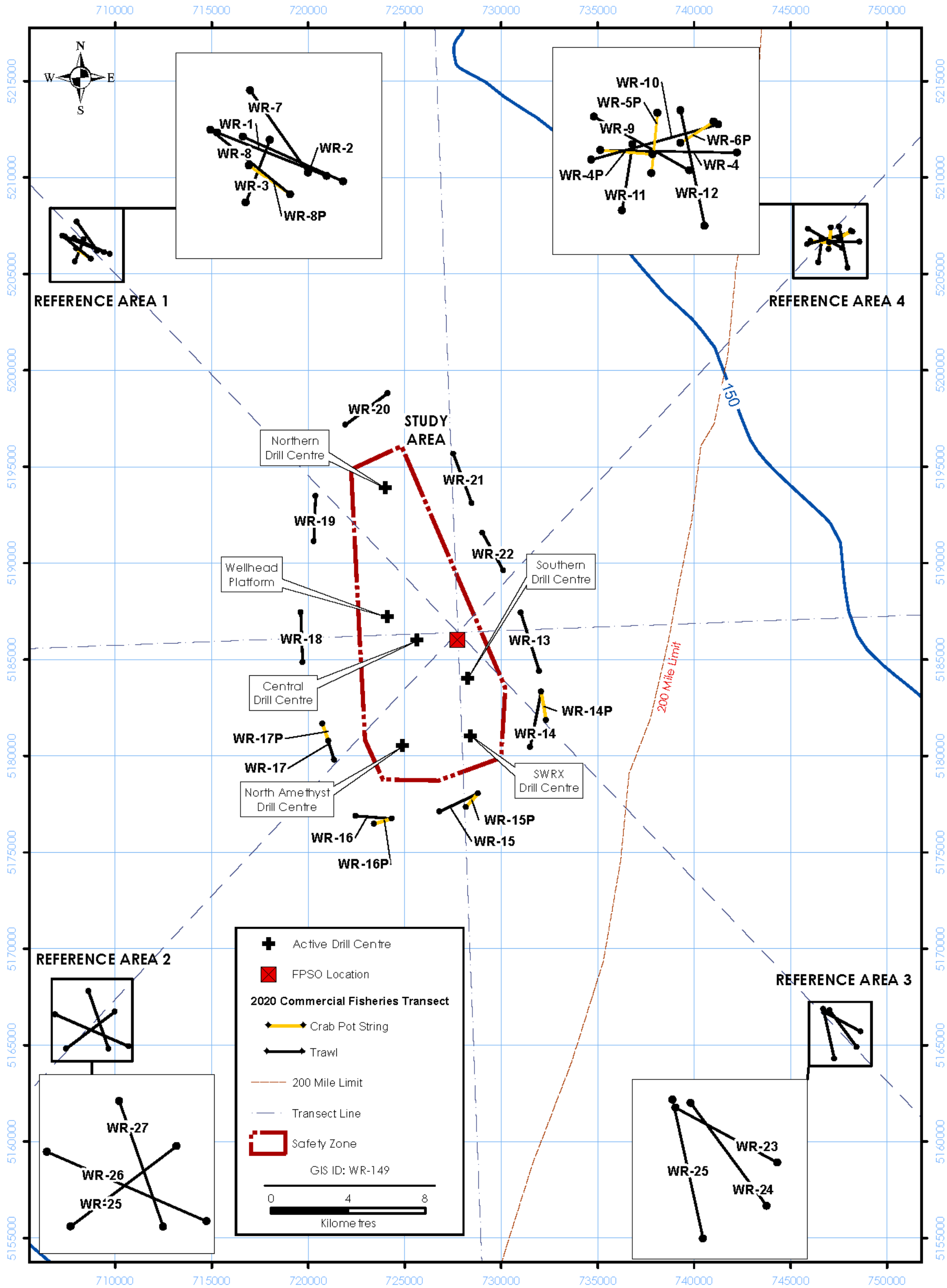

Figure 1-20 2020 EEM Program Commercial Fish Sampling Locations

Notes: Both trawls and crab pot strings were used to collect crab in 2020. Crab pot strings are identified in yellow and by the suffix 'P' in this figure. The indicated Wellhead Platform is a proposed location. See Section 6 for details.

1.6.3 Modifications to the Water Quality Sampling Design

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

1.6.3.1 Seawater Samples

Water samples were collected at 13 randomly selected stations during baseline sampling in 2000 (Figure 1-21[6]). 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 2020, 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 1-28, 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 2010a for details).

1.6.3.2 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 in that and subsequent programs.

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

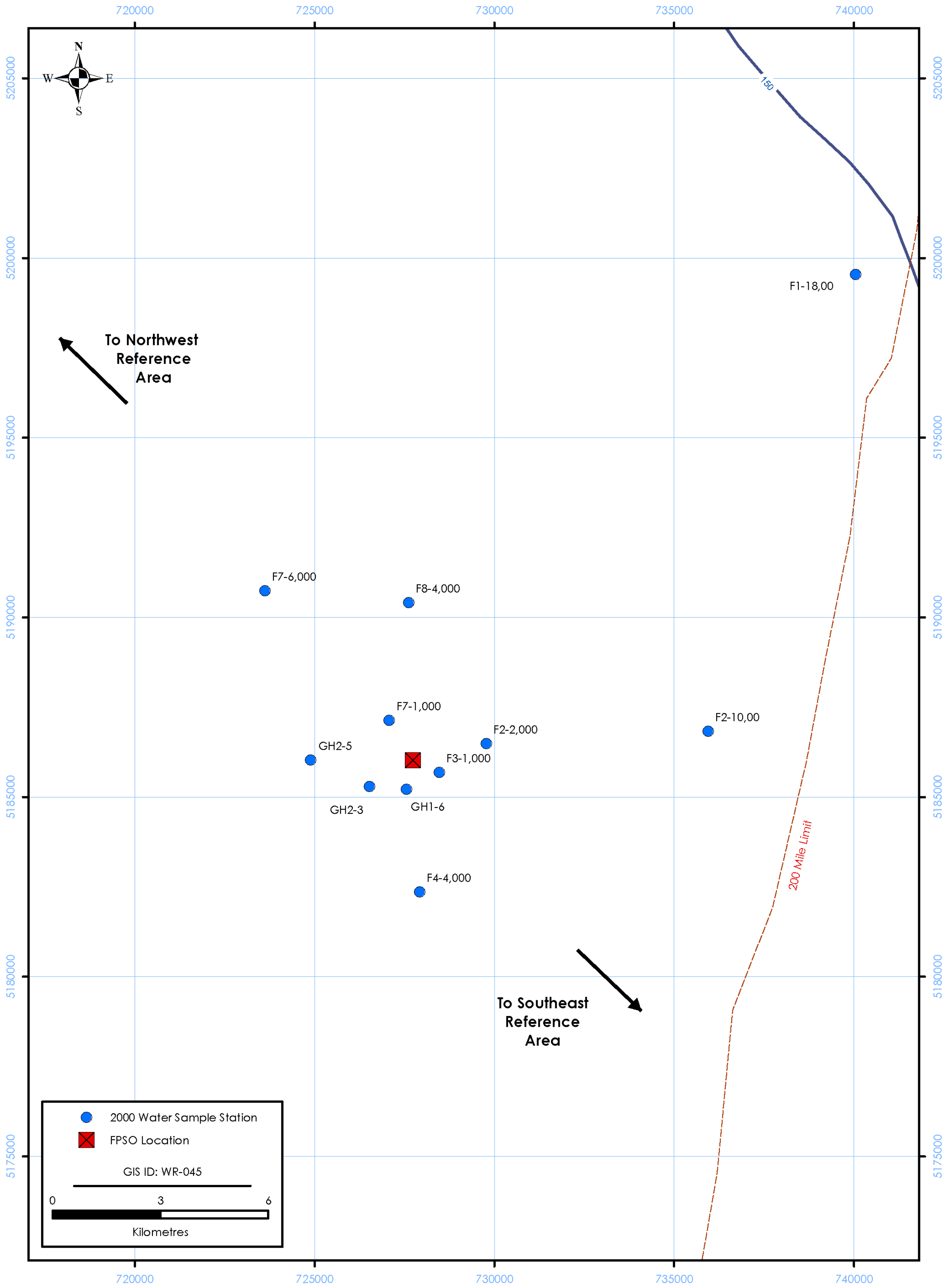

Figure 1-21 2000 Baseline Program Water Quality Stations

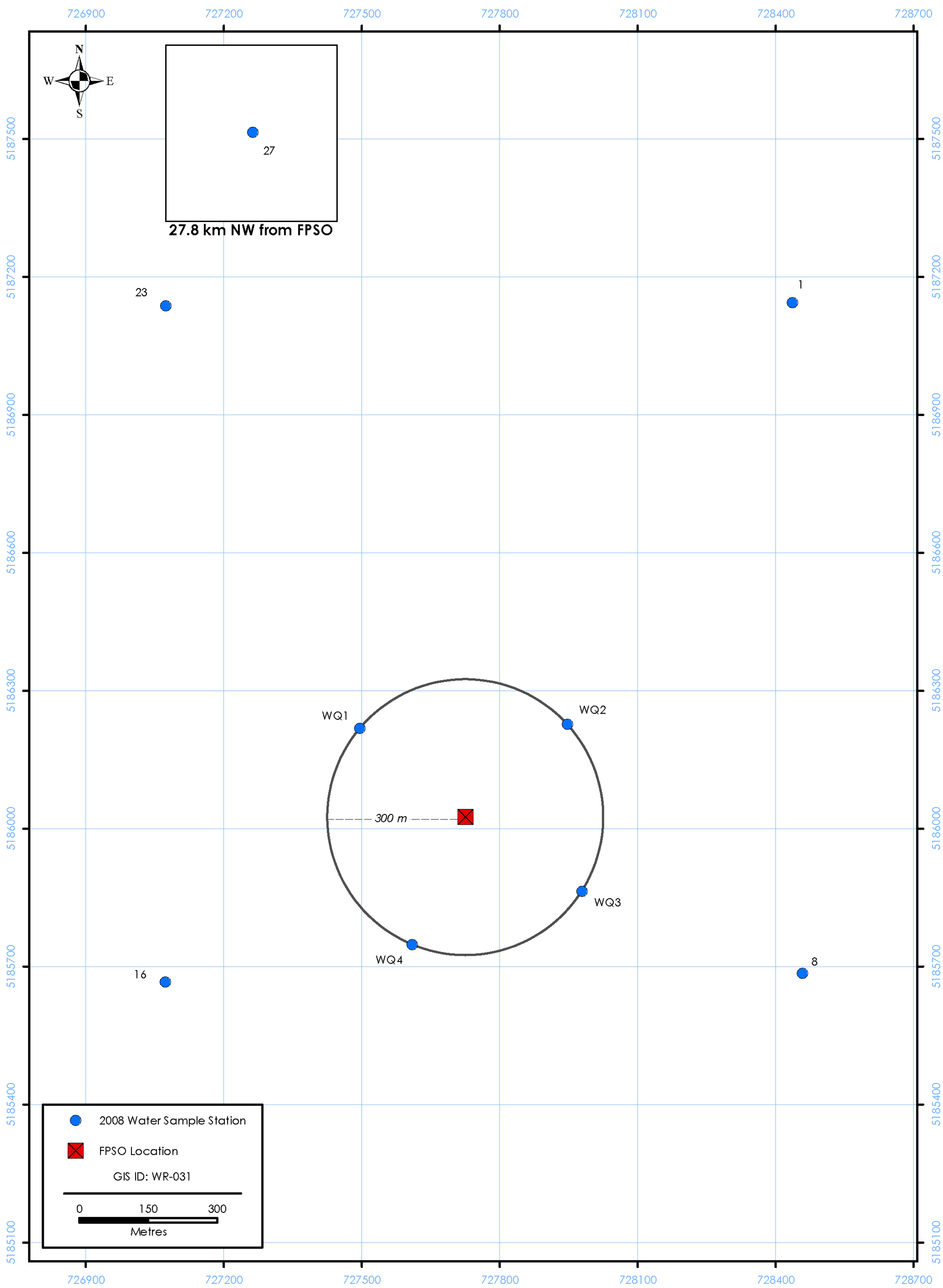

Figure 1-22 2008 EEM Program Water Quality Stations

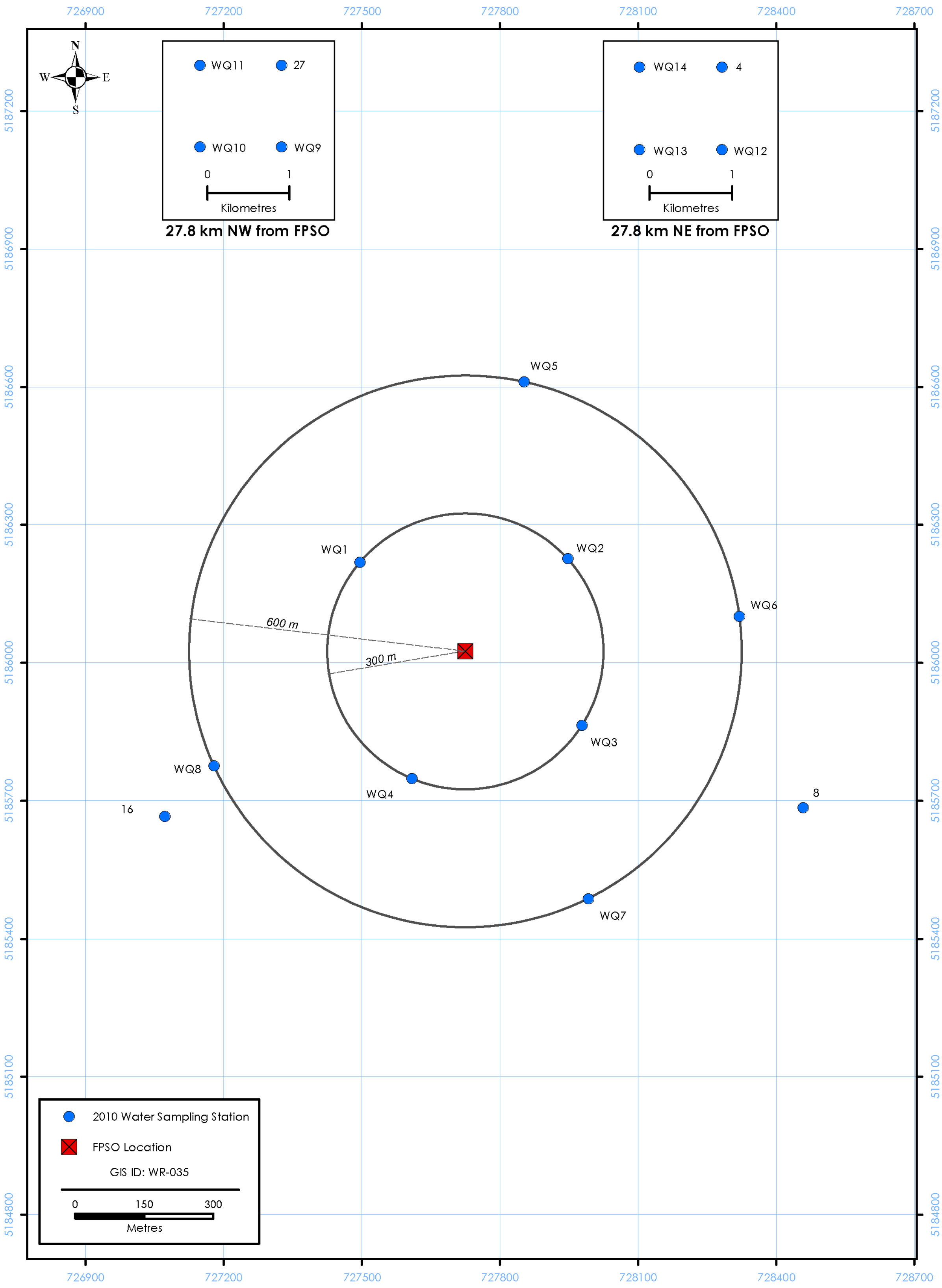

Figure 1-23 2010 EEM Program Water Quality Stations

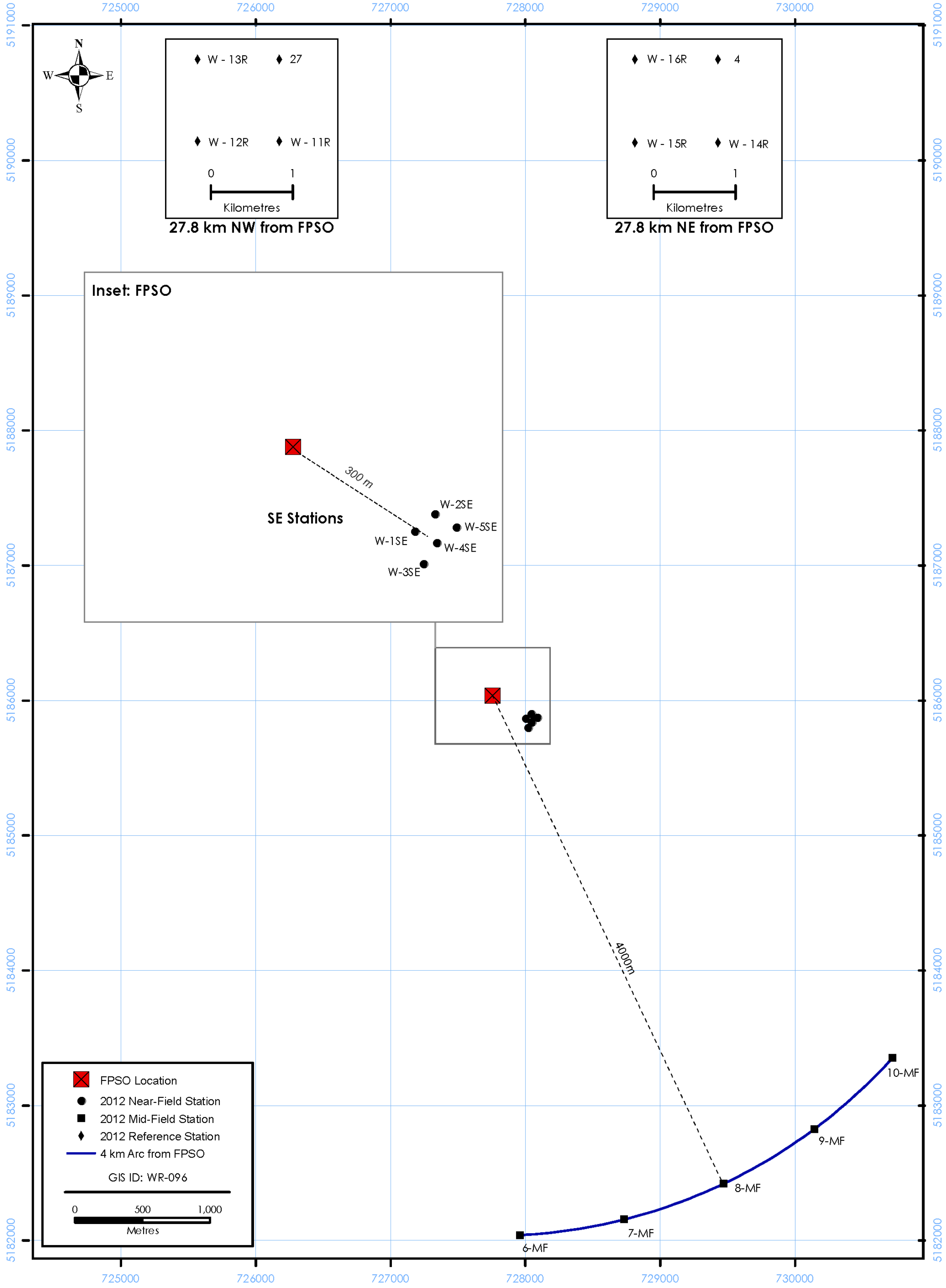

Figure 1-24 2012 EEM Program Water Quality Stations

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.

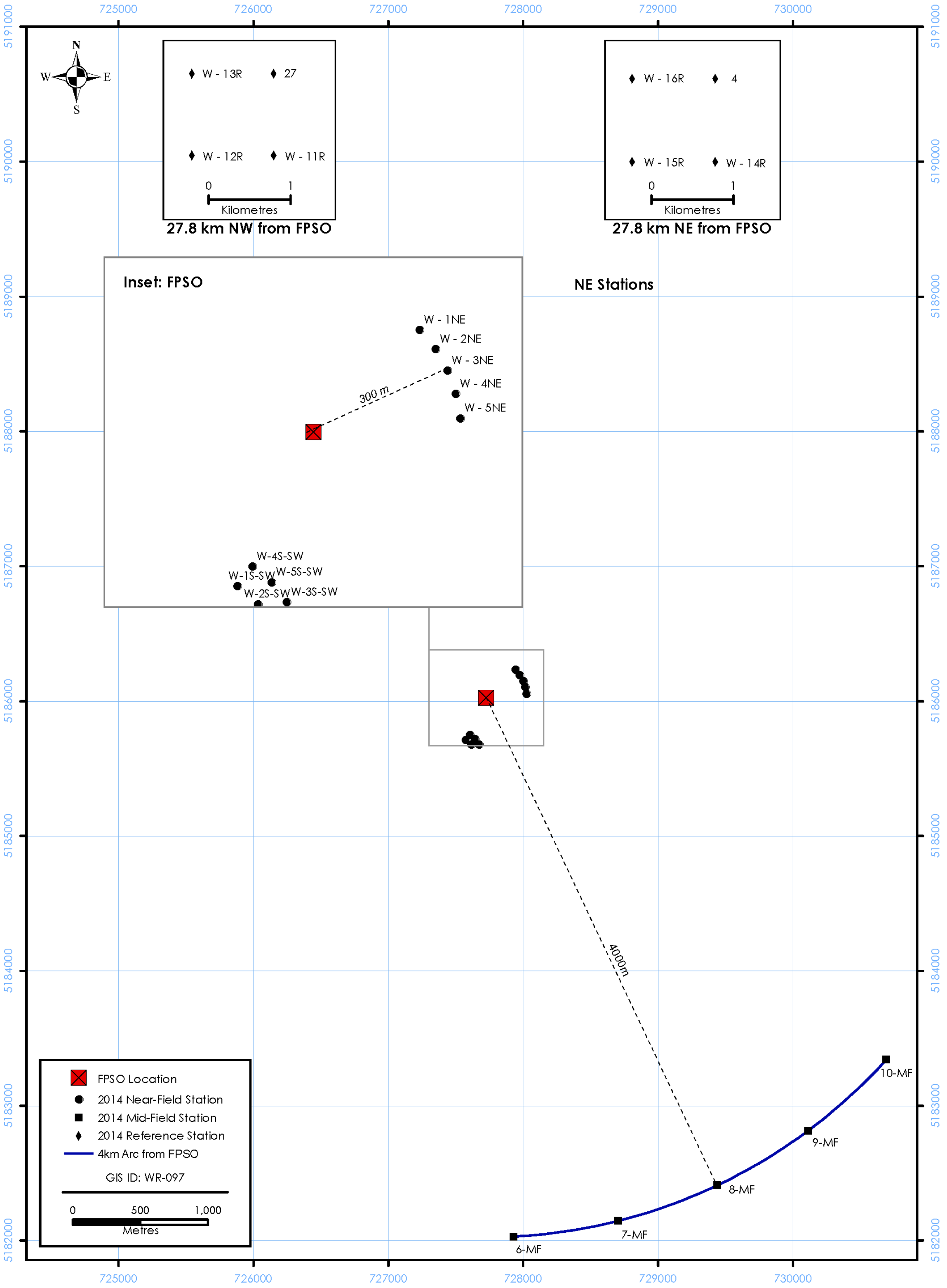

Figure 1-25 2014 EEM Program Water Quality Stations

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.

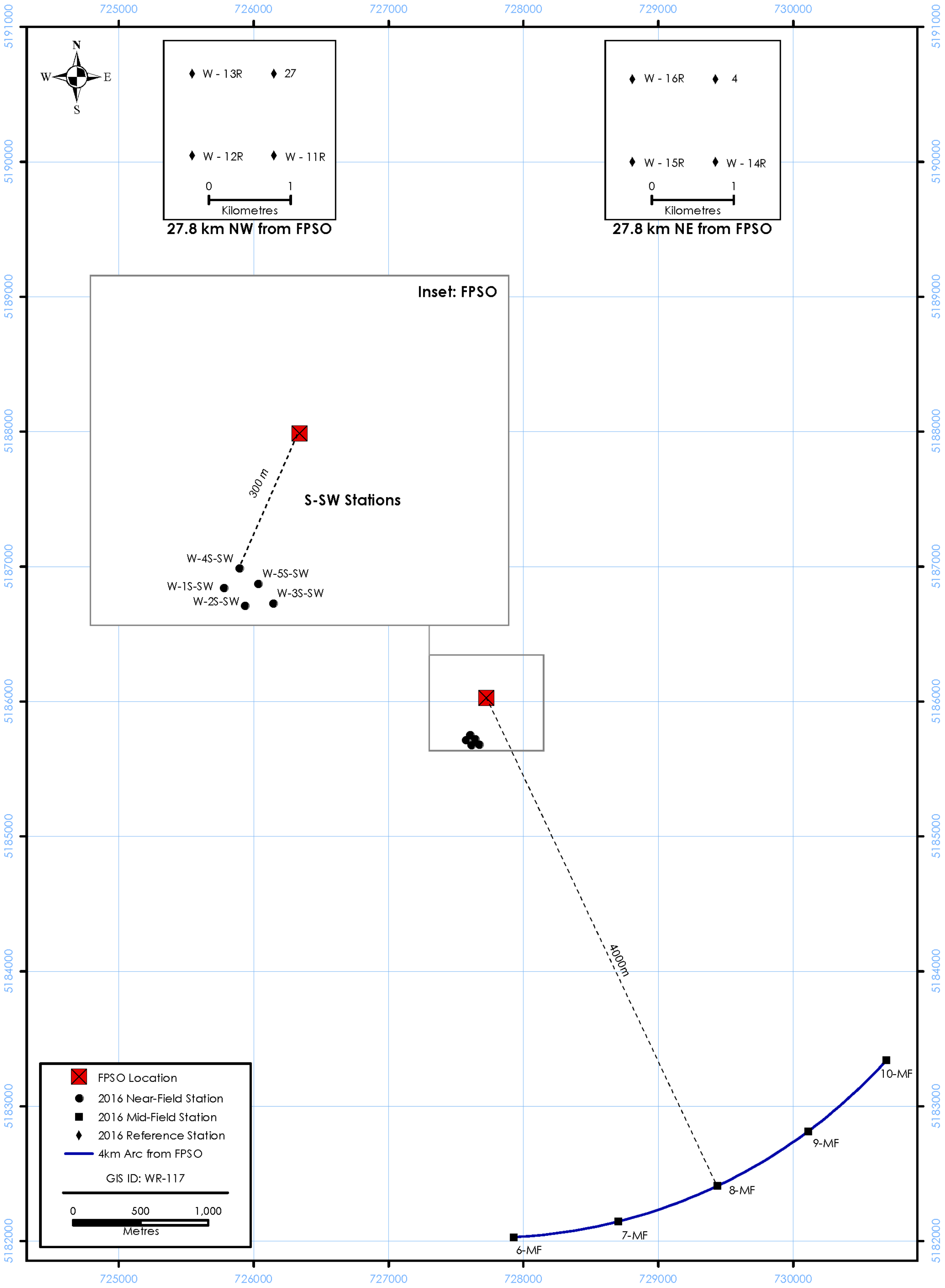

Figure 1-26 2016 EEM Program Water Quality Stations

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.

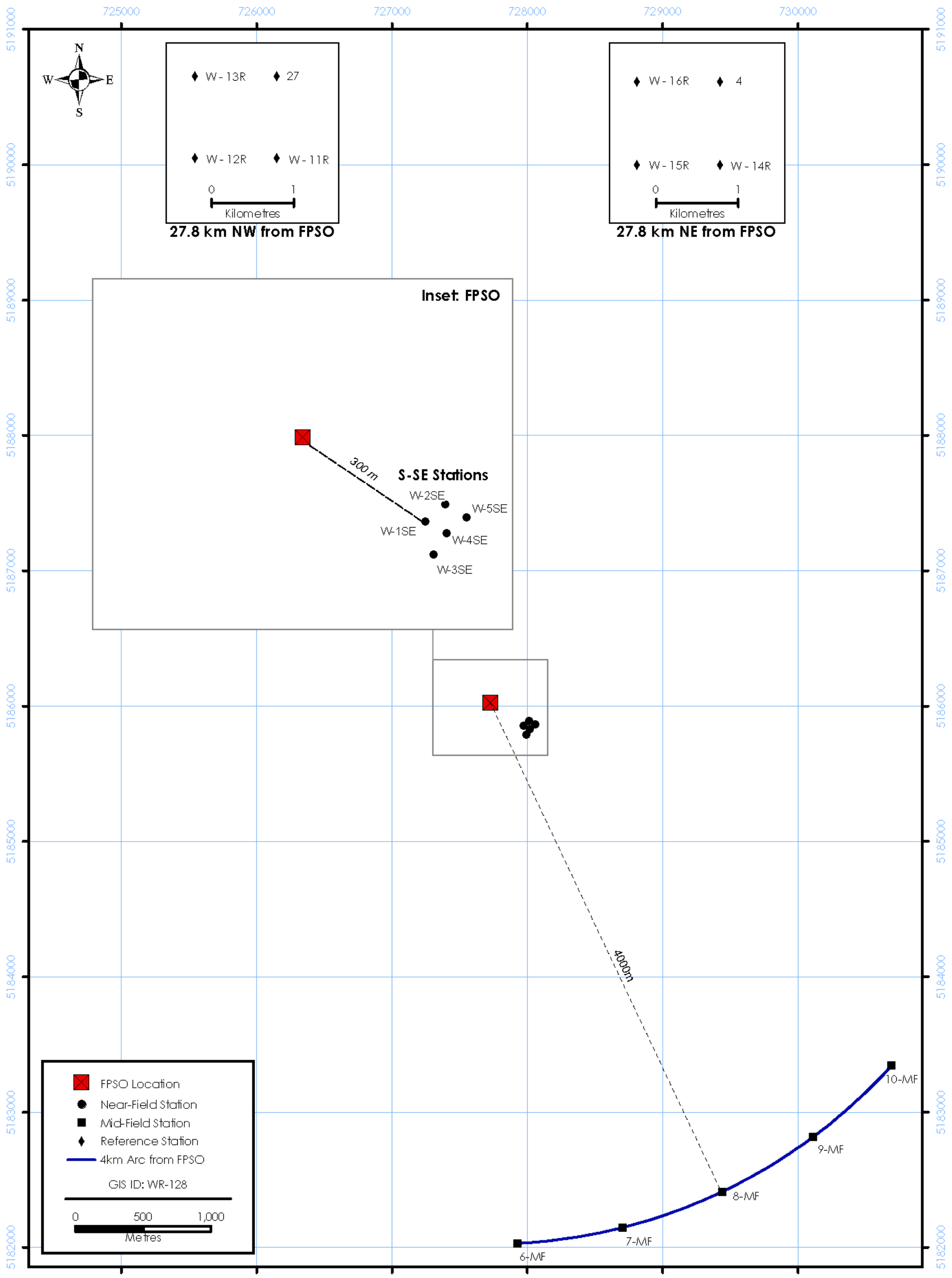

Figure 1-27 2018 EEM Program Water Quality Stations

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.

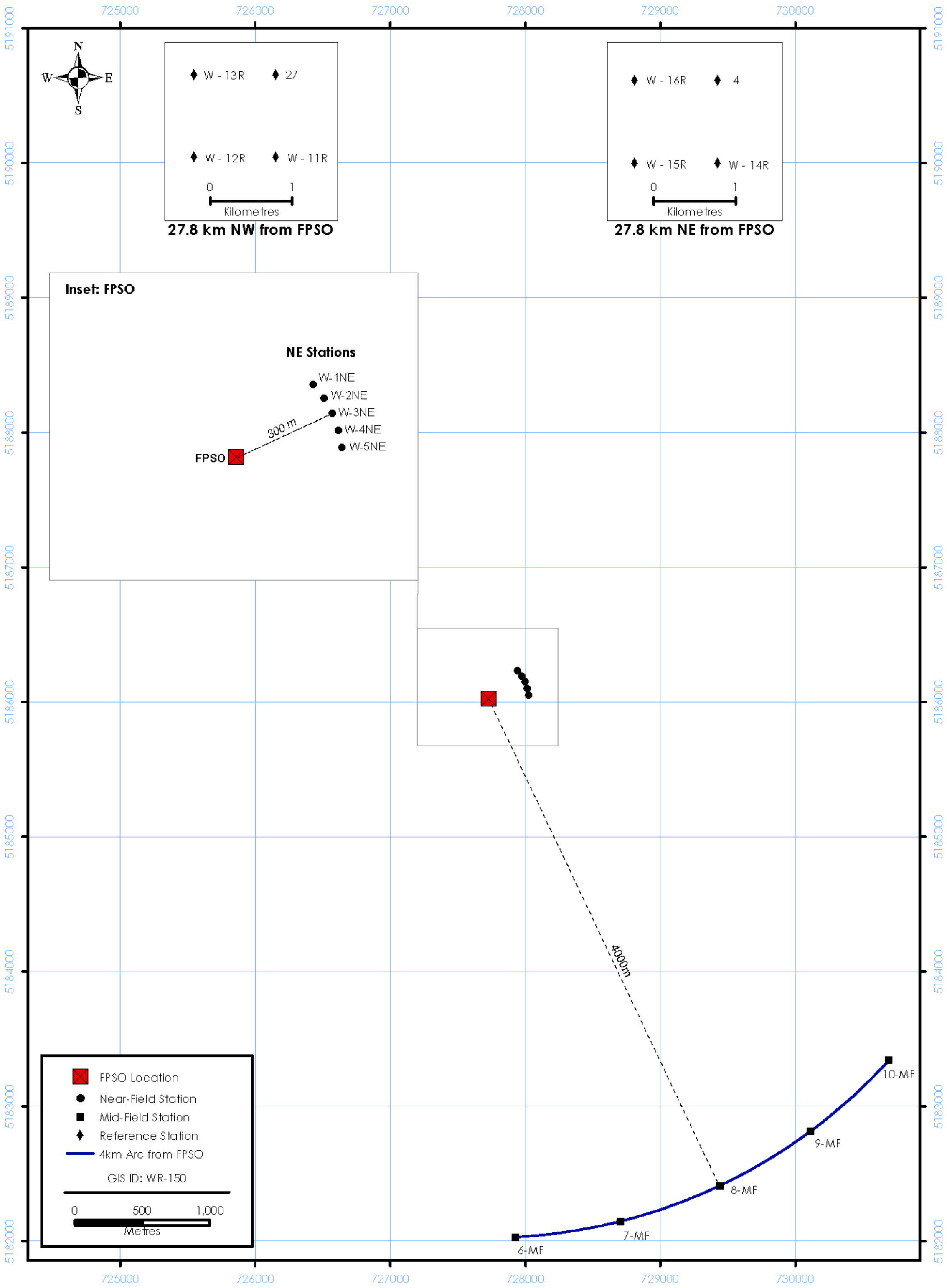

Figure 1-28 2020 EEM Program Water Quality Stations

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, *2020 White Rose Environmental Effects Monitoring Program (Volume 1)*, provides summary results, analyses, and interpretations for the White Rose 2020 EEM program. Where applicable, results from the baseline and previous EEM programs are compared to 2020 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 and EA predictions (Section 1.5).

Most methods are provided in *Volume 1*. However, some more detailed methods as well as ancillary analyses are included in Appendices (*2020 White Rose Environmental Effects Monitoring Program (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 Section 9 of this document. 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.

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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 / individuals] per square metre
µg/L	microgram per litre
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
BTEX	benzene, toluene, ethylbenzene and xylenes
BV	Bureau Veritas
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
EA	Environmental Assessment
EEM	environmental effects monitoring
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
L	litre
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
MODU	mobile offshore drilling unit
mV	millivolts
NE	northeast
NW	northwest
nMDS	non-Metric Multidimensional Scaling
PAH	polycyclic aromatic hydrocarbon

Abbreviations	Definition
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

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 EPCMP 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 2017), 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, 7, and 8.

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 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. Following the previous EEM program in October 2018, Husky experienced an oil spill in the White Rose field from a subsea flowline in the vicinity of the SWRX Drill Centre on November 16, 2018; samples collected post-spill did not identify hydrocarbons associated with the spill. Production was immediately halted and did not resume until February 3, 2019. Full-field production did not fully resume until mid-August 2019. Maintenance shut-downs were conducted between April 20 to May 3, 2019, and July 24 to August 9, 2020, 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 very little drilling activity within the White Rose Field since the 2018 EEM program, with the Henry Goodrich mobile offshore drilling unit (MODU) leaving Husky's Operating Authorization in January 2020. Activities in 2018 and early 2019 were focused on well interventions in the Central Drill Centre, whereas in late 2019 activities were related to well abandonment on the Southern Drill Centre.

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 previous EEM program in 2018. 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 4-1 Cuttings and Water-based Mud Discharges

Year	Drill Centre	Months with Drilling Activity												Total Cuttings Discharged (mt)	Total Muds Discharged (m³)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
2018	Northern													N/A	N/A
	Central					🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	2,354	5,074
	Southern													N/A	N/A
	NADC													N/A	N/A
	SWRX													N/A	N/A
	EEM Program							F	SW						
2019	Northern													N/A	N/A
	Central	🟦	🟦	🟦				🟦	🟦					N/A	1845
	Southern								🟨	🟨	🟨	🟨	🟨	N/A	4021
	NADC													N/A	N/A
	SWRX													N/A	N/A
2020	Northern													N/A	N/A
	Central													N/A	N/A
	Southern	🟨												N/A	1252
	NADC													N/A	N/A
	SWRX													N/A	N/A
	EEM Program										F	SW			

Total Discharge at Northern Drill Centre	1,364	912
Total Discharge at Central Drill Centre	9,786	17,435
Total Discharge at Southern Drill Centre	4,219	11,375
Total Discharge at NADC	6,408	15,442
Total Discharge at SWRX	4,684	14,739
Total Field Discharge	26,461	59,903

Notes:
NADC – North Amethyst Drill Centre.
SWRX – 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
m³ – cubic metre
N/A – no drilling activity in drill centre

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 previous EEM program in 2018. 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.

Table 4-2 Cuttings and Synthetic-based Mud Discharges

Year	Drill Centre	Months with Drilling Activity												Total Cuttings Discharged (mt)	Total Solids Discharged (m³)	Total Base Oil Discharged (m³)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec			
2018	Northern													N/A	N/A	N/A
	Central						■	■		■	■	■	■	1,848	562	125
	Southern													N/A	N/A	N/A
	NADC	■	■											896	296	72
	SWRX													N/A	N/A	N/A
	EEM Program							F	SW							
2019	Northern													N/A	N/A	N/A
	Central													N/A	N/A	N/A
	Southern													N/A	N/A	N/A
	NADC													N/A	N/A	N/A
	SWRX													N/A	N/A	N/A
2020	Northern													N/A	N/A	N/A
	Central													N/A	N/A	N/A
	Southern													N/A	N/A	N/A
	NADC													N/A	N/A	N/A
	SWRX													N/A	N/A	N/A
	EEM Program										F	SW				

Total Discharge at Northern Drill Centre	1,636	2,093	309
Total Discharge at Central Drill Centre	8,847	11,238	1,766
Total Discharge at Southern Drill Centre	4,778	8,817	1,418
Total Discharge at NADC	6,957	3,354	955
Total Discharge at SWRX	7,480	2,484	804
Total Field Discharge	29,698	27,986	5,252

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
m³ – cubic metre
N/A – no drilling activity in drill centre

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 in 2018. 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 4-3 Completion Fluid Discharges

Year	Drill Centre	Months with Drilling Activity												Total Completion Fluids Discharged (m³)
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2018	Northern													N/A
	Central							🟦	🟦	🟦				2795.1
	Southern													N/A
	NADC		🟪											433.5
	SWRX													N/A
	EEM Program							F	SW					
2019	Northern													N/A
	Central	🟦	🟦	🟦				🟦	🟦					1845.1
	Southern								🟨	🟨	🟨	🟨	🟨	4019.8
	NADC													N/A
	SWRX													N/A
2020	Northern													N/A
	Central													N/A
	Southern													N/A
	NADC													N/A
	SWRX													N/A
	EEM Program										F	SW		

Total Discharge at Northern Drill Centre	385
Total Discharge at Central Drill Centre	9,177
Total Discharge at Southern Drill Centre	8,334
Total Discharge at NADC	5,448
Total Discharge at SWRX	3,262
Total Field Discharge	26,606

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 drill centre

4.3.2 Other Discharges from Drilling Operations

Between October 2018 and January 2020, a total of 95 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, 1.4 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 2018 and January 2020, 460 m³ of blowout preventer fluid was discharged. Approximately 29%, or 132 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 2018 and November 2020, a total of 2,588.9 m³ of water was released from the slops tanks, representing 7.41 kg (average 3.8 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 2018 and November 2020, 4,905,884 m³ of produced water was released, representing 74,736 kg (the average for end-of month 30-day rolling averages was 15.93 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 2018 and November 2020, the average residual chlorine concentration prior to release was 0.26 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 2020 EEM Program was conducted from November 11 to 23, 2020, using the offshore supply vessel *Skandi Vinland*. Sampling dates for the baseline program and EEM programs are summarized in Table 5-1. Sediment stations for the baseline and EEM programs are shown in Figures 1-4 to 1-10 (Section 1), with the 2020 station locations provided in Figure 5-1. Differences in sampling locations among years are described in Section 1. More details on the baseline survey and EEM programs from year 1 through 9 can be found in Husky (2001, 2005, 2006, 2007, 2009, 2011, 2013, 2017, 2019). Geographic coordinates, station depth and distances to drill centres for EEM stations sampled in 2020 are provided in Appendix A-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 August 15, 2018
EEM Program Year 10	November 11 to November 23, 2020

Sediment was collected using a large-volume corer (mouth diameter = 35.6 cm, depth = 61 cm) designed to mechanically take an undisturbed sediment sample over approximately 0.1 m^2 (0.0995 m^2) of seabed (Figures 5-2 and 5-3). 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 laboratory amphipod survival. Benthic community variables included total abundance, biomass and richness, abundances of selected individual taxa, and multivariate measures of community composition.

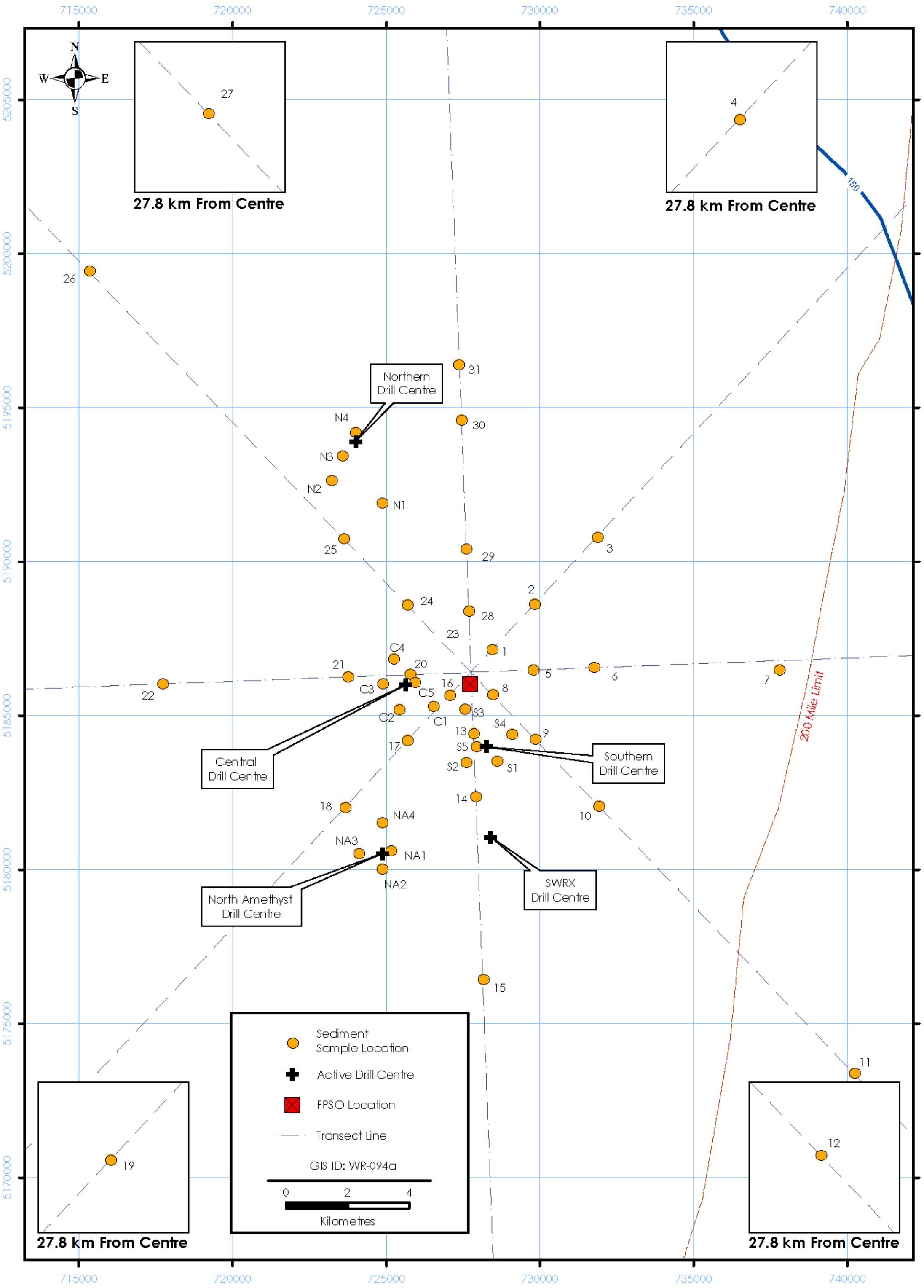

Figure 5-1 2020 Sediment Quality Triad Stations

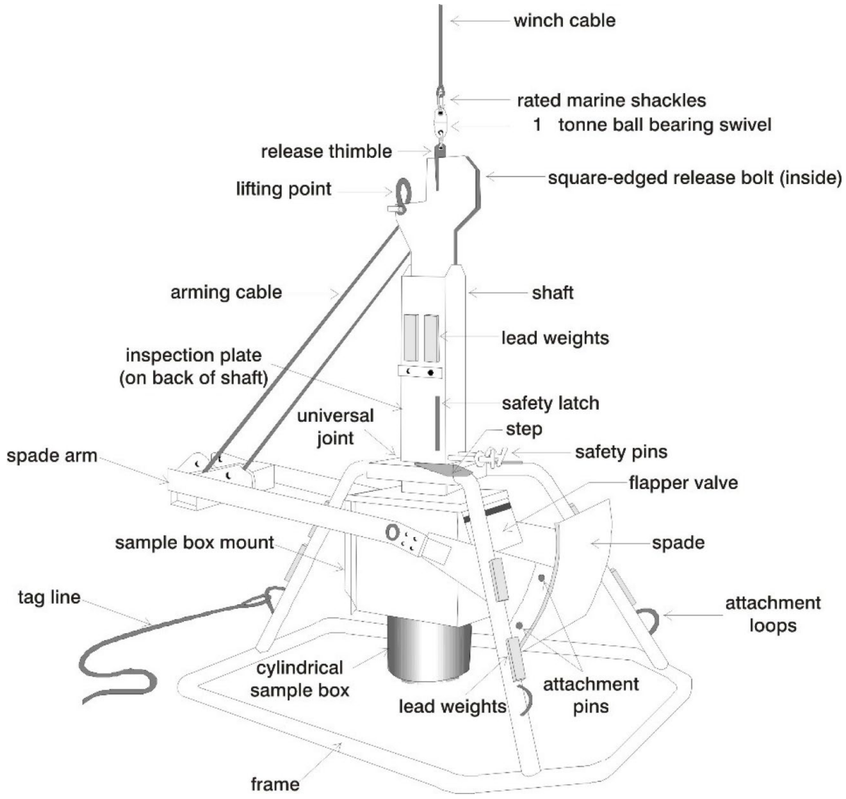

Figure 5-2 Sediment Corer Diagram

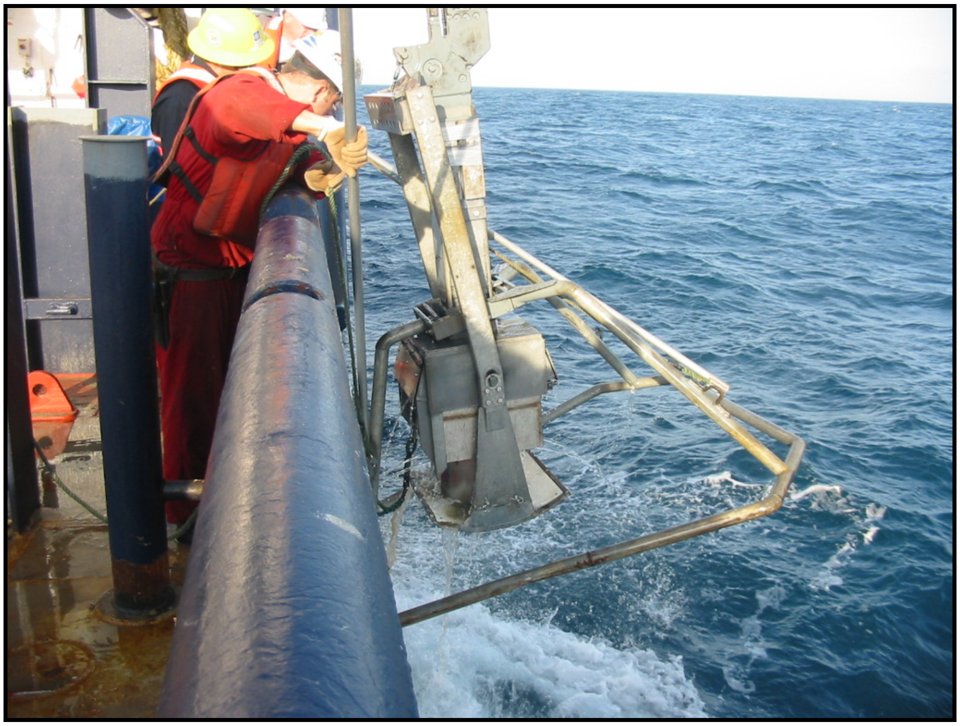

Figure 5-3 Sediment Corer

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 60 to 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. BTEX samples were also stored at 20°C. 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[7]. 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 15, 26, 31, S4, and N4). 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 Bureau Veritas[8] (BV) were transferred to the BV laboratory in St. John's for shipment to the BV laboratory in Halifax, Nova Scotia. Samples to be analyzed by RPC were shipped by overnight courier to the laboratory in Fredericton, New Brunswick. Samples to be analyzed by Avalon Laboratories and the Stantec Materials Laboratory in St. John's and the Stantec Benthic Laboratory in Guelph, Ontario, were transferred to cold storage at Stantec in St. John's and then shipped to the respective laboratories. Where applicable, samples were delivered to laboratories within the prescribed sample holding time.

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

[8] On June 3, 2019, Maxxam Analytics International Company formally changed its name to Bureau Veritas Canada.

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 A-2 for the method summary). Most sediment chemistry analyses were conducted by BV, in Halifax. Sediment organic carbon and inorganic carbon analyses were conducted at RPC. 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 A-3.

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 around 5 minutes.

Table 5-3 Sediment Chemistry Variables (2000, 2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016, 2020)

Variables	Method	Laboratory Detection Limit										Units
		2000	2004	2005	2006	2008	2010/2012	2014	2016	2018	2020	
Hydrocarbons												
Benzene	Calculated	0.03	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	0.03	mg/kg
Ethylbenzene	Calculated	0.03	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	0.05	mg/kg
C_6-C_{10} (less BTEX)	Calculated	3	3	3	4	3	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	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	0.1	g/kg
Organic Carbon	LECO	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.5	0.2	0.1	g/kg
Inorganic Carbon	By Diff	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.5	0.2	0.1	g/kg
Metals												
Aluminum	ICP-MS	10	10	10	10	10	10	10	10	10	10	mg/kg
Antimony	ICP-MS	2	2	2	2	2	2	2	2	2	2	mg/kg
Arsenic	ICP-MS	2	2	2	2	2	2	2	2	2	2	mg/kg
Barium	ICP-MS	5	5	5	5	5	5	5	5	5	5	mg/kg
Beryllium	ICP-MS	5	2	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	0.05	mg/kg
Chromium	ICP-MS	2	2	2	2	2	2	2	2	2	2	mg/kg
Cobalt	ICP-MS	1	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	2020	
Copper	ICP-MS	2	2	2	2	2	2	2	2	2	2	mg/kg
Iron	ICP-MS	20	50	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	0.5	mg/kg
Lithium	ICP-MS	5	2	2	2	2	2	2	2	2	2	mg/kg
Manganese	ICP-MS	2	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	0.01	mg/kg
Molybdenum	ICP-MS	2	2	2	2	2	2	2	2	2	2	mg/kg
Nickel	ICP-MS	2	2	2	2	2	2	2	2	2	2	mg/kg
Selenium	ICP-MS	2	2	2	2	2	2	2	2	2	2	mg/kg
Strontium	ICP-MS	5	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	0.1	mg/kg
Tin	ICP-MS	2	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	0.1	mg/kg
Vanadium	ICP-MS	2	2	2	2	2	2	2	2	2	2	mg/kg
Zinc	ICP-MS	2	5	2	5	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	0.3	mg/kg
Sulphide	SM4500	NA	2	0.2	0.2	0.2	0.2	0.2	0.5	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	0.01	%
Moisture	Grav.	0.1	0.1	0.1	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.
- 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, 2016, 2018 and 2020 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.
- Results and detected limits for carbon, inorganic and organic carbon are reported in % in Appendix A-3, with a laboratory detection limit of 0.01% (equivalent to 0.1 g/kg). Because previous results have been expressed in g/kg, results in % have been converted to g/kg in this section.
- *The detection limit for ammonia varies across a narrow range depending on the moisture content of each sample. Detection limits have been around 0.3 mg/kg. In 2020, the median detection limit across all samples was 0.31 mg/kg.
- 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

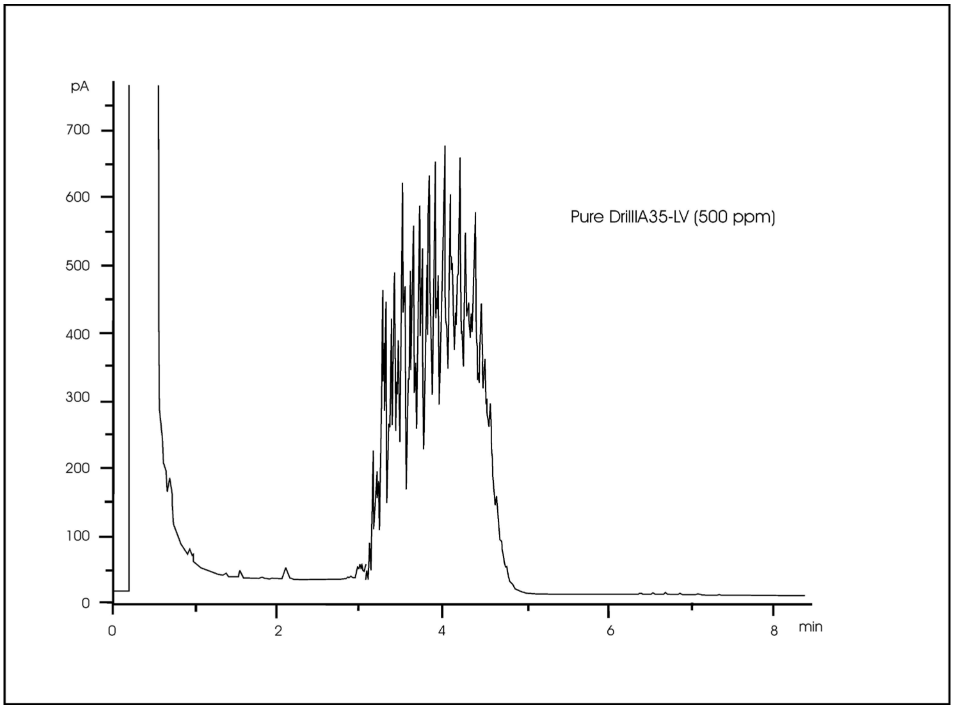

Figure 5-4 Gas Chromatogram Trace for PureDrill IA35-LV

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.

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 amphipod species in the family Phoxocephalidae are generally prevalent 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 2020 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 Appendices A-4 and A-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 (CETIS V1.9.7.9, 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}[9] 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, and 27). Using two reference samples to define toxicity reduces an already very low risk of false positives. Sediments from White Rose stations 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. In the comparison to composite reference sediment (Stations 4, 12, 19, and 27), sediments from White Rose stations were considered toxic if survival was reduced by more than 20% compared to survival in the reference sediment and the result was significantly different from survival in the composite reference.

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

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

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 A-5.

5.1.2.3 Benthic Community Structure

In 2020, 106 benthic samples (11 to 15 L buckets) were provided whole to Stantec's Benthic Taxonomy Laboratory (Guelph, Ontario). Samples were washed and processed to collect and retain biological contents from the inorganic sand and shell material. Formalin was decanted from each sample through a 500-micron sieve and retained. A manageable amount of sediment (approximately 1 L) was placed within a shallow plastic washing tray (8 cm X 30 cm X 45 cm) and water was introduced at a rate that allowed for the elutriation of less dense organic components out of the tray and into a 500-micron sieve. Through careful rocking and rotating motions, organic material and shells were washed into the sieve, until only clean sand was left in the tray to be discarded after a final check for organisms. This was repeated until all of the sediment within the sample bucket was thoroughly processed.

The contents of the sieve were placed within a 500 mL PET[10] jar and labelled with project number and station number transcribed from the source bucket. Formalin was reintroduced to the sample and a stain, comprised of Eosin-B and Biebrich Scarlet was added to improve sorting efficiency. This process was repeated for each of the 106 samples. Samples containing coarser substrates (rock and shell material) were passed through a coarse sieve (3.35 mm) prior to elutriation using the techniques described above. Organisms encrusting rocks or shells were scraped off and included in the sample jars.

Prior to sorting, samples were washed in a 500-micron sieve to remove excess formalin and fine debris. All sieved samples were sorted under a stereomicroscope at 10X to 40X magnification. A manageable portion (5 to 10 mL) of sample was placed within a gridded petri dish and systematically scanned under magnification. Organisms were removed

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[10] PET = polyethylene terephthalate

and placed in a watch glass. Each petri dish of material was then systematically rescanned under magnification so that every sample was sorted twice.

Wet weight biomass (g/sample) was estimated by weighing the collected organisms to the nearest milligram at the time of sorting after blotting to remove surface water.

All samples were sorted in their entirety and no sub-sampling was required.

Certain groups of organisms (meiofauna) such as oligochaetes, protodrilids, copepods, ostracods, nematodes, and nemerteans were not picked from samples, weighed or enumerated, as they were not included in benthic community analyses during prior assessments of the site. Similarly, vertebrates (such as fish) were not weighed or enumerated.

Sorting efficiency was assessed by re-sorting material from 10% (11) of the sorted samples, selected at random. These re-sorts were conducted by a different technician than the one who conducted the original sort. Organisms found in the re-sort were added to the total biomass and counts from the original sort. Sorting efficiency was calculated as the number of organisms originally sorted, divided by the number of organisms after both sorting events were totalled, as a percent. A sorting efficient of 95% was achieved with the 2020 benthic samples.

Organisms were identified to family level using available dichotomous keys and reference material appropriate to the taxa found (see Appendix A-6 for details). To assist with identification, certain groups required wet mounting of anatomical structures on slides to be viewed through a 100X to 1,000X light microscope. Staining with methylene blue was employed to provide contrast for some structures to assist with identification.

A voucher collection of each taxon was made to assist in future identifications.

Benthic invertebrate samples from 2004 to 2018 were processed by Arenicola Marine Limited. Benthic invertebrate samples from 2000 were processed by Envirosphere Limited. Methods and the level of taxonomy was similar to those used for the 2004 to 2020 samples.

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[11] for sediment chemistry. Drill centres were considered active if any drilling had occurred there in the past.

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

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 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[12] are used instead.

Based on regulatory feedback from Fisheries and Oceans Canada (DFO) (see Appendix A in the 2016 EEM Program Report, Husky 2019), 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. Results from Station 31 were included in maps of the spatial distribution of response variables (see below for details).

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. Based on this, the variables selected for detailed analysis in 2020 included $>C_{10}$-C_{12} hydrocarbons, barium, sediment particle size (% fines), ammonia, sulphide, sulphur, organic carbon, redox potential and 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 as per analyses in previous years. Finally, because the metals PCA indicated that lead and strontium behaved differently from other metals (see Section 5.2.18), these two metals were examined separately. Any data below laboratory detection limit for the selected variables were set to ½ the detection limit. 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 typically 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

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[12] 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.

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 2020) 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. However, 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.

Maps (Tool 4) of 2020 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 potential 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. Station 31, predominantly influenced by delineation rather than development drilling, was included in maps. As noted above, the station was not included in analyses.

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 2020 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 2020, 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).

Multivariate assessment of benthic community structure on 2016 and 2018 data submitted in the 2018 EEM report identified Paraonidae, Cirratulidae, Orbiniidae and Tanaidacea as the most affected taxa in both years. Based on this, and recommendations in the 2018 EEM report, these four taxa were also examined in this report. Because of taxonomic discrepancies among years, the abundance from order isopoda (which includes Tanaidacea) was examined[13]. These analyses were secondary to analyses of indices of benthic community structure and were performed to provide insight on the more general indices.

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 for summary indices of benthic community structure or individual taxa: 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.

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[13] Recent revisions to the taxonomic classification of Tanaid families now place these organisms as Order Isopoda, as opposed to Order Tanaidacea, which has been used in previous EEM reports. In order to maintain consistency in interpretation among sampling years, datasets have been updated to place all Tanaids families in Order Isopoda.

Multivariate Analyses

As recommended in the 2014 EEM report (Husky 2017), within year multivariate analyses (specifically, non-Metric Multidimensional Scaling (nMDS)) were undertaken in the 2016, 2018 and 2020 EEM reports. Multiyear analyses including 2016 to 2020 data using nMDS were also included in this (2020) report based on recommendations in the 2016 EEM report (Husky 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 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 A-7.

5.2 Results

5.2.1 Physical and Chemical Characteristics

Appendix A-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 2020. Table 5-4 provides those statistics for 2020, but 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. In other sampling years, PAHs were only detected at Sediment Quality Triad stations in baseline (at one station) and in 2010 (at five stations). Commonly detected metals in all 11 sampling years were aluminum, barium, chromium, iron, lead, manganese, strontium, uranium, and vanadium.

Table 5-4 Summary Statistics for Detected Sediment Variables (2020)

Variable	Units	ISQG	*n*	*n > LDL*	Minimum	Maximum	Median
>C_{10}-C_{21} hydrocarbons	mg/kg		52	44	<0.3	150	0.92
>C_{21}-C_{32} hydrocarbons	mg/kg		52	49	<0.3	2.7	0.47
Total Carbon	mg/kg		52	52	0.6	2.0	1.0
Total Organic Carbon	mg/kg		52	52	0.6	2.0	1.0
Aluminum	mg/kg		52	52	5800	14000	8650
Barium	mg/kg		52	52	110	1300	185
Chromium	mg/kg	52.3	52	52	2.5	8.3	3.5
Iron	mg/kg		52	52	1100	2800	1500
Lead	mg/kg	30.2	52	52	1.8	6.2	2.8
Lithium	mg/kg		52	9	<2	2.4	<2
Manganese	mg/kg		52	52	25	89	39.5
Mercury	mg/kg	0.13	52	1	<0.01	0.011	<0.01
Nickel	mg/kg		52	10	<2	3.9	<2
Strontium	mg/kg		52	52	32	79	49
Thallium	mg/kg		52	1	<0.1	0.12	<0.1
Uranium	mg/kg		52	52	0.15	0.4	0.2
Vanadium	mg/kg		52	52	3.8	8.1	5.2
Zinc	mg/kg	124	52	5	<5	6.5	<5
Ammonia	mg/kg		52	52	1.4	10	4.55
Sulphide	mg/kg		52	10	<0.5	5	<0.5
Sulphur	mg/kg		52	52	0.02	0.098	0.028
% Clay	%		52	52	0.55	1.05	0.73
% Fines	%		52	52	0.8	2.5	1.25
% Gravel	%		52	52	0	4.1	0.85
% Sand	%		52	52	94.7	98.9	97.80
% Silt	%		52	52	0.14	1.45	0.56
Redox	mV		52	52	133	300	243

Notes:
- Station 31 was excluded.
- ISQG = Interim Sediment Quality Guidelines.
- LDL = Laboratory Detection Limit.

As in previous years, sediments collected in 2020 were predominantly sand, with gravel-sized materials comprising up to 4.1% of the sediment (Table 5-4). Organic carbon content was low, with a median of 1.0 g/kg and a maximum of 2.0 g/kg, at Station C-5. Sediment percent fines (*i.e.*, silt and clay fractions combined) content was also low with a median of 1.25% and a maximum value of 2.5%, also at Station C-5. The median concentration of >C_{10}-C_{21} hydrocarbons was 0.92 mg/kg, with a maximum of 150 mg/kg. The median barium concentration was 185 mg/kg with a maximum of 1,300 mg/kg. The maxima for >C_{10}-C_{21} hydrocarbons and barium occurred at station 20.

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).

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

As in previous years, concentrations of >C_{10}-C_{21} hydrocarbons in 2020 were significantly and negatively correlated (*i.e.*, decreased) with distance from the nearest active drill centre (ρ_s = -0.945, $p < 0.001$, All stations; ρ_s = -0.904, $p < 0.001$, repeated-measures stations[14]) (Figure 5-6).

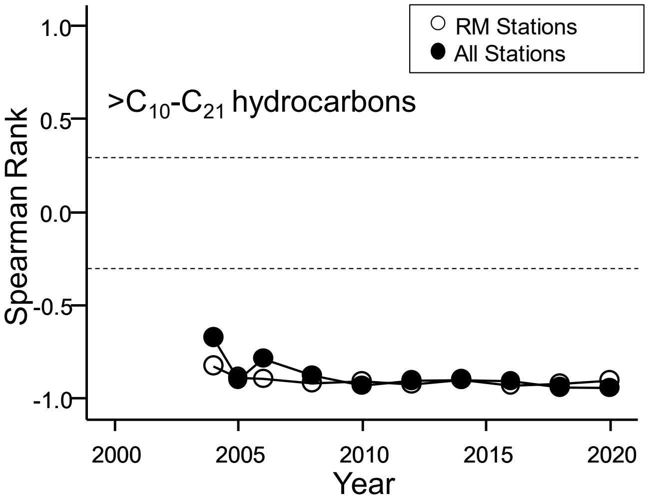

Figure 5-6 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for >C_{10}-C_{21} Hydrocarbons

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 A-7 for details on threshold model methods and results). In 2020, the threshold distance was estimated to be 2.5 km and comparable to that observed in 2018 (Table 5-5). Figure 5-7 provides a graphical representation of threshold models.

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

Year	Threshold Distance (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)
2020	2.5 (1.9, 3.1)

Notes:
- 95% confidence limits are provided in brackets.
- n = 52 in 2020 with Station 31 excluded.

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[14] Refer to Table 1-1, Section 1 for repeated-measures stations.

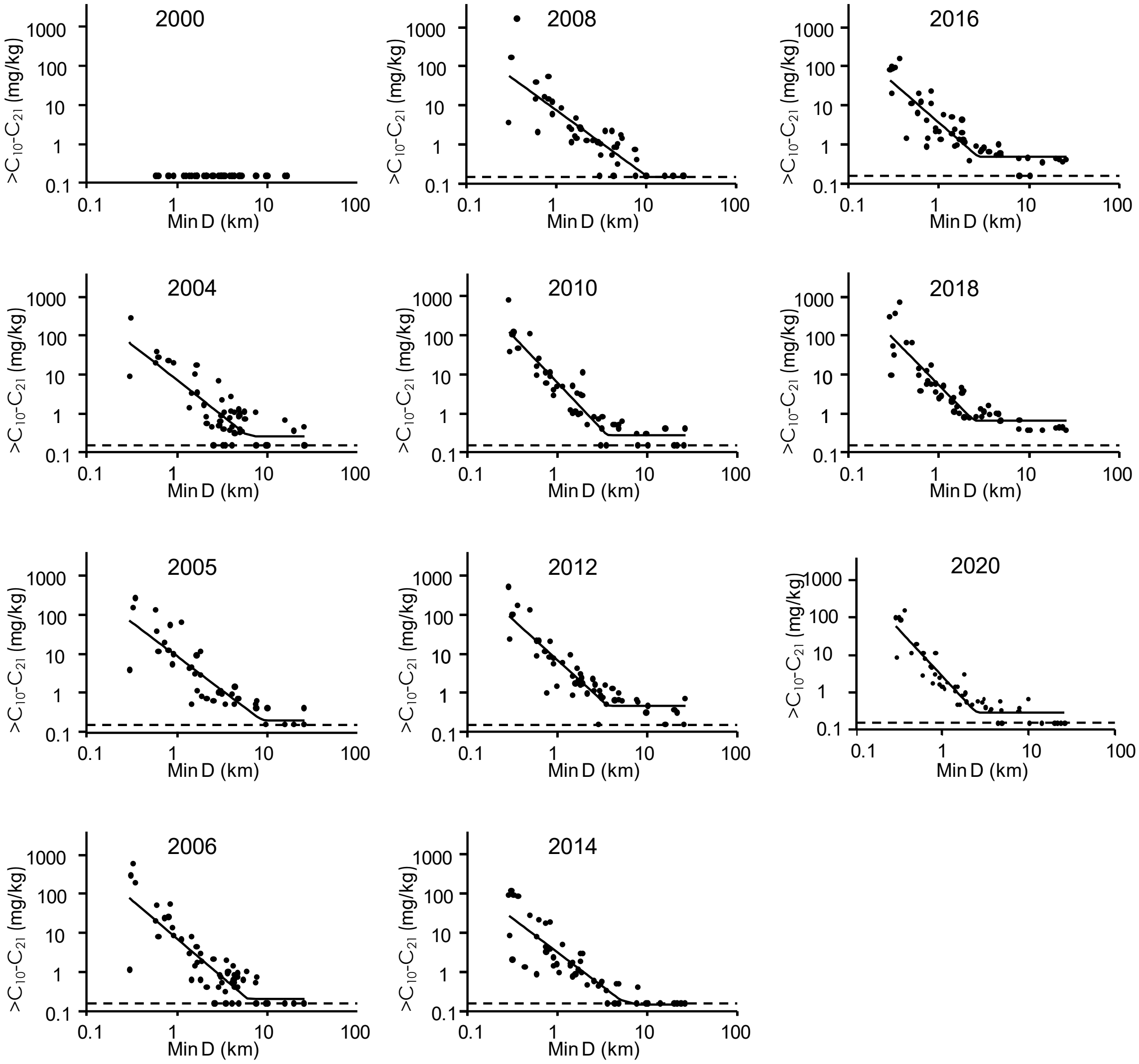

Figure 5-7 **Variations in >C_{10}-C_{21} Hydrocarbon Concentrations with Distance from the Nearest Active Drill Centre (all Years)**

Notes: Station 31 was excluded. 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.

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 2020 (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).

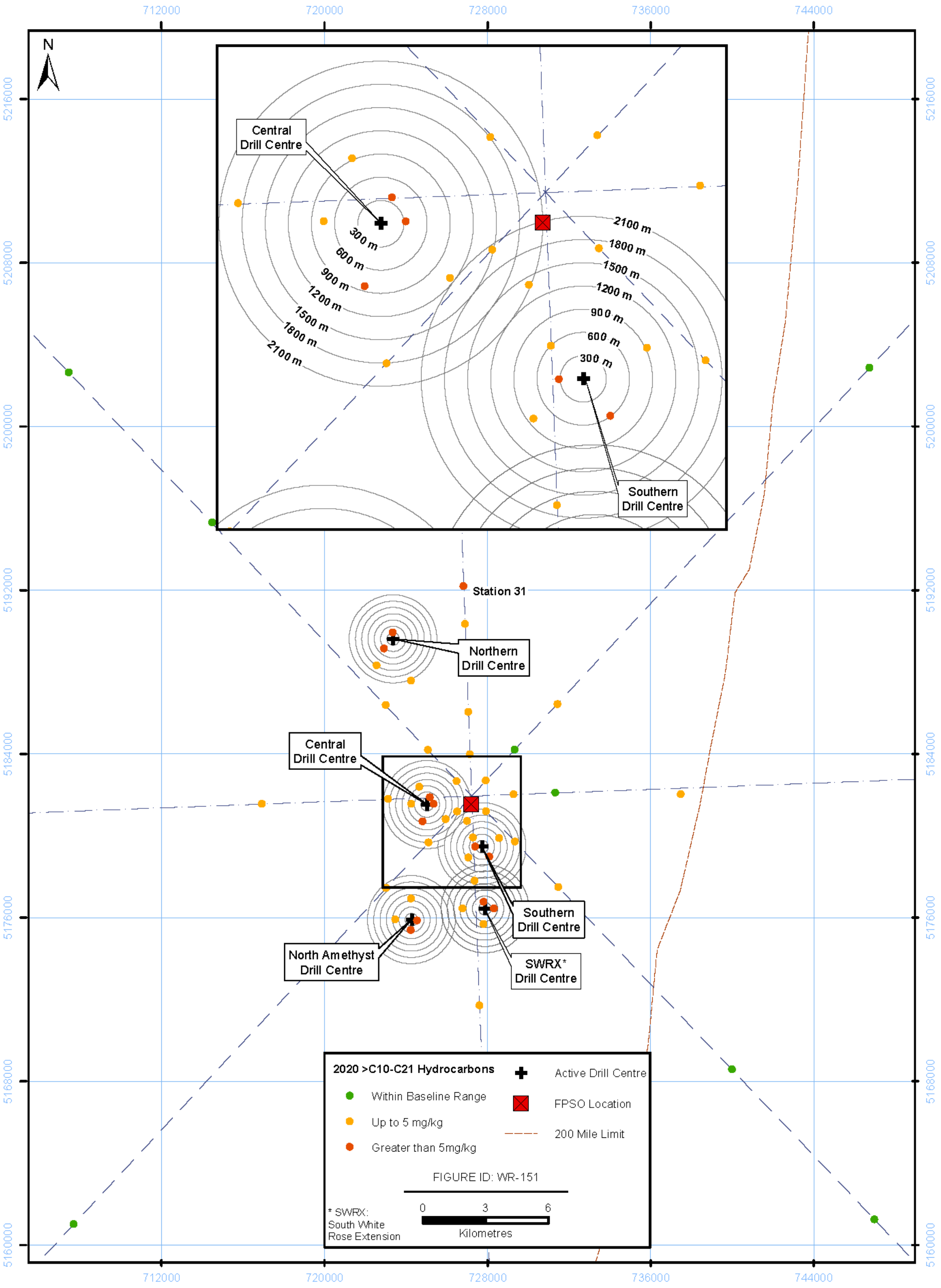

Figure 5-8 Location of Stations with >C_{10}-C_{21} Hydrocarbon Values within the Baseline Range (not detected), Stations Showing Mild Enrichment up to 5 mg/kg, and Stations with Values Greater than 5 mg/kg (2020)

Note: Station 31 is identified in this figure but excluded from other figures and analyses.

Repeated-measures regression indicated no change over time in EEM years in the relationship between distance and concentrations of >C_{10}-C_{21} hydrocarbons for repeated-measures stations (*p* = 0.190; Table 5-6). However, there were significant changes over time in area-wide concentrations (*p* = 0.022), with hydrocarbon levels generally decreasing slightly over time. Overall, 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 Contrast		Before to After Contrast	
Slope	**Mean**	**Slope**	**Mean**
0.190	0.022	NA	NA

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).
- NA = not applicable; the Before to After contrast cannot be performed for >C_{10}-C_{21} hydrocarbons since all concentrations were below detection limit during baseline.

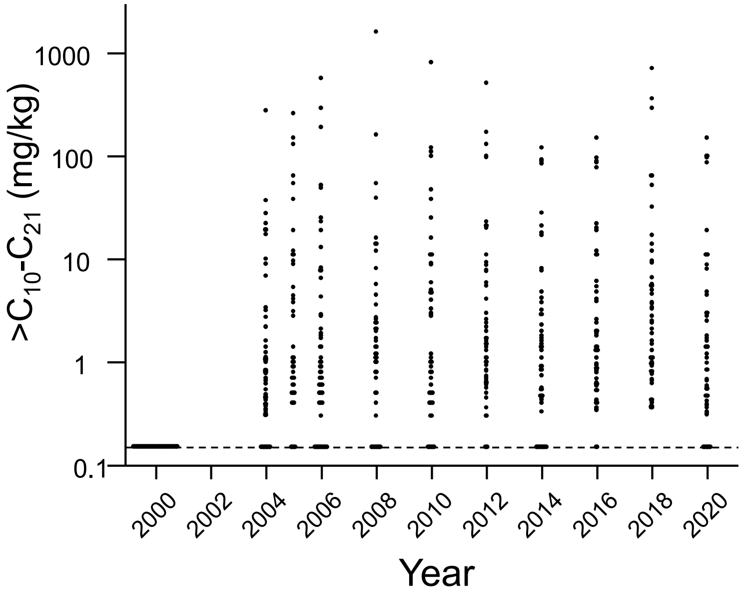

Figure 5-9 Dot Density Plot of >C_{10}-C_{21} Hydrocarbon Values by Year

Note: Station 31 was excluded. 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, sediment barium concentrations were significantly and negatively correlated with distance to active drill centres in 2020 ($\rho_s = -0.810$, $p < 0.001$, All stations; $\rho_s = -0.748$, $p < 0.001$, repeated-measures stations), as in previous EEM years (Figure 5-10).

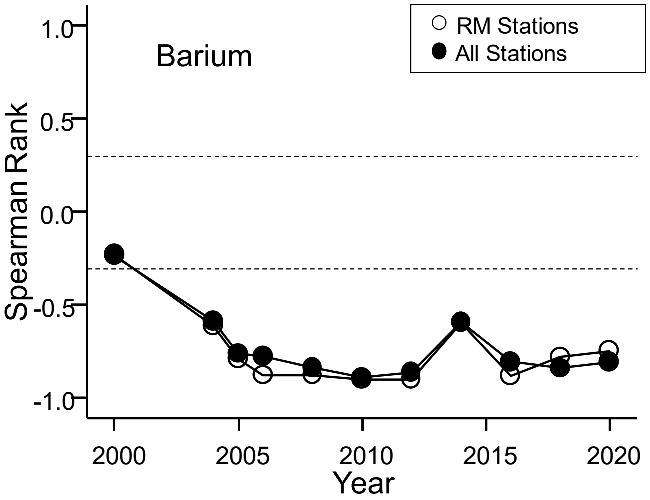

Figure 5-10 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Barium

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 for barium in 2020 was again significant ($p < 0.001$; Appendix A-7). The estimated threshold distance in 2020 was 1.1 km, similar to estimates since 2012 (Table 5-7). 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)
2020	1.1 (0.9 to 1.3)

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

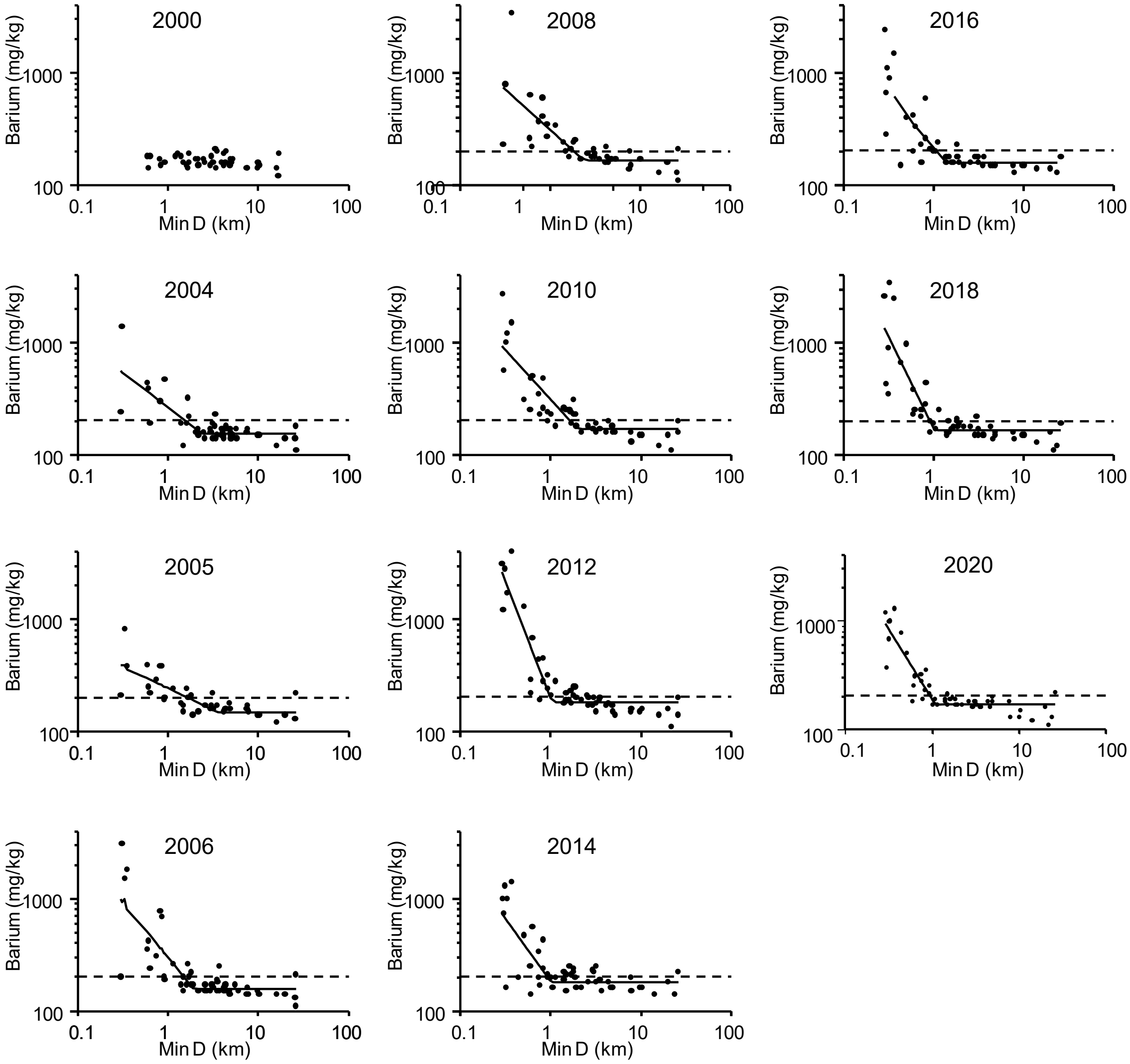

Figure 5-11 Variations in Barium Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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.

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 standard deviations (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).

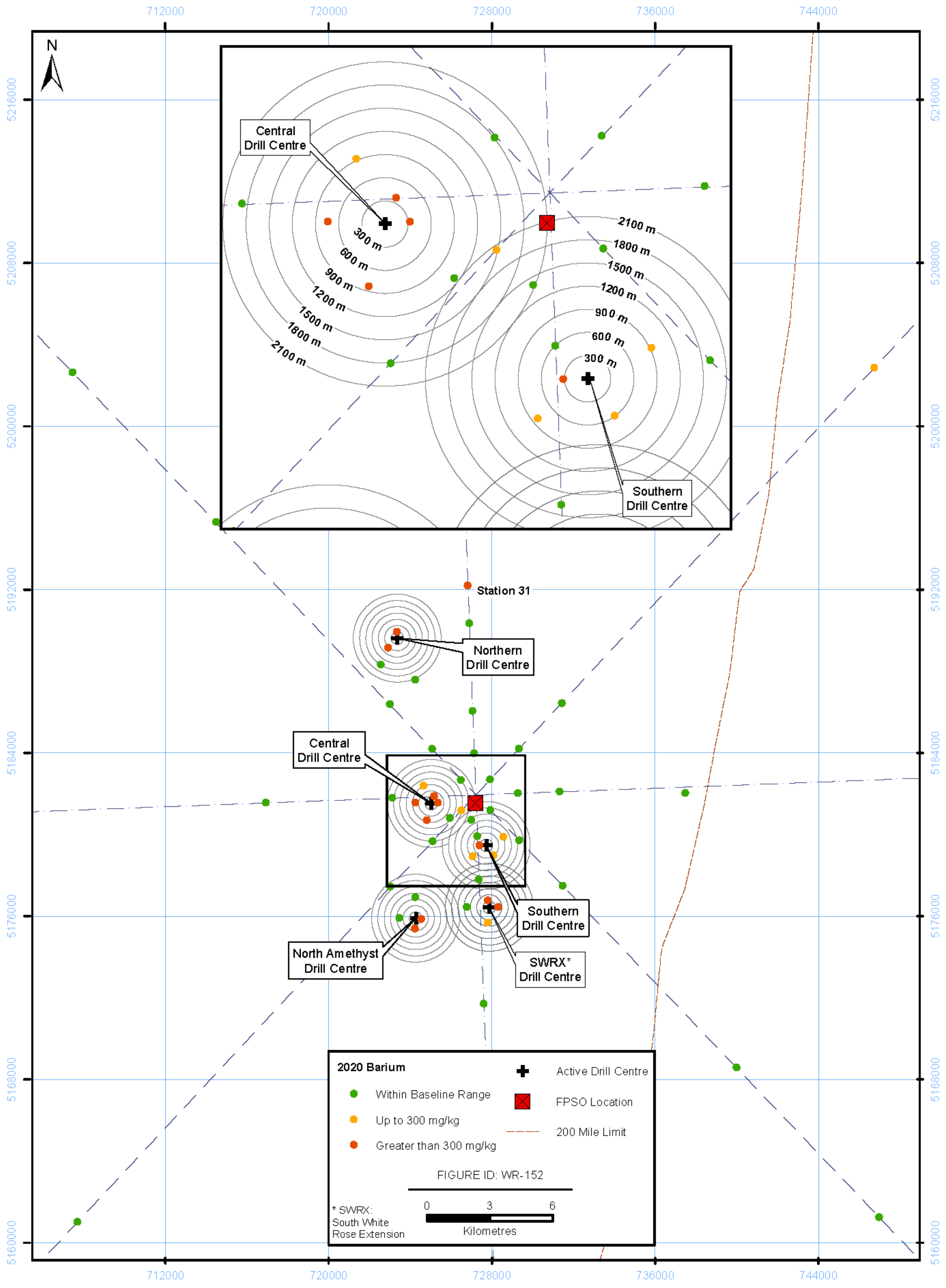

Figure 5-12 **Location of Stations with Barium Levels Within the Baseline Range (up to 202 mg/kg), Stations Showing Mild Enrichment up to 300 mg/kg, and Stations with Values Greater than 300 mg/kg (2020)**

Note: Station 31 is identified in this figure but excluded from other figures and 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* = 0.442; Table 5-8). There was also no change over time in mean barium concentration in EEM years (*p* = 0.446; also see Figure 5-13). Slopes differed from before to after drilling operations began (*p* < 0.001). The correlation between barium and distance to drill centres, although negative, was weak and not significant in 2000. Negative distance correlations (Figure 5-10[15]) have been strong and significant for barium since drilling began. Overall mean barium concentrations have been higher since drilling began in 2004 (*p* < 0.001; Figure 5-13).

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

Trend over Time Contrast		Before to After Contrast	
Slope	Mean	Slope	Mean
0.442	0.446	<0.001	<0.001

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast.

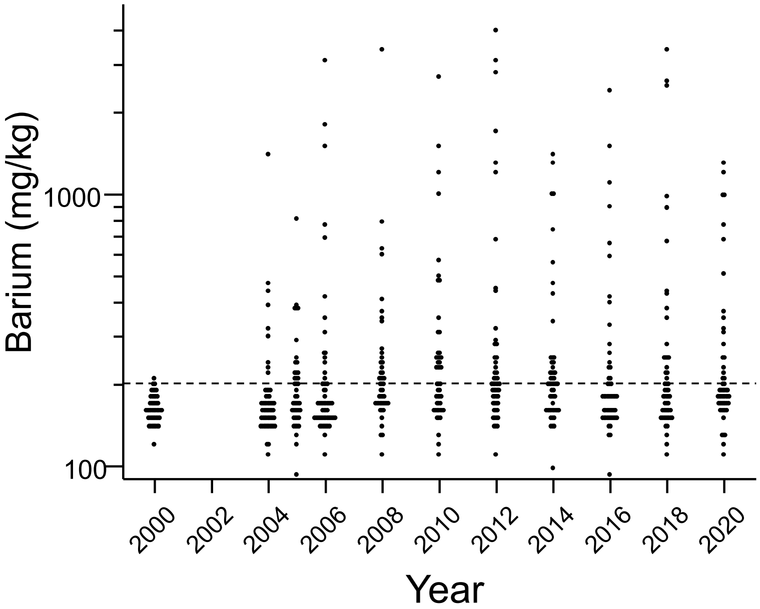

Figure 5-13 Dot Density Plot of Barium Values by Year

Note: Station 31 was excluded. A concentration of 202 mg/kg is indicated by a horizontal line, based on the mean value + 2 SDs using data from the baseline year (2000).

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[15] 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 0.8% and 2.5% across the sampling area in 2020; and the variable was significantly and negatively correlated (*i.e.,* decreased) with distance to drill centres ($\rho_s = -0.433$, $p = 0.001$, All stations; $\rho_s = -0.365$, $p = 0.031$, repeated-measures stations; 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.

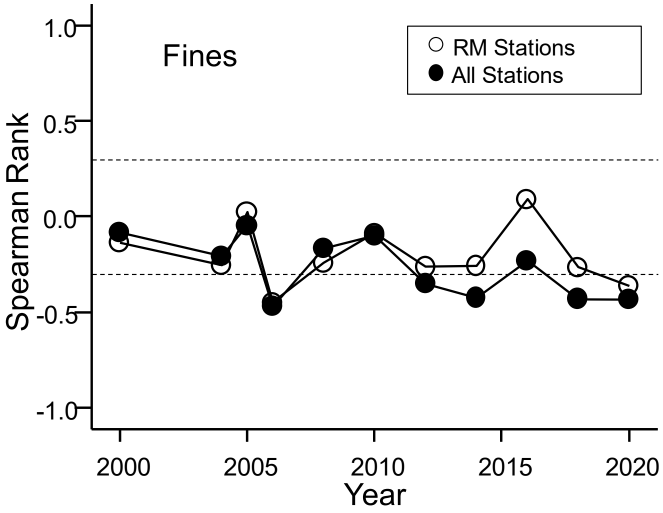

Figure 5-14 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Fines

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. The threshold model for percent fines was significant in 2020 ($p < 0.001$ Appendix A-7), with an estimated threshold distance of 1.3 km (95% confidence limits = 0.60 to 2.5 km). Potential enrichment near drill centres also was noted in other EEM years, particularly since 2010 (Figure 5-15), and the threshold model for fines was also significant in 2014. In 2014, the calculated threshold was 0.7 km (95% confidence limits = 0.4 to 1.2 km).

Consistent with the above, Figure 5-16 indicates that fines were enriched to levels exceeding the baseline range near drill centres in 2020. Fines were also enriched at Station 31, the site of an exploration well, as well as at Station 4, 26.2 km from nearest active drill centres. (Figure 5-16).

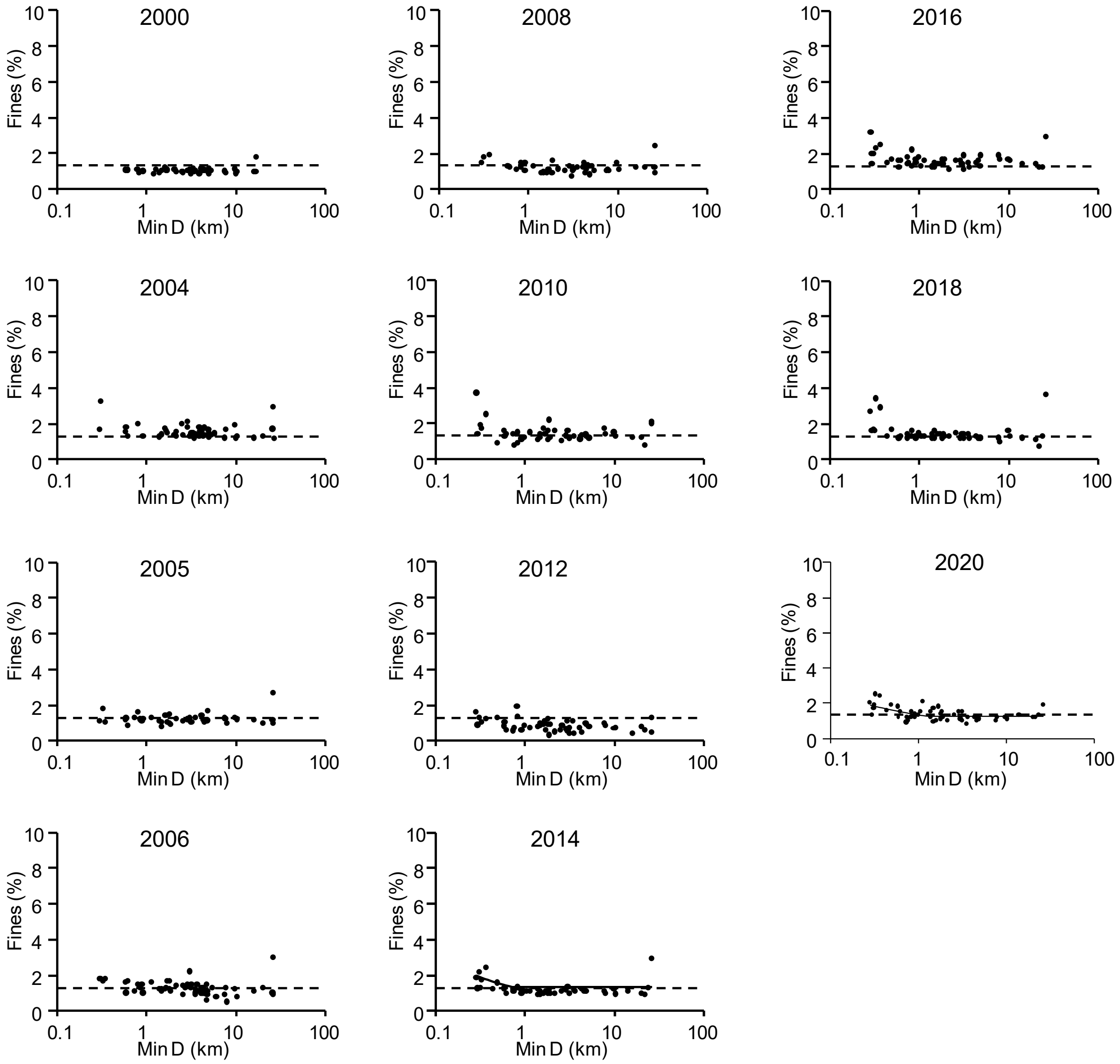

Figure 5-15 Variations in Percent Fines with Distance from the Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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.

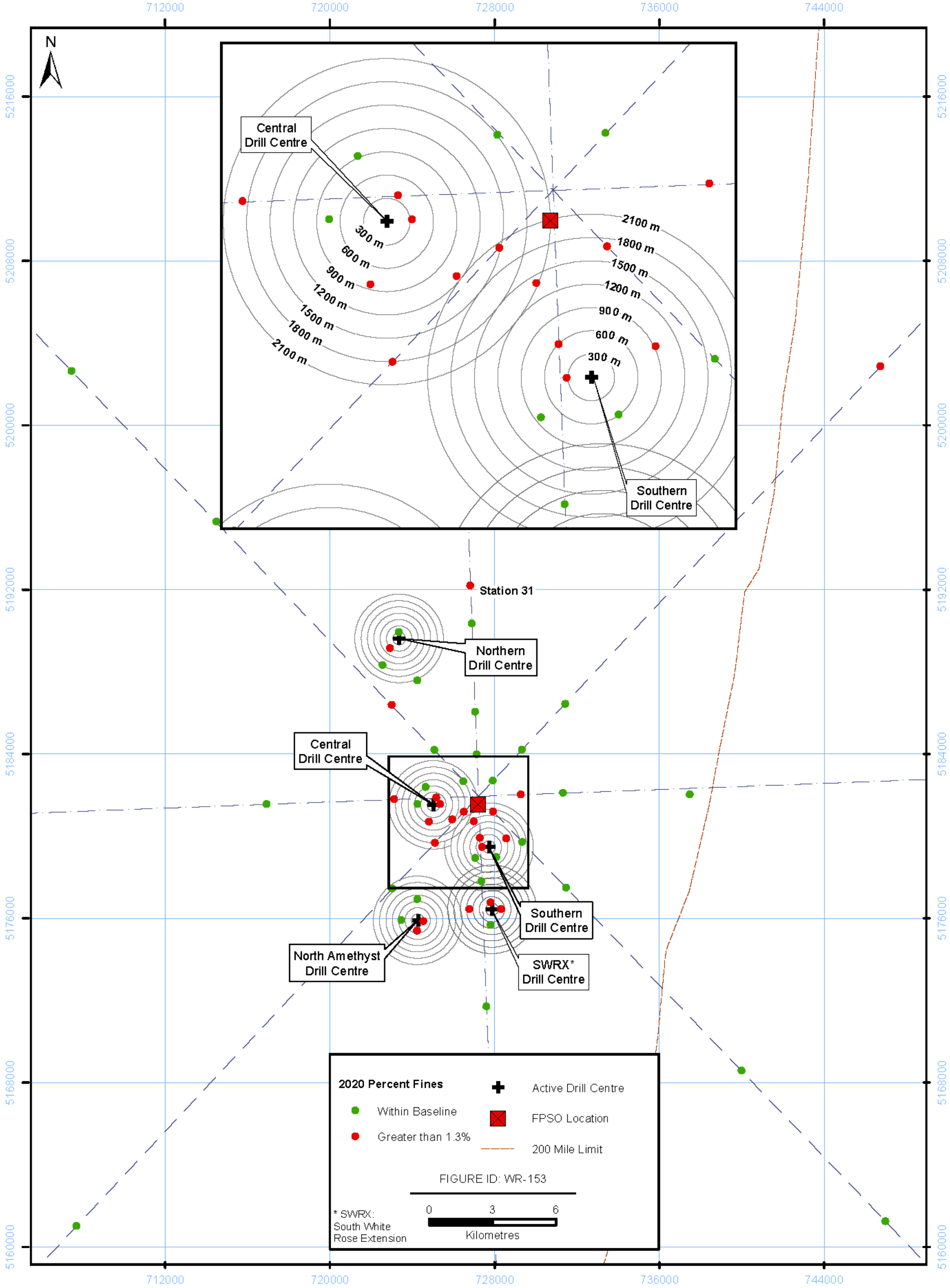

Figure 5-16 Location of Stations with Percent Fines Concentrations (2020) Within and Above the Baseline Range

Note: Station 31 is identified in this figure but excluded from other figures and 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* = 0.213). There was also no change in overall fines levels in EEM years (*p* = 0.283). However, there were significant differences in slopes and overall fines levels from before to after drilling (*p* = 0.044, *p* <0.001, respectively). Slopes were steeper in EEM years (Figure 5-15) indicating enrichment at a few stations near drill centres (Figure 5-15). Overall fines levels were 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 Contrast		Before to After Contrast	
Slope	**Mean**	**Slope**	**Mean**
0.213	0.283	0.044	<0.001

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

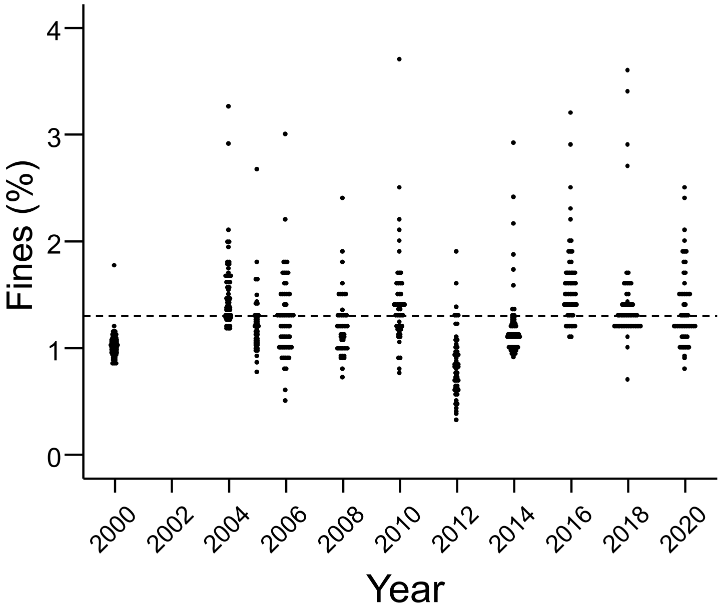

Figure 5-17 Dot Density Plot of Percent Fines by Year

Note: Station 31 was excluded. 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 near drill centres, the more general increase in 2020 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 and negatively correlated with distance from the nearest active drill centre for All Stations in 2020 (ρ_s = -0.345, p = 0.012) but not repeated-measures stations (ρ_s = -0.078, p > 0.05). With all stations considered, these results indicate a significant decrease in organic carbon concentrations with distance from drill centres. Across years, the relationship between organic carbon and distance to drill centres generally has been weak, and the relationship in 2020 was weaker than that noted in 2018 (Figure 5-18).

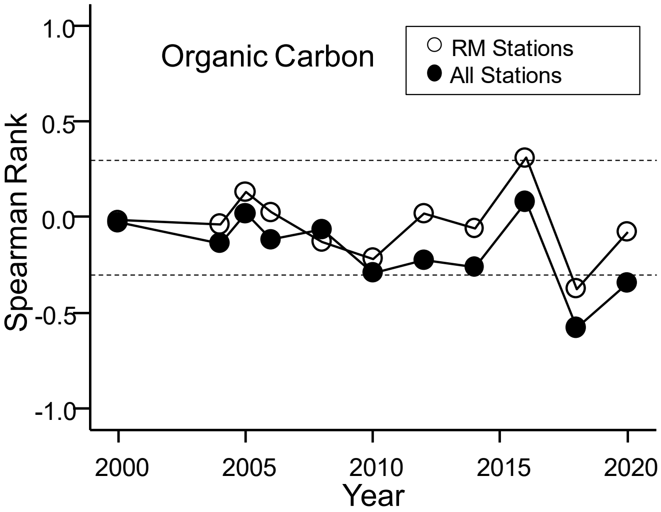

Figure 5-18 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Organic Carbon

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 in 2020 (p < 0.001, Appendix A-7), as it was in 2018 (Figure 5-19). The estimated threshold distance in 2020 was 0.85 km (95% confidence limits = 0.56 to 1.3 km). The estimated threshold in 2018 was 1.0 km (95% confidence limits = 0.70 to 1.4 km). Consistent with these thresholds, enrichment in 2020 was generally limited to stations within approximately 1 km of drill centres, and the majority of remaining stations had organic carbon levels below the upper limit of the baseline range (1.0 g/kg) (Figure 5-20).

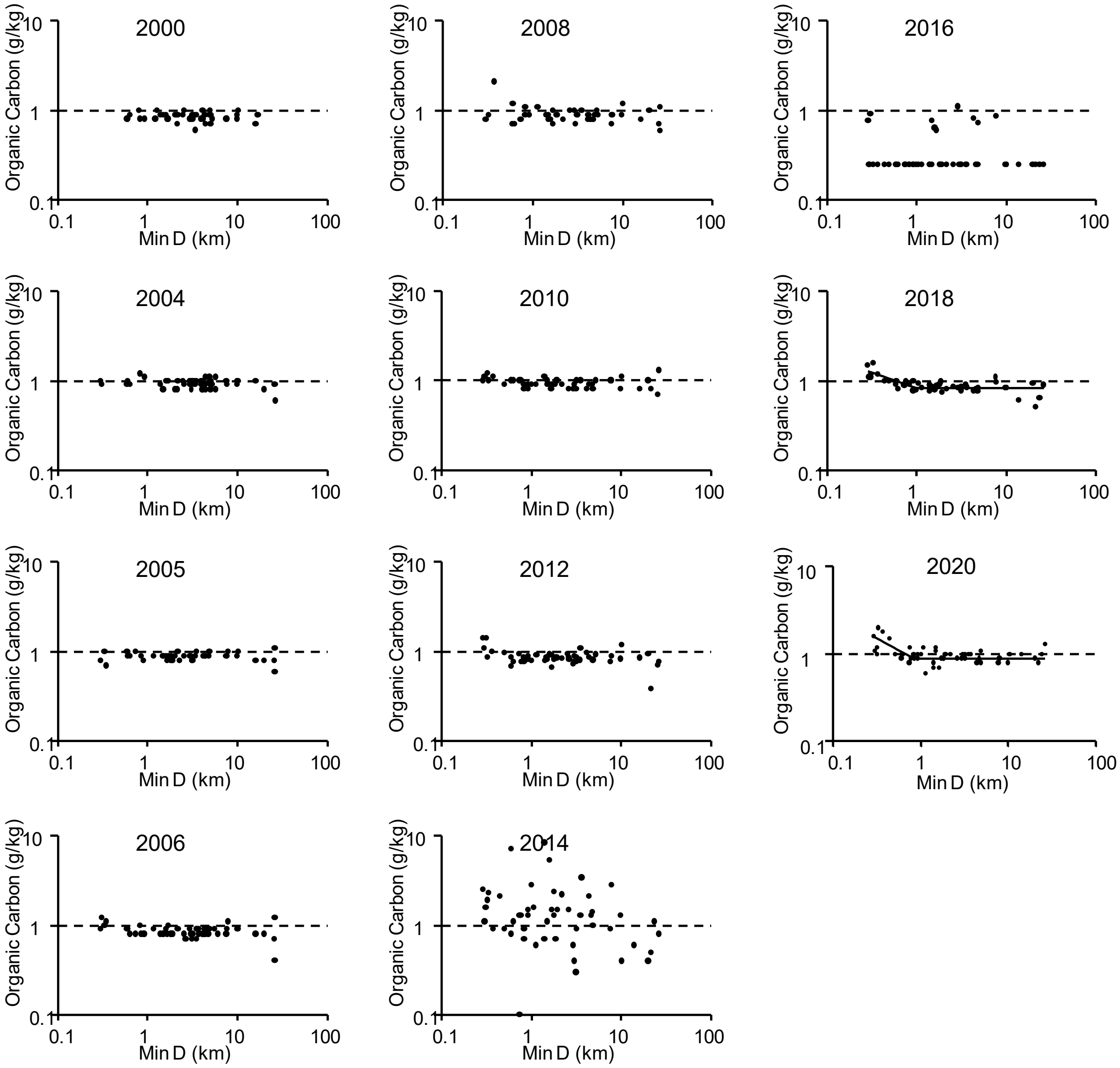

Figure 5-19 Variations in Organic Carbon with Distance from the Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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 2015 for details).

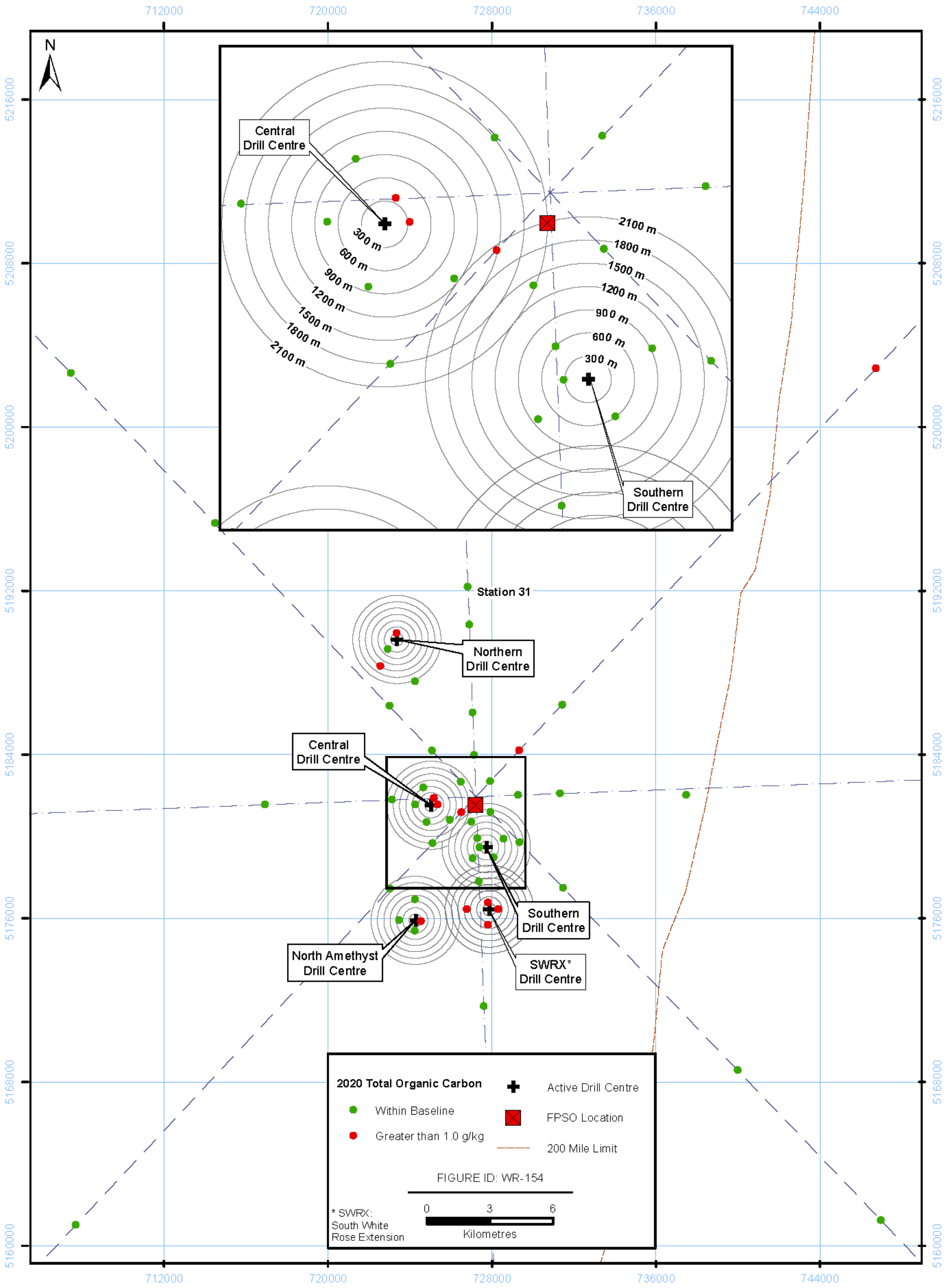

Figure 5-20 Location of Stations with Organic Carbon Concentrations (2020) Within and Above the Baseline Range

Note: Station 31 is identified in this figure but excluded from other figures and 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 = 0.729). There was also no change in slopes from before to after drilling (p = 0.549). Mean values significantly varied (p < 0.001) over time in EEM years, but with no change from before to after drilling began (p = 0.560). The significant difference in overall organic carbon values in EEM years was primarily due to the influence of 2014 and 2016 data. 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 Contrast		Before to After Contrast	
Slope	**Mean**	**Slope**	**Mean**
0.729	<0.001	0.549	0.560

Notes:
- Values are probabilities.
- n = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

A dot density plot of organic carbon concentration by year is provided in Figure 5-21. Twelve samples in 2020 were above the baseline range.

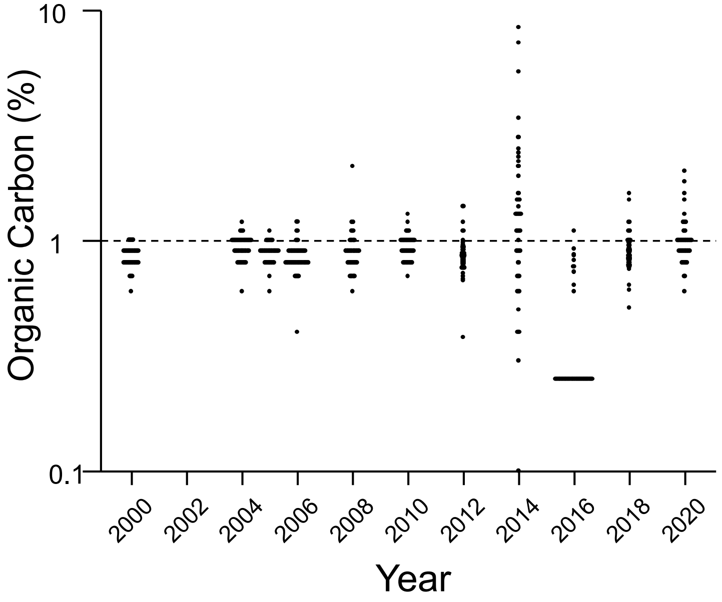

Figure 5-21 Dot Density Plot of Total Organic Carbon by Year

Note: Station 31 was excluded. 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 2015 for details).

5.2.1.5 Ammonia

Ammonia concentrations were generally less than 10 mg/kg in EEM years. Concentrations were significantly and negatively correlated (*i.e.*, decreased) with distance from the nearest active drill centre in 2020 when all stations were considered (ρ_s = -0.477, $p < 0.001$, All stations). However, the relationship was not significant when only repeated-measures stations were considered (ρ_s = -0.228, $p > 0.05$; Figure 5-22). A threshold model describing the relationship between concentrations of ammonia and distance from the nearest active drill centre was significant in 2020 ($p < 0.001$; Appendix A-7). The estimated threshold distance was 5.0 km (95% confidence limits = 0.90 to 27 km). In general, wide confidence limits around threshold estimates indicate a poor model fit and suggest that the threshold estimate might be unreliable and or/that the threshold model provides little improvement over a simple bivariate model (Figure 5-23; also see Appendix A-7 for details). Despite the significant threshold distance, any increase in ammonia near drill centres was subtle (Figure 5-23) and all stations were below the upper limit of the background range of 12.2 mg (Figure 5-24).

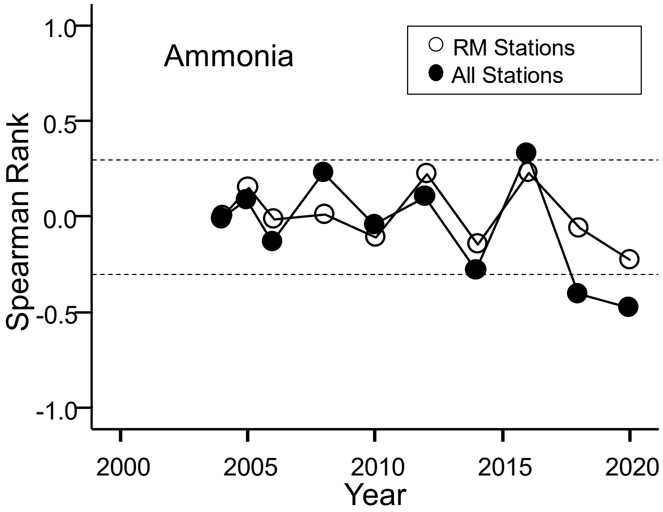

Figure 5-22 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Ammonia

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.

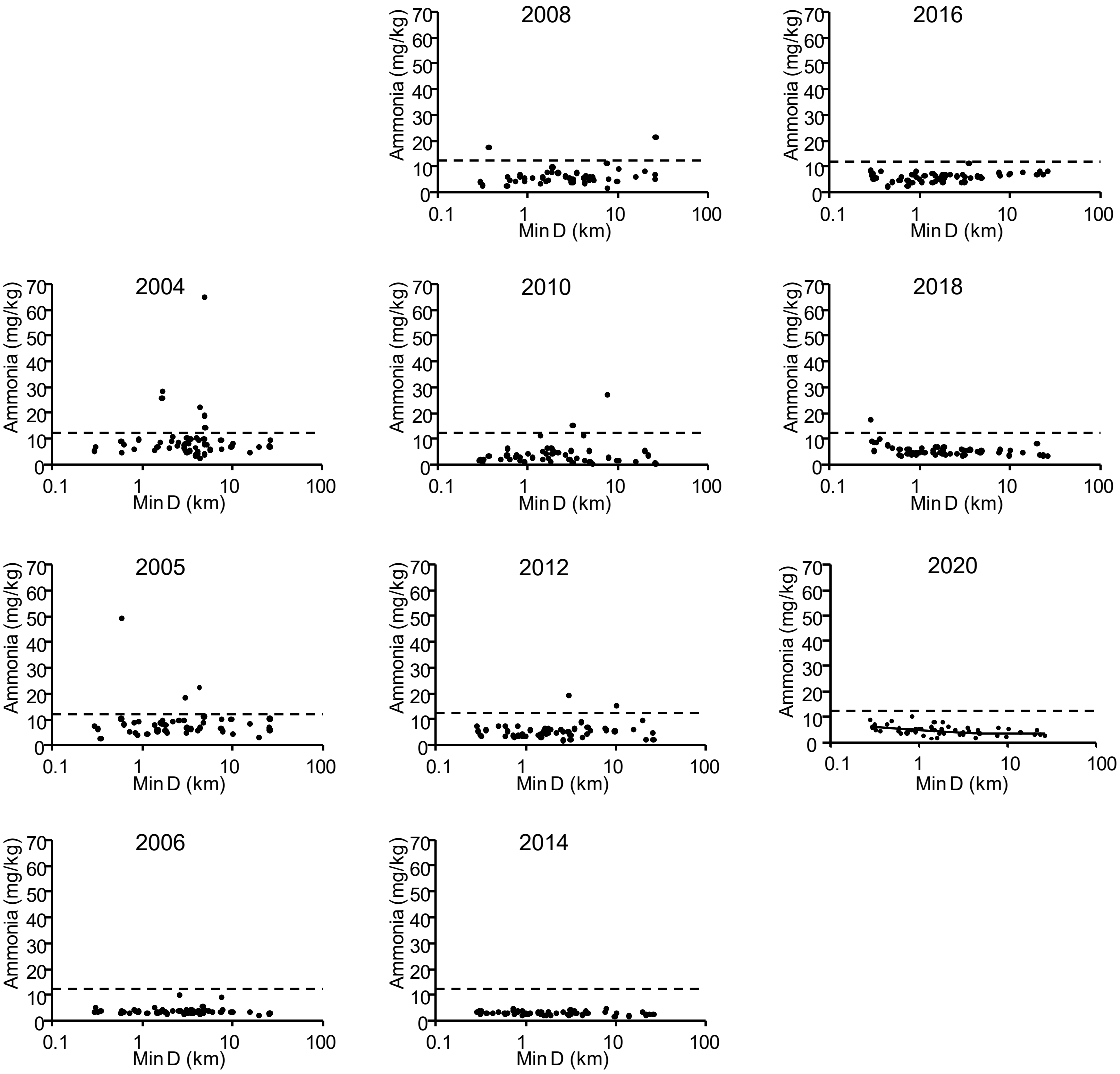

Figure 5-23 Variations in Ammonia Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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).

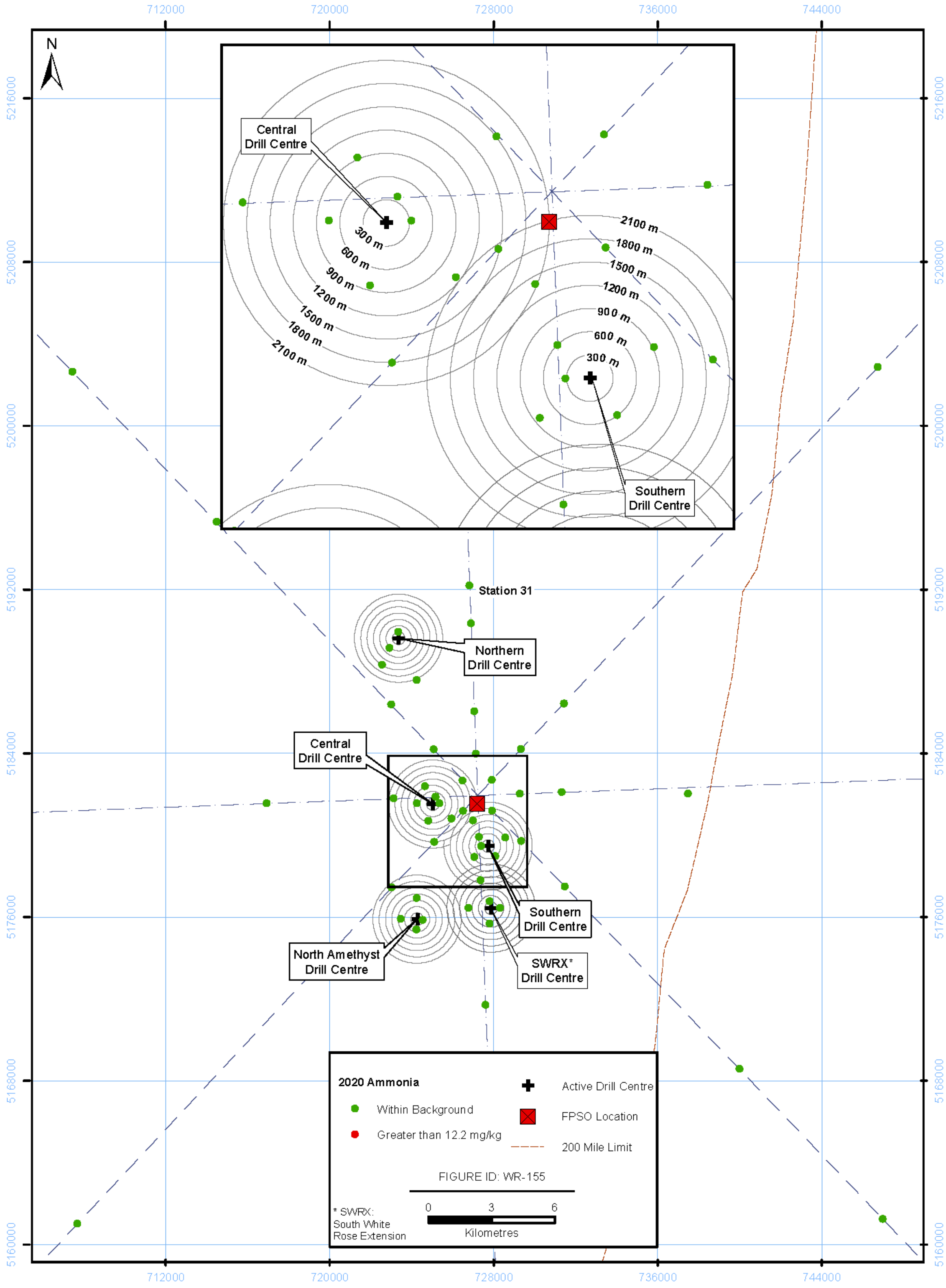

Figure 5-24 Location of Stations with Ammonia Concentrations (2020) Within and Above the Background Range

Note: Station 31 is identified in this figure but excluded from other figures and analyses.

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* = 0.178), but there was significant change over time in mean concentrations across the sampling area (*p* < 0.001, Table 5-11). Concentrations generally decreased over time (Figure 5-25).

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

Trend over Time Contrast		Before to After Contrast	
Slope	Mean	Slope	Mean
0.178	<0.001	NA	NA

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

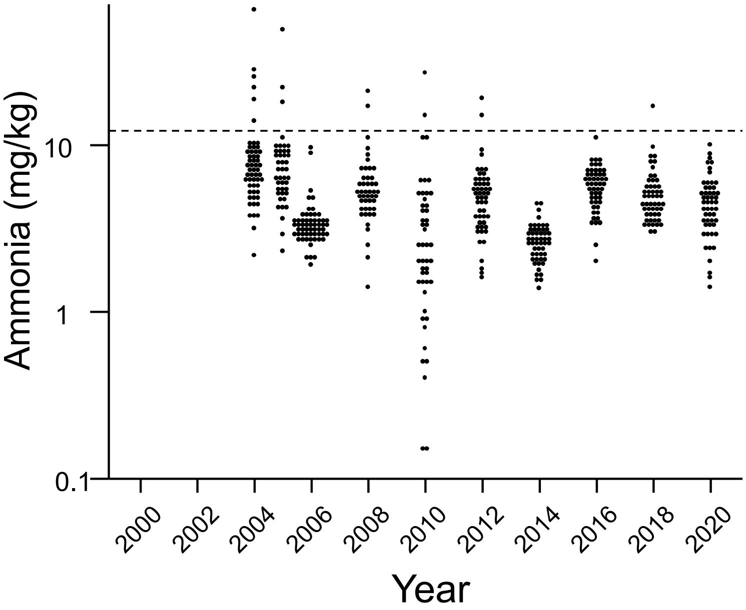

Figure 5-25 Dot Density Plot of Ammonia Concentrations by Year

Note: Station 31 was excluded. 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 2020, 81% of sulphide values were below the laboratory detection limit. 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 2020 (ρ_s = -0.111, $p > 0.05$, All Stations; ρ_s = -0.119, $p > 0.05$ repeated-measures stations) (Figure 5-26).

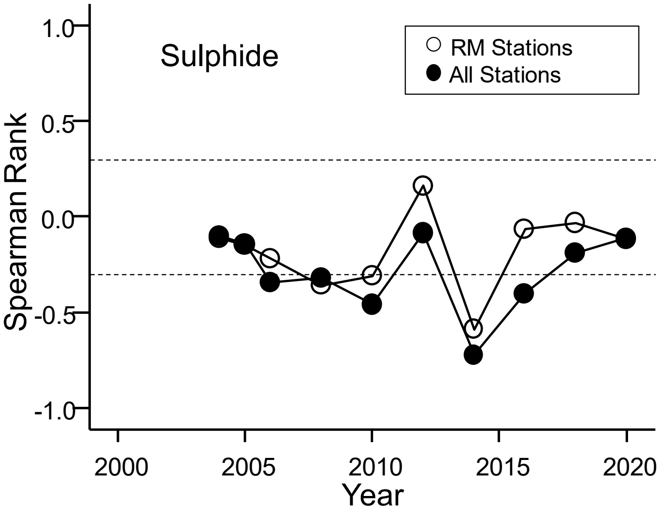

Figure 5-26 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Sulphide

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. Threshold models were significant for sulphide in 2006 and 2008. The threshold in 2006 was 1.05 km (95% confidence limits = 0.74 to 1.49 km). The threshold in 2008 was 1.01 km (95% confidence limits = 0.64 to 1.59 km). In 2020, two stations within 0.5 km from drill centres had sulphide concentrations elevated above background.

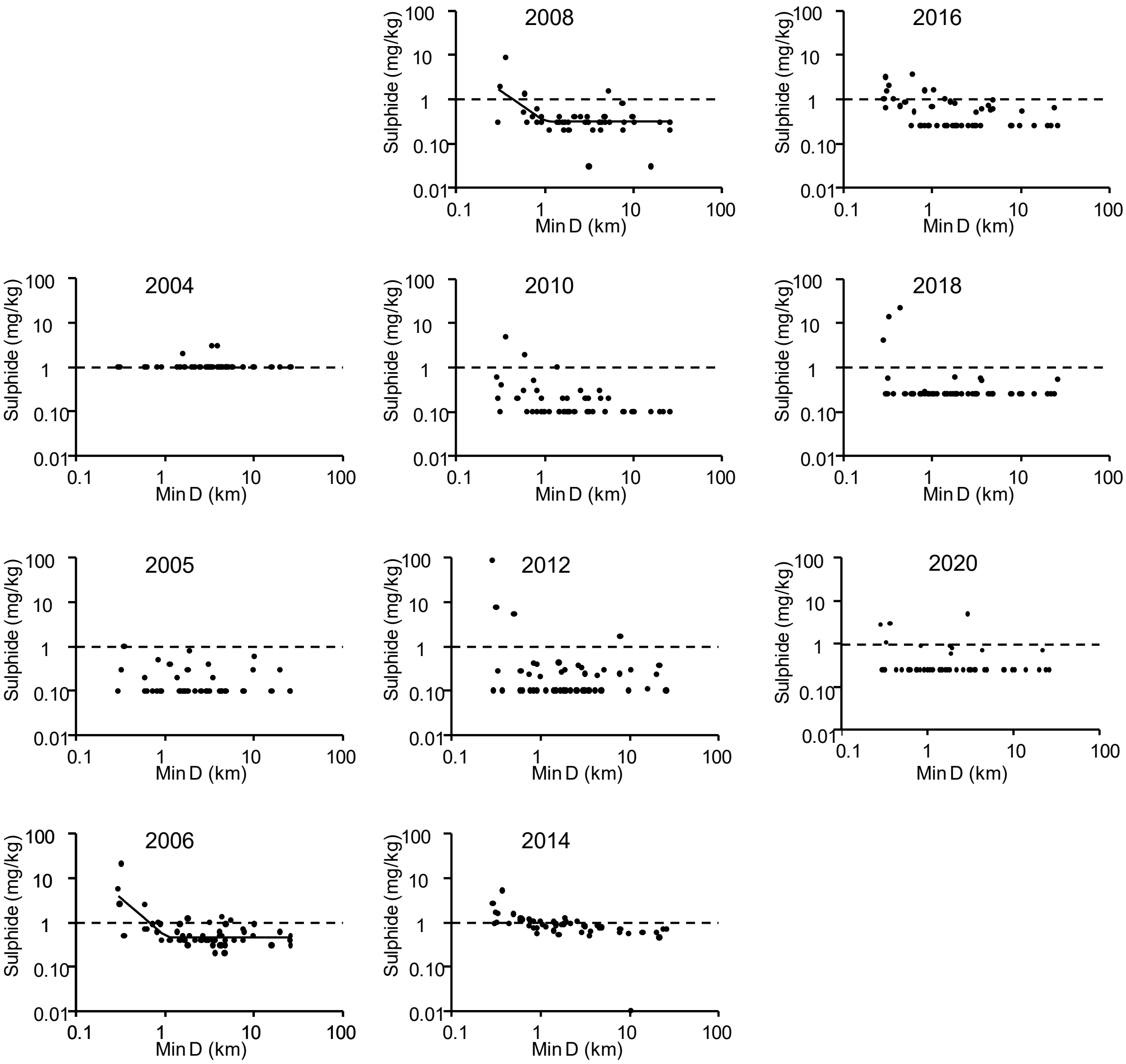

Figure 5-27 Variations in Sulphide with Distance from the Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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 of the relationship between sulphide concentrations and distance from active drill centres in EEM years for repeated-measures stations (*p* = 0.034). For these stations, there was no relationship between sulphide concentrations and distance in 2005, 2006, 2012, 2016, 2018, or 2020; 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 Contrast		Before to After Contrast	
Slope	Mean	Slope	Mean
0.034	NA	NA	NA

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).
- The Before to After Contrast cannot be performed for sulphides because these were not measured during baseline.

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

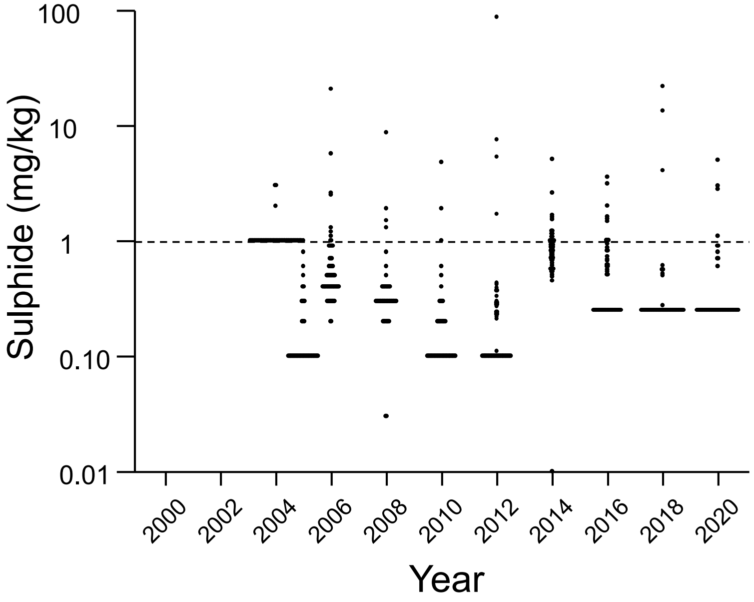

Figure 5-28 Dot Density Plot of Sulphide Concentrations by Year

Note: Station 31 was excluded. 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 when all stations were considered in 2020 (ρ_s = -0.565, p < 0.001). However, distance correlations were not significant when repeated-measures stations were considered (ρ_s = -0.210, p > 0.05; Figure 5-29).

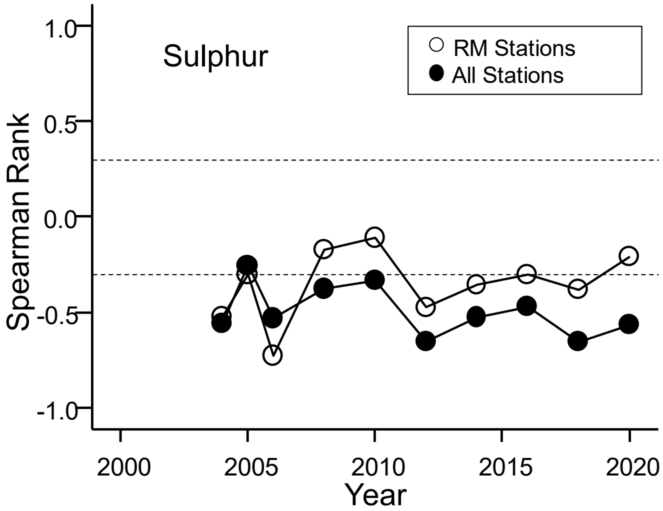

Figure 5-29 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Sulphur

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.

Despite the significant Spearman rank correlation when all stations were considered, the threshold model was not able to estimate a reliable threshold for sulphur in 2020 (Appendix A-7). Figure 5-30 provides a graphical representation of sulphur concentrations with distance from the nearest active drill centre. In 2020, five stations within 0.5 km from drill centres had concentrations elevated above background (Figure 5-31).

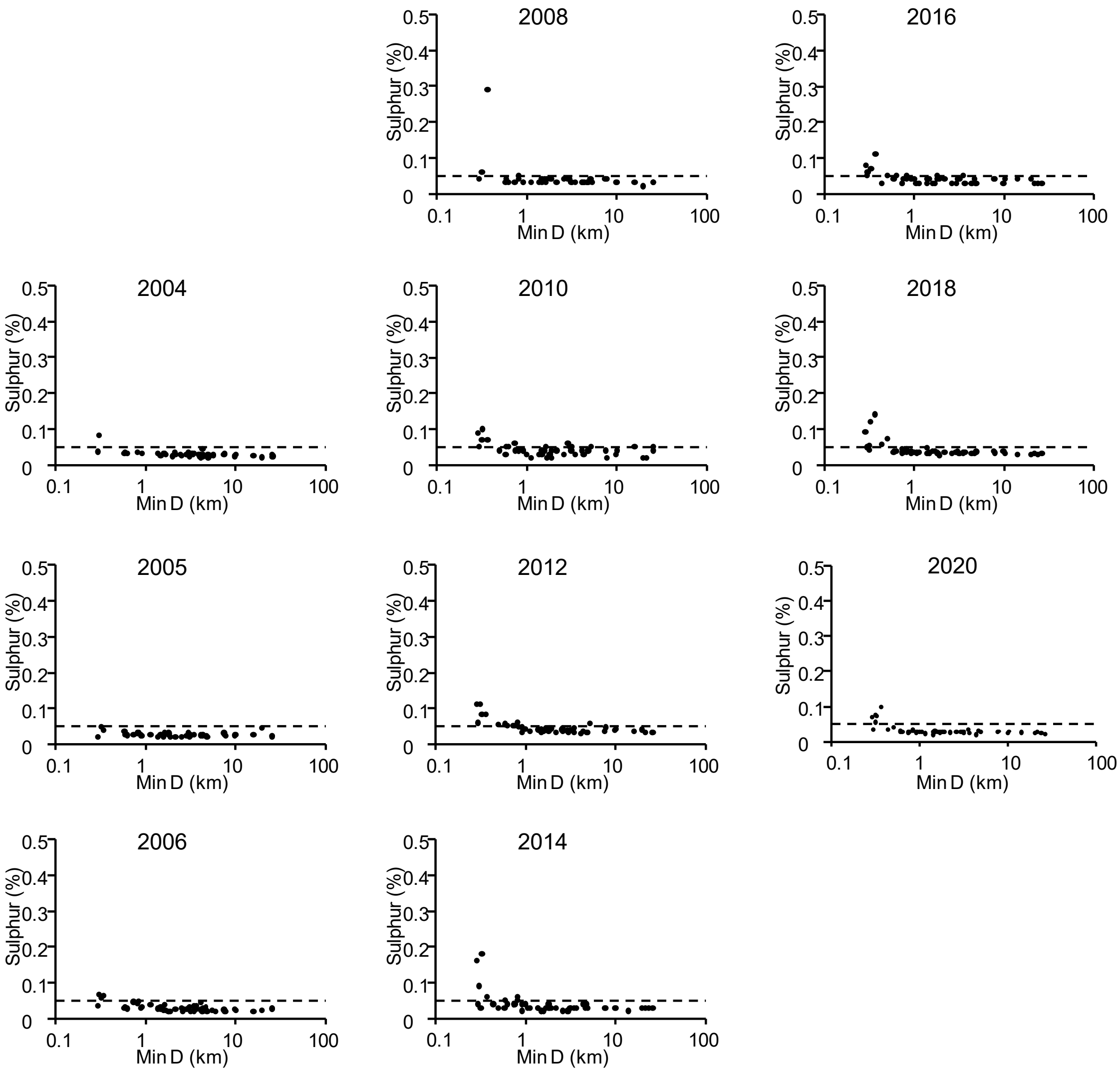

Figure 5-30 Variations in Sulphur Concentrations with Distance from the Nearest Active Drill Centre (all Years)

Note: Station 31 was excluded. 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).

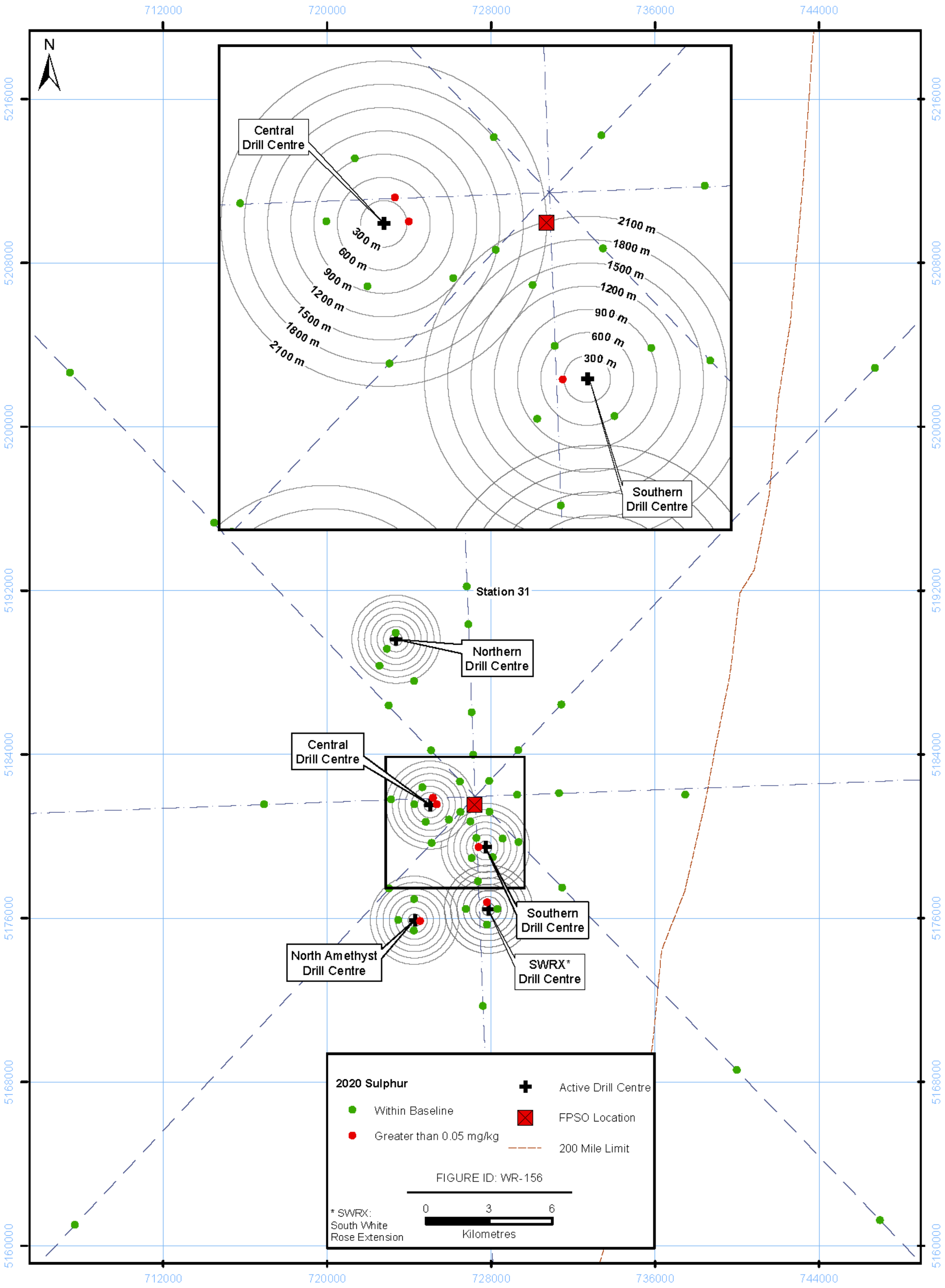

Figure 5-31 Location of Stations with Sulphur (2020) Within and Above the Background Range

Note: Station 31 is identified in this figure but excluded from other figures and 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 ($p = 0.725$). There was a significant linear change in mean sulphur concentrations in the overall sampling area ($p < 0.001$). Sulphur concentrations in sediment have generally increased over time. However, 2020 concentrations were similar to those noted earlier EEM years (Figure 5-32).

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

Trend over Time Contrast		Before to After Contrast	
Slope	**Mean**	**Slope**	**Mean**
0.725	<0.001	NA	NA

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

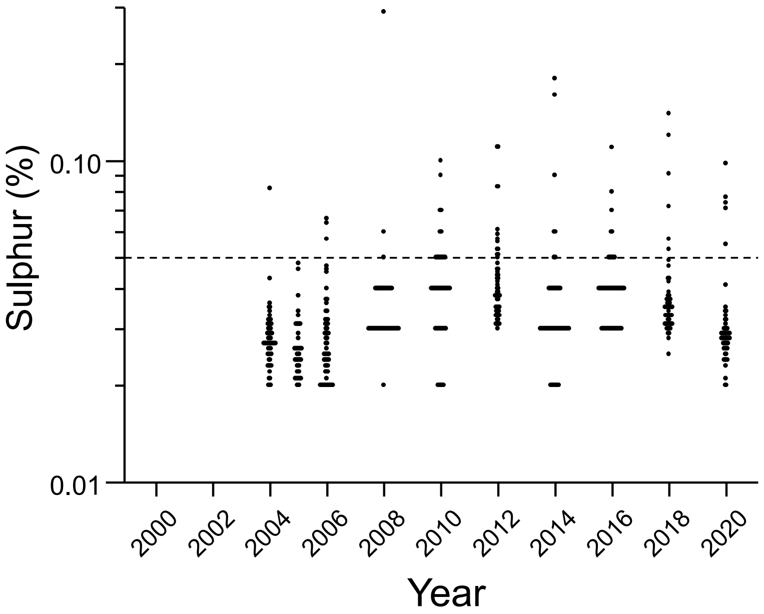

Figure 5-32 Dot Density Plot of Sulphur Concentrations by Year

Note: Station 31 was excluded. 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 except aluminum were strongly associated with the first PCA axis, and all correlations were positive, indicating that these metals all increased 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	0.328	0.320
Chromium	**0.648**	0.168
Iron	**0.899**	0.247
Lead	**0.568**	**-0.738**
Manganese	**0.851**	0.361
Strontium	**0.673**	**-0.671**
Uranium	**0.651**	-0.09
Vanadium	**0.845**	0.22
Percent Variance Explained	49.7	17.2

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

Metals PC1

Metals PC1 scores were not significantly correlated with distance from the nearest active drill centre in 2020 ($\rho_s = -0.231$, $p > 0.05$, All stations; ($\rho_s = -0.012$, $p > 0.05$, repeated-measures stations; Figure 5-33)

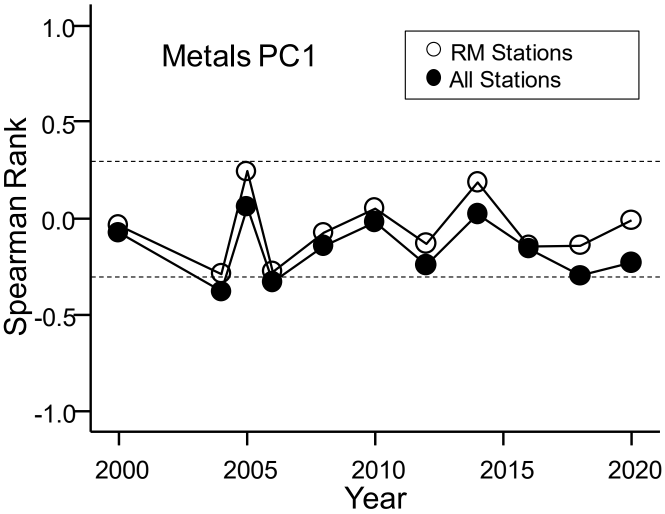

Figure 5-33 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Metals PC1

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.

Figures 5-34 and 5-35 provide a graphical representation of Metals PC1 scores with distance from active drill centres. In 2020, metals PC1 scores were above background average at two stations within 0.5 km from drill centres. The Metals PC1 score was also elevated at one station more than 10 km from drill centres.

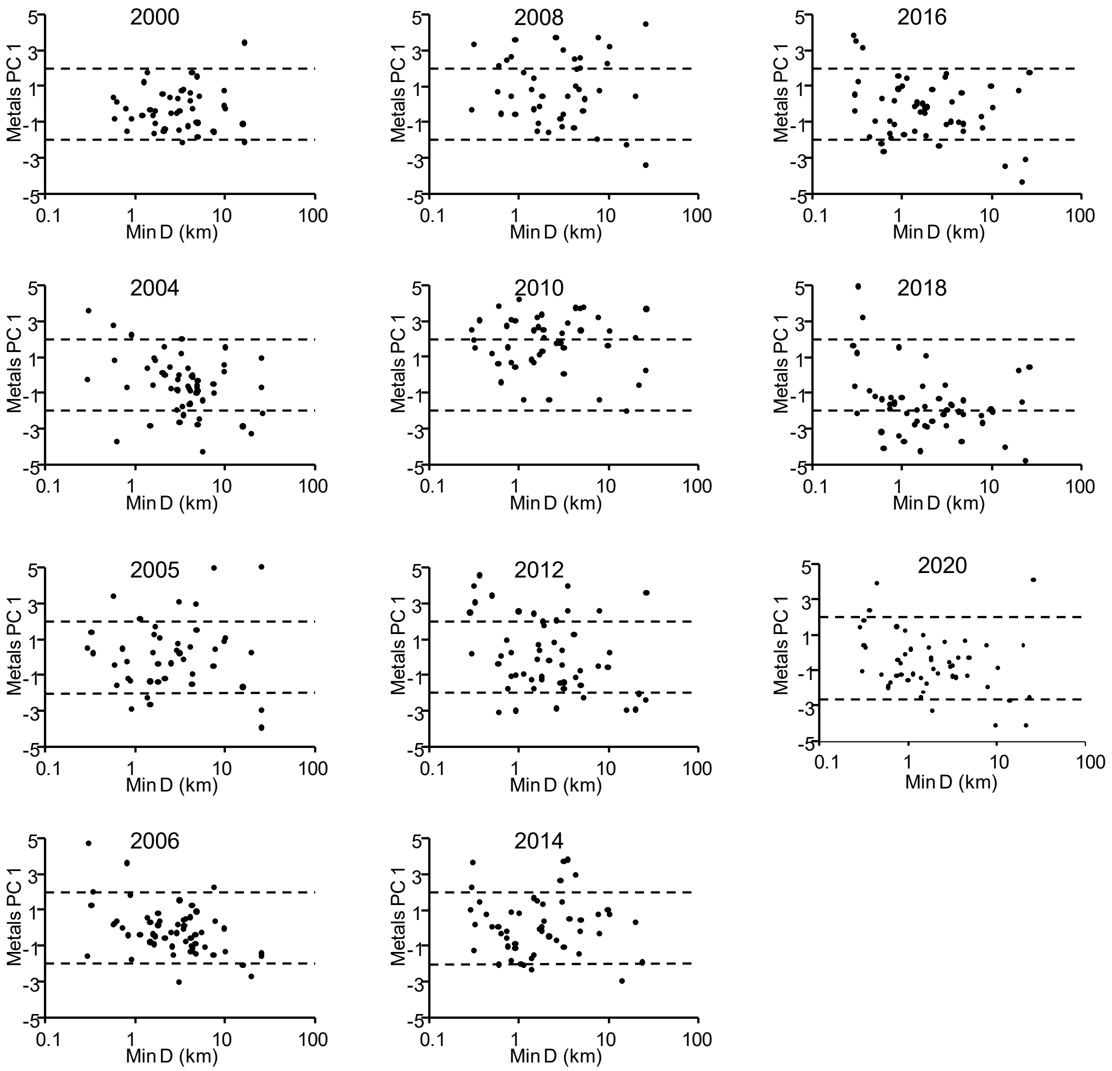

Figure 5-34 Variations in Metals PC1 Scores with Distance from the Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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.

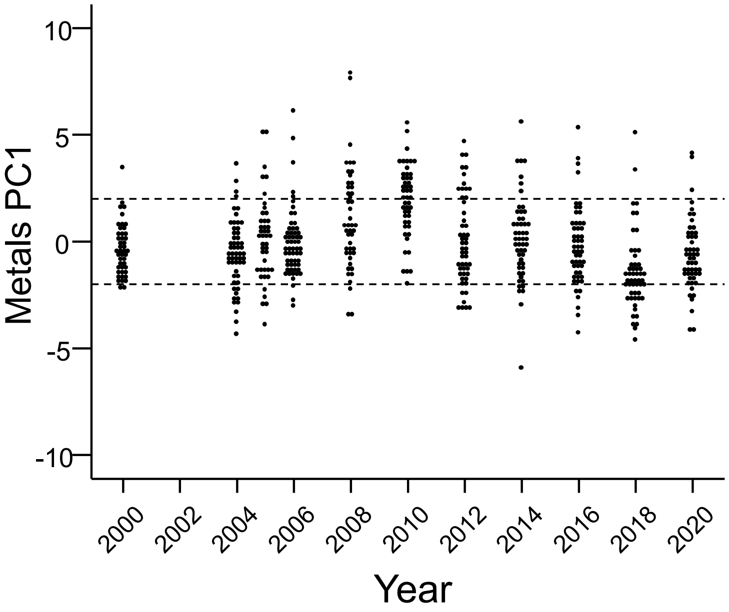

Figure 5-35 Dot Density Plot of Metals PC1 Scores by Year

Note: Station 31 was excluded. Background PC1 scores are indicated by a horizontal line, based on the mean values ± 2 SDs using data from the baseline year (2000).

Repeated-measures regression (Table 5-15) indicated that there was no change in the slope of the relationship between Metals PC1 scores and distance to the nearest active drill centre in EEM years for repeated-measures stations ($p = 0.165$), and no change in slope from before to after drilling began ($p = 0.346$). There also were no differences in mean PC1 axis scores from before to after drilling began ($p = 0.671$). However, there was a significant linear trend in mean values in EEM years ($p < 0.001$), with values generally decreasing in EEM years. The dot density graph of scores (Figure 5-35) illustrates that Metals PC1 scores in 2020 generally were within the baseline range of variation for scores in 2000.

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

Trend over Time Contrast		Before to After Contrast	
Slope	Mean	Slope	Mean
0.165	< 0.001	0.346	0.671

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

Lead

Lead concentrations in sediments were negatively correlated with distance to the nearest active drill centre in 2020 ($\rho_s = -0.543$, $p < 0.001$, All stations; $\rho_s = -0.494$, $p = 0.002$, repeated-measures stations) (Figure 5-36). A threshold model explained significant variation in distance relationships from 2006 to 2020 ($p < 0.001$ in 2020, Appendix A-7), with threshold distances typically near 1 km (Table 5-16; Figure 5-37). In 2020, lead was enriched above the baseline range around the Central, North Amethyst, SWRX, and Southern Drill Centres (Figure 5-38).

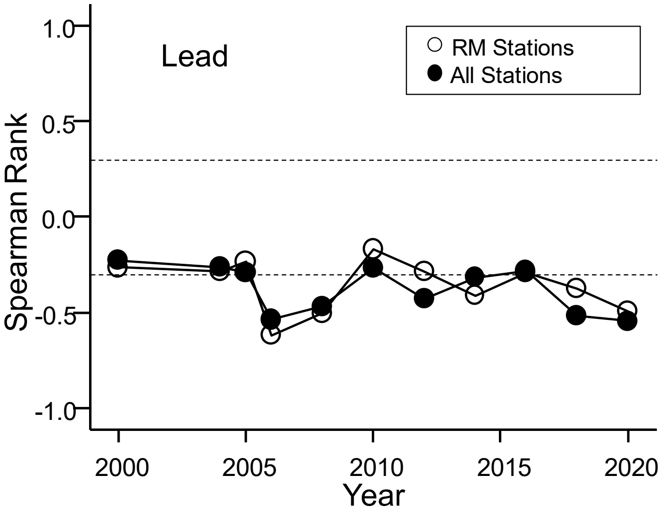

Figure 5-36 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Lead

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	0.8 (0.6, 1.2)
2020	0.8 (0.6, 1.2)

Notes:
- 95% confidence limits are provided in brackets.
- $n = 52$ in 2020 with Station 31 excluded.

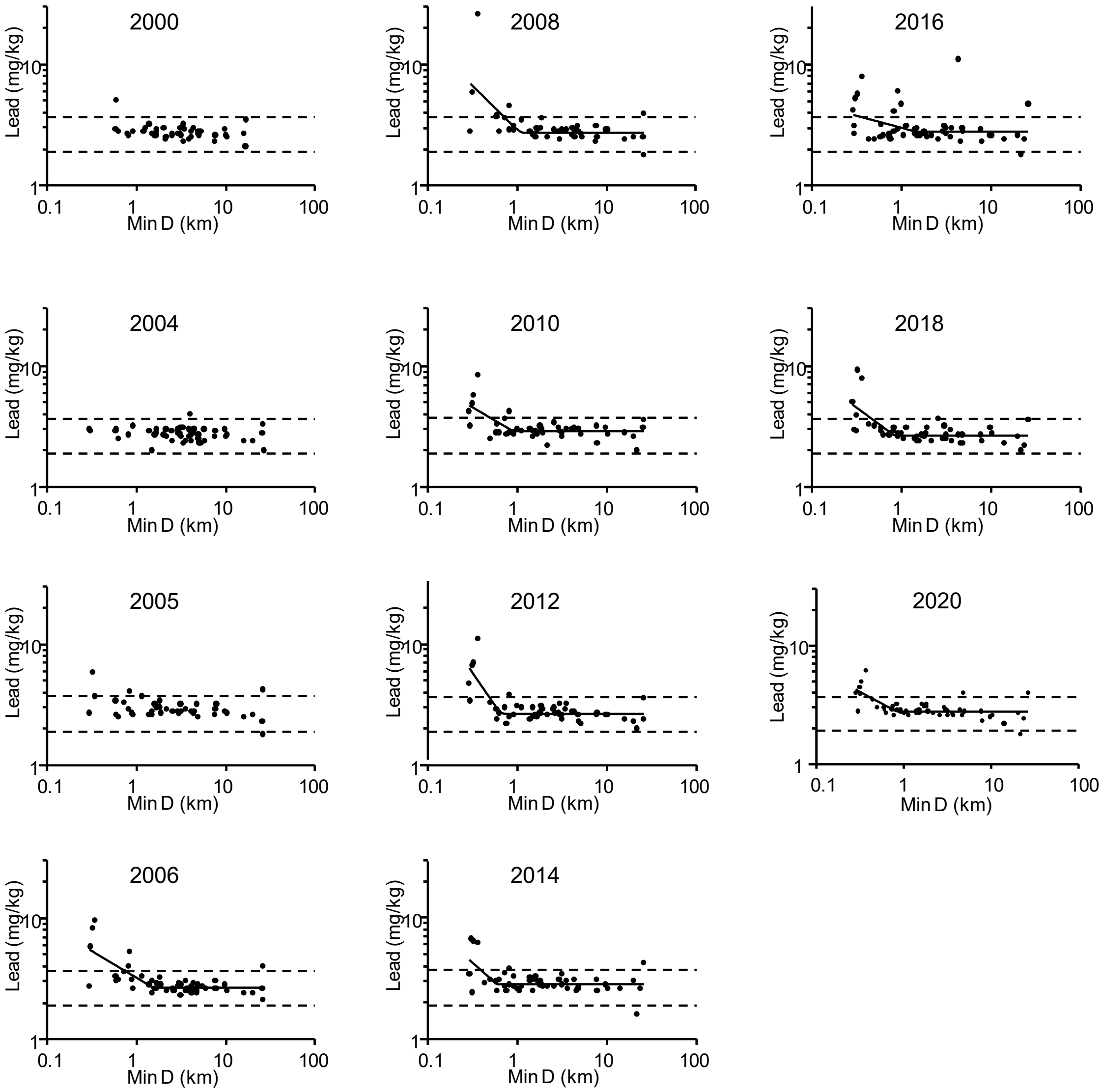

Figure 5-37 Variations in Lead with Distance from the Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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.

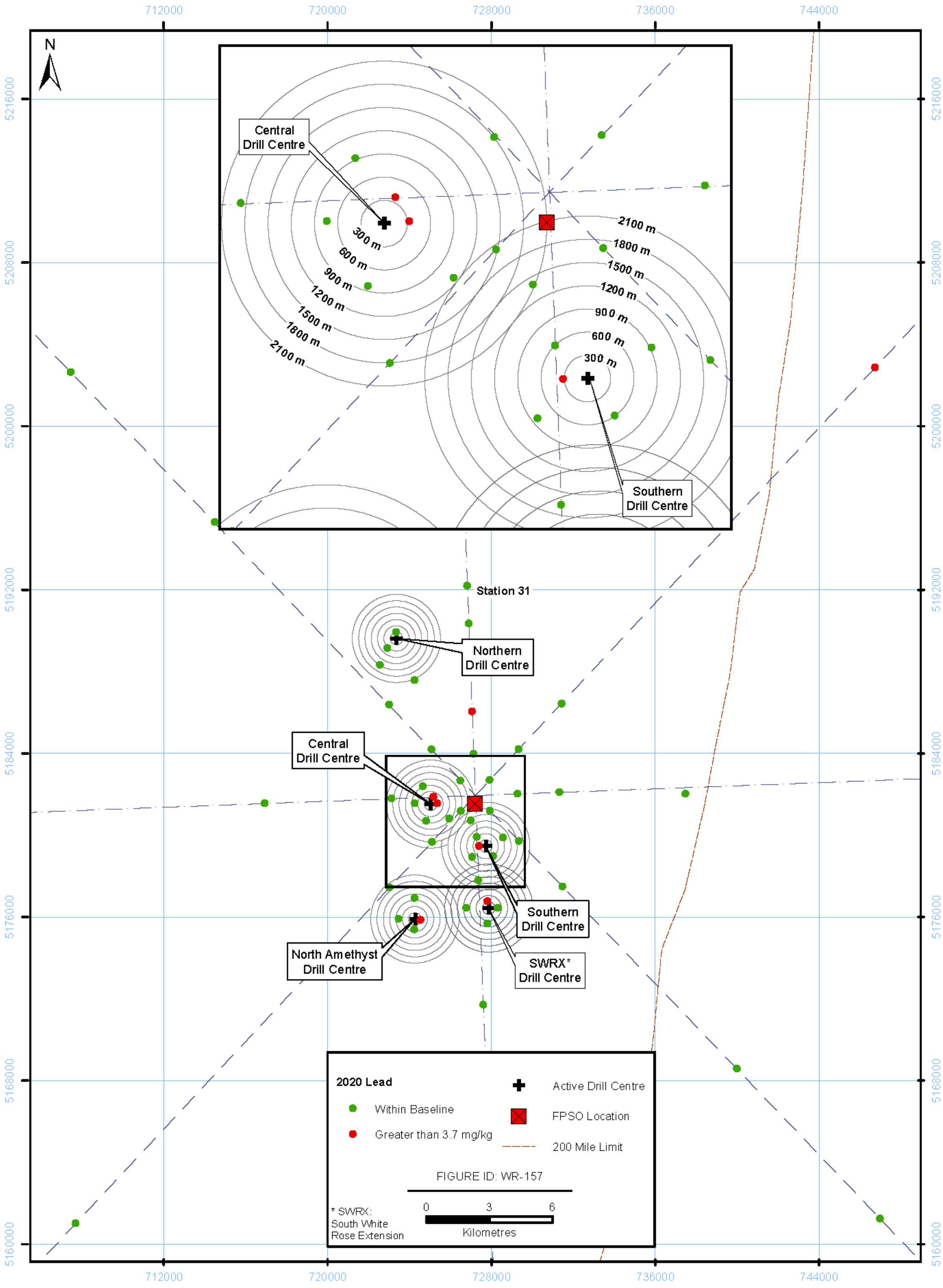

Figure 5-38 **Location of Stations with Lead (2020) Within and Above the Baseline Range**

Note: Station 31 is identified in this figure but excluded from other figures and analyses.

Repeated-measures regression (Table 5-17) indicated that there was no change in the slope of the relationship between lead concentration and distance to the nearest active drill centre in EEM years for repeated-measures stations ($p = 0.260$), and no change in slope from before to after drilling began ($p = 0.116$). There was also no linear trend in mean lead concentration in the overall sampling area in EEM years ($p = 0.364$), but mean 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 5-37 and 5-39).

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

Trend over Time Contrast		Before to After Contrast	
Slope	**Mean**	**Slope**	**Mean**
0.260	0.364	0.116	0.046

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

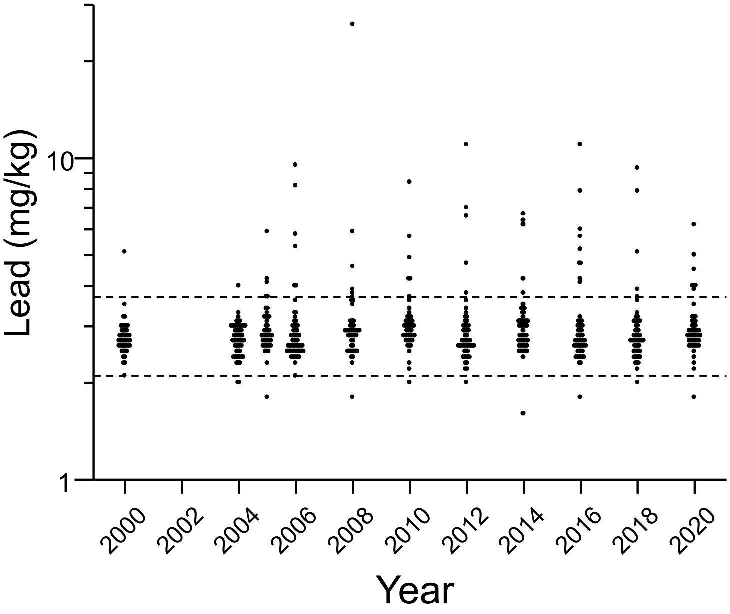

Figure 5-39 Dot Density Plot of Lead by Year

Note: Station 31 was excluded. 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 2020 (ρ_s = -0.593, $p < 0.001$, All stations; ρ_s = -0.513, $p = 0.002$, repeated-measures stations) (Figure 5-40). The threshold model in 2020 was significant ($p < 0.001$; Appendix A-7). The threshold in 2020 was 5.6 km (95% confidence limits 1.6 to 19.5 km). As was the case for ammonia, wide confidence limits around threshold estimates indicate a poor model fit and suggest that the threshold estimate might be unreliable and or/that the threshold model provides little improvement over a simple bivariate model. In this case, the threshold model did not account for any more variation than the simple bivariate model (see Appendix A-7 for details; also compare the fitted line for 2020 in Figure 5-41 to that of 2006, 2008, 2012, and 2018 when confidence limits were narrower). Thresholds for strontium in previous years were typically near 1 km (Table 5-18; Figure 5-41). In 2020, strontium predominantly was enriched above the baseline range within approximately 1 km of drill centres, consistent with previous threshold estimates (Figure 5-42). The inconsistency between visual assessment of the data (Figures 5-41 and 5-42) and threshold model results, and the known limitations of threshold models (Appendix A-7), indicate that the 2020 threshold distance was likely overestimated, and that potential project effects were limited to stations near drill centres. Excluding station 31, seven of the 10 samples from 2020 that had strontium concentrations greater than the upper baseline concentration of 54 mg/kg were collected less than 0.5 km from the nearest active drill centre; two stations were located between 1 and 5 km, and one station was a Reference Station (Figures 5-41 and 5-42).

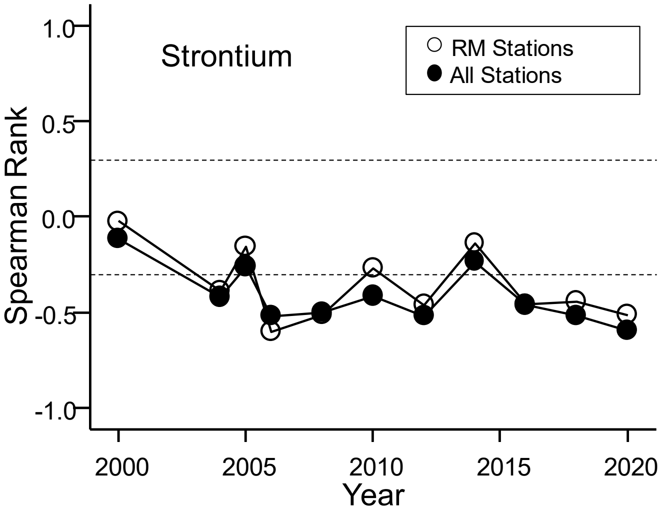

Figure 5-40 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Strontium

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.

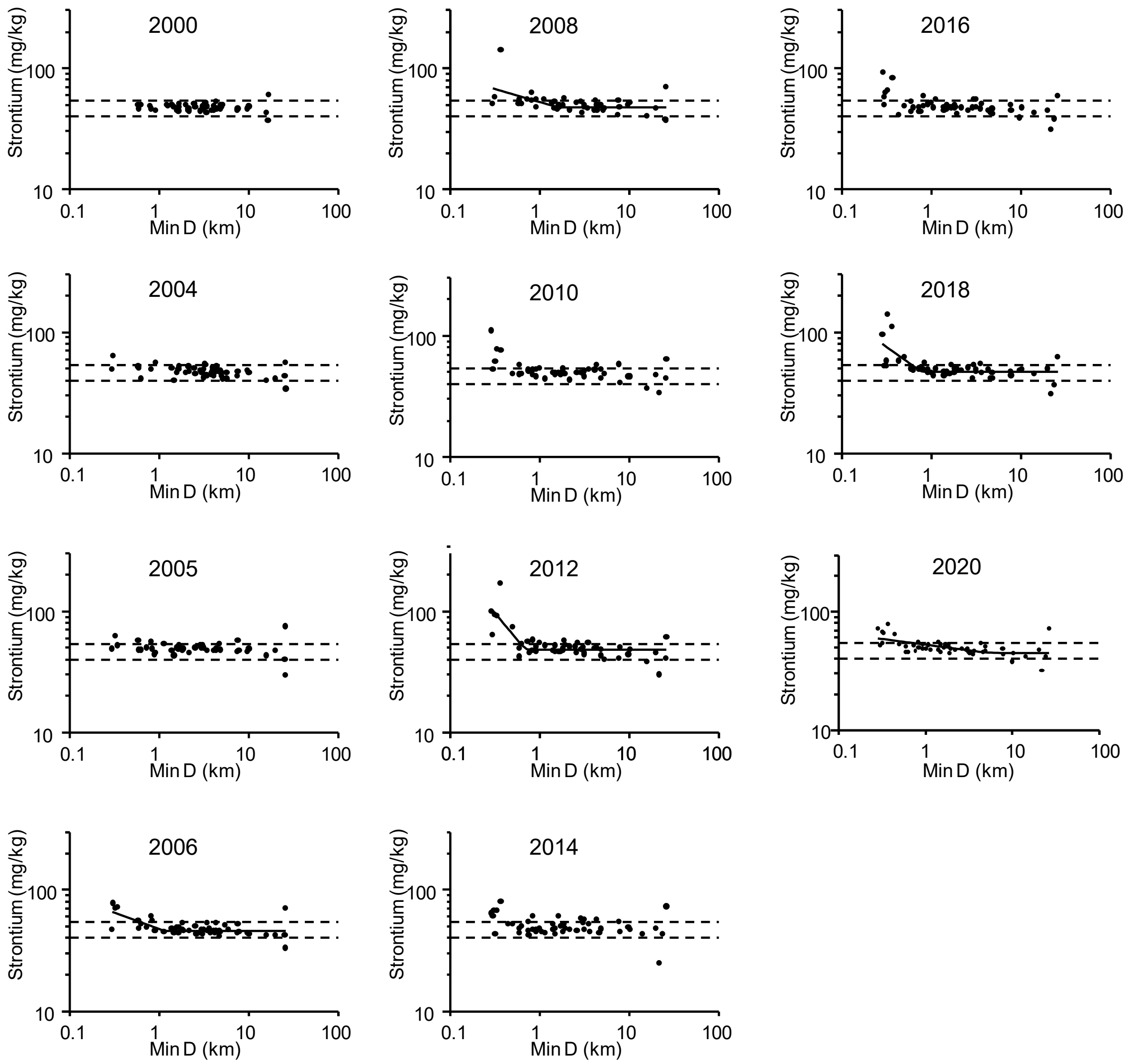

Figure 5-41 Variations in Strontium with Distance from the Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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.

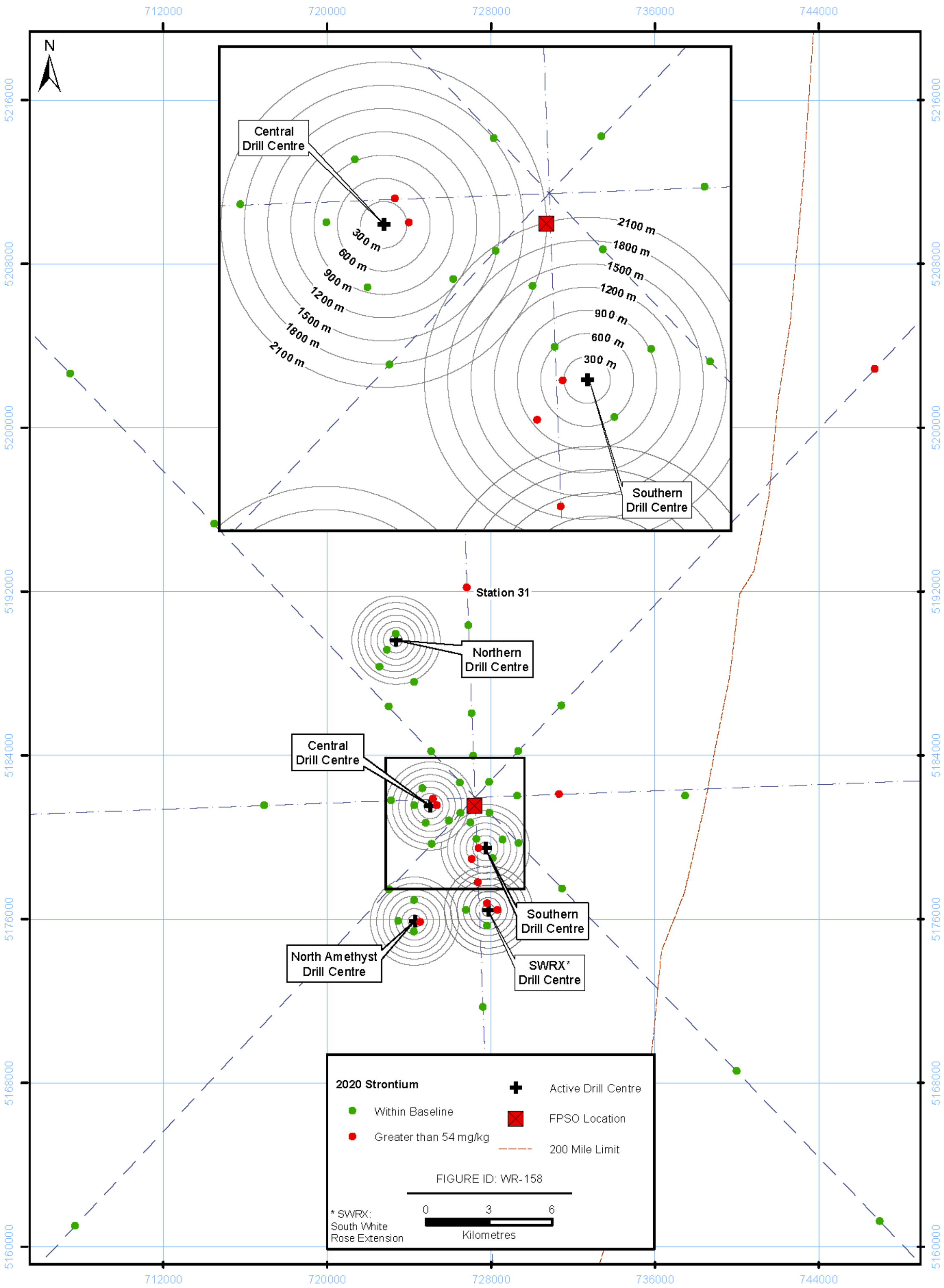

Figure 5-42 Location of Stations with Strontium (2020) Within and Above the Baseline Range

Note: Station 31 is identified in this figure but excluded from other figures and analyses.

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)
2020	5.6 (1.6, 19.5)

Notes:
- 95% confidence limits are provided in brackets.
- *n* = 52 in 2020 with Station 31 excluded.

Repeated-measures regression (Table 5-19) indicated that the slope of the relationship between strontium concentration and distance to the nearest active drill centre varied significantly in EEM years for repeated-measures stations (*p* = 0.038; Table 5-19). Negative slopes have generally increased in strength over time in EEM years (Figure 5-40). Slopes also varied significantly from before to after drilling (*p* = 0.007). Slopes were near zero in 2000 and negative in EEM years (Figure 5-40). Overall strontium concentrations in the sampling area varied significantly in EEM years (*p* = 0.024). This result was driven by decreased variance in strontium concentrations in 2020 relative to other recent years (Figure 5-43). Although not apparent from Figure 5-43, overall strontium concentrations generally increased over time in EEM years. Finally, overall strontium concentrations were generally higher in EEM years than in baseline (*p* = 0.001, Figure 5-43). Figure 5-43 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 higher concentrations of strontium (Figures 5-41 and 5-43).

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

Trend over Time Contrast		Before to After Contrast	
Slope	Mean	Slope	Mean
0.038	0.024	0.007	0.001

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

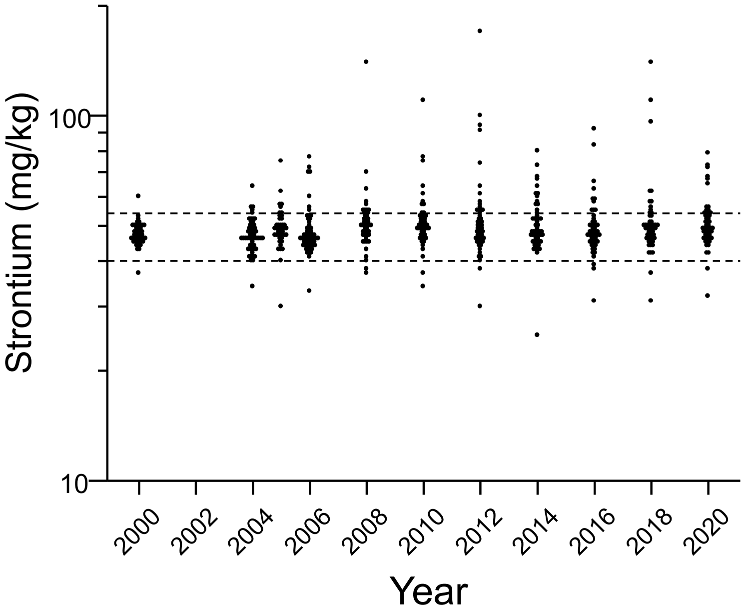

Figure 5-43 Dot Density Plot of Strontium by Year

Note: Station 31 was excluded. 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 126 and 300 mV in 2020 and was not significantly correlated with distance from the nearest active drill centre (ρ_s = -0.028, $p > 0.05$, All stations; ρ_s = -0.019, $p > 0.05$, repeated-measures stations) (Figure 5-44).

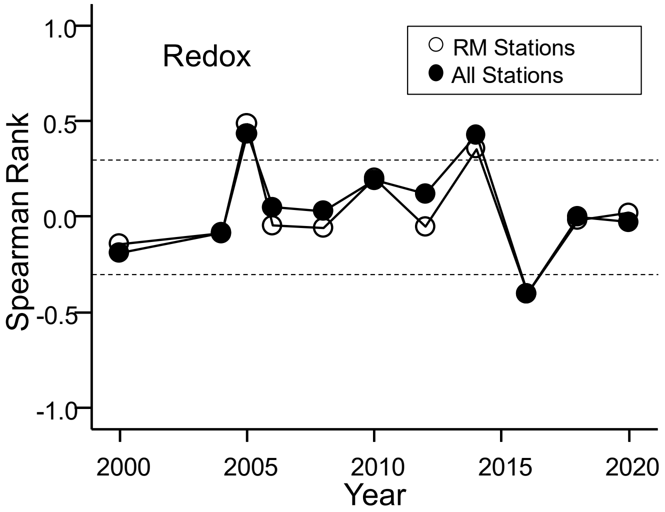

Figure 5-44 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Redox Potential

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 5-45 provides a graphical representation of redox levels with distance from active drill centres.

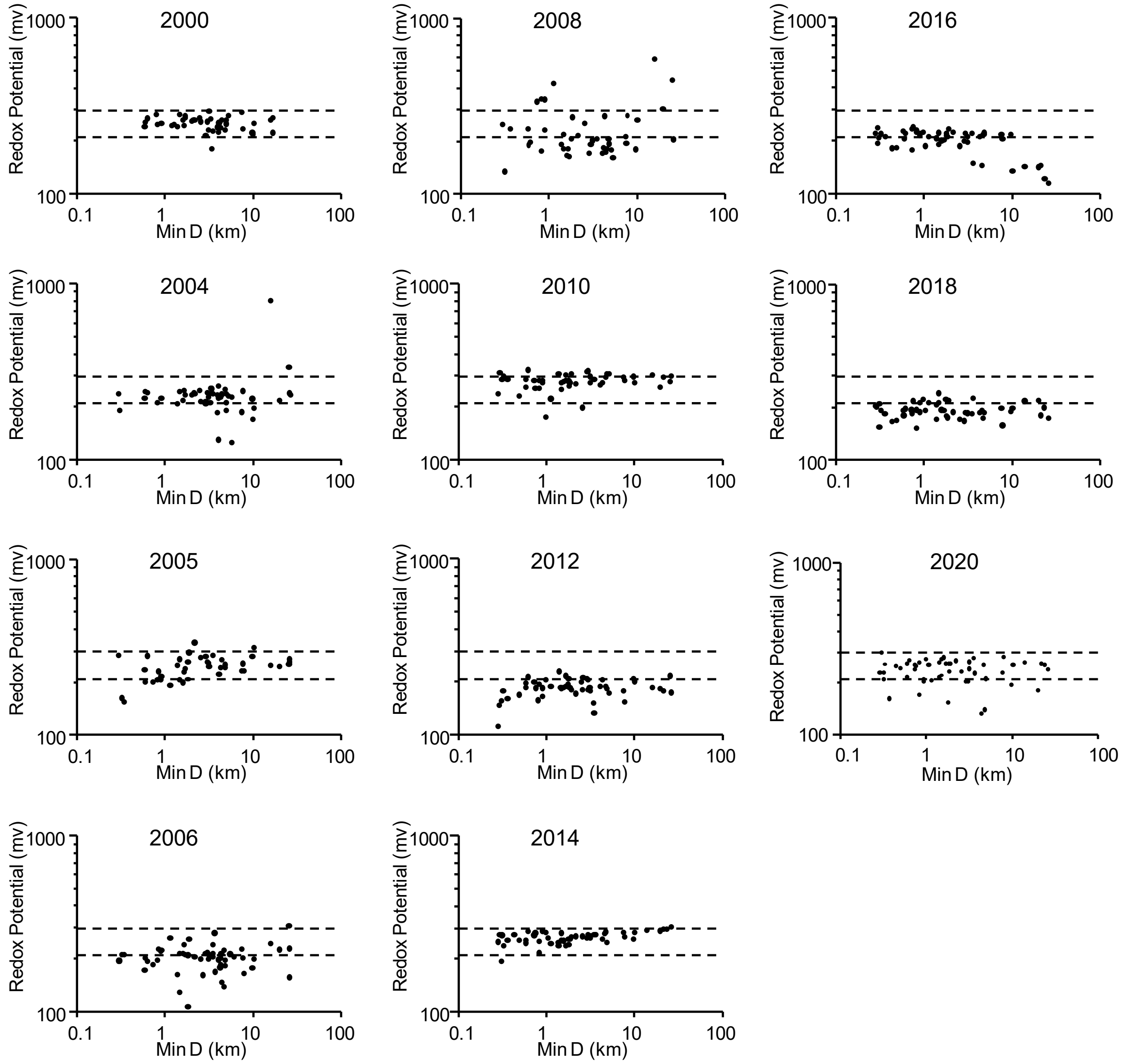

Figure 5-45 Variations in Redox Potential with Distance from the Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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 = 0.028; Figure 5-44). There was no change in EEM years in mean redox potential across the sampling area (p = 0.447), and no change in slopes from before to after drilling (p = 0.826). However, there was a significant change in mean redox potential from before to after drilling (p < 0.001), with lower redox potential values in EEM years (Figure 5-46). In 2020, any association between redox potential and distance from drill centres was unclear, with redox potential in the near-field similar to that at remaining stations (Figure 5-45). The dot density graph (Figure 5-46) illustrates that 2020 redox values generally were comparable to levels in the baseline year. All sediments since baseline have been oxic (>100 mV).

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

Trend over Time Contrast		Before to After Contrast	
Slope	**Mean**	**Slope**	**Mean**
0.028	0.447	0.826	<0.001

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

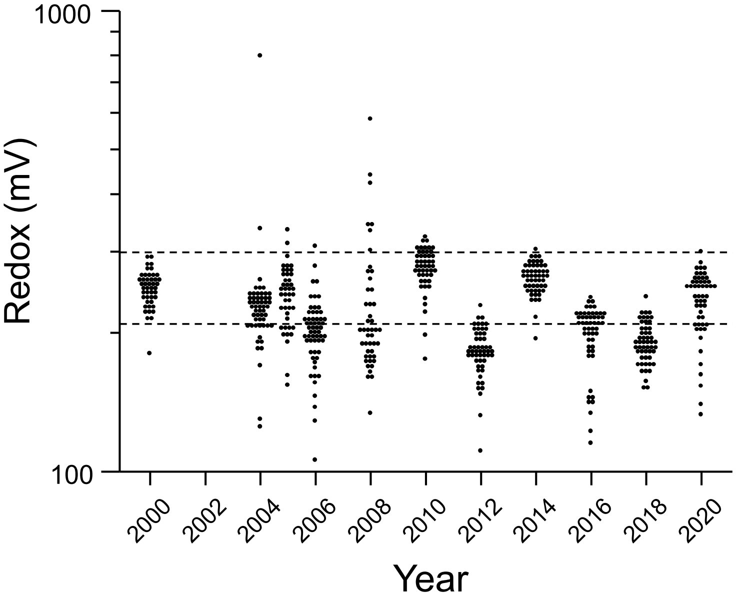

Figure 5-46 Dot Density Plot of Redox Potential by Year

Note: Station 31 was excluded. Background concentrations of 209 and 299 mV are indicated by the horizontal lines, based on the mean value ± 2 SDs using data from 2000.

5.2.2 Toxicity

No samples were toxic to laboratory amphipods in 2020 (Appendix A-4). Significant positive correlations were noted between amphipod survival and organic carbon (p = 0.04) and ammonia (p = 0.001; Table 5-21) *(i.e.,* survival increased with increasing concentrations of ammonia and organic carbon). No significant correlations were found for any of the remaining variables (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 (2020)

Variable	Spearman Rank Correlation (ρ_s) with Amphipod Survival
Distance from nearest active drill centre	-0.159
>C_{10}–C_{21} hydrocarbons	0.144
Barium	0.090
% Fines	0.150
Organic Carbon	0.279*
Ammonia	0.440***
Sulphide	0.232
Sulphur	0.180
Metals PC1	0.087
Lead	-0.010
Strontium	0.046
Redox	0.122

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$.
- n = 52 in 2020 with Station 31 excluded.

In previous years, no samples were 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; sediments from two stations were toxic in 2014; and sediments from one station were toxic in 2018. The 2020 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 from 2005 to 2008, and was similar in 2020 to what was observed in 2000 (baseline) (Figure 5-47).

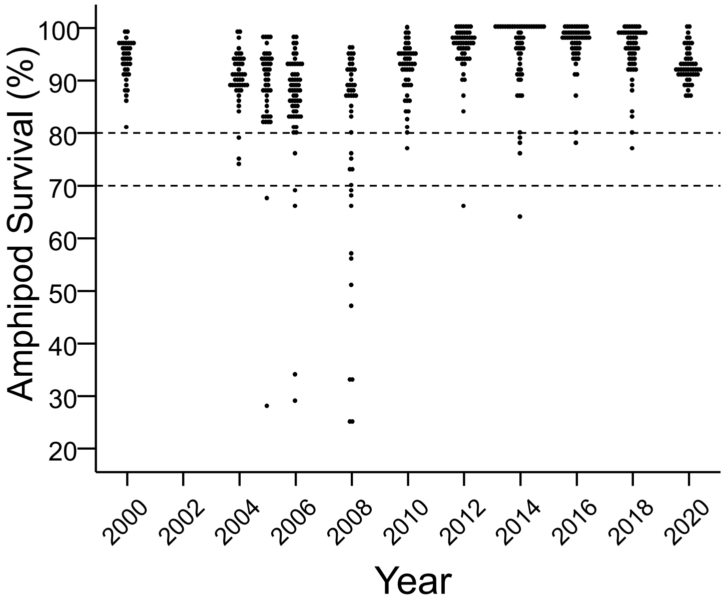

Figure 5-47 Dot Density Plot of Laboratory Amphipod Survival by Year

Note: Stations 31 was excluded. 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.

In 2020, no samples were toxic to Microtox (Appendix A-5). In previous years, one sample was toxic to Microtox in 2010; three samples were toxic in 2014; and two samples were toxic to in 2016. Overall, White Rose sediments have been predominantly non-toxic to Microtox.

5.2.3 Benthic Community Structure

5.2.3.1 General Composition

Raw data for benthic community structure in 2020 are provided in Appendix A-6. A total of 90 families were identified from 106 samples collected from 53 stations in 2020. As in prior years, Polychaeta were numerically dominant, accounting for 77% of total numbers, while Bivalvia (6%), Amphipoda (5%) and Isopoda (4%) were sub-dominant numerically, and Cnidaria, Gastropoda, Cumacea, and Echinodermata were found in trace numbers (1% or less)[16].

5.2.3.2 Univariate Analyses

Total Abundance

In 2020, total abundance of all benthic invertebrates varied between approximately 1,700 organisms per m² to over 10,000 per m² across the sampling area. The relationship between total abundance and distance from the nearest active drill centre was not significant in 2020 (ρ_s = -0.268, $p > 0.05$, all stations; ρ_s = -0.258 $p > 0.05$, repeated-measures stations; Figure 5-48). Significant distance relationships for all stations were noted in 2005, 2006, 2008, 2012 and 2014 (Figure 5-48).

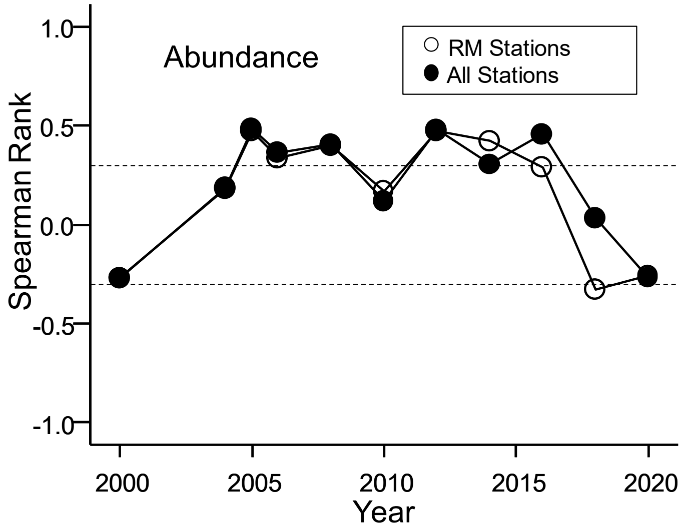

Figure 5-48 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Benthic Abundance

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.

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[16] *n* = 52 in 2020 with Station 31 excluded.

The relationships between total abundance and distance to the nearest active drill centre since 2000 are illustrated in Figure 5-49. 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 2020 (Figure 5-50), as well as variations over time (Figure 5-51).

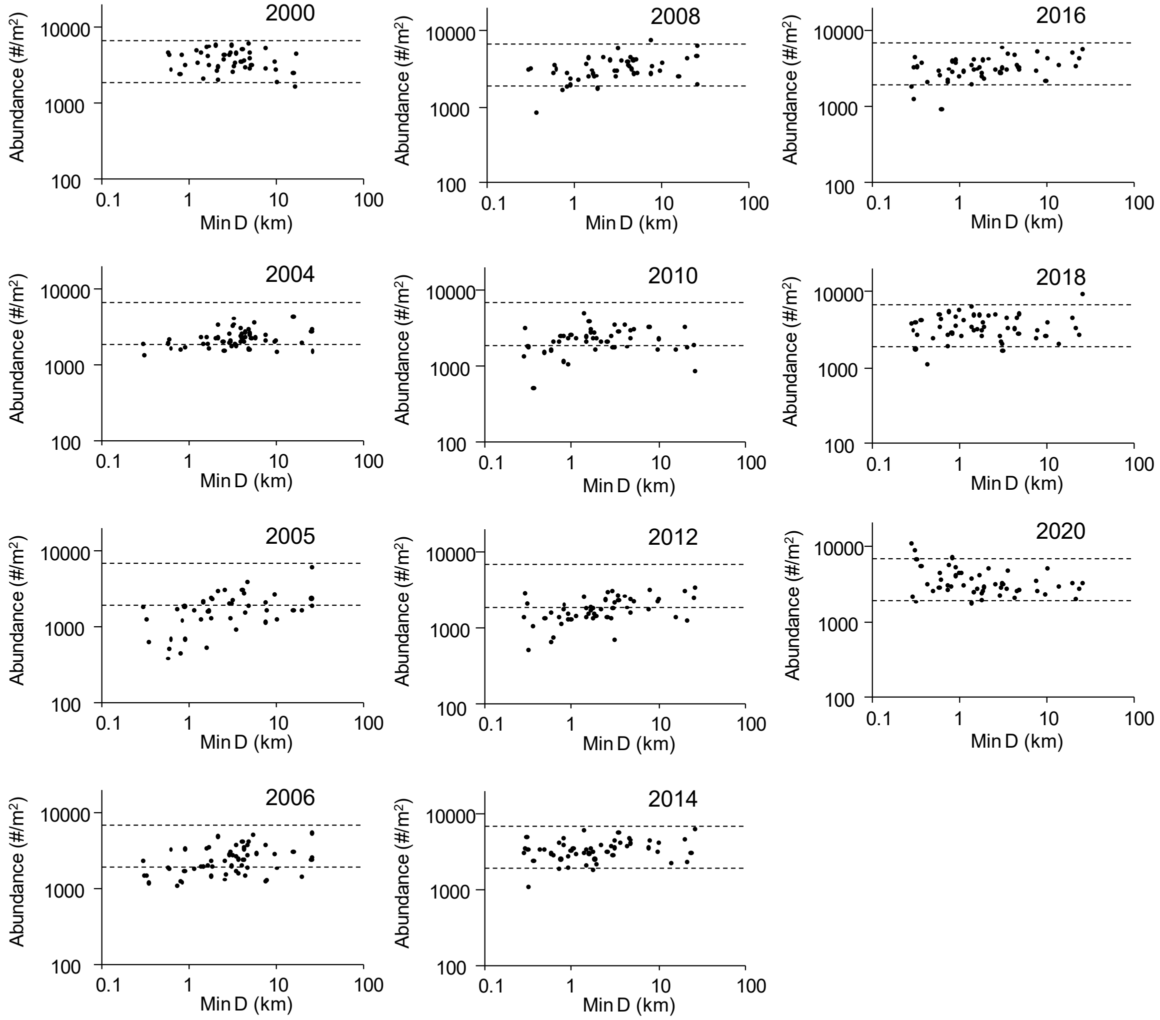

Figure 5-49 Variation in Total Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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).

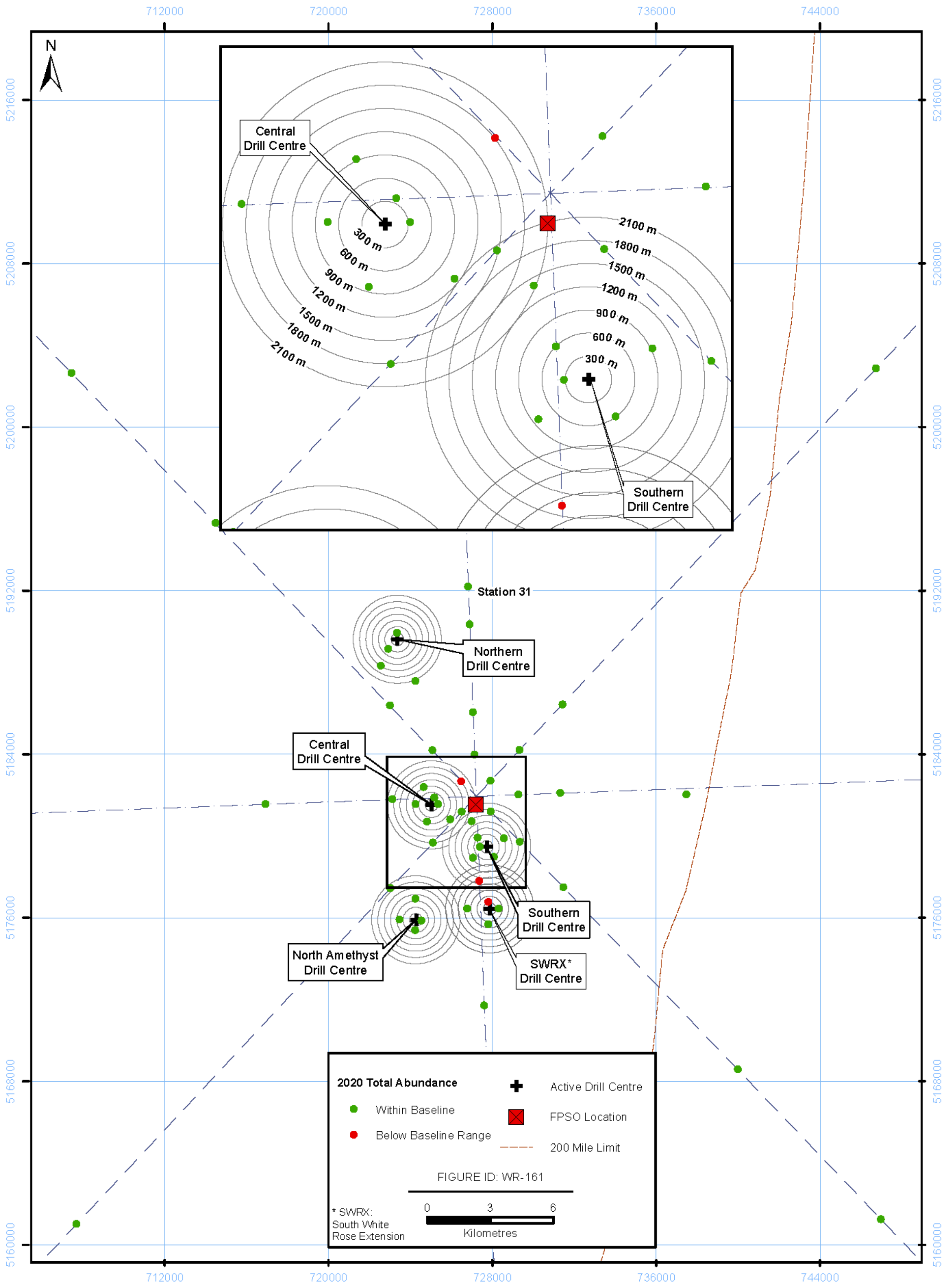

Figure 5-50 Location of Stations with Total Abundance Values Within and Below the Baseline Range (2020)

Note: Station 31 is identified in this figure but excluded from other figures and analyses.

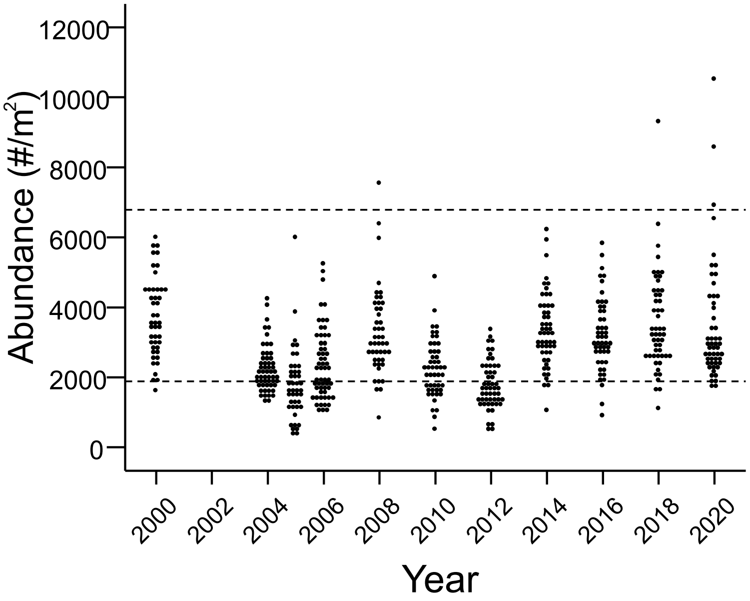

Figure 5-51 Dot Density Plot of Total Benthic Abundance by Year

Note: Station 31 was excluded. 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 2020, two stations near the SWRX Drill Centre and one station near the Central Drill Centre had abundance values lower than the baseline range (Figure 5-50).

Repeated-measures regression (Table 5-22) demonstrated that the relationship between abundance and distance from nearest active drill centre varied significantly over time in EEM years (*p* = 0.001) as well as from before to after drilling (*p* = 0.017). There was a weak (and not significant) distance trend before drilling; and distance trends generally became positive (Figure 5-48), with lower abundance near drill centres, after drilling began (Figure 5-48). However, that trend was more prominent from 2005 to 2016, with distance relationships again weakly negative in 2020 (see Figure 5-48). There was also an increasing trend in overall numbers in EEM years (*p* < 0.001) but no significant change from Before to After drilling (*p* = 0.661). The increasing trend in numbers in EEM years was driven by lower abundances from 2004 to 2012, with abundances since 2014 at levels comparable to baseline (Figure 5-51). Overall, 2020 results for abundance generally are similar to those noted in baseline (see Figures 5-48, 5-49, and 5-51).

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

Trend over Time Contrast		Before to After Contrast	
Slope	**Mean**	**Slope**	**Mean**
0.001	<0.001	0.017	0.661

Notes:
- Values are probabilities.
- *n* = 35.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

Total Biomass

In 2020, total biomass varied from approximately 3.5 to 600 g/m² within 500 m of active drill centres and from approximately 250 to 760 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 2020 for all stations ($\rho_s = 0.375$, $p = 0.006$) but not for repeated-measures stations ($\rho_s = 0.198$, $p > 0.05$, Figure 5-52). The threshold model for biomass was significant in 2020 ($p < 0.001$; Appendix A-7). The estimated threshold distance in 2020 was 2.9 km (95% confidence limits = 0.68 to 12.0 km). Thresholds also could be estimated for biomass in 2012 and 2014 (Figure 5-52). In 2012, the threshold distance was 1.5 km (95% confidence limits = 0.8 to 2.7 km). In 2014, the threshold distance was 5.5 km (95% confidence limits = 1.5 to 20.1 km)[17].

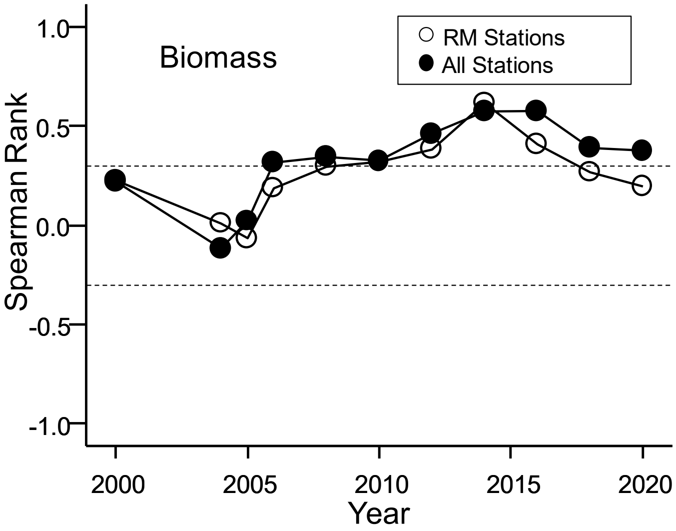

Figure 5-52 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Total Benthic Biomass

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 5-53, 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 were also used to judge spatial variation in the sampling area in 2020 (Figure 5-54) as well as variations over time (Figure 5-55).

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[17] Wide confidence limits around threshold estimates indicate a poor model fit and suggest that the threshold estimate might be unreliable and or/that the threshold model provides little improvement over a simple bivariate model (see Appendix A-7 for details).

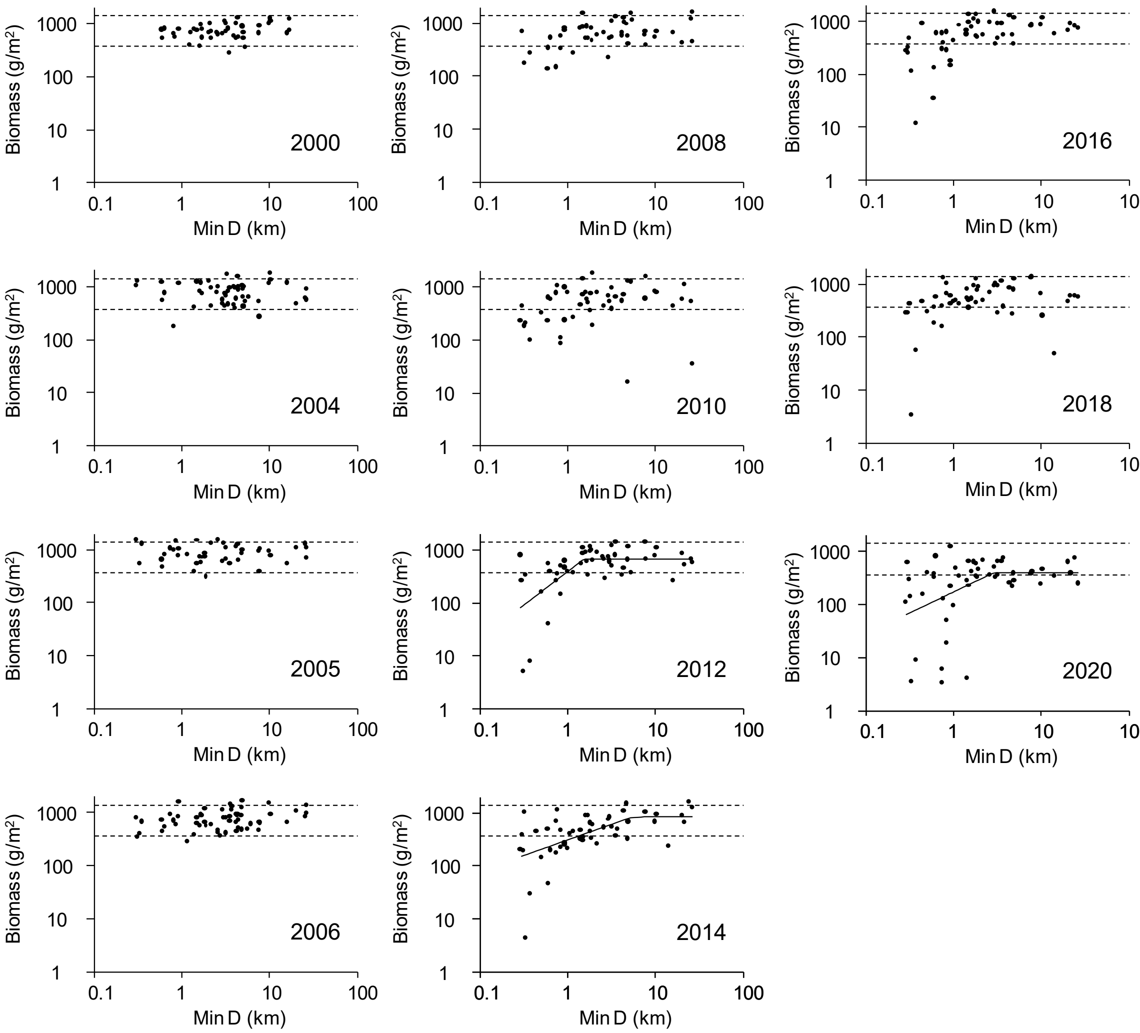

Figure 5-53 Variation in Total Benthic Biomass (g/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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.

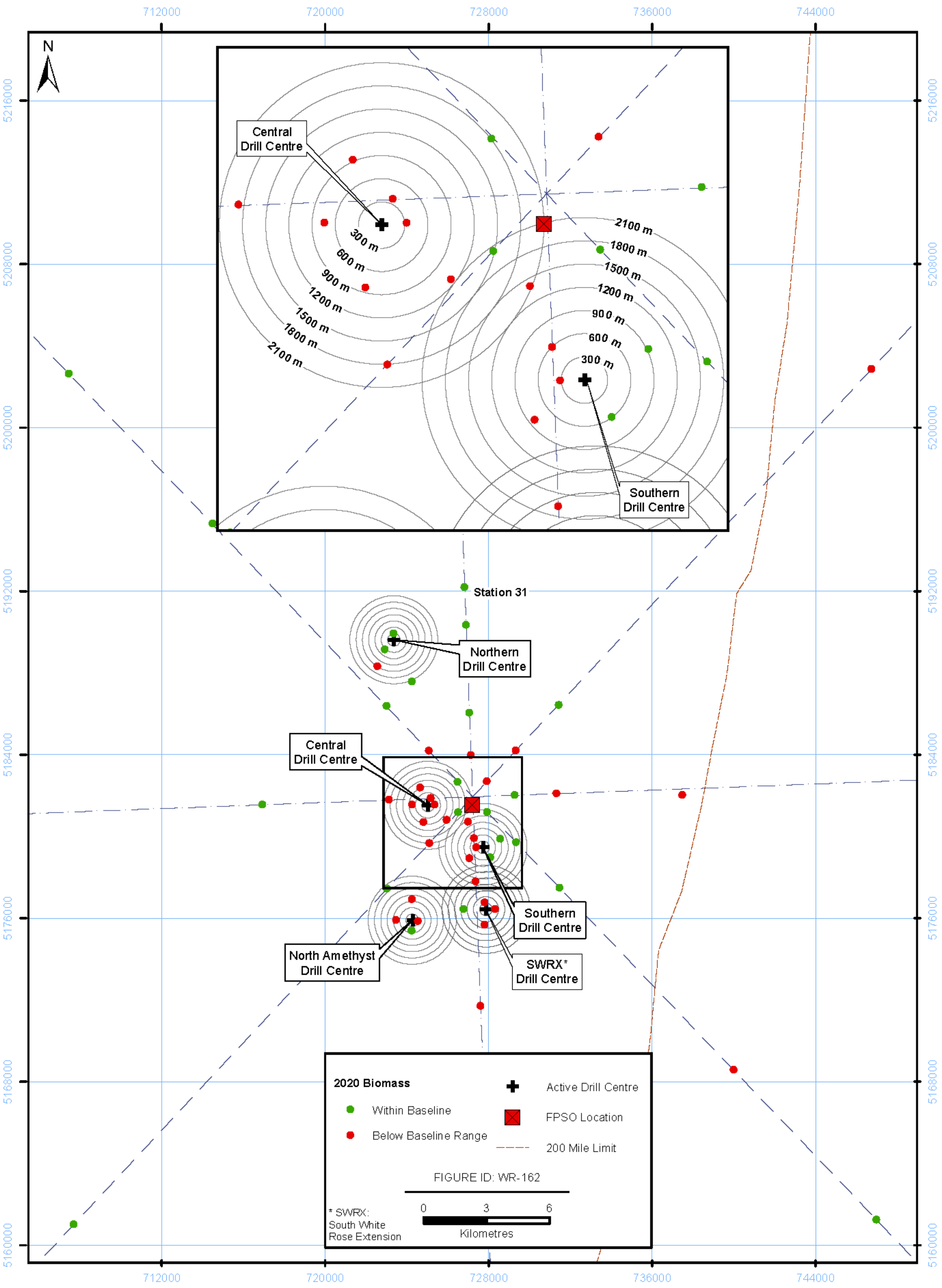

Figure 5-54 Location of Stations with Total Biomass Values Within and Below the Baseline Range (2020)

Note: Station 31 is identified in this figure but excluded from other figures and analyses.

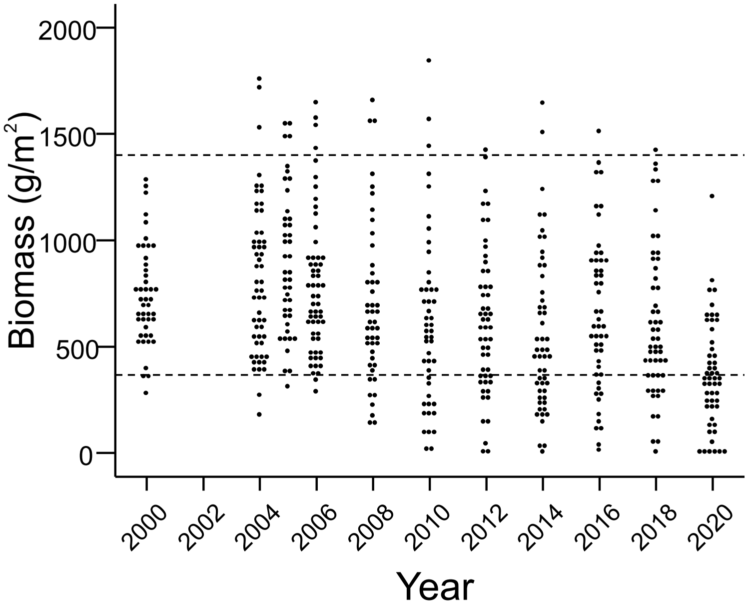

Figure 5-55 Dot Density Plot of Total Benthic Biomass by Year

Note: Station 31 was excluded. 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).

Biomass was below the baseline range at many stations in 2020, including stations more distant from drill centres (Figure 5-54).

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 = 0.026). Slopes generally increased in strength since 2004 (Figure 5-52). There was also a significant difference in the slope of the relationship from before to after drilling (p = 0.033), with slopes generally more positive in EEM years than in baseline. These differences were more pronounced in 2014 and 2016, with slopes for repeated-measures stations in 2020 comparable to the baseline slope (Figure 5-52). Mean biomass was generally greater before drilling than during drilling (p = 0.001; Figure 5-55). Mean biomass also varied among EEM years (p < 0.001), with relatively higher biomass prior to 2008 within progressive declines since then (Figure 5-55). As noted above with reference to Figure 5-54, biomass was below the baseline range at many stations in 2020, indicating a potential influence of natural variation over and above project effects.

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

Trend over Time Contrast		Before to After Contrast	
Slope	Mean	Slope	Mean
0.026	<0.001	0.033	<0.001

Notes:
- Values are probabilities.
- n = 35.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

As indicated previous reports, reductions in biomass near drill centres are related, in part, to reductions in the number of larger echinoderms, particularly Echinarachniidae (sand dollars). In 2020, 29 stations with biomass below the baseline range also had reduced echinoderm abundance relative to remaining stations (these 29 stations had mean = 16 echinoderms/m² at versus 24 echinoderms/m² at remaining stations).

Richness

Number of families per station (*i.e.*, richness) varied between 25 and 45 in 2020, 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 2020 (ρ_s = -0.050, p > 0.05, All stations; ρ_s = -0.167, p > 0.05, repeated-measures stations), or in other years (Figure 5-56). Figure 5-57 provides graphical representations of the relationship between richness and distance to active drill centres. In 2020, richness was above the baseline ranges at all stations (Figure 5-58).

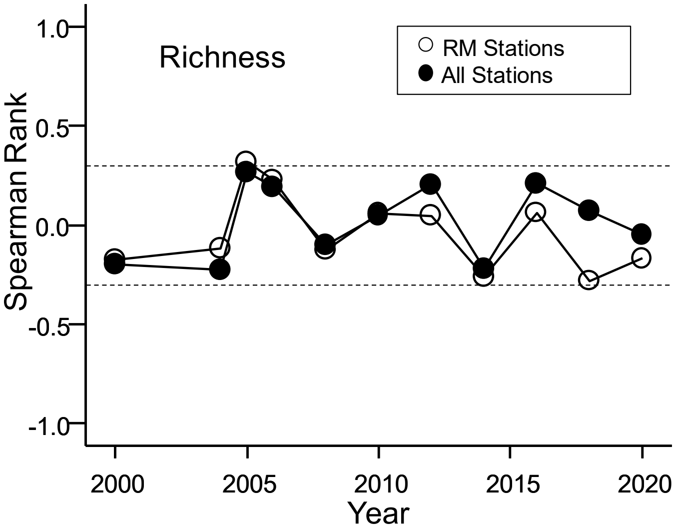

Figure 5-56 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Taxa Richness

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.

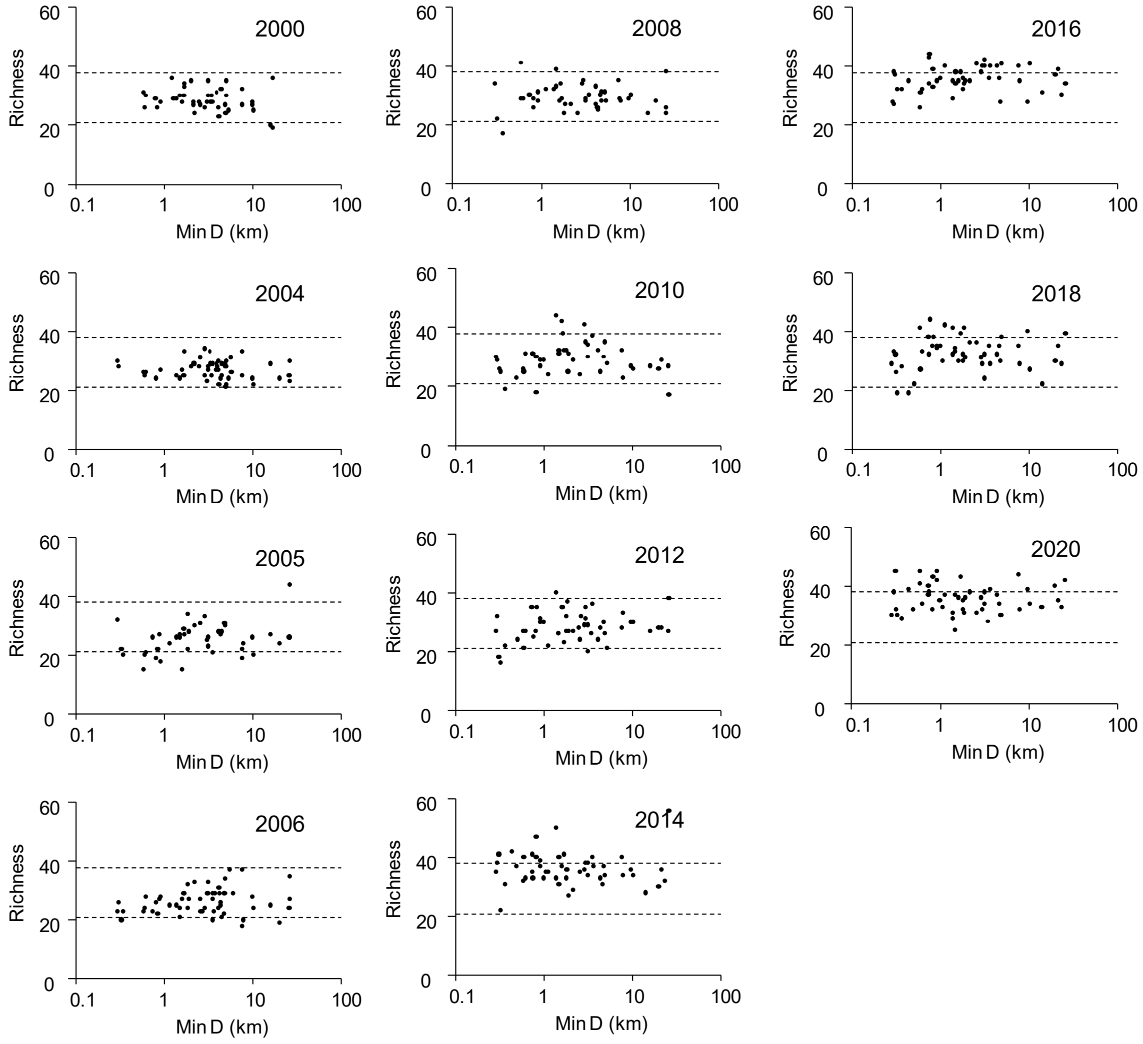

Figure 5-57 Variation in Taxa Richness with Distance from Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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.

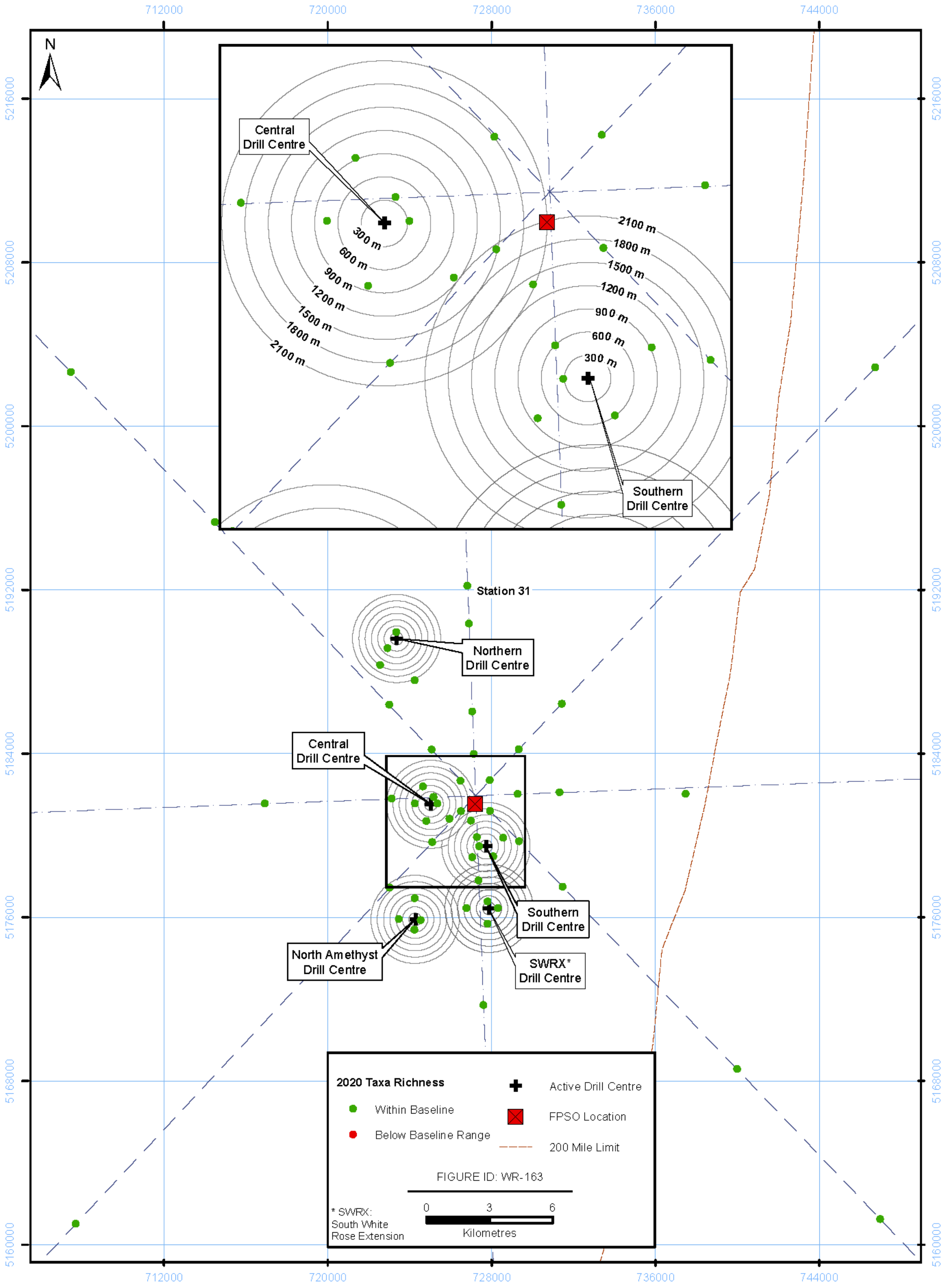

Figure 5-58 Location of Stations with Richness Values Within and Below the Baseline Range (2020)

Note: Station 31 is identified in this figure but excluded from other figures and 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 decreased significantly over time in EEM years for repeated-measures stations (*p* = 0.027; see Figure 5-56). However, the relationship from before to after drilling has not significantly changed (*p* = 0.101). There was a significant trend in mean number of taxa in EEM years (*p* < 0.001), with richness generally increasing over time (Figure 5-59). Mean number of taxa did not differ significantly between EEM years and the baseline year (*p* = 0.182; Figure 5-59).

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

Trend over Time Contrast		Before to After Contrast	
Slope	Mean	Slope	Mean
0.027	<0.001	0.101	0.182

Notes:
- Values are probabilities.
- *n* = 35.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

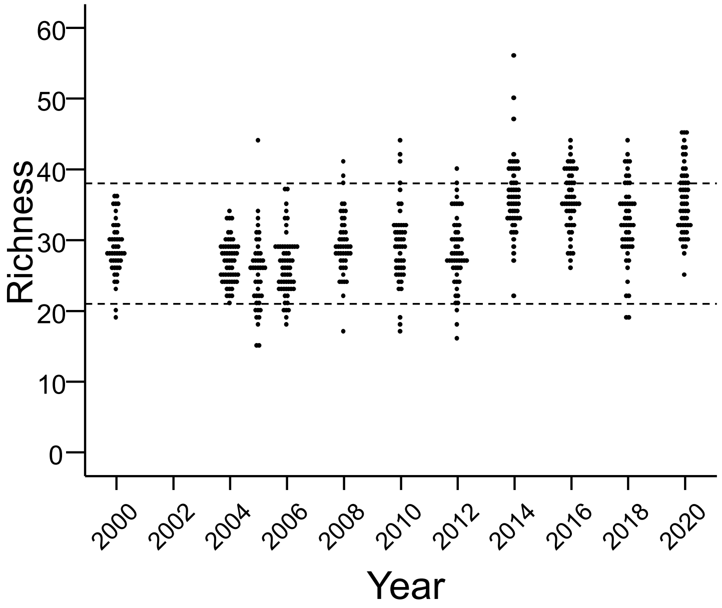

Figure 5-59 Dot Density Plot of Taxa Richness by Year

Note: Station 31 was excluded. 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 2020 (Figure 5-59).

Paraonidae Abundance

Paraonidae abundances have been strongly related to distance from active drill centres (Figure 5-60), with abundances lower near drill centres in most EEM years and in 2020 (ρ_s = 0.706, p < 0.001, All stations; ρ_s = 0.599, p < 0.001, repeated-measures stations). Threshold models were significant for Paraonidae abundance for all years from 2004 to 2020 (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).

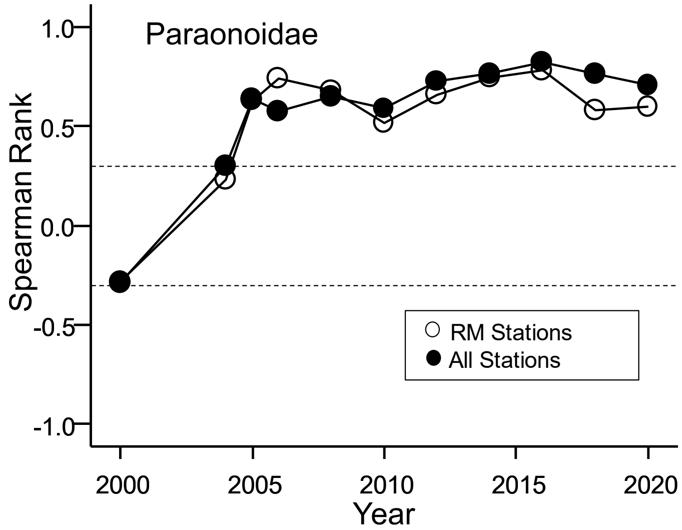

Figure 5-60 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Paraonidae Abundances

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)
2020	1.4 (1.1 to 1.8)

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

Figure 5-61 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 individuals 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 2020 (Figure 5-62) as well as variations over time (Figure 5-63).

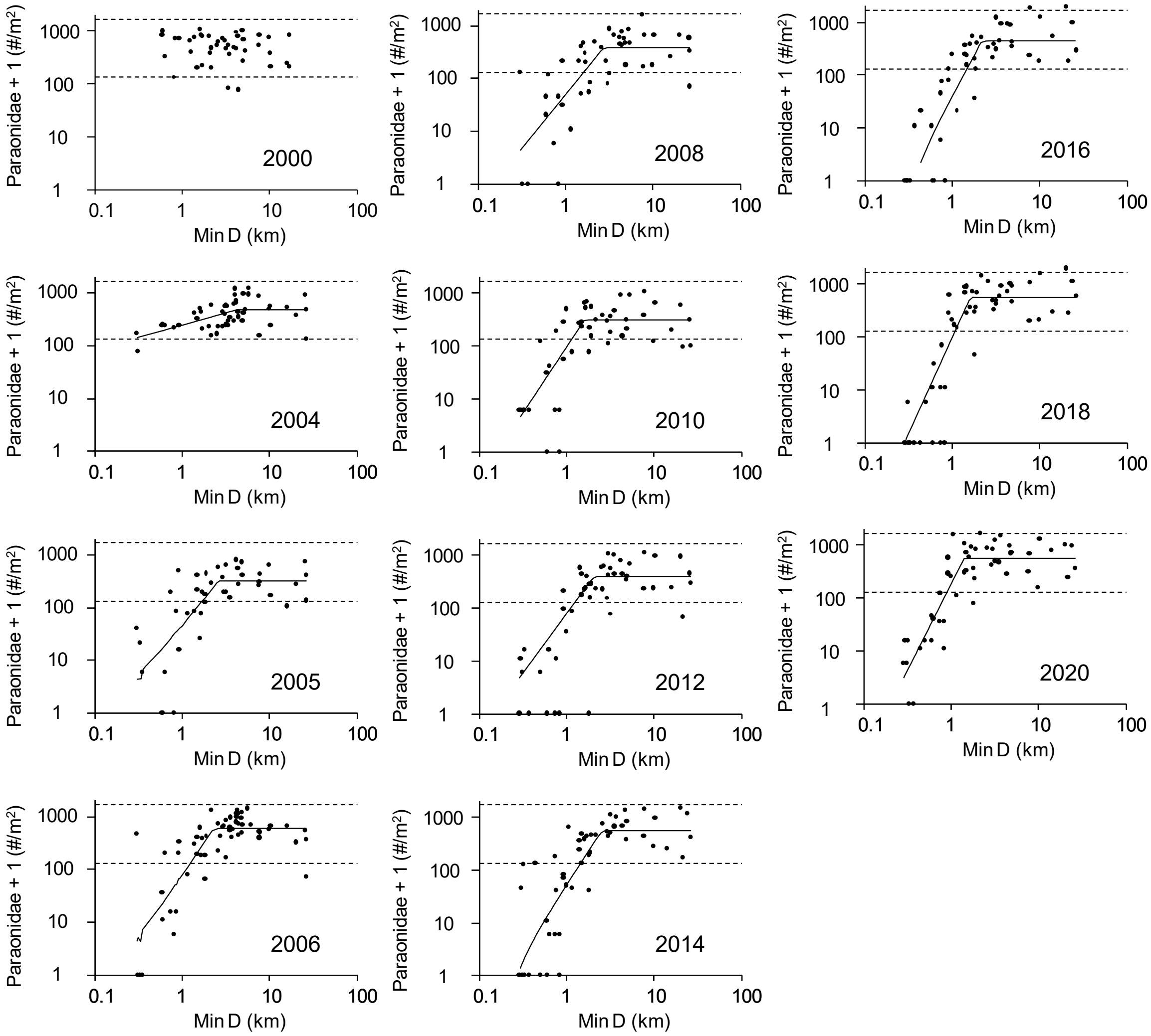

Figure 5-61 Variation in Paraonidae Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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.

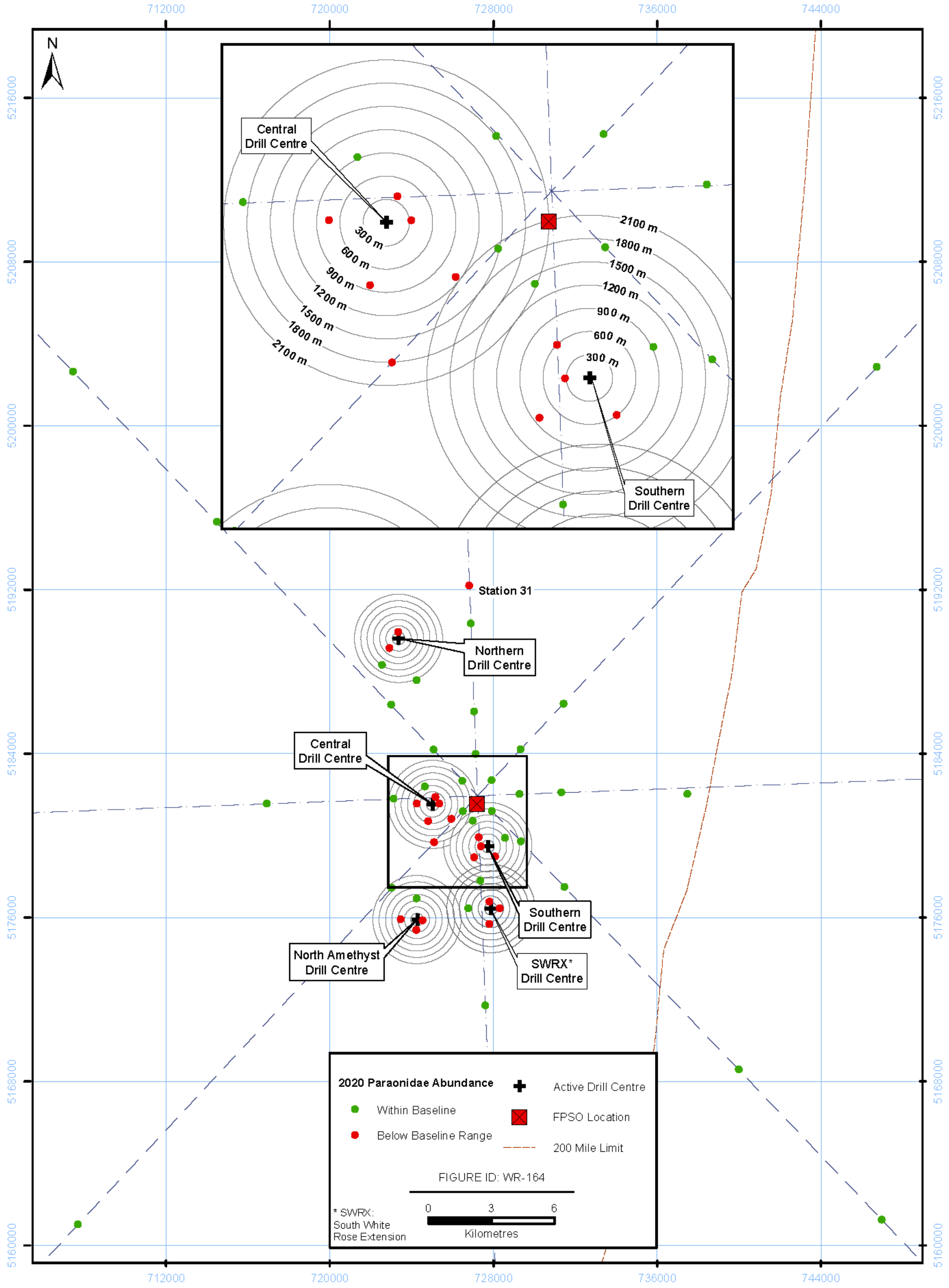

Figure 5-62 Location of Stations with Paraonidae Abundance Values Within and Below the Baseline Range (2020)

Note: Station 31 is identified in this figure but excluded from other figures and analyses.

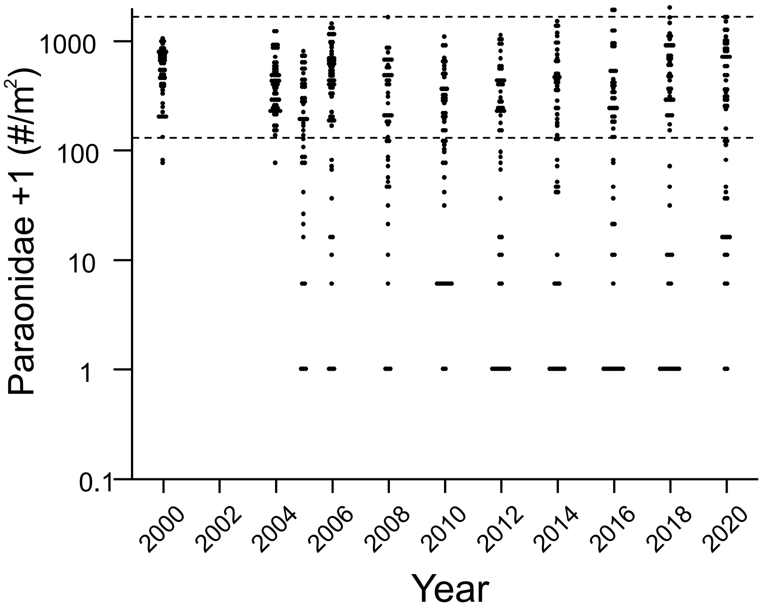

Figure 5-63 Dot Density Plot of Paraonidae Abundance by Year

Note: Station 31 was excluded. 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 2020 (Figure 5-62). 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 slopes, $p = 0.003$; also see Figure 5-60). There was also a difference in the slope from before to after drilling (positive slopes in EEM years versus a negative slope in baseline, $p < 0.001$). There was a linear decrease over time in mean Paraonidae abundances in EEM years ($p = 0.05$); and overall lower numbers of Paraonidae from before to after drilling ($p < 0.001$), with effects reflected by the low abundances near active drill centres (*e.g.*, Figure 5-61).

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

Trend over Time Contrast		Before to After Contrast	
Slope	**Mean**	**Slope**	**Mean**
0.003	0.050	<0.001	<0.001

Notes:
- Values are probabilities.
- *n* = 35.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

Cirratulidae Abundance

Remaining taxa (Cirratulidae, Orbiniidae and Isopoda) were examined individually for the first time in the 2020 report based on recommendations in the 2018 EEM report. In 2020, Cirratulidae abundance was significantly negatively correlated with distance to the nearest active drill centre (ρ_s = -0.709, p < 0.001, All stations; ρ_s = -0.906, p < 0.001, repeated-measures stations). Negative correlations have been significant for all stations and repeated-measures stations since 2010 (Figure 5-64).

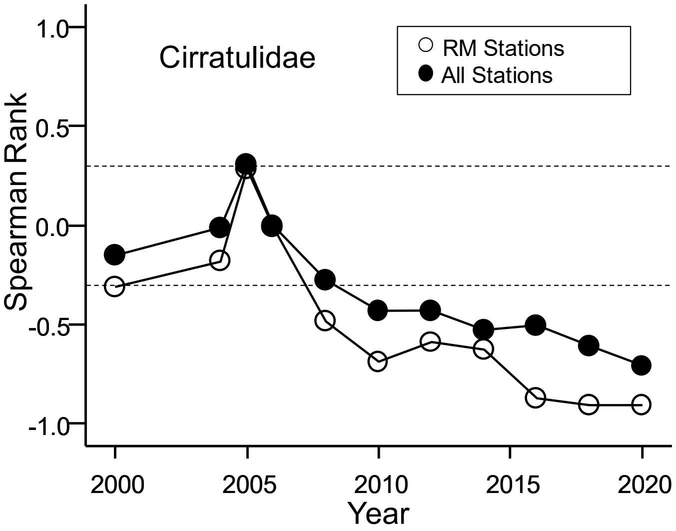

Figure 5-64 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Cirratulidae Abundances

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.

The threshold model was not significant for Cirratulidae in 2020 (Appendix A-7). Threshold models were significant in 2006 and 2012 (Figure 5-65). The threshold in 2006 was 1 km (95% confidence limits = 0.3 to 3.8 km). The threshold in 2012 was 5.4 km (95% confidence limits = 0.8 to 36.3 km)[18].

In spite of the negative correlation between Cirratulidae abundances and distance to drill centres in 2020 and prior years, only a few stations near drill centres had abundance higher than the baseline range (Figure 5-65). In 2020, Cirratulidae abundances were enriched at three stations around the Central Drill Centre and at one station around each of the Southern and North Amethyst Drill Centre (Figure 5-66).

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[18] Wide confidence limits around threshold estimates indicate a poor model fit and suggest that the threshold estimate might be unreliable and/or that the threshold model provides little improvement over a simple bivariate model (see Appendix A-7 for details).

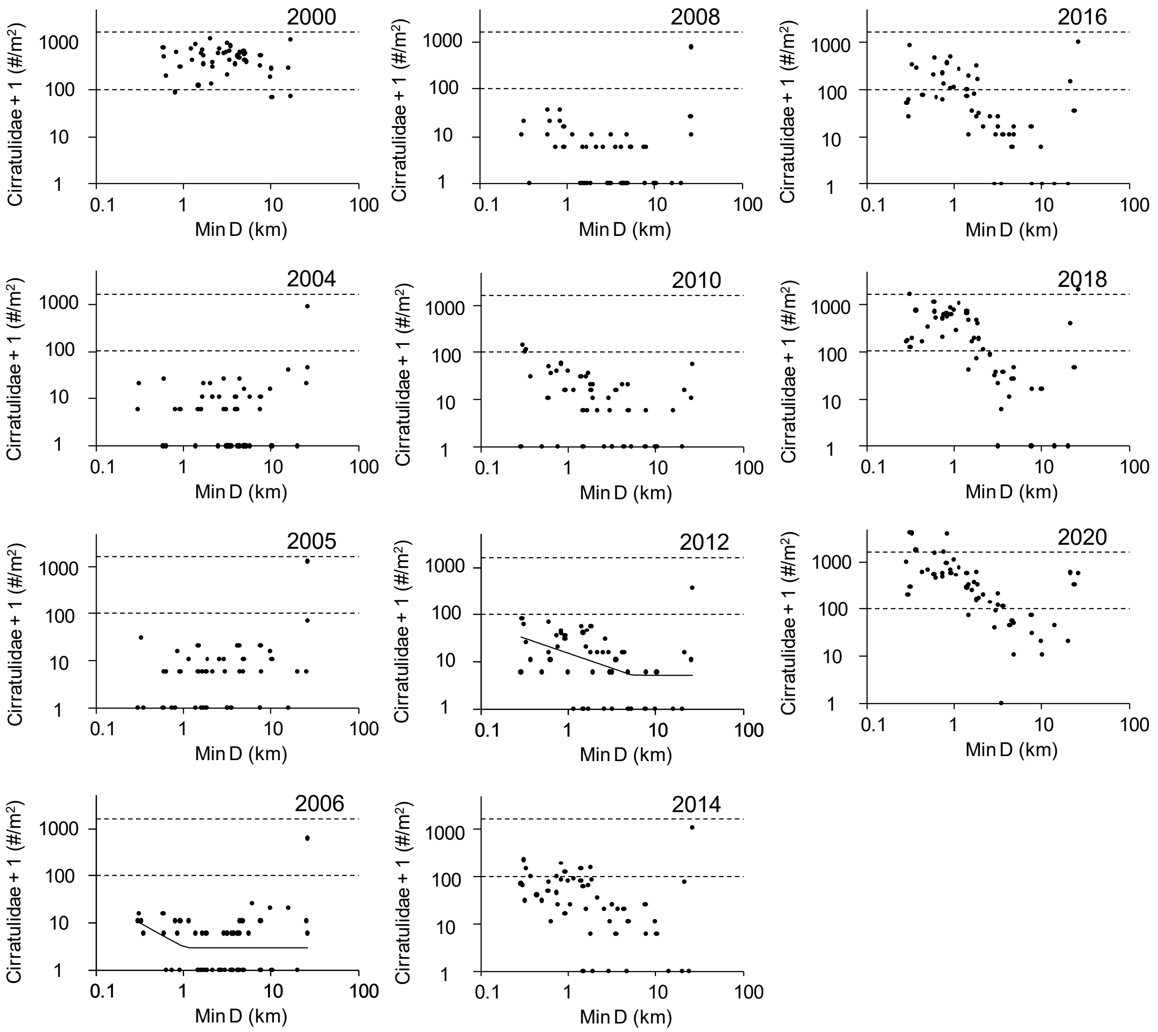

Figure 5-65 Variation in Cirratulidae Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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 101 and 1,620 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

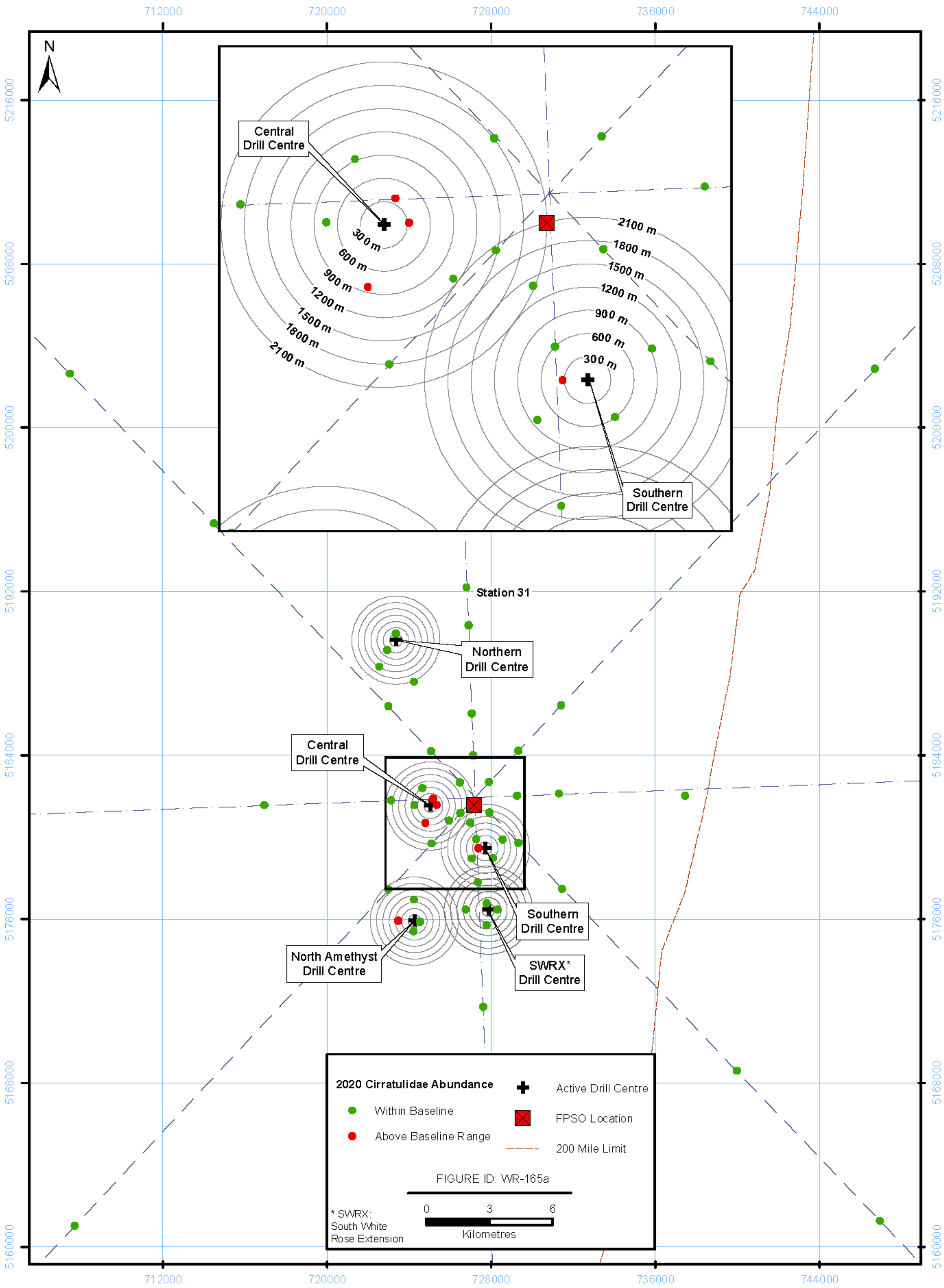

Figure 5-66 Location of Stations with Cirratulidae Abundance Values Within and Above the Baseline Range (2020)

Note: Station 31 is identified in this figure but excluded from other figures and analyses.

Repeated-measures regression (Table 5-27) indicated a significant change in the slope of the relationship between Cirratulidae abundance and distance from the nearest active drill centre in EEM years as well as for Before to After drilling ($p < 0.001$ in both cases). Slopes have increased in strength, becoming more negative, over time ((Figure 5-64). Cirratulidae numbers were higher before drilling than in EEM years ($p < 0.001$; Figure 5-67) with a general decrease below baseline levels in most EEM years (Figures 5-65 and 5-67). The negative relationship between Cirratulidae abundances and distance to drill centres suggests project-related enrichment near drill centres. However, the more general decrease in numbers from before to after drilling is not consistent with a project-effect and suggests natural variation. Overall abundances have increased over time in EEM years ($p < 0.001$, Table 5-27), with mean abundance in 2020 similar to mean abundance in baseline (488 versus 446 individuals·m², respectively).

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

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

Notes:
- Values are probabilities.
- $n = 35$.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

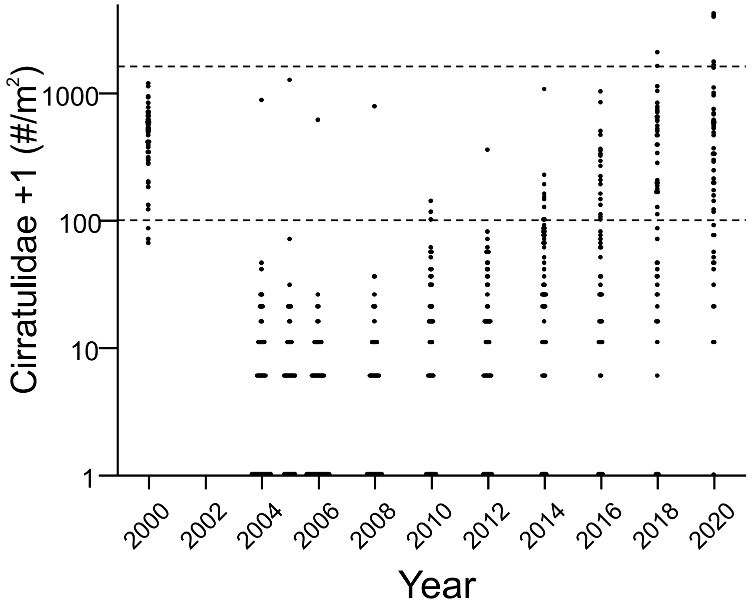

Figure 5-67 Dot Density Plot of Cirratulidae Abundance by Year

Note: Station 31 was excluded. Values of 101 and 1,620 individuals per·m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

Orbiniidae Abundance

Orbiniidae abundances varied between 0 and 750 individuals per m², with an area-wide average of approximately 158 per m² in 2020. Orbiniidae abundances increased significantly with distance to the nearest active drill centre in 2020 ($\rho_s = 0.541$, $p < 0.001$, All stations; $\rho_s = 0.388$, $p < 0.021$, repeated-measures stations); indicating lower Orbiniidae numbers near drill centres. The correlations between Orbiniidae abundance and distance to active drill centres has been significant and positive since 2006 (Figure 5-68). Threshold models were significant for Orbiniidae in most years (Table 5-28). The threshold for 2020 was 1.1 km (95% confidence limit = 0.8 to 1.6 km).

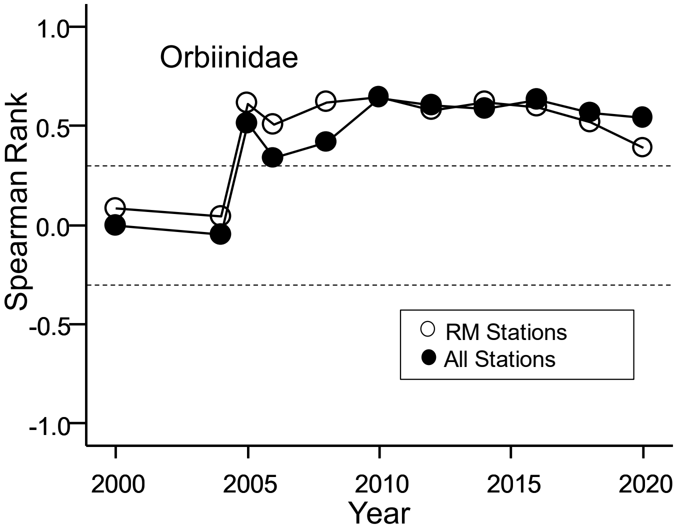

Figure 5-68 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Orbiniidae Abundance

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.

Table 5-28 Threshold Distances Computed from Threshold Regressions on Distance from the Nearest Active Drill Centre for Orbiniidae Abundance

Year	Threshold Distance (km)
2004	2.0 (0.8 to 4.9)
2005	2.8 (1.4 to 5.6)
2006	No threshold
2008	2.9 (1.3 to 6.5)
2010	No threshold
2012	No threshold
2014	2.6 (1.3 to 5.1)
2016	No threshold
2018	1.2 (0.9 to 1.7)
2020	1.1 (0.8 to 1.6)

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

Figure 5-69 provides a graphical representation of the relationship between Orbiniidae abundance and distance to active drill centres. In 2020, Orbiniidae abundances were reduced at few stations around all drill centres except the Northern Drill Centre (Figure 5-70).

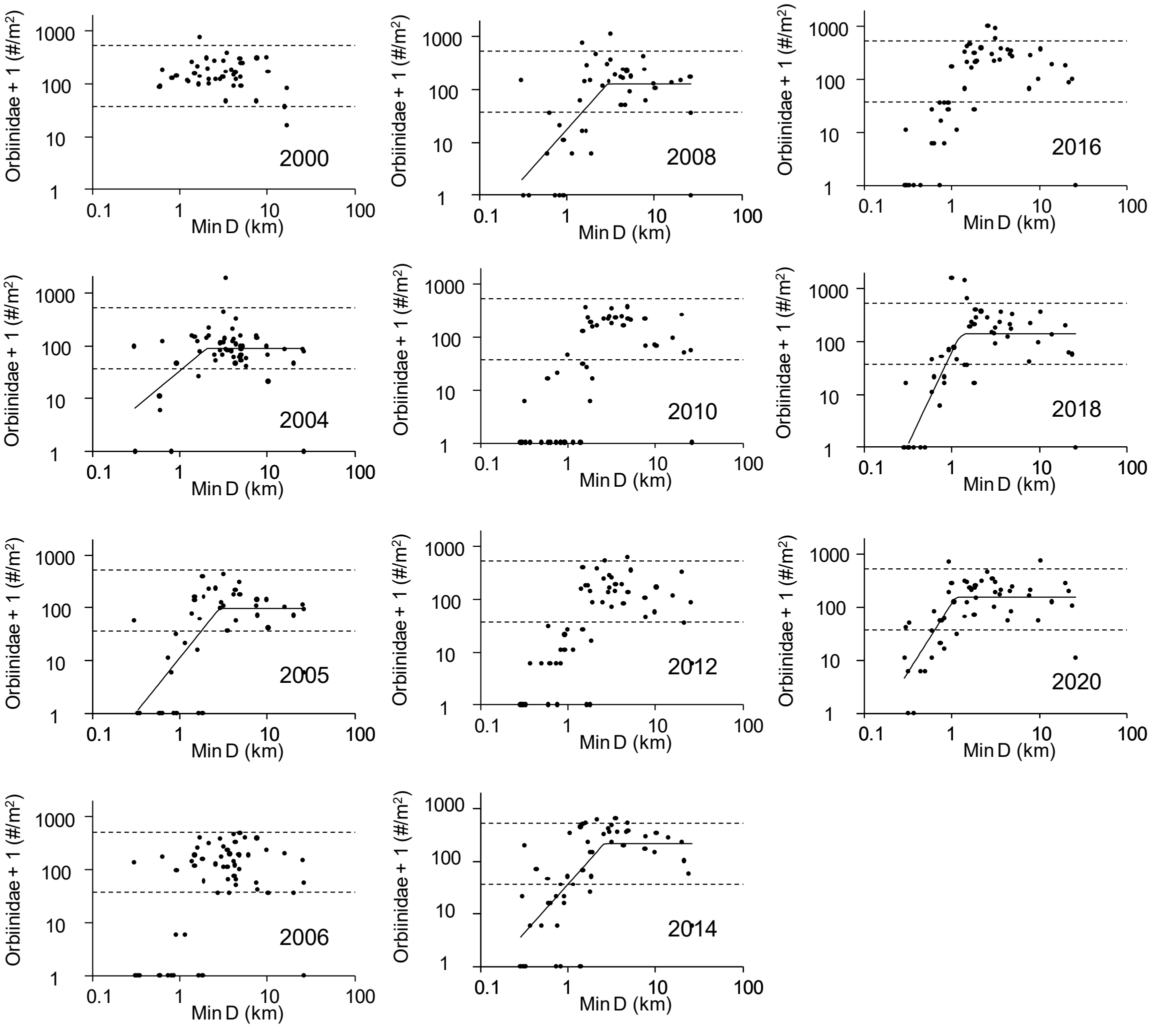

Figure 5-69 Variation in Orbiniidae Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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 37 and 521 individuals per m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

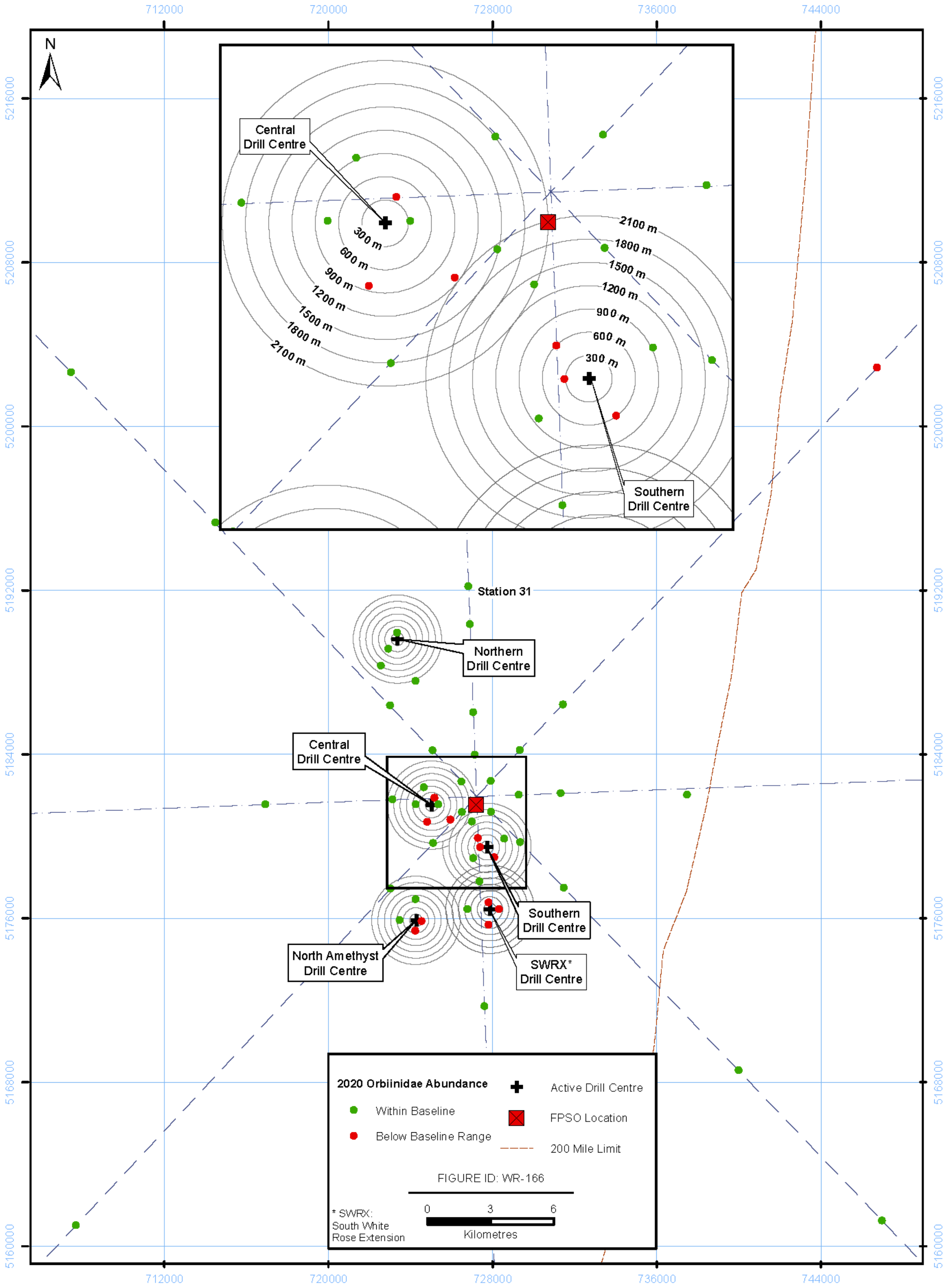

Figure 5-70 Location of Stations with Orbiniidae Abundance Values Within and Below the Baseline Range (2020)

Note: Station 31 is identified in this figure but excluded from other figures and analyses.

Repeated-measures regression (Table 5-29) indicated that the slope of the relationship between Orbiniidae abundance and distance to the nearest active drill centre was significantly different from before to after drilling ($p < 0.001$). However, there was no change in the slope of the relationship during EEM years ($p = 0.365$). In general, the slope of the relationship between Orbiniidae abundances and distance to drill centres was strong and positive in EEM years and the slope during baseline was near zero (Figure 5-68). Mean numbers of Orbiniidae varied significantly over time in EEM years ($p = 0.001$), and from before to after drilling ($p < 0.001$), with a greater number of lower abundances in EEM years (Figure 5-71).

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

Trend over Time Contrast		Before to After Contrast	
Slope	**Mean**	**Slope**	**Mean**
0.365	0.001	<0.001	<0.001

Notes:
- Values are probabilities.
- *n* = 35.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

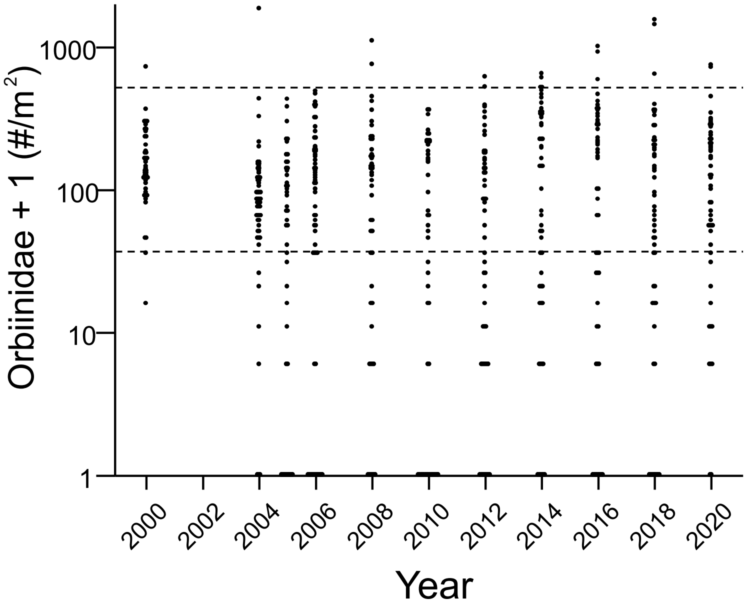

Figure 5-71 Dot Density Plot of Orbiniidae Abundance by Year

Note: Station 31 was excluded. Values of 37 and 521 individuals per m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

Isopoda Abundance

Isopod abundances varied between 5 and 485 individuals per m², with an area-wide average of approximately 133 individuals per m² in 2020. Abundances increased significantly with distance to the nearest active drill centre in 2020 ($\rho_s = 0.471$, $p < 0.001$, All stations; $\rho_s = 0.588$, $p < 0.001$, repeated-measures stations), as in most previous EEM years (Figure 5-72). The threshold model for isopods was significant in 2020 and in most previous years (Table 5-30). The estimated threshold distance in 2020 was 2.1 km; comparable to most previous years when a significant threshold was detected (Table 5-30).

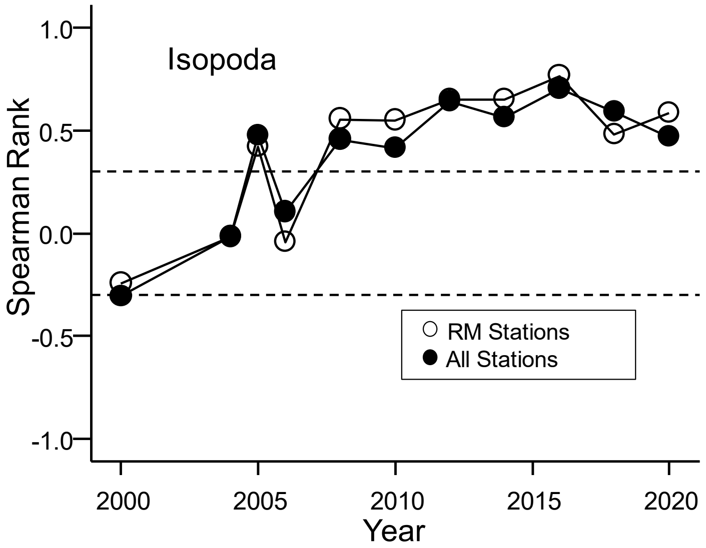

Figure 5-72 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre for Isopoda Abundance

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.

Table 5-30 Threshold Distances Computed from Threshold Regressions on Distance from the Nearest Active Drill Centre for Isopoda Abundance

Year	Threshold Distance (km)
2004	9.1 (0.03 to 2317)*
2005	No threshold
2006	No threshold
2008	2.0 (1.1 to 3.6)
2010	No threshold
2012	1.0 (0.8 to 1.3)
2014	2.5 (1.1 to 5.6)
2016	2.3 (1.3 to 4.0)
2018	No threshold
2020	2.1 (1.0 to 4.2)

Note:
- 95% confidence limits are provided in brackets.
- * [1] Wide confidence limits around threshold estimates indicate a poor model fit and suggest that the threshold estimate might be unreliable and or/that the threshold model provides little improvement over a simple bivariate model (see Appendix A-7 for details). Visual assessment of the fitted line for 2004 in Figure 5.73 provides a good example of this.

Figure 5-73 provides a graphical representation of the relationship between isopod abundance and distance to active drill centres. As indicated in Figure 5-73, the “normal range” of variation for isopod abundance across the sampling area was computed from the 2000 baseline data. Values ranged from 2 to 99 individuals per m² in 2000. The lower range of 2 individuals per m² was used as a “benchmark” against which to variations over time (Figure 5-74). Figure 5-74 indicates isopod abundances were not reduced to below the baseline range at any drill centre in 2020.

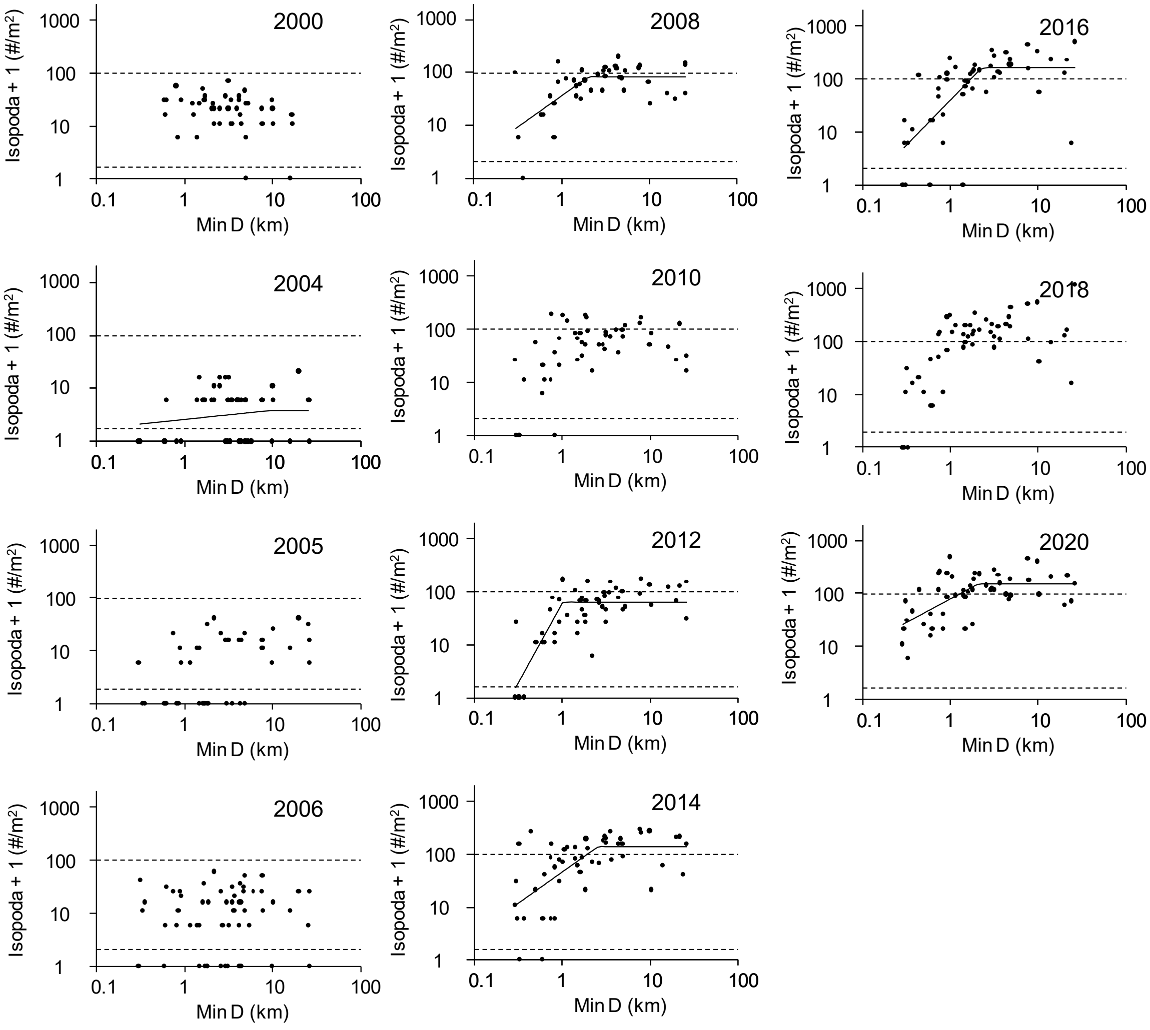

Figure 5-73 Variation in Isopoda Abundance (#/m²) with Distance from Nearest Active Drill Centre (all Years)

Notes: Station 31 was excluded. 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 2 and 99 individuals per m² are indicated by horizontal lines, based on the mean values ± 2 SDs from 2000 (baseline).

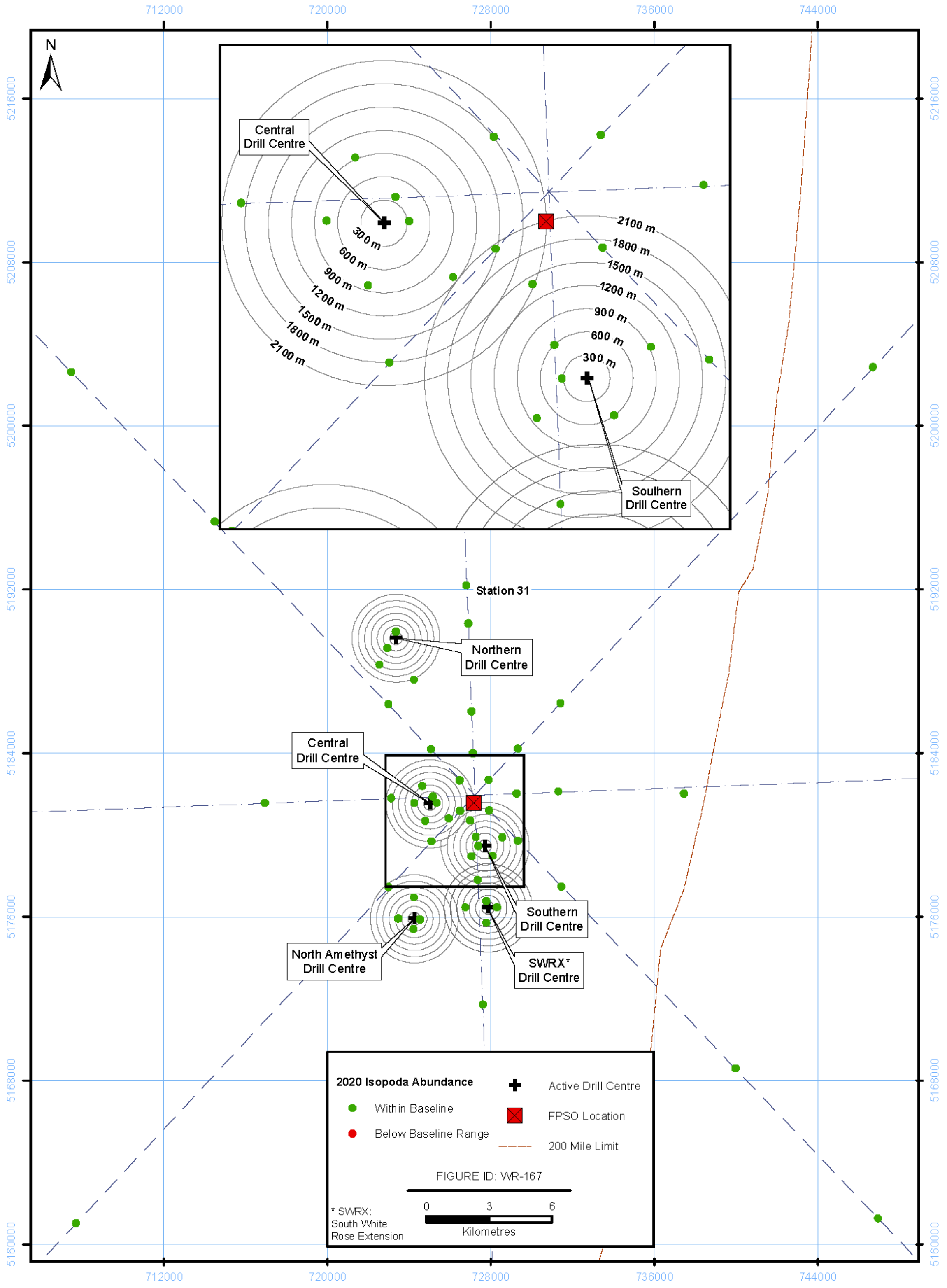

Figure 5-74 Location of Stations with Isopoda Abundance Values Within and Below the Baseline Range (2020)

Note: Station 31 is identified in this figure but excluded from other figures and analyses.

Repeated-measures regression indicated that slopes of the relationship between isopod abundance and distance to the nearest drill centre varied linearly in EEM years (*p* = 0.001, Table 5-31), and from before to after drilling (*p* < 0.001) for repeated-measures stations. The slope of the distance relationship was negative in baseline, it was near zero in the first EEM year (2004) and slopes then generally became positive and gradually increased in strength over time (Figure 5-72). There were significant variations in mean abundance over time in EEM years (*p* < 0.001), but not from before to after drilling (*p* = 0.594). Overall abundance progressively increased over time in EEM years (Figure 5-75). As was the case for Cirratulidae, these more general changes in abundances over time are more likely indicative of natural variation.

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

Trend over Time Contrast		Before to After Contrast	
Slope	**Mean**	**Slope**	**Mean**
0.001	<0.001	<0.001	0.594

Notes:
- Values are probabilities.
- *n* = 35.
- The Mean Term tests for linear trends over time common to most stations either since drilling began (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after the start of drilling (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from drill centres) either since drilling began (Trend over Time Contrast) or for a difference from baseline to after the start of drilling (Before to After Contrast).

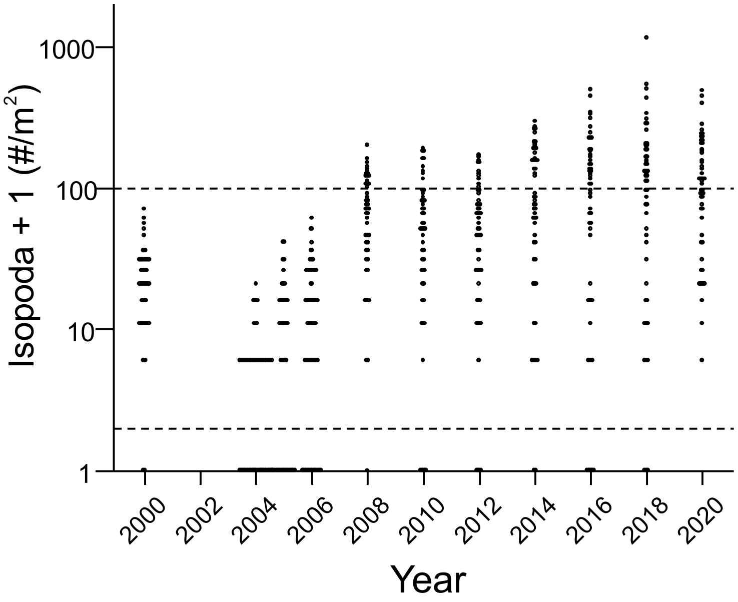

Figure 5-75 Dot Density Plot of Isopoda Abundance by Year

Note: Station 31 was excluded. Values of 17 and 99 individuals per m² are indicated by horizontal lines, based on the mean values ± 2 SDs from the baseline year (2000).

5.2.3.3 Correlations Between Univariate Measures of Benthic Community Structure and Physical Variables

Stronger correlations occurred between physical variables and abundances of individual taxa than they did for summary measures of benthic community structure (Table 5-32). In general, abundances of Paraonidae, Orbiniidae and Isopoda decreased and abundances of Cirratulidae increased with increasing concentrations of sediment >C_{10}-C_{21} hydrocarbons, barium, % fines, sulphur, lead, and strontium. Biomass also decreased with increasing concentrations of >C_{10}-C_{21} hydrocarbons, barium, lead and strontium. To varying degrees, there was evidence of project effects on these physical variables (see preceding sections), although correlations between these and benthic community variables could represent common correlations with distance to drill centres rather than causation.

There were weak correlations between some benthic community variables and sediment ammonia, organic carbon, sulphides and metals concentrations, and many benthic variables were influenced by water depth (Table 5-32). The weak association between total abundance and barium concentration was more likely related to an association between total abundance and overall metals concentration since total abundance was also related to overall metals and was not related to any other variable known to be influenced by project activity (barium covaries with other metals in addition to being influenced by project activity). In 2020, none of the indices of benthic community composition were significantly related to redox potential or laboratory amphipod survival, and richness was not significantly related to any environmental descriptor (Table 5-32).

Table 5-32 Spearman Rank Correlations (ρ_S) of Indices of Benthic Community Composition with Environmental Descriptors (2020)

Environmental Descriptor	**Index of Invertebrate Community Composition**						
	Total Abundance	**Biomass**	**Richness**	**Paraonidae Abundance**	**Cirratulidae Abundance**	**Orbiniidae Abundance**	**Isopoda Abundance**
>C_{10}-C_{21}	0.236	-0.431**	0.065	**-0.767*** **	**0.742*** **	**-0.618*** **	**-0.457*** **
Barium	0.291*	-0.379**	0.101	**-0.668*** **	**0.645*** **	**-0.618*** **	**-0.460*** **
% Fines	0.209	-0.074	-0.003	-0.408**	**0.534*** **	**-0.456*** **	-0.383**
Organic Carbon	0.287*	-0.039	-0.200	-0.181	0.243	-0.259	-0.270*
Ammonia	0.192	-0.029	-0.121	-0.272	0.370**	-0.122	-0.287*
Sulphide	0.016	-0.224	-0.169	-0.352*	0.234	-0.148	-0.143
Sulphur	0.180	-0.174	-0.165	**-0.529*** **	0.317*	-0.295*	-0.383**
Metals PC1	0.311*	-0.133	0.182	-0.152	0.184	-0.265*	-0.062
Lead	0.115	-0.313*	0.039	**-0.517*** **	0.408**	**-0.474*** **	-0.136
Strontium	0.124	-0.378**	0.039	**-0.470*** **	**0.468*** **	**-0.514*** **	0.371**
Redox	-0.043	0.195	-0.193	0.151	-0.050	0.192	0.025
Laboratory Amphipod survival	-0.254	0.245	-0.166	-0.128	0.001	0.070	-0.202
Water Depth	-0.107	0.335*	0.120	0.312*	-0.424**	0.116	0.068

Notes: - *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$ (**in bold**).
- n = 52 with Station 31 excluded.

5.2.3.4 Multivariate Analyses

Significant differences in benthic invertebrate community structure (based on multivariate assessment of taxa abundance) relative to distance from nearest active drill centres were detected among samples collected in 2020 (PERMANOVA Pseudo-$F_{5,46}$ = 7.39; *P*(perm) < 0.001, Table 3-4, Appendix A-7).

Specifically, station groups less than 500 m and 500 to 1,000 m from active drill centres were significantly different from other groups (Figure 5-76). Stations 1,000 to 2,000 m from drill centres were similar to stations located more than 8,000 m from drill centres, but different from stations located from 2,000 to 8,000 m. Station groups from 2,000 to more than 8,000 m were statistically indistinguishable (see Appendix A-7 for details).

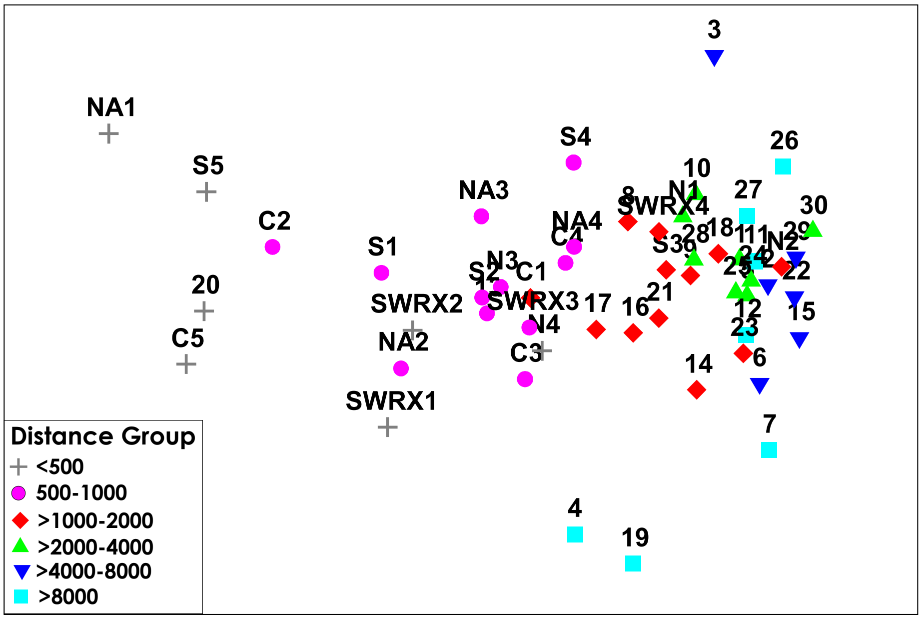

Figure 5-76 nMDS Scatterplot Based on Bray-Curtis Similarities of Benthic Infauna Assemblage Matrix Sampled in 2020 Grouped by Distance

Notes: *n* = 52 with Station 31 excluded. Stress = 0.13. 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 (DISTLM), the resulting model explained 46% of the variation in the benthic assemblages (Table 5-33). The individual sediment physical and chemical variable contributing most to this variation was >C_{10}-C_{21} hydrocarbons (38%). The subsequent addition of sulphur and percent fines explained a further 8% of the variation in the benthic assemblage. The remaining variables: sulphide, redox potential, organic carbon, ammonia, metals PC1, and sediment concentrations of barium, lead and strontium did not significantly improve the multivariate model[19].

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

Table 5-33 Results of DISTLM Multivariate Multiple Stepwise Regression of Predictor Variables on Bray-Curtis Similarities of 2020 Benthic Infauna Assemblage Matrix

Variable	*p*	Sequential Proportion of Variance Explained	Cumulative R^2
>C_{10}-C_{21}	**<0.001*****	0.379	0.379
Sulphur	**<0.001*****	0.052	0.431
% Fines	0.015*	0.025	0.456

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 A-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 Cirratulidae was most influential (12.7%), followed by Paraonidae polychaetes (11.6%) and Cirripedia crustaceans (8.0%). The remaining taxa that contributed to 5% or more of the observed differences between these two distance groups were from the polychaete family Orbiniidae (5.1%). Isopoda contributed only 3.6% of the variation in community structure between samples within 500 m of the nearest active drill centre and those greater than 8,000 m.

The mean abundance of Cirratulidae within 500 m of the nearest active drill centre was 1,354 individuals per m² versus 149 individuals per m² at stations more than 8,000 m away (Table 5-34). A similar trend of enrichment near drill centres was seen for the polychaete Cirripedia. The mean abundance of Paraonidae within 500 m of drill centres was ~5 individuals per m² versus 623 individuals per m² at stations greater than 8,000 m away, with similar trends for Orbiniidae and Isopoda.

Table 5-34 Mean Abundance of Key Benthic Infauna Taxa by Distance Group (2020)

Distance Groups	*n*	Mean Abundance (individuals per m²)				
		Paraonidae	Cirratulidae	Cirripedia	Orbiniidae	Isopoda
<500	7	4.84	1354	334	9.00	34.6
500 to 1,000	12	91.4	971	15.5	81.4	98.8
>1,000 to 2,000	12	517	339	3.00	158	107
>2,000 to 4,000	8	886	94.5	0	248	168
>4,000 to 8,000	6	593	41.2	28	149	159
>8,000	7	623	149	0.410	167	154

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

Multiyear comparison of benthic invertebrate community structure (*i.e.*, taxa abundances from 2016 to 2020) 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 5-35; Figure 5-77). These results indicate that while benthic invertebrate community structure significantly differed among the three years sampled, relationships with distance from nearest active drill centres were statistically indistinguishable between these sampling events (Figure 5-77) (*i.e.,* distance effects in any year were not significantly stronger, or weaker, than any other).

Table 5-35 Results of Two-way PERMANOVA Testing Main Effects of Location and Year on Bray-Curtis Similarities of Benthic Infauna Assemblage Matrix (2016, 2018, and 2020)

Source	df	MS	Pseudo-F	P(perm)	Unique Perms
Distance	5	6468	19.35	**<0.001*****	4969
Year	2	8879	26.56	**<0.001*****	4980
Distance x Year	10	230	0.69	0.9714	4956
Residual	136	334			
Total	153				

Notes: - 2016 - *n* = 50 with Stations 31, NA2, and SWRX4 excluded. In 2016, benthic invertebrate samples from Stations NA2 and SWRX4 returned anomalous results with low abundances and biomass.
-2018 and 2020 – *n* = 52 with Station 31 excluded.
-Further explanations and model details are provided in Appendix A-7.

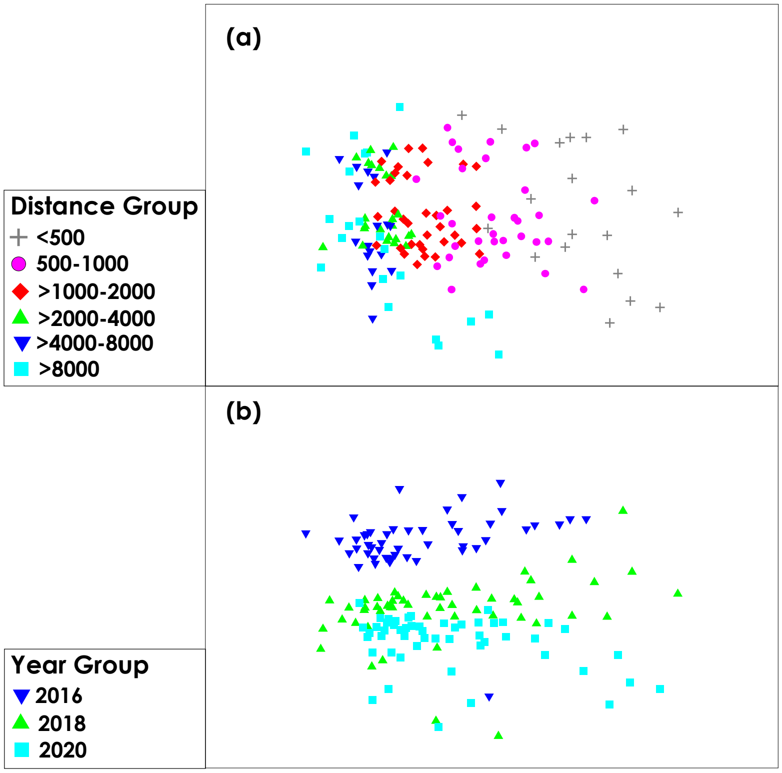

Figure 5-77 nMDS Scatterplot Based on Bray-Curtis Similarities of Benthic Infauna Assemblage Matrix Sampled in 2016, 2018, and 2020 - a) Grouped by Distance, and b) Grouped by Year

Notes: Station 31 was excluded from all years. Stations NA2 and SWRX4 from the 2016 EEM program were excluded because benthic invertebrate samples from that year returned anomalous results. 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 2020, with concentrations elevated up to estimated threshold distances of 2.5 km and 1.1 km from the nearest active drill centre, respectively. Significant threshold distances (*i.e.*, the distance at which values return to background or near 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 2.4 to 5.8 km from 2010 to 2020. 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 weaker and less consistent project-related alterations. Sediment percent fines, organic carbon, ammonia, lead, and strontium exhibited threshold relationships with distance from drill centres in 2020. Percent fines were elevated to 1.3 km from drill centres in 2020. Potential enrichment of percent fines near drill centres has been noted in previous EEM years. Relationships were too weak to assess a threshold distance in most years, but a significant threshold of 0.7 km was noted in 2014. Organic carbon was enriched to 0.85 km in 2020; and it was enriched to a distance of 1.0 km in 2018. Ammonia exhibited a threshold relationship for the first time in 2020, with a threshold distance of 5 km; however, wide confidence intervals about that estimate suggested a poor model fit (see Section 5.2.1.5 above or Appendix A-7 for details). Graphics of ammonia concentrations indicated marginally higher levels near drill centres in some EEM years; and more so in 2018 than in 2020. In 2020, there were no stations with ammonia concentrations above the baseline level and ammonia concentrations have generally decreased over time.

Sediment lead concentrations were elevated to 0.8 km from drill centres in 2020. Elevated lead levels from 0.6 to 1.5 km of drill centres have been noted since 2006. For strontium, the 2020 threshold was 5.6 km. As was the case for ammonia, wide confidence intervals about that estimate suggested a poor model fit (see Section 5.2.1.8 above or Appendix A-7 for details); and graphics of strontium concentrations versus distance from drill centres indicated lower strontium concentrations near drill centres than in some previous EEM years. Examination of concentrations above baseline levels indicated that 70% of stations (or 7 of 10 stations) with elevated strontium concentrations were within 0.5 km of drill centres in 2020. Of the three remaining stations, one was a Reference station. Threshold distances for strontium were also noted in 2006, 2008, 2012, and 2018. Thresholds in those years have been between 1 and 2 km.

Sulphur concentrations were elevated at a few stations in the immediate vicinity of drill centres in 2020, but the relationship was too weak to assess a threshold. There was little evidence of project-effects on sulphides, overall metals concentrations (Metals PC1) and redox potential in 2020. Evidence of effects on these last variables generally has been either weak or absent in EEM years. However, sulphide concentrations exhibited a threshold of approximately 1 km in 2006 and 2008.

Sediments were non-toxic in 2020 using Microtox and laboratory amphipod tests.

In 2020, there was evidence of project effects on benthic biomass and little evidence of effects on total abundance and taxa richness. The distance threshold for effects on benthic biomass was 2.9 km in 2020. Thresholds for biomass were also noted in 2012 (1.5 km) and 2012 (5.5 km). As was the case for ammonia and strontium, wide confidence intervals about the 2012 and 2020 estimates suggested a poor model fit. There has also been a general decline in biomass (*i.e.,* at all or most stations) suggesting some level of natural variation over and above project effects.

Total abundance was reduced to below the baseline range at three stations near drill centres in 2020 (see Section 5.3.2 below), otherwise there was no relationship between total abundance and distance to the nearest drill centre. Evidence of project effects on total abundance has always been weak or absent. In 2020, as in previous years, there was no relationship between taxa richness and distance to drill centres, and richness generally has increased over time.

Individual taxa identified as most affected in the 2018 EEM report were examined separately in the 2020 report. Paraonidae abundance was reduced to a distance of 1.4 km from drill centres in 2020; Orbiniidae abundance was reduced to a distance of 1.1 km; and isopod abundances was reduced to a distance of 2.1 km. Cirratulidae abundances were higher near drill centres (*i.e.,* enrichment). No threshold distances could be estimated for Cirratulidae in 2020, and only a few stations near drill centres had Cirratulidae abundances higher than the baseline range (see Section 5.3.2, below). For isopods and Cirratulidae, there also has been a general increase in abundances over time (*i.e.,* at all or most stations), after an initial decrease, suggesting natural variation.

Multivariate assessment of benthic community structure identified potential project-effects within 2 km of drill centres, and confirmed that Paraonidae, Cirratulidae and Orbiniidae were among the most affected taxa. The analysis also identified that Cirripedia abundance, like Cirratulidae abundance, was enriched near drill centres. Isopods were affected, but less so than the other four taxa (isopods contributed to less than 5% of the variation in community structure). A multi-year comparison of benthic invertebrate community structure for 2016, 2018, and 2020 (*i.e.,* since multivariate assessments began to be performed in these reports) indicated that the relationship between benthic community structure and distance to drill centres has not changed over these years (*i.e.,* there has been no accentuation of effects).

Both the univariate and the multivariate assessments identified sediment concentrations of $>C_{10}$-C_{21} hydrocarbons as a strong correlate with benthic community variables. These and prior results indicate that $>C_{10}$-C_{21} hydrocarbons is a good indicator of the presence of drill muds in sediments.

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.

In 2020, total abundance was reduced to below the baseline range at Stations SWRX1 and 14 around the SWRX Drill Centre, and at Station 23 around the Central Drill Centre. Distances to the nearest drill centre for Stations SWRX1, 14 and 23 are 0.32 km, 1.4 km, and 1.81 km, respectively.

Total biomass was reduced at many stations in 2020, indicating the potential influence of natural variation over and above project-effects, since some of the stations were far from drill centres. Biomass was reduced to below the baseline range at 8 of 10 stations around the Central Drill Centre. The most distant of these stations (Station 21) is located 1.87 km from the drill centre. Biomass was also reduced to below the baseline range at three stations around the North Amethyst Drill Centre, at four stations around each of the SWRX and Southern Drill Centres, and at one station around the Northern Drill Centre. The most distant of these stations to any drill centre is Station S3, 1.4 km from the Southern Drill Centre. As noted, biomass was also reduced at many stations outside of the immediate vicinity of drill centres (*i.e.,* outside of the 2 km radius used to examine individual drill centre effects). The most distant of these stations is Station 4 (a Reference Station), located 26 km from the nearest drill centre.

Richness was not reduced to below the baseline range at any station in 2020.

Paraonidae abundance was reduced to below the baseline range at six stations around the Central Drill Centre, at three stations around each of the North Amethyst Drill Centre and SWRX Drill Centres, at four stations around the Southern Drill Centre and at two stations around the Northern Drill Centre. Stations C5, 20, C3, C2, C1, 17, NA1, NA2, NA3, SWRX1, SWRX2, SWRX3, S5, 13, S1, S2, N4, and N3 had abundances below the baseline range. Most of these stations are within 0.5 km from drill centres. Stations C3, C2, NA3 and SWRX3 are within approximately 1 km of drill centres; and Station 17 is 1.81 km from the Central Drill Centre.

Cirratulidae abundance was above the baseline range at three stations around the Central Drill Centre (Stations C5, 20, and C2) and at one station around each of the North Amethyst and Southern Drill Centres (Stations NA3 and S5, respectively). Stations NA3 and C2 are located at 0.63 and 0.83 km from the nearest drill centre, respectively. Remaining stations are within 0.5 km of drill centres.

Orbiniidae abundance was below the baseline range at three stations around each of the Central, Southern and SWRX Drill Centres, and at two stations around the North Amethyst Drill Centre. Stations 20, C2, C1, NA1, NA2, SWRX1, SWRX2, SWRX3, S1, 13, and S5 had abundances below the baseline range. Six of these stations are located within 0.5 km of drill centres, the remaining five are located within approximately 1 km (1.14 km is the furthest distance to drill centre).

Although isopods showed an increase in abundance with distance from drill centre (see Section 5.3.1, above), their abundance was not reduced to below the baseline range at any drill centre.

Overall, 2020 data suggest that for most benthic indices and individual taxa, the majority of effects occurred within 0.5 to 1 km of drill centres, with more subtle and/or highly localized effects between 1 to 2 km. Effects on biomass could have extended beyond 2 km, but project effects are difficult to decouple from what appears to be a general decline in biomass in the sampling area. That overall effects generally were contained within 2 km is supported by the 2020 multivariate assessment, which showed that stations beyond 2 km of drill centres were indistinguishable from each other. These results are consistent with those noted in previous years.

In terms of magnitude of effect in 2020, and examining only the stations nearest the drill centres, mean >C_{10}-C_{21} hydrocarbon concentration was highest at the North Amethyst Drill Centre and it was also relatively high at the SWRX Drill Centre (Table 5-36). Mean barium concentrations were also relatively high at the North Amethyst and SWRX Drill Centres. The maximum >C_{10}-C_{21} hydrocarbon and barium concentrations occurred at Station NA1, located 0.29 km from the North Amethyst Drill Centre; although concentrations were also relatively high at Station C5, located 0.33 km from the Central Drill Centre, and Station SWRX1, located 0.32 km from the SWRX Drill Centre.

Table 5-36 highlights drill centre stations where benthic indices or taxa abundances were reduced (or enriched for Cirratulidae abundance) by more than 25% of the baseline range in 2020. In general, results indicate stronger effects at the Central, North Amethyst and SWRX Drill Centres than at the Northern or Southern Drill Centres. Total benthic invertebrate abundance, richness, and isopoda abundance were not reduced by more than 25% of the baseline range at any drill centre station. Biomass was reduced by more than 25% of the baseline range at a total of 12 drill centre stations. Most of these reductions occurred around the Central, North Amethyst, and SWRX Drill Centres, with only one station showing biomass reductions around each of the Northern and Southern Drill Centres. Paraonidae abundance also was reduced by more than 25% of the baseline range at a total of 12 stations, with the number of affected stations greater around the Central Drill Centre. Cirratulidae abundance was most affected around the Central Drill Centre, with abundance at two stations around that drill centre enriched by more than 25% of the baseline range. Finally, Orbiniidae abundance was most affected around the SWRX Drill Centre, with abundance at three stations reduced by more than 25% of the baseline range.

Table 5-36 Values at Drill Centre Stations for Selected Variables

Station	Distance to Drill Centre (km)	Barium (mg/kg)	$>C_{10}$-C_{21} (mg/kg)	Abundance (#/m²)	Biomass (g/m²)	Richness	Paraonidae (#/m²)	Cirratulidae (#/m²)	Orbiniidae (#/m²)	Isopoda (#/m²)
Central Drill Centre										
C1	1.14	170	1.8	3020	349	37	110	740	30	90
C2	0.83	350	11	6910	49	43	10	3960	15	20
C3	0.74	320	4.8	2550	3	40	35	560	55	115
C4	0.92	250	2.5	3965	215	45	290	675	185	240
C5	0.33	1000	86	6525	4	30	0	4045	50	5
Mean	**0.79**	**418**	**21.2**	**4594**	**124**	**39**	**89**	**1996**	**67**	**94**
Northern Drill Centre										
N1	2.18	170	0.47	4930	694	38	1665	195	315	230
N2	1.49	170	0.48	2410	225	25	710	75	290	20
N3	0.63	310	8	3495	809	34	40	460	80	20
N4	0.30	370	8.8	2100	623	38	15	195	40	20
Mean	**1.15**	**255**	**4.4**	**3234**	**587**	**34**	**608**	**231**	**181**	**73**
North Amethyst Drill Centre										
NA1	0.29	1200	100	10515	111	30	5	995	10	10
NA2	0.50	510	19	2490	395	32	15	690	5	25
NA3	0.76	190	1.7	5480	129	38	120	1645	55	255
NA4	1.00	170	1.4	4330	95	35	255	1095	275	485
Mean	**0.64**	**518**	**31**	**5704**	**183**	**34**	**99**	**1106**	**86**	**194**
Southern Drill Centre										
S1	0.60	250	11	4345	381	45	15	1575	10	15
S2	0.83	230	3	2885	19	32	35	950	60	40
S3	1.40	190	1.1	3670	284	31	1080	580	305	90
S4	0.92	210	1.6	5180	1204	42	580	580	720	85
S5	0.31	680	100	8570	288	45	5	4185	0	70
Mean	**0.81**	**312**	**23.3**	**4930**	**435**	**39**	**343**	**1574**	**219**	**60**
SWRX Drill Centre										
SWRX1	0.32	990	96	1800	139	32	15	295	5	30
SWRX2	0.44	770	11	3085	156	39	10	610	5	115
SWRX3	0.74	280	4.5	2940	6	37	120	485	20	235
SWRX4	1.06	190	1.2	4300	484	33	1605	525	125	205
Mean	**0.64**	**558**	**28**	**3031**	**196**	**35**	**438**	**479**	**39**	**146**

Notes: - Shading for individual stations indicates values showing a 25% difference from the baseline range for benthic invertebrates. For total abundance, biomass, richness, and abundance of Paraonidae, Orbiniidae, and Isopoda, values 25% below the baseline ranges were below 1,414 #/m², 275 #/m², 17 #/m², 98 #/m², 28 #/m², and 2 #/m², respectively. For Cirratulidae, which showed an increase rather than a decrease in numbers, values 25% above the baseline range were those above 2,025 #/m².

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 October 5 and 16, 2020. 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
2020 EEM Program	Study and Reference Area plaice and crab for body burden and taste analysis. Study and Reference Area plaice for health analysis.	October 5 to October 16, 2020

Notes:
- Since the location of Reference Areas sampled from 2004 to 2020 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 2004 for details).
- Sampling was conducted later in 2020 because of Covid-19 restrictions during Spring/early Summer. Deferral of sampling at Covid-19 alert level 4 or higher was approved by the C-NLOPB.

Details on the collection and processing of samples from 2000 to 2018 are presented in Husky (2001, 2003, 2005, 2006, 2007, 2009, 2011, 2013, 2015, 2017, 2019). Sampling locations for 2020 are provided in Figure 6-1 and Appendix B-1[20].

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[20] Trawl by-catch data are no longer provided in Appendix B-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).

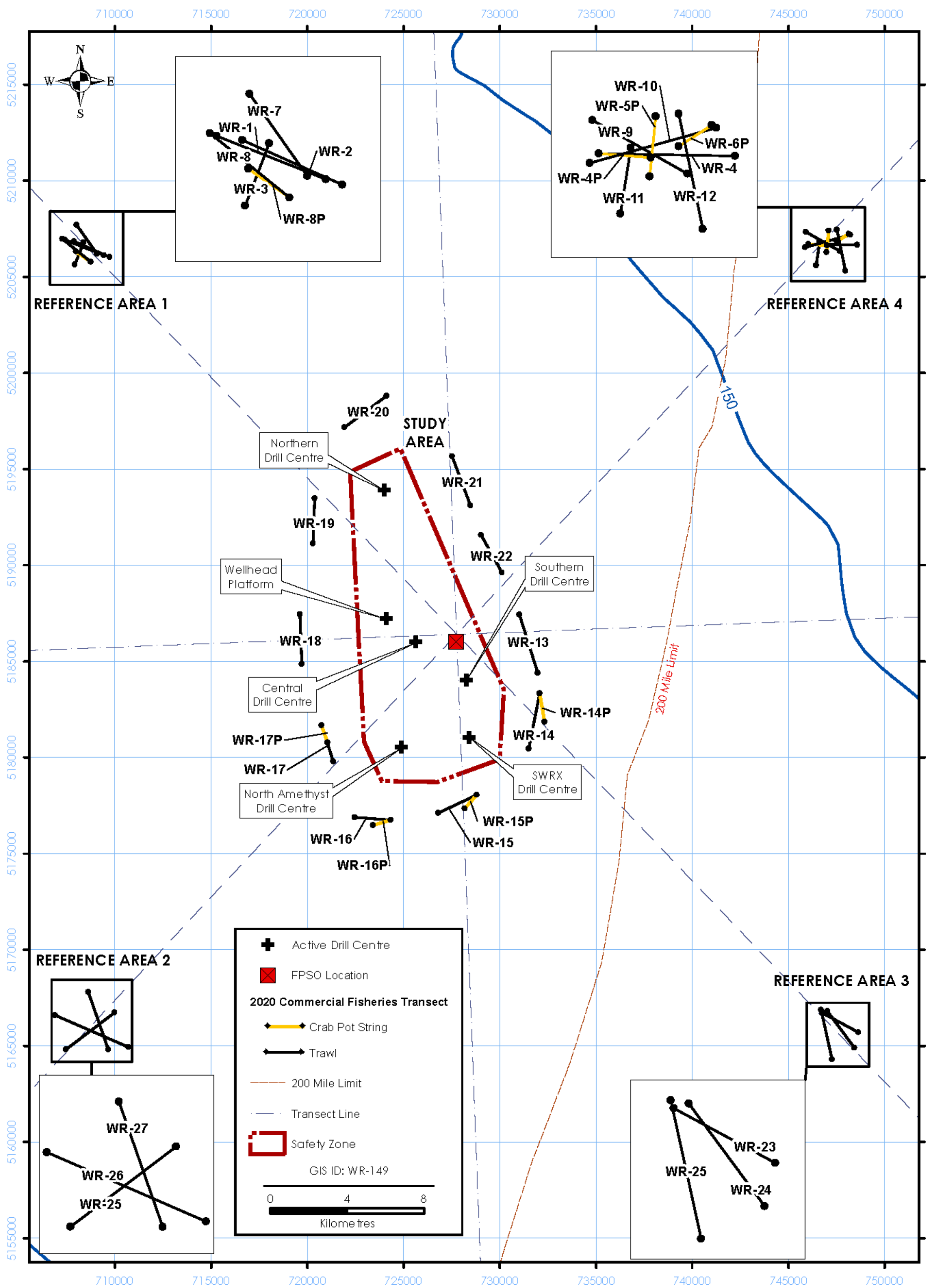

Figure 6-1 2020 EEM Program Commercial Fish Sampling Locations

Notes: Both trawls and crab pot strings were used to collect crab in 2020. Crab pot strings are identified in yellow and by the suffix ‘P’ in this figure. The indicated Wellhead Platform is a proposed location.

Sampling for the 2020 program was conducted under an experimental fishing license (NL-6019-20) using a commercial trawl for plaice, and both a commercial trawl and crab pot strings for crab. A total of 150 plaice and 144 crab from the White Rose Study Area were retained for analysis in 2020; a total of 177 plaice and 148 crab were retained from Reference Areas. Plaice and crab that were not retained were released with as little damage as possible. Five wolffish (federally listed species at risk) were collected during the commercial fish survey: three spotted wolffish (*Anarhichas minor*) were collected in separate trawls (two around the White Rose Safety Zone, one in Reference Area 4); one northern wolffish (*Anarhichas denticulatus*) was collected around the White Rose Safety Zone; and one striped (or Atlantic) wolffish (*Anarhichas lupus*) was collected in Reference Area 2. 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 sampling 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 B-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, measured to the nearest centimetre for total length and weighed to the nearest 2 g on a sea-going balance. 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 DFO in the Newfoundland Region (Annex A, Appendix B-3). Liver and gonad were weighed to the nearest 2 g on a sea-going balance. 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 3- to 5-mm thick slice was cut from the centre portion of the right half of the liver (along the longitudinal axis) and placed in Dietrich fixative for histological processing. The remainder of the right half of the liver 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 locations. 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 2020, as 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 workspace for the duration of processing of each trawl/crab pot string[21].

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 (2020)

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)
WR-13	Study Area	15	1 (15 fish)	512	6
WR-14	Study Area	15	2 (15 fish)	506	6
WR-15	Study Area	15	3 (15 fish)	496	6
WR-16	Study Area	15	4 (15 fish)	500	6
WR-17	Study Area	15	5 (15 fish)	551	6
WR-18	Study Area	15	6 (15 fish)	515	6
WR-19	Study Area	15	7 (15 fish)	506	6
WR-20	Study Area	15	8 (15 fish)	501	6
WR-21	Study Area	15	9 (15 fish)	522	6
WR-22	Study Area	15	10 (15 fish)	551	6
Study Area Total		**150**	**10**	**5,120**	**60**
WR-1	Reference Area 1	21	11 (21 fish)	751	10
WR-2	Reference Area 1	15	12 (15 fish)	748	10
WR-3	Reference Area 1	15	13 (15 fish)	773	10
WR-26	Reference Area 2	15	14 (15 fish)	807	10
WR-27	Reference Area 2	15	15 (15 fish)	690	10
WR-28	Reference Area 2	15	16 (15 fish)	726	10
WR-23	Reference Area 3	15	17 (15 fish)	754	10
WR-24	Reference Area 3	15	18 (15 fish)	760	10

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[21] Field blanks are only processed for chemistry if results from sample tissues indicate potential onboard contamination.

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)
WR-25	Reference Area 3	15	19 (15 fish)	757	10
WR-4	Reference Area 4	11	20 (11 fish)	340	10
WR-9 + WR-10 + WR-11	Reference Area 4	16	21 (16 fish)	420	15
WR-12	Reference Area 4	15	22 (15 fish)	1,602	5
Reference Area Total		**177**	**12**	**9,128**	**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.

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 (2020)

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)
WR-13	Study Area	12	1 (12 crab)	806
WR-14 + WR-14P	Study Area	8	2 (8 crab)	666
WR-15 + WR-15P	Study Area	30	3 (30 (crab)	800
WR-16 + WR-16P	Study Area	21	4 (21 crab)	809
WR-17 + WR-17P	Study Area	16	5 (16 crab)	804
WR-18	Study Area	12	6 (12 crab)	812
WR-19	Study Area	12	7 (12 crab)	822
WR-20	Study Area	12	8 (12 crab)	800
WR-21	Study Area	12	9 (12 crab)	802
WR-22	Study Area	9	10 (9 crab)	816
Study Area Total		**144**	**10**	**7,937**
WR-1	Reference Area 1	12	11 (12 crab)	800
WR-2 + WR-3 + WR-7	Reference Area 1	11	12 (11 crab)	922
WR-8P	Reference Area 1	8	13 (8 crab)	443
WR-26	Reference Area 2	8	14 (8 crab)	678
WR-27	Reference Area 2	18	15 (18 crab)	755
WR-28	Reference Area 2	16	16 (16 crab)	761
WR-23	Reference Area 3	12	17 (12 crab)	726
WR-24	Reference Area 3	6	18 (6 crab)	718
WR-25	Reference Area 3	15	19 (15 crab)	721
WR-4 + WR-4P	Reference Area 4	18	20 (18 crab)	1,110
WR-5P	Reference Area 4	12	21 (12 crab)	552
WR-6P	Reference Area 4	12	22 (12 crab)	560
Reference Area Total		**148**	**12**	**8,746**

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.
- Crab pot strings are identified by the suffix ‘P’ in this table.

6.1.2.2 Body Burden

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

Table 6-4 Body Burden Variables (2000, 2002, 2004, 2005, 2006, 2008, 2010, 2012, 2014, 2016, 2018 and 2020)

Variables	Method	Laboratory Detection Limits							Units
		2000	2002	2004 & 2005	2006	2008, 2010 & 2012	2014	2016, 2018 & 2020	
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

Variables	Method	Laboratory Detection Limits							Units
		2000	2002	2004 & 2005	2006	2008, 2010 & 2012	2014	2016, 2018 & 2020	
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
Other									
Percent 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). 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, homogenized in a food processor and allocated to either the triangle or the hedonic scaling test. Tools and work areas including spoons, bowls, homogenizer and countertops were cleaned thoroughly to avoid contamination between samples. 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 in a steam cooker, 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. Tools and work areas including the steam cooker, spoons, bowls, homogenizer and countertops were cleaned thoroughly to avoid contamination between sample. Crab was served to taste panelists in glass cups at room temperature.

Each panel included 22 to 24 panelists[22] 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.

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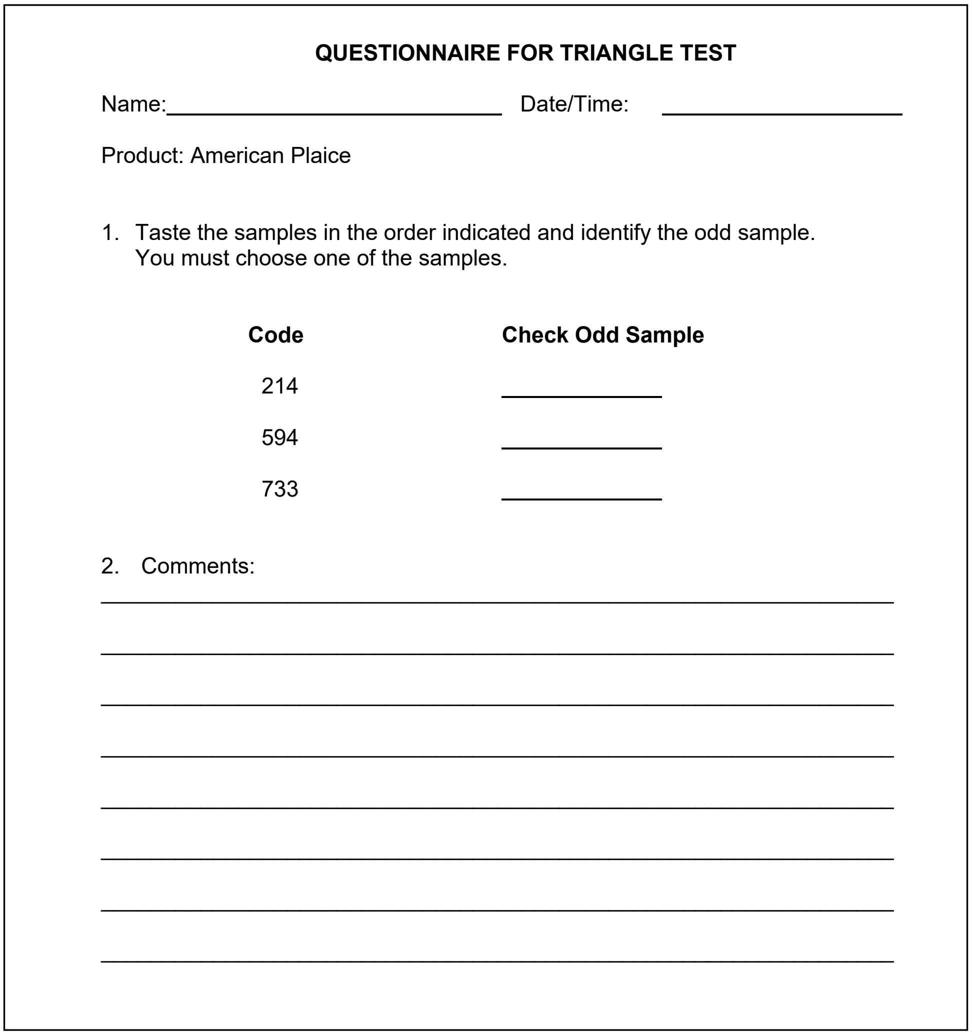
[22] A panel of 24 people is the norm for the White Rose EEM program. In 2020, although 24 people were scheduled for each test, two of these people were absent for the crab triangle test, one was absent for the crab hedonic scaling test, and one response for the plaice hedonic scaling test had to be disqualified because the panellist assessed only one of the two samples provided.



QUESTIONNAIRE FOR TRIANGLE TEST

Name:____________________________ Date/Time: ____________________

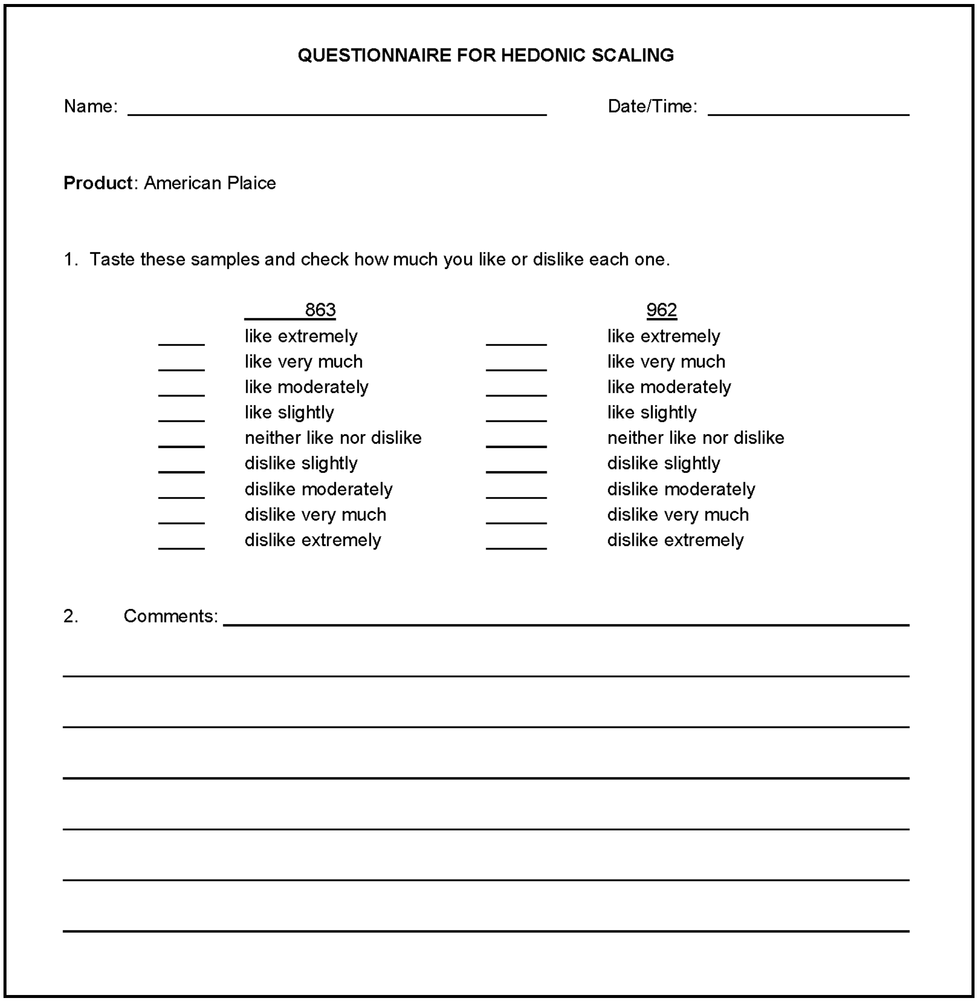
Product: American Plaice

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 B-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. 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 in Section 6.1.3.5). Formal comparisons among years were not conducted.

Plaice

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

Additional analyses of biological characteristics of plaice examined in the context of Fish Health Assessment focused on female fish because too few males were caught for statistical analyses[23]. Differences in maturity stages between the Study and Reference Areas for female fish were assessed with Fisher's Exact Test. Total length, gutted weight and age were compared using asymmetrical ANOVA (*i.e.*, with no covariate or X variable). The regression analogues of three condition indices - Fulton Condition Factor, hepatosomatic index, and gonadosomatic index - were analyzed via asymmetrical Analysis of Covariance (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 a Shell Condition Index[24]. Recent moults included crab with Shell Condition Index values of 1 or 2. Non-recent moults included crab with Shell Condition Index values of 6 (probably one year since moult) and 3 or 4 (two or more years since moult).

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[23] A total of nine males were caught over all Reference Areas, and no males were caught in the Study Area.

[24] The shell condition index used for White Rose is the index used by DFO in Newfoundland and Labrador offshore surveys.

Asymmetrical ANOVA was used to test for significant differences in carapace width and claw height between the Reference and Study Areas. Frequency of recent moults was examined qualitatively.

6.1.3.3 Body Burden

Plaice

Spatial Variations in 2020

Body burden variables that were statistically analyzed were those that were frequently detected[25]. 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.

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

Asymmetrical ANOVA was used to compare body burden data among Areas. Concentrations were corrected for moisture content[26] 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 2020[27] (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).

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[25] In most cases, variables with greater than 25% of samples with test results below laboratory detection limits were not included in statistical analyses.

[26] 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 done.

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

Table 6-5 Asymmetrical ANOVA Used for Comparison of Body Burden Variables Among Years (2020)

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)	9	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	9	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)	9	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 2020

Crab leg body burden variables analyzed were concentrations of seven frequently detected metals (arsenic, copper, mercury, silver, selenium[28], 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 2020[29] (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, Reference Areas were grouped into two groups (a North Reference Area and a South Reference Area), and concentrations were corrected for moisture content and $\log_{10}$-transformed prior to analysis.

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[28] 27% of selenium values were below laboratory detection limit in 2020. However, since the variables was frequently detected in all other years, it was included in analyses.

[29] As with plaice, data from baseline (2000) 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 B-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

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

Liver Histopathology

Fisher’s Exact Test was used to compare nuclear pleomorphism, macrophage aggregates, inflammatory response, hepatocellular vacuolation, and parasites between the Study Area and 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) (2020)

Area	*n*	Min	Max	Mean	SD
Reference Area 1	3	532	658	585	66
Reference Area 2	3	522	597	555	38
Reference Area 3	3	617	772	705	80
Reference Area 4	3	241	1187	580	527
Reference Average	12	241	1187	606	237
Study Area	10	553	1020	726	142

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

There was substantial variation in mean gutted weight among composites from Reference Area 4. The minimum mean gutted weight from that area was only 20% of the maximum gutted weight from that area (241 g versus 1,187 g) (Table 6-6, Figure 6-5).

ANOVA results on mean gutted weight are provided in Table 6-7. Initial results indicated no significant difference in composite mean weight among Areas with all data included. Subsequent removal of one statistical outlier (Studentized residual = 6.503; Reference Area 4 Composite 22) indicated statistically significant differences between Study and Reference Areas ($p = 0.003$) and among Reference Areas ($p = 0.001$; Table 6-7, Outlier Removed). Finally, removal of Reference Area 4 indicated no significant difference among remaining Areas ($p > 0.05$; Table 6-7, Reference Area 4 Removed).

Overall, results indicate that Reference Area 4 differed from remaining Areas and that Composite 22 weight was substantially greater than remaining composite weights. That extreme value obscured the initial ANOVA results.

Table 6-7 Results of Asymmetrical ANOVA Comparing Plaice Composite Mean Gutted Weight (g) Among Areas (2020)

Source	SS	df	MS	F-Ratio	*p*
All Data					
Reference *vs* Study	78353	1	78353	1.750	0.203
Among Reference	40920	3	13640	0.188	0.901
Error	761162	17	44774		
Outlier Removed					
Reference *vs* Study	156066	1	156066	11.952	0.003
Among Reference	225740	3	75247	19.711	0.001
Error	208931	16	13058		
Reference Area 4 Removed					
Reference *vs* Study	58412	1	58412	4.244	0.057
Among Reference	38129	2	19064	4.717	0.059
Error	206460	15	13764		

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

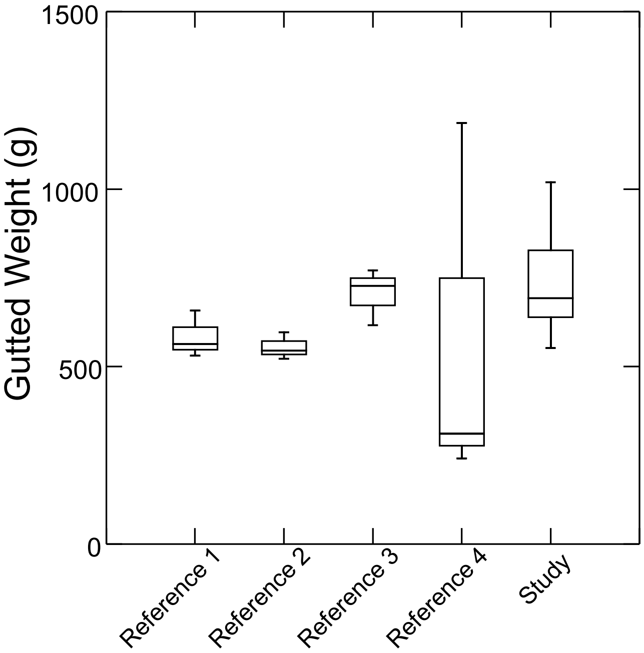

Figure 6-5 Box Plot of Plaice Gutted Weight (g) for Chemistry Composites

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 were undertaken within the context of Fish Health Assessment. Selected information is provided below, with details in Appendix B-3.

Female plaice outnumbered males in all Areas (Table 6-8), accounting for 95% of the 180 fish processed. Sex ratios differed significantly between the combined Reference Areas (F:M≈37:3) and the Study (F:M≈60:0) Area ($p = 0.030$; Fisher's Exact Test).

Table 6-8 Numbers of Female and Male Plaice (2020)

Area	Females		Males		Total
	Number	%	Number	%	Number
Reference 1	28	93.3	2	6.7	30
Reference 2	27	90.0	3	10.0	30
Reference 3	29	96.7	1	3.3	30
Reference 4	27	90.0	3	10.0	30
All References	111	92.5	9	7.5	120
Study	60	100.0	0	0.0	60
All Areas	171	95.0	9	5.0	180

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

Most females examined (79%) were mature (*i.e.,* all fish except immature F-500; $n = 135$ of 171 fish), and very few (1.5%) of the mature females were spent (F-560; $n = 2$ of 135 fish) (Table 6-9). Frequencies of immature (F-500) and pre-spawning females (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 (2020)

	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	6	21	22	79	0	0	28
Reference 2	9	33	18	67	0	0	27
Reference 3	11	38	18	62	0	0	29
Reference 4	13	48	14	52	0	0	27
All References	39	35	72	65	0	0	111
Study	10	17	50	83	0	0	60
All Areas	49	29	122	71	0	0	171

Notes: - [a] Maturity stages were defined per procedures used by DFO (Appendix B-3, Annex A)
- All References = Sum of the four 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 2020, sufficient numbers of immature (F-500) and pre-spawning females (F-510 to F-540) were caught to allow comparison.

Biological characteristics and condition of immature females (expressed as means ± SDs) from the Reference and Study Areas are summarized in Table 6-10. Across all sampling locations, immature females varied in length from 27 to 47 cm, in gutted weight from 120 to 906 g, and in age from 5 to 10 years. Length, gutted weight, and age were significantly lower in the Reference Areas than in the Study Area, driven by low values observed in Reference Area 4 (Tables 6-10 and 6-11). The influence of Reference Area 4 fish was also evident in the significant differences among Reference Areas noted for these same variables (Tables 6-10 and 6-11).

Table 6-10 Mean Biological Characteristics and Condition of Immature Female Plaice (2020)

	Area					
	Ref 1	Ref 2	Ref 3	Ref 4	Study	Total
Number of Fish	6	9	11	13	10	49
Length (cm)	37.8 ± 3	38.1 ± 2.9	37.9 ± 4.5	31.8 ± 3.4	38.8 ± 3.4	36.5 ± 4.5
Weight (g)	511 ± 130.6	482 ± 122.8	523.3 ± 209.5	295.4 ± 122	565.8 ± 126.8	462.4 ± 176.5
Gutted Weight (g)	437.7 ± 121.2	424.4 ± 109.5	458 ± 185.4	253.3 ± 99.8	490.8 ± 120.8	401.7 ± 156.6
Liver Weight (g)	10.3 ± 4.5	15.8 ± 6	16.2 ± 6.4	8.9 ± 7.3	20.2 ± 4.9	14.3 ± 7.3
Gonad Weight (g)	4.3 ± 2	9.3 ± 5.2	3.7 ± 3.3	4.7 ± 4.5	7.6 ± 5.9	5.9 ± 4.8
Age (years)	7.8 ± 1.2	8.2 ± 1	8.4 ± 0.8	6.8 ± 1	8.5 ± 1.3	7.9 ± 1.2
Condition Factor[a]	0.8 ± 0.1	0.8 ± 0	0.8 ± 0.1	0.7 ± 0.1	0.8 ± 0.1	0.8 ± 0.1
HSI[b]	2.4 ± 0.9	3.7 ± 0.9	3.6 ± 1	3.2 ± 1.6	4.2 ± 1	3.5 ± 1.3
GSI[c]	1 ± 0.5	2.2 ± 1	0.7 ± 0.4	1.7 ± 1.1	1.6 ± 1.5	1.5 ± 1.1

Notes: - [a] Condition Factor = 100 × gutted weight/length^3.
- [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 (2020)

Variable (Y)	Covariable (X)	*p*-value	
		Among Reference (AR)	Study versus References (SR)
Length		**< 0.001*****	0.030*
Gutted Weight		**< 0.001*****	0.009**
Age		0.004**	0.045*
Gutted Weight	Length	0.188	0.090
Liver Weight	Gutted Weight	0.095	0.082
Gonad Weight	Gutted Weight	0.002**	0.685

Notes: - Results were based on log-transformed values for all variables except age.
- $^{*}p \leq 0.05$; $^{**}p \leq 0.01$; $^{***}p \leq 0.001$ (in **bold**).

The gonadosomatic index (gonad weight as a function of gutted weight) for immature females differed significantly between Reference Areas (Table 6-11); Reference Area 3 females had lighter gonads relative to gutted weight (Table 6-10). The gonadosomatic index did not differ significantly differ between the Reference Areas and Study Area. condition factor (gutted weight as a function of length) and the hepatosomatic index (liver weight as a function of gutted weight) did not differ significantly among Reference Areas or between the Reference and Study Area for immature females (Tables 6-10 and 6-11).

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 (2020)

	Area					
	Ref 1	Ref 2	Ref 3	Ref 4	Study	Total
Number of Fish	22	18	18	14	50	122
Length (cm)	42.8 ± 3.7	40.7 ± 2.6	45.9 ± 5.4	40.4 ± 9.6	44.8 ± 4.9	43.5 ± 5.6
Weight (g)	797.1 ± 245.3	672.1 ± 148.8	1088.1 ± 384.5	842.7 ± 856.5	973.9 ± 374.3	899.3 ± 432.9
Gutted Weight (g)	666.3 ± 196.8	589.9 ± 130.4	918.4 ± 326.7	740.7 ± 771.3	819.8 ± 299.4	763.7 ± 368.1
Liver Weight (g)	27.2 ± 10.2	28.4 ± 8.5	37.1 ± 13.5	27.6 ± 20.8	33 ± 11.9	31.3 ± 13
Gonad Weight (g)	25.7 ± 16.3	27.6 ± 11.9	40.8 ± 19.8	25.3 ± 31.8	36.2 ± 21.4	32.5 ± 21.2
Age (years)	8.8 ± 1.4	8.5 ± 1.2	10.3 ± 1.2	8.6 ± 2.2	9.8 ± 1.1	9.4 ± 1.5
Condition Factor[a]	0.8 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.9 ± 0.2	0.9 ± 0.1	0.9 ± 0.1
HSI[b]	4.1 ± 0.9	4.8 ± 0.7	4.2 ± 0.9	4.3 ± 1	4.1 ± 0.9	4.2 ± 0.9
GSI[c]	3.6 ± 1.3	4.6 ± 1.3	4.3 ± 1.4	3 ± 1.7	4.2 ± 1.4	4 ± 1.5

Notes: - [a] Condition factor = 100 × gutted weight/length^3.
- [b] HSI = hepatosomatic index = 100 × liver weight/gutted weight.
- [c] GSI = gonadosomatic index = 100 × gonad weight /gutted weight.
- DFO maturity stages F-510 to F-540 were combined for these analyses (see Appendix B-3, Annex A for maturity stage classifications.
- Values are means ± 1 SD.

Across all sampling Areas, pre-spawning females varied in length from 30 to 59 cm, in gutted weight from 186 to 3,000 g, and in age from 6 to 13 years. Length and gutted weight were significantly lower in Reference Areas than in the Study Area, driven by low values in Reference Area 4 (Tables 6-12 and 6-13). Length and gutted weight were also significant different among Reference Areas (Table 6-13). Age was significantly different between the Reference Areas and the Study Area with older fish in the Study Area relative to the mean of all Reference Areas (Tables 6-12 and 6-13). Age was also significantly different among Reference Areas with older fish in Reference Area 3 (Tables 6-12 and 6-13).

Table 6-13 Results of Asymmetrical ANCOVA Comparing Biological Characteristics and Condition of Pre-spawning Females Plaice (2020)

Variable (Y)	Covariable (X)	*p*-value	
		Among Reference (AR)	Study versus References (SR)
Length		0.006**	0.023*
Gutted Weight		0.006**	0.022*
Age		**< 0.001*****	0.003**
Gutted Weight	Length	0.145	1.000
Liver Weight	Gutted Weight	0.091	0.724
Gonad Weight	Gutted Weight	0.011*	0.698

Notes: - ANCOVA were based on log-transformed values.
- DFO maturity stages F-510 to F-540 were combined for these analyses (see Appendix B-3, Annex A for maturity station classifications).
- One statistical outlier (Studentized residual > |4.0|; a Reference Area 4 fish) was identified in each of the analyses for length, gutted weight, condition factor, the hepatosomatic index and the gonadosomatic index. However, removal of this outlier did not change results from significant to not significant, or vice versa. Therefore, the outlier was retained in results presented above.
- $^*p \leq 0.05$; $^{**}p \leq 0.01$; $^{***}p \leq 0.001$ (in **bold**).

The gonadosomatic index (gonad weight as a function of gutted weight) differed significantly differed between Reference Areas, with heavier gonads relative to gutted weight in Reference Area 2 (Tables 6-12 and 6-13). The gonadosomatic index did not significantly differ between the mean of the Reference Areas and the Study Area. condition factor (gutted weight as a function of length) and the hepatosomatic index (liver weight as a function of gutted weight) did not differ significantly among Reference Areas or between the Reference Areas and the Study Area (Tables 6-12 and 6-13).

6.2.1.2 Crab

Shell condition index values for crab collected in 2020 and used for body burden analyses are provided in Table 6-14. The majority of the crab collected had moulted in 2020. The frequency of 2020 moults was comparable for the Study Area and Reference Areas, 1, 2 and 4. Fewer crab moulted in 2020 in Reference Area 3 (Table 6-14).

Table 6-14 Frequency (%) of Index Values Indicating Year Since Moult in Crab (2020)

Index Value	Year of Moult	Area					
		Ref 1	Ref 2	Ref 3	Ref 4	All Ref	Study
1,2	2020	77.4	92.9	48.5	88.1	78.4	81.8
6	2019	16.1	7.1	39.4	11.9	15.5	12.9
3,4	2018 or earlier	6.5	0.0	12.1	0.0	6.1	5.3
Total Crabs (*n*)		31	42	33	42	148	132

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. Both crab carapace width and claw height differed significantly between the Reference and Study Areas ($p < 0.05$; Table 6-16; Figure 6-6), with slightly larger crab in the Study Area than in the combined Reference Areas (Table 6-15). Mean carapace width and claw height also varied significantly between the Reference Areas ($p \leq 0.05$; Table 6-16) with larger crab in Reference Area 3. (Table 6-15, Figure 6-6).

Table 6-15 Summary Statistics for Biological Characteristics of Crab Based on Composite Mean Carapace Width and Claw Height (2020)

Variable	Area	*n*	Min	Max	Mean	SD
Carapace Width (mm)	Reference Area 1	3	79.8	91.1	85.1	5.7
	Reference Area 2	3	93.5	100.9	96.3	4.0
	Reference Area 3	3	97.1	102.2	100.1	2.7
	Reference Area 4	3	83.0	90.4	86.8	3.7
	Reference Average	12	79.8	102.2	92.1	7.5
	Study Area	10	91.8	104.3	96.3	3.3
Claw Height (mm)	Reference Area 1	3	14.4	19.5	17.0	2.6
	Reference Area 2	3	18.6	21.6	19.7	1.6
	Reference Area 3	3	21.4	24.7	23.4	1.7
	Reference Area 4	3	16.8	19.9	18.8	1.7
	Reference Average	12	14.4	24.7	19.7	2.9
	Study Area	10	19.3	23.8	21.5	1.4

Note: - SD = standard deviation.

Table 6-16 Results of Asymmetrical ANOVA Comparing Crab Biological Characteristics Among Areas (2020)

Variable	Source	Type III SS	df	Mean Squares	F-Ratio	*p*-value
Carapace Width	Study *vs* Reference	95.87	1	95.87	6.83	0.018*
	Among Reference	476.02	3	158.67	9.17	0.006**
	Error	238.54	17	14.03		
Claw Height	Study *vs* Reference	17.48	1	17.48	6.32	0.022*
	Among Reference	64.15	3	21.38	5.65	0.022*
	Error	47.05	17	2.77		

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

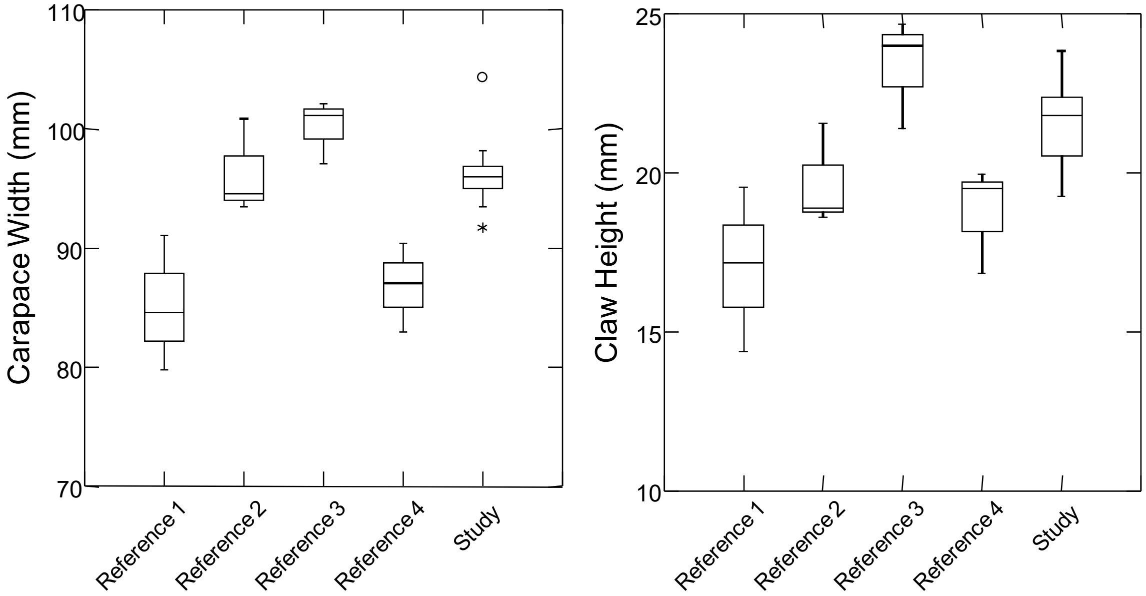

Figure 6-6 Box Plots of Crab Carapace Width (mm) and Claw Height (mm)

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.

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, 2018 and 2020, and raw data for 2020 are provided in Appendix B-2. Arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc were detected frequently in all years. Concentrations of these eight metals, percent fat, 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.; BV, pers. comm.), and similar compounds also have been consistently observed in liver tissue at the nearby Terra Nova site (Suncor Energy 2019). As in previous years, additional Gas Chromatography/Mass Spectrometer analysis of eight liver samples in 2020 (see Appendix B-2) indicated that there was no indication of drill fluid or petroleum hydrocarbons in those samples (see Appendix B-2).

Spatial Variations in 2020

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 6-7. Liver concentrations of $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, arsenic, manganese, and mercury were significantly higher in the Study Area compared to the Reference Areas (Table 6-17; Figure 6-7). Copper concentrations were significantly lower in the Study Area compared to the Reference Areas. Significant differences in selenium concentrations were noted between the Reference Areas and the Study Area. However, greater variation was noted among the Reference Areas with Study Area values intermediate to the grouping of Reference Areas 2 and 3 versus the grouping of Reference Areas 1 and 4 (Table 6-17; Figure 6-7). Concentrations of zinc and selenium varied significantly among Reference Areas (Table 6-17, Figure 6-7). No significant differences among areas were noted for percent fat, cadmium, or iron (Table 6-17; Figure 6-7).

Table 6-17 Results of Asymmetrical ANOVA Comparing Plaice Liver Body Burden Variables among Areas (2020)

Variable	*p*-values	
	Among Reference	Reference *vs* Study
Percent fat	0.269	0.132
Arsenic	0.394	0.018*
Cadmium	0.304	0.354
Copper	0.623	0.012*
Iron	0.495	0.060
Manganese	0.417	0.039*
Mercury	0.527	0.010**
Selenium	0.006**	0.012*
Zinc	0.009**	0.331
$>C_{10}$-C_{21}	0.210	0.042*
$>C_{21}$-C_{32}	0.304	**< 0.001*** **

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

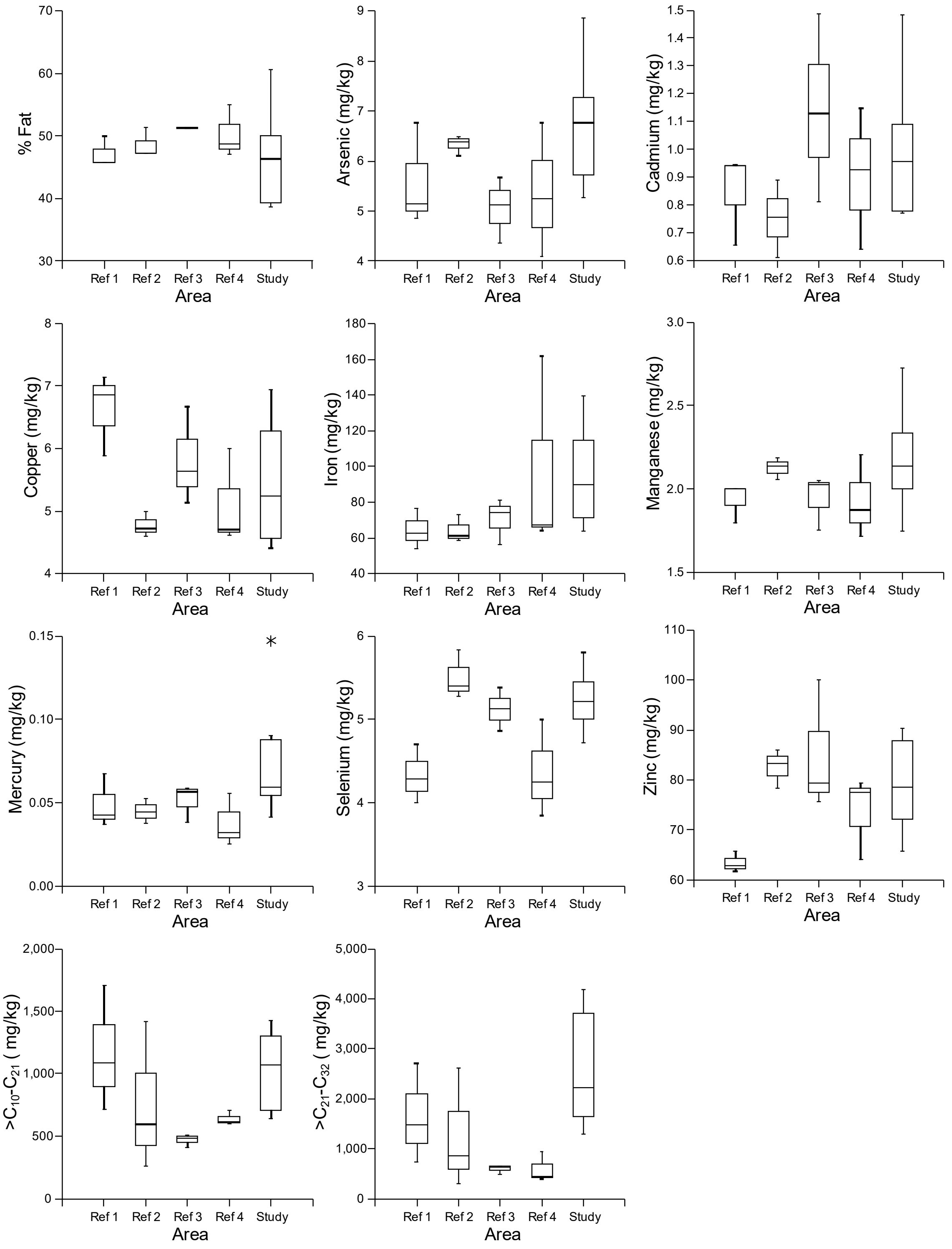

Figure 6-7 Box Plots of Variable Concentrations in Plaice Livers in Reference and Study Areas (2020)

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 2020 are illustrated in Figure 6-8. Significant area-wide quadratic trends (increase followed by a decrease or vice versa) were noted for percent fat, arsenic, cadmium, copper, iron, mercury, selenium, zinc and >C_{10}-C_{21} hydrocarbons (Table 6-18). For most of these variables except percent fat and >C_{10}-C_{21} hydrocarbons, concentrations in liver generally increased to 2014/2016 and then decreased, in all areas. For percent fat, concentrations in all areas were relatively low from 2014 to 2018 relative to other years. For >C_{10}-C_{21} hydrocarbons, concentrations in all areas were lower from 2008 to 2014 than in preceding or subsequent years (Figure 6-8). In addition to significant quadratic trends for variables noted above, there were significant linear trends for all variables (Table 6-18). With the exception of percent fat and copper, which decreased over time in all areas, remaining variables increased over time in all areas (Figure 6-8). In spite of these general trends, concentrations in 2020 were low relative to preceding years for most variables; concentrations of percent fat and >C_{10}-C_{21} and C_{21}-C_{32} hydrocarbons were high relative to preceding years (Figure 6-8).

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 2020)

Variable	Linear		Quadratic	
	Area-Wide Trend	Difference Between Reference and Study	Area-Wide Trend	Difference Between Reference and Study
Percent fat	**<0.001*****	0.622	0.029*	0.925
Arsenic	**<0.001*****	0.578	**<0.001*****	0.578
Cadmium	**<0.001*****	0.759	**<0.001*****	0.201
Copper	**<0.001*****	0.032*	**<0.001*****	0.003**
Iron	**<0.001*****	0.766	**<0.001*****	0.675
Manganese	0.002**	0.951	0.068	0.343
Mercury	**<0.001*****	0.928	**<0.001*****	0.479
Selenium	**<0.001*****	0.578	**<0.001*****	0.955
Zinc	**<0.001*****	0.989	**<0.001*****	0.409
>C_{10}-C_{21}	**<0.001*****	0.085	**<0.001*****	0.179
>C_{21}-C_{32}	**<0.001*****	0.023*	0.455	0.144

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**).

There were significant differences in quadratic trends between the Study and Reference Areas for copper (Table 6-18). Copper concentrations generally increased to 2014 in all areas. However, this increase was slightly more pronounced in the Study Area than in the Reference Areas. Subsequent to 2014, liver copper concentrations were similar between the Study and Reference Areas (Figure 6-8). This difference in the increase in copper concentrations to 2014 also drove the significant difference in linear trends between the Study and Reference Areas (Table 6-18, Figure 6-8). Finally, there was a significant difference in linear trends for >C_{21}-C_{32} hydrocarbons driven by higher concentrations in the Study Area in 2020 (Figure 6-8).

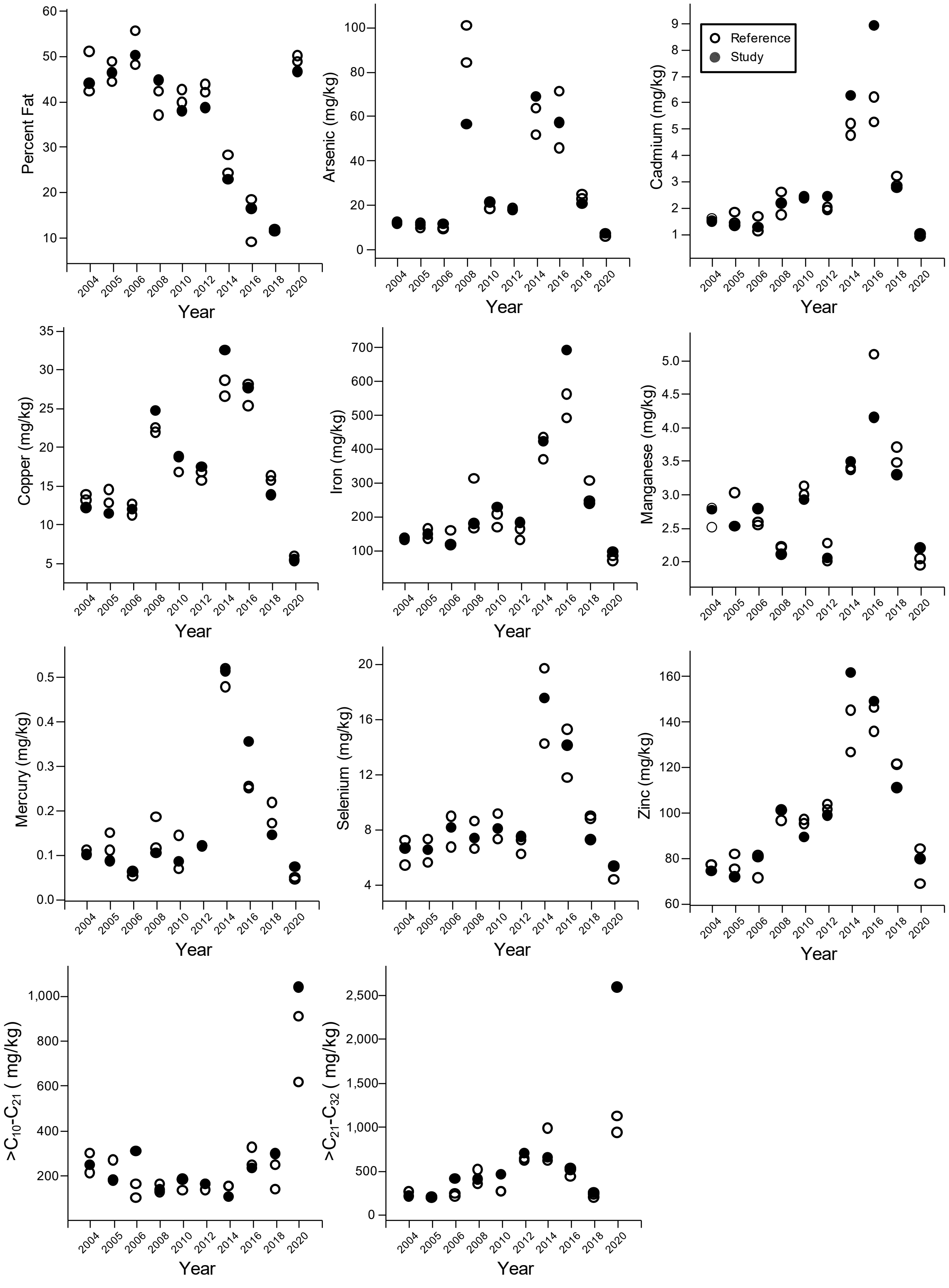

Figure 6-8 Variations in Area Means of Detectable Metals and Hydrocarbons in Plaice Liver Composites from 2004 and 2020

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, 2018, and 2020, and raw data for 2020 are provided in Appendix B-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 B-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 B-2.

Spatial Variations in 2020

In 2020, significant differences were noted between the Study Area and Reference Areas for fillet concentrations of percent fat, arsenic, and mercury (Table 6-19), with higher concentrations in Study Area fillet (Figure 6-9). No area differences were noted for zinc and no differences were noted among Reference Areas for any variable (Table 6-19).

Table 6-19 Results of Asymmetrical ANOVA Comparing Plaice Fillet Body Burden Variables among Areas (2020)

Variable	***p*-values**	
	Among Reference	**Study *vs* Reference**
Percent fat	0.076	0.010**
Arsenic	0.408	0.034*
Mercury	0.143	0.007**
Zinc	0.061	0.214

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.

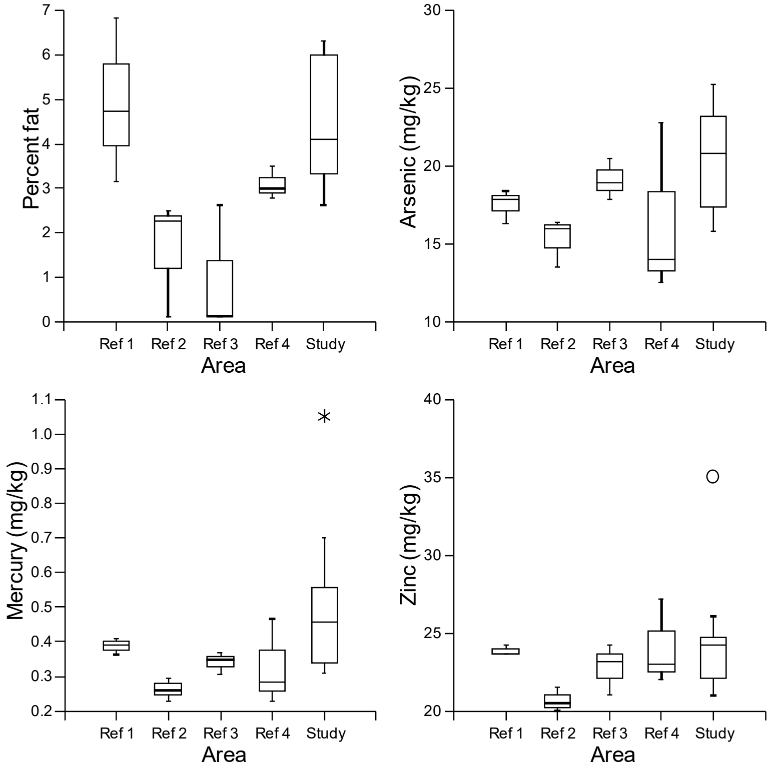

Figure 6-9 **Box Plots of Variable Concentrations in Plaice Fillets in Reference and Study Areas (2020)**

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 quadratic trends were noted for fillet arsenic and zinc (Table 6-20). Concentrations of arsenic generally increased to 2014, and then decreased in all areas (Figure 6-10). For zinc, concentrations were substantially lower in 2008 than in preceding or subsequent years. Lower concentrations in 2008 were also noted for arsenic and mercury, but the difference between 2008 and remaining years was greater for zinc, which led to the significant quadratic term. In addition to these quadratic trends, there were significant area-wide linear trends for all variables (Table 6-20). Percent fat generally decreased over time; remaining variables generally increased over time, in all areas (Figure 6-10). There was a difference in the linear trend between the Study and Reference Areas for mercury. That difference was not apparent with data to 2018 and is driven in part by lower mercury concentrations in Reference Area fillets in 2020 (Figure 6-10).

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 2020)

Variable	Linear		Quadratic	
	Area-Wide Trend	Difference Between Reference and Study	Area-Wide Trend	Difference Between Reference and Study
Percent fat	**<0.001*****	0.553	0.330	0.280
Arsenic	**<0.001*****	0.098	0.021*	0.872
Mercury	**<0.001*****	0.039*	0.538	0.354
Zinc	**<0.001*****	0.665	**<0.001*****	0.665

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* ≤ 0.05; ***p* ≤ 0.01; ****p* ≤ 0.001 (in **bold**).

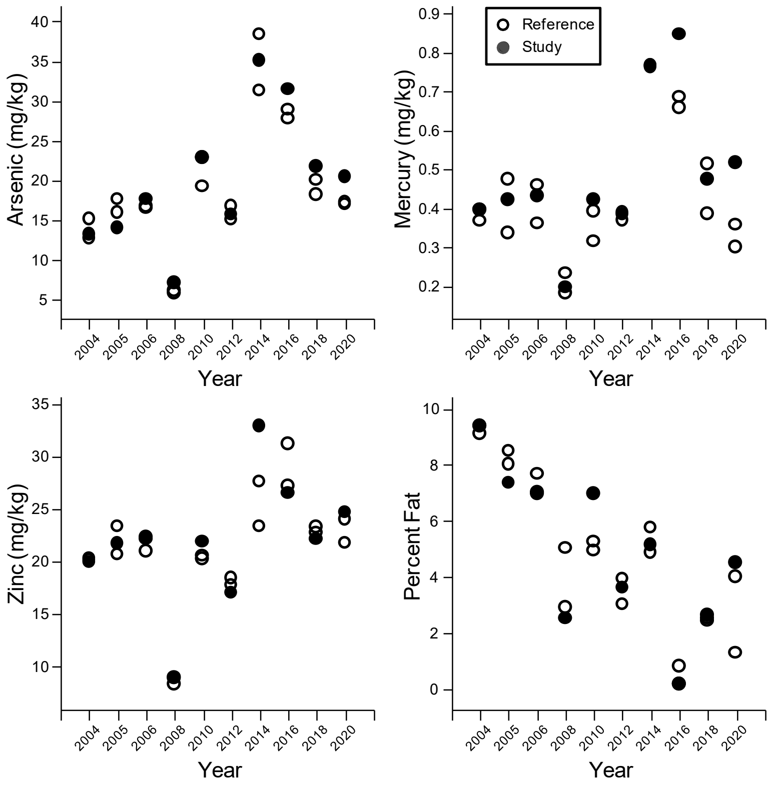

Figure 6-10 Variations in Arsenic, Mercury, and Zinc Concentrations in Plaice Fillets from 2004 to 2020

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, 2018, and 2020 are provided in Appendix B-2, as are raw data for 2020. Arsenic, 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 samples in 2014, when it was measured at a lower detection limit (Table 6-4). Boron was detected frequently in most years, but it only occurred in 18% of samples in 2020, with no change in detection limit (Table 6-4). PAHs were detected in three samples from Reference Areas and in three samples from the Study Area in 2014. PAHs were not detected in any other 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 in 2014. Aluminum, cadmium, cobalt, and lead were detected sporadically across all years (Appendix B-2).

Spatial Variations in 2020

Concentrations of arsenic, copper, selenium, silver, and strontium in crab leg tissue varied significantly among Reference Areas in 2020 (Table 6-21; Figure 6-11). However, there were no significant differences between the Study and Reference Areas for any variable (Table 6-21; Figure 6-11).

Table 6-21 Results of Asymmetrical ANOVA Comparing Crab Body Burden Variables among Areas (2020)

Variable	*p*-value	
	Among Reference	Study *vs* Reference
Arsenic	0.013*	0.079
Copper	**<0.001*****	0.147
Mercury	0.344	0.600
Selenium	0.023*	0.247
Silver	0.024*	0.051
Strontium	0.003**	1.000
Zinc	0.687	0.743

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* ≤ 0.05; ***p* ≤ 0.01; ****p* ≤ 0.001 (in **bold**).

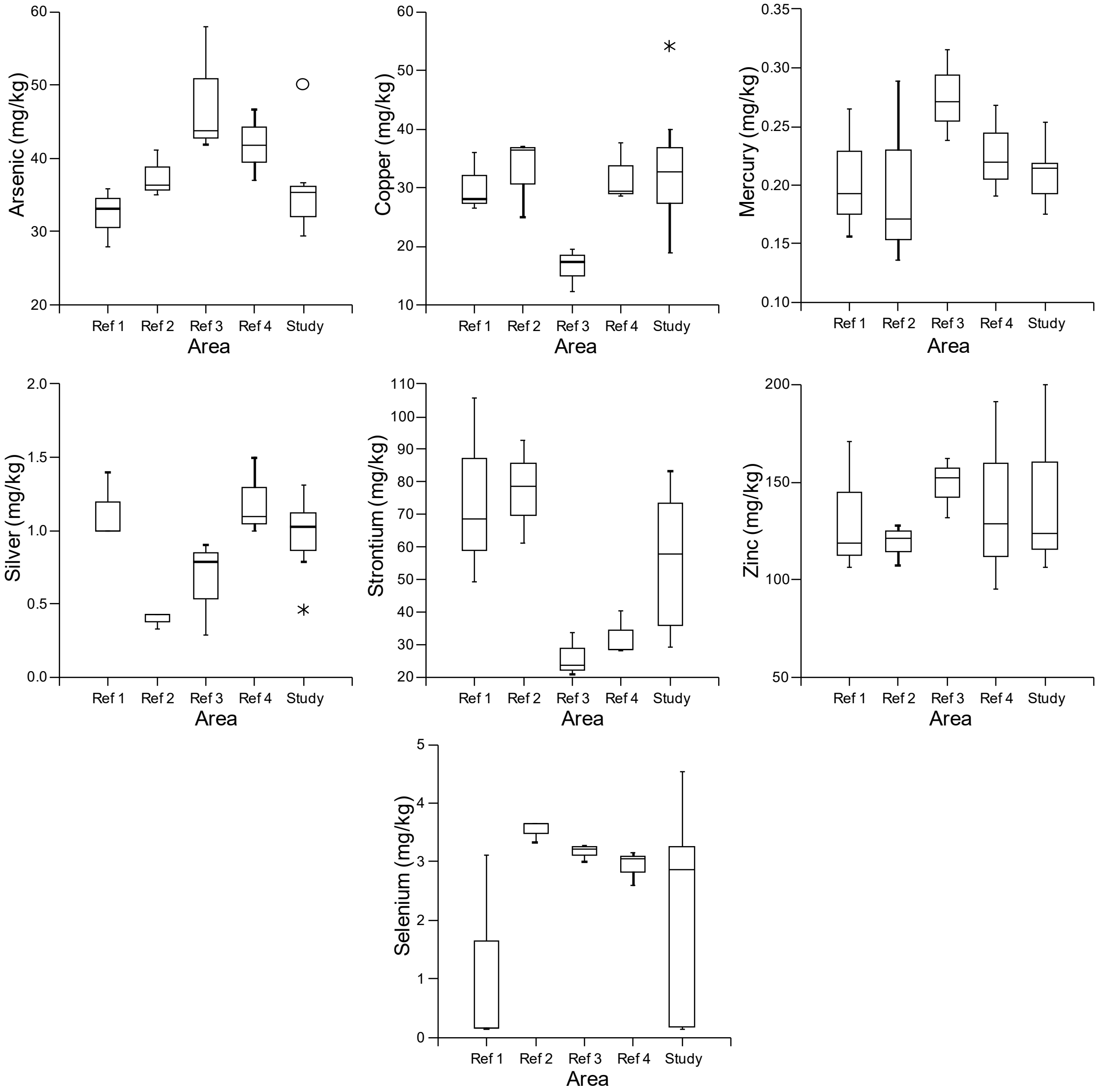

Figure 6-11 Box Plots of Variable Concentrations in Crab Claw in Reference and Study Areas (2020)

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 quadratic trends were noted for arsenic, copper, silver, and zinc (Table 6-22). Concentrations of these variables in crab leg tissue generally decreased to 2008 and then increased, in all areas (Figure 6-12). There were no differences in quadratic trends between the Study and Reference Areas. In addition to quadratic trends, there were area-wide linear trends for arsenic, copper, mercury, and zinc, although these trends were subtle are not readily apparent from Figure 6-12. With the exception of mercury which decreased over time, arsenic, copper, and zinc have progressively increased in all areas. The linear trend for arsenic differed between the Study and Reference Areas, with higher arsenic concentrations in Reference Area leg tissue in most years (Figure 6-12).

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 2020)

Variable	Linear		Quadratic	
	Area-Wide Trend	Difference Between Reference and Study	Area-Wide Trend	Difference Between Reference and Study
Arsenic	0.027*	0.035*	**<0.001*** **	0.286
Copper	<**0.001*** **	0.584	<**0.001*** **	0.249
Mercury	0.010**	0.960	0.944	0.774
Silver	0.645	0.333	**<0.001*** **	0.137
Strontium	0.724	0.756	0.231	0.315
Zinc	0.018*	0.747	**<0.001*** **	0.152

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**).

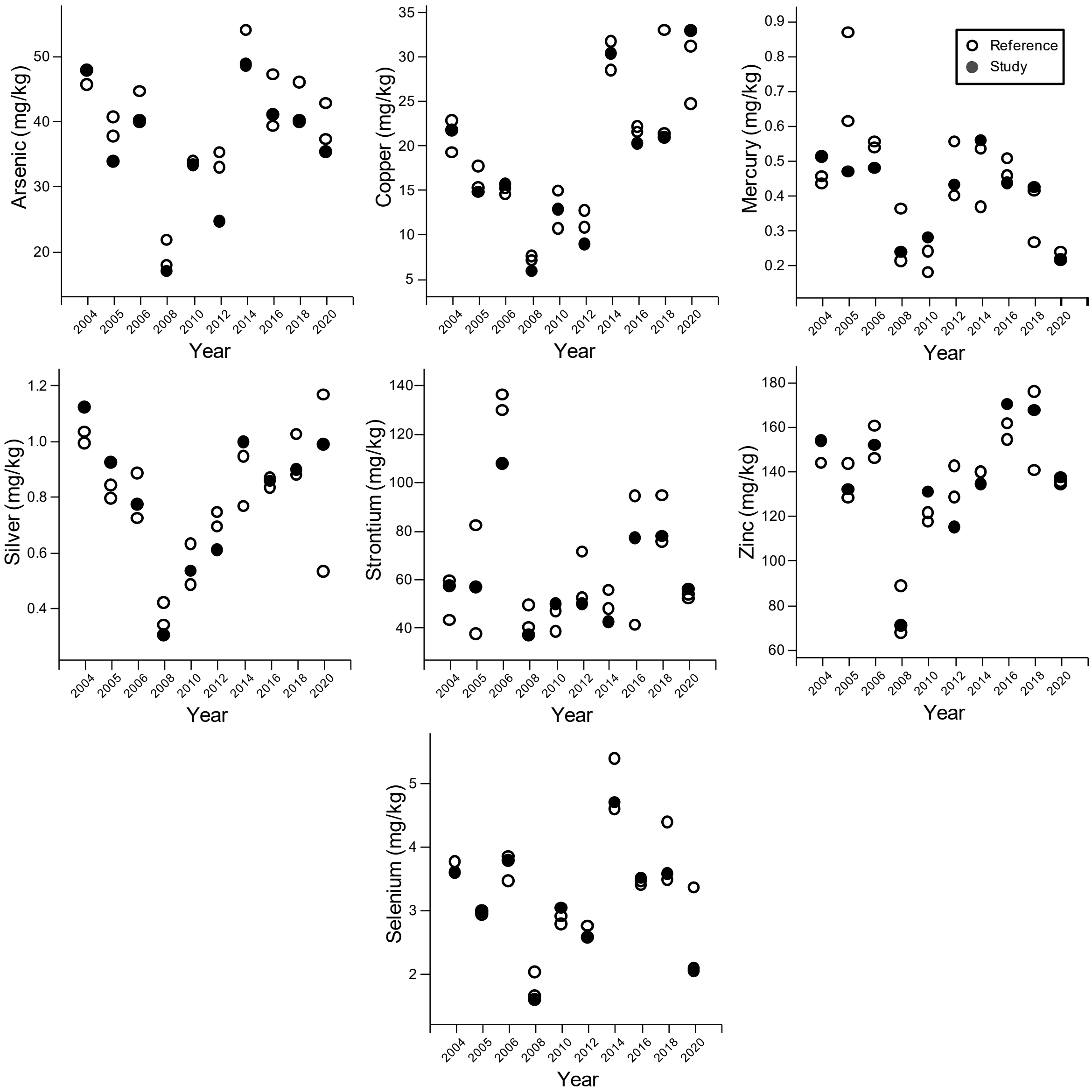

Figure 6-12 Variation in Area Means of Detectable Variable Concentrations in Crab Claw Composites from 2004 to 2020

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 2020 in either the triangle or hedonic scaling tests. Panelists for the triangle test were successful in discriminating 9 out of 24 samples. These results were not significant (*p* > 0.05, Appendix B-4). ANOVA statistics for hedonic scaling are provided in Table 6-23. The results were not significant (*p* = 0.22), and from the frequency histogram (Figure 6-13), there was no marked difference in the assessment of samples from the Study and Reference Areas. From ancillary comments (Tables 6-25 and 6-26, and Appendix B-4), there were no consistent comments identifying abnormal or foreign odour or taste. Together, these results do not indicate taint in White Rose plaice samples.

Table 6-23 ANOVA for Taste Preference Evaluation of Plaice by Hedonic Scaling (2020)

Source of Variation	SS	df	MS	F	*p*-Value
Area	4.26	1	4.26	1.55	0.22
Error	121.22	44	2.75		

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

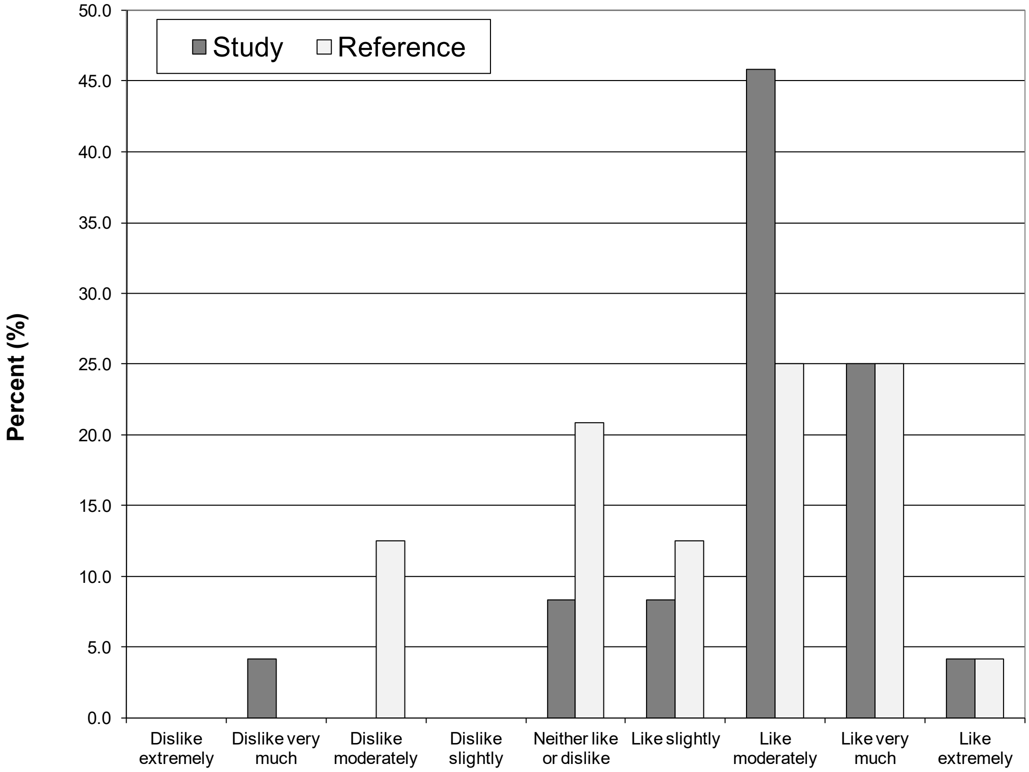

Figure 6-13 Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2020)

Table 6-24 Summary of Comments from the Triangle Taste Test for Plaice (2020)

Reference Area (RA)	Study Area (SA)
Correctly identified as odd sample	**Correctly identified as odd sample**
151 [SA] delicate, nice texture. 255 [SA] less fishy, nice texture; 410 [RA] slightly different. Really, all had very similar taste	Very similar tasting. Thanks
Seems tougher, chewier, less fresh tasting	584 [RA] & 814 [RA] have a more disagreeable taste
Had a much better taste than the other two; more sweet	Stronger fishy flavour
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
stronger taste on 584 [RA]	151 [SA] had a slightly lighter flavour profile
185 [RA] tasted good. The other two tasted slightly metallic	Fresher tasting
	151 [SA] tastes "older", *i.e.*, more "fishy"
	All tasted good to me. First one tasted a little saltier, third one texture a little different. Couldn't really taste any difference

Note: - Comments are transcribed exactly from participant input except that the text for the Reference Areas [RA) and the Study Area [SA] 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 (2020)

Preferred Reference Area [RA]	Preferred Study Area [SA]
880 [SA] very strong flavor. Unpleasant	765 [RA] had a slightly off flavor
Little difference	Little difference
No difference	No difference
enjoyed them both; they were tasty	544 [SA] tastes a bit saltier, more flavorable; 677 [RA] tastes blander
534 [SA] less flavor but good	544 [SA] had a light sweet taste
Neither are particular good. 543 [SA] was more fishy tasting	544 [SA] was sweeter
	Although the flavour of the two is very similar, 543 [SA] had a slightly better texture to it
	They both taste almost the same to me. 130 [RA] is a little drier than 543 [SA]
	Both tasted very similar, but 543 [SA] tasted better and tasted more juicy and flavorful, whereas 130 [RA] seemed more dull and dry
	Both tasted OK; 543 [SA] a slight bit tastier, thanks
	Less "fishy" taste on 880 [SA]
	765 [RA] okay, with slight aftertaste; 880 [SA] tastes good

Note: - Comments are transcribed exactly from participant input except that the text for the Reference Areas [RA) and the Study Area [SA] was inserted. These were blind taste tests and therefore panelists were unaware of the source of samples.
- When there was no preference for either sample, comments are repeated in both columns.

6.2.3.2 Crab

Panelists for the triangle test were successful in discriminating 10 out of 22 samples. These results were not significant (*p* > 0.05, Appendix B-4). ANOVA statistics for hedonic scaling are provided in Table 6-26. The results were not significant (*p* = 0.44), and from the frequency histogram (Figure 6-14), there was no marked difference in the assessment of samples from the Study and Reference Areas. From ancillary comments (Tables 6-28 and 6-29, and Appendix B-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 (2020)

Source of Variation	SS	df	MS	F	*p*-value
Area	1.39	1	1.39	0.61	0.44
Error	99.83	44	2.27		

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

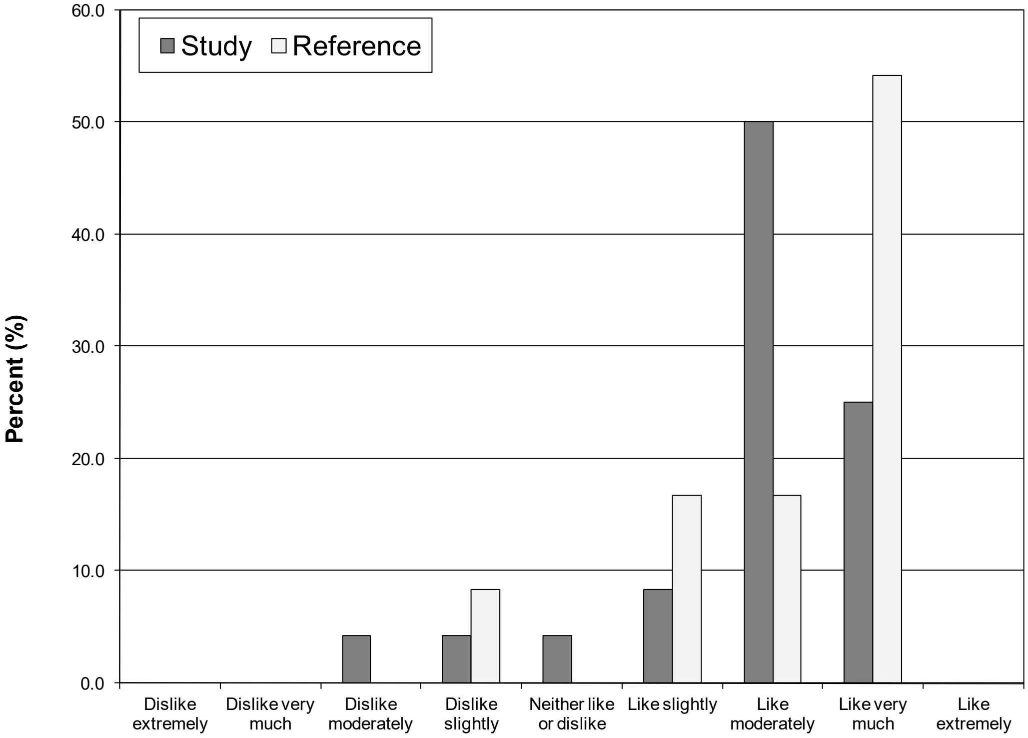

Figure 6-14 Crab Frequency Histogram for Hedonic Scaling Taste Evaluation (2020)

Table 6-27 Summary of Comments from the Triangle Taste Test for Crab (2020)

Reference Area [RA]	Study Area [SA]
Correctly identified as odd sample	**Correctly identified as odd sample**
101 [SA] and 213 [SA] are more moist	sample was blander, other two a little bit "sweeter"
Unable to find a difference between samples (flavor). However, noticeable difference in texture	
All tasty! No preference in either!	
736 [SA] odd texture, 836 [RA] better texture, 912 [SA] odd texture	
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
Very difficult to discern any difference	101 [SA] is blander but all 3 samples are very bland
Very little difference	The odd sample had a stronger crab flavor. All samples were good
No real difference. Last one seemed slightly sweeter	All tasted very similar
	Very difficult to distinguish taste and texture. 736 [A] had a taste slightly less sweet than the others

Note: - Comments are transcribed exactly from participant input except that the text for the Reference Areas [RA) and the Study Area [SA] 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 (2020)

Preferred Reference Area	Preferred Study Area
Sample 809 [6] [SA] was quite bland while 963 [RA] had more flavor	806 [SA] sweeter than 963 [RA]. 963 [RA] "sour" but OK in comparison to 806
595 [RA] has better texture than 730 [SA]. 730 [SA] is watery and mushy; 595 [RA] is a little crunchy	147 [RA] reminded me of the texture of codfish. 499 [SA] almost melted immediately in my mouth. It overwhelmed my senses in a good way
very little difference	very little difference
Both tasted very good. Sample 499 [SA] had a slightly stronger "fishy" taste to it (not that that is bad). Both are good	Both tasted very good. Sample 499 [SA] had a slightly stronger "fishy" taste to it (not that that is bad). Both are good
No discernable difference	No discernable difference
595 [RA] seems to have more flavour	Sample 147 [RA] tastes very sour-like, it has a weird aftertaste. Sample 499 [SA] had no aftertaste but lacks flavour. However, it doesn't have a bad taste
595 [RA] - good crab flavor; 730 [SA] slightly less flavor / bland	
sweeter (595 [RA]). Both samples are acceptable	
595 [RA] had a little better flavour, but 730 [SA] was very bland	
963 [RA] had a slightly sweeter flavor	
Sample 499 [SA] was very mild tasting. Sample 147 [RA] smelled & tasted better. Thanks	
Not a big difference in taste. 499 [SA] seemed like it had the taste washed out a little more than 147 [RA]. Both were good	

Notes: - Comments are transcribed exactly from participant input except that the text for the Reference Areas [RA) and the Study Area [SA] was inserted. These were blind taste tests and therefore panelists were unaware of the source of samples.
- When there was no preference for either sample, 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 B-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 B-3, Annex D. Results of immature and pre-spawning females are summarized in Figure 6-15.

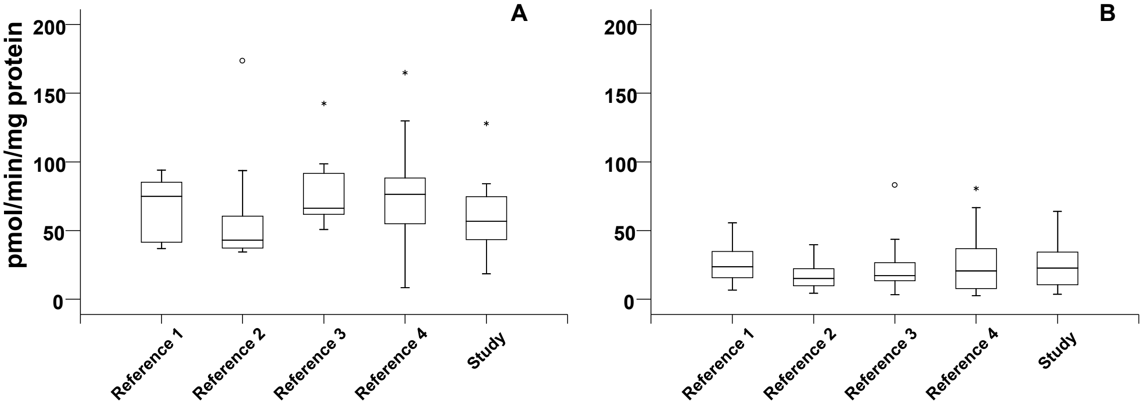

Figure 6-15 **Box Plots of EROD Activity in the Liver of Immature (F-500) and Pre-spawning (F-510 to F-540) Female Plaice**

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 B-3, Annex A for DFO maturity stage classifications.

No significant differences in MFO enzyme activities were found between the Study and Reference Areas for immature or pre-spawning females ($p > 0.05$, Table 6-29). There were also no significant differences among Reference Areas for ($p > 0.05$, Table 6-29).

Table 6-29 **Results of Asymmetrical ANOVA Comparing MFO Activities in Female Plaice (2020)**

Variable (Y)	*p*-value	
	Among Reference	Study *vs* Reference
Immature Females	0.640	0.270
Pre-Spawn Females	0.257	0.749

Note: -See Appendix B-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 from the Study Area, and 30 each from Reference Areas 1, 2, 3, and 4. Results were expressed as 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 B-3, Annex E. Representative photographs of normal liver as well as several histological changes are included in Appendix B-3, Annex G.

Table 6-30 Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions (2020)

Hepatic Lesions	Measure	Area						
		Ref 1	Ref 2	Ref 3	Ref 4	All Ref	Study	Grand Total
Number of Fish	Number	30	30	30	30	120	60	180
Nuclear Pleomorphism	Number	9	2	5	6	22	11	33
	%	30	6.67	16.67	20	18.33	18.33	18.33
Megalocytic Hepatosis	Number	1	0	2	0	3	1	4
	%	3.33	0	6.67	0	2.5	1.67	2.22
Focus of cellular alteration	Number	0	0	0	0	0	1	1
	%	0	0	0	0	0	1.67	0.56
Proliferation of Macrophage Aggregates [a]	Number	11	4	9	5	29	28	56
	%	36.67	13.33	30	16.67	24.17	46.67	31.11
Fibrillar Inclusions	Number	0	0	1	0	1	0	1
	%	0	0	3.33	0	0.83	0	0.56
Inflammatory Response [b]	Number	17	11	16	14	58	45	103
	%	56.67	36.67	53.33	46.67	48.33	75	57.22
Hepatocellular Vacuolation	Number	4	3	1	0	8	6	14
	%	13.33	10	3.33	0	6.67	10	7.78
Parasites	Number	20	12	18	18	68	41	109
	%	66.67	40	60	60	56.67	68.33	60.56

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

There were nine cases of nuclear pleomorphism in Reference Area 1, two cases in Reference Area 2, five cases in Reference Area 3, six cases in Reference Area 4, and eleven cases in the Study Area. There was one case of megalocytic hepatosis in Reference Area 1, two cases in Reference Area 3, and one case in the Study Area. No cases of focus of cellular alteration were observed in the Reference Areas and only one case was observed in the Study Area. Proliferation of macrophage aggregates was detected in 56 fish, in 28 fish from the Study Area and in 11, 4, 9, and 5 fish from Reference Areas 1, 2, 3, and 4, respectively. Fibrillar inclusions were observed in one fish from Reference Area 3 only. Inflammatory response was detected in 103 fish, in 45 fish from the Study Area, and in 17, 11, 16, and 14 fish from Reference Areas 1, 2, 3, and 4, respectively. Fourteen cases of hepatocellular vacuolation were detected, six in the Study Area and four, three, and one in each of Reference Areas 1, 2 and 3 respectively. Finally, parasites were detected in 41 fish from the Study Area and in 20, 12, 18, and 18 fish from References Areas 1, 2, 3, and 4, respectively. Although such liver conditions are of interest, they are generally not a result of the presence of chemical pollutants.

Statistical analyses were conducted on nuclear pleomorphism, macrophage aggregates, inflammatory response, hepatocellular vacuolation, and parasites only because the low incidence of all the other hepatic lesions prevented statistical comparisons. Overall, there were no significant differences in nuclear pleomorphism (Fisher exact test, $p = 1.000$), macrophage aggregates (Fisher exact test, $p = 1.000$), hepatocellular vacuolation, (Fisher exact test, $p = 0.556$), or in the presence of parasites (Fisher exact test, $p = 0.148$) between fish from the Study and Reference Areas. Similarly, no differences were noted amongst Reference Areas (Fisher exact test, $p > 0.05$) for any of these variables.

Inflammatory response was significantly different (Fisher exact test, $p < 0.001$) between fish from the Study and Reference Areas with the highest prevalence in the Study Area (Table 6-30). Significant differences also were noted among the Reference Areas (Fisher exact test, $p = 0.005$) for inflammatory response.

Gill Histopathology

Gill sections were examined for the presence of various lesions associated with chemical toxicity as well as other non-specific lesions commonly observed in fish gills. Detailed results are provided in Appendix B-3. Accurate counts were not possible for two fish from the Reference Area 3, and one fish from the Reference Area 4. Detailed histopathological studies were therefore carried out on gill tissues of 117 fish from the Reference Areas and 60 fish from the Study Area. In all cases, the percentages of lamellae affected by the lesions were low; all were less than 5% (see Appendix B-3, Annex F). Means of percentages of lamellae presenting each type of lesion per site are provided in Table 6-31.

Table 6-31 Mean Percent Occurrence of Lesions in Gill Tissues (2020)

	Area						
	Ref 1	Ref 2	Ref 3	Ref 4	All Reference	Study	Total
Number of Fish	30	30	28	29	117	60	177
Distal Hyperplasia[a]	0.1333%	0.1320%	0.2847%	0.3556%	0.2162%	0.2267%	0.2200%
Tip Hyperplasia[a]	0.2278%	0.0629%	0.1805%	0.2875%	0.1869%	0.2324%	0.2035%
Basal Hyperplasia 1[ab]	0.0833%	0.0629%	0.1666%	0.0984%	0.1008%	0.1247%	0.1095%
Basal Hyperplasia 2[ac]	0.0500%	0.0314%	0.0555%	0.0681%	0.0504%	0.0198%	0.0393%
Fusion[a]	0.0167%	0.0252%	0.0764%	0.0605%	0.0423%	0.0623%	0.0496%
Telangiectasis[a]	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%
Parasites	0.0056%	0.0000%	0.1180%	0.0378%	0.0374%	0.0368%	0.0372%

Note: -[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.

Except for basal hyperplasia (⅓ to ⅔) and tip hyperplasia, none of the gill lesions occurred either more or less frequently in Study Area fish than in Reference Area fish (Fisher Exact test, $p > 0.05$ in all cases). Basal hyperplasia (⅓ to ⅔) was significantly greater (Fisher exact test, $p = 0.030$) in the Study Area than in the Reference Areas (Table 6-32). Tip hyperplasia was also significantly greater (Fisher exact test, $p = 0.017$) in the Study Area than in the Reference Areas. There were no significant differences in gill lesions among Reference Areas (Fisher Exact test, $p > 0.05$ in all cases).

Table 6-32 Number and Percentage of Plaice with Specific Types of Gill Lesions (2020)

Gill Lesions	Measure	Ref 1	Ref 2	Ref 3	Ref 4	Mean Reference	Study
Number of Fish	Number	30	30	28	29	29.25	60
Distal Hyperplasia	Number	9	10	11	16	11.5	23
	%	30	33.33	39.29	55.17	39.32	38.33
Tip Hyperplasia	Number	16	7	12	9	10.5	34
	%	53.33	23.33	42.86	31.03	35.9	56.67
Basal Hyperplasia 1	Number	9	7	9	9	9	28
	%	30	23.33	32.14	31.03	30.77	46.67
Basal Hyperplasia 2	Number	5	3	5	8	6.5	5
	%	16.67	10	17.86	27.59	22.22	8.33
Fusion	Number	3	2	6	5	5.5	15
	%	10	6.67	21.43	17.24	18.8	25
Telangiectasis	Number	0	0	0	0	0	0
	%	0	0	0	0	0	0
Parasites	Number	3	0	0	1	0.5	2
	%	10	0	0	3.45	1.71	3.33

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

6.3.1.1 Biological Characteristics of Plaice and Crab Used in Body Burden Composites

A total of 327 plaice were retained for body burden analysis: 150 from the Study Area; and 177 from the Reference Areas. Mean gutted weight for plaice used in body burden composites was generally lower in Reference Area 4 than in remaining sampling areas. Mean gutted weight also varied widely in Reference Area 4. Excluding Reference Area 4, there was no difference in mean gutted weight among remaining reference areas (Reference Areas 1, 2 and 3) or between those Reference Areas and the Study Area for plaice composites used in body burden analysis.

A total of 292 crab were retained: 144 from the Study Area; and 148 from the Reference Areas. Mean carapace width and claw height for crab used in body burden composites differed between the Study and Reference Areas, with slightly larger crab in the Study Area than in the Reference Areas. The two variables also varied significantly among the Reference Areas, with larger crab in Reference Area 3.

6.3.1.2 Biological Characteristics of Plaice Used in Fish Health Assessment

Additional differences in biological characteristics among Areas were examined for plaice used in fish health assessment (180 of the 327 plaice caught). Only nine male plaice were caught for health assessment, all of these in the Reference Areas. Most of the females caught were mature (135 of 171 females) and most of these were pre-spawning. Only two mature females were spent. 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 hepatosomatic index and gonadosomatic index. Length, gutted weight, and age for both immature and pre-spawning females were significantly lower in Reference Areas than in the Study Area, driven primarily by lower values and the wide variation observed in Reference Area 4 (as was the case for mean gutted weight for body burden composites (Section 6.3.1.1). Remaining biological characteristics did not differ between the Study and Reference Area for either immature or pre-spawning females.

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 2020. 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 2020, liver concentrations of >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons, arsenic, manganese, and mercury were significantly higher in the Study Area compared to the Reference Areas. Copper concentrations were significantly lower in the Study Area compared to the Reference Areas. Selenium concentrations in the Study Area were intermediate to those in Reference Areas 2 and 3 versus Reference Areas 1 and 4. There were no differences between the Study and Reference Areas in liver concentrations of percent fat, cadmium, iron, and zinc.

Across years (2004 to 2020), and with the exception of copper, there were no significant differences between the Study Area and the Reference Areas in linear or quadratic trends over time [30] for frequently detected compounds in plaice liver. Copper concentrations in liver, as well as those of cadmium, mercury, selenium, and zinc, increased to 2014 and then decreased, in all areas. However, the increase and subsequent decrease in copper concentrations was slightly more pronounced in the Study Area than in the Reference Areas. Subsequent to 2014, liver copper concentrations generally were similar between the Study and Reference Areas; and the within year analysis indicated lower copper concentrations in Study Area liver in 2020 (see previous paragraph on 2020 results). The difference in the increase in copper concentrations to 2014 also resulted in a significant difference in linear trends for copper between the Study and Reference Areas.

In 2020, significant differences were noted between the Study Area and Reference Areas for plaice fillet concentrations of percent fat, arsenic, and mercury, with higher concentrations in Study Area fillet. No differences were noted between the Study and Reference Areas for zinc. Across years (2004 to 2020), there were no differences in quadratic trends between the Study and Reference Areas for any of these variables. However, there was a difference in the linear trend between the Study and Reference Areas for plaice fillet mercury concentration. That difference was not apparent in 2018 and was driven in part by higher mercury concentrations in Study Area fillets in 2020.

For crab in 2020, there were no significant differences in concentrations between the Study and Reference Area for any of the frequently detected metals (arsenic, copper, mercury, selenium, silver, strontium, and zinc). Across years (2004 to 2020), there was a difference in the linear trend between the Study and Reference Areas for arsenic

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

concentrations, with higher concentrations in Reference Area leg tissue in most years. There were no other differences in linear or quadratic trends between the Study and Reference Areas for crab.

6.3.3 Taste Tests

There were no significant differences in taste test results between Study and Reference Areas for either plaice or crab and, from ancillary comments, there were no consistent comments identifying abnormal or foreign odour or taste. These results do not indicate taint in White Rose plaice or 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. Low numbers prevented comparison between Areas for males and other female maturity groupings.

Sufficient incidences of liver lesions allowed statistical comparison among Areas for nuclear pleomorphism, macrophage aggregates, inflammatory response, hepatocellular vacuolation and parasite counts. With the exception of inflammatory response, there were no significant differences in these liver conditions between the Study and Reference Areas. Study Area fish exhibited liver inflammatory response in 75% of cases versus 48% of cases for Reference Area fish.

For gill histopathology, with the exception of basal hyperplasia (⅓ to ⅔) and tip hyperplasia, no significant differences were found between the Study and Reference Areas for any of the studied conditions. Basal hyperplasia (⅓ to ⅔) occurred in 47% of fish from the Study Area versus 31% of fish from the Reference Areas. Tip hyperplasia occurred in 57% of fish from the Study Area versus 36% of fish from 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 at Water Quality stations. The sampling design for seawater was based on constituent-based modelling of the produced water discharge in the water column. That exercise suggested that the probability of detection of produced water constituents in seawater was higher in the very-near field down-current from the *SeaRose FPSO*, as well as 4 km away in the direction of the prevailing current (Husky 2011, Appendix D-4).

Examination of sediments relative to produced water discharge focuses on potential iron enrichment and examines iron concentrations at all stations where iron is measured (*i.e.,* sediment and Water Quality stations). Modeling of the accumulation of produced water constituents in sediment indicated that iron potentially could act as a tracer of produced water constituents in sediments (Husky 2013, Appendix D-4).

Result for seawater and sediments are presented separately in the text that follows.

7.2 Seawater

7.2.1 Sample Collection

Water collection for the 2020 EEM Program was conducted from November 20 to 22, 2020, using the offshore supply vessel *Skandi Vinland*. Produced water was being released at the *SeaRose FPSO* during sampling. Collection stations for the 2020 program are shown in Figure 7-1. In 2020, the five near-field stations down-current from the *SeaRose FPSO* were located to the northeast of the FPSO. Station coordinates and distance to the *SeaRose FPSO* are provided in Appendix C-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 BTEX) $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, PAHs and alkyl PAHs, phenols and alkyl phenols, volatile organic acids, metals, inorganic and organic carbon, total suspended solids 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.

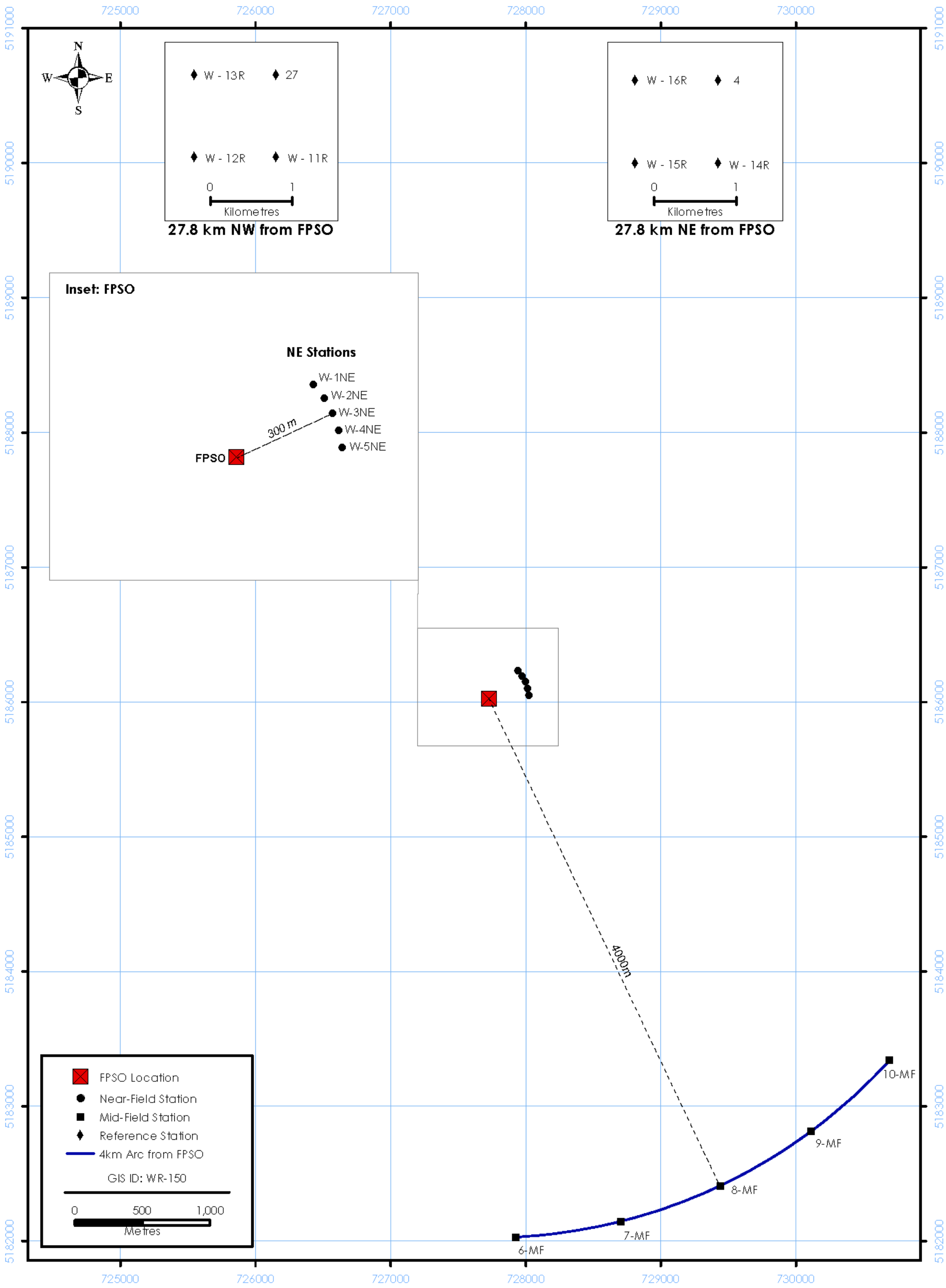

Figure 7-1 Water Quality Stations 2020

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 plastic bottle	None	4ºC	6 months
Mercury	1 - 100 mL clear glass bottle	Hydrochloric acid	4ºC	28 days
Ammonia	1 – 40 mL plastic bottle	Sulphuric acid	4ºC	28 days
Organic Carbon	1 – 120 mL plastic bottle	Sulphuric acid	4ºC	28 days
Suspended Solids	1 – 500 mL plastic bottle	None	4°C	7 days
Inorganic Carbon	1 – 200 mL plastic bottle	No preservative required. Fill to top	4°C	14 Days

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

The following QA/QC protocols were implemented for collection of samples. Field duplicates were collected for water chemistry at four randomly selected station/depth combinations (W7-MF (surface), W9-MF (surface), Stations W-12R (bottom), and W-14R (mid-depth)). Sampling personnel were supplied with new latex gloves for each station. The on-board 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. Before each sample set, the Niskin bottles were rinsed with a mild Alkanox™ solution and flushed with distilled water prior to being attached to the sample string. Seawater then flushed each sample bottle during the bottle descent through the water column. 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 in Fredericton by RPC were transferred to cold storage at Stantec and then shipped to RPC; samples to be analyzed by BV were delivered to the BV Laboratory in St. John’s for shipment to their laboratory in Halifax. Samples were delivered to laboratories within prescribed sample holding time.

7.2.2 Laboratory Processing

Water samples were processed for constituents listed in Table 7-2. In the 2010 EEM program, most constituents were processed at RPC. From 2012 to 2020, inorganic constituents (trace metals, mercury) were processed at BV (Halifax) because detection limits for most inorganic constituents of interest were lower at that analytical laboratory. Organic and inorganic carbon, suspended solids and ammonia were also processed at BV from 2012 to 2020. The remaining constituents were processed at RPC. Details on analytical methods for RPC and BV are provided in Appendix C-2.

Table 7-2 Water Chemistry Constituents (2010, 2012, 2014, 2016, 2018 and 2020)

Constituent	Unit	Detection Limit					
		2010	2012	2014	2016	2018	2020
Hydrocarbons							
Benzene	mg/L	0.001	0.001	0.001	0.001	0.001	0.001
Toluene	mg/L	0.001	0.001	0.001	0.001	0.001	0.001
Ethylbenzene	mg/L	0.001	0.001	0.001	0.001	0.001	0.001
Xylenes	mg/L	0.001	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	0.01
>C_{10}-C_{21}	mg/L	0.05	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	0.1
Phenols and Alkyl Phenols							
Phenol	µg/L	10	10	10	10	10	10
o-cresol	µg/L	10	10	10	10	10	10
m,p-cresol	µg/L	10	10	10	10	10	10
Total C2 Phenols	µg/L	20	20	20	20	20	20
Total C3 Phenols	µg/L	20	20	20	20	20	20
Total C4 Phenols	µg/L	20	20	20	20	20	20
Total C5 Phenols	µg/L	20	20	20	20	20	20
4-*n*-hexylphenol	µg/L	10	10	10	10	10	10
2,5-diisopropylphenol	µg/L	10	10	10	10	10	10
2,6-diisopropylphenol	µg/L	10	10	10	10	10	10
2-*tert*-butyl-4-ethylphenol	µg/L	10	10	10	10	10	10
6-*tert*-butyl-2,4-dimethyphenol	µg/L	10	10	10	10	10	10
4-*n*-heptylphenol	µg/L	10	10	10	10	10	10
2,6-dimethyl-4-(1,1-dimethypropyl)phenol	µg/L	10	10	10	10	10	10
4-(1-ethyl-1-methylpropyl)-2-methylphenol	µg/L	10	10	10	10	10	10
4-*n*-octylphenol	µg/L	10	10	10	10	10	10
4-*tert*-octylphenol	µg/L	10	10	10	10	10	10
2,4-di-*sec*-butylphenol	µg/L	10	10	10	10	10	10
2,6-di-*tert*-butylphenol	µg/L	10	10	10	10	10	10
4-*n*-nonylphenol	µg/L	20	20	20	20	20	20
2-methyl-4-*tert*-octylphenol	µg/L	10	10	10	10	10	10
2,6-di-*tert*-butyl-4-methylphenol	µg/L	10	10	10	10	10	10
4,6-di-*tert*-butyl-2-methylphenol	µg/L	10	10	10	10	10	10
PAHs and Alkyl PAHs							
Naphthalene	µg/L	0.01	0.05	0.05	0.05	0.05	0.05
1-Methylnapthalene	µg/L	NA	NA	0.05	0.05	0.05	0.05
2-Methylnapthalene	µg/L	NA	NA	0.05	0.05	0.05	0.05
Acenaphthylene	µg/L	0.01	0.01	0.01	0.01	0.01	0.01
Acenaphthene	µg/L	0.01	0.01	0.01	0.01	0.01	0.01
Fluorene	µg/L	0.01	0.01	0.01	0.01	0.01	0.01
Phenanthrene	µg/L	0.01	0.01	0.01	0.01	0.01	0.01
Anthracene	µg/L	0.01	0.01	0.01	0.01	0.01	0.01
Fluoranthene	µg/L	0.01	0.01	0.01	0.01	0.01	0.01
Pyrene	µg/L	0.01	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	0.01
Chrysene/Triphenylene	µg/L	0.01	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	0.01
Benzo(*k*)fluoranthene	µg/L	0.01	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	0.01
Benzo(*a*)pyrene	µg/L	0.01	0.01	0.01	0.01	0.01	0.01
Indenopyrene	µg/L	0.01	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	0.01
Dibenzo(*a,h*)anthracene	µg/L	0.01	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	0.01
C2-Naphthalenes [a]	µg/L	0.05	0.10	0.10	0.10	0.10	0.01
C3-Naphthalenes	µg/L	0.05	0.10	0.10	0.10	0.10	0.01
C1-Phenanthrenes	µg/L	0.05	0.10	0.10	0.10	0.10	0.01
C2-Phenanthrenes	µg/L	0.05	0.10	0.10	0.10	0.10	0.01
C3-Phenanthrenes	µg/L	0.05	0.10	0.10	0.10	0.10	0.01
Dibenzothiophene	µg/L	0.05	0.10	0.10	0.10	0.10	0.01
C1-Dibenzothiophenes	µg/L	0.05	0.10	0.10	0.10	0.10	0.01
C2-Dibenzothiophenes	µg/L	0.05	0.10	0.10	0.10	0.10	0.01
C3-Dibenzothiophenes	µg/L	0.05	0.10	0.10	0.10	0.10	0.01
Perylene	µg/L	0.01	0.01	0.01	0.01	0.01	0.01

Constituent	Unit	Detection Limit					
		2010	2012	2014	2016	2018	2020
Biphenyl	µg/L	0.01	0.05	0.05	0.05	0.05	0.05
Organic Acids							
Acetic Acid	mg/L	2	2	2	2	2	2
Propionic Acid	mg/L	2	2	2	2	2	2
Iso-butyric Acid	mg/L	2	2	2	2	2	2
Butyric Acid	mg/L	2	2	2	2	2	2
Iso-valeric Acid	mg/L	2	2	2	2	2	2
n-valeric Acid	mg/L	2	2	2	2	2	2
Metals							
Aluminum	µg/L	5	10	10	10	10	10
Antimony	µg/L	1	0.5	0.5	0.5	0.5	0.5
Arsenic	µg/L	10	0.5	0.5	0.5	0.5	0.5
Barium	µg/L	0.1	1	1	1	1	1
Beryllium	µg/L	0.05	1	1	1	1	1
Boron	µg/L	10	50	50	50	50	50
Cadmium	µg/L	0.05	0.05	0.05	0.05	0.05	0.05
Calcium	mg/L	0.05	1	1	1	1	1
Chromium	µg/L	2	0.5	0.5	0.5	0.5	0.5
Cobalt	µg/L	0.5	0.1	0.1	0.1	0.1	0.1
Copper	µg/L	5	0.5	0.5	0.5	0.5	0.5
Iron	µg/L	10	5	5	10	2	2
Lead	µg/L	0.05	0.1	0.1	0.1	0.1	0.1
Lithium	µg/L	5	20	20	20	20	20
Magnesium	mg/L	10	1	1	1	1	1
Manganese	µg/L	0.01	0.5	0.5	0.5	0.5	0.5
Mercury	µg/L	0.025	0.013	0.013	0.013	0.013	0.013
Molybdenum	µg/L	0.1	1	1	1	1	1
Nickel	µg/L	5	0.2	0.2	0.2	0.2	0.2
Potassium	mg/L	20	1	1	1	1	1
Phosphorus	µg/L	NA	50	50	50	50	50
Selenium	µg/L	10	0.5	0.5	0.5	0.5	0.5
Silicon	µg/L	NA	100	100	1000	1000	1000
Silver	µg/L	0.02	0.05	0.05	0.05	0.05	0.05
Sodium	mg/L	0.05	1	1	1	5	2[b]
Strontium	µg/L	10	10	10	10	10	10
Sulphur	mg/L	0.05	20	20	20	20	20
Thallium	µg/L	2	0.1	0.1	0.1	0.1	0.1
Tin	µg/L	NA	1	1	1	1	1
Titanium	µg/L	NA	10	10	10	10	10
Uranium	µg/L	0.1	0.05	0.05	0.05	0.05	0.05
Vanadium	µg/L	1	10	10	10	10	10
Zinc	µg/L	1	1	1	1	1	1
Other							
Un-ionized Ammonia	mg/L	NA	0.0001	0.0001	0.0001	0.0001	0.001[c]
Inorganic Carbon	mg/L	0.5	0.5	0.5	0.5	0.5	1
Organic Carbon	mg/L	0.5	5	5	5	0.5	0.5
Suspended Solids	mg/L	5	0.5	0.5	1	1	1

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

[b] The increase in detection limit for sodium in 2020, relative to years prior 2018, is inconsequential because sodium concentrations are much higher than the 2018 detection limit of 5 mg/L.

[c] The detection limit for un-ionized ammonia varied for each sample over the range 0.00057 to 0.0019 mg/L and four un-ionized ammonia values were below detection limit (Appendix C-2). The median detection limit of 0.001 mg/L is entered in the table above. BV state that detection limits in 2020 were based on the detection limit for ammonia concentration in the sample and field measurements of temperature and pH from the sample upon collection. Since these varied from sample to sample, the detection limit for un-ionized ammonia varied from sample to sample. In previous years, detection limits were based on the lowest attainable detection limit assuming a constant field temperature and pH (5°C and 7, respectively) and a constant detection limit for ammonia. Calculation methods were reviewed in 2019 and in line with continuous improvement, the method was revised to reflect sample-specific detection limits. Note that the detection limit for ammonia in seawater samples in 2020 was constant at 0.05 mg/L. Therefore, only field temperature and pH affected variability in detection limits in 2020.

7.2.3 Data Analysis

7.2.3.1 General Water Quality

Data analyses focused on 2020 data, with qualitative comparisons to results from 2010 to 2018. 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 (2001) and (2010), respectively.

7.2.3.2 Frequently Detected variables

In 2020, the Water Quality component of the White Rose EEM program used a multiple-Reference and multiple Study Area design, with two Reference Areas and one near-field and one mid-field Study Area. Boxplots of variables that occurred above laboratory detection limit in more than 75% of cases (*i.e.,* frequently detected variables) were generated for each Area.

Overall Area differences in frequently detected variables were tested quantitatively 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. Statistical analyses were performed using Systat (version 13) and Excel 2007.

7.2.3.3 Infrequently Detected Variables

Percent occurrence of infrequently detected variables[31] 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.

7.2.3.4 Produced Water Constituents

Concentrations of produced water constituents were compared to concentrations of seawater variables at Reference Area stations to generate an estimate of expected enrichment resulting from release of produced water. All variables listed in Table 7-2 were included in this comparison. Individual stations were then examined for produced

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[31] Variables that occurred above laboratory detection limit in less than 75% of cases.

water constituents with expected concentrations on release more than 10 times that of seawater concentrations at Reference Area stations[32]. The concentration of constituents in produced water was obtained from produced water samples obtained on November 21 and 22, 2020.

7.2.4 Results

7.2.4.1 General Water Quality

Raw data and summary statistics for variables measured in seawater samples (Table 7-2) are provided in Appendix C-2. CTD profiles are provided in Appendix C-3. The location of the thermocline was highly variable during November sampling in 2020. The thermocline extended from near surface to approximately 70 m depth at most near-field stations, except at Station W2-NE, where it extended from approximately 30 to 50 m. At mid-field stations, the thermocline extended from approximately 40 m to 70 m at most stations. The thermocline was slightly deeper at mid-field Station W9-MF (from approximately 60 to 80 m); and it extended to a greater depth at mid-field Station W10-MF (to approximately 90 m). In the NW Reference Area, the beginning thermocline ranged from approximately 10 to 30 m, with the end of the thermocline approximately 70 to 80 m, except at Station 27, where the end of the thermocline was shallower (approximately 40 m). CTD profiles for the NE Reference Area (which is deeper than the other sampling areas) showed three layers of stratification, with cooler water at mid-depth than at the surface or the bottom. The upper mixed layer (*i.e.,* the thermocline) in the NE Reference Area was located from approximately 40 and 60 m. These results indicated differences in mixing of thermal layers within and among the four sampling areas. However, mid-depth samples (40 m depth) were generally collected within or near the thermocline.

7.2.4.2 Frequently Detected Variables

In 2020, arsenic, barium, boron, calcium, inorganic carbon, lithium, magnesium, molybdenum, potassium, sodium, strontium, sulphur, and uranium were detected in all samples. Nickel and phosphorus were detected in 98% of samples; un-ionized ammonia was detected in 93% of samples; suspended solids were detected 89% of samples; and organic carbon was detected in 87% of samples. With the exception of inorganic carbon, which varied over the narrow range of 22 and 24 mg/L, all these variables were included in quantitative analyses for 2020.

Boxplots by Area and Depth for frequently detected variables 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 nickel (54.4 µg/L from a bottom sample at Station W13R - a Reference Area station) was excluded from the boxplot for nickel. Inclusion of that value influenced the scale of the figure and obscured visualization of variability for remaining data.

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[32] The '10 times' cut-off is arbitrary and used to focus the examination to the most relevant variables.

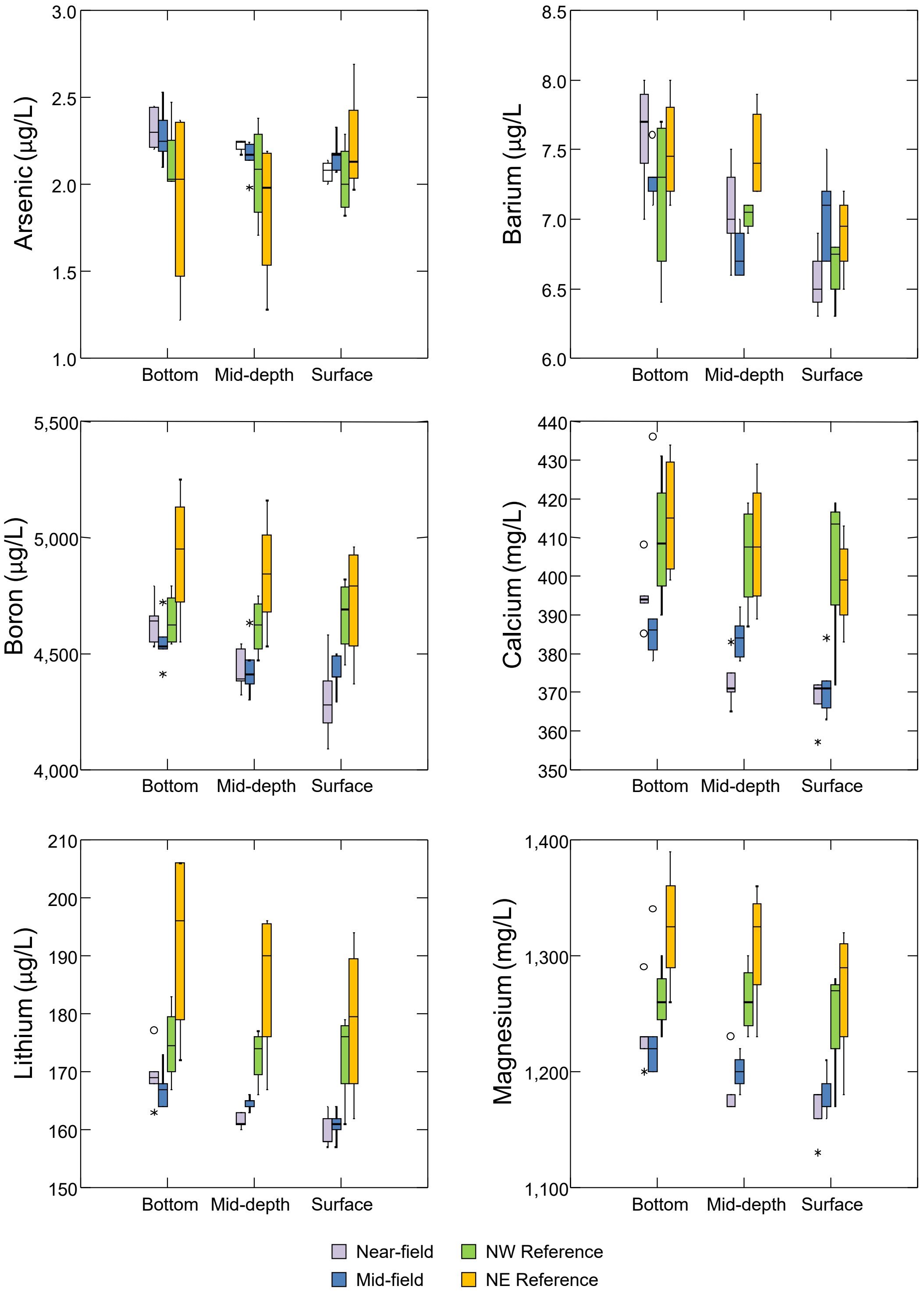

Figure 7-2 Boxplots of Water Chemistry by Area and Depth for 2020

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

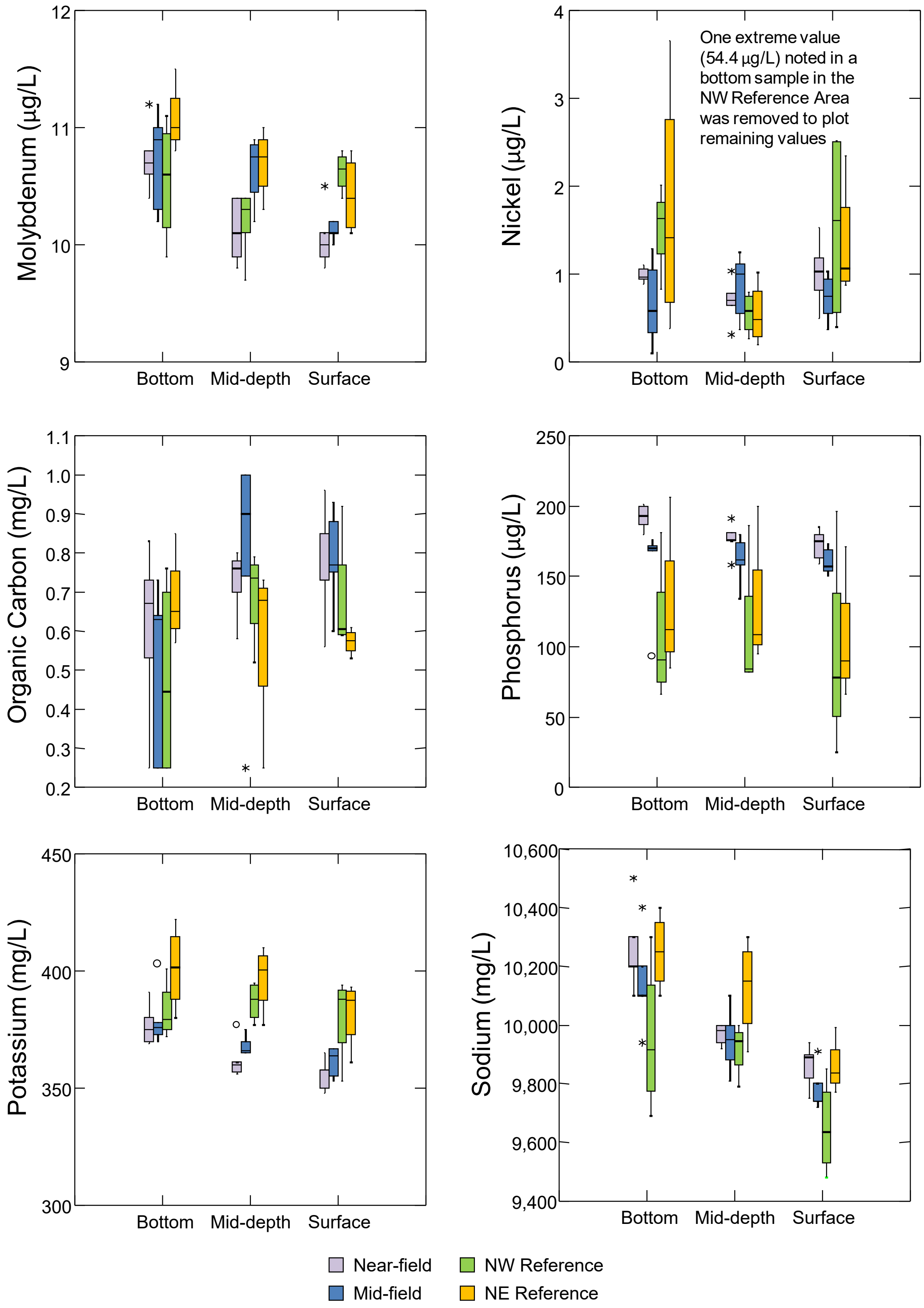

Figure 7-2 Boxplots of Water Chemistry by Area and Depth for 2020 (cont.)

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.

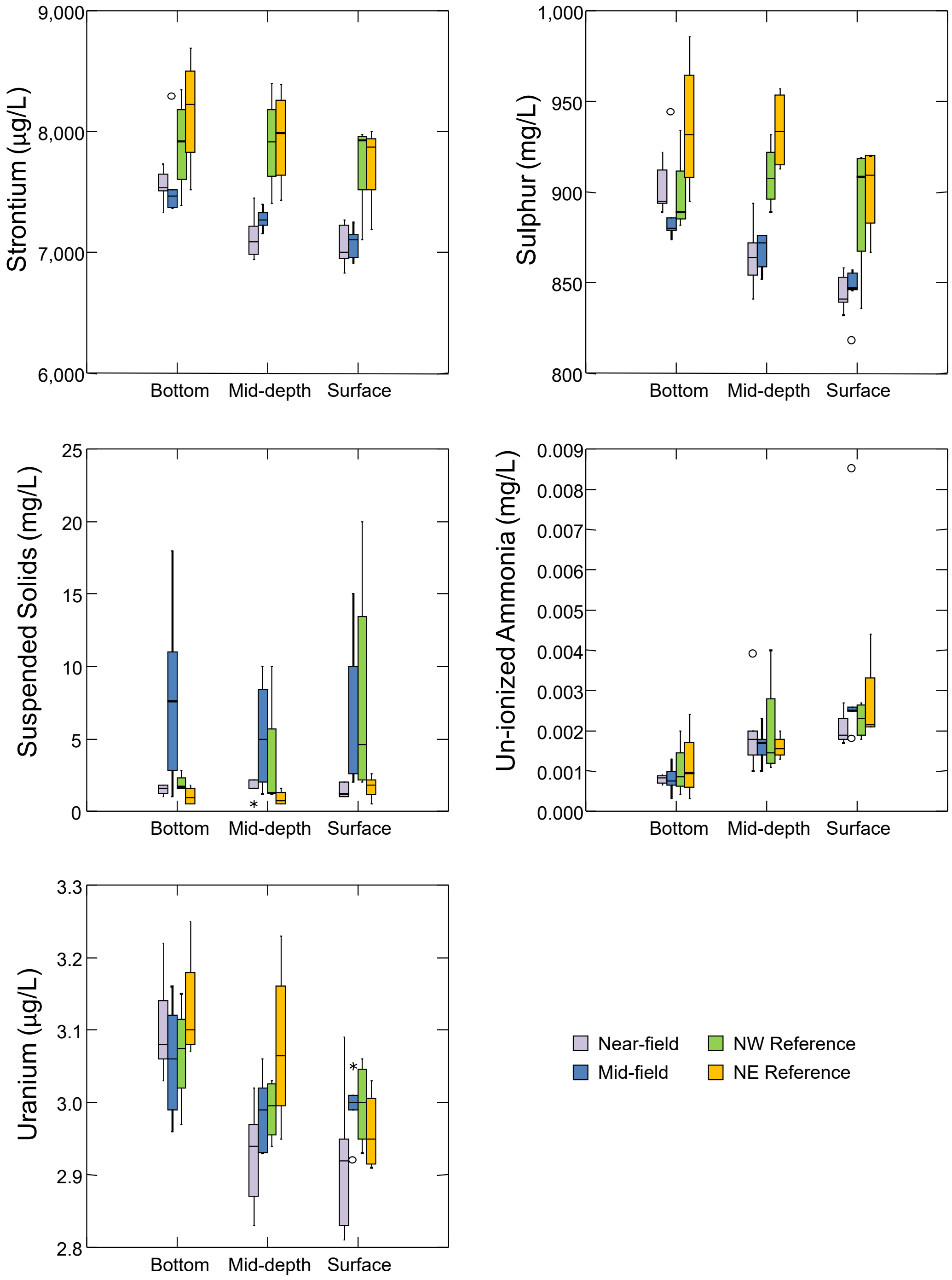

Figure 7-2 Boxplots of Water Chemistry by Area and Depth for 2020 (cont.)

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.

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
Arsenic	0.073	0.657	0.289					
Barium	0.081	**<0.001*** **	0.037*					
Boron	**<0.001*** **	0.011*	0.488	**<0.001*** **	0.838	0.016*	**<0.001*** **	**<0.001*** **
Calcium	**<0.001*** **	0.001**	0.606	**<0.001*** **	0.416	0.866	**<0.001*** **	**<0.001*** **
Lithium	**<0.001*** **	0.008**	0.819	**<0.001*** **	0.815	0.001**	**<0.001*** **	**<0.001*** **
Magnesium	**<0.001*** **	0.001**	0.769	**<0.001*** **	0.468	0.022*	**<0.001*** **	**<0.001*** **
Molybdenum	0.003**	**<0.001*** **	0.126	0.002**	0.809	0.447	0.006**	0.012*
Nickel	0.208	0.070	0.095					
Organic carbon	0.732	0.044*	0.424					
Phosphorus	**<0.001*** **	0.397	0.914	**<0.001*** **	0.270	0.099	**<0.001*** **	**<0.001*** **
Potassium	**<0.001*** **	0.001**	0.515	**<0.001*** **	0.305	0.080	**<0.001*** **	**<0.001*** **
Sodium	**<0.001*** **	**<0.001*** **	0.561	0.528	0.351	0.006**	0.298	0.995
Strontium	**<0.001*** **	0.001**	0.783	**<0.001*** **	0.569	0.498	**<0.001*** **	**<0.001*** **
Sulphur	**<0.001*** **	**<0.001*** **	0.215	**<0.001*** **	0.802	0.052	**<0.001*** **	**<0.001*** **
Suspended solids	**<0.001*** **	0.227	0.795	0.023*	**<0.001*** **	0.002**	0.591	**<0.001*** **
Un-ionized ammonia	0.974	**<0.001*** **	0.839					
Uranium	0.144	**<0.001*** **	0.230					

Notes:

- Shaded cells indicate that the test was not performed because Area differences were not significant.
- '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.
- $*p \le 0.05$; $**p \le 0.01$; $***p \le 0.001$ (in **bold**).
- Statistical outliers were noted for arsenic, nickel, and phosphorus. However, none of these outliers changed the significance of terms above from significant to not significant, or vice versa. Therefore, statistical outliers were retained in analyses.

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, calcium lithium, magnesium, molybdenum, phosphorus, potassium, sodium, strontium, sulphur, and suspended solids. Study versus Reference contrasts were significant for all these variables except sodium. Differences in sodium concentrations occurred between the two Reference Areas with sodium concentrations higher in the NE Reference Area than in the NW Reference Area (Table 7-3, Figure 7-2). For all remaining variables, except phosphorus and suspended solids, concentrations were lower in the Study Areas compared to the Reference Areas (Figure 7-2).

Concentrations of phosphorus were higher in the Study Area compared to the Reference Areas, and those differences held when either the near-field or mid-field samples were compared to Reference Area samples (Table 7-3, Figure 7-2).

Concentrations of suspended solids differed among most areas (Table 7-3). Concentrations generally were highest in mid-field samples, followed by NW Reference Area samples, then near-field samples; with concentrations lowest in NE Reference Area samples (Figure 7-2). The strongest differences occurred between near-field and mid-field samples in the Study Areas, and between the mid-field and combined

Reference Area samples (lowest *p*-values in Table 7-3). Concentrations were lower in near-field samples than in mid-field samples (Figure 7-2). Concentrations were generally higher in mid-field samples than in combined Reference Area samples (although this is difficult to see in Figure 7-2). The difference between concentrations in NE and NW Reference area samples was weaker but still significant (Table 7-3). Concentrations were higher in NW Reference Area samples relative to NE Reference Area samples (Figure 7-2).

The difference between near-field samples concentrations of suspended solids versus combined Reference Area concentrations was not significant (Table 7-3). However, suspended solids concentrations were significantly lower at near-field stations than at stations in the NW Reference Area ($p = 0.036$).

A significant Area x Depth interaction was noted for barium in Table-7-3. Consequently, analysis was performed by depth class with results in Table 7-4. Barium concentrations did not differ significantly among areas in surface or bottom samples (Table 7-4). Differences occurred at mid-depth with barium concentrations highest in NE Reference Area samples, similar between NW Reference Area and near-field Study Area samples, and lowest in mid-field Study Area samples (Figure 7-2). The strongest difference occurred between mid-field samples and combined Reference Area samples (lowest *p*-value in Table 7-4), although the difference between the two Reference Areas was also significant. Concentrations were lower in mid-field samples than in Reference Area samples; and concentrations were lower in the NW Reference Area than in the NE Reference Area (Figure 7-2). The difference between near-field concentrations of barium versus combined Reference Area concentrations was not significant (Table 7-4). However, barium concentrations were significantly lower at near-field stations than at stations from the NE Reference Area ($p = 0.038$).

Table 7-4 Results of ANOVA (*p*-values) by Depth Class for Barium

Variable	*p*-values					
	Area	SR	BS	BR	NF vs R	MF vs R
Surface	0.073					
Mid-depth	0.011*	0.017*	0.092	0.035*	0.231	0.006**
Bottom	0.431					

Notes
- Shaded cells indicate that the test was not performed because Area differences were not significant.
- '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**)

Differences among Areas have been noted in previous years and most differences within year reasonably can be attributed to natural variability. In 2010, molybdenum and sulphur concentrations were lower in the Study Area (Husky 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 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 2017). In 2016, differences were noted for many variables 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 2019). In 2018, the NW Reference Area differed from remaining areas, including the NE Reference Area, for many variables: molybdenum concentrations were lower in mid-field Study Area samples than in the Reference Areas samples; 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 than in the Reference Areas.

Over the years, barium has shown more frequent differences among Areas, with differences also noted at mid-depth in 2020. However, differences have been slight and inconsistent, with Study Area concentrations higher or lower in some years and at some depths compared to Reference Area concentrations. In 2020, median barium concentrations at mid-depth in the near-field, mid-field and NW and NE Reference Areas were 7.0 µg/L, 6.7 µg/L, 7.1 µg/L and 7.4 µg/L, respectively. As noted above, there were no differences in barium concentration among areas at other depths in 2020.

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: chromium, iron, zinc, aluminum, copper, mercury, lead, manganese, cadmium cobalt, and tin. Other variables noted in Table 7-2 were not detected in water samples.

Chromium, iron, zinc, aluminum, and copper occurred in more than 30% of samples (Figure 7-3). All these variables occurred more frequently at Reference Area stations. The highest values (maxima) for aluminum, chromium, copper, and iron occurred at Reference Area stations (42, 3.65, 11.2 and 31 µg/L, respectively). The highest value for zinc (26.4 µg/L) occurred at a mid-field station.

Remaining variables were detected in less than 30% of samples. Mercury was detected in 11 of 54 samples (in eight samples from near-field stations, one sample from mid-field stations and two samples from Reference Area stations). Lead was detected in nine samples (in one sample from near-field stations, five samples from mid-field stations, and three samples from Reference Area stations). Manganese was detected in three samples (in one sample in each of the near-field, mid-field and Reference Areas). Cadmium was detected in two samples (in one sample from the mid-field and one sample from Reference Areas). Cobalt was detected in one sample from mid-field stations and tin was detected in one sample from Reference Areas.

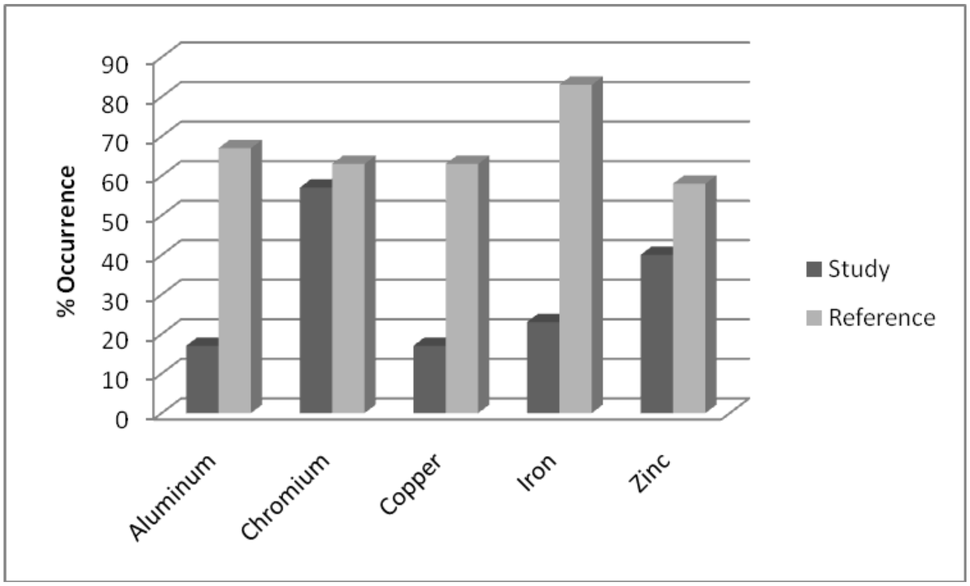

Figure 7-3 **Percent Occurrence by Area of Variables that Occurred Above Laboratory Detection Limit in 30 to <75% of Samples**

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

Sporadic occurrences of various analytes have been noted in previous years, with no consistency within Areas among years. The most obvious difference among areas in 2020 is the more frequent occurrence of mercury at near-field stations. However, in 2016, mercury occurred more frequently at Reference Area stations. In 2014, mercury was detected at all stations with no significant difference in concentrations among areas. Mercury was not detected at any station in 2010, 2012 and 2018. When it occurred in 2020, mercury concentrations were low. The maximum concentration of 0.025 µg/L noted in a bottom sample at near-field Station W1-NE is near the laboratory detection limit of 0.013 µg/L.

7.2.4.3 Produced Water Constituents in Seawater

This section focuses on co-occurrence of potential produced water constituents at the station level. The co-occurrence of high values of produced water constituents in seawater samples can be used as an indication of the presence of produced water in samples.

Examination of seawater chemistry in Reference Areas and produced water chemistry indicates that the following variables have a greater potential to be detected in Study Area samples as a result of produced water discharge: iron, barium, total nitrogen[33], manganese, organic carbon, lithium, strontium, and suspended solids. Summary statistics of Reference Area concentrations for these variables and produced water

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[33] Calculations of the concentration of ammonia in produced water relative to that of seawater was based on total nitrogen. Estimates of un-ionized ammonia would be irrelevant for produced water since pH and temperature would affect the relative concentration of un-ionized ammonia immediately upon release to seawater. However, both total nitrogen and un-ionized ammonia concentrations were examined in field samples.

concentrations are provided in Table 7-5. Note that because no organic compounds were detected in seawater samples in 2020, no organic compounds are listed in Table 7-5, even though organic compounds are present in produced water.

Table 7-5 Summary Statistics for Reference Area Concentrations and Produced Water Concentrations for Variables that are Enriched in Produced Water

Variable	Units	Reference Areas					Produced Water	Enrichment Factor
		No. Samples	*n* < DL	Mini	Max	Median		
Iron	µg/L	24	4	<2	31	5.8	7,880	1,359X
Barium	µg/L	24	0	6.3	8	7.1	9,410	1,325X
Total nitrogen	mg/L	24	2	<0.05	0.19	0.07	22	314X
Manganese	µg/L	24	22	<0.5	2.64	<0.5	124	248X
Organic carbon	mg/L	24	3	<0.5	0.92	0.63	130	206X
Lithium	µg/L	24	0	161	206	176.5	5,900	33X
Strontium	µg/L	24	0	7,110	8,690	7,930	243,000	31X
Suspended solids	mg/L	24	4	<1	20	1.6	28	18X

Notes:
- DL = Detection Limit.
- The enrichment factor is the concentration in produced water relative to the median concentration in Reference Area samples.
- The table excludes those variables that were not detected in either the Reference or Study Areas in 2020, as well as variables that were not enriched in produced water by a factor of 10X or more (see Section 7.2.3 for details).
- Reference Area medians were used to assess the enrichment factor. When medians were below DL, the DL was used to assess enrichment.
- Produced water concentrations were obtained from samples collected immediately prior to discharge from the *SeaRose FPSO* on November 21 and 22, 2020.

Table 7-6 provides station-level concentrations of variables that occur in high concentrations in produced water for Study Area stations and Reference Area stations, respectively. Concentrations are identified in these tables as highest, second highest and third highest. This ranking was done across all areas, not within each area.

In general, maximum values of variables listed in Table 7-5 tended to occur more frequently in Reference Area samples than in Study Area samples (Table 7-6). This is consistent with the quantitative analysis of frequently detected variables. The highest values for the variables listed in Table 7-5 occurred in 13% of Study Area samples and in 38% of Reference Area samples. This alone provides little indication that produced water was detected in Study Area samples. The highest value for both barium and total nitrogen occurred at one near-field Study Area station and one Reference Area station, again providing no strong evidence for the presence of produced water. Two mid-field Study Area stations had the highest organic carbon concentrations (1 µg/L; Table 7-6). However, that concentration was not substantially higher than concentrations noted at Reference Area stations (Table 7-6). This is consistent with the quantitative analysis above that showed no Area differences in organic carbon concentrations. Highest concentrations occurred at Reference Area stations for all other variables.

Table 7-6 Station-level Concentrations in the Study and Reference Areas for Variables that Occur in Relative High Concentrations in Produced Water

Area	Station	Depth	Fe (µg/L)	Ba (µg/L)	Total N (mg/L)	Un-ionized NH_3 (mg/L)	Mn (µg/L)	Organic C (µg/L)	Li (µg/L)	Sr (µg/L)	Suspended Solids (mg/L)
Near-field	W2-NE	Bottom	<2	8	0.059	0.0007	<0.5	0.73	169	7650	1
	W3-NE		<2	7	0.071	0.00087	<0.5	0.83	168	7510	1.2
	W5-NE		<2	7.7	<0.05	0.00066	<0.5	<0.5	177	7730	1.6
	W4-NE		2.3	7.4	0.071	0.00092	0.58	0.53	163	7330	1.8
	W1-NE		5.5	7.9	0.067	0.00083	<0.5	0.67	170	7540	1.8
	W1-NE	Middle	5.6	6.6	0.074	0.0014	<0.5	0.78	160	6990	<1
	W5-NE		<2	7	0.069	0.0018	<0.5	0.58	161	6940	1.6
	W3-NE		<2	6.9	0.073	0.001	<0.5	0.76	161	7090	2.2
	W2-NE		<2	7.3	0.092	0.002	<0.5	0.7	163	7220	2.2
	W4-NE		<2	7.5	0.19	0.0039	<0.5	0.8	163	7450	2.2
	W1-NE	Surface	<2	6.4	0.065	0.0017	<0.5	0.96	158	7000	1
	W3-NE		<2	6.7	0.095	0.0027	<0.5	0.73	164	7270	1
	W2-NE		<2	6.3	0.065	0.0018	<0.5	0.73	157	6950	1.2
	W5-NE		<2	6.9	0.075	0.0023	<0.5	0.56	158	6830	2
	W4-NE		<2	6.5	0.064	0.0019	<0.5	0.85	162	7230	2
Mid-field	W6MF	Bottom	<2	7.2	0.058	0.0013	<0.5	<0.5	164	7370	<2*
	W8MF		<2	7.3	0.074	0.00099	<0.5	0.5	164	7370	2.8
	W7MF		<2	7.3	0.05	<0.00064	<0.5	0.64	168	7470	7.6
	W10MF		5.1	7.6	0.062	0.00076	<0.5	0.73	173	8290	11
	W9MF		<2	7.1	0.056	0.00065	<0.5	0.63	167	7520	18
	W6MF	Middle	<2	6.9	0.09	0.0023	<0.5	<0.5	165	7270	1.2
	W10MF		23.5	7	0.071	0.0014	<0.5	1	164	7160	2
	W8MF		<2	6.7	0.062	0.0018	<0.5	1	163	7230	5
	W9MF		<2	6.6	0.079	0.0017	<0.5	0.9	166	7330	8.4
	W7MF		<2	6.6	0.058	0.001	<0.5	0.74	165	7400	10
	W6MF	Surface	<2	6.7	0.051	<0.0017	<0.5	0.93	160	6960	2
	W9MF		3.5	7.5	0.069	0.0026	<0.5	0.75	162	7250	2.6
	W10MF		30.3	6.7	0.066	0.0018	<0.5	0.6	161	7110	10
	W8MF		<2	7.2	0.066	0.0025	<0.5	0.77	164	7150	10
	W7MF		<2	7.1	0.088	0.0025	<0.5	0.88	157	6910	15
NE Reference	4	Bottom	6.1	7.1	0.19	0.0024	<0.5	0.66	172	7520	<1
	W15R		14.1	7.3	<0.05	<0.00065	<0.5	0.64	206	8320	<1
	W14R		8.5	8	0.062	0.00089	<0.5	0.85	186	8690	1.4
	W16R		8.1	7.6	0.075	0.001	<0.5	0.57	206	8140	1.8
	4	Middle	8.9	7.2	0.1	0.0016	<0.5	0.73	167	7430	<1
	W16R		3.7	7.2	0.084	0.0015	2.64	0.67	196	7850	<1
	W14R		<2	7.6	0.1	0.002	<0.5	0.69	185	8390	1
	W15R		3.2	7.9	0.076	0.0013	<0.5	<0.5	195	8130	1.6
	W16R	Surface	2	6.9	0.083	0.0022	<0.5	0.53	194	7850	1.2
	W15R		6	7.2	0.081	0.0021	<0.5	0.57	185	7890	1.8
	W14R		31	7	0.071	0.0021	<0.5	0.58	174	8000	1.8
	4		2.7	6.5	0.18	0.0044	<0.5	0.61	162	7190	2.6
NW Reference	W13R	Bottom	20.6	6.4	<0.05	0.00083	<0.5	0.64	173	8020	1.6
	W12R		23.1	7.7	0.066	0.00081	<0.5	0.76	183	8350	1.6
	27		5.2	7.6	0.067	0.00092	<0.5	<0.5	167	7390	1.8
	W11R		5.6	7	0.14	0.002	<0.5	<0.5	176	7820	2.8
	27	Middle	<2	7.1	0.06	0.0013	<0.5	0.72	166	7410	1.2
	W12R		8.6	7	0.06	0.0011	<0.5	0.79	177	7970	1.2
	W13R		<2	7.1	0.07	<0.0016	<0.5	0.52	173	8400	1.4
	W11R		<2	6.9	0.18	0.004	<0.5	0.75	175	7860	10
	W13R	Surface	2.5	6.7	0.065	0.002	<0.5	0.59	175	7920	2
	27		17.6	6.3	0.089	0.0027	0.56	0.62	161	7110	2.4
	W11R		4.1	6.8	0.072	0.0026	<0.5	0.59	179	7980	6.8
	W12R		7.9	6.8	0.063	0.0018	<0.5	0.92	177	7940	20

🟥 **Highest concentration** 🟧 **Second highest concentration** 🟨 **Third highest concentration**

Notes: - Ranks were assigned across both the Study and Reference Areas, not within Areas.
- The detection limit of un-ionized ammonia varied for each sample (see Table 7-2 for details).
- * The detection limit for suspended solids for this sample was increased because of insufficient sample volume.

Table 7-6 also identifies other relatively high concentrations. The co-occurrence of maxima with relatively high concentration for other variables can provide further evidence for the presence of produced water in Study Area samples. At Station W4-NE, the maximum for total nitrogen noted in the Study Area co-occurred with a relatively high value for un-ionized ammonia. This is to be expected since un-ionized ammonia is calculated from total nitrogen. One of the maxima for organic carbon in the Study Area co-occurred with a relatively high iron concentration at Station W10MF. However, maxima and relatively high concentrations of other variables co-occurred much more frequently in the Reference Areas (Table 7-6).

Overall, there is little to no evidence that produced water constituents were detected in Study Area samples in 2020. Across years, possible evidence of produced water at some near-field stations was noted in 2016 and 2018.

7.3 Produced Water Constituents in Sediment

7.3.1 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 Data Analysis

Quantitative analysis of sediment data for the Water Quality portion of the White Rose EEM program focuses on iron concentration in sediments (see Section 7.1 and Husky 2013, Appendix D, for details). Quantitative analyses on other sediment quality variables at Sediment Quality Triad stations are provided in Section 5.

The following procedures were used to determine if iron concentrations in sediments were associated with releases from the *SeaRose FPSO*. The analysis was carried out in four main steps. First, correlations between iron concentrations in sediments and distance to the *SeaRose FPSO* were computed for each year. Plots of the Spearman rank correlations over time were produced to make it easier to visualize changes in the strength of the distance relationship. The second step involved the production of scatterplots of iron concentrations in relation to distance from the *SeaRose FPSO*, for each year of the program. The third step involved maps of iron concentrations in 2020 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 to 2006) to after (2008 to 2020)), 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. 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 concentrations were then examined using Spearman rank correlations, scatterplots, maps and repeated-measures regression, similar to what was done with concentrations of iron.

7.3.3 Results

Summary statistics for sediment physical and chemical characteristics at Water Quality stations are provided in Appendix C-2. Raw data for sediment physical and chemical characteristics at all sediment stations (Sediment Quality Triad and Water Quality stations) are provided in Appendix A. Sediment chemistry results at Water Quality stations were qualitatively similar to results at Sediment Quality Triad stations. Aluminum, barium, chromium, iron, lead, manganese, strontium, uranium, and vanadium were detected at every station[34]. In 2020, no PAHs were detected at Water Quality stations. In 2018, low levels of 13 PAHs were detected at three Water Quality stations. In 2010, low levels of four PAHs were detected at one Water Quality station.

7.3.3.1 Principal Components Analysis

All metals except aluminum were strongly associated (*i.e.*, $r_P > |0.6|$) with scores on the first PCA axis (Table 7-7). 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 7-7 Principal Component Analysis Component Loadings (Correlations) of Metals Concentrations (All Years)

Parameter	Principal Component	
	1	2
Aluminum	0.34	0.40
Barium	**0.68**	**-0.62**
Chromium	**0.63**	0.37
Lead	**0.75**	-0.52
Manganese	**0.71**	0.51
Strontium	**0.84**	-0.44
Uranium	**0.63**	0.19
Vanadium	**0.77**	0.43
Variance Explained	46.6	20.3

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

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[34] Sediment chemistry results at Water Quality stations are not fully independent from results at Sediment Quality Triad stations. Two stations, 4 and 27, were common to both the Sediment Quality and the Water Quality programs from 2012 to 2020. Four stations, 4, 8, 16 and 27, were common to both the Sediment Quality and the Water Quality programs in 2010.

7.3.3.2 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 when all stations were considered in 2020 (ρ_s = -0.170, $p > 0.05$); however, they were significant and negatively correlated with distance to the *SeaRose FPSO* for repeated-measures stations (ρ_s = -0.339, $p = 0.05$). Despite the significant Spearman rank correlation when repeated-measures stations were considered, the threshold model was not able to estimate a reliable threshold for iron in 2020 (see Section 5 and Appendix A-7 for details on threshold models). A bivariate log-log regression of repeated-measures stations iron concentrations in relation to distance to the *SeaRose FPSO* was also not significant ($p = 0.069$). Rank correlations were not significant for iron in any previous year (Figure 7-4).

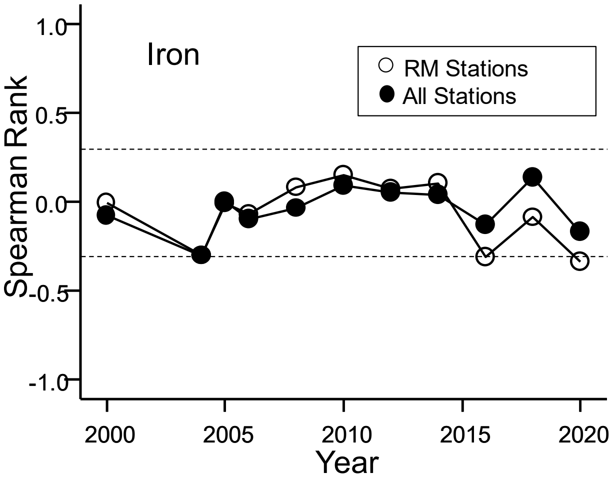

Figure 7-4 Spearman Rank Correlations with Distance from *SeaRose FPSO* for Iron Concentrations in Sediments

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).

Rank correlations were not significant for iron residuals when all stations or repeated-measures stations were considered in 2020 (ρ_s = 0.084 $p > 0.05$, All stations; ρ_s = -0.013, $p > 0.05$, repeated-measures stations; Figure 7-5). However, there were significant positive correlations in some previous years, indicating lower values for iron residuals near the *SeaRose FPSO.*

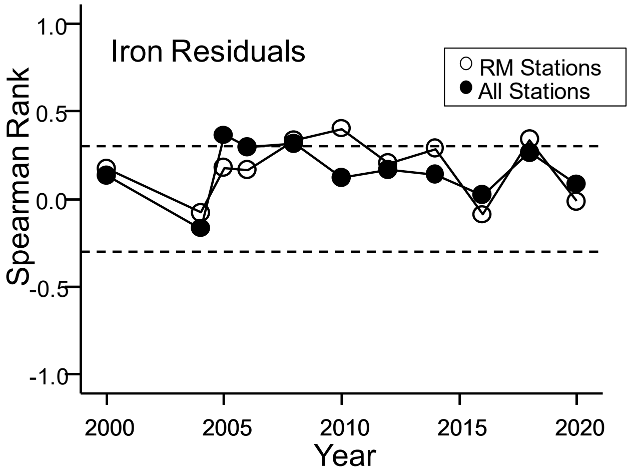

Figure 7-5 Spearman Rank Correlations with Distance from the *SeaRose FPSO* for Iron Residuals

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).

7.3.3.3 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 marked increase in iron concentrations in sediments near the *SeaRose FPSO*.

7.3.3.4 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 10 stations, with no discernable 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 19 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 2013). This increase in iron residuals between 5 and 10 km from the *SeaRose FPSO* was less apparent in 2014, but higher iron residual values did tend to occur more frequently to the northwest of the *SeaRose FPSO* (Husky 2017). In 2016, this trend continued within 2 and 10 km of the *SeaRose FPSO*, predominantly to the east and southeast (Husky 2019). This trend did not appear to be repeated with either 2018 or 2020 data (Figures 7-8 and 7-9).

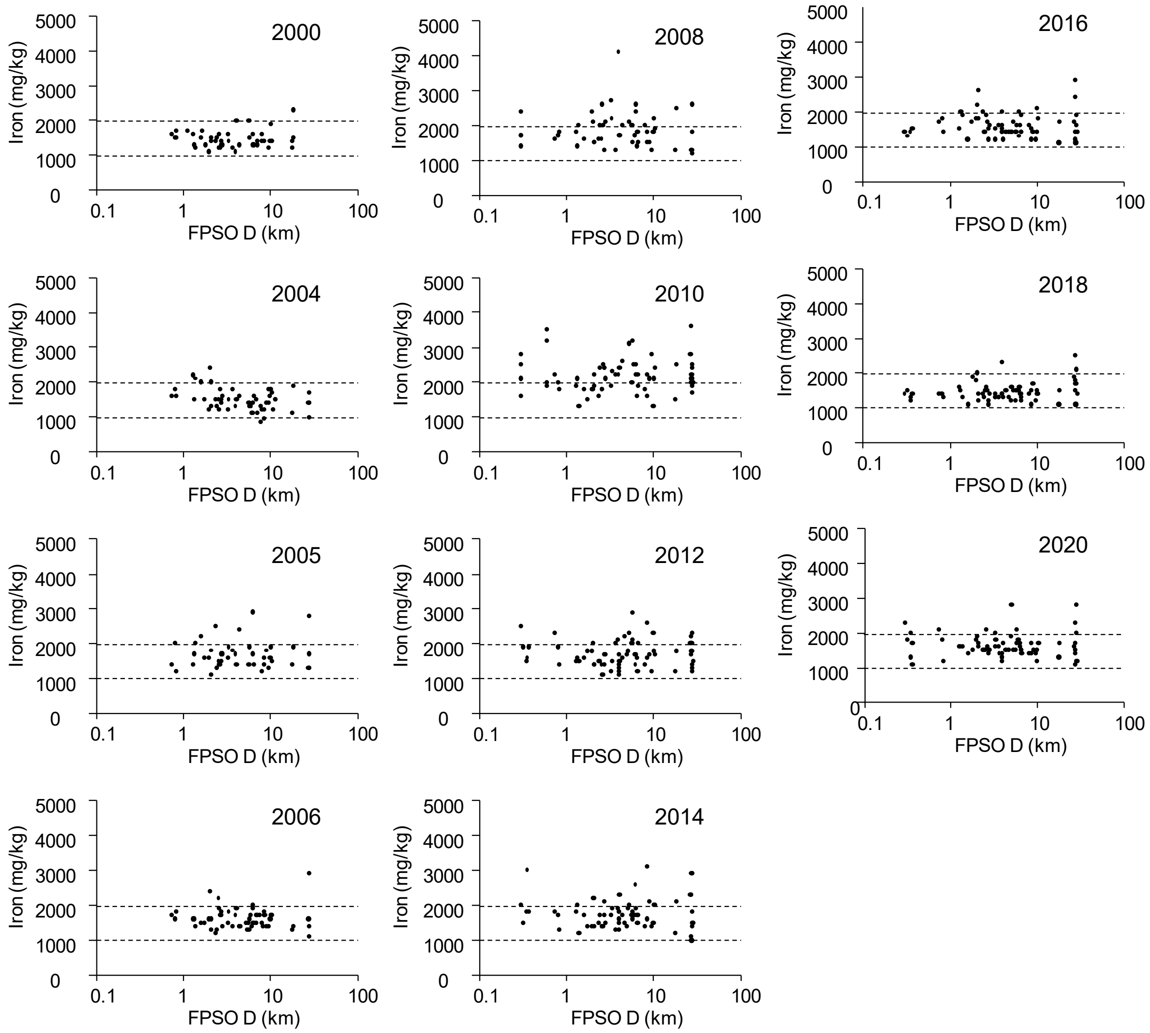

Figure 7-6 Variation in Iron Concentrations in Sediments (mg/kg) with Distance from the *SeaRose FP*SO (FPSO D) (all Years)

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).

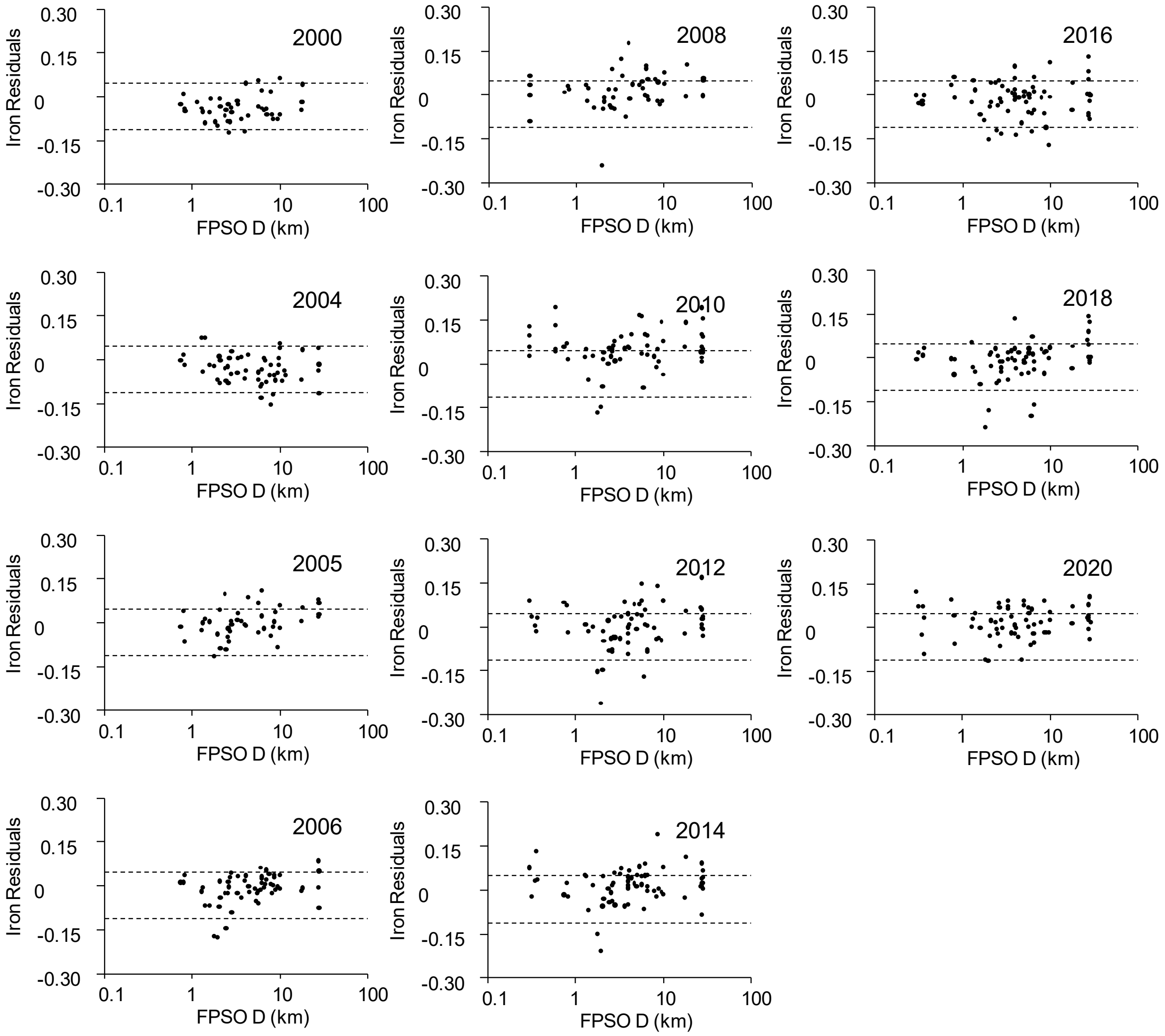

Figure 7-7 Variation in Iron Residuals with Distance from the *SeaRose FPSO* (FPSO D) (all Years)

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).

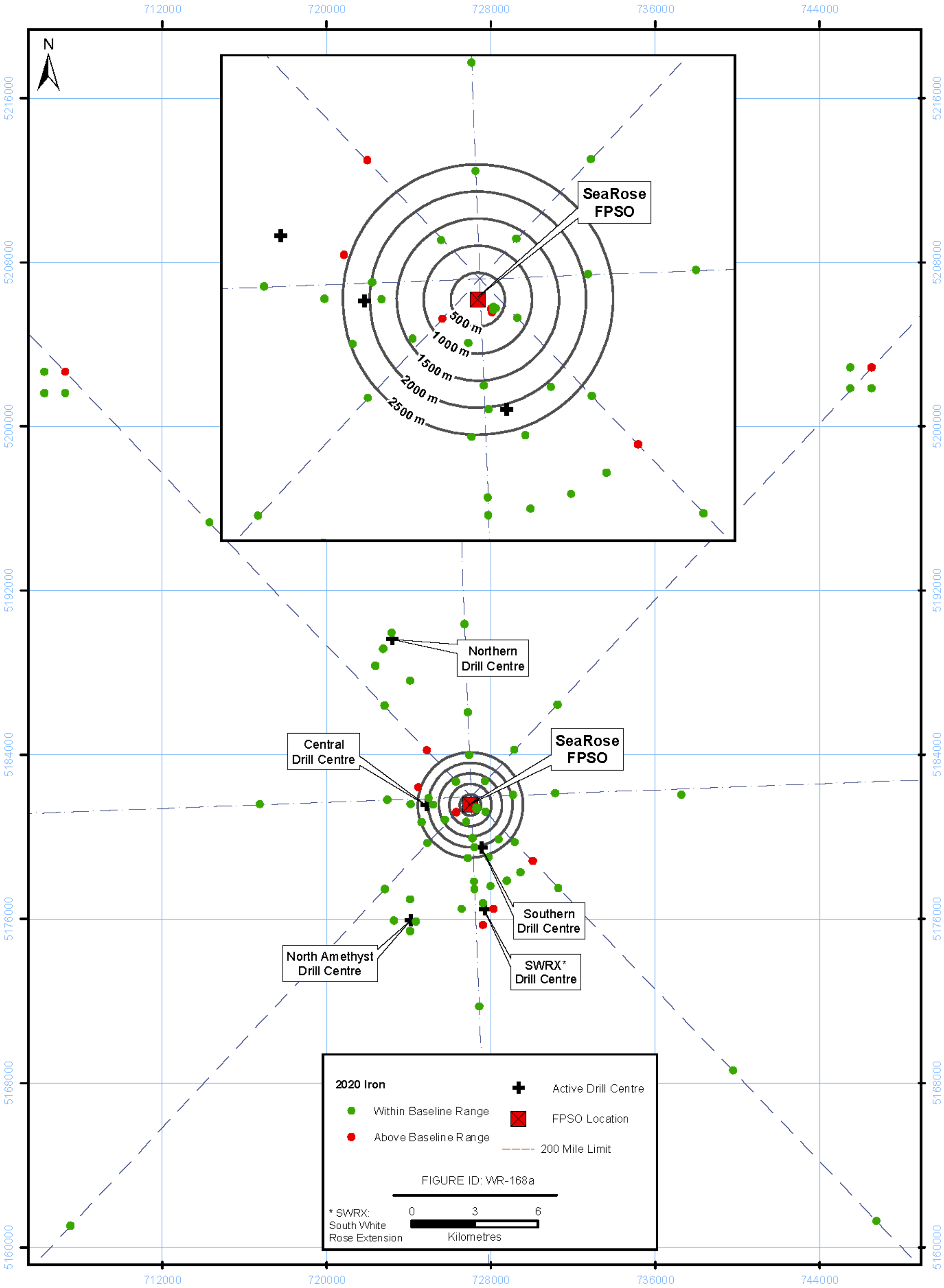

Figure 7-8 Location of Stations with Iron Concentrations Within and Above the Baseline Range (2020)

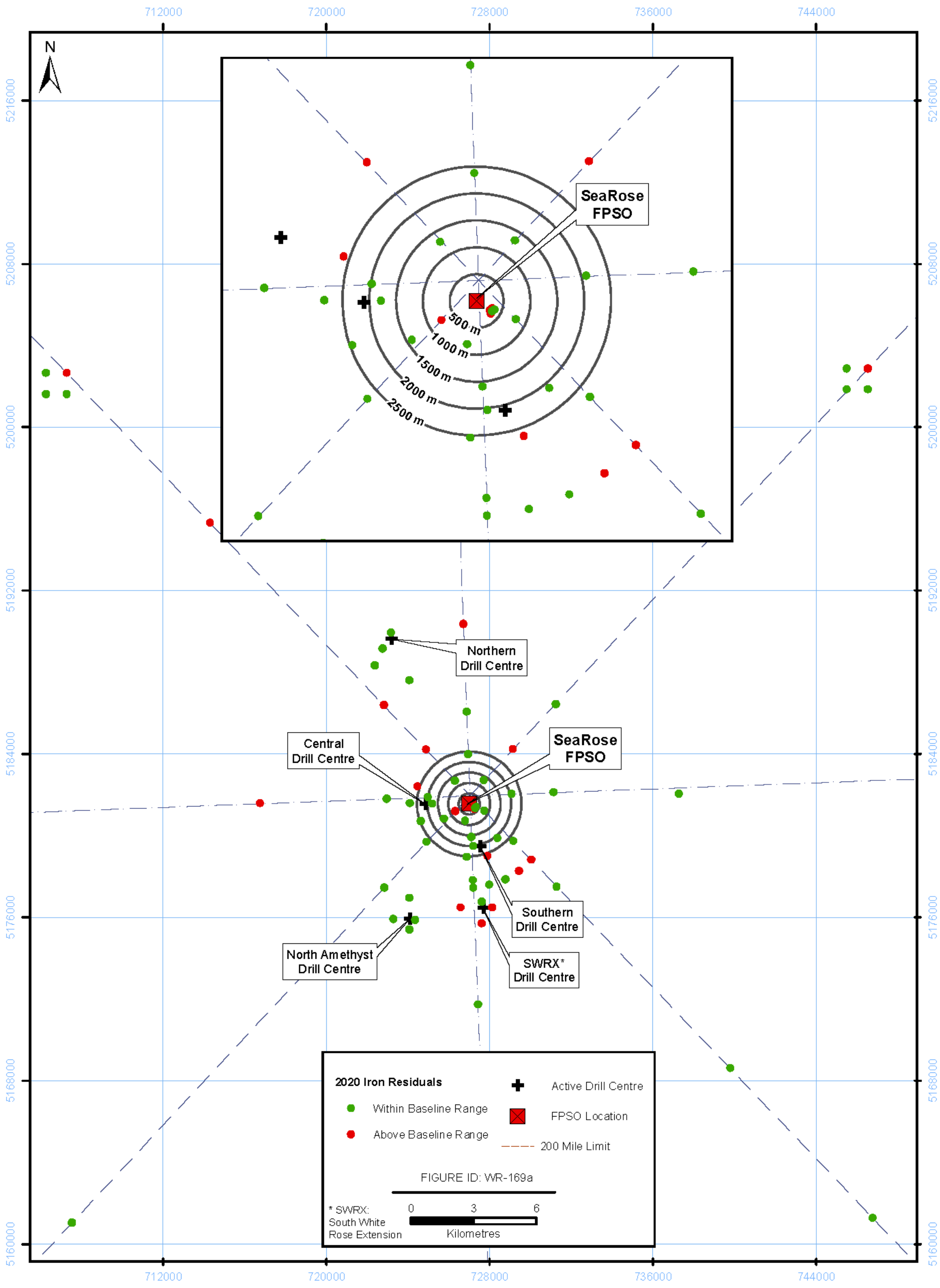

Figure 7-9 Location of Stations with Iron Residuals Within and Above the Baseline Range (2020)

7.3.3.5 Repeated-Measures Regression

Results of repeated-measures regression results are provided in Table 7-8. For repeated-measures stations, there was no change over time in the slope of the relationship between iron concentrations and distance to the *SeaRose FPSO* in years after release of produced water ($p = 0.058$) or from before to after release of produced water (in March 2007) ($p = 0.284$ Table 7-8; Figures 7-6 and 7-7). There were changes in mean iron concentrations in years subsequent to release of produced water ($p = 0.002$) and from before to after release of produced water ($p < 0.001$). Mean iron concentrations were generally higher in years subsequent to release of produced water, but concentrations have decreased since 2010 (Figure 7-10).

Table 7-8 Repeated-measures Regression Testing for Changes in Iron Concentrations and Iron Residuals over Time

Trend over Time Contrast		Before to After Contrast	
Slope	Mean	Slope	Mean
Iron Concentrations			
0.058	0.002	0.284	< 0.001
Iron Residuals			
0.032	0.978	0.758	0.001

Notes:
- Values are probabilities.
- *n* = 35 with Station 31 excluded.
- The Mean Term tests for linear trends over time common to most stations either since produced water discharge began in 2007 (Trend over Time Contrast) or it tests for a difference common to most stations from baseline to after release of produced water (Before to After Contrast).
- The Slope Term tests for changes in distance relationships (increases or decreases with distance from the *SeaRose FPSO*) either since discharge of produced water began in 2007 (Trend over Time Contrast) or for a difference from before to after released of produced water (Before to After Contrast).

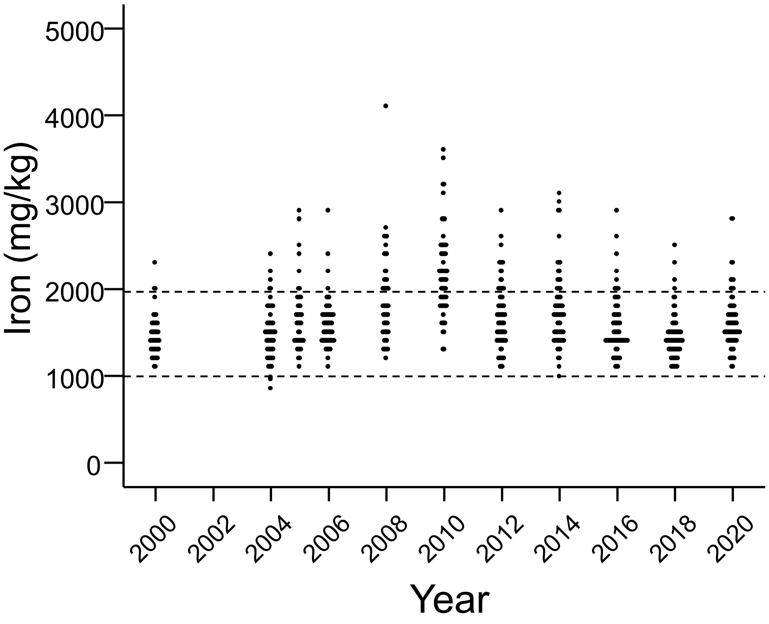

Figure 7-10 Dot Density Plot of Iron Concentrations in Sediments (mg/kg) by Year

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.

There were changes over time in the slope of the relationship between iron residuals and distance from the *SeaRose FPSO* in years after release of produced water ($p = 0.032$, Table 7-8), driven by weaker slopes in 2016 and 2020 (Figure 7-5). However, there were no changes in slopes from before to after release of produced water ($p = 0.758$). There were changes in mean iron residuals from before to after release of produced ($p = 0.001$), driven by slight increases in 2008 and 2010 (Figure 7-11).

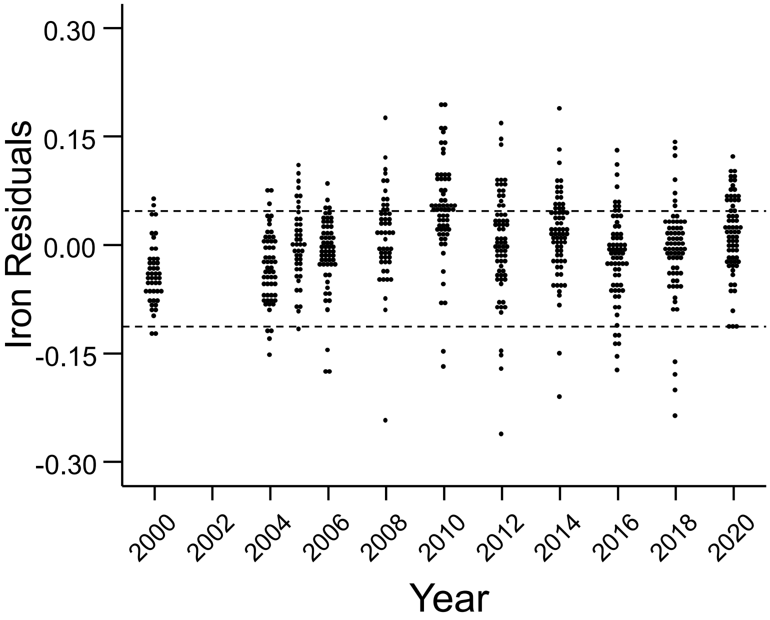

Figure 7-11 Dot Density Plot of Iron Residuals by Year

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 analyses above, evidence of enrichment of iron in sediments is weak and change since the release of produced water has been subtle. In 2020, there was no evidence of an association between iron enrichment in sediments (as determined by an examination of iron residuals) and distance from the *SeaRose FPSO*.

7.4 Summary of Results

7.4.1 Water

The following variables were detected in all seawater samples in 2020: arsenic, barium, boron, calcium, inorganic carbon, lithium, magnesium, molybdenum, potassium, sodium, strontium, sulphur, and uranium. Nickel and phosphorus were detected in 98% of samples; un-ionized ammonia was detected in 93% of samples; suspended solids were detected 89% of samples; and organic carbon was detected in 87% of samples. With the exception of inorganic carbon, which varied over the narrow range of 22 and 24 mg/L, all these variables were included in quantitative analyses for 2020.

Significant differences among Areas were noted for boron, calcium, lithium, magnesium, molybdenum, phosphorus, potassium, sodium, strontium, sulphur, and suspended solids. Concentrations of boron, calcium, lithium, magnesium, molybdenum, potassium, sodium, strontium, and sulphur were lower in Study Area samples than in Reference

Area samples. Sodium concentrations differed between the two Reference Areas only. Concentrations of phosphorus were higher in Study Area samples compared to the Reference Areas samples. This difference held when either near-field or mid-field samples were compared to Reference Area samples. Suspended solids concentrations were higher in mid-field Study Area samples compared to Reference Area samples. However, concentrations between the two Reference Areas also differed, with suspended solid concentration higher in the NW Reference Area. Concentrations in near-field samples did not differ from Reference Area samples overall. However, suspended solids concentrations were significantly lower at near-field stations compared to stations from the NW Reference Area. Finally, barium concentrations did not differ among areas when all depths were considered; but area differences were noted between mid-field Study Area samples and Reference Area samples, with lower levels in mid-field samples.

In summary, higher levels of phosphorus and suspended solids occurred in some instances in the Study Area in 2020. Higher levels occurred in both the near- and mid-field Study Area for phosphorus. Higher levels of suspended solids occurred in mid-field Study Area samples. Differences in phosphorus concentrations between the Study and Reference Areas were approximately two-fold, with Study and Reference Area medians of 174 and 93 µg/L, respectively. Differences in suspended solids concentrations between the mid-field Study and Reference Areas was approximately five-fold, with medians of 7.6 and 1.6 mg/L, respectively.

Variables that occurred in less than 75% of samples were examined qualitatively. Of the variables that occurred from 30% to 75% of samples (aluminum, chromium, copper, iron, and zinc), all occurred more frequently in the Reference Areas. There were sporadic occurrences of other constituents. Of these, mercury tended to occur more frequently in near-field Study Area samples (mercury occurred in 8 of 15 samples in the near-field, in 1 of 15 samples from the mid-field, and in 2 of 24 samples from the Reference Areas). When it occurred, mercury concentrations were low. The maximum concentration of 0.025 µg/L noted is near the laboratory detection limit of 0.013 µg/L. BTEX, $>C_{10}$-C_{21} hydrocarbons, $>C_{21}$-C_{32} hydrocarbons, PAHs, phenols and alkyl phenols, and organic acids were not detected in any water samples in 2020.

Finally, samples were examined for the presence of constituents that occur in high concentrations in produced water. Based on this exercise, there was no evidence that produced water was detected in Study Area samples in 2020.

7.4.2 Sediment

In 2020, as in 2018, there was little evidence that iron in sediment 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. When baseline information is lacking for those variables added to the program after 2000, occurrence above or below the range of values observed at more than 10 km from drill centres from 2004 to 2014[35] is used to assess effects.

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 the 2020 EEM Program, with concentrations elevated up to estimated threshold distances[36] of 2.5 and 1.1 km from the nearest active drill centre, respectively. These results are similar to those noted in 2018; with threshold distances of 2.4 and 1.0 km for $>C_{10}$-C_{21} hydrocarbons and barium, 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 2020. 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. 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 2020 relative to earlier EEM years.

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. In 2020, the maximum concentrations for $>C_{10}$-C_{21} hydrocarbons and barium (150 and 1,300 mg/kg, respectively) occurred at Station 20, located 0.37 km from the Central Drill Centre. Over all EEM years, the highest concentrations of $>C_{10}$-C_{21} hydrocarbons and barium (1,600 and 4,000 mg/kg, respectively) also occurred at Station 20. The highest concentration for $>C_{10}$-C_{21} hydrocarbons occurred in 2008, while the highest concentration for barium occurred in 2012.

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[35] 2004 to 2014 provided a sufficient number of samples ($n = 43$) to assess background variation.

[36] *i.e.*, the distance at which values return to background or near 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
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

Year	Distance from Drill Centres (m)	$>C_{10}$-C_{21} (mg/kg)	Barium (mg/kg)
2020	<500	8.8 to 150	370 to 1300
	500 to 1000	1.4 to 19	170 to 510
	>1000 to 2000	0.48 to 3	170 to 210
	>2000 to 4000	0.32 to 0.68	160 to 180
	>4000 to 8000	<0.3 to 0.57	130 to 200
	>8000	<0.3 to 0.66	110 to 220

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 2019). For brevity, Table 8-1 has been modified from previous reports to 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 weaker and less consistent project-related alterations in 2020. Sediment percent fines, organic carbon, ammonia, lead and strontium exhibited threshold relationships with distance from drill centres in 2020. Percent fines were elevated to 1.3 km from drill centres. Potential enrichment of percent fines near drill centres has been noted in previous EEM years. Relationships were too weak to assess a threshold distance in most years, but a significant threshold of 0.7 km was noted in 2014. Organic carbon was enriched to 0.85 km in 2020; and it was enriched to a distance of 1.0 km in 2018.

Overall, evidence of effects on ammonia remains weak. Ammonia exhibited a threshold relationship for the first time in 2020, with a threshold distance of 5 km. However, the wide confidence intervals about that estimate suggested a poor model fit, which indicates that the threshold distance should be interpreted with caution[37]. Graphics of ammonia concentrations indicated marginally higher levels near drill centres, but less so in 2020 than in 2018. There were no stations with ammonia concentrations above background levels in 2020 and ammonia concentrations have generally decreased over time.

Sediment lead concentrations were elevated to 0.8 km from drill centres in 2020. Elevated lead levels from 0.6 to 1.5 km of drill centres have been noted since 2006.

For strontium, the 2020 threshold was 5.6 km. As was the case for ammonia, wide confidence intervals about that estimate suggested a poor model fit which indicates that the threshold distance should be interpreted with caution[37]. Graphics of strontium concentrations versus distance from drill centres indicated lower strontium concentrations near drill centres in 2020 than in some previous EEM years. Examination of concentrations above baseline levels indicated that 70% of stations (or seven of ten stations) with elevated strontium concentrations were within 0.5 km of drill centres in 2020. Of the three remaining stations, one was a Reference Area station. Therefore, there is evidence that the 2020 threshold was overestimated. Threshold distances for

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[37] Piegorsch and Bailer (2005) provide several cautions about fitting non-linear models, many of which apply to threshold models. First, these threshold models, which are fit iteratively, can produce several different localized solutions providing similar r^2 values, but different estimates of thresholds. Secondly, when relationships are weak, more complex non-linear models are unlikely to improve either fit or understanding relative to simpler bivariate parametric or rank-rank linear regressions. In general, threshold estimates are more robust when confidence intervals about the threshold are narrow. As such, threshold estimates with wide confidence intervals which may indicate a poor fit need to be interpreted with caution. Confidence intervals about all threshold estimates are provided in Section 5 and in Appendix A-7.

strontium were also noted in 2006, 2008, 2012, and 2018. Thresholds in those years have been between 1 and 2 km.

Sulphur concentrations were elevated at a few stations in the immediate vicinity of drill centres in 2020, but the relationship was too weak to assess a threshold. There was little evidence of project-effects on sulphides, overall metals concentrations (Metals PC1) and redox potential in 2020. Evidence of effects on these last variables generally has been either weak or absent in EEM years. However, sulphide concentrations exhibited a threshold of approximately 1 km in 2006 and 2008.

Maxima for percent fines and organic carbon (2.5% and 2.0 mg/kg, respectively) occurred at Station C5 in 2020. The maximum for ammonia (10 mg/kg) occurred at Station C2. Maxima for lead, strontium, and sulphur (6.2 mg/kg, 79 mg/kg, and 0.098%, respectively) occurred at Station 20. All these maxima are lower than maxima noted in other EEM years. Over remaining years, the highest values for percent fines, organic carbon, ammonia, lead, strontium, and sulphur respectively were 3.7% (in 2010), 8.4 mg/kg (in 2014), 64.6 mg/kg (in 2004), 26 mg/kg (in 2008), 170 mg/kg (in 2012) and 0.29 % (in 2008).

8.1.2 Laboratory Toxicity Tests

No samples were toxic to Microtox or laboratory amphipods in 2020. Over all EEM years, 6 (of 546) samples have been toxic to Microtox, and 15 (of 546) samples have been toxic to laboratory amphipods, indicating that sediments at White Rose are generally non-toxic.

8.1.3 Benthic Invertebrate Community Structure

There has been evidence of project effects on total abundance of benthic invertebrates in some EEM years. However, the relationship between total abundance and distance to drill centres was weak and not significant in 2020, as in 2018. In 2020, total abundance was reduced at only three stations near drill centres (details on effects by drill centre are provided below). Multivariate analysis indicated that the most affected taxa in 2020 were the polychaetes Paraonidae, Cirratulidae and Orbiniidae, as well as the crustaceans Cirripedia and Isopoda. In both 2016 and 2018 (the other years in which a multivariate analysis on benthos was conducted), Paraonidae, Cirratulidae, Orbiniidae, and members of the family Isopoda were also among the most affected taxa. The abundances of Paraonidae, Orbiniidae and Isopoda were lower near drill centres in 2020; and the abundances of Cirratulidae and Cirripedia were higher near drill centres. Because abundances of some taxa decreased, and abundances of others increased, the overall effect on total abundance was minor.

There was evidence of project-effects on biomass in 2020, as in previous years. The distance threshold for effects on benthic biomass was 2.9 km in 2020. Thresholds were noted in 2012 (1.5 km) and 2012 (5.5 km). As was the case for ammonia and strontium, wide confidence intervals about the 2012 and 2020 estimates suggested a poor model fit, which indicates that the threshold distances should be interpreted with caution[37]. There has also been a general decline in biomass (*i.e.,* at all or most stations) from earlier to later EEM years, suggesting some level of natural variation over and above project-effects. As indicated in previous reports, reductions in biomass near drill centres are related, in part, to reductions in the number of larger echinoderms.

There was no evidence of effects on richness in 2020. Evidence of effects on richness has been weak or absent in all EEM years.

Univariate analyses of the abundances of individual taxa are performed with White Rose data to provide insight into summary measures of benthic community structure (*i.e.,* total abundance, biomass and richness). In 2020, univariate analyses were performed on Paraonidae, Cirratulidae, Orbiniidae, and Isopoda. These were the four taxa identified as most affected through multivariate analysis on benthos in 2018.

Paraonidae abundance has been strongly and negatively related to distance from active drill centres, with threshold distances significant in every EEM year (*i.e.,* abundances increased with distance to drill centres in every EEM year). The threshold distance for effects on Paraonidae in 2020 was estimated at 1.4 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 2020).

No threshold could be estimated for the relationship between Cirratulidae and distance to drill centres in 2020, and abundance gradually decreased with distance. Threshold distances of 1 and 5.4 km were noted in 2006 and 2012 for Cirratulidae abundance[38]. There was also a general increase in Cirratulidae abundance in EEM years (*i.e.,* at all or most stations), after an initial decline; with abundances in 2020 similar to those noted in baseline (2000). As was the case for biomass, these general patterns suggest natural variation over and above project-effects.

Orbiniidae abundance increased with distance to drill centres to a threshold distance of 1.1 km in 2020. Thresholds were noted for Orbiniidae in five of the nine previous EEM cycles, with threshold distances ranging from 1 to 3 km[39]. Finally, the abundance of Isopoda increased with distance to drill centres to a distance of 2.1 km in 2020. Thresholds were also noted for Isopoda in five of the nine previous EEM years, with threshold distances ranging from 1 to 9 km[40]. There was also a general increase in Isopoda abundances (*i.e.,* at all or most station) in EEM years.

Both the univariate and the multivariate assessments identified sediment concentrations of $>C_{10}$-C_{21} hydrocarbons as a strong correlate with benthic community variables. These and prior results indicate that $>C_{10}$-C_{21} hydrocarbons is a good indicator of the presence of drill cuttings in sediments.

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

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[38] The threshold for 2012 had wide confidence intervals about that estimate suggesting a poor model fit which indicates that the threshold distance should be interpreted with caution. Refer to footnote 37 for details.

[39] The 3 km threshold had wide confidence intervals about the estimate suggesting a poor model fit which indicates that the threshold distance should be interpreted with caution. Refer to footnote 37 for details.

[40] The 9 km threshold had wide confidence intervals about the estimate suggesting a poor model fit which indicates that the threshold distance should be interpreted with caution. Refer to footnote 37 for details.

efficient assessment of effects of individual drill centres as well as potential cumulative effects from multiple drill centres.

In 2020, total abundance was reduced to below the baseline range at Stations SWRX1 and 14 around the SWRX Drill Centre, and at Station 23 around the Central Drill Centre. Distances to the nearest drill centre for Stations SWRX1, 14 and 23 are 0.32, 1.4, and 1.81 km, respectively.

Total biomass was reduced at many stations in 2020, indicating the potential influence of natural variation over and above project-effects, since some of the stations were far from drill centres. Biomass was reduced to below the baseline range at eight of ten stations around the Central Drill Centre. The most distant of these stations (Station 21) is located 1.87 km from the drill centre. Biomass was also reduced to below the baseline range at three stations around the North Amethyst Drill Centre, at four stations around each of the SWRX and Southern Drill Centres, and at one station around the Northern Drill Centre. The most distant of these stations to any drill centre is Station S3, 1.4 km from the Southern Drill Centre. As noted, biomass was also reduced at many stations outside of the immediate vicinity of drill centres. The most distant of these stations is Station 4 (a Reference Area station), located 26 km from the nearest drill centre.

Richness was not reduced to below the baseline range at any station in 2020.

Paraonidae abundance was reduced to below the baseline range at six stations around the Central Drill Centre, at three stations around each of the North Amethyst and SWRX Drill Centres, at four stations around the Southern Drill Centre and at two stations around the Northern Drill Centre. Stations C5, 20, C3, C2, C1, 17, NA1, NA2, NA3, SWRX1, SWRX2, SWRX3, S5, 13, S1, S2, N4, and N3 had abundances below the baseline range. Most of these stations are within 0.5 km from drill centres. Stations C3, C2, NA3, and SWRX3 are within approximately 1 km of drill centres; and Station 17 is 1.81 km from the Central Drill Centre.

Cirratulidae abundance was above the baseline range at three stations around the Central Drill Centre (Stations C5, 20, and C2) and at one station around each of the North Amethyst and Southern Drill Centres (Stations NA3 and S5, respectively). Stations NA3 and C2 are located at 0.63 and 0.83 km from the nearest drill centre, respectively. Remaining stations are within 0.5 km of drill centres.

Orbiniidae abundance was below the baseline range at three stations around each of the Central, Southern and SWRX Drill Centres, and at two stations around the North Amethyst Drill Centre. Stations 20, C2, C1, NA1, NA2, SWRX1, SWRX2, SWRX3, S1, 13, and S5 had abundances below the baseline range. Six of these stations are located within 0.5 km of drill centres, the remaining five are located within approximately 1 km (1.14 km is the furthest distance to drill centre).

Although isopods showed an increase in abundance with distance from drill centre (see the whole-field assessment above), their abundance was not reduced to below the baseline range at any drill centre.

Overall, examination of 2020 data at the whole field level and by-drill-centre suggests that for most benthic indices and individual taxa, the majority of effects occurred within 0.5 to 1 km of drill centres, with more subtle and/or highly localized effects between 1 to

2 km. Effects on biomass could have extended beyond 2 km in 2020. However, effects on biomass were weaker in 2018 than in previous EEM years or 2020, with reduced biomass only in the immediate vicinity of drill centres; and there has been little change, and arguably a decrease, in drilling discharge from 2018 to 2020[41]. This lack of consistency and the more general decline in biomass across the sampling area suggests natural variation over and above project effects[42]. That overall effects on benthos generally were contained within 2 km is supported by the 2020 multivariate assessment, which showed that stations beyond 2 km of drill centres were indistinguishable from each other. These results are consistent with those noted in previous years.

The spatial extent of effects on benthic invertebrates at White Rose is consistent with effects of contamination from other 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, consistent with White Rose results.

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 the benthic community is reduced to one or two types of organisms, and with either very high or very low abundances. This is not the condition at White Rose. In 2020, total abundance was reduced to less than the baseline range at three stations, and those reductions were slight (less than 25% lower than the baseline range). Richness was unaffected by project activity.

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 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[43].

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[41] Water-based mud, synthetic-based mud base oil, and completion fluid discharges from 2017 to 2018, leading up to the 2018 EEM program, were 7,747, 540, and 5,915 m³, respectively). Water-based mud, synthetic-based mud base oil, and completion fluid discharges from 2019 to 2020, leading up to the 2020 EEM program, were 7,118, 0, and 5,865 m³, respectively (Section 4 of this report).

[42] Recommendations regarding biomass assessment in future EEM programs are provided in Section 8.6.

[43] In some years, sampling one or two of the Reference Areas was not possible because of intense commercial fishing activity. All Reference Areas were sampled in 2020.

Compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon range were again detected in all plaice liver samples in 2020. 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 been speculated in previous EEM reports that these compounds are natural in origin and perhaps diet related.

In 2020, there were no differences between the Study and Reference Areas in plaice liver concentrations of percent fat, cadmium, iron, and zinc. However, liver concentrations of $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons, arsenic, manganese, and mercury were higher in the Study Area compared to the Reference Areas; and copper concentrations were lower in the Study Area compared to the Reference Areas. Differences among the four Reference Areas were noted for selenium; selenium concentrations in the Study Area were intermediate to those in Reference Areas 2 and 3 versus Reference Areas 1 and 4. Differences among the four Reference Areas were also noted for selenium and zinc.

As in previous years, differences in plaice liver metals concentrations between the Study Area and the Reference Areas were slight. The mean arsenic concentration in the Study Area versus the mean in the combined Reference Areas was 6.70 mg/kg versus 5.59 mg/kg[44]. Mean manganese concentrations were 2.19 mg/kg versus 1.98 mg/kg. Mean mercury concentrations were 0.07 mg/kg versus 0.05 mg/kg. Mean copper concentrations were 5.41 mg/kg versus 5.58 mg/kg. Mean selenium concentrations were 5.25 mg/kg in the Study Area versus 5.32 mg/kg in Reference Areas 2 and 3 and 4.35 mg/kg in Reference Areas 1 and 4. Differences between the Study and Reference Areas were somewhat larger for compounds in the hydrocarbon range. Mean $>C_{10}$-C_{21} hydrocarbon concentrations were 1,034 mg/kg versus 759 mg/kg in the Study and Reference Areas, respectively. Mean $>C_{21}$-C_{32} hydrocarbon concentrations were 2,581 mg/kg versus 1,023 mg/kg in the Study and Reference Areas, respectively. As noted above, these compounds are not petrogenic, and are more likely of natural origin and related to diet.

Differences noted in plaice liver in 2020 have not persisted over time, with concentrations sometimes higher, sometimes lower, in the Study Area compared to the Reference Areas. There were general trends over time for most variables and these trends were common to all sampled areas. Trends differed between the Study and Reference Areas only for copper. Copper concentrations in liver increased to 2014 and then decreased, in all areas. This trend was not unique to copper. Cadmium, mercury, selenium, and zinc also increased to 2014/2016, and then decreased, in all areas. However, the increase and subsequent decrease in copper concentrations was slightly more pronounced in the Study Area than in the Reference Areas. Subsequent to 2014, liver copper concentrations generally were similar between the Study and Reference Areas; and, as noted above, liver copper concentrations in 2020 were lower in the Study Area than in the Reference Areas.

Concentrations of compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon range in plaice liver were higher in 2020 than in previous years, in all areas. Since the presence of these compounds is thought to be related to diet, a difference in sampling time from the

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[44] All weights reported for tissues are corrected for moisture content as described in Section 6.

usual June/July to October may have contributed to this result[45]; as diet would be expected to vary seasonally.

Plaice fillet concentrations of fat (percent fat), arsenic, and mercury were higher in the Study Area than in the Reference Area in 2020. There were no differences in fillet zinc concentrations between the Study and Reference Areas. The mean percent fat concentration in the Study Area versus the mean in the combined Reference Areas was 4.51% versus 2.67%, respectively. Mean arsenic concentrations were 20.41 mg/kg versus 17.10 mg/kg, respectively. Mean mercury concentrations were 0.52 mg/kg versus 0.33 mg/kg, respectively. There were trends over time common to all sampling areas for all variables. Fillet arsenic concentrations increased to 2014, and then decreased, in all areas. Fillet zinc concentrations were lower in 2008 than in preceding or subsequent years. Percent fat generally increase over time, in all areas. Arsenic, mercury, and zinc generally increased over time in all areas. The increase in mercury concentration over time differed between the Study and Reference Areas. Mercury concentrations have been similar between the Study and Reference Areas in most years. However, mercury concentrations in fillets were higher in the Study Area in 2016 and 2020[46]. In all years including 2016 and 2020, differences between the Study and Reference Areas were smaller than differences across years common to all areas[47].

For crab leg tissue in 2020, there were no differences in metal concentrations between the Study and Reference Area for any of the frequently detected metals (arsenic, copper, mercury, selenium, silver, strontium, and zinc). Across years, there was a difference in trends between the Study and Reference Areas for arsenic concentrations, with higher concentrations in Reference Area leg tissue in most years.

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. Metals concentrations were within the range of, or lower than, values noted in previous years and any differences among areas can reasonably be attributed to natural variability. Concentrations of compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon range in liver were higher in 2020. Additional tests on hydrocarbons performed in this and previous EEM programs indicate that these compounds are natural in origin and possibly diet related. The change in sampling time from June/July to October could be responsible for this result.

8.2.2 Taste Tests

In 2020, there were no significant differences in taste test results between Study and Reference Areas for plaice and crab and, from ancillary comments, there were no consistent comments identifying abnormal or foreign odour or taste. These results do not indicate taint in White Rose plaice or crab samples.

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[45] Sampling was delayed to October in 2020 because of COVID-19 restrictions.

[46] Although mercury concentrations were higher in the Study Area in 2016, that difference was not significant.

[47] As noted above, Study versus Reference means in 2020 were 0.52 mg/kg versus 0.33 mg/kg, respectively. In 2016, those means were 0.85 mg/kg versus 0.67 mg/kg, respectively. Mercury was highest across all areas in 2014, with an overall mean of 0.76 mg/kg (Study/Reference means were 0.76 and 0.77 mg/kg, respectively). Mercury was lowest across all areas in 2008, with an overall mean of 0.21 mg/kg (Study/Reference means were 0.20 and 0.22, respectively). Also see multi-year figures in Section 6 for graphics of inter-annual variability.

8.2.3 Fish Health Indicators

Cellular and sub-cellular biomarker 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; also see Appendix B-3 for an extended discussion). However, it is recognized that as for fish growth or fish organ condition, biomarker endpoints can display some natural variability and, therefore, the focus should be on the prevalence of observations (a weight-of-evidence approach) and recurrences or trends over time, which allows for a comprehensive evaluation of fish health and provides a good indication of environmental quality for assessment purposes (Giltrap *et al.* 2017).

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, 71% were pre-spawning and 29% were immature. The frequency of pre-spawning and immature females did not differ between the Study and Reference Areas.

Fish length, gutted weight and age were significantly lower for pre-spawning and immature females from the Reference Areas compared to the Study Area. There were also differences among the Reference Areas for length, gutted weight, age, and gonad weight relative to gutted weight. For pre-spawning females, Reference Area 2 fish were younger, smaller and with heavier gonads relative to gutted weight. For immature females, Reference Area 4 fish were younger, smaller and with heavier gonads relative to gutted weight.

Overall, the differences observed in biological characteristics between the Study and the Reference Areas, and among the Reference 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 because of 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 among the Reference Areas.

8.2.3.4 Histopathology

Detailed histopathological studies were carried out on liver tissues of 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 conditions noted, nuclear pleomorphism, macrophage aggregates, inflammatory response, hepatocellular vacuolation, and parasites occurred with sufficient frequency to perform statistical analysis. There were no differences in the occurrence of liver conditions between the Study and Reference Area except for inflammatory response. Inflammatory response was noted in 75% of fish from the Study Area versus 48% of fish from the Reference Areas. The frequency of inflammatory response also differed among the Reference Areas, with the highest prevalence (57%) in Reference Area 1.

Inflammatory responses are non-specific lesions that are known to appear following viral, bacterial, or parasitic infections as well as tissue damage, and are usually encountered during the analysis of liver pathology (*e.g.*, Feist *et al.* 2004). According to ICES (1998), non-specific lesions, including inflammatory responses, are considered of lesser importance for environmental monitoring purposes, but should nevertheless be recorded.

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 (⅓ to ⅔) and tip hyperplasia, which were 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 (⅓ to ⅔) occurred in 47% of fish from the Study Area versus 31% of fish from the Reference Areas. Tip hyperplasia occurred in 57% of fish from the Study Area versus 36% of fish from the Reference Areas. Similar results were observed during the White Rose EEM program in 2016 when fish from the Study Area had a higher incidence of tip hyperplasia, and in 2018, when fish from the Study Area had a higher incidence of basal hyperplasia.

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). In the White Rose EEM program, the lack of statistical significance in other markers of exposure (*e.g.*, EROD activity) between fish from the Study and Reference Areas adds weight to the possibility that the hyperplasia seen in the gills of the fish might be due to stressors other than hydrocarbons. 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 2020 indicate that the overall health of American plaice is similar between the Reference Areas and the Study Area. The increase in basal and tip hyperplasia in the gills of 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.

8.3 Water Quality Component

The Water Quality monitoring program at White Rose involves collection of sediment and seawater samples in two Study Areas (the near- and mid-field Study Areas) and in two Reference Areas (the NE and NW 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 in 2020: arsenic, barium, boron, calcium, inorganic carbon, lithium, magnesium, molybdenum, potassium, sodium, strontium, sulphur, and uranium. Nickel and phosphorus were detected in 98% of samples; un-ionized ammonia was detected in 93% of samples; suspended solids were detected 89% of samples; and organic carbon was detected in 87% of samples. With the exception of inorganic carbon, which varied over the narrow range of 22 and 24 mg/L, all these variables were included in quantitative analyses for 2020. Remaining variables were detected in less than 75% of samples. Variables that were detected in at least one sample were examined qualitatively and are discussed below. BTEX, $>C_{10}$-C_{21} hydrocarbons, $>C_{21}$-C_{32} hydrocarbons, PAHs, phenols and alkyl phenols, and organic acids were not detected in any water samples in 2020.

Of the variables assessed in quantitative analyses, higher concentrations of phosphorus and suspended solids occurred in some instances in Study Area samples compared to Reference Area samples. Concentrations of phosphorus were higher in both near-field and mid-field Study Area samples compared to Reference Area samples. Suspended solids concentrations were higher in mid-field Study Area samples compared to

Reference Area samples. However, concentrations between the two Reference Areas also differed, with suspended solids concentrations higher in the NW Reference Area. Concentrations in near-field samples did not differ from Reference Area samples overall. However, suspended solids concentrations were significantly lower at near-field stations compared to stations from the NW Reference Area. These results indicate high variability in concentrations of suspended solids over the four sampling areas.

Differences in phosphorus concentrations between the Study and Reference Areas in 2020 were approximately two-fold, with Study and Reference Area medians of 174 and 93 µg/L, respectively[48]. Differences in suspended solids concentrations between the mid-field Study and Reference Areas was approximately five-fold, with medians of 7.6 and 1.6 mg/L, respectively.

Remaining variables examined in quantitative analyses in 2020 most often indicated no difference among Areas (arsenic, nickel, organic carbon, un-ionized ammonia, and uranium); or higher concentrations in Reference Area samples (boron, calcium lithium, magnesium, molybdenum, potassium, strontium, and sulphur). For sodium, concentrations differed between the two Reference Areas only, with sodium levels in Study Area samples intermediate to those in the two Reference Areas. For barium, differences only occurred at mid-depth, with higher overall barium concentrations in Reference Area samples.

Differences among areas have been noted in previous years in quantitative analyses; 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 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 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 2017). In 2016, differences were noted for many variables 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 2019). In 2018, the NW Reference Area differed from remaining areas, including the NE Reference Area, for many variables; molybdenum concentrations were lower in mid-field Study Area samples than in the Reference Areas samples; 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 than in the Reference Areas. There has been no consistent pattern across years for phosphorus and suspended solids, the two variables with higher concentrations in the Study Area in 2020. Quantitative analysis was only performed on suspended solids in 2014 and 2016 because both suspended solids and phosphorus occurred infrequently in other years[49]. In years when they occurred infrequently, frequency of detection was approximately the same among areas in both cases, or frequency of detection was higher in Reference Areas. In 2014 and 2016, there were no differences among areas in suspended solids concentrations.

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[48] Phosphorus is not in high concentration in produced water. The concentration in 2020 was 64 µg/L and near the laboratory detection limit of 50 µg/L.

[49] Phosphorus was not measured in 2010 but was measured from 2012 to 2020. Suspended solids were measured from 2010 to 2020.

Over the years, barium has shown the most frequent differences among areas in quantitative analyses, with differences noted again in 2020. However, differences have been slight and inconsistent, with Study Area concentrations higher or lower in some years and at some depths compared to Reference Area concentrations. In 2020, median barium concentrations at mid-depth in the near-field, mid-field, and NW and NE Reference Areas were 7.0, 6.7, 7.1, and 7.4 µg/L, respectively. Also, as noted above, mid-field concentrations at mid-depth were lower than in Reference Areas.

Variables that occurred in less than 75% of seawater samples were examined qualitatively. In 2020, chromium, iron, zinc, aluminum, and cooper occurred in 30% to 75% of samples. All of these metals occurred more frequently in Reference Area samples. Mercury, lead, manganese, cadmium, cobalt, and tin were detected in 1% to 30% of samples. Of these, only mercury appeared to occur more frequently in Study Area samples. Mercury occurred in 30% of Study Area samples and in 8% of Reference Area samples in 2020. Sporadic occurrences of various analytes have been noted in previous years, with no consistency within areas among years. In 2016, mercury occurred more frequently at Reference Area samples. In 2014, mercury was detected in all samples with no significant difference in concentrations among areas. Mercury was not detected in any sample in 2010, 2012, and 2018. When mercury occurred in 2020, concentrations were low. The maximum concentration of 0.025 µg/L noted at a Study Area sample is near the laboratory detection limit of 0.013 µg/L.

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. Overall, there was little evidence that produced water constituents were detected in Study Area samples in 2020. Across years, possible evidence of produced water at some near-field stations was noted in 2016 and 2018.

In 2020, as in previous years, there was little evidence that activities at White Rose are affecting water quality.

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 2013). In 2020, as in 2018, there was little evidence of iron enrichment in sediment. 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.

8.4 Summary of Effects Relative to Monitoring Hypotheses and EA Predictions

As discussed in Section 1.7, monitoring hypotheses were developed in Husky (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.

Given results observed in the 2020 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 EA predictions indicated that there would be change in Sediment Quality Triad variables with distance from discharge sources.

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).

The following summarizes project effects and relates them, as applicable, to EA predictions in the original White Rose EA (Husky 2000) and a subsequent EA (LGL 2006) aimed at White Rose field expansion.

The spatial extent of sediment contamination from drilling discharges was assessed through the modelling exercise associated with the original White Rose EA. That exercise indicated that drill cuttings and associated alterations to sediment physical and chemical characteristics could extent to 9 km from discharge source. As predicted, sediment alterations in physical and chemical characteristics occurred. Concentrations of $>C_{10}$-C_{21} hydrocarbons and barium were elevated by drilling activity near drill centres in 2020. To a lesser extent, sediment particle size (percent fines) and concentrations of organic carbon, ammonia, lead, strontium, lead, strontium, and sulphur were also affected by drilling.

The spatial extent of contamination in 2020 was consistent with original predictions on the spatial extent of drill cuttings. $>C_{10}$-C_{21} hydrocarbon contamination extended to threshold distance of 2.5 km from source. Barium contamination extended to 1.1 km from source. Percent fines were elevated to 1.3 km from source; organic carbon was elevated to 0.85 km from source; and lead was elevated to 0.8 km from source. For ammonia and strontium, results indicated that the assessment of the threshold distance was overestimated, and graphics indicated contamination only in the immediate vicinity of drill centres (see Section 8.1.1). Nevertheless, those estimates (5.0 km for ammonia and 5.6 km for strontium) are still within the predicted 9 km zone of influence of drill cuttings. A threshold distance could not be estimated for sulphur because the relationship between sulphur concentration and distance from source was weak. From graphics, elevated sulphur concentrations occurred within 0.5 km from source[50].

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[50] When thresholds cannot be fit to the data, estimates are qualitative rather than quantitative.

No sample was toxic using the Microtox or laboratory amphipods toxicity tests in 2020. The Microtox and amphipod toxicity tests continue to indicate that sediments at White Rose are predominantly non-toxic. There were no predictions specific to toxicity in the White Rose EAs.

White Rose EA predictions on effects on benthos are general. Both EAs associated with the development identified that benthic community disruption would occur near source, and both predicted no significant effect on fish and fish habitat as a result of these disruptions. To provide insight into effects on benthos, the EEM program targets specific benthic community indices. Overall, examination of 2020 data suggest that for most benthic indices and individual taxa, the majority of effects occurred within 0.5 to 1 km of drill centres, with more subtle and/or highly localized effects between 1 to 2 km. These results are consistent EA predictions and with those noted in previous years. Results for biomass were questionable in 2020, with indication of depressed biomass at many stations outside the immediate vicinity of drill centres. This more wide-spread decreases in biomass suggested natural variation over and above any project-effects (see details in Sections 8.1.3 and recommendations in Section 8.6). Assessment of the magnitude effects on the benthic community indicated that disruptions were not large relative to commonly accepted criteria (see Section 8.1.3). Total abundance was reduced to values lower than those noted during baseline collections at three stations near drill centres, and reductions were slight (less than 25% lower than the baseline range). There was no evidence of effects on richness.

Sediment contamination and effects on benthos noted in 2020 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 or plaice, neither resource was tainted, and plaice health was similar between White Rose and more distant Reference Areas. EEM results from 2020, as well as those from previous years, continue to support the EA prediction of no significant effects on fish.

For water quality, the White Rose EA predicted that changes to physical and chemical characteristics of seawater as a result of liquid discharge would be localized near discharge source. In 2020, there was little evidence of project-related alterations 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. There was also no evidence that produced water constituents were detected in seawater samples in 2020.

8.5 Conclusion

Results from the 2020 EEM program for White Rose indicate that environmental effects at White Rose are consistent with those anticipated in the White Rose EAs and the overall EA prediction of no significant effect on fish and fish habitat. There is no evidence that additional mitigation measures are required at this time.

8.6 Consideration for the 2022 EEM Program

As noted above, there are limitations to the effectiveness of threshold models, particularly when distance relationships are weak. When confidence intervals about threshold estimates are wide, additional information should be used to supplement model results and draw conclusions on potential effects.

Overall, univariate assessment of the abundances of Orbiniidae and Isopoda did not provide substantial information over and above that provided by the assessment the abundance of Paraonidae, because all responded similarly to project activity. As such, it is recommended to exclude analyses for Orbiniidae and Isopoda in the 2022 report. Analyses on Paraonidae and Cirratulidae should be retained because these two taxa provide different information; Paraonidae abundance is negatively affected and Cirratulidae abundance is enriched by project activity. Multivariate assessment should continue to provide insight on remaining taxa.

At present, all organisms within each benthos sample are weighed together to obtain a single measure of biomass. In order to better assess the influence of echinoderms on biomass, individual taxa within the echinoderms should be weighed separately. A biomass measure with and without echinoderms would then be available to best quantify potential influences.

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10.0 Addendum

Comments on Husky 2020 EEM Report: Volume 1

Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB)

No comments on the 2020 EEM Report

Noted.

Fisheries and Oceans Canada (DFO)

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 centers, however, we agree that localized effects on macrofauna are unlikely to have significant ecological effects on fisheries. Toxicity tests during the 2020 program continue to indicate the sediments are predominantly non-toxic. Results of the 2020 EEM program indicate the environmental effects at White Rose continue to be consistent with those anticipated in the Project EAs.

Noted and thank you.

Specific Comments

Figure 1-20: 2020 EEM program Commercial Fish Sampling Locations - The use of crab pots for catching commercial crab is new to the 2020 program. It would be useful if the use of crab pots was referenced and additional details provided in the 1.6.2 introductory text.

Agreed. The following paragraph will be added to section 1.6.2:

> "Plaice and crab were caught using a DFO Campelen trawl from baseline to the 2008 EEM program; and they were caught using a commercial trawl from 2010 to the present. In 2020, crab were also caught using crab pots because of low catch rates using only the trawl in the previous (2018) EEM program."

Section 6.1.1: Field Collection (page 143, 1st sentence, Table 6-1) - States that the commercial fish component of the 2020 EEM program was conducted between October 5 and 16, 2020. This is much later than previous EEM programs. It would be useful to indicate why sampling was conducted much later in the year.

A footnote will be added to the Table 6-1 stating the following:

> "Sampling was conducted later in 2020 because of Covid 19 restrictions during Spring/early Summer. Deferral of sampling at Covid 19 alert level 4 or higher was approved by the C-NLOPB."

Section 8.2.3.1: Biological Characteristics and Condition of Fish (Page 221, 2nd paragraph) - States "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, 71% were pre-spawning and 29% were immature." A discussion pertaining to composition of captured American plaice during the 2020 EEM compared to previous programs would be beneficial to determine if catch was influenced by the time of year the field program was completed.

Catch is generally consistent from year to year because the EEM sampling program targets a total number of 180 plaice for health analyses. Poor catches resulted in lower numbers in 2008 (113 fish) when sampling occurred earlier than in other years (see Figure 1, attached, for sampling dates). A total of 179 to 180 fish were caught in remaining EEM years, including 2020.

Males have generally accounted for a smaller proportion of the catch in most EEM years. Excluding 2008, males have accounted for 1 to 16% of the catch. The percent of males in the catch in 2020 was 5%. The percent of males in the catch in 2018 was also 5%. Therefore, there is no indication that the later sampling time in 2020 affected sex ratios. However, there is indication that the earlier sampling time in 2008 affected sex ratios, with males making up 59% of the catch.

There has been inter-annual variation in the proportion of immature, pre-spawning and spent females in the catch. Table 1 (attached) provides the proportion (%) of females by DFO maturity class across EEM years. This inter-annual variability is expected, and it is one of the reasons why MFO analysis is performed within, but not across years (MFO results are affected by maturity stage). The catch has been dominated by pre-spawning females since 2014, with very little difference between the ratio of immatures to pre-spawning females from 2016 to 2020. These data do not indicate that the later sampling in 2020 affected the proportion of female maturity stages.

These observations are of general interest and discussion is provided within this forum. However, since the EEM program targets project effects specifically, a further discussion within the report is not warranted.

Environment and Climate Change Canada (ECCC)

4.2 - Project Activities, 4.3 - Drilling and Completions Operations - Section 4.2 of the report states that "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."

Section 4.3.1 (Drilling Mud and Completion Fluids Discharges) of the report states that "There was very little drilling activity within the White Rose Field since the 2018 EEM program". Is the EEM program able to discern trends associated with these milestones in 2005, 2010, 2015 and 2018?

> Generally yes. The White Rose EEM program is designed to assess overall project effects and effects of each drill centre. New drill centre stations were added around the North Amethyst in 2008, prior to drilling, and the subsequent EEM program (in 2010) identified effects around the drill centre. New drill centre stations were added around the SWRX drill centre in 2012, prior to drilling, and the subsequent EEM program (in 2014) identified effects (albeit minor) around the drill centre (stronger effects were noted around the SWRX drill centre in the 2016 EEM program). There were no effects specifically associated with the start of production in 2005, but there were effects associated with the drilling and construction operations that preceded this. These were noted in the 2004, 2005, and 2006 EEM programs. Finally, the spatial extent and/or magnitude of effects at the White Rose field have decreased over time, coincident with a decrease in drilling activity.

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." How did you decide on 25% as a threshold?

> The specific threshold of 25% is based on professional judgement and experience. Variables with many values below laboratory detection limit are not suitable for parametric analysis because assumptions of heterogeneity of variance and normal distribution are violated, even after substitution of ½ the detection limit. Also see Quinn G.P. and M.J. Keough 2002. [Experimental Design and Data Analysis for Biologists. Cambridge University Press, Cambridge, UK. 537 pp.] for further discussion on assumption required for parametric analyses.

5.2.1.8 - Metals other than Barium - The report states that "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."

Although it is useful to categorize metals for the purposes of the principal component analysis and subsequent statistical comparisons, it is assumed that anomalies of individual metal parameters will still be investigated.

> Yes. PCA identifies anomalies in individual metals, or groups of metals. The first PC axis identifies the major axis of co-variance among metals. Subsequent PC axes will identify if individual or groups of metals vary somewhat differently from the remainder of metals. In 2020, PCA analysis indicated that lead and strontium varied differently from the remainder of metals. Therefore, these two metals were examined separately. Barium, as a major component of drilling muds, is always examined separately.

6.11 - Field Collection - Table 6.1 illustrates that, for 2020, fish was conducted much later in the year compared to previous EEM studies. Please comment on the significance of this change.

> Within year, any seasonal variation is accounted for through a Study versus Reference comparison, in that the Reference Areas are subjected to the same seasonal variation as the Study Area. Across years, we do not expect direct project effects on crab and plaice to be influenced by seasonality. If crab and plaice are present in the Study Area, then they may be exposed to project discharge. Although project discharges are variable, they do not vary seasonally. However, indirect effects could be influenced by seasons. For instance, levels of naturally occurring organic compounds in plaice liver were higher in 2020 than in years when sampling occurred earlier. As noted in the discussion, this is likely related to a difference in diet later in the year. If that change in diet had involved consumption of more, or less, highly contaminated prey, then a change in indirect project effects could have occurred. We saw no evidence of this with the 2020 data. As in previous years, there was little evidence of project effects on crab and plaice body burden. Excluding naturally occurring organic compounds, there was no increase or decrease in body burden variables outside of the range of natural variability noted across previous EEM years. There was no evidence of taint, and overall plaice health was similar between the Study and Reference Areas. See response to DFO - Comment 4 for further discussion on potential seasonal effects on plaice numbers, sex ratios, and maturity.

8.3.1 - Seawater Chemistry - The report states that “Variables that occurred in less than 75% of seawater samples were examined qualitatively.” How did you decide on 75% as a threshold?

> Please see the response to ECCC - Comment 6. For sediments and water chemistry and fish body burden, quantitative analysis includes only those variables that occur in 75% of samples (i.e., excludes those variables with greater than 25% of test results below laboratory detection limit). Because produced water constituents are expected to occur very infrequently in seawater samples, the water quality component of the EEM programs also performs a qualitative examination of constituents that occur in less than 75% of samples to assess for the presence of these constituents.

8.6 - Consideration for the 2022 EEM Program - The report states that “Overall, univariate assessment of the abundances of Orbiniidae and Isopoda did not provide substantial information over and above that provided by the assessment the abundance of Paraonidae, because all responded similarly to project activity. As such, it is recommended to exclude analyses for Orbiniidae and Isopoda in the 2022 report."

Analyses on Paraonidae and Cirratulidae should be retained because these two taxa provide different information; Paraonidae abundance is negatively affected and Cirratulidae abundance is enriched by project activity. Multivariate assessment should continue to provide insight on remaining taxa." ECCC is open to discussions on proposed modifications to the sediment assessment program.

Noted.

8.6 - Consideration for the 2022 EEM Program - The report states that "At present, all organisms within each benthos sample are weighed together to obtain a single measure of biomass. In order to better assess the influence of echinoderms on biomass, individual taxa within the echinoderms should be weighed separately. A biomass measure with and without echinoderms would then be available to best quantify potential influences."

ECCC is supportive of this approach.

Noted.