terra nova

TERRA NOVA

2020 ENVIRONMENTAL EFFECTS MONITORING PROGRAM

YEAR 11

(VOLUME 1)

DECEMBER 2021; Revised Submission MARCH 2023

EXECUTIVE SUMMARY

The Terra Nova Environmental Effects Monitoring (EEM) program was established to fulfil commitments made in the Terra Nova Environmental Impact Statement (EIS) (Suncor Energy[1] 1996) and addendum document (Suncor Energy 1997). The design of the EEM Program drew on a number of information sources, including the Terra Nova Baseline Characterization Program (Suncor Energy 1998a), dispersion model results for drill cuttings and produced water (Seaconsult 1998) and input from experts and the public. In 2009, Suncor Energy revised the water quality monitoring portion of its EEM program in response to Condition 32 of Operations Authorization No. 23001-001. That document and additional changes to the program[2] were integrated into Suncor Energy's control document TN-IM-EV02-X00-001, last updated in January 2021. The main goals of the program have been to assess effects predictions made in the EIS and determine the zone of influence of project contaminants[3].

The first through tenth EEM Programs were conducted in 2000, 2001, 2002, 2004, 2006, 2008, 2010, 2012, 2014 and 2017. This report discusses the results of the eleventh EEM Program, conducted in the fall of 2020, and relates these to findings of previous EEM years (Suncor Energy 2001, 2002, 2003, 2005, 2007, 2009, 2011, 2013, 2017, 2019) and to the baseline (1997) program (Suncor Energy 1998a).

In 2020, seafloor sediments were sampled at 53 locations along transect lines centred on the location of the Terra Nova floating production, storage, and offloading (FPSO) facility. Physical and chemical analyses were conducted on sediment samples. Toxicity tests that characterized whether sediments were toxic to a marine amphipod and a marine polychaete species were performed, and benthic invertebrate infaunal species were identified and enumerated and community structure was analyzed.

Samples of a flatfish species (American plaice) were collected in the Study Area and in the Southeast Reference Area in the Fall of 2020. These samples were analyzed for chemical body burden, taste, a series of health indices and morphometrics and life history characteristics (size, shape, fecundity, maturity status). The Terra Nova EEM program also includes collection of a bivalve (Iceland scallop). However,

[1] For simplicity, historical submissions under the name Petro-Canada will now be referenced as Suncor Energy.
[2] Changes to the program were made in response to reviewer comments on EEM program reports.
[3] The term contamination is used in this report to indicate elevated levels of a chemical as compared to background levels (GESAMP 1993).

technical difficulties prevented their collection in 2020. Scallop were collected in 2021, with results provided in an addendum document.

Seawater samples are normally collected during EEM sampling to assess potential effects of produced water discharge on water quality. Because the Terra Nova FPSO was offsite and had not been releasing produced water since December 2019, no water sampling was conducted in 2020. Water quality monitoring will resume once production activities resume.

As in previous years, there were few project-related effects at Terra Nova relative to the number of variables examined.

Barium and $>C_{10}$-C_{21} hydrocarbons are important constituents of drill muds used at Terra Nova and levels of both compounds were elevated in sediments near drill centres in 2020. Although contamination increased in EEM years overall, contamination has decreased in recent years compared to levels observed in 2004 and 2006. Reduction in contamination coincided with reduced drilling activities in the field after 2006. In 2020, maximum barium and $>C_{10}$-C_{21} hydrocarbon concentrations (3,900 and 1,600 mg/kg, respectively) occurred at Station 30(FE), located 0.14 km from the Far East (FE) Drill Centre. Over all EEM years, the highest noted barium concentration (16,000 mg/kg) occurred in 2006; the highest noted $>C_{10}$-C_{21} hydrocarbon (6,550 mg/kg) occurred in 2004; both at Station 30(FE).

There has been some evidence of project effects on sediment sulphur and fines content in some EEM years, but evidence of effects was weak or absent in 2020. Higher sulphide and lower redox levels at a few stations in the immediate vicinity of drill centres indicate that decomposition of synthetic-based drill fluid or naturally occurring organic carbon may be occurring. In 2020, as in most previous years, all sediments were oxic.

Sediment contamination did not extend beyond the zone of influence predicted by Seaconsult (1998). The model predicted that on completion of drilling, drill cuttings could be dispersed to 15 km from source, with the heaviest deposition occurring within approximately 5 to 10 km from drill centres. Consistent with these model predictions, concentrations of barium decreased to background levels within approximately 1 km from drill centres; concentrations of $>C_{10}$-C_{21} hydrocarbons decreased to levels near the laboratory detection limit (0.3 mg/kg) within approximately 2 km from drill centres.

There was little to no evidence of project-related sediment toxicity, as measured through laboratory tests with polychaetes and amphipods.

There was evidence that project activities altered community composition near drill centres in 2020, with abundances of some taxa increasing and abundances of other taxa decreasing near drill centres and at higher barium and $>C_{10}$-C_{21} hydrocarbon concentrations. Total abundance was also higher near drill centres. There was weaker evidence of potential increases in biomass and richness near drill centres in 2020. As in previous years, the distance gradient for these changes was too weak to provide robust estimates of the spatial extent of effects, but 2020 results suggest effects on the most affected taxa extending to approximately 1 to 2 km of drill centres.

Effects of drill cuttings on benthic invertebrates were expected to be fairly large in the immediate vicinity of drill centres and mild within a few hundred metres of the drill centres (Suncor Energy 1996). Large effects on benthic invertebrates at Terra Nova were only noted in 2008 at Station 30(FE), located nearest (0.14 km from) to a drill centre. In that year, total abundance, biomass, and richness were substantially lower at Station 30(FE) than at other stations. Otherwise, the predominant effect at Terra Nova has been a change in community composition, with enrichment of the benthic community near drill centres. These results are consistent with EIS predictions.

No effects were noted on American plaice, a commercial fish species selected for the program. No tissue contamination was noted; no tainting of this resource was observed; and overall plaice health, as measured through various health indicators, was similar between the Terra Nova Study Area and the more distant Reference Area.

Conclusion

Effects at Terra Nova remain limited and within the predicted range. In 2020, sediment contamination did not extend beyond the zone of influence that was predicted after completion of drilling, effects on benthic invertebrates were consistent with EIS predictions, no tissue contamination or effects on taste were noted for American plaice, and plaice heath was similar between the Terra Nova Study Area and the Reference Area.

ACKNOWLEDGEMENTS

The Terra Nova EEM program (2020) was led by Stantec Consulting Ltd. (St. John's, NL) under contract to Suncor Energy and under the direction of Trudy Wells (Suncor Energy). Stantec Consulting Ltd. led data collection. Participants in the sediment survey included Doug Rimmer, Ralph MacLean, Tony Parr, Catie Young, Kristian Greenham, and Justin Bath from Stantec Consulting Ltd. Fugro Jacques Geosurveys Inc. (Shane Sullivan and Trevor Lewis) provided geopositional services for sediment 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, NS and St. John's, NL). Chemical analyses of sediment were conducted by Bureau Veritas and RPC (Fredericton, NB). Chromatograms were interpreted by Dr. Joe Kiceniuk. Particle size analysis was conducted by Stantec Consulting Ltd. Sediment toxicity tests were conducted by Avalon Laboratories. Participants in the commercial fish survey included Doug Rimmer and Kristian Greenham from Stantec Consulting Limited and Mirelle Caouette-Houle and Shanshan Liu from Oceans Ltd. Fish processing and filleting was provided by Pisces International personnel. Taste tests were performed at the Marine Institute of Memorial University. Laboratory work and data analysis for fish health indicators were supervised by Dr. Juan Perez Casanova (Oceans Ltd.). Remaining data analyses were performed by Drs. Elisabeth DeBlois (Elisabeth DeBlois Inc.) and Marc Skinner (Stantec Consulting Ltd.). Drs. Elisabeth DeBlois, Marc Skinner and Juan Perez Casanova wrote sections of the report. Consolidation of text within each section was done by Dr. Elisabeth DeBlois. Technical review was done by Drs. Elisabeth DeBlois and Marc Skinner (each reviewing the others' work). 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 Trudy Wells at Suncor 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 and Mary Murdoch reviewed the report from a quality control perspective at Stantec Consulting Ltd. Trudy Wells (Suncor Energy) provided final review of the document before final production.

TABLE OF CONTENTS

Page No.

LIST OF FIGURES

Page No.

LIST OF TABLES

Page No.

1.0 INTRODUCTION

1.1 PROJECT SETTING AND FIELD LAYOUT

The Terra Nova oil field is located on the Grand Banks, approximately 350 km east-southeast of St. John's (Figure 1-1). Suncor Energy has acted as operator for the development on behalf of the owners (Suncor Energy Inc., ExxonMobil Canada Properties, Husky Oil Operations Ltd., Statoil Canada Ltd., Murphy Oil Company Ltd., Mosbacher Operating Ltd., and Chevron Canada Ltd.). The ownership of the Terra Nova partnership changed in September 2021. Suncor Energy continues to act as operator, now on behalf of Suncor Energy Inc., Cenovus Energy Inc., and Murphy Oil Company Ltd.

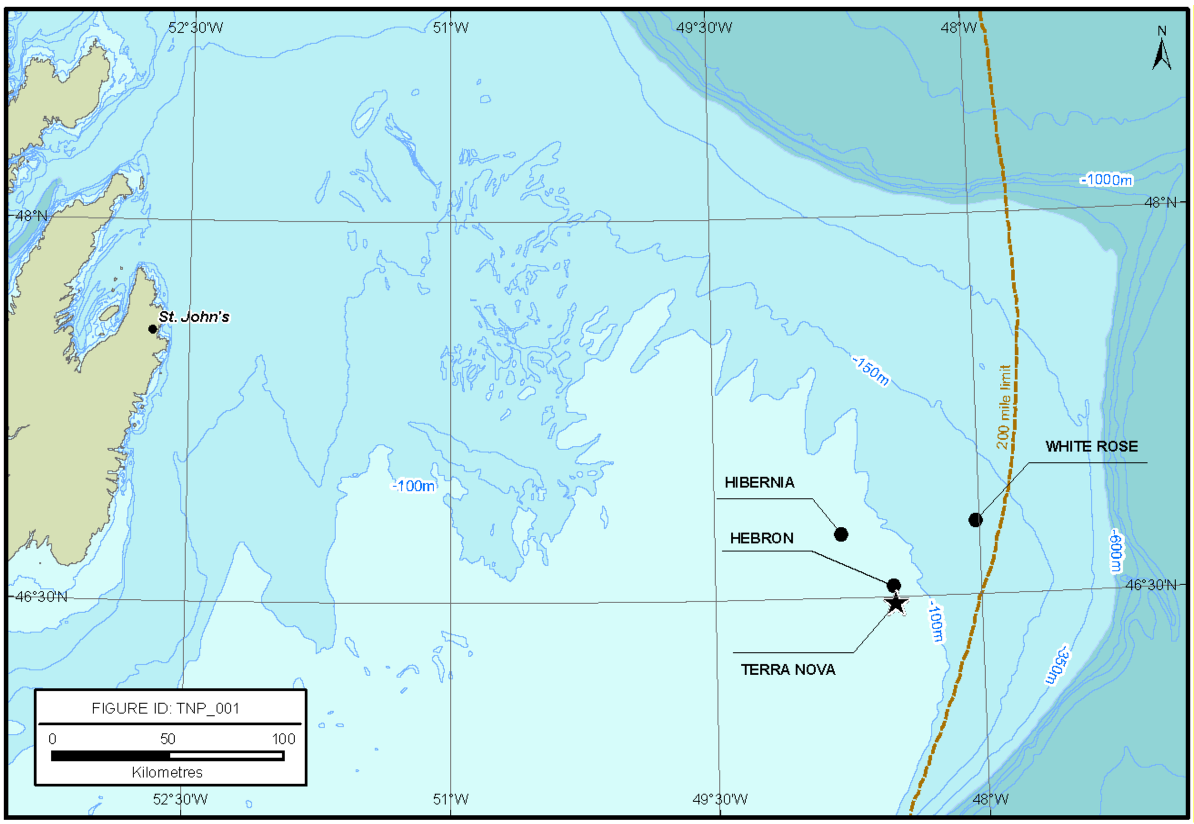

Figure 1-1 Terra Nova and Other Oil Field Locations on the Grand Banks

The oil field is being developed using a floating production, storage, and offloading (FPSO) facility and a semi-submersible drilling rig (Figure 1-2). From 1999 through 2001, seven drilling templates were installed in the five drill centres to protect them from iceberg impact (Figure 1-3); wells are drilled through these templates. Trenched and bermed flowlines connected to flexible risers link the subsea installations to the FPSO.

Figure 1-2 Terra Nova Oil Field Schematic

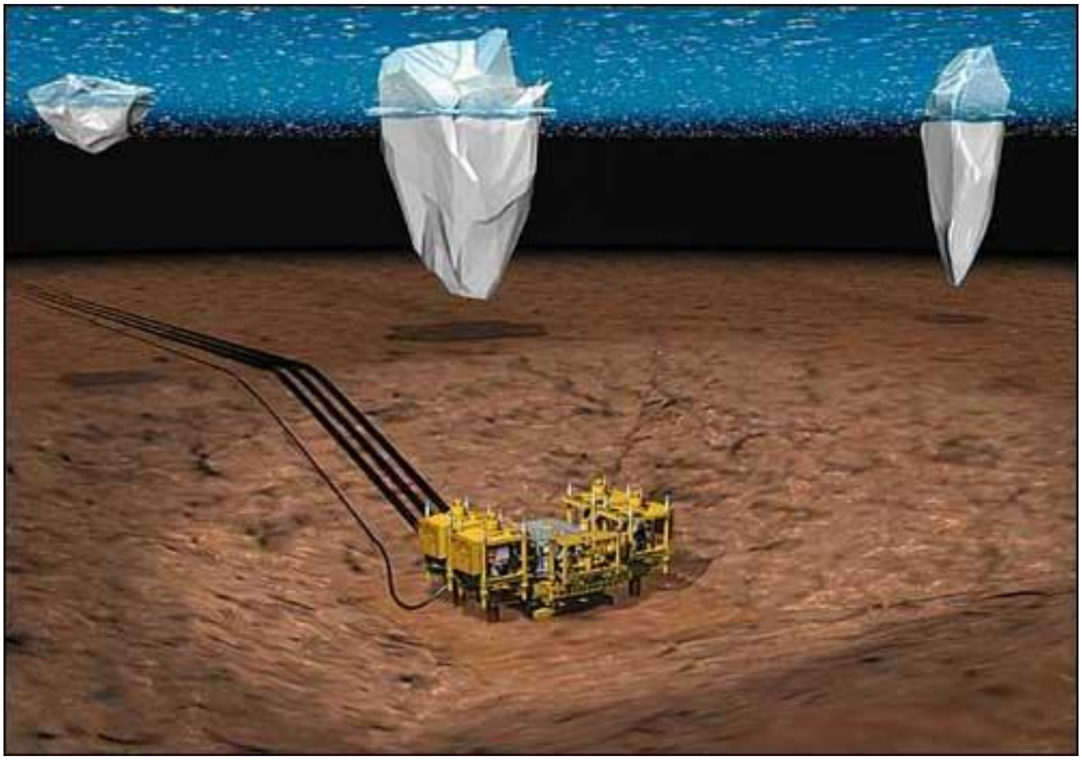

Figure 1-3 Typical Drill Centre Configuration

1.2 PROJECT COMMITMENTS

In 1996, Suncor Energy (then Petro-Canada) prepared an Environmental Impact Statement (EIS) as part of its Development Application to the Canada-Newfoundland Offshore Petroleum Board[4]. Pursuant to the Memorandum of Understanding concerning the Environmental Assessment of the Terra Nova Development, a Panel was established to review the EIS (Suncor Energy 1996) and addendum (Suncor Energy 1997). The Panel, guided by the scoping sessions and full public hearings (April 1997), issued a document containing recommendations with respect to the Development in August 1997. Based on that set of recommendations, the Canada-Newfoundland Offshore Petroleum Board supported the plan to develop the Terra Nova oil field, subject to conditions, in December 1997 (Decision 97.02).

In both the EIS and addendum, and at the Panel hearings, Suncor Energy, on behalf of the Terra Nova Development proponents, made a commitment to design and implement an EEM program. The timing of the EEM program design submission was set out in Condition 23 of the Decision 97.02 report, which required that the

[4] The name of this organization has since been changed to Canada-Newfoundland and Labrador Offshore Petroleum Board.

proponent submit its EEM program design with respect to the drilling and production phases of Terra Nova before starting drilling operations.

1.3 EEM PROGRAM DESIGN

EEM program design drew on expert and stakeholder input, EIS predictions and findings from the Terra Nova Baseline program undertaken in 1997 (Suncor Energy 1998a).

Suncor Energy solicited input on its EEM program from government agencies. Meetings were held with Fisheries and Oceans Canada (DFO) scientific and management staff on August 11, 21 and 24, 1998. A meeting with Environment Canada was held on August 25, 1998.

Suncor Energy held an in-house workshop with EEM experts on September 8, 1998, to discuss existing knowledge on EEM and develop a monitoring strategy. The design team consisted of Urban Williams and Mona Rossiter (Suncor Energy, St. John's, NL), Kathy Penney, Mary Murdoch, Ellen Tracy and Sandra Whiteway (Stantec Consulting Ltd., St. John's, NL), Dr. Michael Paine (Paine, Ledge and Associates, North Vancouver, BC), Judith Bobbitt (Oceans Ltd., St. John's, NL), Dr. David Schneider (Memorial University, St. John's, NL), Don Hodgins (Seaconsult Marine Research Ltd., Salt Spring Island, BC) and Lou Massie (Marine Environmental Consultant, Scotland, UK). David Burley, from the Canada-Newfoundland and Labrador Offshore Petroleum Board also attended.

A public information session was held in St. John's on September 22, 1998. General invitations were issued through *The Evening Telegram* and *The Clarenville Pacquet*. Specific invitations were sent to government agencies and stakeholders involved in the EIS Panel hearings.

The design document (Suncor Energy 1998b) was submitted to the Canada-Newfoundland Offshore Petroleum Board in October 1998, and the EEM program has since been implemented eleven times, in 2000, 2001, 2002, 2004, 2006, 2008, 2010, 2012, 2014, 2017 and 2020. Changes to the program have occurred over these years as a result of regulatory requirements and recommendations from the EEM report review process. Suncor Energy submitted a revised water quality monitoring program document in response to Condition 32 of Operations Authorization No. 23001-001. That document and additional changes to the program were integrated into Suncor Energy's control document TN-IM-EV02-X00-001, last updated in January 2021.

On May 9, 2016, the C-NLOPB accepted Suncor Energy's proposal to revise the Terra Nova EEM program's sampling interval from every two years to every three years. This report represents the second program conducted on the three-year-interval cycle.

1.4 EEM PROGRAM OBJECTIVES

The primary objectives of the program are to:

- assess the spatial extent and magnitude of project-related contamination; and
- verify effects predictions made in the EIS (Suncor Energy 1996).

Secondary, and related, objectives are to:

- assess the effectiveness of the implemented mitigation measures;
- provide an early warning of changes in the environment; and
- improve understanding of environmental cause-and-effect.

1.5 TERRA NOVA EIS PREDICTIONS

EIS predictions (Suncor Energy 1996) on physical and chemical characteristics of sediment and water, and predictions on benthic invertebrates, fish and fisheries, apply to the Terra Nova EEM program.

In general, development operations at Terra Nova were expected to have the greatest effects on near-field sediment physical and chemical characteristics through release of drill cuttings. Regular operations were expected to have the greatest effect on physical and chemical characteristics of water through release of produced water. The zone of influence[5] for these waste streams was not expected to extend beyond approximately 15 km from source for drill cuttings, with the heaviest deposition occurring in the immediate vicinity of drill centres (Figure 1-4). The zone of influence for produced water was not expected to extend beyond approximately 5 km from source (Figure 1-5). Most other waste streams (see Section 4 for details) were expected to have negligible effects on sediment and water, as well as biota. However, deck drainage was expected to have minor effects, as described below.

[5] Zone where project-related physical and chemical alternation might occur.

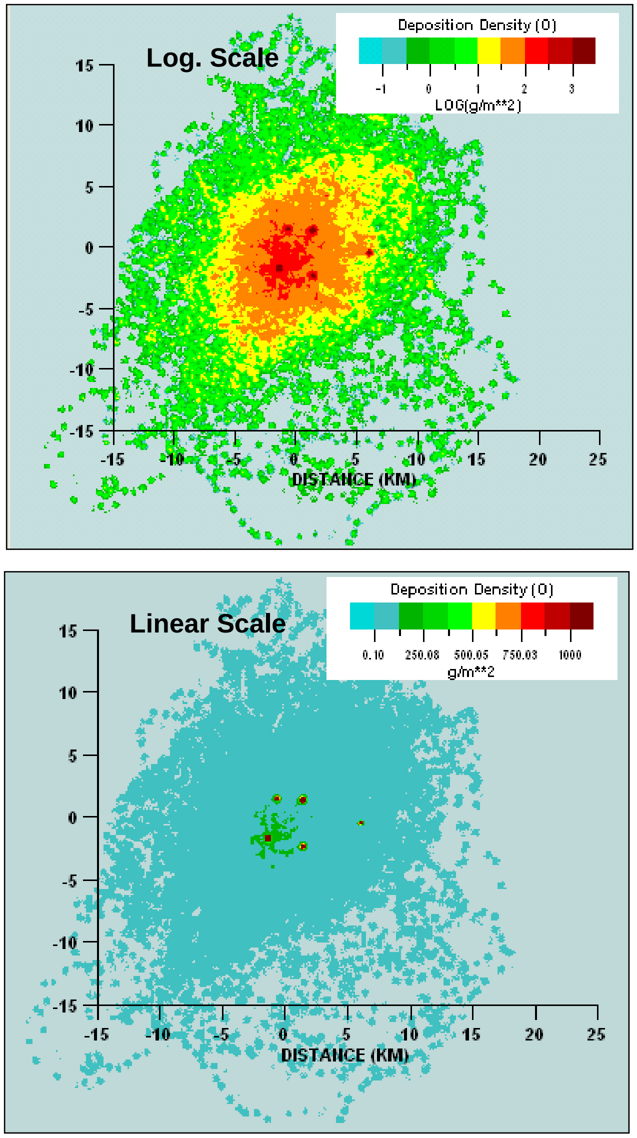

Figure 1-4 Zone of Influence for Drill Cuttings After Completion of Drilling

(Seaconsult 1998)

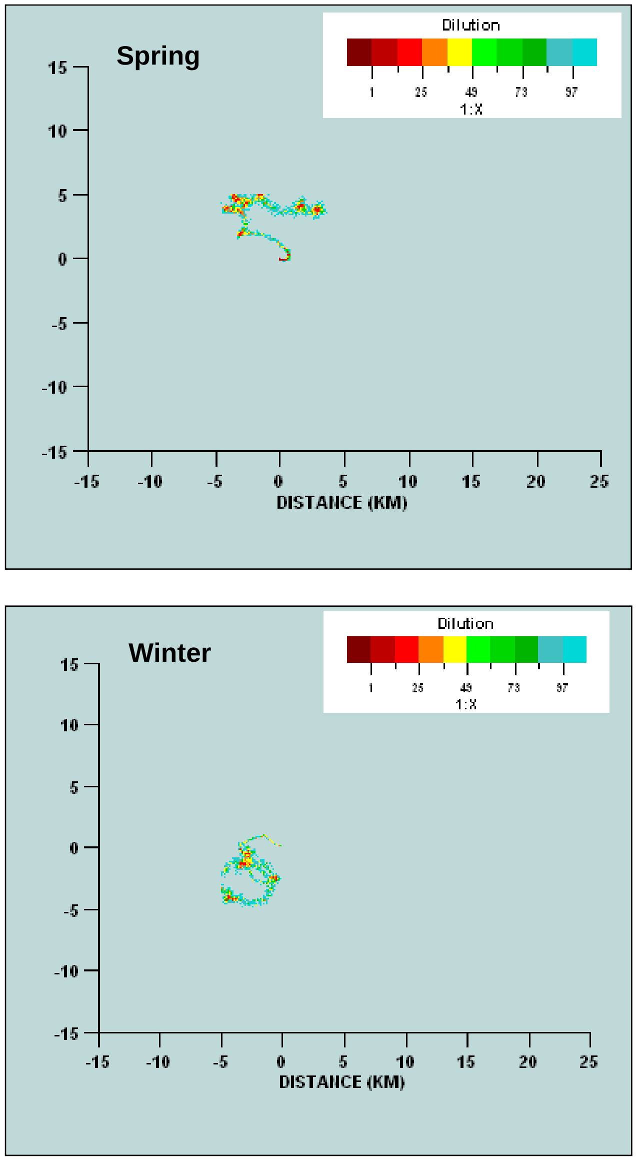

Figure 1-5 Snap-Shot of the Distribution of Produced Water

(Seaconsult 1998)

Effects of drill cuttings on benthic invertebrates were expected to be mild a few hundred metres away from drill centres, but fairly large in the immediate vicinity of drill centres (see Suncor Energy 1996 for details on effects assessment methodology). However, direct effects to fish populations, rather than benthic invertebrates (on which some fish feed), as a result of drill cuttings discharge were expected to be unlikely. Effects resulting from contaminant uptake by individual fish (including taint) were expected to be negligible.

Effects of produced water on plankton and physical and chemical characteristics of water were expected to be localized near the point of discharge. Liquid waste streams were not expected to have any effect on physical and chemical characteristics of sediment or benthic invertebrates. Direct effects on adult fish were expected to be negligible.

Deck drainage was expected to have minor, highly localized, short-term effects on physical and chemical characteristics of water.

Further details on effects and effects assessment methodologies can be obtained from the Terra Nova EIS (Suncor Energy 1996). For the purpose of the EEM program, testable hypotheses that drew on these effects predictions were developed and are provided in Section 1.7.

1.6 EEM PROGRAM COMPONENTS

Consistent with the effects assessment (Suncor Energy 1996), the Terra Nova EEM program is divided into three components dealing with effects on Sediment Quality, Water Quality and Commercial Fish species, including Iceland scallop (scallop) (*Chlamys islandica*) and American plaice (plaice) (*Hippoglossoides platessoides*). Assessment of Sediment Quality includes measurement of alterations in chemical and physical characteristics, measurement of sediment toxicity and assessment of benthic community structure. These three sets of measurements are commonly known as the Sediment Quality Triad (Chapman et al. 1987; Chapman 1992). Assessment of Water Quality includes measurement of chemical characteristics, physical characteristics, and chlorophyll concentration. Assessment of effects on Commercial Fish species includes measurement of body burden, taint and morphometric and life history characteristics for scallop and plaice, and measurement of various health indices for plaice. Components of the Terra Nova EEM program are shown in Figure 1-6. Further details on the selection of variables are provided in the Terra Nova EEM design document (Suncor Energy (2021), control document TN-IM-EV02-X00-001), as well as the Baseline program report (Suncor Energy 1998a).

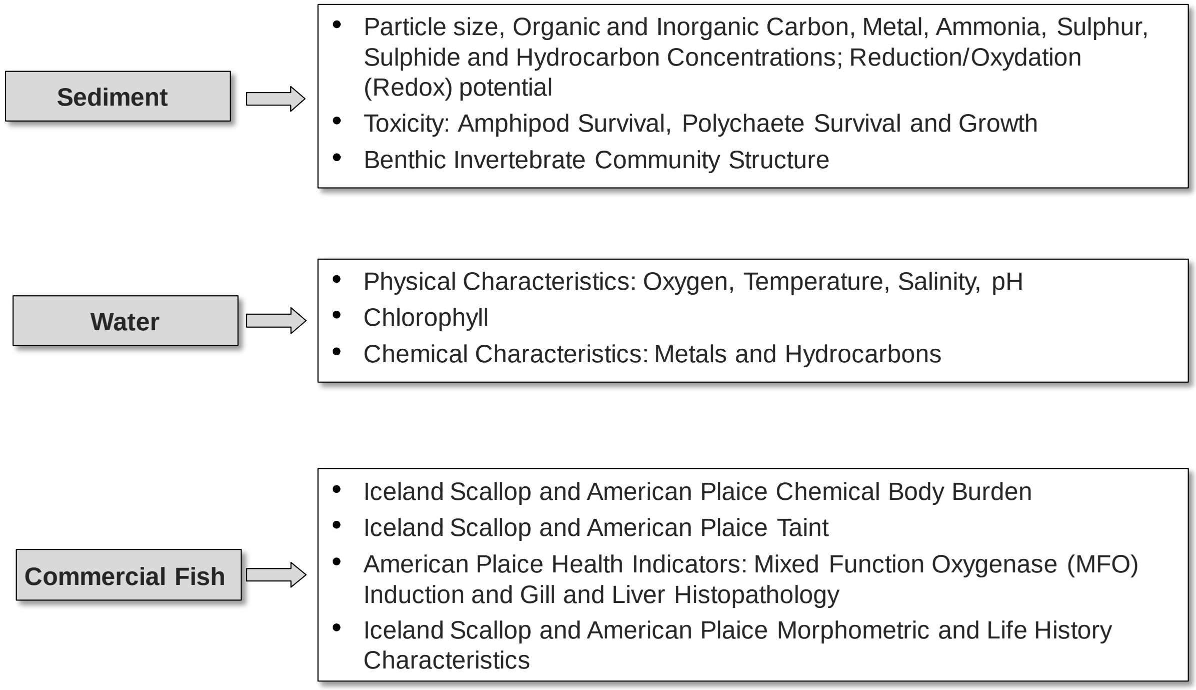

Figure 1-6 EEM Components

Note: The Microtox toxicity test performed in previous EEM programs was replaced with the polychaete survival and growth toxicity test after regulatory approval of recommendations in the 2014 and 2017 EEM program reports.

1.7 MONITORING HYPOTHESES

Monitoring, or null (H_0), hypotheses were part of EEM program design. Null hypotheses (H_0) differ from EIS effects predictions. They are an analysis and reporting construct established to aid in the assessment of effects on the environment. Null hypotheses (H_0) will always state “no effects” even if effects have been predicted as part of the EIS. Monitoring hypotheses for Terra Nova are provided in Table 1-1.

Table 1-1 Monitoring Hypotheses

Sediment Quality
H_0: There will be no attenuation of physical or chemical alterations or biological effects with distance from project discharge points.
Water Quality
H_0: Project discharges will not result in changes to physical and chemical characteristics of the water column, or to phytoplankton densities near discharge points in the Terra Nova Project area.
Commercial Fish
H_0: Project discharges will not result in taint of fish resources within the Terra Nova Project area, as measured using taste panels. H_0: Project discharges will not result in adverse effects to fish health within the Terra Nova Project area, as measured using histopathology and MFO[6] induction.

Note:
- No hypotheses were developed for fish body burden and morphometric and life history characteristics, as these are considered to be supporting variables, providing information to aid in the interpretation of results from other monitoring variables, such as taint or health indicators.
- The Water Quality monitoring hypothesis was not addressed in 2020. The Water Quality component of the EEM program was not implemented in this EEM cycle because the FPSO had not been releasing produced water since December 2019 and left the Terra Nova Field in June 2020.

1.8 SAMPLING DESIGN

In the EEM program at Terra Nova, sediment has been sampled at discrete stations located at varying distances from drill centres, while water and commercial fish have been sampled in the vicinity of Terra Nova (Study Area) and in one or two more distant Reference Area(s). Fish samples have been collected in one Reference Area located 20 km southeast of the development. Water samples are normally collected in two Reference Areas located 20 km southeast and 20 km southwest of the development. The sediment sampling design is commonly referred to as a gradient design, while the water and commercial fish sampling designs are control-impact design (see Suncor Energy (2021) control document TN-IM-EV02-X00-001 for details).

1.8.1 MODIFICATIONS TO SAMPLING DESIGN

In 2020, the Water Quality component of the Terra Nova EEM program was not implemented because the FPSO had not been releasing produced water since December 2019 and left the Terra Nova Field in June 2020. Water quality monitoring will resume once production activities and produced water discharge resume. Technical difficulties prevented the collection of plaice samples in the Reference Area, and scallop samples in both the Study and Reference Areas. Scallop were collected in 2021 and results will be reported in an addendum document. Plaice from White Rose Reference Areas 1 and 2 (the two nearest Terra Nova) are used as Reference Area fish for Terra Nova in this report.

[6] MFO: Mixed Function Oxygenase.

In addition to the above, the general spatial distribution of sampling sites established during the design phase of the Terra Nova EEM program underwent some modifications over the years to accommodate changes in drill centre location (proposed versus actual) and a Fisheries Exclusion Zone (FEZ)[7] around construction activities.

The FEZ was not yet established and therefore posed no restrictions for the Baseline program in 1997 and for fish collections in Spring of 2000. However, sediment could not be collected inside the FEZ in the Fall of 2000. Fish and sediment collections were not possible inside the FEZ in 2001 because of safety concerns. Since 2002, because of reduced construction at Terra Nova, sediment samples usually have been collected at four stations inside the FEZ, but Station 48(FEZ) could not be sampled in 2004 because of drilling activity.

Station locations for sediment for the Baseline program are shown in Figure 1-7. Station locations for sediment for the EEM programs are shown in Figure 1-8. Station name changes that have occurred since the Baseline program are identified in Table 1-2. Transect locations for plaice for the Baseline program and the EEM programs are shown in Figures 1-11 to 1-22. Station locations for water collections and transect locations for scallop provided in previous reports have been excluded from this report because results for water quality and scallop are not provided in this report (see above).

[7] The name 'Fisheries Exclusion Zone' was changed to Safety Zone in 2019. This report continues to use Fisheries Exclusion Zone and its acronym FEZ because discontinuing use would require relabelling a number of stations in figures (e.g., Figures 1-7 and 1-8), tables and in the multi-year EEM data records for Terra Nova.

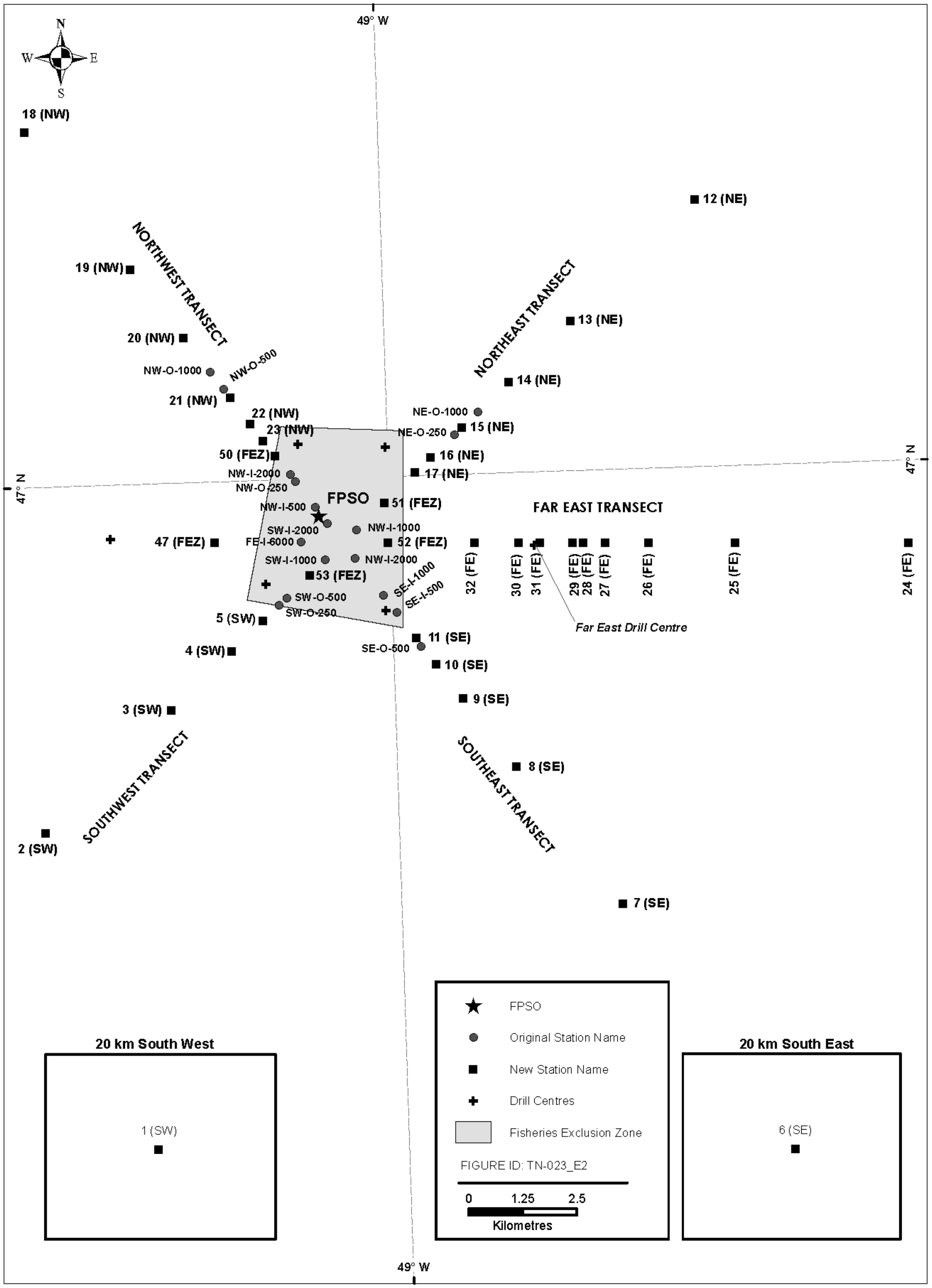

Figure 1-7 Station Locations for the Baseline Program (1997) Sediment Collections

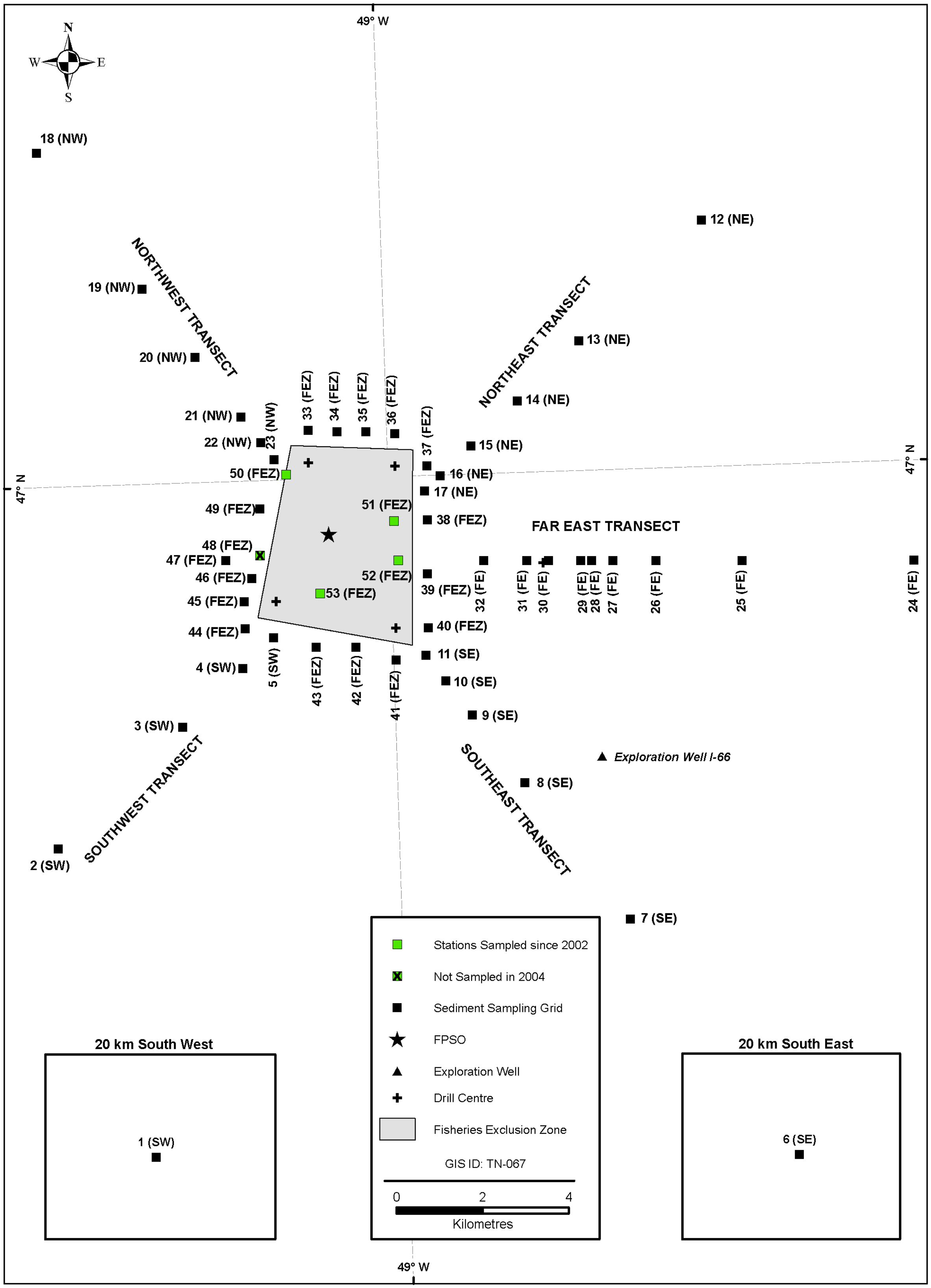

Figure 1-8 Station Locations for the EEM Program Sediment

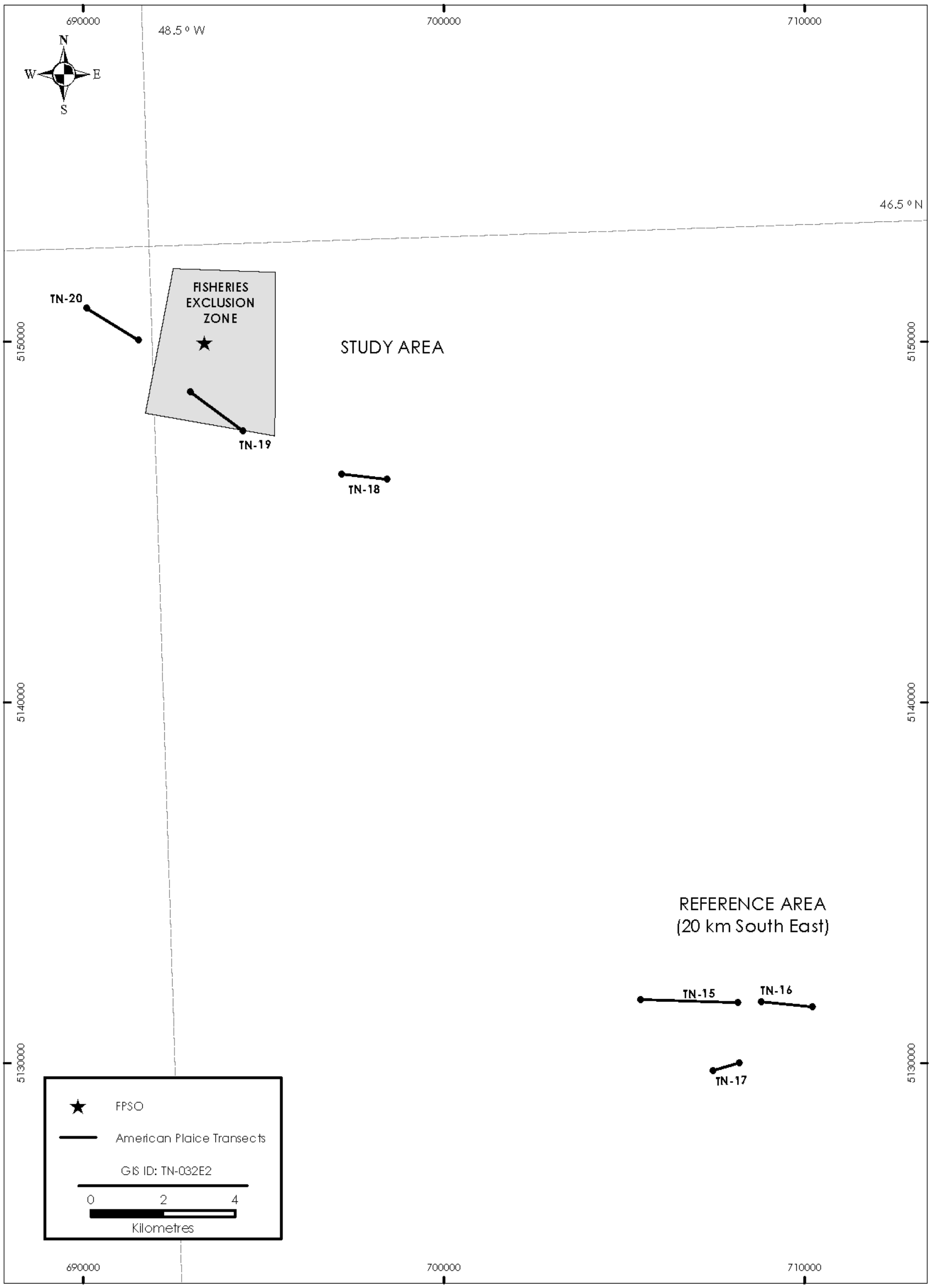

Figure 1-9 Transect Locations for Plaice (1997)

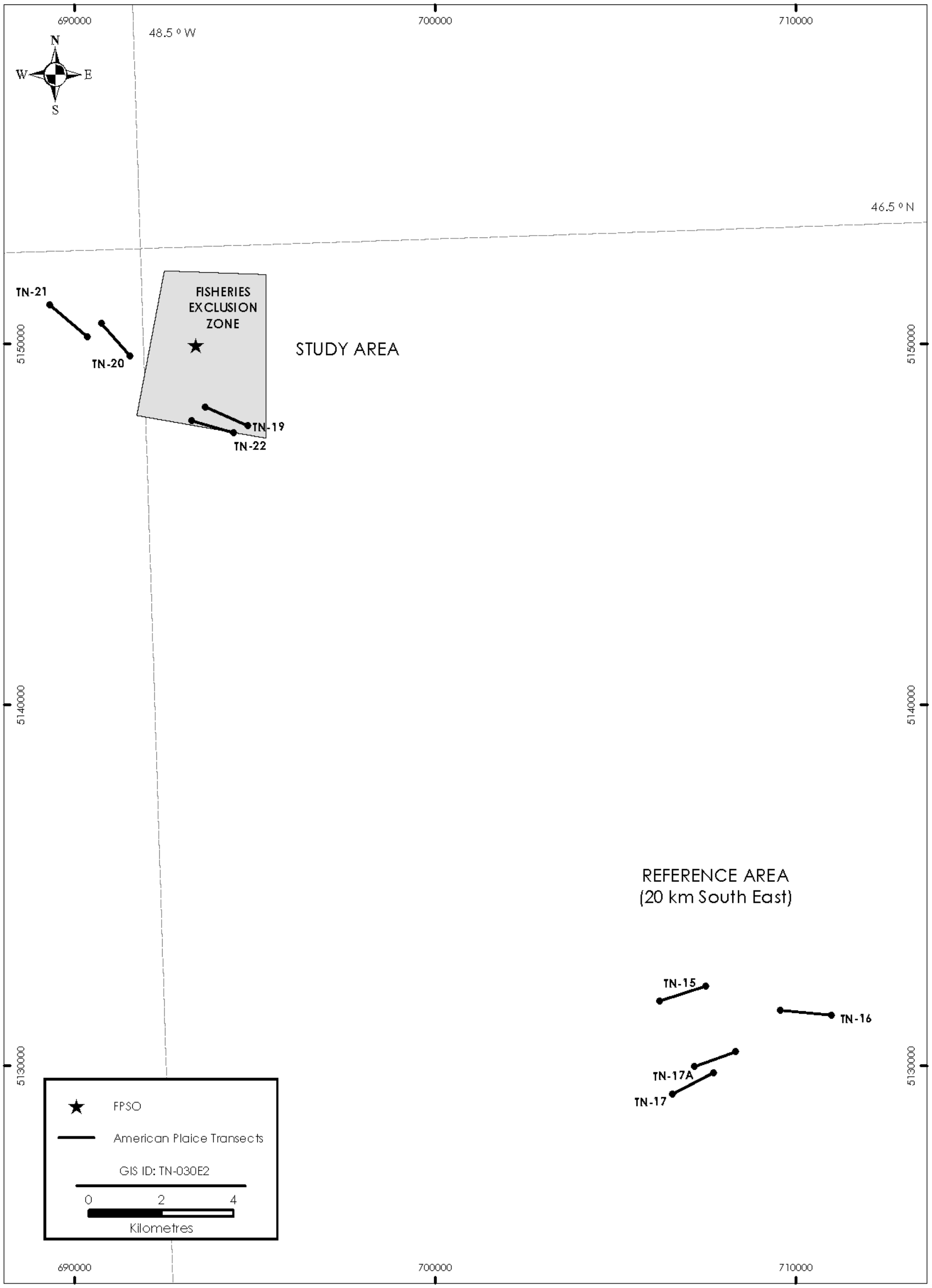

Figure 1-10 Transect Locations for Plaice (2000)

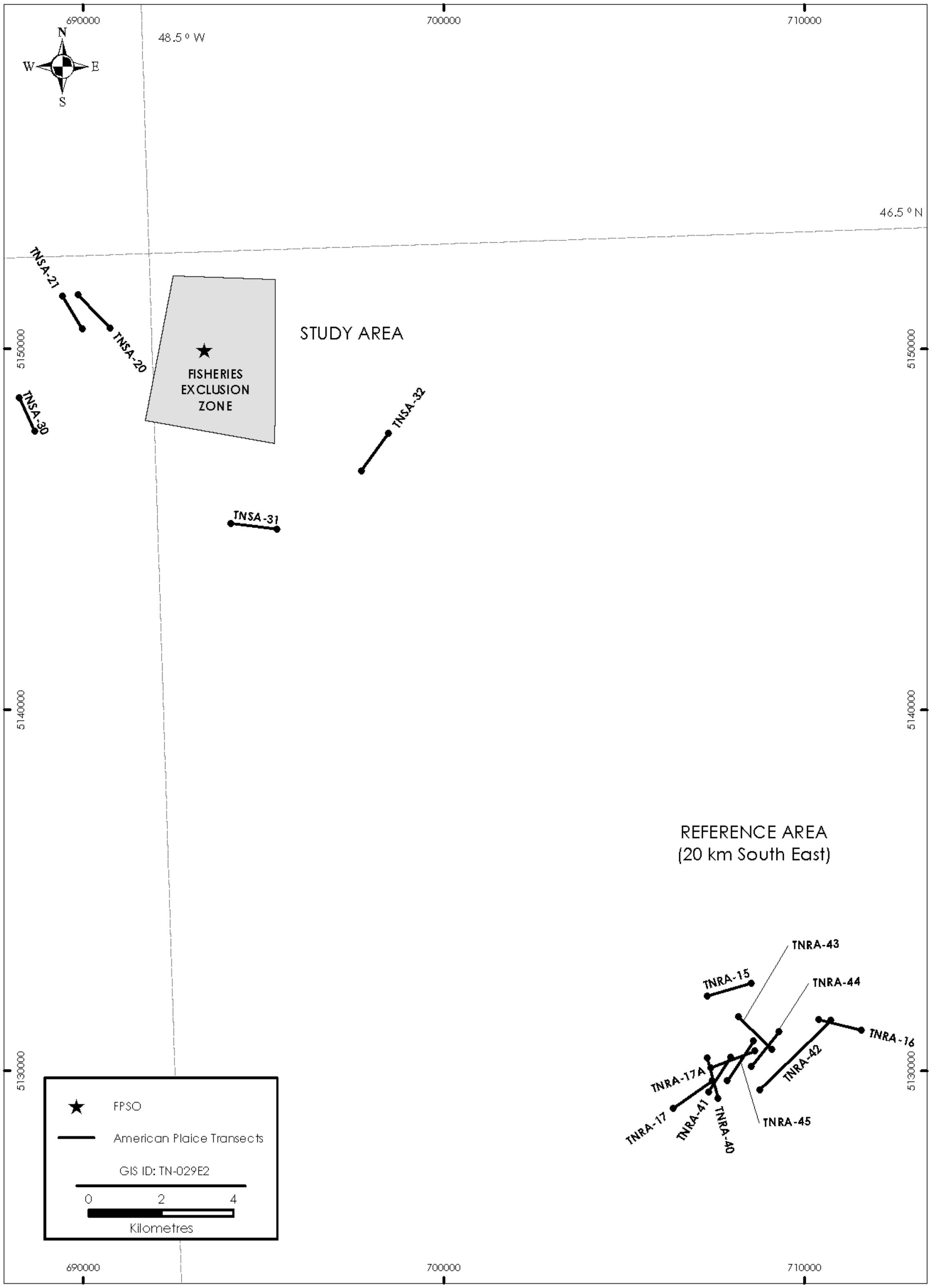

Figure 1-11 Transect Locations for Plaice (2001)

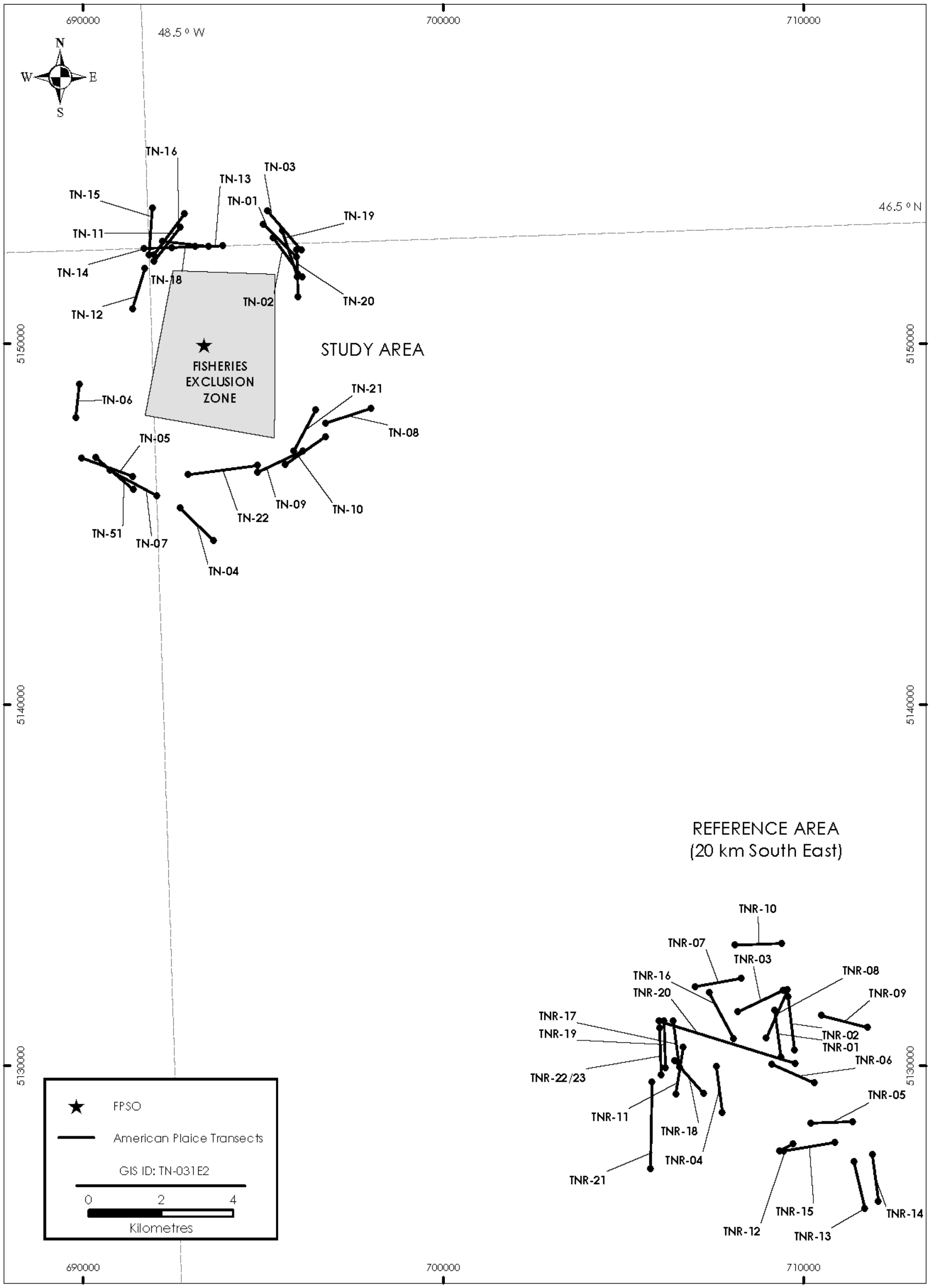

Figure 1-12 Transect Locations for Plaice (2002)

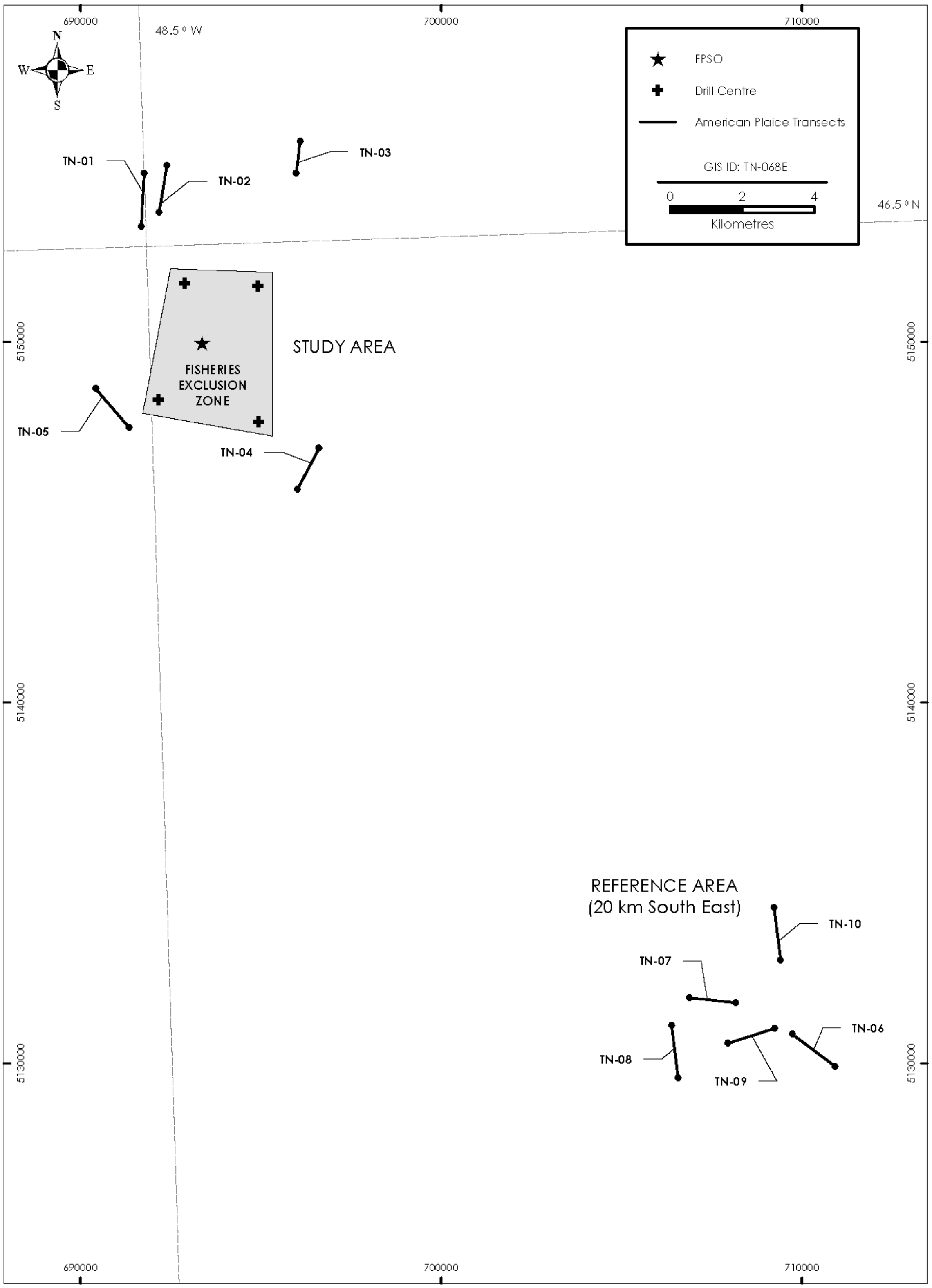

Figure 1-13 Transect Locations for Plaice (2004)

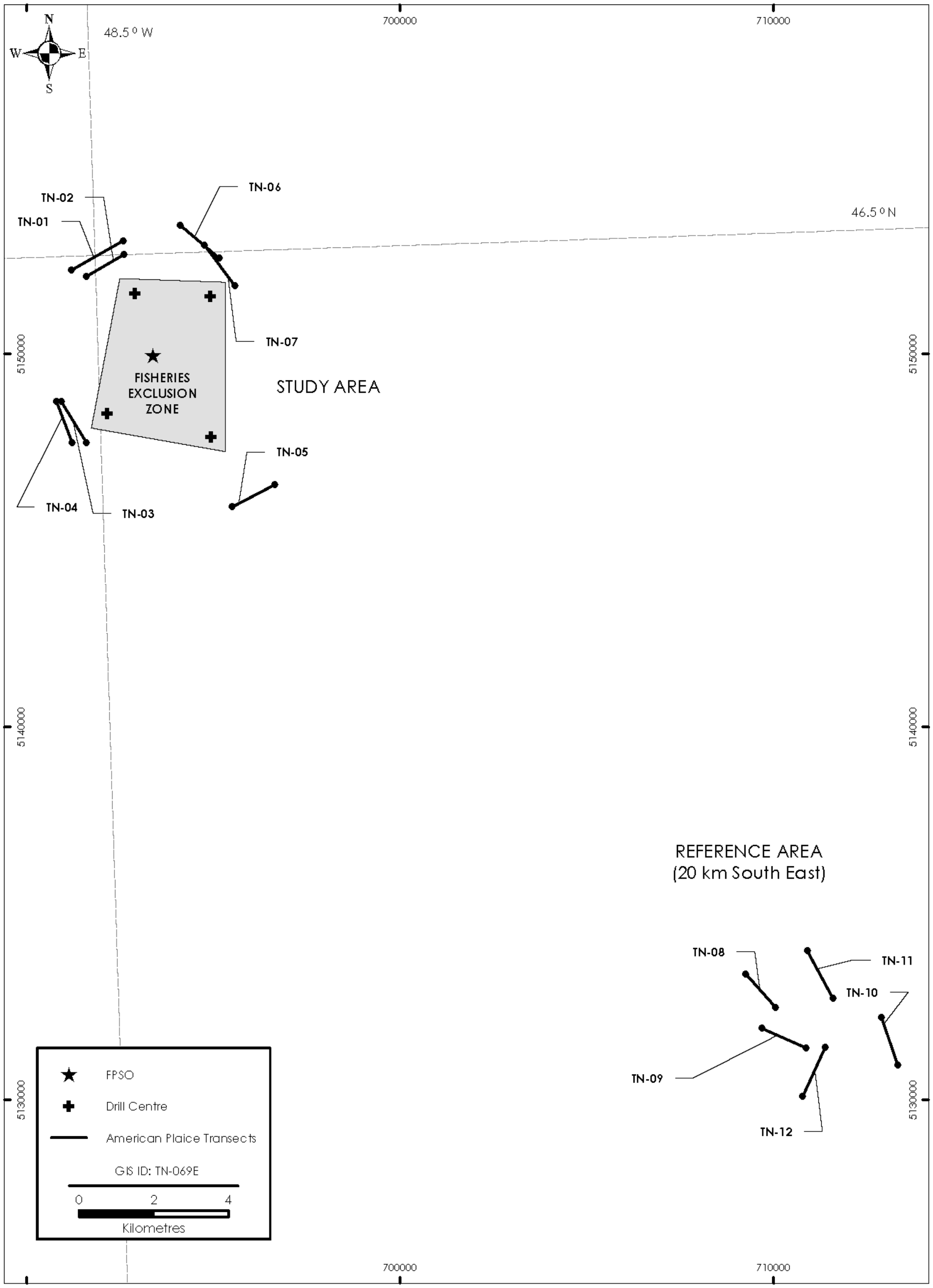

Figure 1-14 Transect Locations for Plaice (2006)

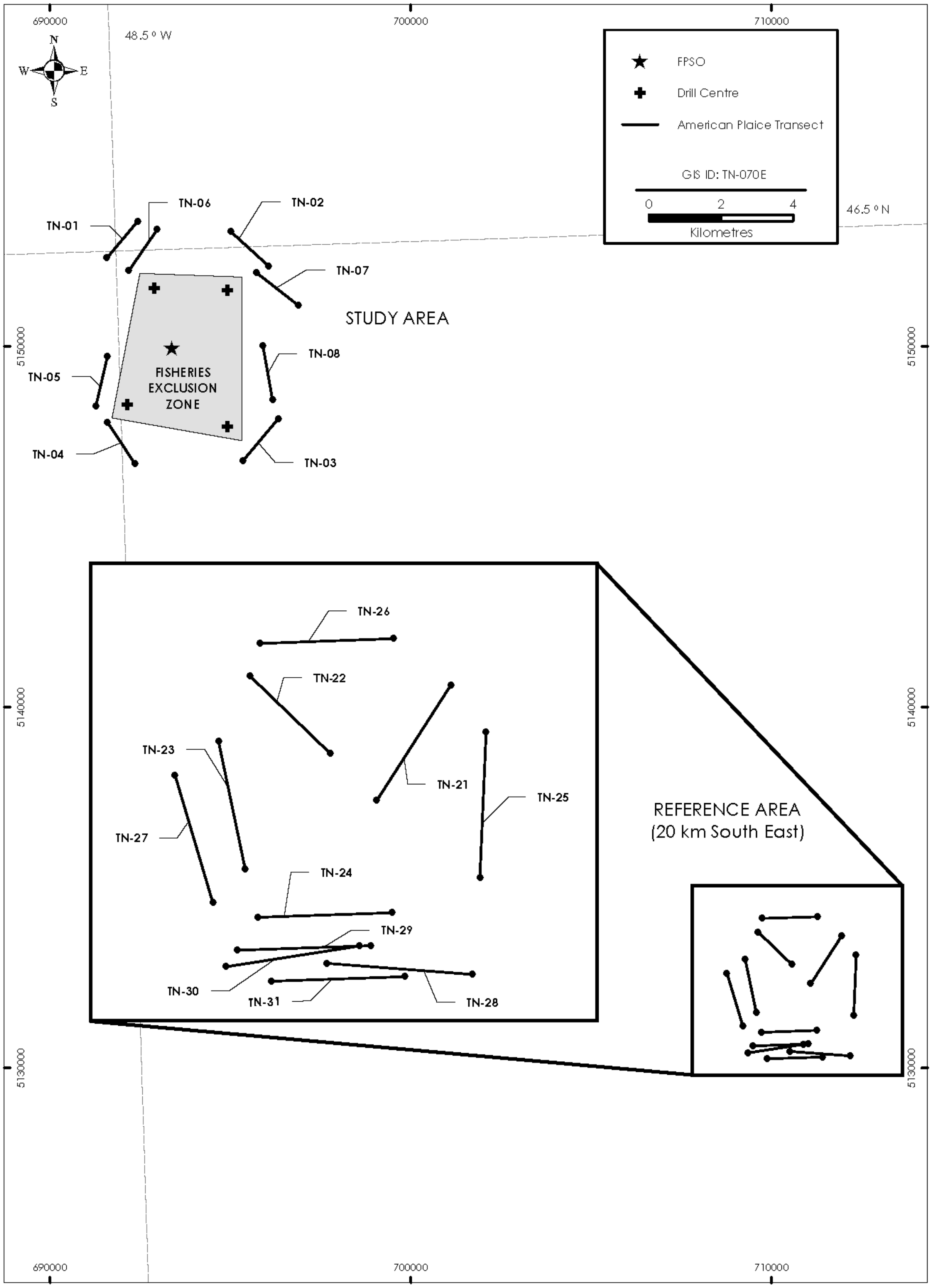

Figure 1-15 Transect Locations for Plaice (2008)

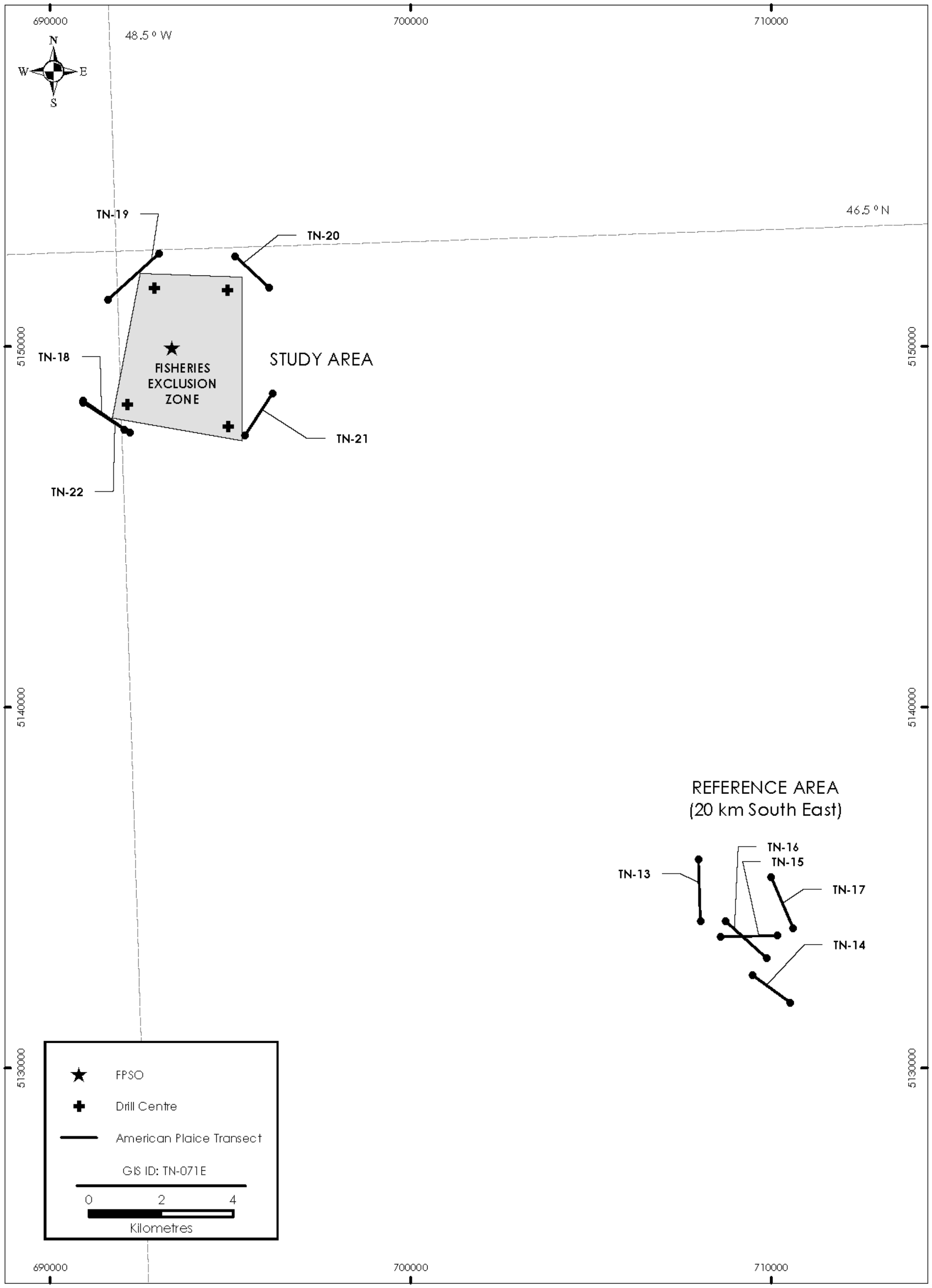

Figure 1-16 Transect Locations for Plaice (2010)

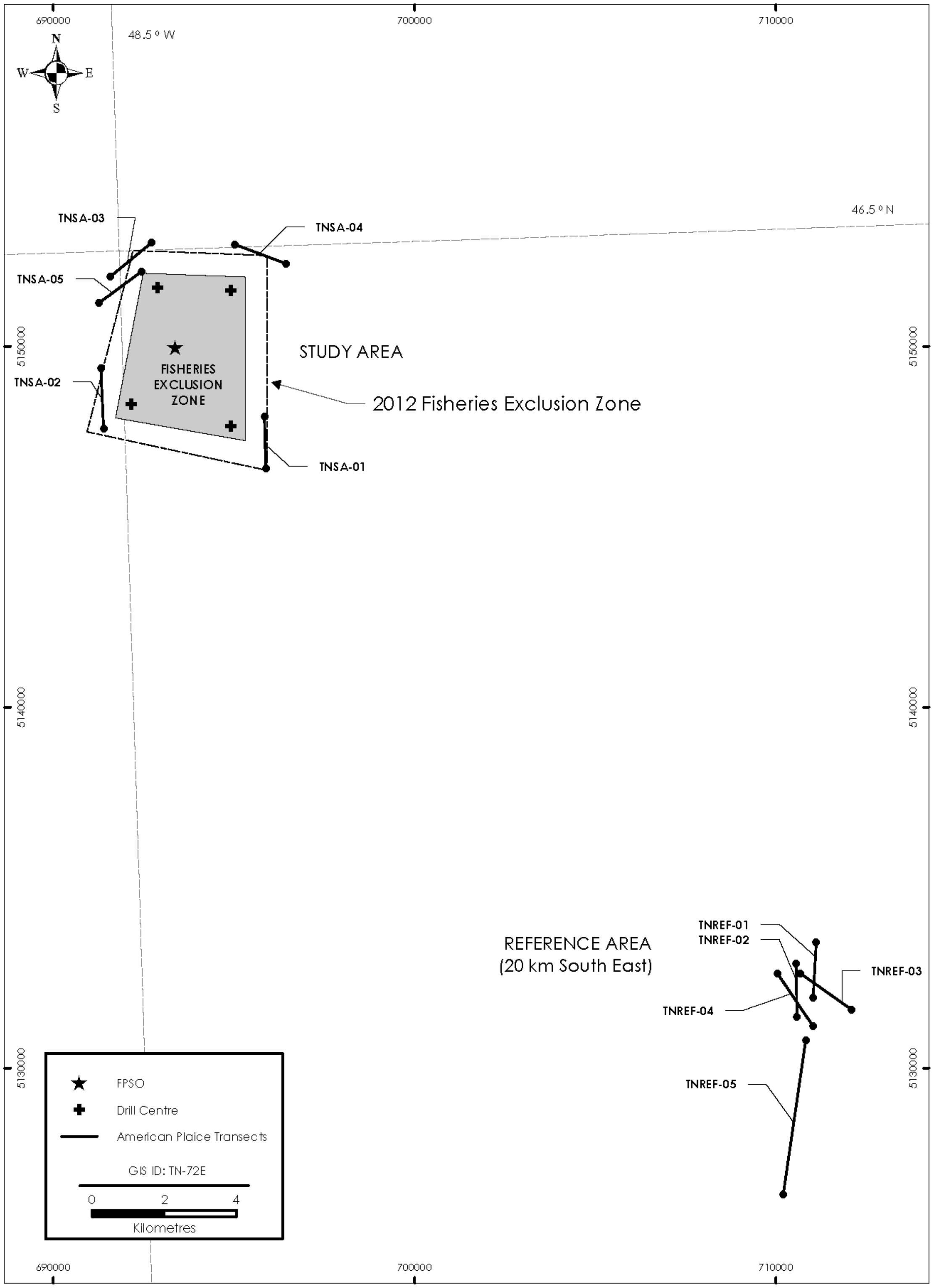

Figure 1-17 Transect Locations for Plaice (2012)[8]

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[8] For safety reasons, the FEZ was expanded in 2012 to accommodate construction activities.

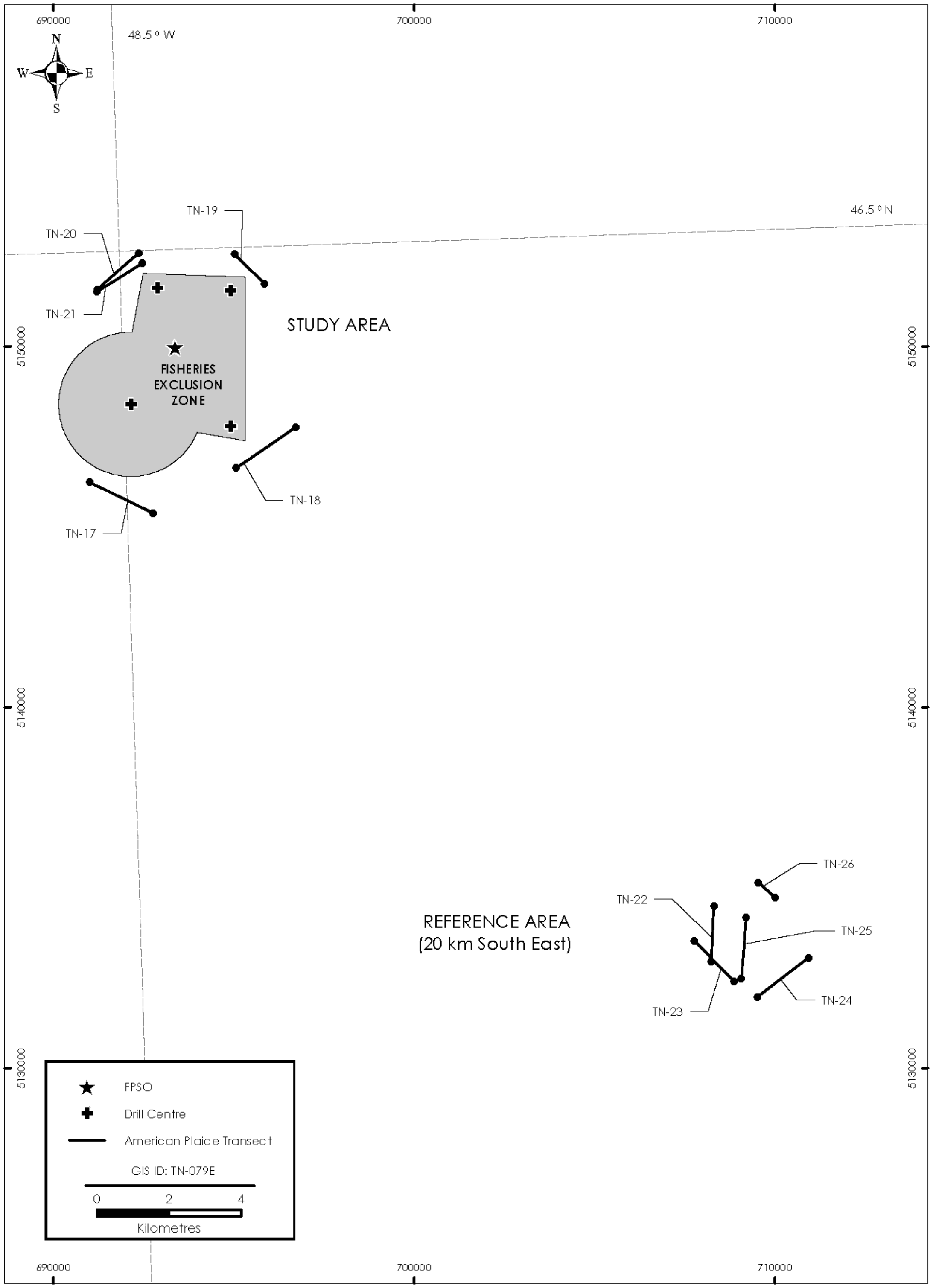

Figure 1-18 Transect Locations for Plaice (2014)[9]

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9 The SW corner of the FEZ was expanded in 2014 to accommodate the drill rig anchors at the SW Drill Centre.

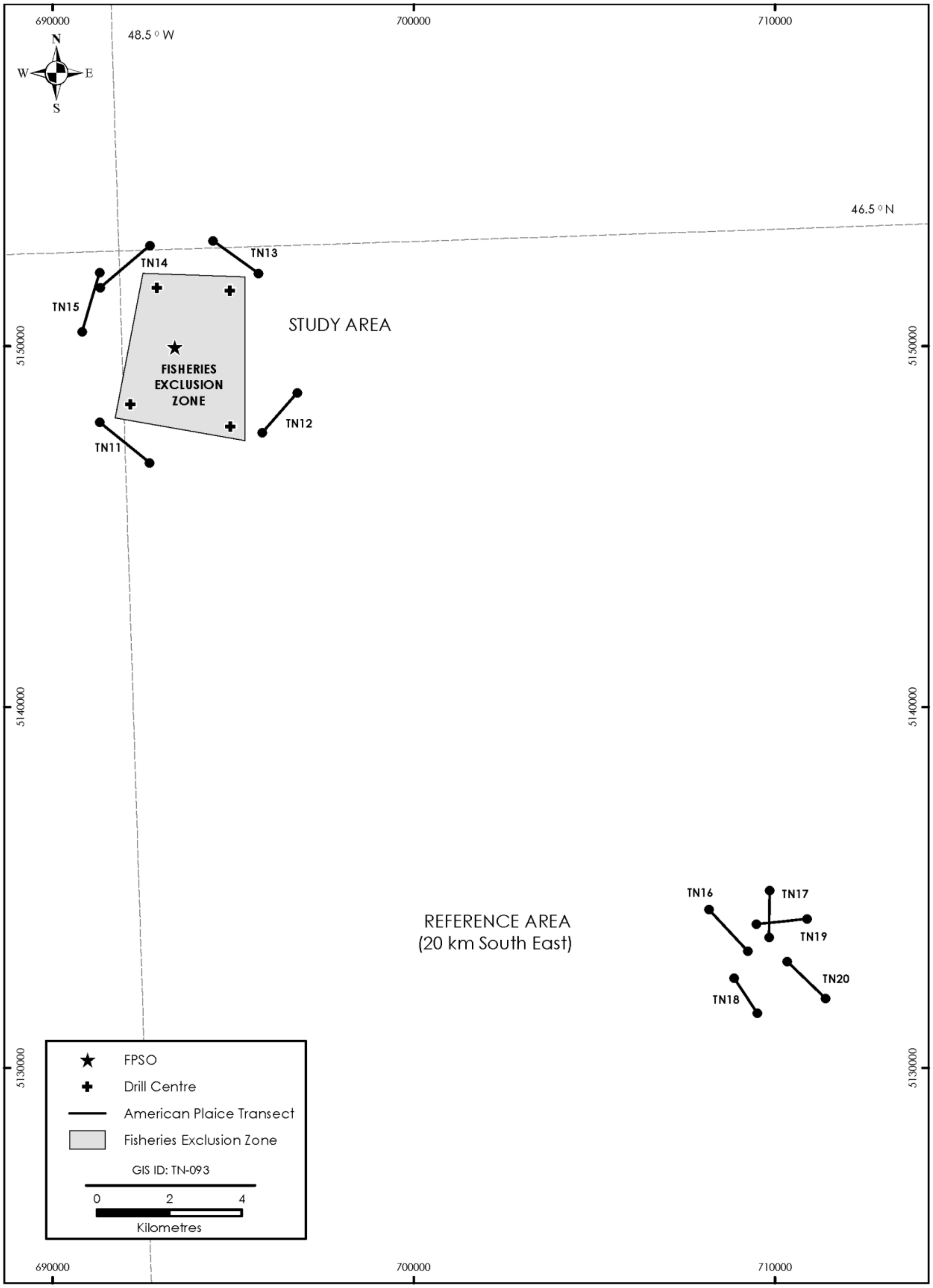

Figure 1-19 Transect Locations for Plaice (2017)

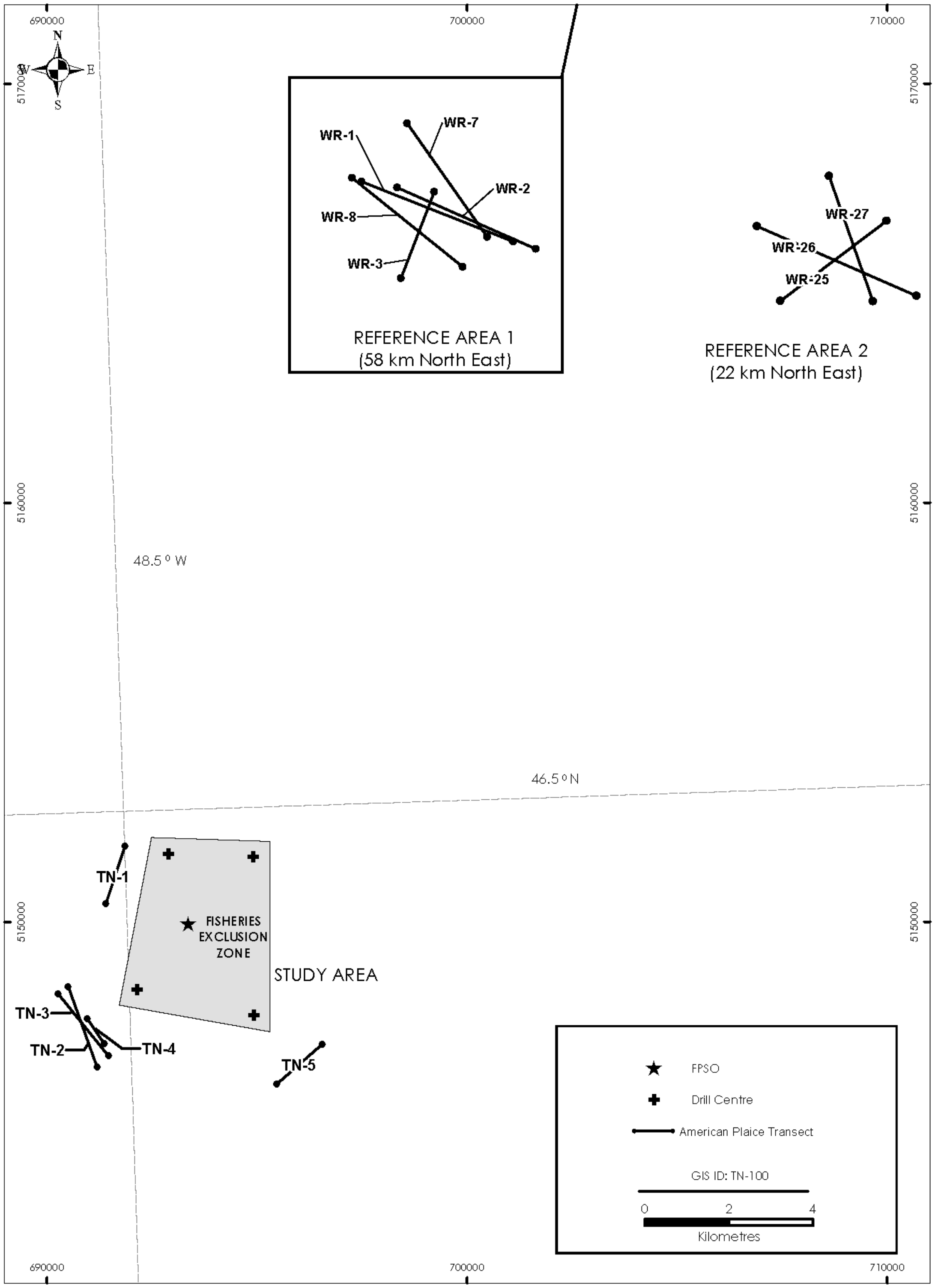

Figure 1-20 Transect Locations for Plaice (2020)

Note - Because of technical difficulties, plaice could not be collected in the usual Terra Nova Reference Area in 2020. Plaice collected in White Rose Reference Areas 1 and 2, the two nearest to Terra Nova, are used as Reference Area fish for Terra Nova in this report. White Rose transects are labelled with a WR prefix.

Table 1-2 Terra Nova Station Name Changes

Sample type	EEM Station Name	Baseline Station Name
Sediment	1(SW)	SW-O-20000
	2(SW)	SW-O-8000
	3(SW)	SW-O-4000
	4(SW)	SW-O-2000
	5(SW)	SW-O-1000
	6(SE)	SE-O-20000
	7(SE)	SE-O-8000
	8(SE)	SE-O-4000
	9(SE)	SE-O-2000
	10(SE)	SE-O-1000
	11(SE)	SE-O-250
	12(NE)	NE-O-8000
	13(NE)	NE-O-4000
	14(NE)	NE-O-2000
	15(NE)	NE-O-500
	16(NE)	NE-I-500
	17(NE)	NE-I-1000
	18(NW)	NW-O-8000
	19(NW)	NW-O-4000
	20(NW)	NW-O-2000
	21(NW)	NW-O-250
	22(NW)	NW-I-500
	23(NW)	NW-I-1000
	24(FE)	FE-O-8000
	25(FE)	FE-O-4000
	26(FE)	FE-O-2000
	27(FE)	FE-O-1000
	28(FE)	FE-O-500
	29(FE)	FE-O-250
	30(FE)	FE-I-500
	31(FE)	FE-I-1000
	32(FE)	FE-I-2000
	33(FEZ)	NW-N-750
	34(FEZ)	NW-NE-1
	35(FEZ)	NW-NE-2
	36(FEZ)	NE-N-750
	37(FEZ)	NE-E-750
	38(FEZ)	NE-SE-1
	39(FEZ)	NE-SE-2
	40(FEZ)	SE-E-750
	41(FEZ)	SE-S-750
	42(FEZ)	SW-SE-2
	43(FEZ)	SW-SE-1
	44(FEZ)	SW-SW-1
	45(FEZ)	SW-W-750
	46(FEZ)	NW-SW-3
	47(FEZ)	FE-I-8000

Sample type	EEM Station Name	Baseline Station Name
	48(FEZ)	NW-SW-2
	49(FEZ)	NW-SW-1
	50(FEZ)	NW-O-1000
	51(FEZ)	NE-I-2000
	52(FEZ)	FE-I-4000
	53(FEZ)	SW-I-500

2.0 SCOPE AND REPORT STRUCTURE

This document, 2020 *Terra Nova Environmental Effects Monitoring Program (Volume 1)*, provides summary results, analysis, and interpretation for the Terra Nova 2020 EEM program. Presentation of results has been structured to provide a logical sequence of information from project discharges to potential effects on the receiving environment, including the physical/chemical environment, benthic invertebrates, and commercially important species. Because analysis of results is 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. The discussion also includes recommendations for future EEM programs based on findings in 2020.

Most methods are provided in *Volume 1*. However, some more detailed methods as well as ancillary analyses are included in Appendices (*Terra Nova Environmental Effects Monitoring Program 2020 (Volume 2))*. Raw data and other information supporting *Volume 1* are also provided in *Volume 2*.

3.0 ACRONYMS, ABBREVIATIONS AND UNITS OF MEASURE

The following acronyms, abbreviations and units of measure are used in this report. Acronyms for more detailed statistics are not provided below but are defined as they are used.

Acronym	**Meaning**
°C	Degrees Celsius
ANCOVA	Analysis of CoVariance
ANOVA	Analysis Of Variance
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CCME	Canadian Council of Ministers of the Environment
CI	Confidence Interval
cm	Centimetre
CV	Coefficients of Variation
DFO	Fisheries and Oceans Canada
EEM	Environmental Effects Monitoring
EIS	Environmental Impact Statement
EROD	7-ethoxyresorufin O-deethylase
FE	Far East (Drill Centre)
FE *d*	Distance to the FE Drill Centre
FEZ	Fisheries Exclusion Zone
FEZ *d*	Distance to the nearest FEZ Drill Centre
FPSO	Floating Production, Storage and Offloading
g	Gram
g/kg	Gram per kilogram
km	Kilometre
L	Litre
m^2	Square Metre
m^3	Cubic Metre
MFO	Mixed Function Oxygenase
mg	Milligram
mg/kg	Milligram per Kilogram
mg/L	Milligram per Litre
Min *d*	Distance to the Nearest Drill Centre
ml	Millilitre
mm	Millimetre
mV	Millivolt
NE	North East (Drill Centre)

Acronym	Meaning
NMDS	Non-metric Multidimensional Scaling
NW	North West (Drill Centre)
PAH	Polycyclic Aromatic Hydrocarbon
PC	Principal Component
PCA	Principal Component Analysis
PSEP	Puget Sound Estuary Program
QA/QC	Quality Assurance/Quality Control
SD	Significant Difference
SE	South East (Drill Centre)
SW	South West (Drill Centre)
TNRS	Terra Nova Reference Station

4.0 PROJECT-RELATED ACTIVITIES AND DISCHARGES

A number of site development activities occurred between 1997, when baseline field collection took place, and November 2020, when the sediment collections for the eleventh sampling year of the EEM program were performed. These activities were related to site development and operation, as described in the following sections[10].

4.1 CONSTRUCTION ACTIVITIES

Drill centre construction began at the Terra Nova site in July 1998. This activity was unsuccessful and was stopped later that year. Following this first attempt, a resistivity survey of the seabed was conducted in October 1998, using the *Maersk Placentia*. This activity involved some disruption of surficial sediment. Seabed coring was conducted in November and December 1998 from the *Lowland Cavalier*.

In 1999, five drill centres were excavated at the Terra Nova site using the *Queen of the Netherlands*. Dredge spoils from the drill centres were deposited at two locations; one north and one south of the Terra Nova field (Figure 4-1). The spider buoy, moorings system, and riser bases were installed at the Terra Nova field in 1999 using the *Maxita*. Moorings installation included installation of nine mooring chains, each piled into the seabed at the chain termination. Fifteen gravity-base-style riser bases were also installed on the seabed during this installation campaign.

From 1999 through 2001, seven drilling templates were installed in the drill centres using the mobile offshore drilling units *Glomar Grand Banks* and *Henry Goodrich*. Each template was piled into the seabed using a drilled piling technique.

[10] Please note that the statistics present within this section pertain only to those operational activities that occurred prior to and including November 2020, when EEM sediment sampling was performed. The discharge statistics do not reflect activities conducted beyond this period.

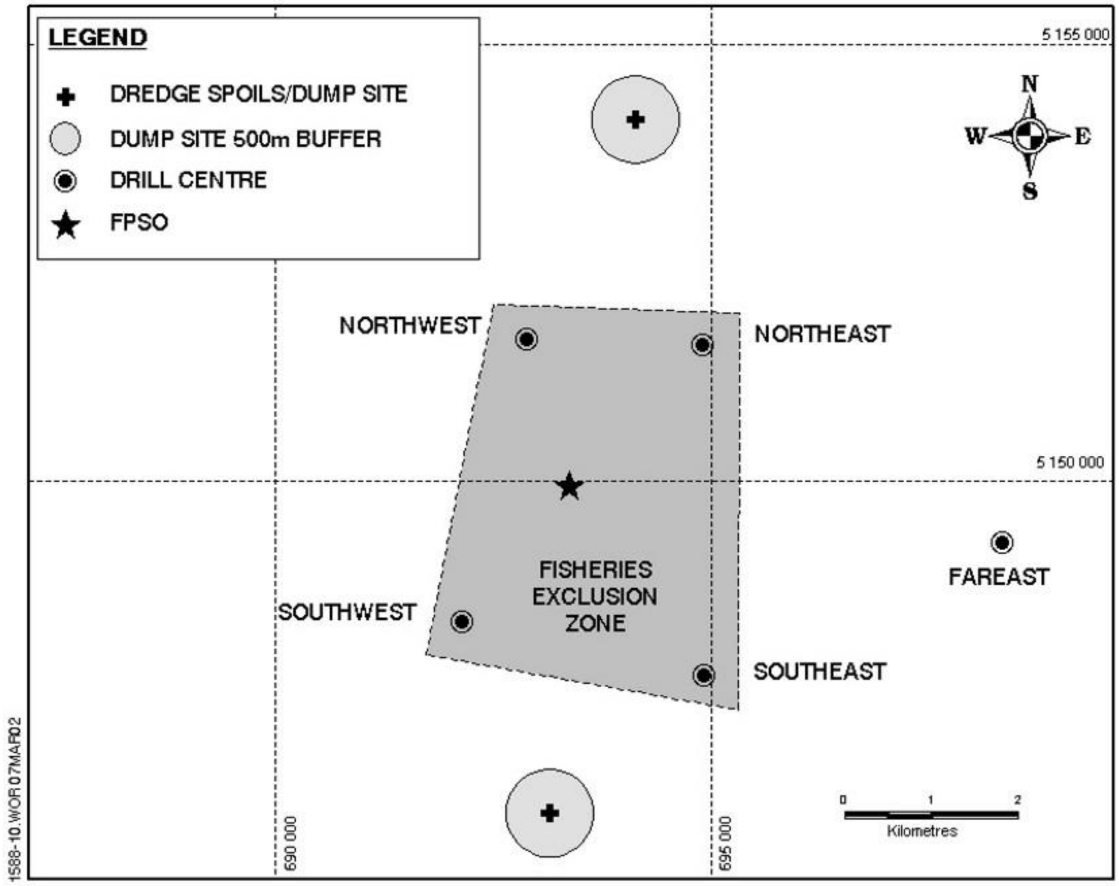

Figure 4-1 Drill Centre Locations and Dump Sites for Dredge Spoils

In 2000 and 2001, flowline and riser installation was carried out at the Terra Nova field prior to the FPSO coming on-station in the fourth quarter of 2001. Fifteen risers were installed at the spider buoy, together with approximately 30 km of flowlines to the respective drill centres: Northwest (NW); Northeast (NE); Southeast (SE); and Southwest (SW) (see Figure 4-1 for drill centre locations). Flowlines were trenched via a mechanical trenching technique to a depth less than 2 m from mean seabed elevation and/or rock was dumped to provide stability and insulation. In addition, concrete mattresses and mechanical anchors were installed on the flowlines and risers to provide supplemental stability. Flowline and riser installation was completed by the *Smit Pioneer*. Riser/flowline connection, including connection at both the spider buoy and subsea manifold systems, was performed by the *DSV Marianos*.

The *DSV Marianos* campaign also included installation of concrete mattresses and specialized valve and connector installation in-field to permit FPSO pull-in, in addition to miscellaneous construction tasks. Additionally, during August 2006, the

CLDSV Acergy Discovery installed a section of gas injection flowline servicing Host D in the SW Drill Centre parallel to the existing flowline that had failed.

Rock dumping on flowlines was performed over three separate campaigns at Terra Nova in 2000, 2001, and 2002 using the *Trollnes* and *MV Seahorse*. Locally quarried rock from Argentia and Bay Bulls was the primary source for rock dumping operations. Rock dumping operations were not performed for the section of flowline installed during August 2006.

In-field construction activities between 2008 and 2020 were limited primarily to maintenance and repair activities for subsea equipment components, including tree cap replacements, flowline tee replacements, subsea control module replacement, jumper replacements, well annulus venting campaigns, and in-line flowline connector repair and replacement. However, the evolution of H_2S in the Terra Nova reservoir resulted in the need to replace the subsea flexible piping system (i.e., risers, flowlines, and jumpers). Between June and November 2012, there were nine existing production, gas injection and gas lift risers, eight production and gas lift jumpers, and nine weak-link jumpers replaced with materials suitable for sour service. In August 2014, one flowline and one riser were replaced in the NW Drill Centre.

4.2 DRILLING ACTIVITIES

Development drilling at the Terra Nova oil field was initiated in July 1999 by the *Glomar Grand Banks*. This rig continued drilling at the site until early February 2000. The *Henry Goodrich* started drilling activities in late February 2000 and finished its work in August 2007. The *Henry Goodrich* also conducted operations in the Terra Nova field during the months of April to July, and October and November of 2009. As of the end of the last drilling campaign in October 2019, 41 distinct wellbores and sidetracks have been drilled within the field. Since first oil in 2002, 33 wells in the NW, NE, SW and SE Drill Centres have been used for production activities. Of these 33 wells, 18 were oil producers, 4 were gas injectors, and 11 were water injectors. One of the oil producers, one of the gas injectors, and two of the water injectors have been abandoned.

There are three major forms of effluent discharged to sea during drilling activities:

1. Water-based drill muds;
2. Synthetic-based drill muds; and
3. Water-based completion fluid.

Water-based drill muds are used during the first two hole sections (conductor and surface) of each well. Synthetic-based drill muds are used to facilitate drilling of the intermediate and main hole sections of each well. Water-based completion fluids are then used for the final stage, or completion, of a well before it can be used in production.

4.2.1 WATER-BASED DRILL MUD DISCHARGES

Water-based drill muds are 90% water and the remaining 10% is comprised of barite, gel, caustic soda, and lime. Cuttings generated using water-based drill muds are returned to the seafloor and then transferred out of the drill centre using the cuttings transfer system. Water-based drill muds were used for drilling activities conducted during the period of July 2017 to October 2019.

From the beginning of drilling to October 2019, Suncor reported cumulative water-based mud discharges of 54,990 m^3 at development drill centres. Of these, 24,307 m^3 were discharged at the SW Drill Centre, 11,371 m^3 were discharged at the NE Drill Centre, 4,593 m^3 were discharged at the SE Drill Centre, 10,854 m^3 were discharged at the NW Dill Centre, and 3,865 m^3 were discharged at the Far East (FE) Dill Centre. In addition to this, 6,328 m^3 were discharged at the drill site for the exploration well I-66 (PF8).

4.2.2 SYNTHETIC-BASED DRILL MUD DISCHARGES

The composition of synthetic-based drill muds is approximately 70% base oil (Suncor product called PureDrill IA35-LV), 17% water, 6% additives, and 7% weight material (barite), for a generic 1,150 kg/m^3 drill mud. PureDrill IA35-LV is a synthetic isoalkane fluid that is hydroisomerized and hydrogenated. It is composed of aliphatic carbon compounds in the $>C_{10}$-C_{21} range and contains no aromatic hydrocarbon compounds (see Appendix A for details). Synthetic-based drill muds were used for drilling activities during the period July 2017 to October 2019.

Drill cuttings from the synthetic-based drill mud hole sections are discharged overboard at 18 m below the waterline and allowed to freefall to the seafloor. Cuttings displaced to drill centres are transferred outside drill centres using a cuttings transfer system. The mass of base oil discharged on drill cuttings can be derived from reporting of synthetic-based mud-on-cuttings, in keeping with the Offshore Waste Treatment Guidelines (National Energy Board et al. 2010).

Since the beginning of drilling to October 2019, Suncor reported cumulative synthetic-based mud-on-cuttings discharges of 6,753 tonnes at those drill centres: 2,259 tonnes were discharged at the SW Drill Centre; 521 tonnes were discharged at the NW Drill Centre; 2,135 tonnes were discharged at the NE Drill Centre; 1,278 tonnes were discharged at the FE Drill Centre; and 545 tonnes were discharged at the SE Drill Centre. In addition to this, 184 tonnes were discharged at the drill site for the exploration well I-66 (PF8), and 38 tonnes were discharged at the drill site for the West Flank (E-19) well.

4.2.3 WATER-BASED COMPLETION FLUID DISCHARGES

In order to complete the well, water-based completion fluids are used and discharged overboard during the completion phase of each well. Water-based completion fluids, sometimes called completion brine, are 92% water; the remaining 8% is comprised of the following: sodium chloride; calcium bromide; barite; glycol; viscosifier; corrosion inhibitor; well-bore clean-up surfactant and solvent; biocide; sodium hypochlorite; caustic soda; calcium chloride; and sodium sulphite.

Completion operations were conducted in the Terra Nova field during the period of August 2017 to October 2019 (as detailed in Table 4-1).

Table 4-1 Completion Fluids Discharged at Development Drill Centres from August 2017 to October 2019

Year	Month	Well(s)	Drill Centre	Completion Fluids Discharged to Sea Volume (m^3)
2017	August-December	F88 2 (E1); F88 1Z (E2)	SE	1,615.2
2018	January	F88 1Z (E2)	SE	1,861.8
2018	August- September	L-98 14 (C6)	SW	1,523.9
2018	September-December	G90 7 (F3)	NE	1,199.6
2019	January -April	G90 7 (F3)	NE	26.5
2019	August-October	L 98 15 (C7)	SW	1,008.8
Total				**7,235.8**

Note: -Drilling discharge statistics refer only to discharges from since the last (2017) EEM program to the end of Drilling in 2019.

From the beginning of drilling to October 2019, Suncor reported cumulative water-based completion fluid discharges of 52,671 m^3: 14,933 m^3 were discharged at the SW Drill Centre: 26,900 m^3 were discharged at the NE Drill Centre; 6,114 m^3 were discharged at the SE Drill Centre; and 4,725 m^3 were discharged at the NW Drill Centre.

4.3 PRODUCED WATER

The FPSO arrived at the Terra Nova oil field on August 4, 2001. Start-up of oil production occurred on January 20, 2002, with the opening of the HPE5 well from the SW Drill Centre at 1720 hours. Production was shut-down 11 times between June 2017 and December 2019 and remains shut-down. Shut-down periods are listed in Table 4-2.

Table 4-2 Production Shut-Down Periods from June 2017 to June 2020

Year	Shut-Down Interval
2017	August 2 - September 3
	September 5
	September 25 - October 3
2018	January 21 - 22
	June 24 - 29
	August 1 - August 29
	November 9 - December 1
2019	March 9 -15
	May 15 - 25
	October 10 - 26
	December 20 – December 31
2020	January 1 to present

Produced water flow represents the major reportable discharge stream for the FPSO. Produced water was first discharged from the FPSO on April 22, 2003. Produced water includes formation water and injection water that is extracted along with oil and gas during petroleum production. In addition to oil, produced water contains both organic and inorganic compounds resulting from exposure to the reservoir and the various drilling and production operations. The monthly average oil-in-water concentrations and volumes for produced water from June 2017 to December 2019, when production operations ceased, are provided in Table 4-3. The FPSO departed the Terra Nova Field for Quayside on June 22, 2020.

Table 4-3 Produced Water Discharges from June 2017 to June 2020

Period	Monthly Average Effluent Oil Concentration (mg/L)	Total Monthly Effluent Flow (m^3/month)
June 2017	16.5	448,380
July 2017	17.6	469,361
August 2017*	-	-
September 2017	23.8	52,984
October 2017	23.0	411,599
November 2017	19.4	462,777
December 2017	12.7	391,625
January 2018	12.4	559,910
February 2018	12.9	437,765

Period	Monthly Average Effluent Oil Concentration (mg/L)	Total Monthly Effluent Flow (m^3/month)
March 2018	9.8	510,139
April 2018	10.2	240,700
May 2018	10.0	312,656
June 2018	8.6	344,055
July 2018	8.9	496,040
August 2018*	-	-
September 2018	10.5	344,177
October 2018	11.6	376,554
November 2018	11.2	109,111
December 2018	16.2	460,930
January 2019	16.3	239,756
February 2019	20.6	232,903
March 2019	21.4	258,114
April 2019	16.2	298,676
May 2019	19.3	320,194
June 2019	20.6	469,388
July 2019	11.9	396,546
August 2019	16.6	604,030
September 2019	16.6	576,590
October 2019	17.0	210,099
November 2019	19.1	512,717
December 2019**	15.5	425,271

Notes: * No Production.
** Production Operations ceased in December 2019 and have not resumed.

4.4 OTHER WASTE STREAMS

A number of other waste streams are monitored for compliance under Suncor's Terra Nova Environmental Protection Plans. These are reported monthly to the Canada-Newfoundland and Labrador Offshore Petroleum Board, separately for the drilling unit program (the *Transocean Barents*) and production on the FPSO.

The *Transocean Barents* (drilling) effluent streams and their compliance limits were:

1. Bilge Water – compliance limit of 15 mg/L oil;
2. Hazardous Drilling Area Deck Drainage – compliance limit of 15 mg/L oil; and
3. Non-hazardous Deck Drainage – compliance limit of 15 mg/L oil.

Water on the *Transocean Barents* passes through a designated oily water separator system before discharge to the marine environment. While in the Terra Nova field from August 2017-October 2019, the total volume of bilge water and non-hazardous deck drainage water discharged was 2,047 m^3. Hazardous drilling area deck drainage water was either shipped to shore for disposal or processed through an oily water separator and discharged.

The FPSO (production) effluent streams and their compliance limits were:

1. Chlorinated Seawater – compliance limit of 2.0 mg/L; Suncor targets a residual concentration of 0.5 to 0.7 mg/L;
2. Bilge Water – compliance limit of 15 mg/L oil; and
3. Deck Drainage – compliance limit of 15 mg/L oil.

A grab sample for chlorine discharge is collected daily for the topsides and biweekly for the vessel cooling systems for compliance. Suncor did not exceed its compliance limit for chlorinated seawater discharge during the period from June 2017 to June 2020, when the FPSO departed the Terra Nova Field for Quayside.

Bilge water and deck drainage for the FPSO are pumped to the slops tanks for settling and pass through the FPSO's Watex oil-in-water filtration system and analyzer before being discharged. The total volume of water discharged from June 2017 to June 2020 was 17,035 m^3. Suncor met the oil-in-water compliance requirements during this period.

Deck drainage from uncontaminated and known non-oily areas is discharged directly overboard without treatment.

Sewage is macerated to 6 mm prior to discharge.

5.0 SEDIMENT COMPONENT

5.1 METHODS

5.1.1 FIELD COLLECTION

The sediment component of the 2020 EEM program was conducted from November 29 to December 4 using the offshore supply vessel *M/V Siem Pilot.* Sampling dates for the baseline program and for EEM programs are provided in Table 5-1. More details on these surveys can be found in Suncor Energy (1998a, 2001, 2002, 2003, 2005, 2007, 2009, 2011, 2013, 2017, 2019). Sediment collection stations for the 2020 program are shown in Figure 1-8 (Section 1). Geographic coordinates and distance to drill centres are provided in Appendix B-1.

Table 5-1 Sampling Dates of Sediment Portion of EEM Program

Trip	Date
Baseline program	September 24 to October 7, 1997
EEM program Year 1	September 27 to October 4, 2000
EEM program Year 2	August 30 to September 5, 2001
EEM program Year 3	September 3 to September 13, 2002
EEM program Year 4	October 5 to October 10, 2004
EEM program Year 5	August 13 to August 22, 2006
EEM program Year 6	September 5 to September 17, 2008
EEM program Year 7	October 14 to October 23, 2010
EEM program Year 8	May 25 to June 1, 2012
EEM program Year 9	October 23, to October 30, 2014
EEM program Year 10	May 3 to May 9, 2017
EEM Program Year 11	November 29 to December 4, 2020

Note: - Sampling was interrupted in 2010 from October 17 to 20 because of weather conditions.

Sediment samples were collected using a large-volume corer (mouth diameter = 35.6 cm, depth = 61 cm) designed to mechanically take an undisturbed sediment sample over approximately 0.1 m² of seabed (Figures 5-1 and 5-2). Three cores were performed at each station to collect sufficient sediment volume for assessment of sediment physical and chemical characteristics, toxicity, and benthic community structure (Sediment Quality Triad components; see Section 1).

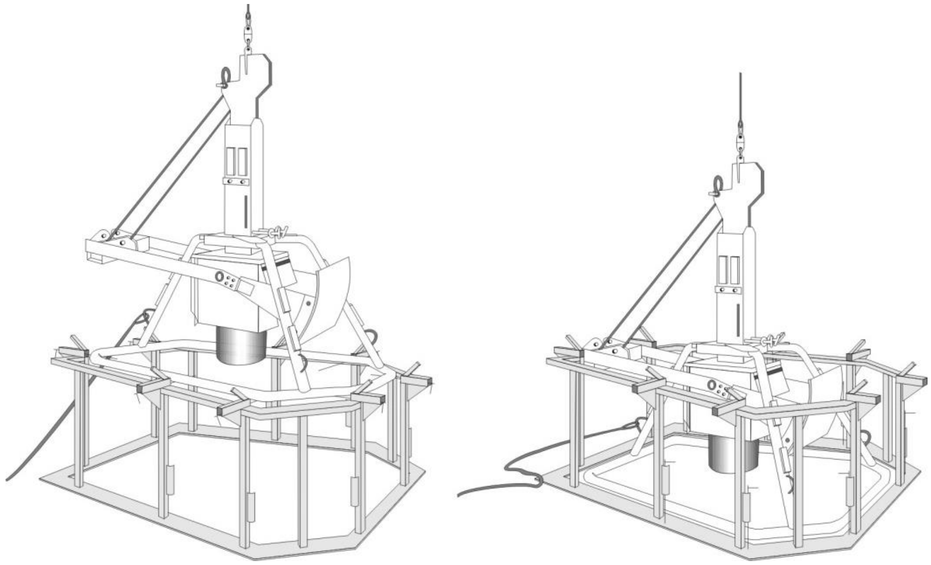

Figure 5-1 Sediment Corer Diagram

Figure 5-2 Sediment Corer

Sediment reduction/oxidation (redox) potential was measured on sediment cores before sample collection. Sediment samples collected for physical and chemical analysis[11], as well as for archive, were a composite from the top 3 cm of all three cores (Figure 5-3). These samples were stored in pre-labelled glass jars at -20°C. Sediment samples collected for toxicity (amphipod survival and polychaete survival and growth[12]) were collected from the top 7.5 cm of one core and stored in the dark at 4°C in a 4-L high-density food-grade polyethylene bucket with an O-ring seal. 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. These samples were preserved with approximately 1 L of 10% buffered formalin. Samples were collected at each of the 53 Terra Nova stations except for samples for the polychaete toxicity test. Those samples were collected at stations within 3 km from drill centres and at Reference Stations 1(SW) and 6(SE) (see Figure 1-8, Section 1 for station names and locations).

The following Quality Assurance/Quality Control (QA/QC) protocols were followed for collection of samples. Sediment chemistry field blanks, composed of clean sediment obtained from the analytical laboratory, were “collected” (i.e., handled) at stations 9(SE), 41(FEZ), and 49(FEZ). Blank vials were opened as soon as the core sampler from these three stations was brought on board the vessel and the vials remained opened until chemistry samples from that station were processed. Blank vials were then sealed and stored with other chemistry samples. Field duplicates were collected for chemical analysis at stations 1(SW), 6(SE), 8(SE), 24(FE) and 44(FEZ). Blanks and duplicates were collected for analysis of hydrocarbons, ammonia, sulphur, sulphides, and total organic and total inorganic carbon content. Both blanks and duplicates were assigned randomly to stations.

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[11] Sediment physical and chemical characteristics included sediment particle size, hydrocarbons (benzene, toluene, ethylbenzene, and xylenes (BTEX), $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons and polycyclic aromatic hydrocarbons (PAHs)), total inorganic and total organic carbon, metals, sulphur, sulphide, and ammonia.

[12] The Microtox™ toxicity test performed in previous EEM programs was replaced with the polychaete survival and growth toxicity test after regulatory approval of recommendations in the 2014 and 2017 EEM program reports.

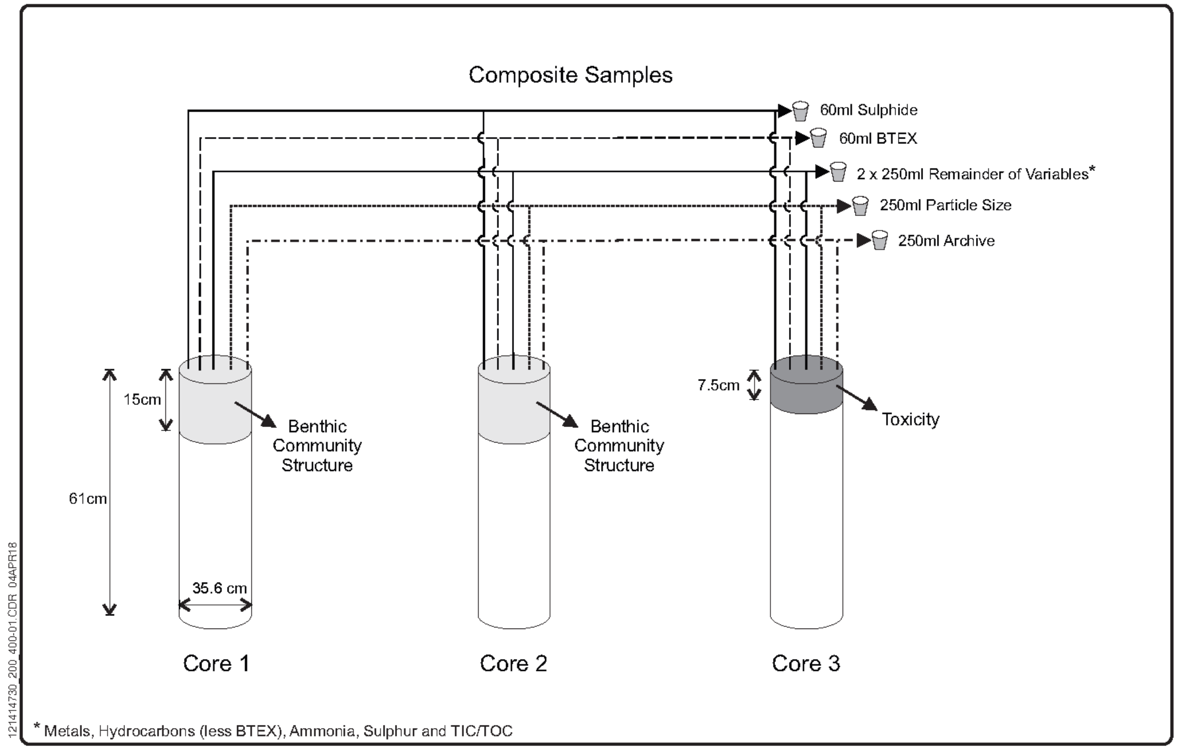

Figure 5-3 Allocation of Samples from Cores

Core samples were immediately covered with clean, plastic-lined metal covers and moved to a working area near the laboratory facility. The laboratory facility and sampling tools were washed with isopropanol then rinsed with distilled water between each station to prevent cross-contamination between stations. Processed samples were transferred to cold storage within one hour of collection. Once ashore, samples to be analyzed by Bureau Veritas were transferred to the Bureau Veritas laboratory in St. John's for shipment to their laboratory in Halifax. Samples to be analyzed by RPC, Avalon Laboratories, and the Stantec Materials Laboratory and Stantec Benthic Laboratory were transferred to cold storage at Stantec Consulting Ltd. and then shipped to the respective laboratories. Where applicable, samples were delivered to laboratories in sufficient time to allow for analysis within the prescribed sample holding time.

5.1.2 LABORATORY ANALYSIS

5.1.2.1 Physical and Chemical Characteristics

Sediment samples were processed for the variables listed in Tables 5-2 and 5-3. Particle size was assessed by Stantec Consulting Ltd.'s materials testing laboratory in St. John's, Newfoundland and Labrador. Most sediment chemistry analyses were conducted by Bureau Veritas, in Halifax, Nova Scotia. Sediment organic and inorganic carbon analyses were conducted at RPC in Fredericton, New Brunswick. Methods summaries from these laboratories are provided in Appendix B-2.

Table 5-2 Particle Size Classification

Size Classification (Wentworth)	Size Range (mm)	PHI Scale Range
Gravel	2 to 64	-1.000 to -6.000
Sand	0.063 to 2	3.989 to -1.000
Silt	0.002 to 0.063	8.966 to 3.989
Clay	< 0.002	< 8.986

Note: - Silt + clay fractions are referred to as "fines".

Table 5-3 Sediment Chemistry Variables (1997 to 2020)

Variable	Method	Laboratory Detection Limit										Units
		1997	2000	2001	2002	2004	2006	2008	2010 & 2012	2014	2017 & 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	0.03	0.03	0.04	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}	Calculated	3	3	3	3	3	3	3	3	3	3	mg/kg
$>C_{10}$-C_{21}	GC/FID	15	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	15	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	mg/kg
PAHs												
1-Chloronaphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
2-Chloronaphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
1-Methylnaphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
2-Methylnaphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Acenaphthene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Acenaphthylene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Anthracene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Benz[*a*]anthracene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Benzo[*a*]pyrene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Benzo[*b*]fluoranthene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Benzo[*ghi*]perylene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Benzo(j)fluoranthene	GC-MS	NA	NA	NA	NA	NA	NA	NA	NA/0.01	0.01	0.01	mg/kg
Benzo[*k*]fluoranthene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Chrysene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Dibenz[*a,h*]anthracene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Fluoranthene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Fluorene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Indeno[1,2,3-*cd*]pyrene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Naphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Perylene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Phenanthrene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg
Pyrene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.01	0.01	0.01	mg/kg

Variable	Method	Laboratory Detection Limit										Units
		1997	2000	2001	2002	2004	2006	2008	2010 & 2012	2014	2017 & 2020	
Carbon												
Total Carbon	LECO	NA	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	g/kg
TOC	LECO	NA	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	g/kg
TIC	By Difference	NA	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	g/kg
Metals (total)												
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	5	5	5	2	2	2	2	2	2	mg/kg
Cadmium	ICP-MS	0.3	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
Copper	ICP-MS	2	2	2	2	2	2	2	2	2	2	mg/kg
Iron	ICP-MS	20	20	20	20	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	5	5	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	CVAAS	0.01	0.01	0.01	0.01	0.01	0.01	0.01	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	2	2	2	5	5	5	5	5	5	mg/kg

Variable	Method	Laboratory Detection Limit										Units
		1997	2000	2001	2002	2004	2006	2008	2010 & 2012	2014	2017 & 2020	
Other												
Ammonia (as N)	COBAS	NA	NA	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	mg/kg
Sulphur	LECO	NA	NA	0.03	0.03	0.02	0.002	0.01	0.03	0.03	0.01	%
Sulphide	COBAS(SM4500-S2-D)	NA	NA	20	20	2	0.2	0.2	0.2	0.2	0.5	mg/kg
Moisture	Gravimetry	0.1	0.1	0.1	0.1	1	1	1	1	1	1	%

Notes: - The laboratory detection limit is the lowest concentration that can be reliably achieved 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.
- NA = Not Analyzed.
- TOC = Total organic carbon; TIC = Total inorganic carbon.
- In some years, laboratory detection limits for hydrocarbons and ammonia were reported at more significant digits than what is shown above. As this was not a difference in detection limit but rather a difference in the rounding of the values, the higher of the reported detection limits are used in this report (e.g., a detection limit of 0.25 mg/kg is reported as 0.3 mg/kg).
- Results and detected limits for total carbon and total inorganic and organic carbon are reported in % in Appendix B-2, 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 approximately 0.3 mg/kg. In 2020, the median detection limit across all samples was 0.31 mg/kg.

Within the hydrocarbons, BTEX refers to 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 the range where lightweight fuels such as 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 aromatic, n-alkane (straight chain), isoalkane (branched chain) and cycloalkane (cyclic, non-aromatic 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 over the C_6-C_{32} range (see Appendix B-2 for gas chromatogram results for each sample at Terra Nova). 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 drill mud base oil (PureDrill IA35-LV) used at Terra Nova is a synthetic isoalkane fluid consisting of molecules ranging from >C_{10}-C_{21} (Appendix A). 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 6 minutes.

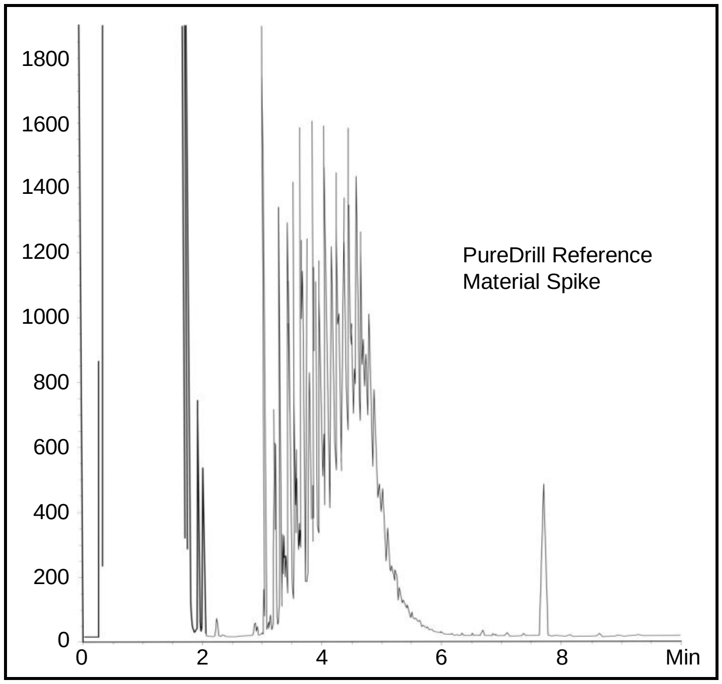

Figure 5-4 Gas Chromatogram Trace for PureDrill IA35-LV

5.1.2.2 Toxicity

Avalon Laboratories in St. John's, Newfoundland and Labrador, conducted the sediment toxicity analyses. All sediment samples were examined using the amphipod survival test and the juvenile polychaete test. The Microtox toxicity test performed in previous EEM programs for Terra Nova was replaced with the juvenile polychaete test after regulatory approval of recommendations in the 2014 and 2017 EEM reports. The juvenile polychaete test has two components - the polychaete growth test, which measures sub-lethal effects, and the polychaete survival test, which measures lethal effects.

Amphipod survival tests were conducted using the marine amphipod *Rhepoxynius abronius* obtained from Whidbey Island, Washington State (USA). Avalon Laboratories conducted the tests in accordance Biological Test Method: Acute Test for Sediment Toxicity using Marine or Estuarine Amphipods (EPS 1/RM/26 December 1992 with October 1998 amendments) (Environment Canada 1992) and Biological Test Method: Reference Method for Determining Acute Lethality of Sediment to Marine or Estuarine Amphipods (EPS 1/RM/35 December 1998) (Environment Canada 1998), with further guidance from Environment and Climate Change Canada. The test involves 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 amphipod test container was set up with 20 test organisms and maintained for ten days under appropriate test conditions, after which survival was recorded. Another test container was used for water quality monitoring only. Negative control sediment was tested concurrently, since negative controls provide a baseline response to which test organisms can be compared. Negative control sediment, known to support a viable population, was obtained from the collection site for the test organisms. A positive (toxic) control using an aqueous solution was tested for each batch of test organisms received. The positive control uses a standard chemical toxicant to measure the sensitivity of the test organisms in order to establish confidence in the toxicity testing results[13]. The amphipod toxicity test met performance criteria set in the test method and are, therefore, considered valid.

All samples for the amphipod toxicity tests were initiated within the recommended six weeks holding period recommended by EPS 1/RM/35 December (1998).

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[13] With each batch of sediment toxicity tests, a reference toxicant test using cadmium chloride is conducted. The reference toxicant bioassay is a 4-day static LC_{50} bioassay using a geometric series of dilutions of cadmium chloride. This assay is conducted in the dark and is initiated on day 0. The laboratory will initiate the reference toxicant the day prior to sample test initiation, when appropriate. The test vessels are covered with tin foil to ensure that the test is conducted under dark conditions.

The 20-day juvenile polychaete (*Neanthes arenaceodentata*) sediment toxicity test was conducted as per protocols described by the Puget Sound Estuary Program (Puget Sound Estuary Program [PSEP] 1995)[14]. The testing protocol involves setting up 1-L test chambers with approximately 175 ml of sediment and approximately 800 ml overlying clean seawater were initiated (Figure 5-6). Although the protocol accounts for five replicate chambers to be set up for each sediment sample, fewer replicates (three to four) were set up for approximately half of the sediments (19 test sediments, 1 reference sediment – 1SW), due to a shortage of test organisms (see Appendix B-3 for details). Each test container was set up with five test organisms (one to two weeks post-emergence) and maintained for 20 days under appropriate test conditions, after which survival and growth were measured.

Figure 5-6 Juvenile Polychaete Toxicity Test

A sixth test container for each sediment was set up without test organisms and used for water quality monitoring only. Every three days, approximately one-third of the water in each jar was removed and replaced with clean seawater, taking care not to disturb the sediment. Water quality parameters were measured from the water quality replicate prior to each water renewal. For feeding, each test chamber with test organisms was provided with ground Nutrafin™ fish flakes every two days (8 mg per test organism, based on five organisms in each test chamber) during the test period.

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[14] The PSEP (1995) method was adopted because it is the method used in the EEM program for the Hibernia field (HMDC 2013).

Concurrently, negative or clean controls were conducted and for a test to be valid, mean survival in the negative control had to be ≥ 90% and mean growth had to be ≥0.38 mg/individual/day. In addition, a positive or toxic control was conducted using cadmium as the reference toxicant to assess the health and sensitivity of the organisms. The polychaete toxicity test met performance criteria set by PSEP (1995) and are, therefore, considered valid.

All samples for the juvenile polychaete test were initiated within the six-week holding period recommended in the Guidelines for Conducting Laboratory Bioassays on Puget Sound Sediments (PSEP 1995).

Testing methods for amphipods and polychaetes require measurement of pore water pH, salinity, and ammonia. However, based on recommendations from Environment and Climate Change Canada to Avalon Laboratories ensuing from discussions on the 2014 EEM report, these measurements were replaced with measurement of sediment ammonia, sulphides, and redox potential.

Interpretation of Results

The statistical endpoint for the amphipod survival 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).

Avalon Laboratories conducted amphipod toxicity tests using a negative control sediment collected from the source site for the amphipods and two Terra Nova reference stations (TNRS; stations 1-SW and 6-SE). Using two reference samples to evaluate toxicity of test sediments reduces an already very low risk of false positives.

Amphipod survival test results for sediments were considered toxic if survival was reduced by more than 30% as compared to the negative control sediment and the result was statistically significantly different from survival in the negative control sediment. Amphipod survival was also compared to TNRS sediments. For this comparison, amphipod survival test results for sediments were considered toxic if survival was reduced by more than 20% as compared to TNRS sediment and the result was statistically significantly different from survival in the TNRS sediment.

Amphipod toxicity test results were then examined for the potential influence of sediment ammonia, sulphide, and redox potential, as described in Appendix B-3.

Environment and Climate Change Canada and PSEP offer no interpretative guidance for evaluating toxicity of sediments for the juvenile polychaete test. Consistent with methods for the EEM program for the Hibernia field (HMDC 2013), the amphipod survival test interpretative guidance is used for the interpretation of juvenile polychaete data. Therefore, the juvenile polychaete survival test results are considered toxic if the endpoint (mortality) is more than 30% lower and significantly different from mortality in the negative control sediment. The juvenile polychaete growth test results are considered toxic if the endpoint (mean growth (mg/individual/day) is more than 30% lower and significantly different than mean growth in the negative control sediment. As is done for amphipods, juvenile polychaete survival and growth are also compared to TNRS sediment. Results are considered toxic if they are more than 20% lower compared to TNRS sediment and they are statistically significantly different from TNRS sediment.

As was the case for the amphipod tests, polychaete toxicity test results were then examined for the potential influence of sediment ammonia, sulphide, and redox potential, as described in Appendix B-3.

5.1.2.3 Benthic Community Structure

In 2020, 106 benthic samples were provided whole to Stantec's Benthic Taxonomy Laboratory (Guelph, Ontario). Upon arrival, sample buckets were cross-checked with chain of custody information to confirm the number of samples sent and received as well as station identification labels to resolve any discrepancies or inconsistencies. Approximately half of the samples consisted of fine to medium sand with the remainder comprised of a mix of fine to coarse sand, gravel, cobble, and shell material.

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 plastic 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 sample buckets. 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 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.

While the majority of samples were sorted in their entirety, samples from 28 stations contained large amounts of complex material (shell fragments, barnacle encrusted rocks) and/or large numbers of organisms and were subsampled to save time and effort. In these cases, one or both of the samples from each of these stations were homogenized and split into equal fractions by area on a 500-micron sieve[15]. Samples were subsampled to ⅛, ¼ or ½ in this way such that the organisms found could be picked, weighed, identified, and enumerated within the allotted time. Wet weight biomass estimates, and benthic organisms counts for subsampled samples, were then extrapolated to the whole sample by multiplying by the inverse of the fraction sorted. The potential influence of subsampling on community composition was assessed; no significant difference was found between samples that were processed whole and those that were subsampled (see Appendix B-4 for details).

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.

[15] One or both of the samples from stations 5(SW), 7(SE), 11(SE), 15(NE), 17(NE), 18(NW), 20(NW), 22(NW), 23(NW), 24(FE), 26(FE), 31(FE), 33(FEZ), 35(FEZ), 36(FEZ), 37(FEZ), 38(FEZ), 39(FEZ), 41(FEZ), 42(FEZ), 44(FEZ), 45(FEZ), 46(FEZ), 47(FEZ), 48(FEZ), 49(FEZ), 51(FEZ), and 52(FEZ) were subsampled (see Appendix B-4 for details).

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 efficiency of 96% was achieved with 2020 samples.

Organisms were identified to lowest practical level using available dichotomous keys and reference material appropriate to the taxa found (see Appendix B-4 for a list of reference material). 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.

Benthic invertebrate samples collected in 2001 and 2002 were processed (sieved and identified) by Pat Stewart of Envirosphere Ltd. Pat Stewart identified invertebrates in 2000. Arenicola Marine Limited identified invertebrates in 1997 and sieved and identified samples from 2004 to 2017. Arenicola Marine Limited, Envirosphere Ltd. and the Stantec Guelph Taxonomic Laboratory use similar sieving and identification methods and results from these three laboratories are comparable. However, 11 of the 49 samples collected in 2000 and all samples collected in 1997 were sieved using the wash method rather than the elutriate method and recoveries for these samples were less than in remaining samples (see Suncor Energy 2001 for details).

5.2 DATA ANALYSIS

5.2.1 GENERAL APPROACH

The sediment quality assessment involved the assessment of chemical/physical, toxicological, and biological (benthic invertebrate communities) component data. These components comprise the classical “sediment quality triad” of data as described by Chapman et al. (1991) and Green et al. (1993). The data were analyzed in steps to address the following guiding questions:

4. Were temporal and spatial variations in sediment quality variables indicative of effects from project activities?

5. Were there biological effects (toxicity, alteration of benthic invertebrate communities) associated with alteration of sediment physical and chemical characteristics from project activities?

The various statistical tools described below were used to assess the data relative to these questions.

5.2.2 PHYSICAL AND CHEMICAL CHARACTERISTICS

The assessment of sediment physical property and chemical concentration data involved: 1) calculation of summary statistics and, for metals, comparison of summary statistics in 2020 to Interim Sediment Quality Guidelines (Canadian Council of Ministers of the Environment (CCME) for those metals for which there are guidelines; 2) identification or computation of key summary variables; and 3) statistical analysis of data to explore annual and spatial variations.

5.2.2.1 Key Variables

The following sediment quality variables were examined to determine the influence of drilling operations:

- primary drilling mud constituents ($>C_{10}$-C_{21} hydrocarbons and barium);
- particle size (% fines, sand, and gravel) and organic carbon;
- metals other than barium; and
- other variables (sulphur, sulphide, ammonia, redox potential).

The above variables were analyzed separately because they are “markers” for drilling activity, or because they could directly or indirectly reflect physical impact to benthic habitats.

$>C_{10}$-C_{21} hydrocarbons are major constituents of synthetic-based drilling muds. Barium is a major constituent of both water-based and synthetic-based drilling muds. Enrichment of either of these substances in sediments points to the presence of drill muds.

Deposition of fine drill cuttings and hydrocarbons from synthetic-based drilling muds could elevate fines and organic carbon content in sediments. Organic carbon, regardless of source, is typically associated with finer particles, as are metals and synthetic hydrocarbons.

Metals other than barium, several of which occur naturally at high concentrations in marine sediments, were primarily treated as indicators of the natural variance of barium concentrations that might be expected in the absence of drilling. However, concentrations of some metals could also increase in sediments as a result of project activity. A principal component analysis (PCA) of frequently detected metals was carried out to generate two "proxy" variables of sediment concentrations. The PCA was carried out on the correlation matrix of log_{10}-transformed sediment concentrations.

Sulphur (in barium sulphate) is a constituent of synthetic- and water-based drilling muds and could be considered a secondary drilling mud indicator. However, background sulphur levels are greater than background barium levels and can be affected by many natural factors. Sulphides are naturally present in marine sediments and may be produced from biodegradation of natural and synthetic organic compounds under reducing conditions.

High ammonia concentrations could occur in sediments as a result of breakdown of hydrocarbons originating from project activities and also would occur wherever natural decomposition of organic materials occurs. Decomposition of organic materials could lower redox potential in sediments.

5.2.2.2 Statistical Analysis

The following analytical steps were carried out for each of the key variables.

In **Step 1**, temporal variations were explored visually using dot-density distributions generated in SYSTAT.

In **Step 2**, bivariate Spearman rank correlations between the response variable (i.e., the chemical or physical sediment variable) and distance to the nearest active drill centre (Min *d*) were computed for 2020 data to understand the degree of the association with drilling activity in the current year. Multiple regression also was used on ranks of concentration and distance data (see Appendix B-5 for details) to determine the relative influence of the FE and FEZ drill centres (i.e., FE *d* and FEZ *d*) on sediment variables in 2020. Data from all (n = 53) stations were used in this analysis.

A scatterplot of the relationship between the response (sediment) variable and Min *d* in 2020 was generated for visual inspection in **Step 3**. For $>C_{10}$-C_{21} hydrocarbons and barium, bubble plots were constructed to further illustrate spatial variations in $>C_{10}$-C_{21} hydrocarbons and barium concentrations in the sampling field.

Visual inspection of $>C_{10}$-C_{21} hydrocarbons and barium concentrations in relation to Min *d* suggested there were "threshold" distances beyond which drilling operations had no or negligible effect. Therefore, hockey-stick models (see details in Appendix B-5) were used in **Step 4** to compute the threshold distances for $>C_{10}$-C_{21} hydrocarbons and barium for the 2020 data. Threshold distances were previously computed for data from prior years using the same methods.

The influence of drilling activity on the response variable could be anticipated to change over time in relation to variations in drilling activities. In **Step 5**, annual variations in Spearman rank correlation coefficients between responses variables and Min *d* were illustrated graphically.

Finally, repeated-measures regression was used in **Step 6** to test for variations in sediment chemical and physical properties variables over time in relation to distance from the FE and FEZ drill centres (see Appendix B-5 for details).This approach differs from the Spearman rank correlations used in Step 5, which identified changes over time relative to Min *d*. Data from 1997 were excluded from repeated-measures regression, as were data from Stations 50(FEZ) to 53(FEZ) and Station 48(FEZ)[16]. The analysis was carried out using ranks of key variables and distances to allow the analysis to detect correlations even if there were hockey-stick-type relationships for some variables (i.e., hydrocarbons and barium). Data were ranked across years for repeated-measures regression. Annual variations in FE and FEZ regression slopes (multiple regression on ranks, again see Appendix B-5) were inspected visually (graphically) to assist in the interpretation of the repeated-measures regression results.

[16] Repeated-measures regression requires that the same stations be re-sampled over time and many baseline (1997) stations were relocated in EEM years. Remaining stations were excluded because they could not be sampled in various EEM years because of construction activity in the field.

Values below Laboratory Detection Limit

Concentrations of >C_{10}-C_{21} hydrocarbons less than the laboratory detection limit in EEM years were set to ½ the laboratory detection limit of 0.3 mg/kg[17] for analyses and plots.

Chromium concentrations were below the laboratory detection limit in two samples in 2006, in three samples in 2014, and in two samples in 2020. Concentrations below detection limit were set to ½ the detection limit of 2 mg/kg.

Concentrations of organic carbon were below the laboratory detection limit in two samples in 2020. Those concentrations were set to ½ the detection limit of 0.1 g/kg.

Concentrations of ammonia were less than the laboratory detection limit in three samples in 2002 and in one sample in 2020. The concentrations were set to ½ the laboratory detection limit of 0.3 mg/kg.

Detection limits for sulphur have varied since it was first measured in 2001. Sulphur concentrations less than the laboratory detection limit were set to half of the detection limit of 0.03% (2001, 2002, 2010, 2012, and 2014), half the detection limit of 0.02% (2004), or half the detection limit of 0.01% (2017 and 2020). There were no values below detection limit in 2006 and 2008.

Sulphide values less than the laboratory detection limit were set to ½ the laboratory detection limit of 0.2 mg/kg (2006 to 2014) or 0.5 mg/kg (2017 and 2020). Sulphide measurements for 2001 and 2004, when laboratory detection limits were substantially higher (2 to 20 mg/kg), were excluded from analysis.

Repeated-measures regression was not performed on sulphide because of the large number of values below laboratory detection limit over the years, and because of substantive changes in laboratory detection limits from 2002 to 2020 (see Table 5-3).

[17] The reported laboratory detection limit for >C_{10}-C_{21} in EEM years has varied from 0.25 to 0.3 mg/kg because of rounding by the analytical laboratory and does not represent true differences in the precision of the instruments.

5.2.3 TOXICITY

5.2.3.1 Key Variables

Sediment toxicity variables were laboratory amphipod survival (%), juvenile polychaete survival (%), and juvenile polychaete growth (mg/worm/day).

5.2.3.2 Statistical Analysis

Amphipod survival and polychaete survival and growth for 2020 were analyzed using methods similar to those applied to sediment physical and chemical characteristics.

In **Step 1**, the Spearman rank correlations between amphipod survival, polychaete survival, and polychaete growth were computed using the 2020 data, as a general indication of the agreement between the data sets.

In **Step 2**, Spearman rank correlations between each of the toxicity variables and all sediment physical and chemical variables identified above were computed to identify factors that were potentially influencing toxicity.

In **Step 3**, bivariate Spearman rank correlations between the toxicity variables and Min *d* were computed in order to understand the degree of the association with drilling activity in the current year. Multiple rank regression was conducted (see Appendix B-5 for details) to determine the relative influence of the FE and FEZ drill centres on toxicity variables.

In **Step 4**, a scatterplot of the relationship between each of the three toxicity variables and Min *d* was generated for visual inspection.

Multi-year comparisons were not performed on amphipod survival in this or prior EEM reports because survival has been uniformly high. The polychaete test was implemented for the first time in 2020 (i.e., no previous data were available).

5.2.4 BENTHIC COMMUNITY STRUCTURE

Assessment of benthic community data involved identification of key summary variables, then analysis of the data to explore annual and spatial variations. Key variables from the sediment physical and chemical component and the sediment toxicity component were used in an overall integrated analysis of the benthic community data.

Invertebrates from the 54 stations sampled in 1997 (baseline) and from 11 of 49 stations sampled in 2000 were recovered using the Wash method. Invertebrates from 38 stations sampled in 2000 and all stations sampled from 2001 to 2020 were recovered using the more efficient Elutriate method. For most community variables, differences between the two recovery methods were greater than natural or project effects (see Suncor Energy 2001 for details). Therefore, all analyses reported here were restricted to Elutriate samples.

5.2.4.1 Key Variables

Benthic invertebrate community variables analyzed were summary measures based on abundances or occurrences of all taxa, and abundances of selected dominant and sub-dominant taxa. Summary measures analyzed were:

- total abundance (*N*) (number of organisms per station);
- biomass (*B*) (wet weight of invertebrates per station);
- taxonomic richness (*S*) (number of taxa, usually families, per station);
- adjusted richness (*S2*) (richness adjusted for total abundance, a measure of diversity); and
- multivariate measures of community composition.

Adjusted richness values were residuals (deviations) from regressions of log *S* on log *N* for all Elutriate samples. If the residuals from the $\log_{10}$-$\log_{10}$ regression are back-transformed, they will be observed richness relative to richness predicted by the *S*-*N* relationship, with an overall average of approximately 1. For example, a residual of 0.07918 (back-transformed adjusted richness value = 1.2) indicates that richness at that station was 20% greater than “average richness” expected based on total abundance at that station.

Non-metric Multidimensional Scaling (NMDS)[18] was used to assess community composition and provide summary measures for further analyses. NMDS can be considered a non-parametric analog of PCA (Clarke 1993). NMDS was applied to Elutriate samples from 2000 to 2020. Abundances of each taxon were expressed as a percentage of total abundance (relative abundance) per sample to reduce the effects of and correlations with total abundance. Bray-Curtis distances were then calculated between all possible pairs of stations. The Bray-Curtis distances are % differences in overall community composition since they were based on relative (%)

[18] NMDS data are rank transformed and incorporated into statistical analyses of key variables, as per methods in Section 5.2.4.2.

abundances of individual taxa (family level or higher). The Bray-Curtis distance matrix was used in NMDS to generate multivariate community composition measures (i.e., scores along NMDS axes), which were considered "proxy" variables (i.e., NMDS1, NMDS2).

Abundances of the following taxa were incorporated into the analyses at various times to support the interpretation of the assessment of the key variables:

- the dominant polychaete (Polychaeta) families (Spionidae, Cirratulidae, and Syllidae);
- selected sub-dominant polychaete families (Orbiniidae, Paraonidae, Phyllodocidae, Sabellidae, and Sigalionidae);
- the most abundant bivalve (Bivalvia) family, Tellinidae;
- the most abundant crustaceans, Balanidae;
- amphipods (Amphipoda); and
- echinoderms (Echinodermata).

5.2.4.2 Statistical Analysis

For each of the key benthic community variables, the following analytical steps were carried out.

In **Step 1**, temporal variations were explored visually using dot-density distributions generated in SYSTAT.

In **Step 2**, bivariate Spearman rank correlations between the response variable (i.e., the benthic community variable) and Min *d* were computed for 2020 data in order to understand the degree of the association with drilling activity in the current year; and multiple rank regression was used (see Appendix B-5 for details) to determine the relative influence of the FE and FEZ drill centres on benthic community variables.

A scatterplot of the relationship between the response variable and Min *d* was generated in **Step 3,** for visual inspection.

The influence of drilling activity on the benthic community variables could be anticipated to change over time in relation to variations in drilling activities. In **Step 4**, annual variations in Spearman rank correlation coefficients were illustrated graphically.

Repeated-measures regression (see Appendix B-5 for details) was used in **Step 5** to test for variations in benthic community variables over time in relation to distance from the FE and FEZ drill centres (whereas Spearman rank correlations examined temporal variations relative to Min *d*). Data from 1997 and 2000 were excluded from repeated-measures regression, as were data from Stations 50(FEZ) to 53(FEZ) and Station 48(FEZ)[19].

As was done for sediment chemistry, data were ranked across years[20]. Annual variations in FE and FEZ regression slopes were inspected visually (graphically) to assist in the interpretation of the repeated-measures regression results.

5.2.4.3 Integrated Assessment

The purpose of the integrated assessment was to better articulate the magnitude and nature of the covariation among core variables identified in analyses of sediment physical and chemical characteristics, toxicity, and benthic community structure, with an emphasis on identifying those variables that fundamentally influenced the composition of the invertebrate community.

The integrated assessment relied on PCA to summarize the variation and covariation of core variables identified from previous analyses. Results of the PCA were used to help identify a further subset that included variables with relatively strong correlation (r_p> 0.6) with Principal Component axes. The relationship between these variables and indices of benthic community structure was then assessed using Spearman rank correlations by year and scatterplots.

Assessment of benthic community data involved identification of key summary variables, then analysis of the data to explore annual and spatial variations. Key variables from the sediment physical and chemical component and the sediment toxicity component were used in an overall integrated analysis of the benthic community data.

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[19] Repeated-measures regression requires that the same stations be re-sampled over time and many baseline (1997) stations were relocated in EEM years. Remaining stations were excluded because they could not be sampled in various EEM years because of construction activity in the field. Data from 2000 were excluded because a different sieving method was used for some samples in that year (see Section 5.2.4).

[20] Data were ranked across all years from 2000 to 2020 to provide continuity between the repeated-measures and NMDS datasets since both datasets involve ranks.

5.3 RESULTS

5.3.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

Summary statistics and raw data for sediment physical and chemical characteristics from 1997 to 2020 are provided in Appendix B-2. No PAHs were detected in sediments in 2020 (Appendix B-2).

Table 5-4 provides summary statistics for detected compounds in 2020. As in prior years, sediments collected in 2020 were predominantly sand, organic carbon content was low, and all detectable metals for which there is a sediment quality guideline had median concentrations below their Interim Sediment Quality Guideline (CCME 2001, 2015; Table 5-4). A more detailed analysis on individual compounds or groups of compounds follows.

Table 5-4 Summary of Commonly Detected Sediment Variables (2020)

Variable	Units	*n*	*n*<LDL*	Minimum	Median	Maximum	ISQG**
>C_{10}-C_{21} Hydrocarbons	mg/kg	53	12	<0.3	0.74	1600	
>C_{21}-C_{32} Hydrocarbons	mg/kg	53	2	<0.3	0.54	9.9	
Total carbon	g/kg	53	0	0.2	1	15.1	
Inorganic carbon	g/kg	53	34	<0.1	<0.1	6.2	
Organic carbon	g/kg	53	2	<0.1	0.9	9.3	
Aluminum	mg/kg	53	0	3,400	5,400	8,200	
Barium	mg/kg	53	0	57	130	3,900	
Cadmium	mg/kg	53	52	<0.05	<0.05	0.73	0.7
Chromium	mg/kg	53	2	<2	2.8	43	52.3
Cobalt	mg/kg	53	52	<1	<1	1	
Iron	mg/kg	53	0	540	1,000	1,800	
Lead	mg/kg	53	0	1.2	1.9	4.2	30.2
Lithium	mg/kg	53	50	<2	<2	2.4	
Manganese	mg/kg	53	0	9.5	22	54	
Mercury	mg/kg	53	52	<0.01	<0.01	0.026	0.13
Nickel	mg/kg	53	46	<2	<2	58	
Strontium	mg/kg	53	0	17	35	260	
Uranium	mg/kg	53	1	<0.1	0.13	0.3	
Vanadium	mg/kg	53	0	2.5	3.8	8.3	
Zinc	mg/kg	53	52	<5	<5	73	123
Sand	%	53	0	67.20	91.90	99.20	
Gravel	%	53	0	0.00	7.10	30.40	
Silt	%	53	0	0.19	0.75	2.29	
Clay	%	53	0	0.15	0.56	1.14	
Fines	%	53	0	0.70	1.40	3.40	
Ammonia	mg/kg	53	1	<0.31	4.3	42	
Sulphur	%	53	7	<0.01	0.022	0.27	
Sulphide	mg/kg	53	31	<0.5	<0.5	4.9	
Redox	mV	53	0	163	277	311	

Note: - * LDL = Laboratory Detection Limit.
- ** ISQG = Interim Sediment Quality Guideline.

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

There was an increase in >C_{10}-C_{21} hydrocarbon concentrations in sediments from 2000 to 2004/2006, with a subsequent decrease in concentration (Appendix B-2; Figure 5-7). Baseline (1997) data cannot be compared to subsequent years because laboratory detection limits in 1997 (15 mg/kg) were higher than laboratory detection limits in subsequent years (0.3 mg/kg); and >C_{10}-C_{21} hydrocarbon concentrations in 1997 were below the detection limit of 15 mg/kg in all samples. Median >C_{10}-C_{21} hydrocarbon concentrations increased from 0.67 mg/kg in 2000 to 4.30 mg/kg in 2006, then decreased to concentrations ranging from 0.7 to 1.4 mg/kg from 2008 to 2020 (Appendix B-2). The maximum >C_{10}-C_{21} hydrocarbon concentration over all years (6,550 mg/kg) occurred in 2004 (Figure 5-6), at Station 30(FE), located 0.14 km from the FE Drill Centre. The highest concentration in 2020 (1,600 mg/kg) also occurred at Station 30(FE). All chromatograms for stations with >C_{10}-C_{21} hydrocarbon concentrations above the laboratory detection limit (41 of 53 stations in 2020) have showed an Unresolved Complex Mixture in the range of PureDrill IA35-LV (Appendix B-2; Suncor Energy 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2017, 2019). In 2020, as in previous years, concentrations decreased rapidly with distance from drill centres (Figure 5-8).

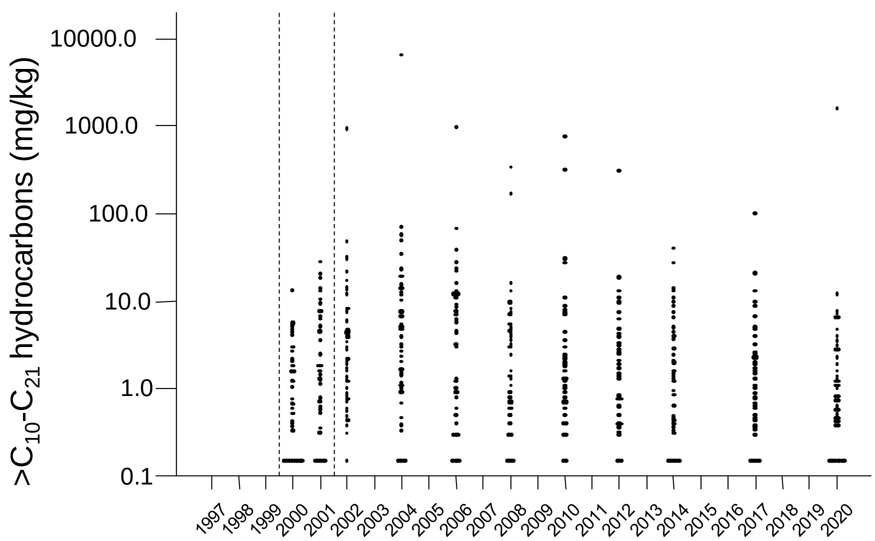


Figure 5-7 Annual Distributions for >C_{10}-C_{21} Hydrocarbon Concentrations (2000 to 2020)

Note: Dashed lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).
- Concentrations of >C_{10}-C_{21} hydrocarbons in 1997 are not shown because all were below the laboratory detection limit of 15 mg/kg used in that year. A detection limit of 0.3 mg/kg was used in subsequent years.

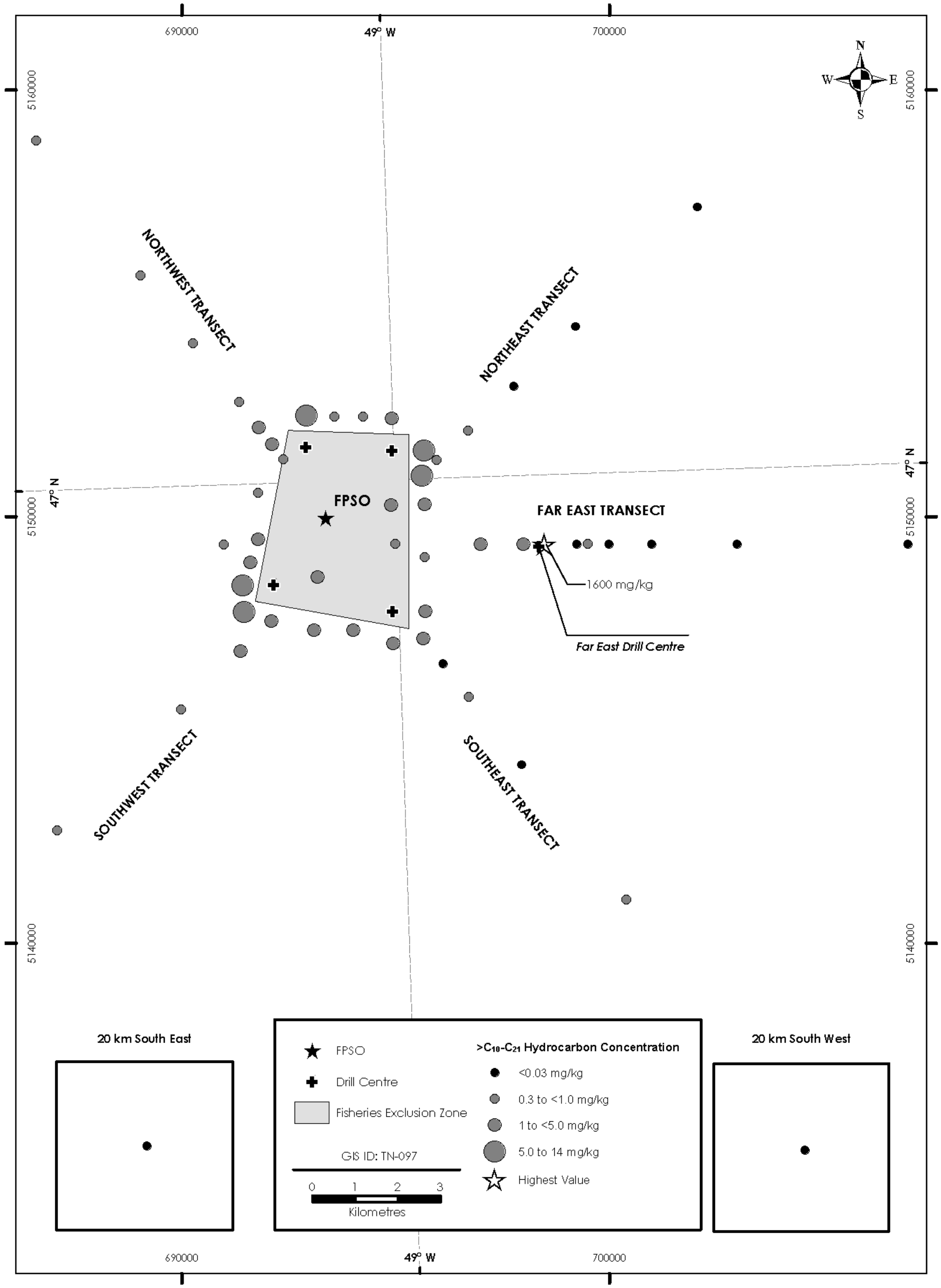


Figure 5-8 Spatial Distribution of >C_{10}-C_{21} Hydrocarbon Concentrations (2020)

Decreases of >C_{10}-C_{21} hydrocarbons with distance from the nearest drill centre (Min *d*) were significant in 2020 (Spearman rank: r_s = -0.76, p < 0.001, Table 5-5), as in previous EEM years (Figure 5-9). In 2020, the Spearman rank value for Min *d* was similar to the multiple regression of the rank of >C_{10}-C_{21} hydrocarbon concentrations on the rank of distances from the FEZ and FE drill centres (Multiple R); it was also similar to the partial correlation of >C_{10}-C_{21} hydrocarbon ranks on ranks of distances to the FEZ drill centres. The partial correlation between >C_{10}-C_{21} hydrocarbon ranks and ranks of distances to the FE Drill Centre was not significant (Table 5-5), as in previous years.

Table 5-5 Results of Rank-Rank Regression of >C_{10}-C_{21} Hydrocarbons on Distance Variables (2020)

Multiple R	**Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)**		**Min *d* (r_s)**
	FEZ *d* (FE *d* constant)	**FE *d* (FEZ *d* constant)**	
0.74* **	**-0.75*** **	0.04	**-0.76*** **

Note: -*p ≤ 0.05; **p ≤ 0.01; ***p ≤ 0.001 (in **bold**)
- n=53

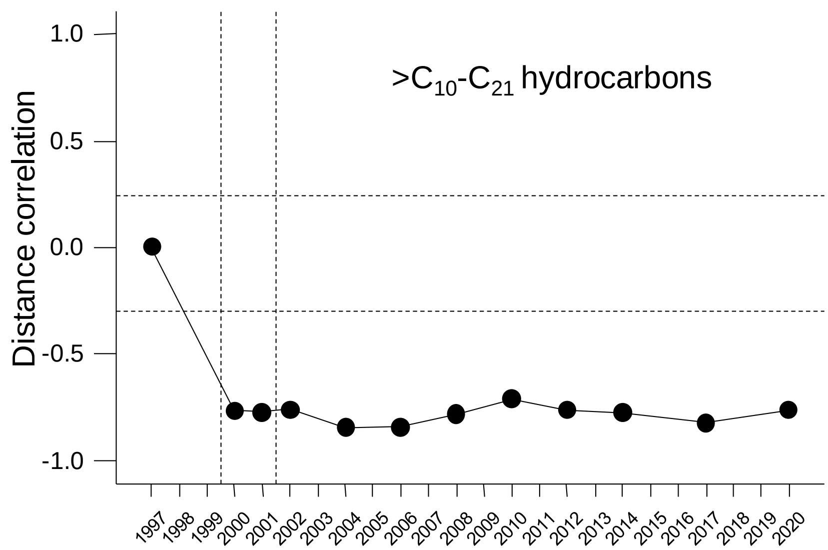


Figure 5-9 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for >C_{10}-C_{21} Hydrocarbons (1997 to 2020)

Notes: The horizontal dashed line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at p ≤ 0.01, depending on sample size in the given year. Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020. Distance correlations in 1997 are assumed to be zero.

Table 5-6 provides results of bivariate and hockey-stick models for $\log_{10}$ >C_{10}-C_{21} hydrocarbon concentrations versus $\log_{10}$ Min *d*. Bivariate models and the addition of a threshold in hockey stick models have been significant in all years since 2004. The fitted line in Figure 5-10 shows the hockey-stick model for 2020. In 2020, the estimated threshold distance (zone of influence) for >C_{10}-C_{21} hydrocarbons was 2.0 km, with a 95% Confidence Interval (CI) of 1.5 to 2.7 km. Since CIs overlapped, the 2020 threshold is not statistically different from the threshold distances that were computed from 2008 to 2017. However, the threshold distance in 2020 is smaller than those computed in 2004 and 2006 (Table 5-6).

Table 5-6 Distance Relationships and Thresholds for >C_{10}-C_{21} Hydrocarbons (2000 to 2020)

Year	*r* bivariate	*R* hockey-stick	*p* threshold	Threshold distance (km)	95% CI (km)
2000	-0.761***	0.772	0.175	Not estimated	
2001	-0.798***	0.802	0.414	Not estimated	
2002	-0.785***	0.792	0.215	Not estimated	
2004	-0.845***	0.872	0.003	4.6	2.9 to 7.1
2006	-0.868***	0.891	0.003	5.2	3.4 to 7.9
2008	-0.782***	0.833	**<0.001**	2.5	1.8 to 3.5
2010	-0.714***	0.752	0.014	2.8	1.7 to 4.6
2012	-0.764***	0.810	0.001	2.4	1.7 to 3.4
2014	-0.755***	0.785	0.020	4.5	2.4 to 8.4
2017	-0.796***	0.711	0.002	3.0	2.1 to 4.4
2020	-0.715***	0.666	**<0.001**	2.0	1.5 to 2.7

Notes:
- *$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in **bold**).
- Distance (*X*) is distance from the nearest active drill centre (Min *d*).
- Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020.
- Distance (*X*) and *Y* variables were log-transformed.
- *n* = 49 stations in 2000 and 2001; 53 stations in 2002; 52 stations in 2004; and 53 stations from 2006 to 2020.
- Not estimated = threshold was not estimated because p >0.05 for adding the threshold.

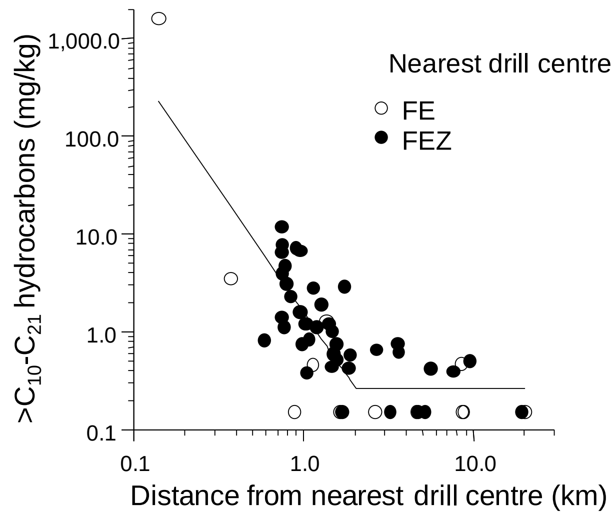


Figure 5-10 Distance Gradient for >C_{10}-C_{21} Hydrocarbons (2020)

The relationship between >C_{10}-C_{21} hydrocarbons and distance to the FE Drill Centre was visually apparent in Figure 5-10, but this is largely because of high concentration at Station 30(FE) and, to a lesser extent, at Station 31(FE). The influence of Stations 30(FE) and 31(FE) was reduced in rank-rank regressions (partial r_s only 0.04 (Table 5-5)), which indicates that, other than at those two stations, the FE Drill Centre had a minor influence on >C_{10}-C_{21} hydrocarbons concentrations. In contrast, rank-rank regression indicated a stronger influence from the FEZ drill centres (partial r_s = -0.75 (Table 5-5)). There were several stations with elevated >C_{10}-C_{21} hydrocarbons within 2 km of the FEZ drill centres and a more continuous distance gradient for stations near the FEZ (Figure 5-10).

Results of repeated-measures regression for >C_{10}-C_{21} hydrocarbons are provided in Table 5-7. Appendix B-5 provides details on how the analysis is carried out and interpreted. Briefly, the Among Stations terms test relationships between multi-years means and the two distance measures (FEZ *d* and FE *d*). The Within-Stations terms test for variations in distance regression intercepts (Year terms) or slopes (Year × FE *d* term, or Year x FEZ *d* term) among all years. Significant Year terms (i.e., intercepts) indicate that *Y* values on average varied significantly over time, and generally represent natural large-scale changes, and less so project effects. Significant variations in distance slopes (i.e., distance gradients) over time could represent either natural or project effects.

The Before-vs-After FE Drilling, Linear and Quadratic Trend contrasts represent independent tests of more specific changes. The Linear and Quadratic Trend contrasts test whether distance slopes varied over time in a linear or quadratic fashion. The specific contrasts can be interpreted (and may be statistically significant) even if the overall within-stations term test is not-significant (and thus provides additional certainty that the analysis will detect change when it occurs). Here and in the sections that follow, the specific contrasts are interpreted, and the within-stations terms are discussed if the specific contrasts are not significant.

Table 5-7 Results (F Values) of Repeated-Measures Regressions Comparing >C_{10}-C_{21} Hydrocarbon Concentrations Among EEM Years (2000 to 2020)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 & 2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
FEZ *d*	**109.1*** **				
FE *d*	0.0				
Year		**11.4*** **	8.5**	**50.1*** **	0.4
Year x FEZ *d*		2.0*	0.1	2.5	0.4
Year x FE *d*		**4.2*** **	8.6**	2.1	0.5

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- *n* = 48 stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Distance variables (*X*) and *Y* variables were rank-transformed.
- See Appendix B-5 for description and interpretation of terms in the repeated-measures regression models.
- *F values* were rounded to one decimal place.

The overall distance slope from the nearest FEZ drill centre was highly significant ($F = 109.1$, $p \leq 0.001$, Table 5-7), and negative (Figure 5-11). A negative slope indicates a decrease in >C_{10}-C_{21} hydrocarbons with distance from the FEZ drill centres over all EEM years. Distance slopes from the FEZ drill centres varied among years ($F = 2.0$, $p \leq 0.05$), with slopes generally weaker (less negative) from 2008 to 2020 (Figure 5-11). The overall distance slope from the FE Drill Centre was not significant ($F = 0.0$, $p > 0.05$, Table 5-7), suggesting a stronger influence from the FEZ drill centres. Distance slopes from the FE Drill Centre varied over time ($F = 4.2$, $p < 0.001$), with slopes positive prior to drilling at the drill centre and slightly negative or near zero after drilling began ($F = 8.6$, $p \leq 0.01$; Figure 5-10). This change likely resulted from an increase in >C_{10}-C_{21} hydrocarbon concentrations in the immediate vicinity of the FE Drill Centre (i.e., stations 30(FE) and 31(FE)) after drilling began. As noted above, there were changes in overall >C_{10}-C_{21} hydrocarbon concentrations over time ($F = 50.1$, $p \leq 0.001$), with overall levels generally decreasing from 2002 to 2020 (Figure 5-7).

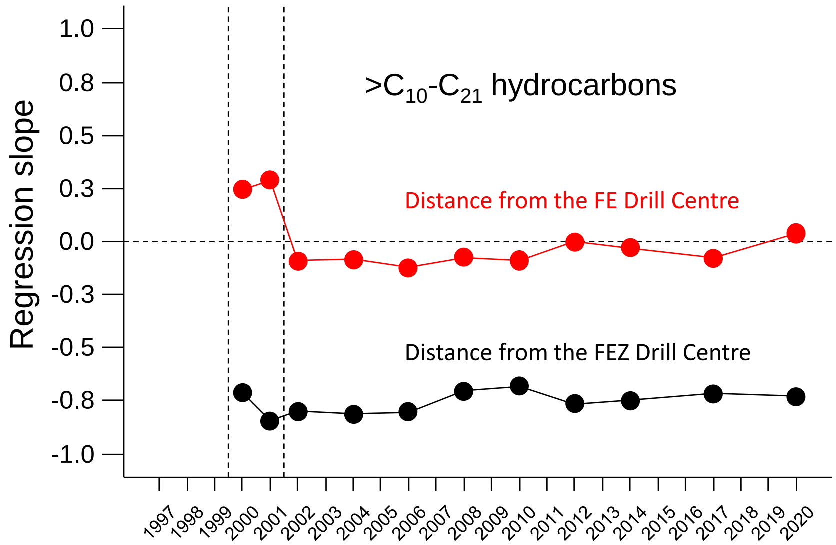


Figure 5-11 Annual Multiple Regression Distance Slopes for >C_{10}-C_{21} Hydrocarbons (2000 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

5.3.1.2 Barium

Annual variations in barium concentrations among years are shown in Figure 5-12. Median barium concentrations increased from 120 mg/kg in the baseline year (1997) to between 130 and 170 mg/kg between 2000 and 2020 (Appendix B-2). In 2020, median barium concentration was 130 mg/kg. The maximum barium concentration over all years (16,000 mg/kg) occurred in 2006 (Figure 5-12), at Station 30(FE), located 0.14 km from the FE Drill Centre. The highest concentration in 2020 (3,900 mg/kg) also occurred at Station 30(FE).

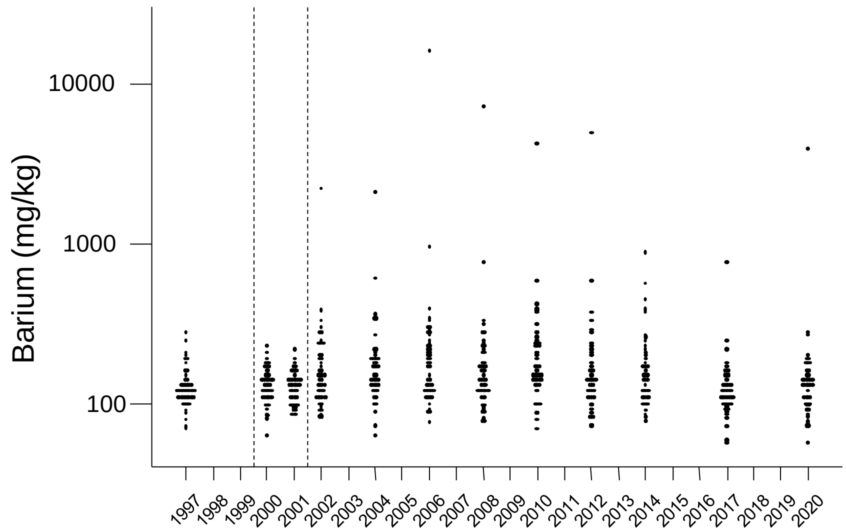


Figure 5-12 Annual Distributions for Barium Concentrations (1997 to 2020)

Note: Dashed lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

As was the case with >C_{10}-C_{21} hydrocarbons, barium concentrations decreased with distance from drill centres, although that decrease is less apparent from Figure 5-13 than it has been in previous years. For interpretation of results in Figure 5-13, barium concentrations less than 200 mg/kg can be considered within the background range and below the estimated upper 95th percentile of baseline concentrations (based on an arithmetic mean plus two standard deviations)[21]. Concentrations between 200 and 300 mg/kg can be considered elevated above background, although still near the maximum concentration (280 mg/kg) observed in baseline. Concentrations above 300 mg/kg can be considered outside the background range and evidence of contamination from drill cuttings discharges.

Barium concentrations decreased significantly with Min *d* in 2020 (r_s = -0.53, $p \leq 0.001$; Table 5-8). The negative correlation reflects higher concentrations of barium in sediments near drill centres. The Spearman rank value for Min *d* was greater than the correlation for the multiple regression of barium on distances from the FEZ and FE drill centres, and for the partial correlations of barium on distances to the FEZ or FE drill centres. The correlation for the multiple regression and the partial correlation on distances to the FEZ drill centres were significant. The partial correlation on distance from the FE Drill Centre was not significant (Table 5-8), indicating a greater influence from the FEZ drill centres.

[21] The 95% percentile for baseline values was 208 mg/kg, rounded to 200 mg/kg for Figure 5-13.

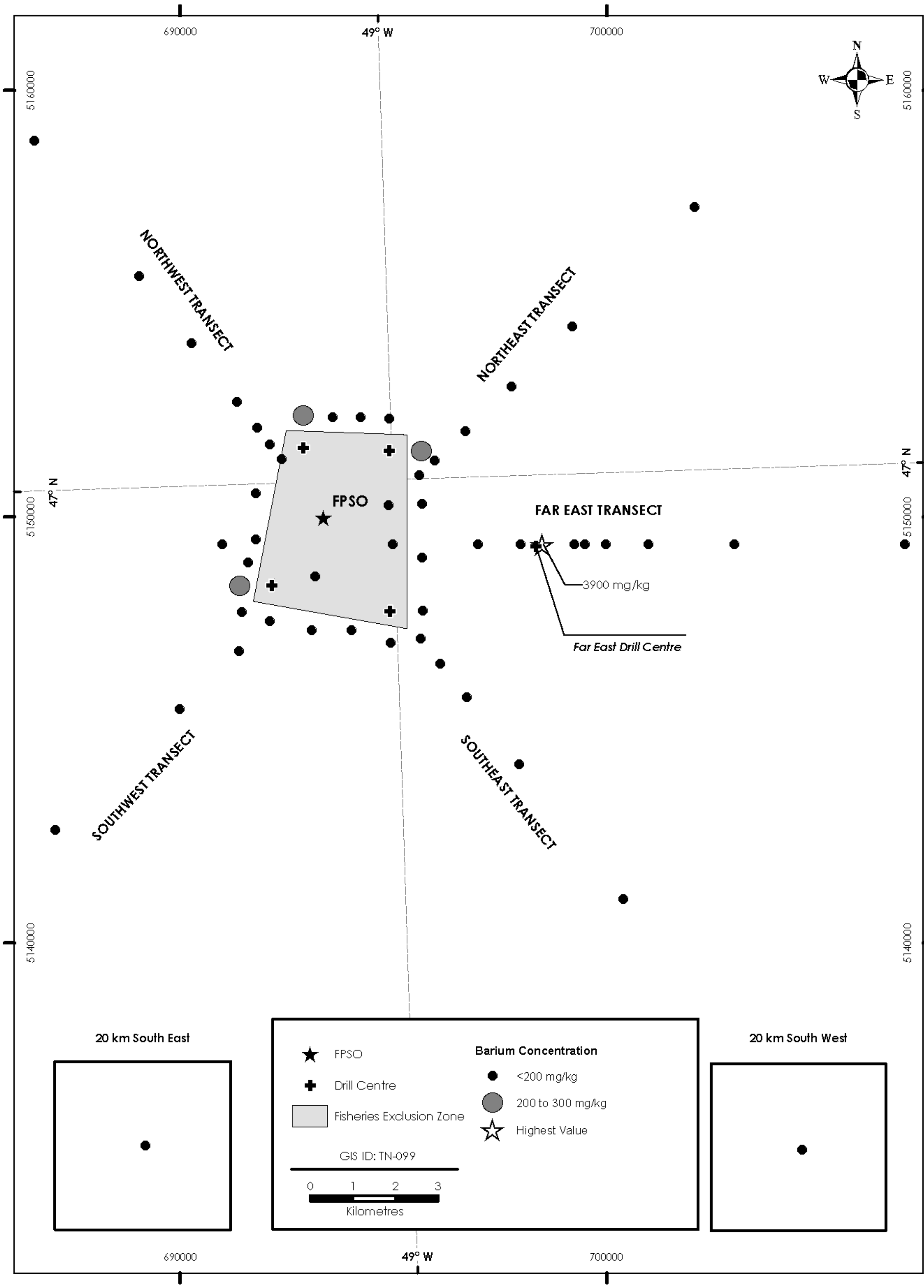


Figure 5-13 Spatial Distribution of Barium Concentrations (2020)

Table 5-8 Results of Rank-Rank Regression of Barium on Distance Variables (2020)

Multiple R	Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)		Min *d* (r_s)
	FEZ *d* (FE *d* constant)	FE *d* (FEZ *d* constant)	
0.48**	-0.49***	0.05	**-0.53*** **

Note: -*$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in **bold**).
- *n* = 53

In 1997 (baseline), barium concentrations decreased with distance from the nearest future drill centre, although that baseline distance gradient was weak, with a Spearman rank correlation of $r_s = -0.26$ ($p > 0.05$). Barium distance correlations progressively increased in strength from 2000 to 2006 and have generally decreased slightly in strength since then (Figure 5-14).

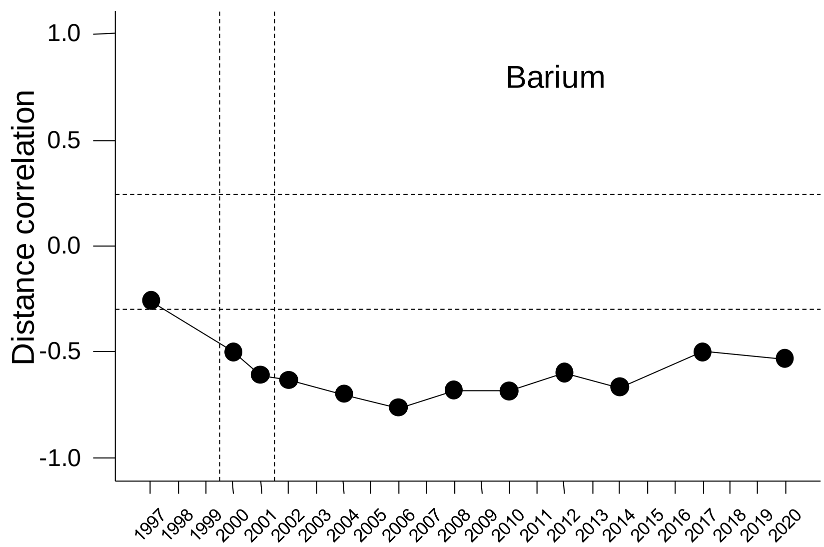


Figure 5-14 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Barium (1997 to 2020)

Notes: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \le 0.01$, depending on sample size in the given year. Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020. The NE and SW drill centres were considered active for 1997 (baseline).

Table 5-9 provides results of bivariate and hockey-stick models for $\log_{10}$ barium concentrations versus $\log_{10}$ Min *d*. Bivariate models and the addition of a threshold in hockey stick models have been significant in all years since 2002. The estimated threshold distance for barium in 2020 was 1.0 km, with a 95% CI of 0.8 to 1.2 km; significantly lower than in 2002, 2010 and 2014, and similar to other EEM years where a threshold could be estimated.

Table 5-9 Distance Relationships and Thresholds for Barium (1997 to 2020)

Year	*r* bivariate	*R* hockey-stick	*p* threshold	Threshold distance (km)	95% CI (km)
1997	-0.247*	0.247	1	Not estimated	
2000	**-0.480*** **	0.48	1	Not estimated	
2001	**-0.567*** **	0.593	0.153	Not estimated	
2002	**-0.621*** **	0.739	**≤0.001**	1.8	1.3 to 2.6
2004	**-0.679*** **	0.822	**≤0.001**	1.2	1.0 to 1.5
2006	**-0.682*** **	0.894	**≤0.001**	1.1	0.9 to 1.2
2008	**-0.631*** **	0.868	**≤0.001**	1.0	0.9 to 1.2
2010	**-0.686*** **	0.796	**≤0.001**	2.0	1.5 to 2.6
2012	**-0.577*** **	0.802	**≤0.001**	1.1	0.9 to 1.3
2014	**-0.648*** **	0.711	0.008	2.7	1.6 to 4.7
2017	**-0.496*** **	0.590	**≤0.001**	1.2	0.9 to 1.4
2020	**-0.505*** **	0.662	**≤0.001**	1.0	0.8 to 1.2

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- Distance (*X*) was distance from the nearest active drill centre (Min *d*).
- Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020. The NE and SW drill centres were considered active for analysis of 1997 (baseline) data.
- Distance (*X*) and *Y* variables were log-transformed.
- *n* = 54 stations in 1997; 49 stations in 2000 and 2001; 53 stations in 2002; 52 stations in 2004; and 53 stations from 2006 to 2020.
- Not estimated = threshold was not estimated because $p > 0.05$ for adding the threshold.

A relationship between barium concentrations and distance to the FE Drill Centre is visually apparent in Figure 5-15, but this is largely because of the higher concentrations at Station 30(FE) and, to a lesser extent, at Station 31(FE). Like >C_{10}-C_{21} hydrocarbons, the influence of these stations was statistically reduced in rank-rank regressions (r_S = -0.05, Table 5-8). In contrast, there were elevated barium concentrations at more stations within approximately 1 km from FEZ drill centres (Figure 5-15).

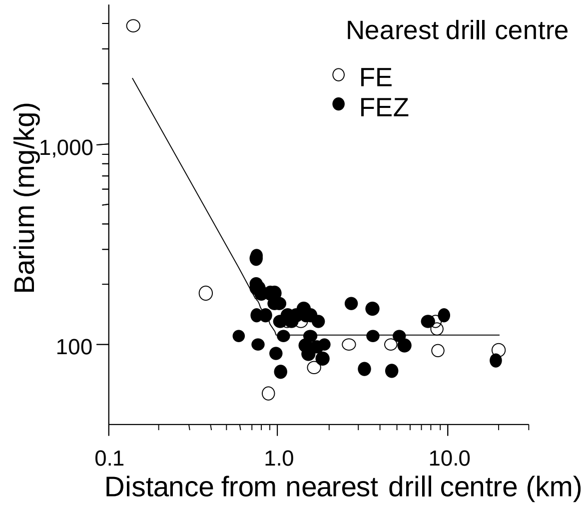


Figure 5-15 Distance Gradient for Barium (2020)

Results of repeated-measures regression for barium are provided in Table 5-10. The overall multiple regression slope for barium was stronger for the FEZ drill centres ($F = 27.7$, $p \leq 0.001$) than it was for the FE Drill Centre ($F = 0.6$ and not significant; Table 5-10; also see Figure 5-16); again, suggesting a stronger influence from the FEZ drill centres. Across years, overall barium concentrations increased to 2006 and then decreased ($F = 20.8$, $p \leq 0.001$, Figure 5-12 and Appendix B-2). There were variations in FEZ distance slopes among EEM years ($F = 2.2$, $p \leq 0.05$), with slopes generally decreasing in strength over time (Figure 5-16). Similar to what was seen for >C_{10}-C_{21} hydrocarbons, distance slopes from the FE Drill Centre were generally more negative after drilling started at the FE Drill Centre ($F = 4.7$, $p \leq 0.05$, Figure 5-16); although the slope for 2020 is similar to those noted before drilling started at the FE Drill Centre (Figure 5-16).

Table 5-10 Results (F Values) of Repeated-Measures Regressions Comparing Barium Concentrations Among EEM Years (2000 to 2020)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 & 2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
FEZ *d*	**27.7***				
FE *d*	0.6				
Year		**11.1***	**17.4***	**27.4***	**20.8***
Year x FEZ *d*		2.2*	1.1	3.1	1.0
Year x FE *d*		2.2*	4.7*	1.8	2.3

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- $n = 48$ stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Distance variables (X) and Y variables were rank-transformed.
- *F values* were rounded to one decimal place.

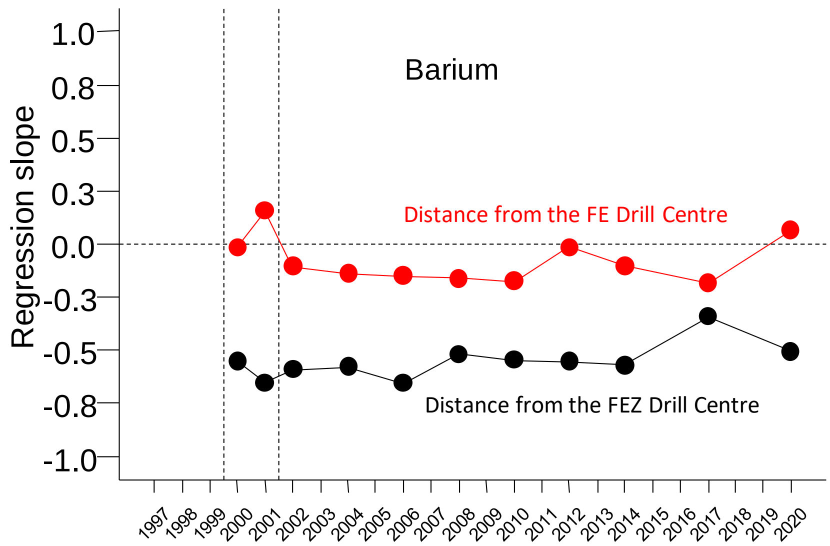


Figure 5-16 Annual Multiple Regression Distance Slopes for Barium (2000 to 2020)

Notes: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

5.3.1.3 Sediment Particle Size

Sediments in 2020 were predominantly sand, with median sand content of approximately 92% (Appendix B-2; Figure 5-17). Fines (silt + clay) content was generally low (median = 1.4%; range 0.7% to 3.4%). Gravel content varied widely, from 0% to approximately 30%, with a median of 7.1% (Appendix B-2; Figure 5-17).

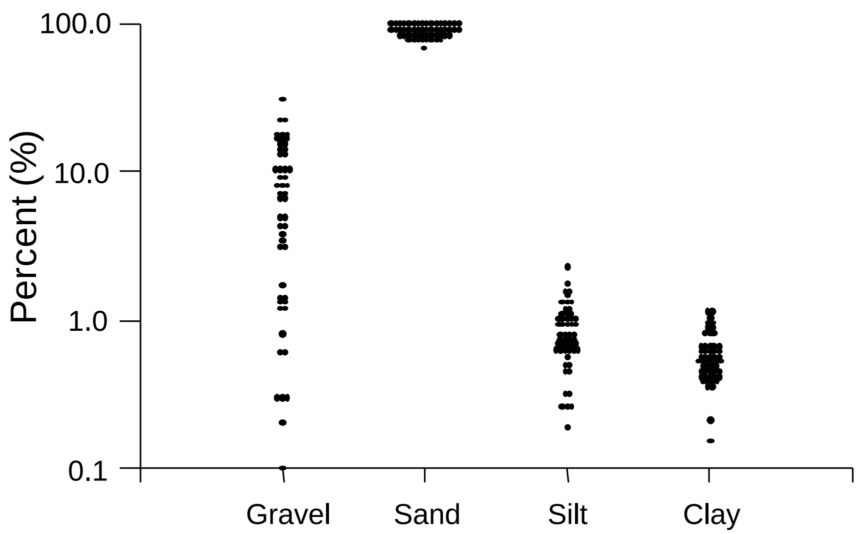


Figure 5-17 Distribution of Values for Four Particle Size Categories (2020)

Sand and gravel content were strongly negatively correlated because gravel was the major "non-sand" component of the sediments (Table 5-11). Because of these correlations, sand content was not included in further analyses.

Table 5-11 Spearman Rank Correlations (r_S) Among Sediment Particle Size Categories (2020)

	% fines	**% sand**
% sand	-0.414**	
% gravel	0.332*	**-0.992*** **

Note: -*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- $n = 53$

Among years, fines have generally accounted for between 1% and 3% of sediments, while gravel content has varied between trace amounts to upwards of approximately 10% to 30% of sediment grains (Figure 5-18).

In 2020, the Spearman rank correlation between % fines and Min *d* was not significant (r_S = -0.15, p > 0.05; Table 5-12; also see Figure 5-19); nor were the overall multiple correlation coefficient (R = 0.19, p > 0.05) and partial correlations with distance to the FEZ and FE drill centres (Partial *r*'s = -0.03 and -0.18, respectively, p > 0.05). Percent fines have generally decreased with distance from drill centres in all years, including baseline, and correlations were relatively strong and significant in 2000, 2006, 2010, and 2017 (Figure 5-20).

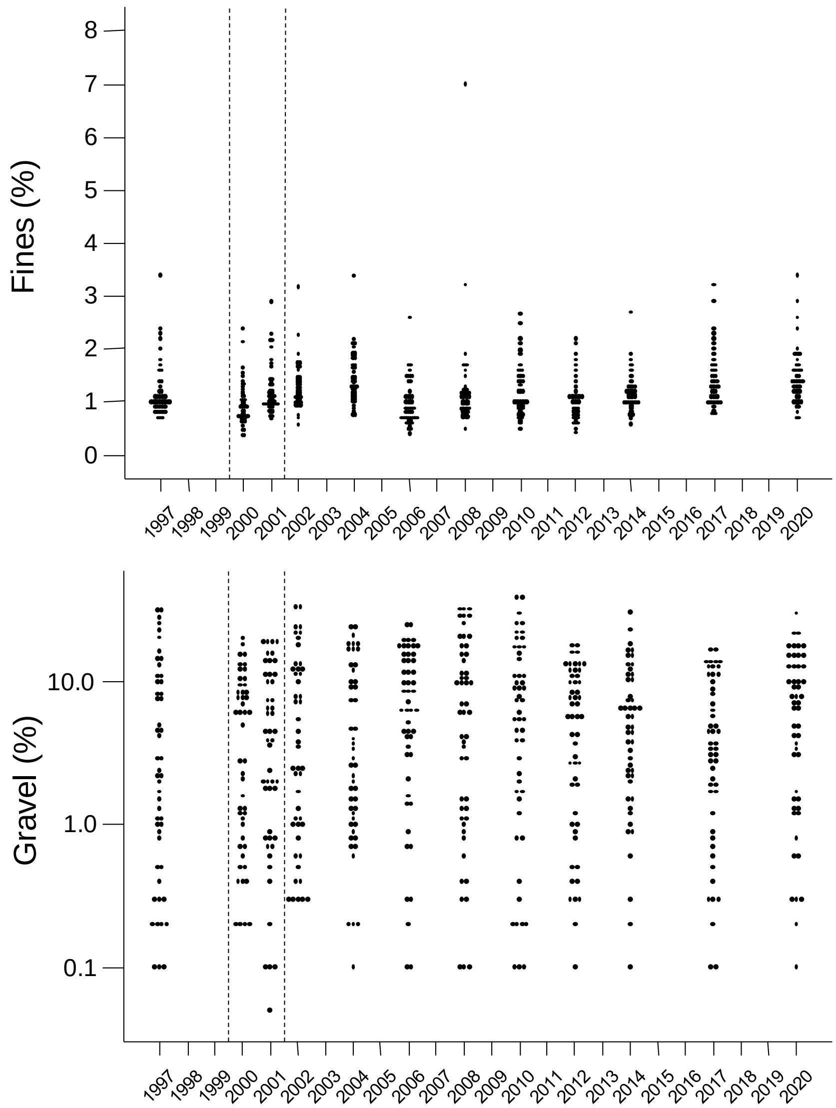


Figure 5-18 Annual Distributions for Fines and Gravel Content (1997 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

Table 5-12 Results of Rank-Rank Regression of Fines and Gravel on Distance Variables (2020)

Response Variable	**Multiple R**	**Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)**		**Min *d* (r_s)**
		FEZ *d* (FE *d* constant)	**FE *d* (FEZ *d* constant)**	
Fines	0.19	-0.03	-0.18	-0.15
Gravel	0.23	0.02	-0.23	-0.17

Note: -**p* ≤ 0.05; ***p* ≤ 0.01; ****p* ≤ 0.001 (in **bold**).
- *n*=53

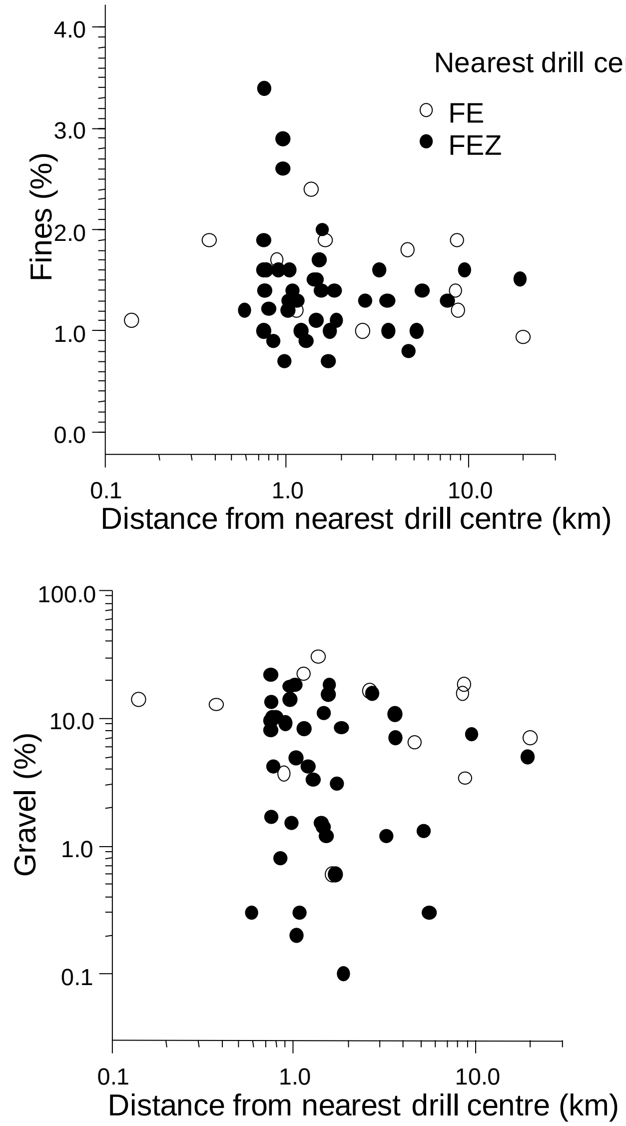


Figure 5-19 Distance Gradients for Fines and Gravel Content (2020)

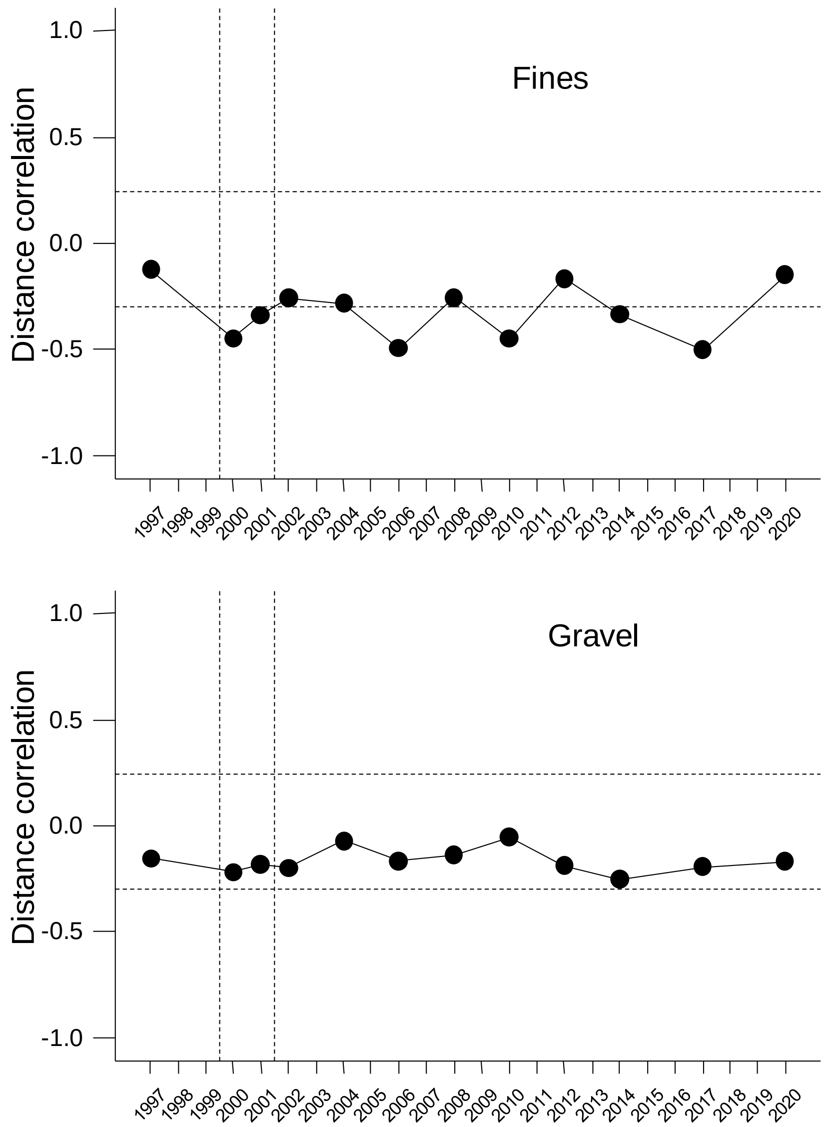


Figure 5-20 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Fines and Gravel Content (1997 to 2020)

Notes: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020. The NE and SW drill centres were considered active for 1997 (baseline).

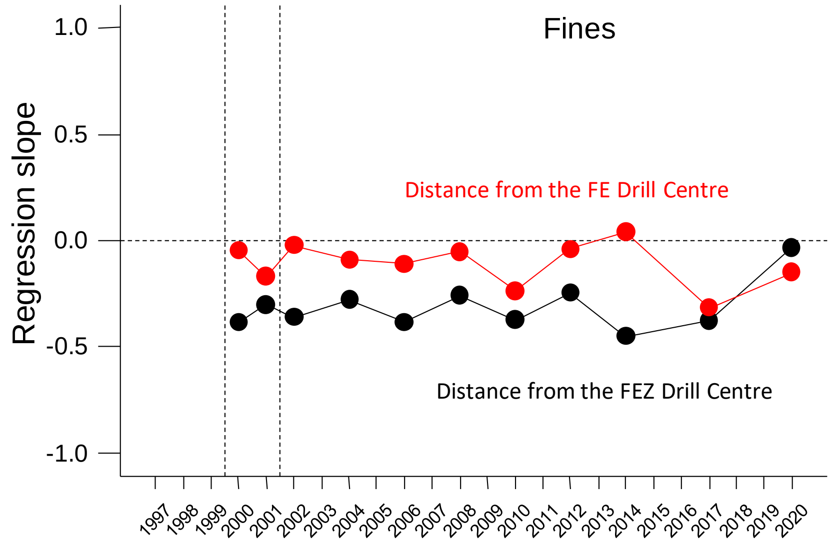
Percent gravel was also not significantly correlated with distance measures in 2020 (Table 5-12; all *p*'s > 0.05). The relationship between % gravel and Min *d* in 2020 and across years is illustrated in Figures 5-19 and 5-20, respectively. These figures show no visually and obviously strong association between gravel content in sediments and proximity to a drill centre.

Table 5-13 provides results of repeated-measures regression analyses for sediment fines and gravel content. The overall FEZ distance slope for fines content was significant ($F = 10.5$, $p \leq 0.01$), with fines content decreasing with increasing distance from the FEZ drill centres in every year including baseline (the slope from the FEZ drill centres in baseline (1997) was -0.33). Although the slope from the FEZ drill centres was weaker in 2020 (Figure 5-21), FEZ distance slopes did not vary significantly among EEM years, did not differ from before to after drilling at the FE Drill Centre, and did not vary in a linear or quadratic fashion between 2002 and 2020. The overall FE distance slope for fines was not significant, the FE distance slopes did not vary among years, did not vary from before to after drilling started at the FE Drill Centre, and did not vary in a linear or quadratic fashion between 2002 and 2020. There were changes in overall fines levels over EEM years ($F = 4.2$, $p \leq 0.001$; Figure 5-18), and fine levels were somewhat higher in earlier and later EEM years, and somewhat lower from 2006 to 2012 ($F = 4.6$, $p \leq 0.05$; although these subtle changes are difficult to see from Figure 5-18).

Table 5-13 Results (F Values) of Repeated-Measures Regressions Comparing Fines and Gravel Among EEM Years (2000 to 2020)

Effect	**Test**				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 & 2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
Fines					
FEZ *d*	10.5**				
FE *d*	1.4				
Year		**4.2*** **	5.0*	1.1	4.6*
Year x FEZ *d*		1.1	0.3	0.7	2.7
Year x FE *d*		1.0	0.0	0.9	0.0
Gravel					
FEZ d	1.3				
FE d	0.7				
Year		0.7	0.6	0.1	0.1
Year x FEZ d		0.5	0.2	0.3	0.0
Year x FE d		0.4	0.0	0.0	2.3

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 48 stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Distance variables (X) and Y variables were rank-transformed.
- *F values* were rounded to one decimal place.



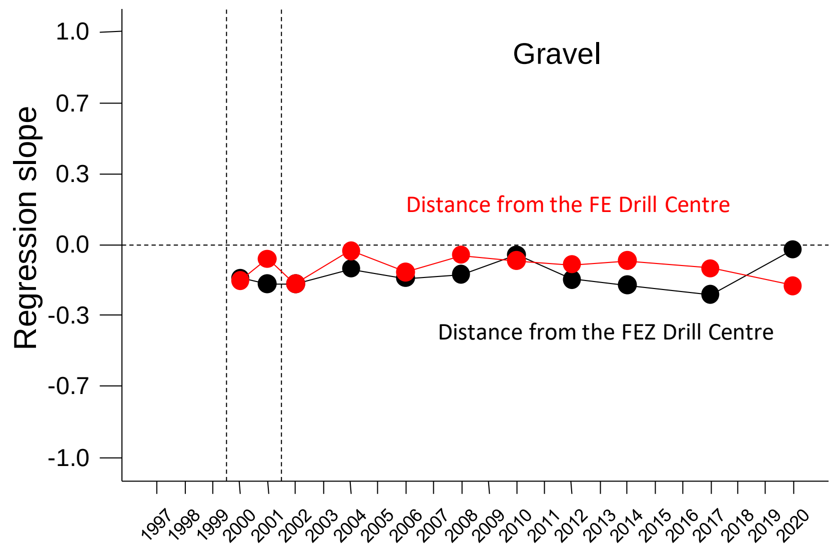


Figure 5-21 Annual Multiple Regression Distance Slopes for Fines and Gravel Content (2000 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

The overall FE and FEZ distance slopes for % gravel were not significant; FE and FEZ distance slopes did not vary among years; from before to after drilling started at the FE Drill Centre, nor did they vary in a linear or quadratic fashion between 2002 and 2020. The lack of strong distance gradients is illustrated in Figure 5-21.

5.3.1.4 Organic Carbon Content

In 2020, sediment organic content varied from <0.1 to 9.3 mg/kg, with a median of 0.9 mg/kg (Appendix B-2). Organic carbon content was more variable in 2014 (Figure 5-22) because of a difference in methodology between that year and remaining EEM years (see Suncor Energy 2017 for details).

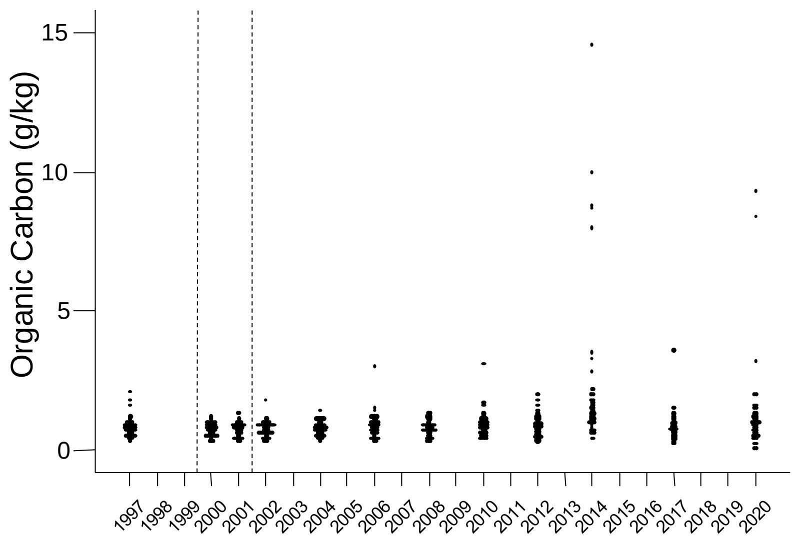


Figure 5-22 Annual Distributions for Organic Carbon Content (1997 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

The relationship between organic content and Min *d* was significant in 2020 (r_s = -0.28, $p \leq 0.05$, Table 5-14; Figure 5-23), but the multiple correlation ($R = 0.30$) was not significant ($p > 0.05$). As in previous years, the partial correlation with distance from the FEZ drill centres was stronger than the partial correlation with distance from the FE Drill Centre (partial $r = -0.30$, $p \leq 0.05$ vs $r = 0.14$, $p > 0.05$, Table 5-14). The negative partial correlation with distance from the FEZ drill centres indicates a decrease in organic carbon content from the centre of the development.

Table 5-14 Results of Rank-Rank Regression of Organic Carbon Content on Distance Variables (2020)

Response Variable	Multiple R	Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)		Min *d* (r_s)
		FEZ *d* (FE *d* constant)	FE *d* (FEZ *d* constant)	
Organic Carbon	0.30	**-0.30***	0.05	-0.28*

Note: -*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- $n = 53$.

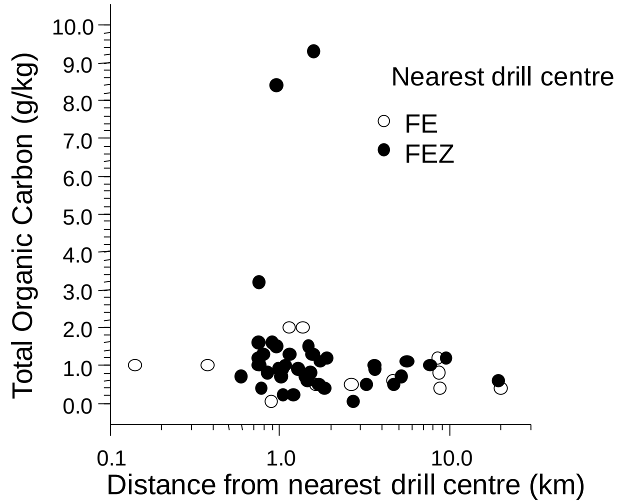


Figure 5-23 Distance Gradient for Organic Carbon Content (2020)

The relationships between Min *d* and organic carbon content were statistically significant in 1997 (baseline), 2000, 2001, 2006, 2008, 2017 and 2020 (Figure 5-24). The baseline (1997) correlation of approximately r_s = -0.4 was among the strongest distance correlation observed for those two variables.

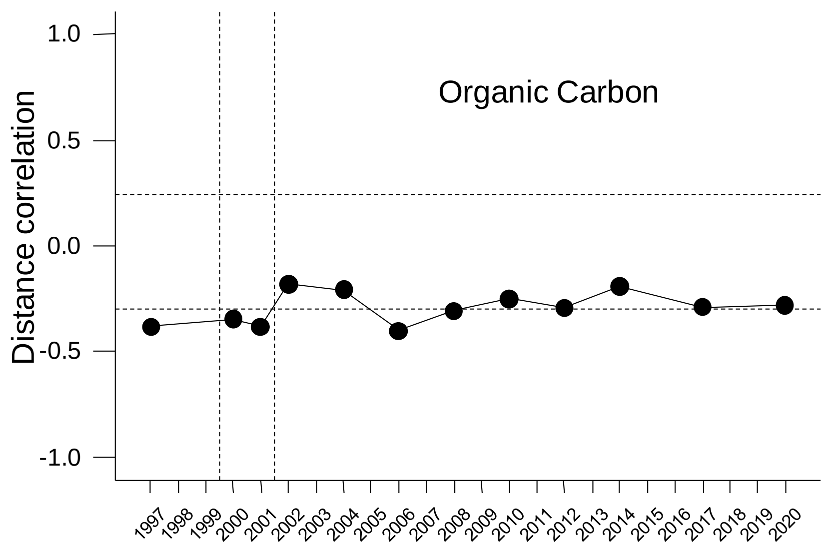


Figure 5-24 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Organic Carbon Content (1997 to 2020)

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020. The NE and SW drill centres were considered active for 1997 (baseline).

Results of repeated-measures regression for organic carbon content are provided in Table 5-15. Results in Table 5-15 excluded data from 2014 because a different analytical technique was used for total organic carbon in that year (see text above for details). Results including 2014 are provided in Appendix B-5.

Table 5-15 Results (F Values) of Repeated-Measures Regressions Comparing Organic Carbon Content Among EEM Years (2000 to 2020, Excluding 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 & 2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
FEZ *d*	**20.0*** **				
FE *d*	5.3*				
Year		**2.0***	6.1*	2.0	0.1
Year x FEZ *d*		1.5	0.3	2.2	0.1
Year x FE *d*		0.3	0.0	0.3	0.3

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- *n* = 48 stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Distance variables (*X*) and *Y* variables were rank-transformed.
- *F values* were rounded to one decimal place.

The overall FEZ and FE regression slopes were significant for organic carbon content ($F = 20.0$, $p \leq 0.001$; $F = 5.3$, $p \leq 0.01$, respectively), because organic carbon content decreased with distance from the FEZ drill centres and increased with distance from the FE Drill Centre in all years (Figure 5-25), including baseline (the baseline correlations were -0.47 and 0.15 for the FEZ and FE drill centres, respectively). There were significant variations in overall organic carbon levels over time ($F = 2.0$, $p \leq 0.01$ and $F = 6.1$, $p \leq 0.01$), reflecting differences in overall organic carbon content among years. These changes were subtle. Excluding 2014, median values ranged from 0.7 to 0.9 mg/kg (Appendix B-2). As would be expected, inclusion of 2014 in RM regression increased the strength of Year terms and resulted in a weakly significant difference among years for FEZ regression slopes (see Appendix B-5 for details).

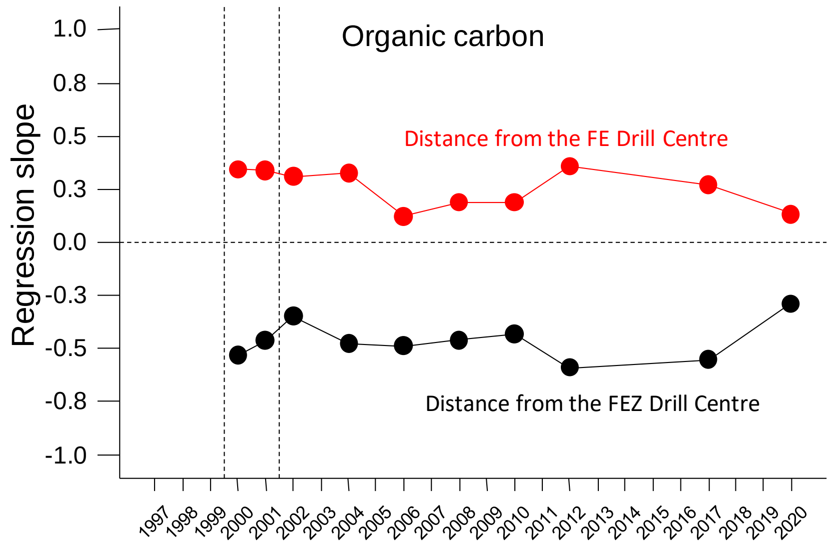


Figure 5-25 Annual Multiple Regression Distance Slopes for Organic Carbon Content (2000 to 2020, excluding 2014)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

5.3.1.5 Metals Other than Barium

A PCA of metals concentrations (excluding barium concentrations) was carried out in order to produce two proxy variables (i.e., first Principal Component (metals PC1) and Principal Component 2 (metals PC2)) that could be used to explore spatial and temporal variations in metals concentrations more efficiently.

Aluminum, iron, lead, manganese, strontium, and vanadium were detected at every station in all years. Chromium was normally detected but was at non-detect levels in two samples in 2006, three samples in 2014 and two samples in 2020. Concentrations of aluminum, chromium, iron, lead, manganese, and vanadium were positively correlated with each other and strongly correlated ($r_p \geq 0.6$) with the Metals PC1 derived from those concentrations (Table 5-16). Strontium was also weakly positively associated with Metals PC1 ($r_p = 0.56$). Metals PC1 accounted for 61% of the total variance and served as a summary measure of “total metals”. Metals PC2 accounted for 18% of the total variance and was strongly negatively correlated with strontium concentration and strongly positively correlated with manganese concentrations ($r_p = -0.62$ and 0.60, respectively). Metals PC2 was also weakly ($r_p < 0.6$) negatively correlated with aluminum and lead concentrations, and weakly positively correlated with iron and chromium concentrations. Metals PC2 scores reflected variations in metals concentrations independent of the general increase-decrease in overall metals concentrations associated with PC1. Lower Metals PC2 scores indicated higher strontium (and to a lesser extent, aluminum, and lead) levels relative to manganese (and to a lesser extent, iron, and chromium) levels.

Table 5-16 Pearson Correlations (r_p) Between Metal Concentrations and Principal Components Derived from those Concentrations (1997 to 2020)

Variable	Correlation (r_p) with Axis	
	Metals PC1	**Metals PC2**
Aluminum	**0.81**	-0.40
Chromium	**0.70**	0.20
Iron	**0.88**	0.41
Lead	**0.79**	-0.39
Manganese	**0.75**	**0.60**
Strontium	0.56	**-0.62**
Vanadium	**0.92**	0.04
Percent of Variance Explained	60.7	18.0

Notes:
- $|r_p| \geq 0.6$ in **bold.**
- Concentrations were log-transformed prior to deriving PC.
- *n = 628* stations; 54 in 1997, 49 in 2000 and 2001, 53 in 2002, 52 in 2004, and 53 in 2006, 2008, 2010, 2012, 2014, 2017 and 2020.
- PCs were retained if they explained more than 10% of the variance.

Metals PC1 scores were somewhat higher in 1997 and 2010, and somewhat lower in 2020 (Figure 5-26). Metals PC2 scores generally had similar ranges across all years of study (Figure 5-26).

The distance relationship with Min *d* for Metals PC1 was significant in 2020 (r_S = -0.34, $p \leq 0.05$; Table 5-17, also see Figure 5-27). Results indicate a stronger relationship with distance from the FEZ drill centres (partial r = 0.31, $p \leq 0.05$) than from the FE Drill Centre (partial r = -0.09, p > 0.05). Distance relationships were not significant for Metals PC2 (Table 5-17).

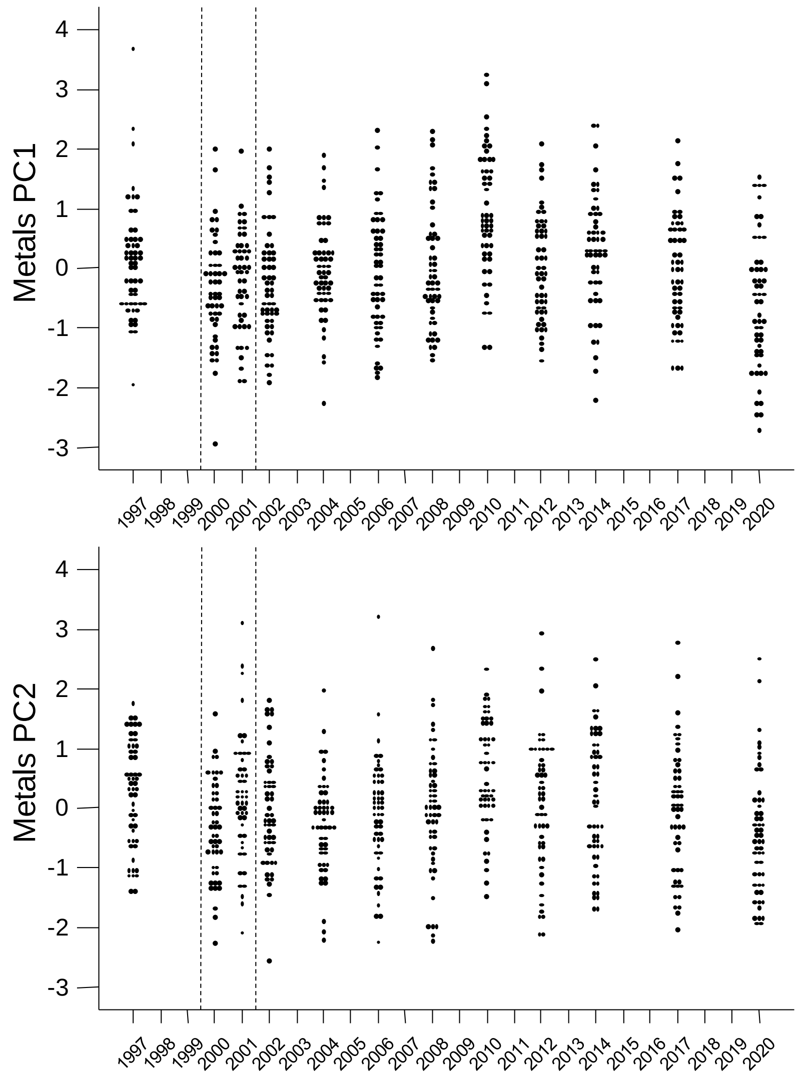


Figure 5-26 Annual Distributions for Metals PC1 and Metals PC2 (1997 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

Table 5-17 Results of Rank-Rank Regression of Metals PC1 and PC2 on Distance Variables (2020)

Response Variable	**Multiple R**	**Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)**		**Min *d* (r_s)**
		FEZ *d* (FE *d* constant)	**FE *d* (FEZ *d* constant)**	
Metals PC1	0.33	-0.31*	-0.09	-0.34*
Metals PC2	0.09	0.06	0.05	0.20

Note: -*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- $n = 53$

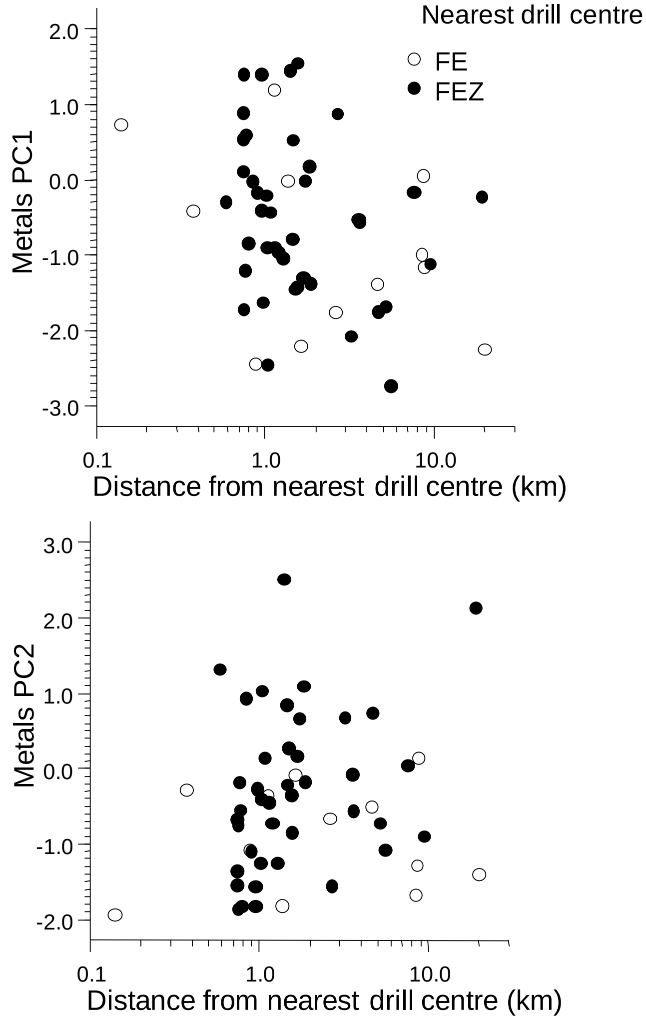


Figure 5-27 Distance Gradients for Metals PC1 and Metals PC2 (2020)

Metals PC1 scores generally decreased, though not always significantly, with Min *d* in every year, including baseline (Figure 5-28). The strongest distance correlation occurred in 2001 (r_s ~-0.6). Correlations in other EEM years varied between approximately r_s = -0.2 and -0.3. Distance correlations for Metals PC2 scores (predominantly strontium concentrations relative to manganese) were strong and positive between 2004 and 2008, and weaker (but still positive) from 1997 to 2002 and from 2010 to 2020 (Figure 5-28).

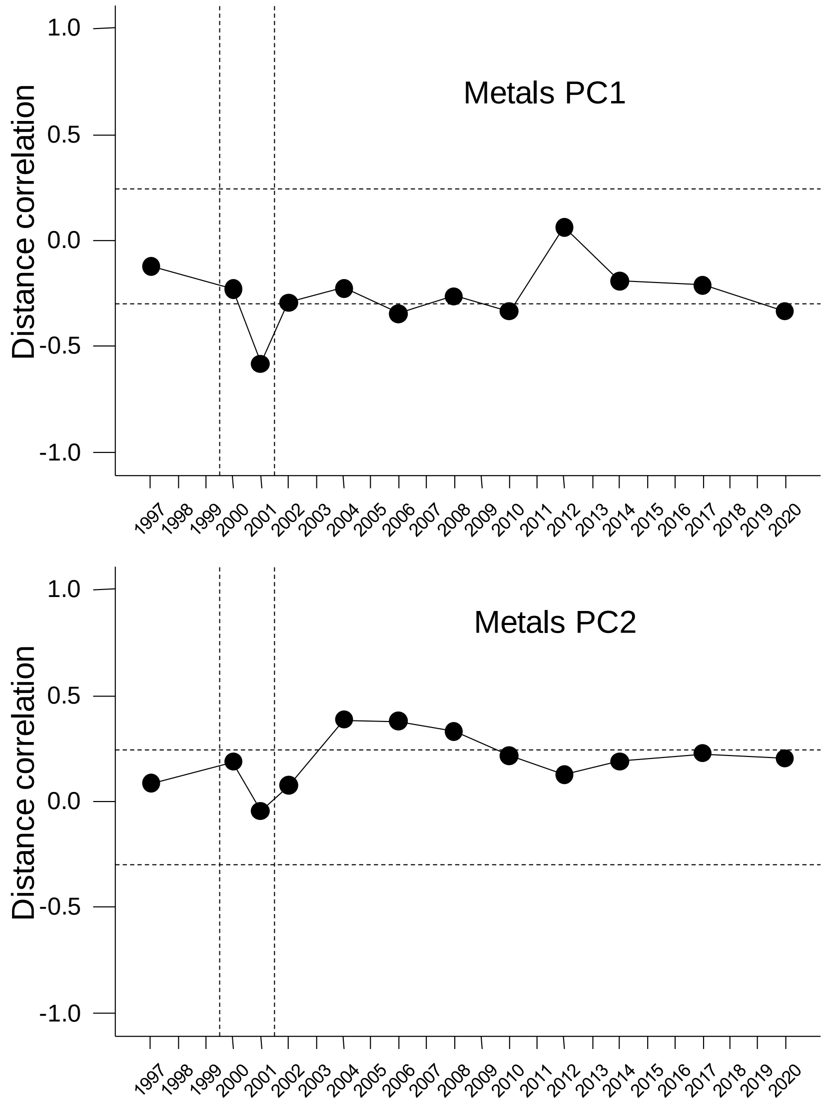


Figure 5-28 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Metals PC1 and Metals PC2 (1997 to 2020)

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020. The NE and SW drill centres were considered active for 1997 (baseline).

Results from repeated-measured regression on metals are provided in Table 5-18. Overall FEZ regression slopes were significant for Metals PC1 ($F = 8.4$, $p \leq 0.01$), consistent with the negative relationships in Figures 5-27 and 5-28. There was no change in distance slopes for Metals PC1 over time (all p's > 0.05). However, and as noted above, overall Metals PC1 scores were somewhat higher in 2010, leading to a significant quadratic term in Table 5-18 ($F = 6.3$, $p \leq 0.05$; also see Figure 5-26).

Table 5-18 Results (F Values) of Repeated-Measures Regressions Comparing Metals PC1 and Metals PC2 Among EEM Years (2000 to 2020)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 & 2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
Metals PC1					
FEZ *d*	8.4**				
FE *d*	1.6				
Year		1.5	0.3	0.0	6.3*
Year x FEZ *d*		1.2	3.8	1.0	0.0
Year x FE *d*		0.4	0.3	1.1	0.4
Metals PC2					
FEZ d	2.0				
FE d	1.5				
Year		2.6**	1.2	0.1	1.8
Year x FEZ d		1.0	1.4	0.0	0.2
Year x FE d		1.1	0.8	0.3	3.3

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- $n = 48$ stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Distance variables (X) and Y variables were rank-transformed.
- *F values* were rounded to one decimal place.

Metals PC2 scores were unrelated to any distance measures (all p's > 0.05, Table 5-18). There were minor changes in overall Metals PC2 scores among years, with scores generally lower in 2000, 2004 and 2020, and higher in 2010. Any change was subtle and not visually apparent in Figure 5-29.

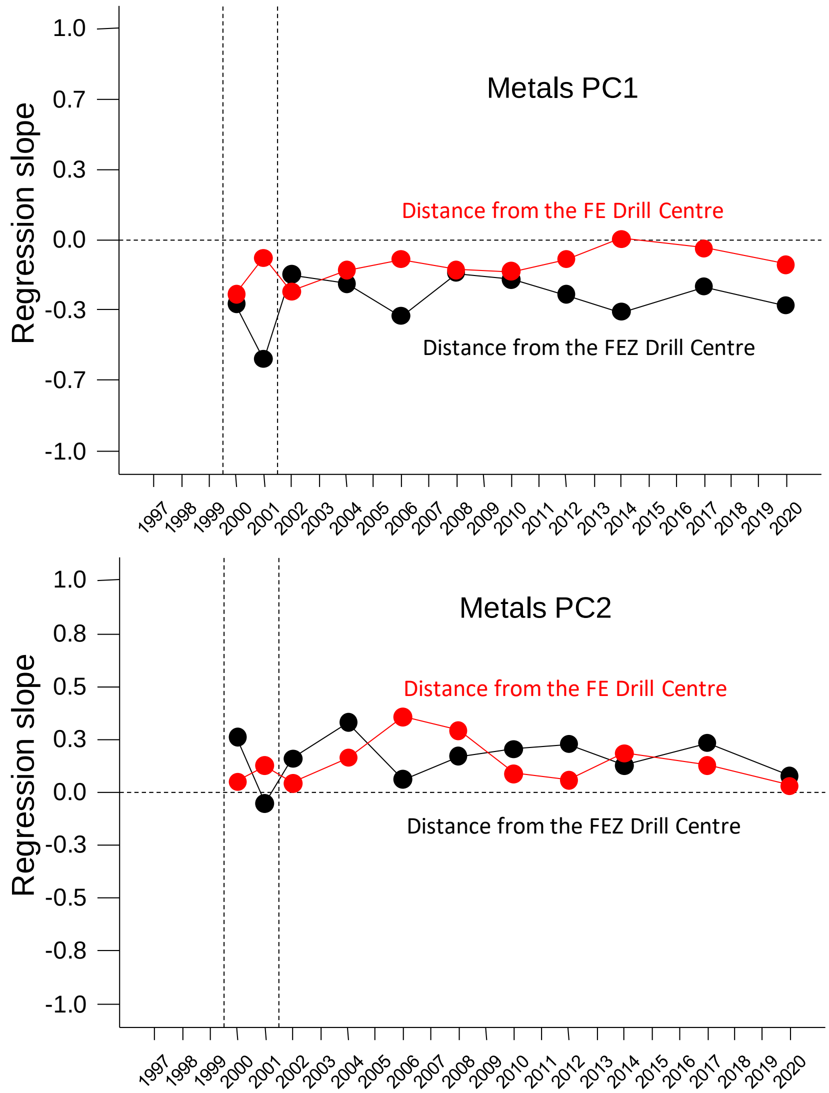


Figure 5-29 Annual Multiple Regression Distance Slopes for Metals PC1 and Metals PC2 (2000 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

5.3.1.6 Ammonia

Ammonia measurements started in 2001 at Terra Nova. Concentrations were generally higher in that year than in subsequent years (Figure 5-30).

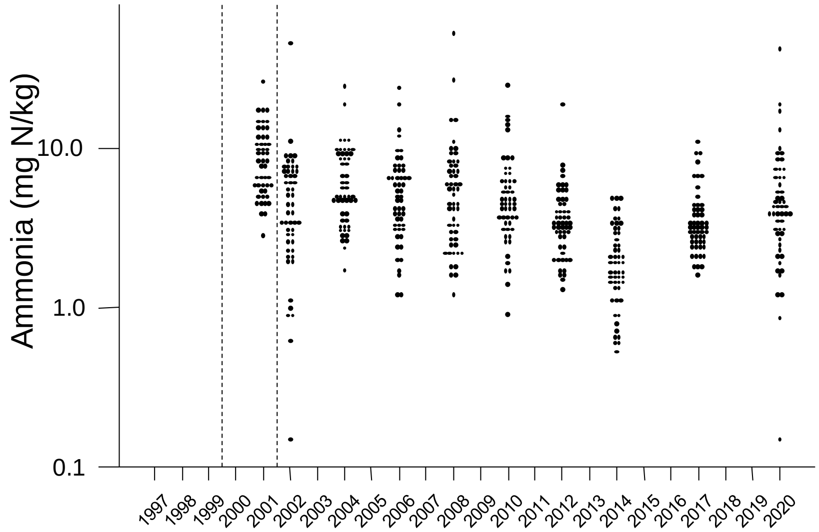


Figure 5-30 Annual Distributions for Ammonia Concentrations (2001 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

Ammonia concentrations were not significantly correlated with Min *d* in 2020 (r_S = -0.12, $p > 0.5$, Table 5-19; also see Figure 5-31). Weak, but significant, negative correlations with Min *d* were noted in 2010 and 2017 (Figure 5-32). In 2020, the distance correlation from the FEZ drill centre was negative and the correlation from the FE Drill Centre was positive, but neither correlation was significant at $p > 0.05$ (Table 5-19).

Table 5-19 Results of Rank-Rank Regression of Ammonia on Distance Variables (2020)

Response Variable	**Multiple R**	**Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)**		**Min *d* (r_s)**
		FEZ *d* (FE *d* constant)	**FE *d* (FEZ *d* constant)**	
Ammonia	0.27	-0.24	0.19	-0.12

Note: -*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- *n* = 53

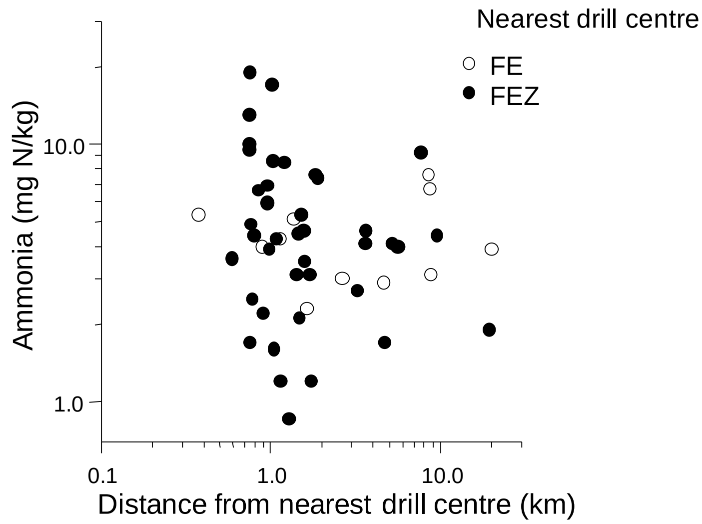


Figure 5-31 Distance Gradient for Ammonia (2020)

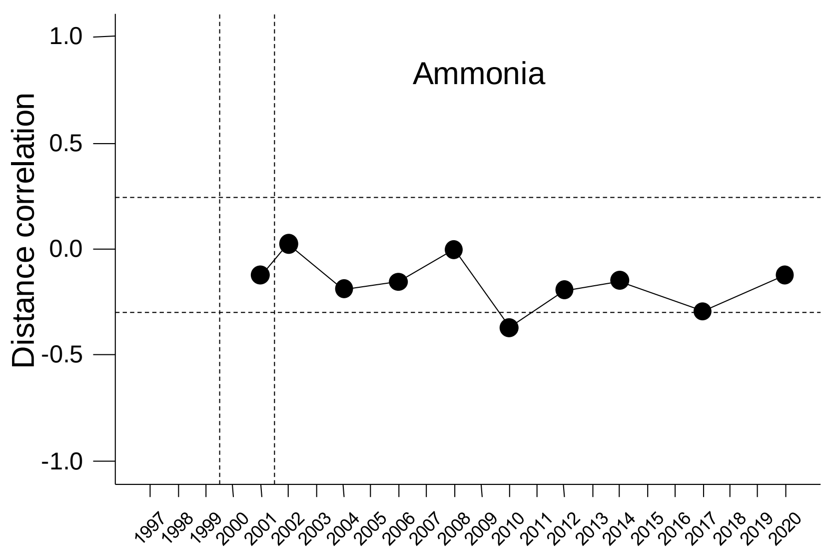


Figure 5-32 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Ammonia (1997 to 2020)

Notes: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: all FEZ drill centres in 2001; and all drill centres from 2002 to 2020.

Results from repeated-measured regression for ammonia are provided in Table 5-20. When all years were considered, overall FEZ and FE regression slopes were significant (F = 16.3, $p \leq 0.001$, F = 5.5, $p \leq 0.05$, respectively), with ammonia decreasing with distance from the FEZ drill centres and increasing with distance

from the FE Drill Centre (Figure 5-33). The negative distance slope from the FEZ drill centres was generally weaker in 2001 than in subsequent years (F = 4.5, $p \le$ 0.05) (with the exception of 2008). FE distance slopes did not vary significantly among years. Overall ammonia levels varied over time (F = 18.5, $p \le$ 0.001), with ammonia levels generally decreasing linearly from 2001 to 2020 (F = 9.4, $p \le$ 0.01; Figure
5-30).

Table 5-20 Results (F Values) of Repeated-Measures Regressions Comparing Ammonia Among EEM Years (2000 to 2020)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
FEZ *d*	**16.3*** **				
FE *d*	5.5*				
Year		**5.4*****	**18.5*****	9.4**	1.2
Year x FEZ *d*		0.8	4.5*	0.2	0.0
Year x FE *d*		0.5	0.1	1.3	0.1

Notes: - *$p \le$ 0.05; **$p \le$ 0.01; ***$p \le$ 0.001 (in **bold**).
- n = 48 stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Distance variables (X) and Y variables were rank-transformed.
- *F values* were rounded to one decimal place.

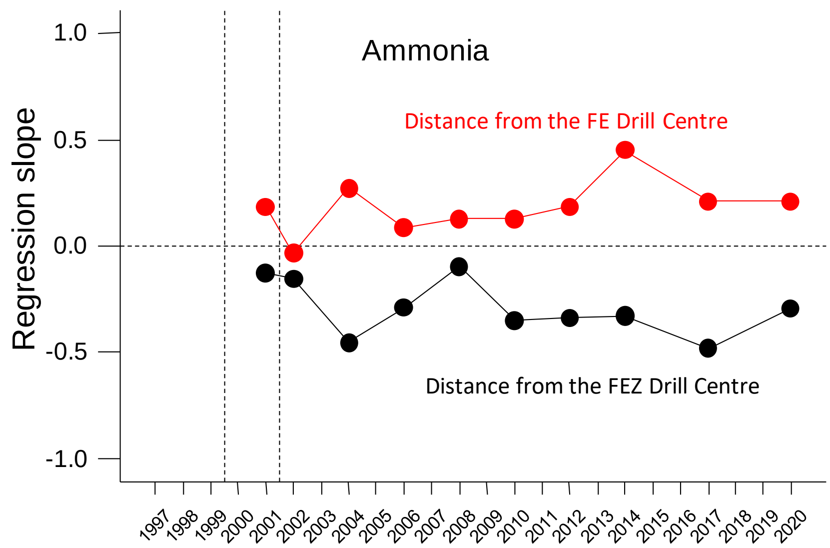


Figure 5-33 Annual Multiple Regression Distance Slopes for Ammonia (2001to 2020)

Notes: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

5.3.1.7 Redox

Redox decreased from 2000 to 2004, increased in 2006, decreased in 2008, increased in 2010, and has remained similar to 2000 levels since then (Figure 5-34). There was one extreme high value (863 mV) in 2008, at the southeast reference station (Station 6(SE)). Otherwise, most values were between 100 and 300 mV.

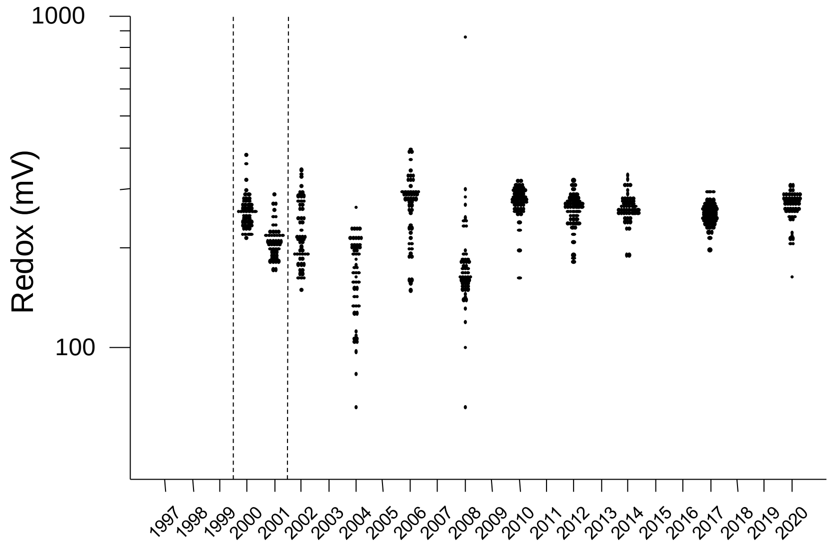


Figure 5-34 Annual Distributions for Redox (1997 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

Redox was not correlated with Min *d* in 2020 (r_s = 0.03, p > 0.05, Table 5-21; Figure 5-35). However, redox increased with distance from the FEZ drill centres; redox was lower near FEZ drill centres (partial r = 0.36, $p \leq 0.01$, Table 5-21) and decreased with distance from the FE Drill Centre; redox was higher near the FE Drill Centre (partial r = -0.60, $p \leq 0.001$). These two opposing relationships explain the lack of relationship with Min *d* overall. The increase in redox with distance from the FEZ drill centres is not visually apparent in Figure 5-35. The decrease in redox from the FE Drill Centre is clearer in that figure, with a high redox value at the nearest station and a low redox value at the furthest station. However, redox values at intermediate stations are similar and in the range of 275 to 300 mV. In spite of relationships with distance from the FEZ and FE drill centres, redox values in 2020 varied over a narrow range, were similar to redox values noted since 2010, as well as in baseline (Figure 5-34) and all sediments were oxic (>100 mV).

Table 5-21 Results of Rank-Rank Regression of Redox on Distance Variables (2020)

Response Variable	Multiple R	Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)		Min *d* (r_s)
		FEZ *d* (FE *d* constant)	FE *d* (FEZ *d* constant)	
Redox	**0.64*** **	0.36**	**-0.60*** **	0.03

Note: -*$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in **bold**).
- $n = 53$

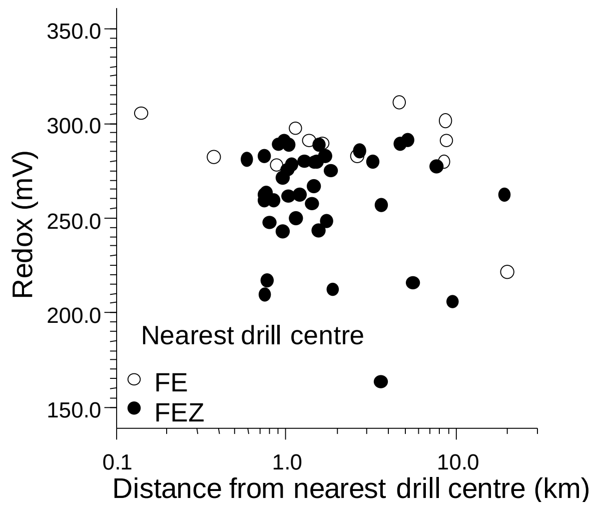


Figure 5-35 Distance Gradient for Redox (2020)

Significant positive correlations between redox and Min *d* have occurred in 2000, 2002, 2004, and 2014 (Figure 5-36).

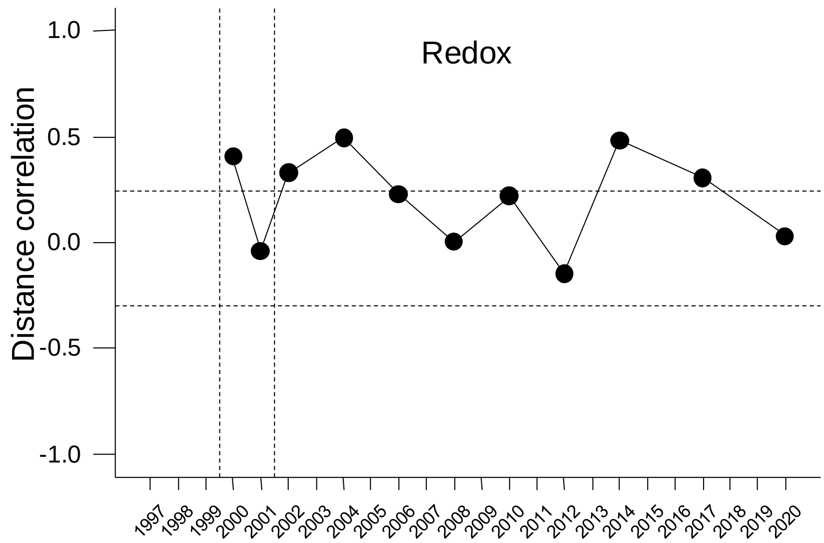


Figure 5-36 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Redox (2000 to 2020)

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020. The NE and SW drill centres were considered active for 1997 (baseline).

Results of repeated-measured regression for redox are provided in Table 5-22. The overall regression slopes for redox from the FEZ drill centres was significant (positive; $F = 48.3$, $p \leq 0.001$), indicating a general increase in redox with distance from the FEZ drill centres. The FEZ regression slopes varied over time (most Year x FEZ *d* terms highly significant in Table 5-22). The predominant change over time was a decrease in FEZ regression slopes from 2002 to 2012, with an increase in slopes since then ($F = 22.0$, $p \leq 0.001$, Figure 5-37).

Table 5-22 Results (F Values) of Repeated-Measures Regressions Comparing Redox Among EEM Years (2000 to 2020)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 & 2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
FEZ *d*	**48.3*** **				
FE *d*	3.6				
Year		**14.6*** **	1.9	**90.4*** **	0.7
Year x FEZ *d*		**6.2*** **	1.4	**13.1*** **	**22.0*** **
Year x FE *d*		**5.0*** **	0.6	0.9	**23.5*** **

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- $n = 48$ stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Distance variables (*X*) and *Y* variables were rank-transformed.
- *F* values were rounded to one decimal place.

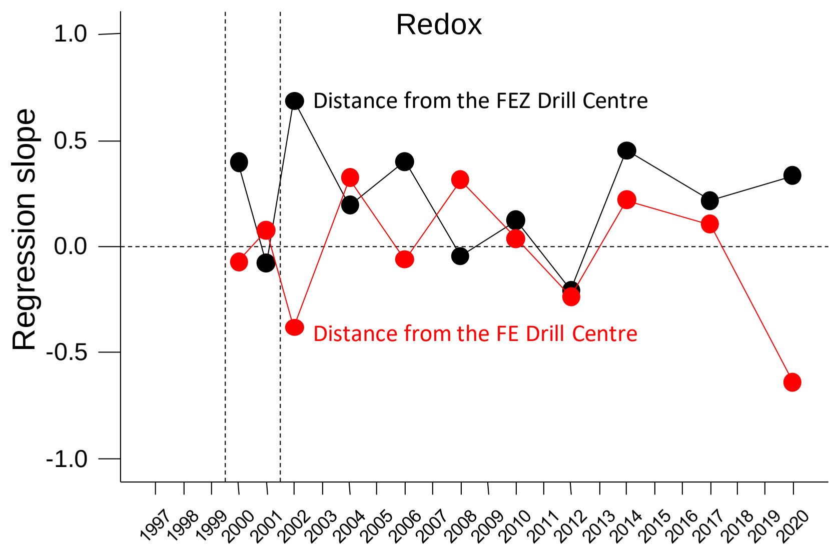


Figure 5-37 Annual Multiple Regression Distance Slopes for Redox (2000 to 2020)

Notes: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

The overall regression slope for the FE Drill Centre was not significant (Table 5-22). Regression slopes varied among years (two of four Year x FE *d* terms significant in Table 5-22). Regression slopes from the FE Drill Centre have been highly variable, sometimes positive, sometime negative (Figure 5-37). However, FE regression slopes did not vary from before to after drilling started at the FE Drill Centre. Regressions slopes from the FE Drill Centre were generally stronger in 2002 and 2020 than in intervening years (Figure 5-36), likely contributing to the significant quadratic term in Table 5-22. The strong negative slope in 2020 was likely driven by a high redox value at the station nearest the FE Drill Centre (Station 30(FE)) and a lower redox value at the station furthest away (Station 6(SE) – a Reference Station). Otherwise, remaining values near the FE Drill Centre were between 250 and 300 mV (see Figure 5-35).

Overall redox levels have varied significantly over time (both the Within Station and the Linear Trend Terms are significant in Table 5-22). The significant Linear Trend term in Table 5-22 indicates a general increase in redox levels since 2002 (although not apparent from Figure 5-34). As noted above, levels since 2010 have been similar to baseline levels.

5.3.1.8 Sulphur and Sulphide

Sulphur and sulphide were first monitored at Terra Nova in 2001, but sulphide was measured at higher laboratory detection limits from 2001 to 2004 than in subsequent years (Table 5-3) and those data are excluded from analysis. Sulphur concentrations usually have been below 0.1% since 2001. Sulphide concentrations usually have been below 10 mg/kg since 2006 (Figure 5-38).

Sulphur concentration was significantly correlated with Min *d* in 2020 (r_s = 0.27, $p \leq 0.05$; Table 5-23, Figure 5-39). Multiple regression results indicate a positive correlation with distance from the FEZ drill centres (partial r = 0.28, $p \leq 0.05$). These results indicate an increase in sediment sulphur concentration with distance from the FEZ drill centres (*i.e.,* lower sulphur concentrations near FEZ drill centres). Sulphur concentration was not significantly correlated with distance to the FE Drill Centre in 2020 (Table 5-23). However, the highest sulphur concentration was noted at Station 30(FE), located 0.14 km from the FE Drill Centre (Figure 5-39), indicating potential project effects at this one station. Sulphur showed modestly strong negative relationships with Min *d* in earlier EEM years (Figure 5-40), with higher concentrations near drill centres. Relationships have weakened over time, and the 2020 relationship indicate a positive rather than negative relationship.

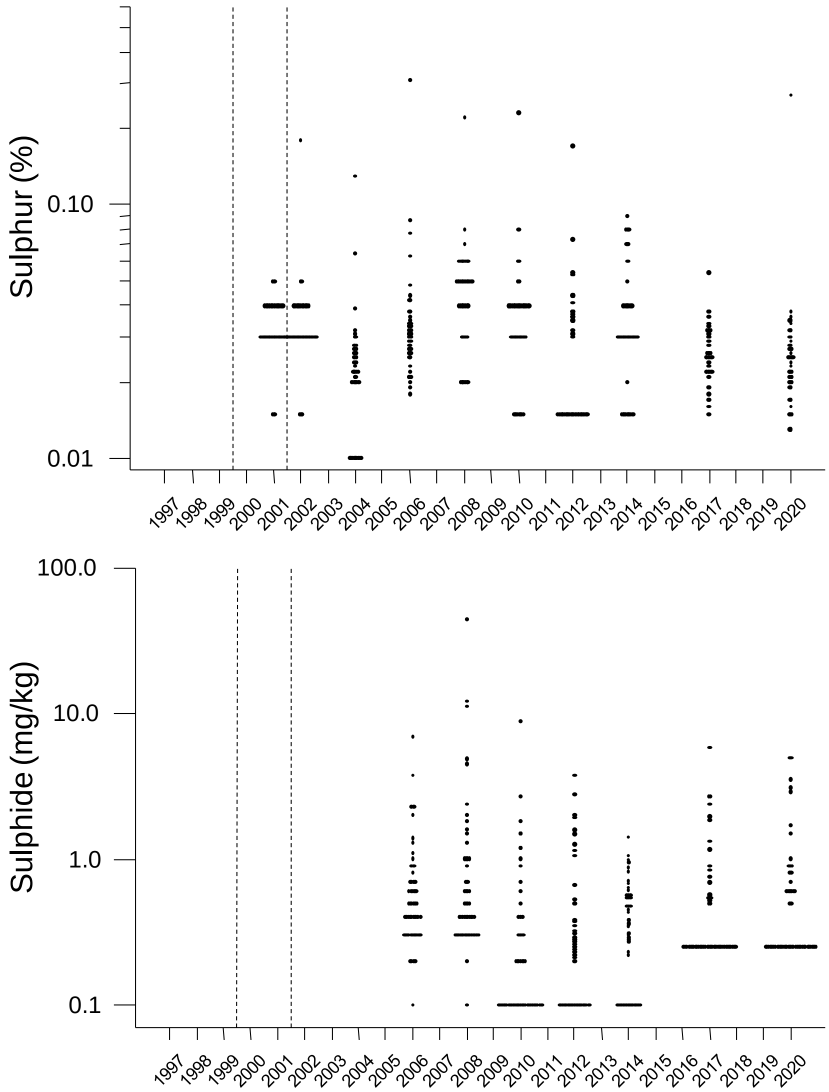


Figure 5-38 Annual Distributions of Concentrations for Sulphur (2001 to 2020) and Sulphide (2006 to 2020)

Notes: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

Table 5-23 Results of Rank-Rank Regression of Sulphur and Sulphide on Distance Variables (2020)

Response Variable	**Multiple R**	**Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)**		**Min *d* (r_s)**
		FEZ *d* (FE *d* constant)	**FE *d* (FEZ *d* constant)**	
Sulphur	0.33	0.28*	0.13	0.27*
Sulphide	**0.58*** **	-0.53***	-0.14	-0.55***

Note: -**p* ≤ 0.05; ***p* ≤ 0.01; ****p* ≤ 0.001 (in **bold**).
- *n* = 53

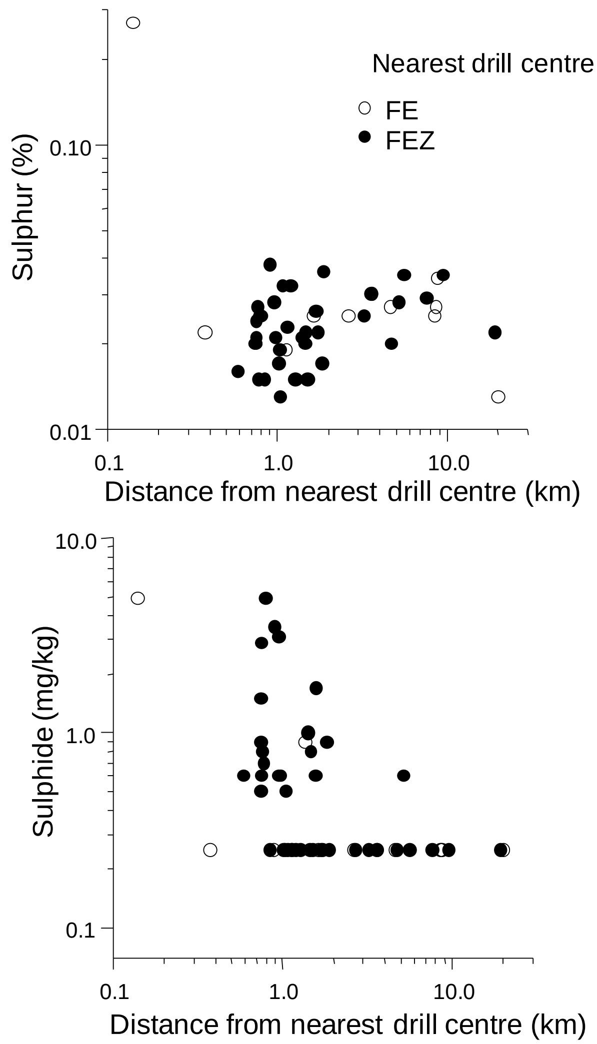


Figure 5-39 Distance Gradients for Sulphur and Sulphide (2020)

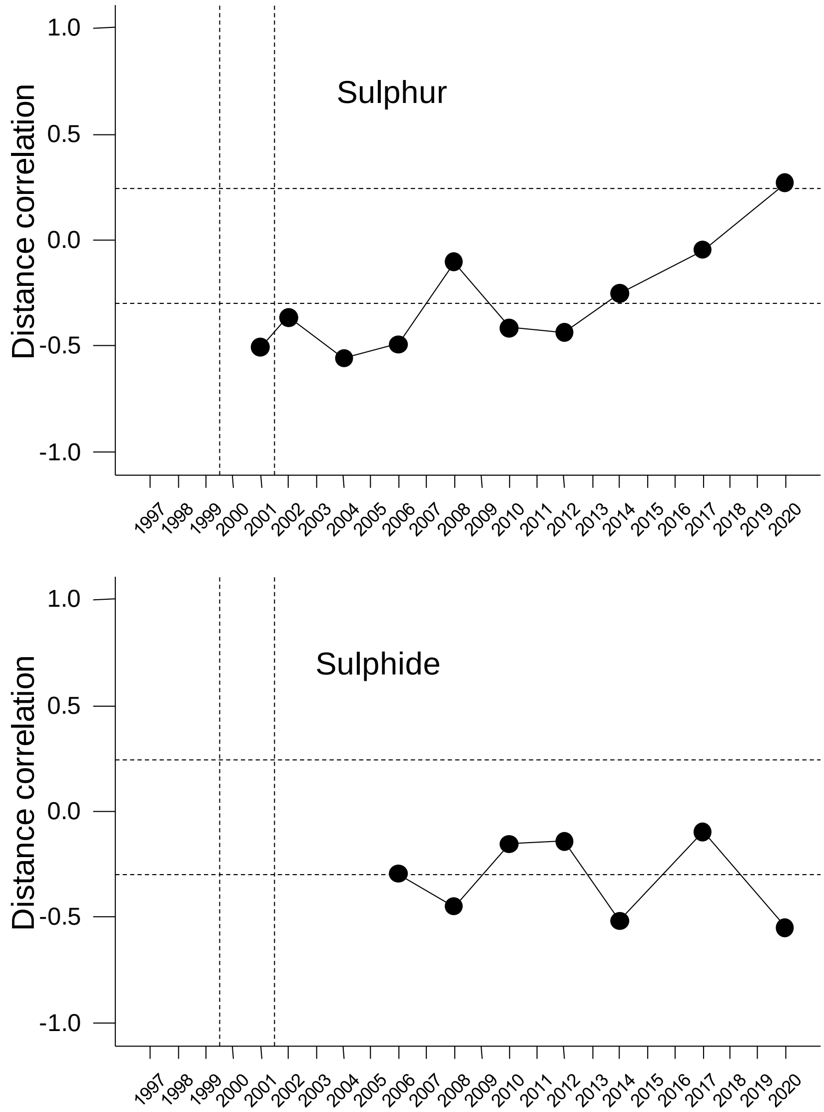


Figure 5-40 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Sulphur (2001 to 2020) and Sulphide (2006 to 2020)

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: all FEZ drill centres in 2001; and all drill centres from 2002 to 2020.

Sulphide concentrations also were significantly correlated with min *d* in 2020 (r_S = -0.55, $p \leq 0.001$; Table 5-23; Figure 5-39); with sulphide levels decreasing with distance from the FEZ drill centres (partial r = -0.53, $p \leq 0.001$). Sulphide concentrations were not significantly correlated with distance from the FE Drill Centre. However, like sulphur, the highest concentration in 2020 occurred at Station 30(FE). Sulphide levels decreased significantly with distance from drill centres in 2008, 2014 and 2020 (Figure 5-40).

Results from repeated-measures regression for sulphur are provided in Table 5-24. There was a significant overall FEZ regression slope (F = 11.4, $p \leq 0.001$) with slopes predominantly negative to 2017 (indicating higher sulphur levels near drill centres) (Figure 5-41). Within-year slopes from the FEZ drill centres decreased, became more negative, in 2010 and have since increased to a positive slope in 2020 (F = 16.0, $p \leq 0.001$; Figure 5-41).

Table 5-24 Results (F Values) of Repeated-Measures Regressions Comparing Concentrations Among EEM Years for Sulphur (2001 to 2020)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
FEZ *d*	**11.4****				
FE *d*	0.1				
Year		**7.9*****	10.4**	**21.1*****	**20.4*****
Year x FEZ *d*		3.5	0.8	7.7**	**16.0*****
Year x FE *d*		1.9*	1.1	0.8	2.0

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 48 stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Distance variables (X) and Y variables were rank-transformed.
- F values were rounded to one decimal place.

The overall FE regression slope for sulphur was not significant. There were significant variations in FE regression slopes (F = 1.9, $p \leq 0.05$), but the variations were not consistent with the start of drilling at the FE Drill Centre (F = 0.8, $p > 0.05$). FE regression slopes were negative from 2001 to 2006, positive in 2008 and 2010, near zero from 2012 to 2017, and positive again in 2020 (Figure 5-41). There were significant variations in overall sulphur levels (all Year terms significant Table 5-24), with sulphur levels generally increasing from 2004 to 2010 and then decreasing in subsequent years (F = 20.4, $p \leq 0.001$; Figure 5-38).

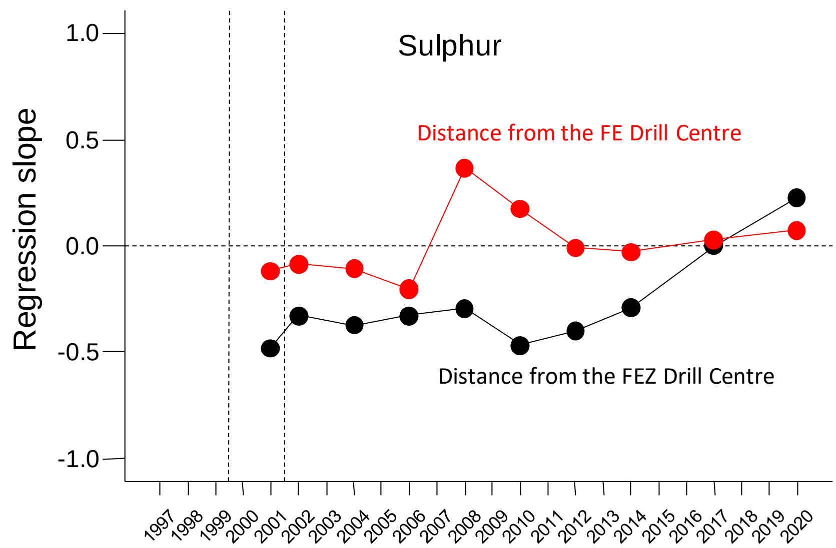


Figure 5-41 Annual Multiple Regression Distance Slopes for Sulphur (2001 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

There was no repeated-measures regression analysis for sulphides because 58% of sulphide values were below the laboratory detection limit in 2020 and because comparable sulphide data were only available from 2006 to present.

5.3.2 TOXICITY

Appendix B-3 provides amphipod survival test results from 1997 to 2020. The polychaete test was initiated in 2020. Those results are also provided in Appendix B-3.

In 2020, amphipod survival ranged from 80% to 100%, with a median survival of 95%, and no samples were classified as toxic following Environment and Climate Change Canada's (1998) interpretative guidance for sediments. Polychaete survival ranged from 47% to 100%, with a median of 90%, and one sample (from Station 46(FEZ)) was considered toxic.

Polychaete growth (mg/individual/day) was not reduced to below 30% of growth in negative control sediment in sediments from any station[22]. However, polychaete growth was reduced to below 20% of growth in reference sediment in sediments from 6 of the 41 stations tested (Stations 5(SW), 21 (NW), 29(FE), 31(FE), 37(FEZ), 49(FEZ)).

5.3.2.1 Relationships with Sediment Physical and Chemical Characteristics

All correlations between the three toxicity test variables and sediment physical and chemical variables were weak and non-significant in 2020. There were also no correlations between the toxicity variables (Table 5-25).

Table 5-25 Spearman Rank Correlations (r_s) Between Toxicity Test Responses and Sediment Physical and Chemical Characteristics (2020)

Physical/Chemical Variable	Amphipod Survival	Polychaete Survival	Polychaete Growth
Polychaete Survival	0.113		
Polychaete Growth	0.190	0.018	
>C_{10}-C_{21}	-0.099	0.054	-0.052
Barium	-0.217	0.044	-0.072
% Fines	-0.244	-0.144	0.044
% Gravel	-0.178	0.040	-0.037
Organic Carbon	-0.202	-0.083	0.009
Metals PC1	-0.178	0.172	-0.021
Strontium	-0.261	-0.050	-0.145
Sulphur	-0.258	0.046	-0.177
Sulphide	-0.169	0.189	0.105
Ammonia	-0.120	0.112	0.007
Redox	-0.059	0.032	0.073

Note: -*$p \le 0.05$; **$p \le 0.01$; ***$p \le 0.001$ (in **bold**).
- n = 53 for amphipods; n = 41 for polychaetes

5.3.2.2 Distance Relationships

Amphipod survival, polychaete survival and polychaete growth were uncorrelated to distance from drill centres in 2020 (Table 5-26; Figure 5-42).

[22] Polychaete growth was not reduced in the sample from Station 46(FEZ) that was considered toxic for survival. Although no guidance is provided in PSEP (1995), we caution against examining sublethal effects in samples for which there is a significant difference in survival because there can be density-dependent effects on the sublethal endpoint given that organisms are fed during the tests and no adjustments are made based on the number of polychaetes present.

Table 5-26 Results of Rank-Rank Regressions of Toxicity Test Responses on Distance Variables (2020)

Response Variable	Multiple R	Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)		Min *d* (r_s)
		FEZ *d* (FE *d* constant)	**FE *d* (FEZ *d* constant)**	
Amphipod survival	0.18	-0.17	0.11	-0.07
Polychaete survival	0.12	-0.02	-1.12	-0.01
Polychaete growth	0.23	-0.23	0.03	0.02

Note: -*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**)
- n = 53 for amphipods; n = 41 for polychaetes

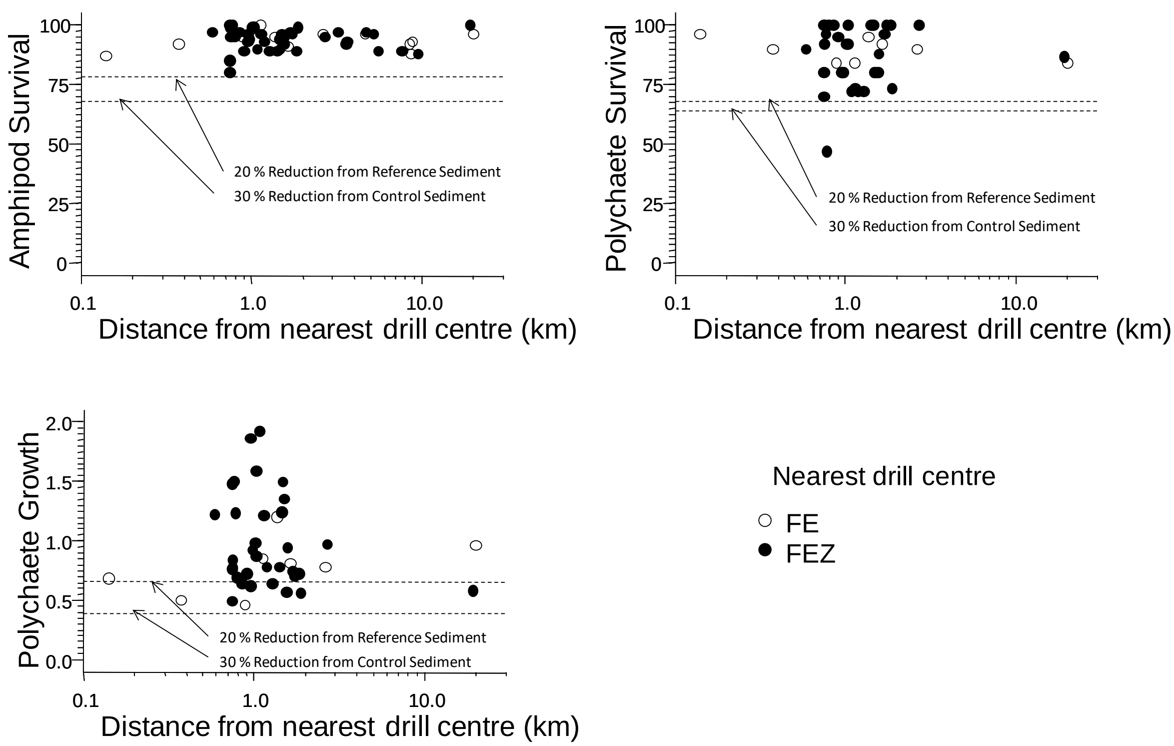


Figure 5-42 Distance Gradients for Toxicity Test Responses (2020)

Notes: The horizontal dashed lines in the left panel are the thresholds of 30% reduction in survival or growth versus control sediments and 20% reduction in survival or growth versus reference sediments. Units are % for survival and mg/worm/day for growth.

No multi-year analyses are performed on amphipod survival because survival has been uniformly high. Polychaete survival and growth were not assessed in years prior to 2020.

5.3.3 BENTHIC COMMUNITY STRUCTURE

5.3.3.1 Overview

Over 12 sample years (from 1997 to 2020), more than 600 individual kinds of invertebrates from over 200 families (excluding meiofauna such as oligochaetes, protodrilids, copepods, ostracods, nematodes, nemerteans) have been collected, sorted from sediments, and identified. A summary of the relative abundance and prevalence[23] of abundant taxa from 2000 to 2020 is provided in Table 5-27.

In 2020, over 63,000 individual benthic macro-invertebrates were collected in 106 samples from 53 stations. Samples in 2020 were dominated by barnacles (Family Balanidae), which accounted for 36.8% of organisms versus only 2.3% of organisms in previous years (Table 5-27). While Balanidae prevalence was greatest in 2020 (83.0%), this taxon was still prevalent in many samples from 2000 to 2017 (57.1%). Relative abundances and prevalence of other Crustacean taxa (Amphipoda, Cumacea, Isopoda) were generally comparable through time. Gastropods were the most abundant molluscs, with relative abundances and prevalence also comparable through time. The relative abundance of Echinodermata was low, and this taxon is included in Table 5-27 because of its potential influence on biomass.

Polychaetes, which traditionally accounted for a high proportion of total abundance from 2000 to 2017 (76.6%), continued to contribute to high proportion in 2020 (42.0%). However, the overall contribution to total abundance of polychaetes and that of individual polychaete families was reduced because of high barnacle counts. In 2020, as in previous years, polychaete abundance was dominated by three families: Spionidae (14.6% of total abundance); Cirratulidae (8.5%); and Syllidae (3.5%). These three families, along with Phyllodocidae, were collected at every station in 2020. Most of the other common families were also polychaetes (Table 5-27).

[23] Prevalence refers to the frequency of occurrence of a taxon in samples.

Table 5-27 Abundant Taxa (Families) in Benthic Invertebrate Elutriate Samples (2000 to 2020)

Taxon			2000 to 2017		2020	
Phylum	**Class or Order**	**Family**	**Relative Abundance (% of organisms)**	**Prevalence (% of samples)**	**Relative Abundance (% of organisms)**	**Prevalence (% of samples)**
Annelida	Polychaeta	Capitellidae	1.3	87.0	1.3	96.2
		Cirratulidae	13.4	99.4	8.5	100
		Maldanidae	1.6	74.1	1.4	79.2
		Orbiniidae	1.3	75.9	2.1	88.7
		Paraonidae	3.1	87.9	1.7	77.4
		Phyllodocidae	3.2	98.7	2.3	100
		Polynoidae	0.9	81.8	1.7	86.8
		Sabellidae	3.1	84.1	1.8	84.9
		Sigalionidae	3.3	84.9	2.1	75.5
		Spionidae	33	99.4	14.6	100
		Syllidae	12	99.4	3.5	100
		Terebellidae	0.8	60.2	1.0	75.5
Arthropoda	Amphipoda	Oedicerotidae	0.6	75.5	1.0	94.3
		Phoxocephalidae	1.4	72.6	1.4	67.9
	Cumacea	Leuconidae	0.6	74.7	1.9	90.6
	Isopoda	Anthuridae	2.0	62.8	2.0	75.5
	Thecostraca	Balanidae	2.3	57.1	36.8	83.0
Mollusca	Bivalvia	Tellinidae	1.2	74.9	0.6	73.6
	Gastropoda	Lepetidae	1.4	50.6	1.6	58.5
Echinodermata	Asteroidea	Asteriidae	0.02	10.9	0.003	3.8
		Solasteridae	0.001	0.6	0.03	5.7
	Echinoidea	Echinarachniidae	0.2	49.6	0.7	84.9
		Strongylocentrotidae	0.1	42.1	0.1	45.3
	Holothuroidea	Psolidae	0.01	7.7	0.02	9.4
	Ophiuroidea	Ophiuridae	0.9	48.9	0.9	50.9
		Ophiopholidae	0.03	11.7	0.1	24.5

Note: With the exception of Echinodermata, only those taxa that accounted for >1% of total numbers in 2020 or in the years prior to 2020 are listed. Echinodermata were included because of their potential influence on biomass. For this reason, they are also examined separately in this report (see Section 5.2.4.1).

In 2020, as in previous years, there was wide variation among stations for summary measures of benthic invertebrate community. Total abundance varied by more than 50-fold among stations (from 84 to 4,454 individuals per station) in 2020 (Table 5-28). In addition to the typically high numbers of polychaetes, total abundance was influenced by high numbers of barnacles (Family Balanidae), with more that 50% of samples containing in excess of 200 individuals. Standard deviations (SD) of abundances of individual taxa were more than 100% of the mean (i.e., the coefficient of variation (CV)) for most major groups (Table 5-28).

Table 5-28 Summary Statistics for Invertebrate Community Variables (2020)

Variable	Unit/Interpretation	Min	Max	Median	Mean	SD	CV (%)
Summary Measures							
Total abundance (N)	No. organisms/station	84	4454	897	1198	965	81
Biomass (B)	g wet/station	11	449	186	193	105	54
Richness (S)	No. taxa/station	20	74	52	49	14	28
Adjusted Richness (S2)	Observed: Expected S	0.7	1.6	1.0	1.0	0.2	19
Taxon Abundance							
Cirratulidae	No. organisms/station	3	448	83	101.4	102.9	101
Orbiniidae	No. organisms/station	0	151	18	25.1	28.2	112
Paraonidae	No. organisms/station	0	124	12	20.5	27.0	132
Phyllodocidae	No. organisms/station	1	88	22	27.5	21.2	77
Sabellidae	No. organisms/station	0	443	7	23.5	43.7	186
Sigalionidae	No. organisms/station	0	363	10	24.5	40.6	166
Spionidae	No. organisms/station	1	624	154	175.4	134.9	77
Syllidae	No. organisms/station	1	324	71.5	81.9	54.0	66
Amphipoda	No. organisms/station	7	341	39	72.2	75.0	104
Balanidae	No. organisms/station	0	2692	279	440.5	540.1	123
Tellinidae	No. organisms/station	0	64	2	7.1	12.3	173
Echinodermata	No. organisms/station	0	156	9	24.0	33.7	140

Notes: - *n* = 53 stations.
- Adjusted richness values express observed richness relative to richness expected based on total abundance, with higher values indicating greater diversity and/or evenness.
- CV = Coefficient of Variation (SD as % of mean).

Biomass varied by over 40-fold (approximately 11 to 449 g wet/station) among stations, with a CV of 54% (Table 5-28). Richness and adjusted richness varied less (i.e., had lower CVs) among stations than abundances and biomass (Table 5-28). In 2020, 20 to 74 taxa were collected per station.

Correlations Among Community Variables

Table 5-29 provides rank correlations among benthic invertebrate community summary measures for 2020 stations. Richness adjusted for abundance (adjusted richness) greatly decreased the positive correlation between raw richness and abundance. Biomass was not significantly correlated with richness or abundance.

Table 5-29 Spearman Rank Correlations (r_S) Among Primary Benthic Invertebrate Community Variables (2020)

Parameter	Total Abundance (N)	Biomass (B)	Richness (S)
Biomass (B)	0.203		
Richness (S)	**0.770*** **	0.038	
Adjusted Richness (S2)	0.028	-0.215	**0.612*** **

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 53 stations.

Abundances of all taxa selected for further examination, except Orbiniidae and Paraonidae, were significantly positively correlated with total abundance (Table 5-30). Biomass was significantly positively correlated with Cirratulidae and Echinodermata abundance (Table 5-30).

Table 5-30 Spearman Rank Correlations (r_S) Between Benthic Invertebrate Community Summary Measures vs Taxon Abundances (2020)

Taxon Abundance	Total Abundance (N)	Biomass (B)	Richness (S)	Adjusted Richness (S2)
Cirratulidae	**0.622*** **	0.354**	0.263**	-0.347**
Orbiniidae	-0.105	0.046	-0.058	-0.025
Paraonidae	-0.025	-0.225	-0.012	-0.047
Phyllodocidae	**0.682*** **	0.226	**0.56*** **	0.096
Sabellidae	**0.718*** **	0.143	**0.701*** **	0.227
Sigalionidae	**0.822*** **	0.217	**0.796*** **	0.292**
Spionidae	**0.824*** **	0.207	**0.629*** **	0.002
Syllidae	0.385**	0.057	0.345**	0.039
Amphipoda	**0.713*** **	0.124	**0.633*** **	0.106
Balanidae	**0.914*** **	0.123	**0.708*** **	0.064
Tellinidae	**0.641*** **	0.187	**0.515*** **	-0.008
Echinodermata	**0.648*** **	0.378**	**0.619*** **	0.154

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 53 stations.

Trends in taxa correlations with richness were comparable to those for total abundances. Adjusting richness for total abundance generally reduced the strength of the correlation between adjusted richness and the individual taxa. However, correlations between adjusted richness and taxa abundances became negatively significant for Cirratulidae polychaetes, and Sigalionidae abundance remained significantly positively correlated despite adjusting for total abundance.

5.3.3.2 Abundance

Total abundance generally increased from 2000 to 2020, with highest values noted in 2017 and 2020 (Figure 5-43). Up to approximately 1,000 organisms per station were noted in 2000; with up to approximately 2,400 organisms per station noted in 2017, followed by abundances greater than 3,900 organisms per station in 2020. Greater total abundance in 2020 resulted from greater abundances of barnacles, which accounted for approximately 37% of total abundance in 2020 versus 2% in previous years. Amphipod abundance was also highest in 2020, and Syllidae abundance was lowest. Variability in the abundances of remaining taxa was within the range observed in previous years (Figure 5-44).

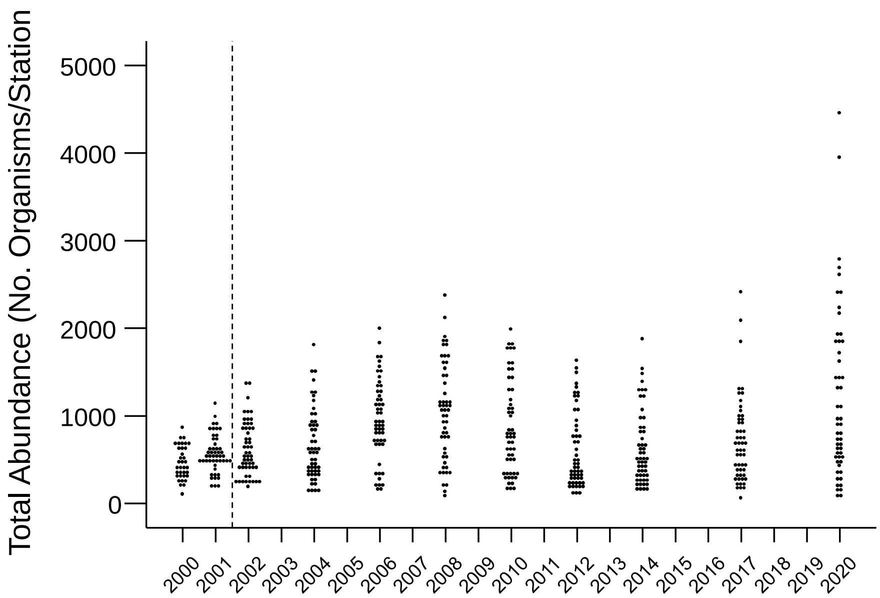


Figure 5-43 Annual Distributions for Total Abundance (2000 to 2020)

Note: The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program).

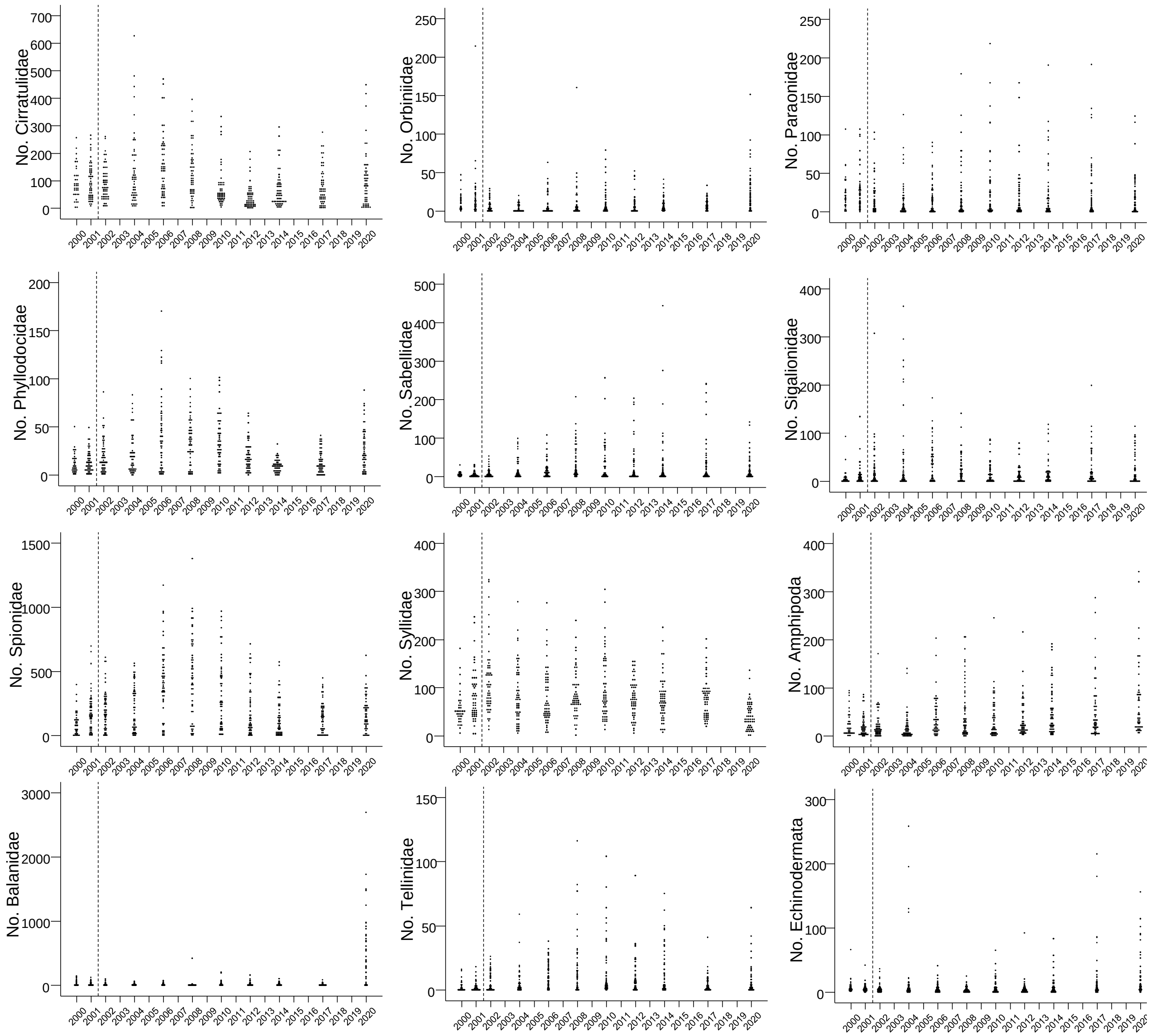


Figure 5-44 Annual Variations in Abundances of Selected Taxa (2000 to 2020)

Note: The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program).

Total abundance was negatively correlated with Min *d* in 2020 (r_s = -0.44, $p \leq 0.05$, Table 5-31; Figures 5-45 and 5-46); indicating a decrease in total abundance with distance from drill centres overall. Additionally, the multiple regression incorporating FEZ *d* and FE *d* was significant. The partial correlation with distance to the FEZ drill centre drove this trend (partial r = -0.48, $p \leq 0.001$). The relationship with distance from the FE Drill Centre was not significant (partial r = -0.02, $p \geq 0.05$).

Table 5-31 Results of Rank-Rank Regression of Total Abundance on Distance Variables (2020)

Response Variable	Multiple R	Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)		Min *d* (r_s)
		FEZ *d* (FE *d* constant)	FE *d* (FEZ *d* constant)	
Abundance	0.47**	**-0.48*** **	0.02	**-0.44*** **

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

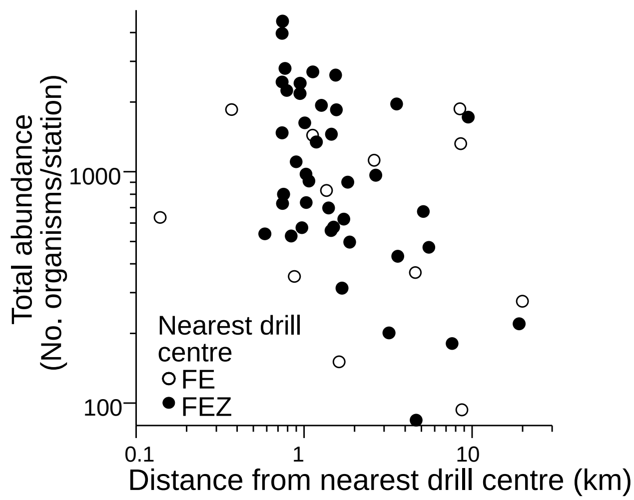


Figure 5-45 Distance Gradient for Total Abundance (2020)

Distance correlations with Min *d* for total abundance have been weakly negative in all years, with correlations significant in 2004, 2014, 2017, and 2020 (Figure 5-46). Distance correlations with Min *d* for selected individual taxa are examined within the context of the NMDS analyses in Section 5.3.3.6.

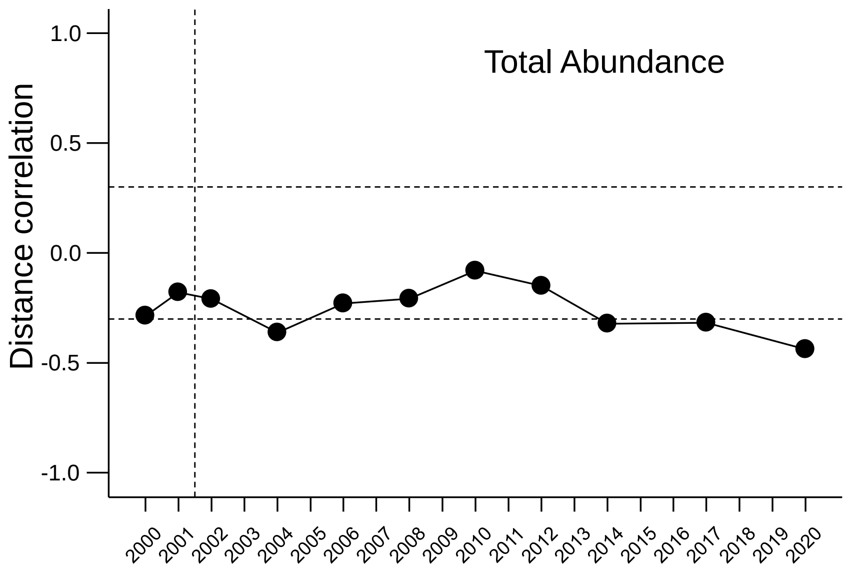


Figure 5-46 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Total Abundance (2000 to 2020)

Notes: The dashed horizontal lines indicate a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020.

Results of repeated-measures regression for total abundance are provided in Table 5-32[24]. The overall FEZ regression slope was weakly significant ($F = 6.7$, $p \leq 0.05$), with significant changes in distance slopes over time ($F = 7.0$, $p \leq 0.05$). FEZ regression slopes were generally negative (Figure 5-47), indicating a decrease in total abundance with distance from the FEZ drill centres in most years. However, this relationship weakened from 2004 to 2010 and subsequently strengthened (Figure 5-47). The overall FE regression slope was not significant and there were no significant changes in FE regression slopes over time. As noted above, there were changes in overall abundance over time. Total abundance generally increased to 2008 and then decreased ($F = 22.1$, $p \leq 0.001$), with a subsequent increase in total abundance in 2017 and 2020 (Figure 5-43).

[24] As noted in Section 5.2.4, data from 2000 were not included in repeated-measured analyses for benthos because a different sieving method was used for some stations in that year.

Table 5-32 Results (F Values) of Repeated-Measures Regressions Comparing Total Abundance Among EEM Years (2001 to 2020)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
FEZ *d*	6.7*				
FE *d*	0.01				
Year		**4.4*****	0.4	1.4	**22.1*****
Year x FEZ *d*		2.1	3.2	1.4	7.0*
Year x FE *d*		1.1	0.9	0.2	1.7

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- *n* = 48 stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Repeated-measures regression excluded 2000 since not all samples were processed using the elutriate methods in that year.
- Distance variables (*X*) and *Y* variables were rank-transformed.
- *F* values were rounded to one decimal place.

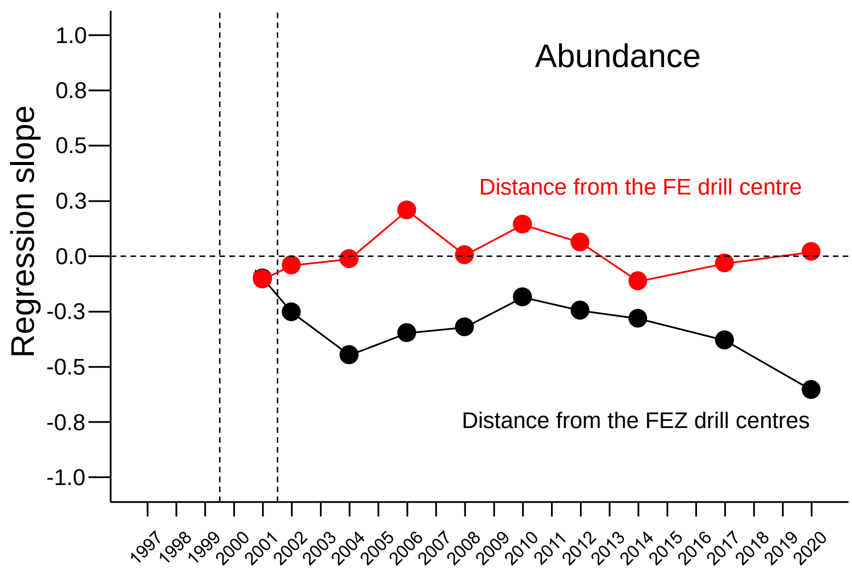


Figure 5-47 Annual Multiple Regression Distance Slopes for Total Abundance (2001 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

5.3.3.3 Biomass

Total benthic biomass generally increased to 2012 and subsequent decreased (Figure 5-48). Variations in biomass in 2020 were comparable to those noted in earlier EEM years.

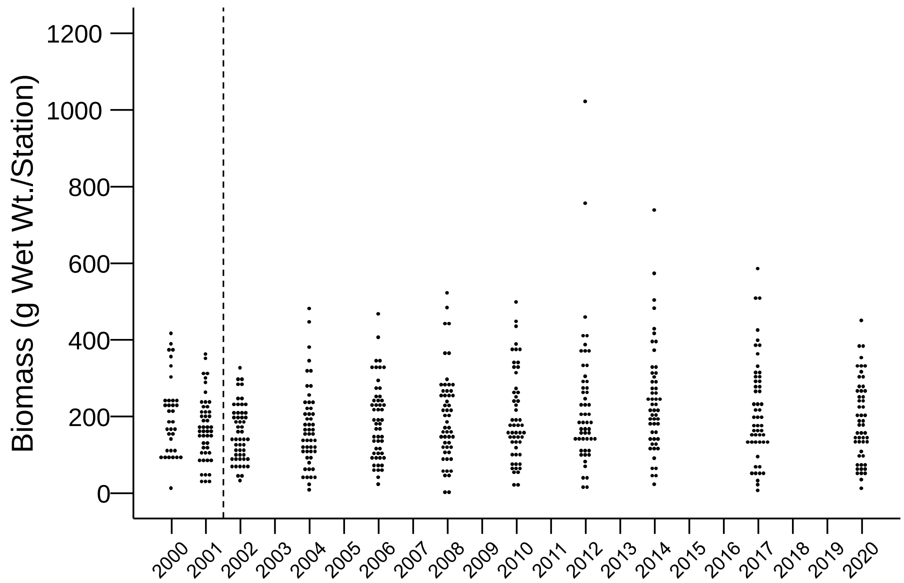


Figure 5-48 Annual Distributions for Biomass (2000 to 2020)

Note: The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program).

Biomass was not significantly correlated with Min *d* in 2020 (r_S = -0.14, Table 5-33; Figure 5-49). However, the multiple correlation (Multiple R) incorporating FEZ *d* and FE *d* was significant (Table 5-33). Biomass significantly decreased with increasing distance from the FEZ drill centres (FEZ *d* partial r = -0.34, $p \leq 0.01$) and significantly increased with increasing distance from the FE Drill Centre (FE *d* partial r = 0.38, $p \leq 0.01$, Figure 5-49). These two opposing relationships account for the absence of a significant relationship with Min *d*. The abundances of Cirratulidae and Echinodermata were significantly correlated with biomass (Table 5-30). Like total biomass, Cirratulidae abundance decreased with distance from the FEZ drill centres (FEZ *d* partial r = -774; $p \leq 0.01$) and increased with distance from the FE Drill Centre (FE *d* partial r = 0.312, $p \leq 0.05$). Echinodermata abundances were not correlated to distance from either the FEZ or FE drill centres (partial r p > 0.05 in both cases).

Table 5-33 Results of Rank-Rank Regression of Biomass on Distance Variables (2020)

Response Variable	Multiple R	Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)		Min *d* (r_s)
		FEZ *d* (FE *d* constant)	FE *d* (FEZ *d* constant)	
Biomass	0.46**	-0.34**	0.38**	-0.14

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

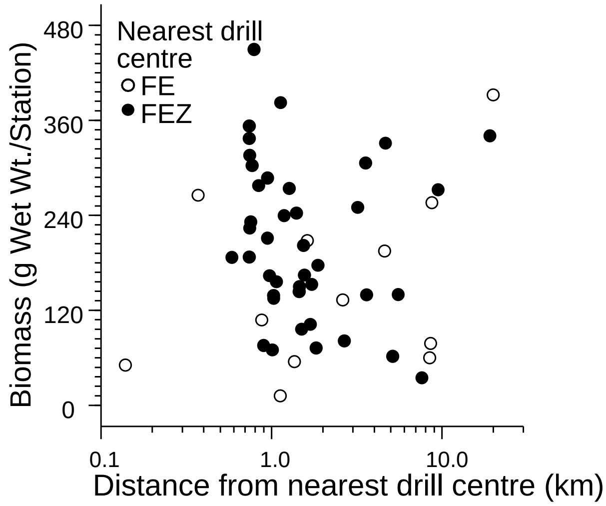


Figure 5-49 Distance Gradient for Biomass (2020)

Biomass was only significantly correlated with Min *d* in 2004 (Figure 5-50), when the relationship was significant and positive, indicating increasing biomass with increasing distance from drill centres.

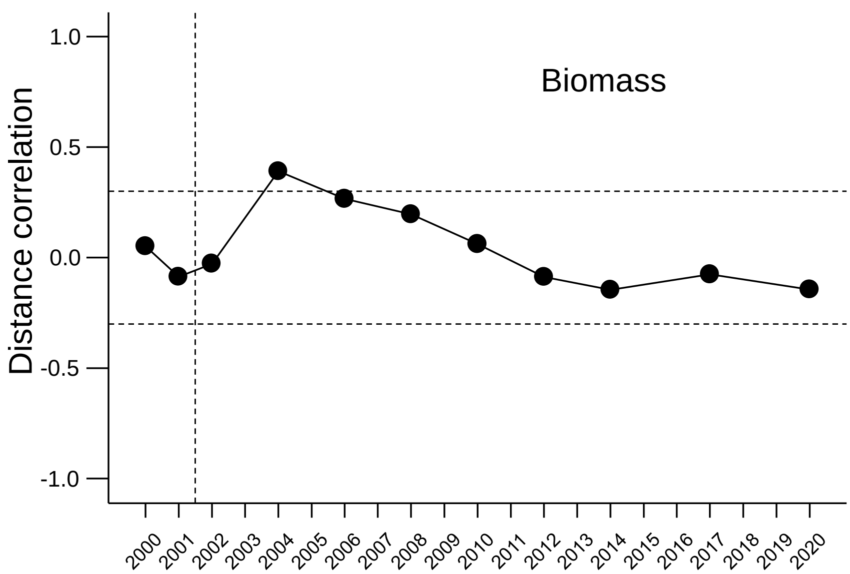


Figure 5-50 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Biomass (2000 to 2020)

Notes: The dashed horizontal lines indicate a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020.

Results of repeated-measures regression for biomass are provided in Table 5-34. The overall FEZ regression slope was significant (F = 7.5; $p \leq 0.01$) and negative indicating an overall decrease in biomass with distance from the FEZ drill centres. Slopes from the FEZ drill centres generally became more negative from 2002 to 2020 (F = 8.9, $p \leq 0.01$; Figure 5-51). The overall FE regression slope also was significant (F = 30.3, $p \leq 0.001$), with slopes positive indicating an overall increase in biomass with distance from the FE Drill Centre (Figure 5-51). As noted above, there were changes in overall biomass over time (F = 6.2, $p \leq 0.05$, Figure 5-48). Total biomass increased to 2012 and subsequent decreased (Figure 5-48).

Table 5-34 Results (F Values) of Repeated-Measures Regressions Comparing Biomass Among EEM Years (2001 to 2020)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
FEZ *d*	7.5**				
FE *d*	**30.3*** **				
Year		2.0*	0.4	2.3	6.2*
Year x FEZ *d*		1.7	0.01	8.9**	0.1
Year x FE *d*		1.7	0.01	0.3	1.4

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 48 stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Repeated-measures regression excluded 2000 since not all samples were processed using the elutriate methods in that year.
- Distance variables (X) and Y variables were rank-transformed.
- F values were rounded to one decimal place.

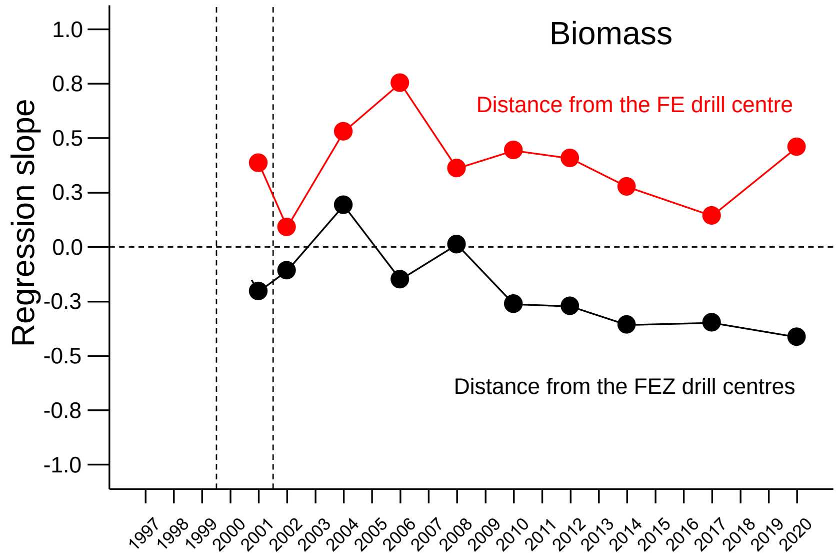


Figure 5-51 Annual Multiple Regression Distance Slopes for Biomass (2001 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

5.3.3.4 Richness

As was the case for total abundance, richness increased in 2020 and 2017 (Figure 5-52). Up to 74 taxa per station were noted in 2020. Up to 68 taxa per station were noted in 2017. In previous years, that maximum did not exceed 60 taxa per station.

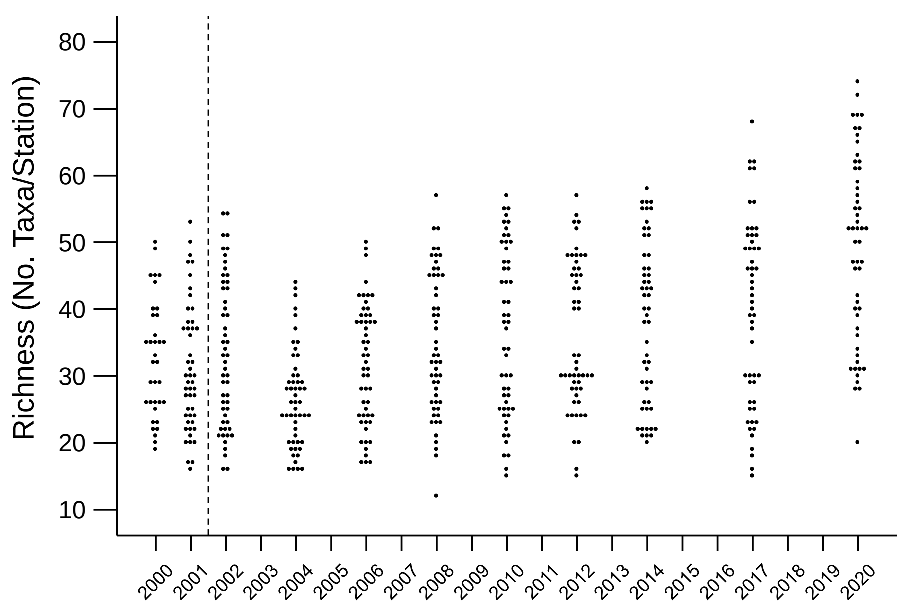


Figure 5-52 Annual Distributions for Richness (2000 to 2020)

Note: The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program).

Richness varied significantly with Min *d* in 2020 (r_s = -0.31, Table 5-35; Figure 5-53). Richness decreased with distance from drill centres, as did total abundance However, the correlation from the multiple regression incorporating FEZ *d* and FE *d* (Multiple *R*) was not significant; and neither were the partial correlations (Table 5-36; Figure 5-53).

Table 5-35 Results of Rank-Rank Regression of Richness on Distance Variables (2020)

Response Variable	**Multiple R**	**Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)**		**Min *d* (r_s)**
		FEZ *d* (FE *d* constant)	**FE *d* (FEZ *d* constant)**	
Richness	0.30	-0.24	-0.14	-0.31**

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

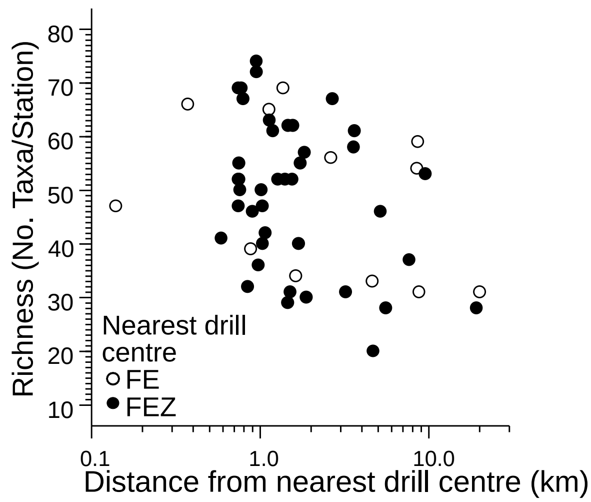


Figure 5-53 Distance Gradient for Richness (2020)

Richness has not been correlated with distance to drill centres in previous years, although the negative relationship has gained strength since 2010 (Figure 5-54).

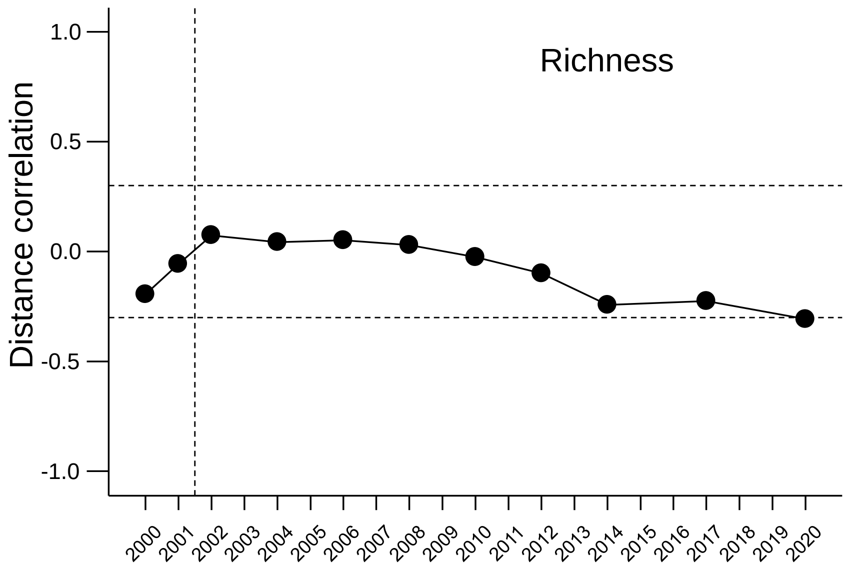


Figure 5-54 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Richness (2000 to 2020)

Notes: The dashed horizontal lines indicate a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020.

Results of repeated-measures regression for richness are provided in Table 5-36. Although there was no significant overall FEZ regression slope, FEZ regression slopes decreased significantly over time ($F = 20.2$, $p \leq 0.001$) from near zero from 2008 to 2010, to negative in subsequent years (Figure 5-55). There was no significant overall FE regression slope, and no significant variations over time FE distance slopes (Table 5-37; Figure 5-55). There were significant variations in overall richness over time ($F = 6.5$, $p \leq 0.05$), with richness generally higher in years subsequent to 2001 (Figure 5-52).

Table 5-36 Results (F Values) of Repeated-Measures Regressions Comparing Richness Among EEM Years (2001 to 2020)

Effect	Test				
	Among Stations	Within Stations	Before vs After FE Drilling (2001 vs 2002 to 2020)	Linear Trend 2002 to 2020	Quadratic Trend 2002 to 2020
FEZ *d*	0.6				
FE *d*	0.3				
Year		3.2**	6.5*	1.9	1.6
Year x FEZ *d*		**4.3*** **	2.2	**20.2*** **	1.7
Year x FE *d*		0.8	1.4	1.6	0.2

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- $n = 48$ stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Repeated-measures regression excluded 2000 since not all samples were processed using the elutriate methods in that year.
- Distance variables (*X*) and *Y* variables were rank-transformed.
- *F* values were rounded to one decimal place.

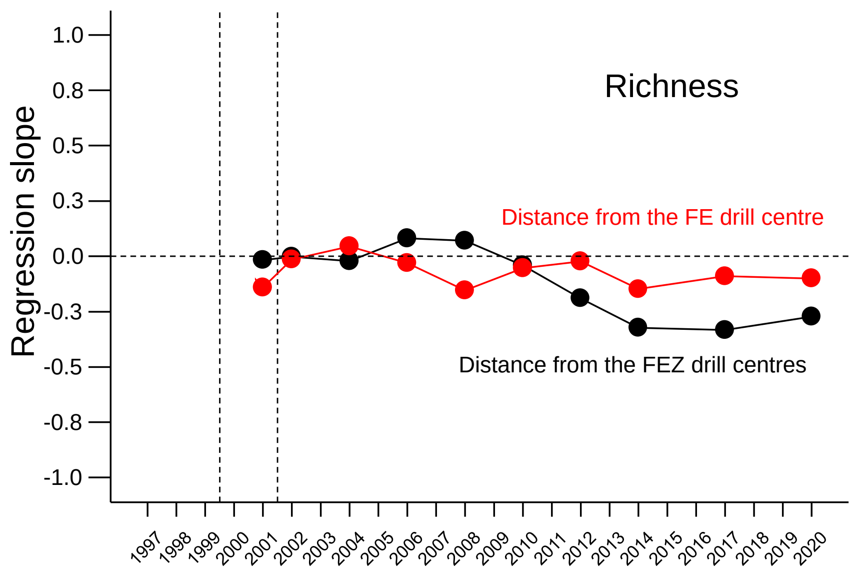


Figure 5-55 Annual Multiple Regression Distance Slopes for Richness (2001 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

5.3.3.5 Adjusted Richness

Adjusted richness was generally low from 2004 to 2010 (Figure 5-56). In 2020, adjusted richness values ranged between approximately 0.7 and 1.6, similar to what was observed in earlier and more recent EEM years.

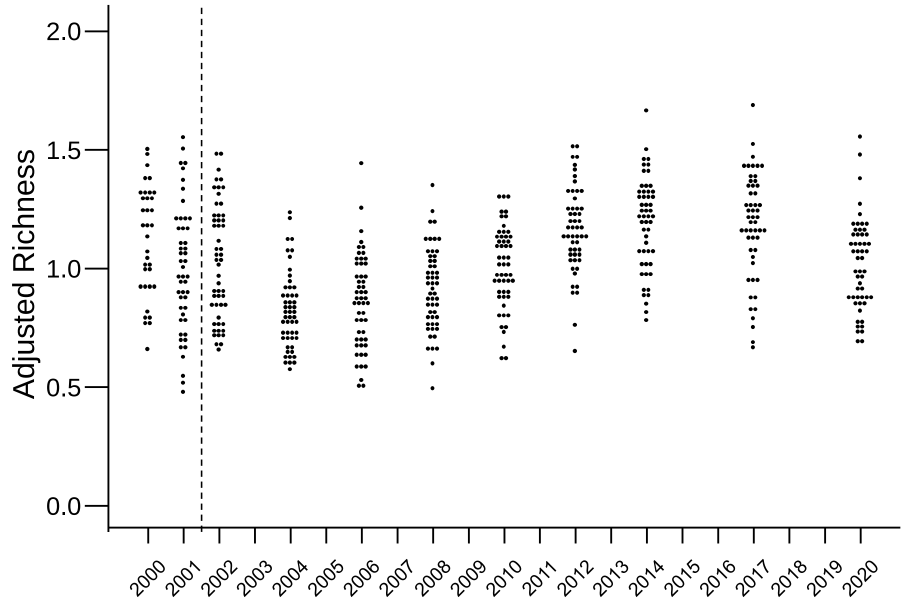


Figure 5-56 Annual Distributions for Adjusted Richness (2000 to 2020)

Note: The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program).

The relationship between adjusted richness and Min *d* was not significant in 2020 (r_S = 0.03, Table 5-37; Figure 5-57). The correlation from the multiple regression incorporating FEZ *d* and FE *d* was not significant and neither were the partial correlations (Table 5-37, Figure 5-57).

Table 5-37 Results of Rank-Rank Regression of Adjusted Richness on Distance Variables (2020)

Response Variable	Multiple R	Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)		Min *d* (r_s)
		FEZ *d* (FE *d* constant)	**FE *d* (FEZ *d* constant)**	
Adjusted Richness	0.27	0.18	-0.23	0.03

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

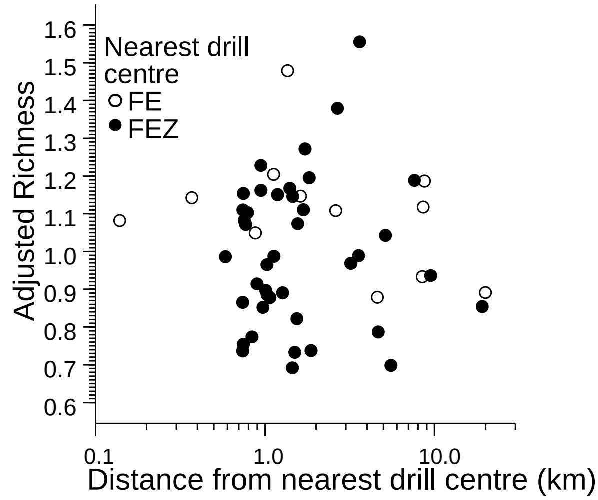


Figure 5-57 Distance Gradient for Adjusted Richness (2020)

Correlations with Min *d* were stronger, positive, and significant in 2004, 2006, and 2008, indicating greater adjusted richness with distance from drill centres in those years (Figure 5-58).

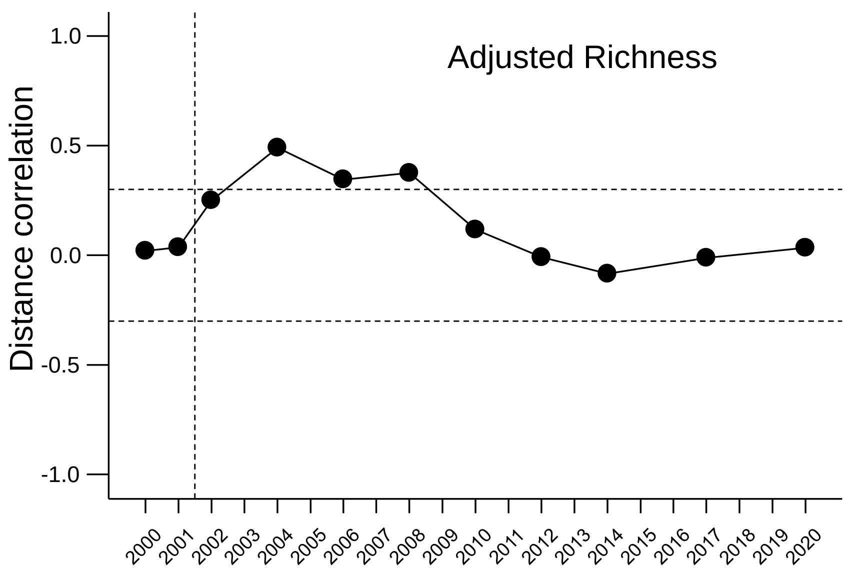


Figure 5-58 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Adjusted Richness (2000 to 2020)

Notes: The dashed horizontal lines indicate a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020.

Results of repeated-measures regression for adjusted richness are provided in Table 5-38. There were no significant overall FE and FEZ regression slopes for adjusted richness. There were variations in FEZ regression slopes with slopes generally becoming more negative over time (F = 12.1, $p \leq 0.001$). However, this slope became more positive in 2020 (Figure 5-59). Negative slopes indicate marginally higher values for adjusted richness near FEZ drill centres, relative to values at greater distances; positive slopes indicate marginally lower values near drill centres. There were no variations in FE regression slopes. As noted above, overall adjusted richness was marginally lower from 2004 to 2010 than in other years (F = 4.1, $p \leq 0.05$; Figure 5-52).

Table 5-38 Results (F Values) of Repeated-Measures Regressions Comparing Adjusted Richness Among EEM Years (2001 to 2020)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
FEZ *d*	3.1				
FE *d*	1.4				
Year		1.7	0.83	0.01	4.1*
Year x FEZ *d*		**4.0*** **	1.1	**12.1*** **	0.1
Year x FE *d*		1.0	0.1	2.9	0.6

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 48 stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Repeated-measures regression excluded 2000 since not all samples were processed using the elutriate methods in that year.
- Distance variables (*X*) and *Y* variables were rank-transformed.
- *F* values were rounded to one decimal place.

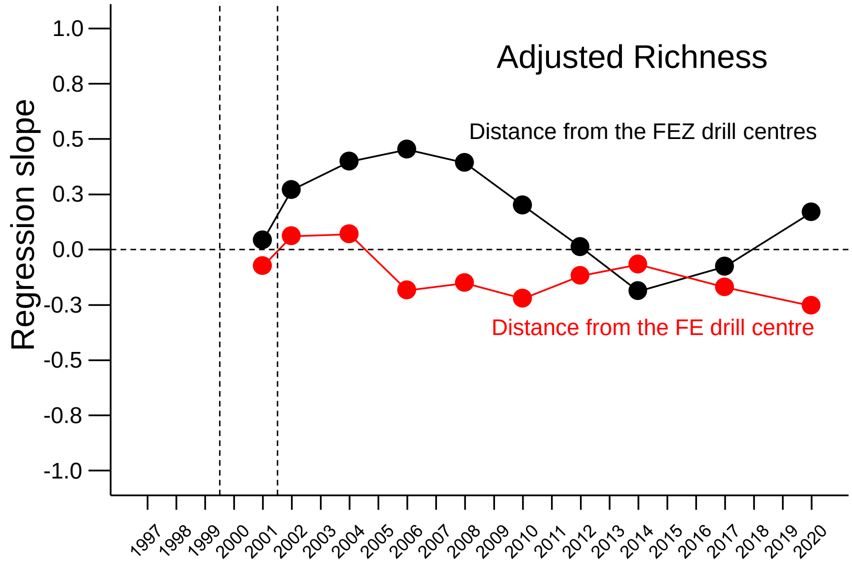


Figure 5-59 Annual Multiple Regression Distance Slopes for Adjusted Richness (2001 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

5.3.3.6 Non-Metric Multidimensional Scaling

NMDS was used to summarize the multivariate nature of the invertebrate community data. The stress coefficient, a measure of the fit between the original pair-wise Bray-Curtis distances between stations and distances between those stations in the NMDS plots, was 0.19. Stress values can range from 0 (perfect fit) to 1 (no fit). A stress coefficient of 0.19 indicates a reasonable two-dimensional fit to the pair-wise Bray-Curtis distances among the 560 stations used in the analysis. Distances between stations in the two-dimensional plot of station scores reflect differences in percentage community similarity, since the NMDS was based on the Bray-Curtis distance of relative (or %) abundances[25]. In Figure 5-60, the vertical and horizontal dashed lines indicate NMDS1 = 0 and NMDS2 = 0, respectively. The “origin”, where NMDS1 = NMDS2 = 0, represents the “average” community over all stations and years.

Overall, NMDS plots in Figure 5-60 show a diffuse distribution along NMDS1 and NMDS2 in 2020, similar to that noted in 2000; and a shift in community composition over time along the NMDS1 axis for communities located within 1 km from drill centres.

[25] Abundances at the family level were used most frequently in NMDS. Higher taxonomic levels were used when identification at the family level was not possible.

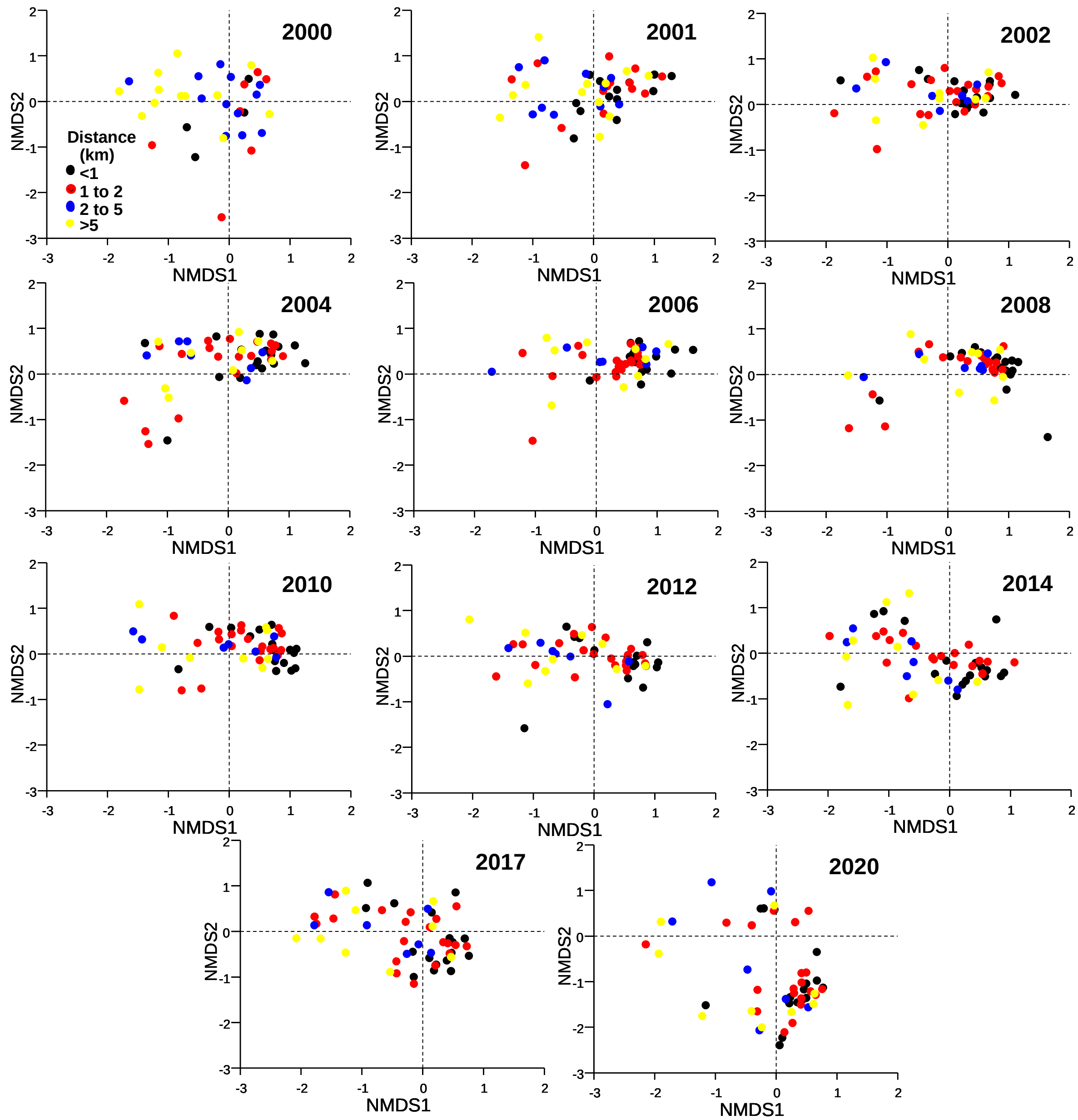


Figure 5-60 Non-Metric Multidimensional Scaling Plots Based on Relative Abundances of Invertebrate Taxa (2000 to 2020)

Note: Distances are distances from the nearest active drill centre (NE, SW in 2000; all FEZ drill centres *in 2001; all drill centres from 2002 to 2020).*

Figure 5-61 is a plot of Spearman rank correlations (r_S) between relative abundances of individual taxa and the station scores along the two NMDS axes. An "overlay" of Figure 5-60 onto Figure 5-61 would indicate approximately the associations between stations and taxa. For example, stations in the lower left quadrant of Figure 5-60 (negative NMDS1 and NMDS2 scores) would have greater relative abundances of taxa in the lower left quadrant of Figure 5-61 (negative correlations with NMDS1 and

NMDS2). Many taxa were relatively rare and were poorly correlated with NMDS axis scores, and thus clustered near the centre of the plot of taxa correlation (i.e., r_s with both NMDS axes approximately 0).

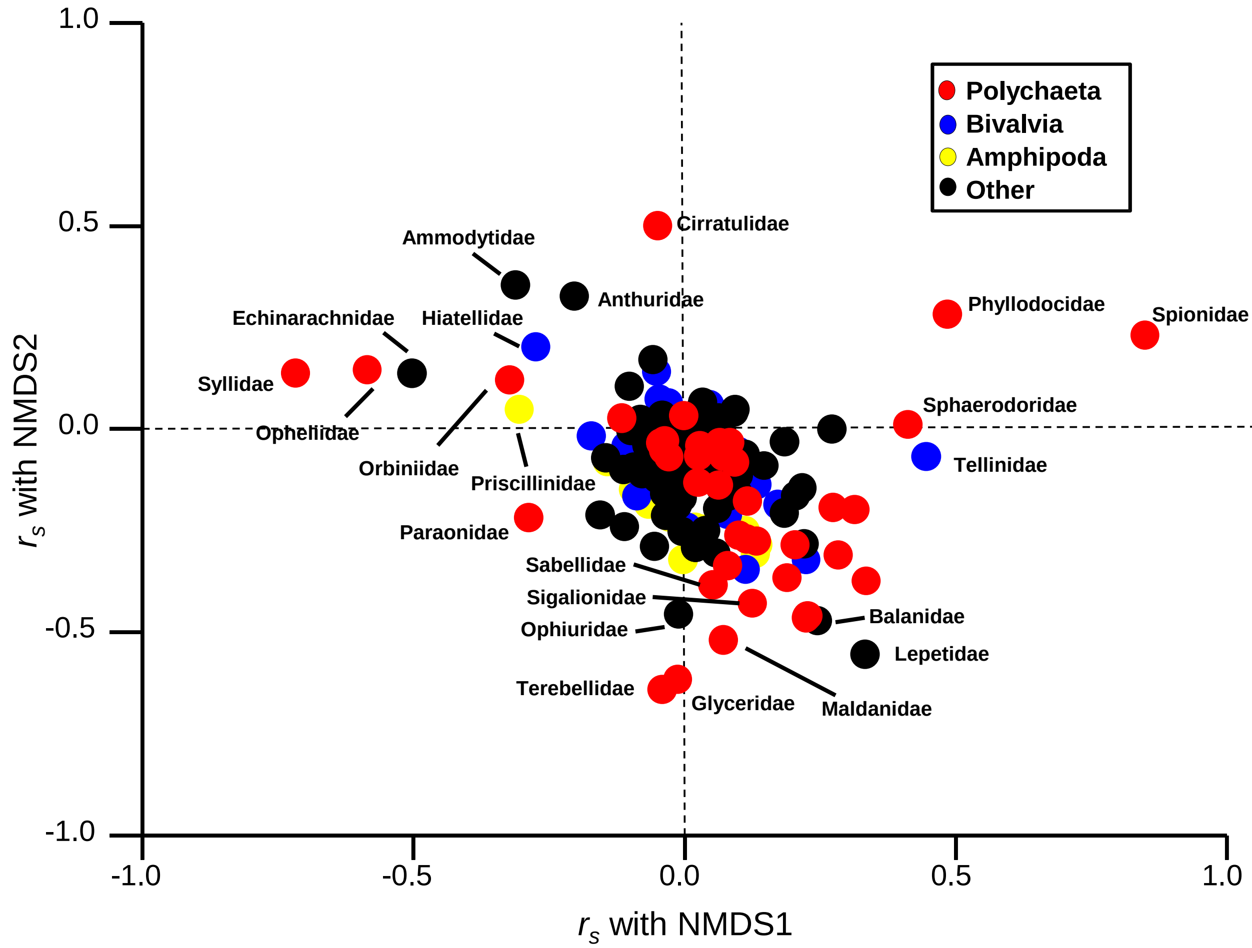


Figure 5-61 Spearman Rank Correlations Between Taxa Relative (%) Abundances and Non-Metric Multidimensional Scaling Axes (2000 to 2020)

The three dominant polychaete families (Spionidae, Syllidae, and Cirratulidae) largely defined overall community differences along the NMDS axes among stations in Figure 5-60, and differences among taxa or groups of taxa in Figure 5-61. The first NMDS axis (NMDS1) was strongly positively correlated with the relative abundance of Spionidae and strongly negatively correlated with the relative abundance of Syllidae (Figure 5-61). In general terms, NMDS1 can be considered to represent Spionidae dominance because this taxon correlated most strongly with NMDS1.

NMDS2 scores were most strongly positively correlated with the relative abundances of the dominant Cirratulidae and strongly negatively correlated with abundances of several sub-dominant taxa (e.g., Terebellidae, Glyceridae, Lepitidae and others) (Figure 5-61). Therefore, NMDS2 can be considered to represent Cirratulidae dominance.

NMDS1 and NMDS2 scores were correlated with abundance and richness and uncorrelated with biomass and adjusted richness (Table 5-39), as in previous years. Scores were also correlated with the relative abundance of many of the taxa examined separately in this report (Table 5-39).

Table 5-39 Spearman Rank Correlations (r_S) Between Benthic Invertebrate Community Summary Measures and Taxa Abundance and NMDS Axis Scores (2020)

Variable	NMDS1	NMDS2
Summary Measure		
Abundance	**0.56*** **	**-0.51*** **
Biomass	0.11	0.12
Richness	**0.51*** **	**-0.46*** **
Adjusted Richness	0.15	-0.20
Taxa Abundance		
Cirratulidae	0.395**	0.027
Orbiniidae	-0.284*	0.227
Paraonidae	-0.135	-0.093
Phyllodocidae	**0.680*** **	-0.01
Sabellidae	**0.456*** **	-0.382**
Sigalionidae	0.361**	**-0.552*** **
Spionidae	**0.784*** **	-0.113
Syllidae	-0.078	0.008
Amphipoda	0.332**	-0.296*
Balanidae	**0.514*** **	**-0.718*** **
Tellinidae	**0.521*** **	-0.096
Echinodermata	0.176	-0.327**
Cirratulidae	0.395**	0.027
Orbiniidae	-0.284*	0.227
Paraonidae	-0.135	-0.093

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 53 stations.

NMDS1 scores were negatively associated with Min *d* in 2020 (r_S = -0.38, $p \leq 0.01$, Table 5-40; Figure 5-62). Effects on NMDS1 were not remarkably apparent from Figure 5-62, although scores were relatively high at a few stations near the FEZ and FE drill centres. In keeping with these relatively weak effects, the correlation from the multiple regression incorporating FEZ *d* and FE *d* (Multiple R) was not significant and no partial correlations were significant (Table 5-40).

Variations in abundances of selected taxa in relation to Min *d* in 2020 are illustrated in Figure 5-63. Stations nearer drill centres tended to have higher numbers of Cirratulidae, Phyllodocidae, Sabellidae, Spionidae, Balanidae, and Tellinidae, and lower numbers of Paraonidae (all r_S p's ≤ 0.05). No significant trends with Min *d* were noted in 2020 for Orbiniidae, Sigalionidae, Syllidae, Amphipoda, or Echinodermata (Figure 5-63).

NMDS2 scores were not significantly correlated with any distance measure in 2020 (r_S = 0.05, Table 5-41; Figure 5-62). Partial correlations with distances from the FEZ and FE drill centres, as well as the multiple correlation coefficient, also were not significant (Table 5-41).

Table 5-40 Results of Rank-Rank Regression of NMDS 1 and 2 on Distance Variables (2020)

Response Variable	Multiple R	Regression on distance from nearest FEZ and FE Drill Centres (Partial *r*)		Min *d* (r_S)
		FEZ *d* (FE *d* constant)	**FE *d* (FEZ *d* constant)**	
NMDS1	0.30	-0.27	-0.08	-0.38**
NMDS2	0.08	-0.03	0.08	0.05

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

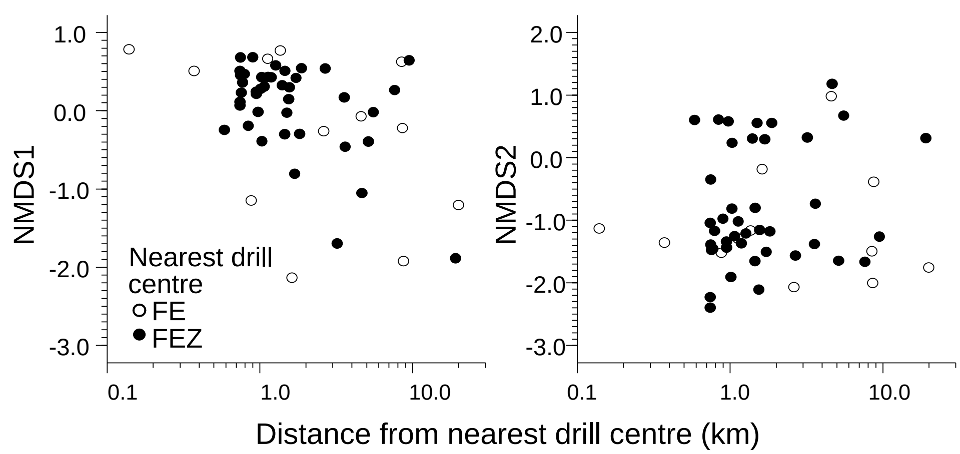


Figure 5-62 Distance Gradient for NMDS 1 and 2 (2020)

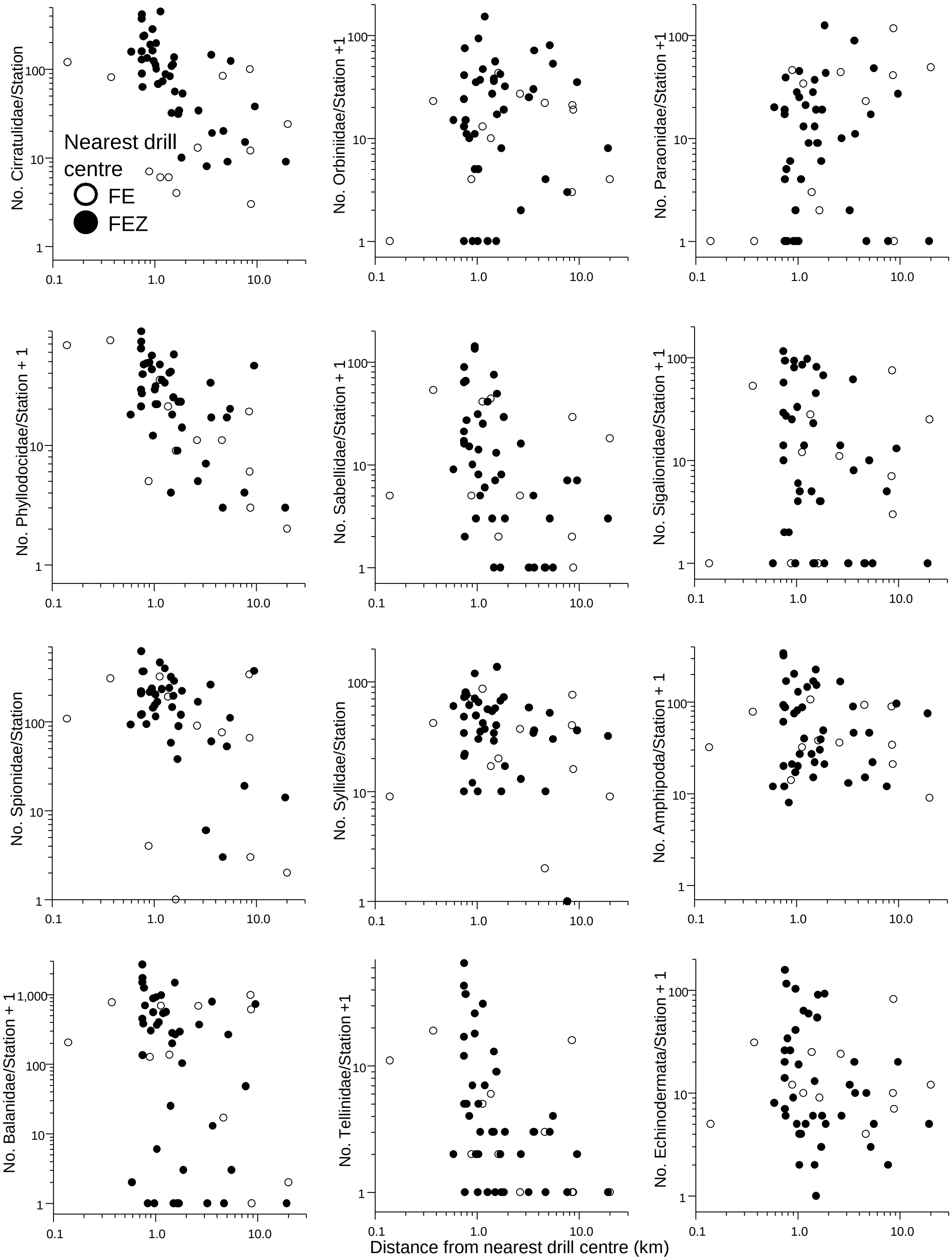


Figure 5-63 Distance Gradient for Selected Benthic Taxa (2020)

Across years, NMDS1 score correlations with Min *d* have generally been negative (Figure 5-64). Numbers of Cirratulidae, Phyllodocidae, Sabellidae, Spionidae, and Tellinidae have typically decreased with distance from drill centres across sampling years, while numbers of Orbiniidae and Paraonidae have typically increased with distance across sampling years (Figure 5-65).

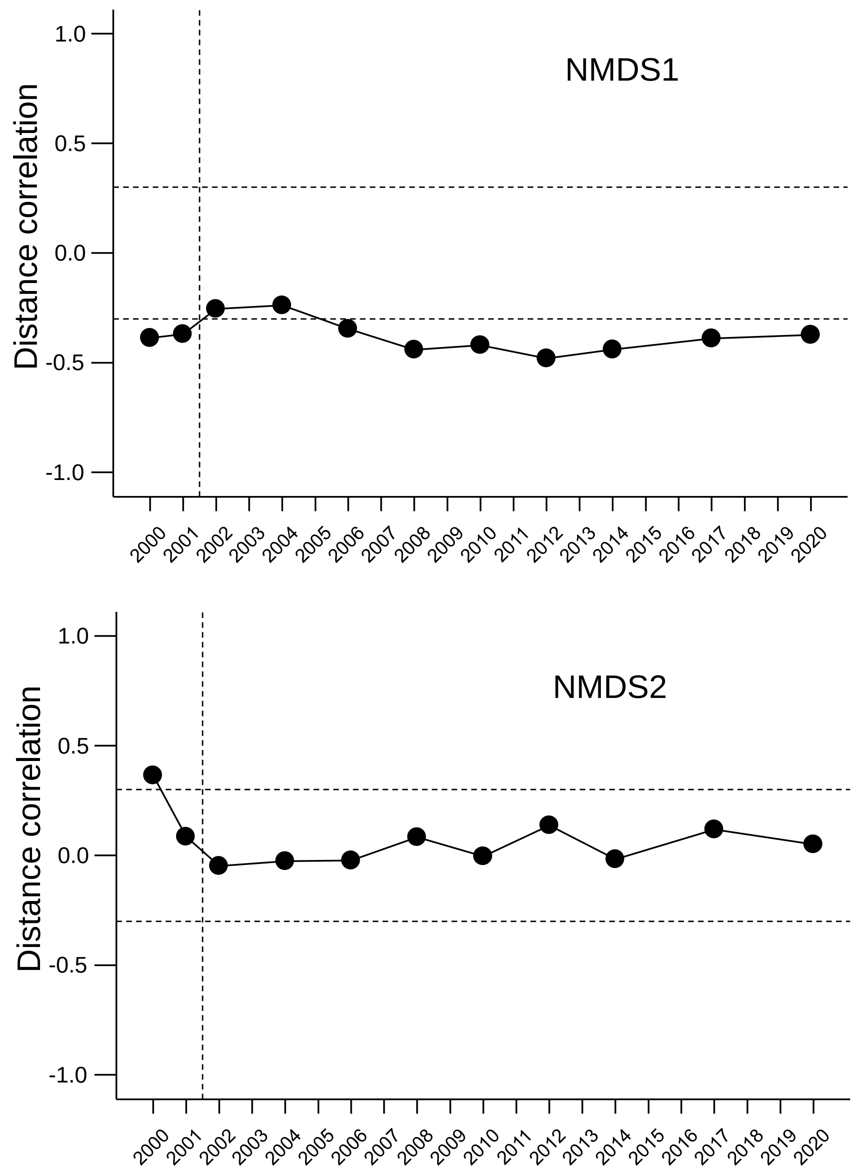


Figure 5-64 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for NMDS1 and NMDS2 (2000 to 2020)

Notes: The dashed horizontal lines indicate a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020.

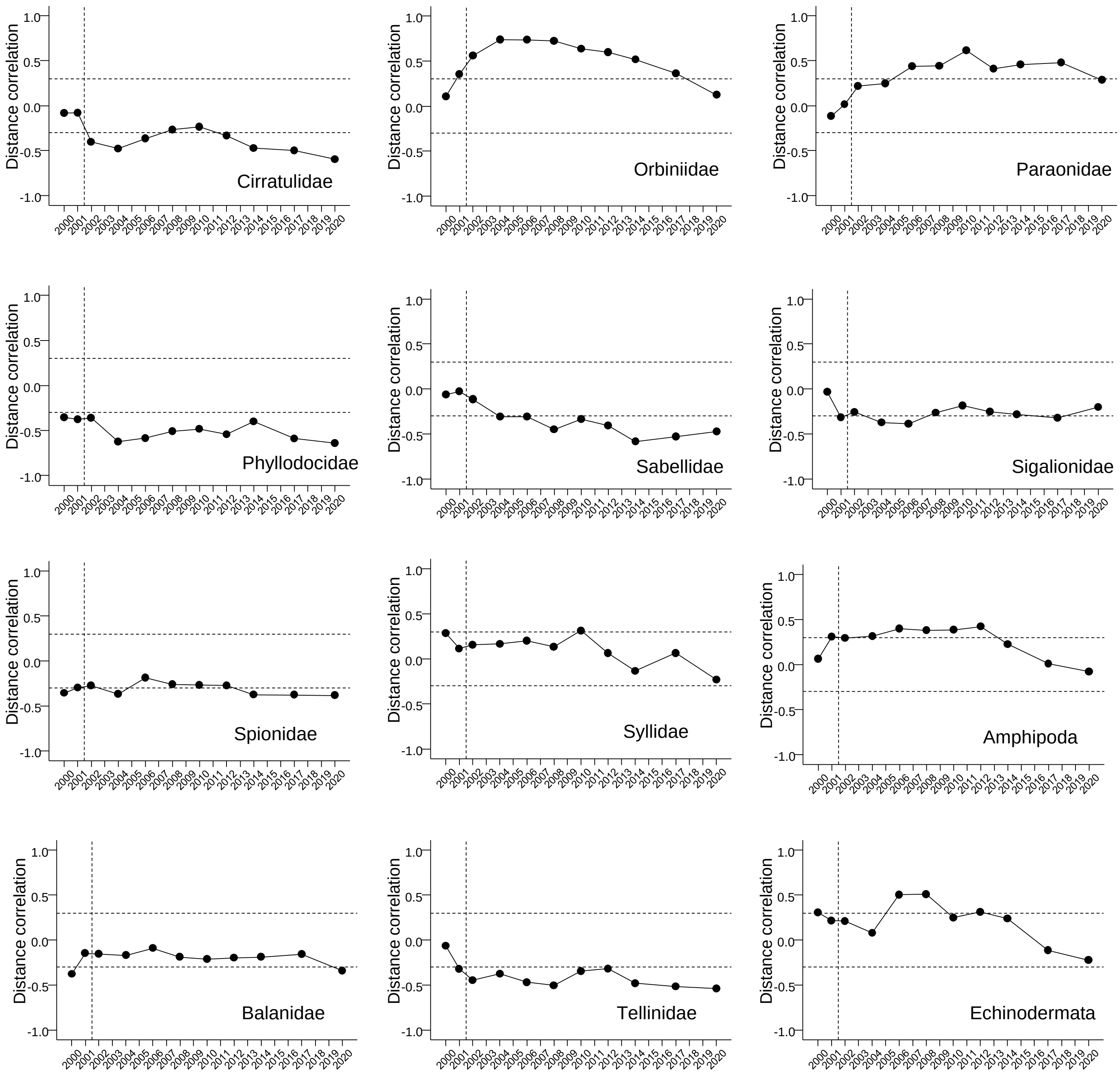


Figure 5-65 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Major and Numerically Dominant Benthic Taxa (2000 to 2020)

Notes: The dashed horizontal lines indicate a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at $p \leq 0.01$, depending on sample size in the given year. The dashed vertical line indicates the start of drilling at the FE Drill Centre (prior to the 2002 EEM sampling program). Active drill centres were: NE, SW in 2000; all FEZ drill centres in 2001; and all drill centres from 2002 to 2020.

Numbers of Balanidae decreased with distance from drill centres in 2000 and again in 2020 (Figure 5-65). Correlations for other selected taxa have been more variable. NMDS2 scores have generally never correlated significantly with Min *d*, except in year 2000, when the relationship was positive (Figure 5-64).

Results of repeated-measures regression for NMDS scores are provided in Table 5-41. The overall FEZ regression slope was significant for NMDS1 (F = 14.4, $p \leq 0.001$). NMDS1 FEZ regression slopes generally increased over time (F = 4.9, $p \leq 0.05$, Figure 5-66). The overall FE regression slope was not significant for NMDS1 (Table 5-42). However, NMDS1 FE slopes changed over time; FE slopes were generally lower from 2002 to 2020, relative to 2001 (F = 5.3, $p \leq 0.05$); and slopes generally decreased over time (F = 16.8, $p \leq 0.001$; Figure 5-66). Overall NMDS1 scores have varied over time (F = 13.1, $p \leq 0.001$; F = 11.4, $p \leq 0.01$; Table5-42; Figure 5-60).

Table 5-41 Results (F Values) of Repeated-Measures Regressions Comparing NMDS 1 and 2 Among EEM Years (2001 to 2020)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After (2001 vs 2002 to 2020)**	**Linear Trend 2002 to 2020**	**Quadratic Trend 2002 to 2020**
NMDS1					
FEZ *d*	**14.4*** **				
FE *d*	1.3				
Year		**5.7*** **	1.1	11.4**	**13.1*** **
Year x FEZ *d*		1.4	0.03	4.9*	0.8
Year x FE *d*		**5.1*** **	5.3*	**16.8*** **	0.4
NMDS2					
FEZ *d*	0.01				
FE *d*	0.9				
Year		2.1*	1.1	6.0*	0.1
Year x FEZ *d*		1.7	0.1	2.5	1.4
Year x FE *d*		0.5	0.1	0.01	0.01

Notes:
- *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 48 stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Repeated-measures regression excluded 2000 since not all samples were processed using the elutriate methods in that year.
- Distance variables (X) and Y variables were rank-transformed.
- F values were rounded to one decimal place.

There were no significant overall FEZ or FE regression slopes for NMDS2 (Table 5-41). There were also no significant annual variations in FEZ or FE regression slopes (Figure 5-66). Overall NMDS2 scores have significantly decreased over time (F = 6.0; $p \leq 0.05$; Figure 5-60).

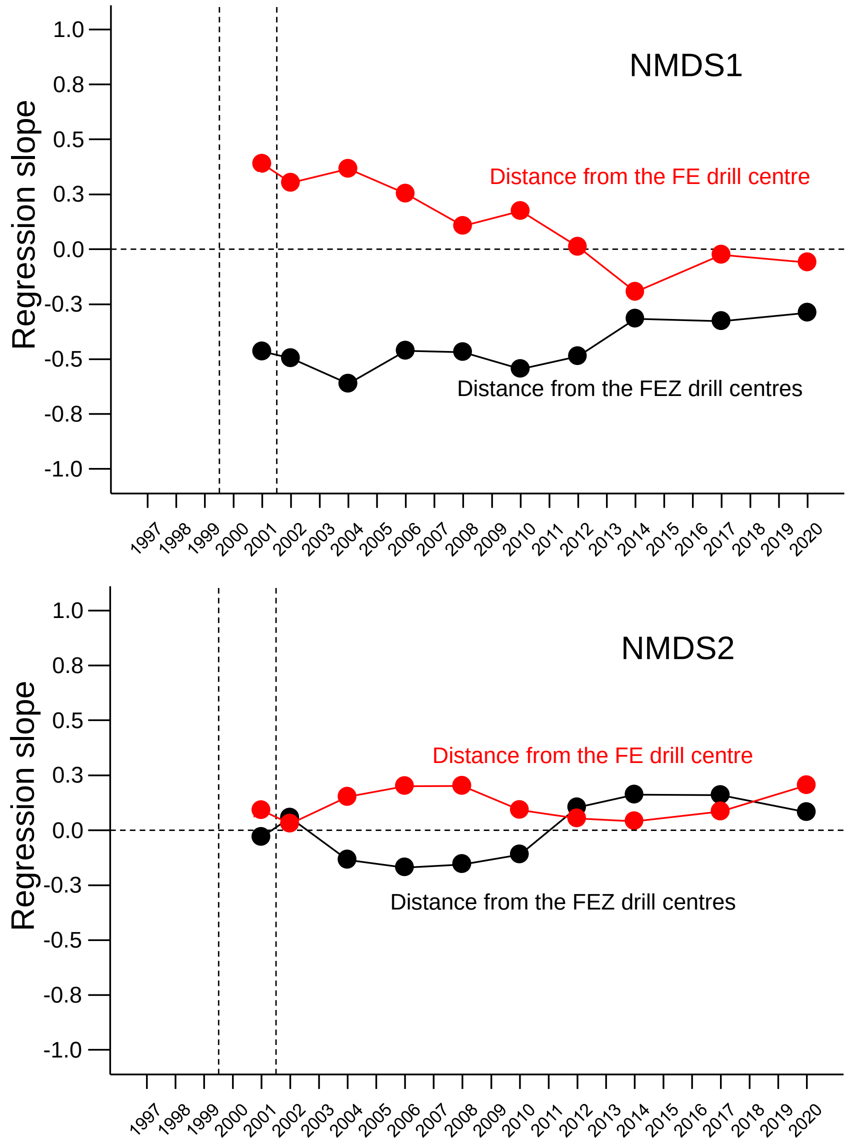


Figure 5-66 Annual Multiple Regression Distance Slopes for NMDS 1 and NMDS 2 (2001 to 2020)

Note: Dashed vertical lines indicate the start of drilling at the FEZ drill centres (prior to the 2000 EEM sampling program) and at the FE Drill Centre (prior to the 2002 EEM sampling program).

5.3.3.7 Integrated Assessment

Various analyses were used in the sections above to describe the relationships among chemical, physical, toxicological, and biological measures. The purpose of this section is to carry out a more integrated analysis that articulates to a greater degree the magnitude and nature of the covariation among the core variables, with an emphasis on identifying those variables that fundamentally influence the composition of the invertebrate community. The following core variables were carried forward into the integrated assessment:

- Distance to drill centres: The variable Min *d* was used as the single measure of distance to active drill centres on the basis that many physical, chemical, or biological variables correlated with this measure.
- Sediment chemistry: Barium and >C_{10}-C_{21} hydrocarbons were selected because they are the principal indicators of the presence of drill cuttings in sediments.
- Metals PC1 was selected because it described the principal metals gradient.
- Sediment physical condition: Percent fines, gravel, and organic carbon content were selected because they collectively described the physical configuration and organic content of the sediments, factors that fundamentally influence benthic community composition.
- Laboratory amphipod survival was selected to represent toxic and non-toxic sediments[26].
- Sediment biology: Summary invertebrate community measures including abundance, biomass, richness, adjusted richness, NMDS1 scores, and NMDS2 scores were selected because they represent the principal attributes of interest in the community.

The analysis was carried out in two parts. The first part consisted of a PCA of core variables listed above. The PCA was carried out using data from 2000 to 2020 (i.e., 560 observations). The PCA results in this integrated assessment were used as a first assessment of the associations among the core variables.

Pearson correlations of the original variables with the principal component axes are provided in Table 5-42. Correlations of magnitude >|0.6| were considered strongly associated with a PCA axis and are used to interpret the axes.

[26] Polychaete toxicity data were not used in the integrated assessment because the test was not performed in years prior to 2020.

Table 5-42 Correlations (r_p) Between Core Sediment Variables and Principal Component Axis Station Scores (2000 to 2020)

Variable	Correlation with Principal Component Axis	
	1	**2**
Min *d*	-0.41	-0.34
Abundance	**0.87**	-0.05
Biomass	0.08	0.21
Richness	**0.89**	-0.36
Adjusted Richness	0.59	**-0.61**
NMDS1	**0.77**	0.31
NMDS2	**-0.76**	0.53
Amphipod Survival	-0.28	-0.01
Barium	0.52	**0.65**
>C_{10}-C_{21} Hydrocarbons	**0.69**	**0.61**
Metals PC1	0.56	0.28
Organic Carbon	**0.73**	0.07
% Fines	**0.82**	0.04
% Gravel	**0.72**	-0.39
Variance Explained	43.6	14.8

Notes: - Abundance, biomass, richness, barium, >C_{10}-C_{21} hydrocarbons, TOC, fines, and gravel were log_{10}-transformed for PCA.
- PCA axes were retained if they explained more than 10% of the total variation in the data.
- $r_p \geq 0.60$ in bold.

The first PCA axis scores were strongly positively correlated with total abundance, taxa richness, NMDS1, >C_{10}-C_{21} hydrocarbon concentrations, organic carbon content, % fines, and % gravel. The first PCA axis scores were also strongly negatively correlated with NMDS2. The second PCA axis scores were strongly positively correlated with adjusted richness, barium and >C_{10}-C_{21} hydrocarbon concentrations, indicating that these three variables behaved somewhat differently.

The second step in the analysis involved the calculation of Spearman rank correlations between measures of benthic community composition and select physical/chemical measures describing the sediment, and visualization of those relationships using scatterplots. The selection of variables for this step was based in part on the results of the PCA above; that is, the selection of variables that provided somewhat unique information. All of the key invertebrate community summary measures were included because each summary measure is considered an important descriptor. Barium and >C_{10}-C_{21} hydrocarbons concentrations were retained because they were the principal indicators of the presence of drill cuttings in sediments. Percent of the sediment as gravel and fines are somewhat redundant with organic carbon content since the variables are correlated. Therefore, gravel and fines were excluded, and organic carbon content was retained. Metals PC1, amphipod survival and Min *d* were not included because they were not strongly correlated with PCA axis scores.

In 2020, total benthic abundances and taxa richness were significantly positively correlated with organic carbon content, and barium and $>C_{10}$-C_{21} hydrocarbon concentrations, as in most years (Figures 5-67 and 5-68). The positive relationships for abundance and richness with organic carbon content and barium, and $>C_{10}$-C_{21} hydrocarbon concentrations indicates that sediments with higher amounts of these compounds had higher abundances and higher taxa richness.

Biomass in 2020 was not significantly correlated with organic carbon content or barium, as in most previous years (Figure 5-69). Biomass was weakly positively correlated (i.e., increased) with $>C_{10}$-C_{21} hydrocarbon concentrations ($r_s = 0.26$, $p \leq 0.05$), as it was in 2014.

Adjusted richness was not significantly correlated with organic carbon content, barium or $>C_{10}$-C_{21} hydrocarbon concentrations in 2020, as in most previous years (Figure 5-70).

NMDS1 scores (reflecting Spionidae dominance) were significantly positively associated with organic carbon content, barium, and $>C_{10}$-C_{21} hydrocarbon concentrations across all years (Figure 5-71). The association between NMDS1 scores and organic carbon content has generally been comparable to the association with the two drill cuttings indicators (Figure 5-71). However, since organic carbon was not visibly affected by project activities, the association may be natural and could indicate that natural distance gradients existed for benthos during baseline[27], like it did for organic carbon, sediment fines content, and many other variables.

In 2020, NMDS2 scores (reflecting Cirratulidae dominance) were significantly and negatively correlated with sediment barium concentrations, as they were in 2001, 2008, 2010, and 2017 (Figure 5-72).

[27] Baseline data are unavailable for benthic invertebrates.

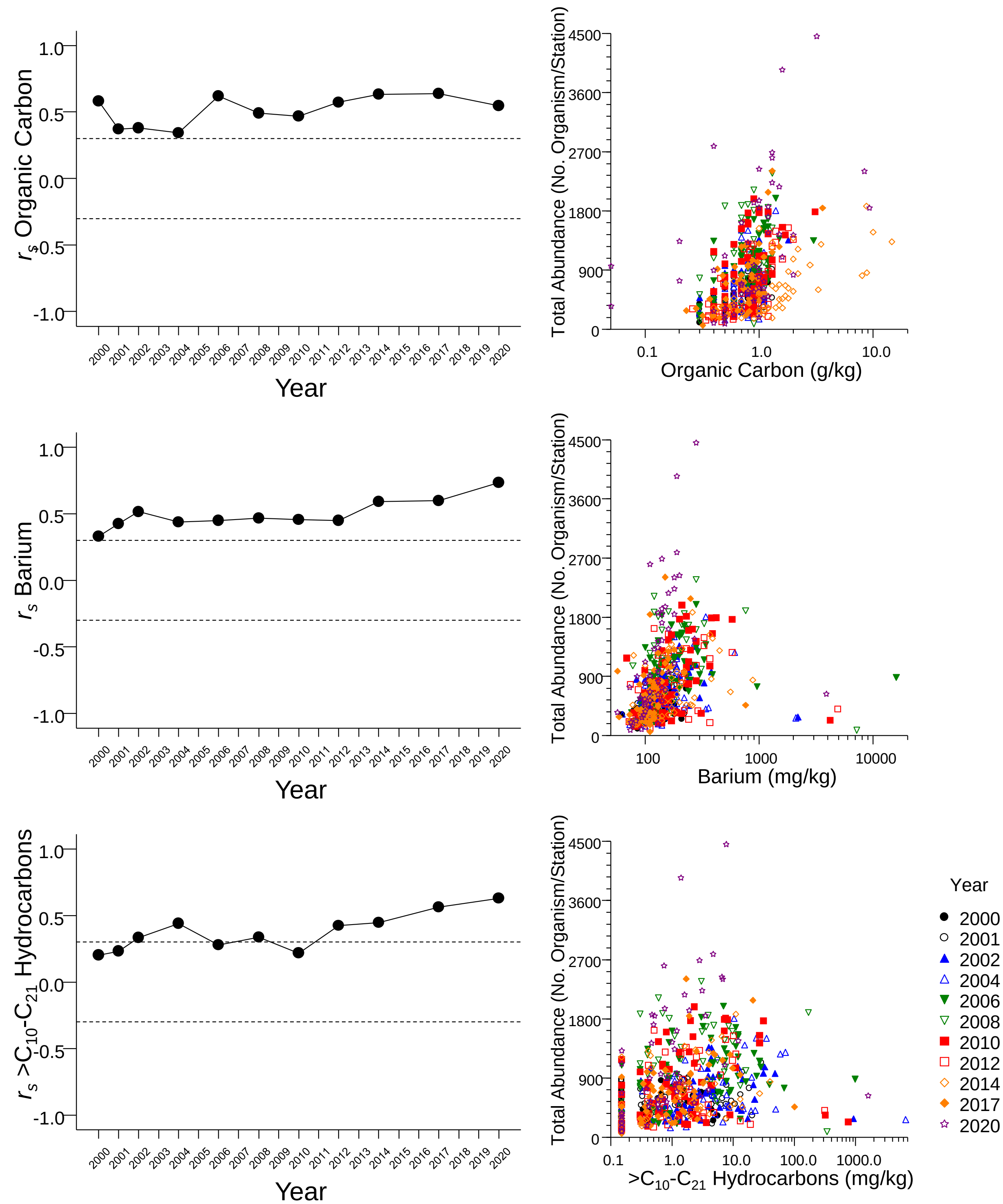


Figure 5-67 Spearman Rank Correlations Over Time and Scatterplots of Total Abundance in Relation to Organic Carbon, Barium, and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at p ≤ 0.01, depending on sample size in the given year. Variables were log_{10}-transformed for correlations.

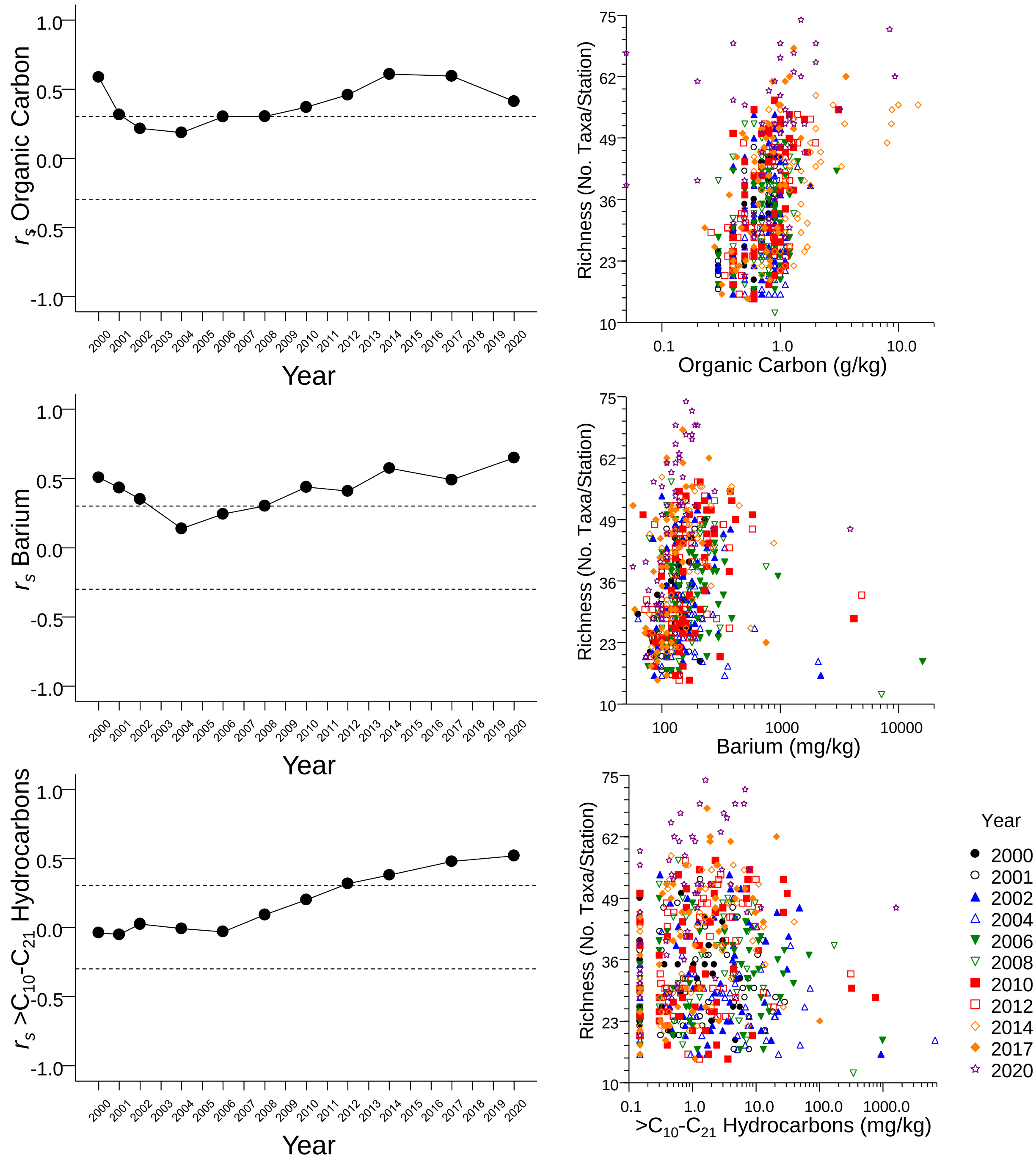


Figure 5-68 Spearman Rank Correlations Over Time and Scatterplots of Richness in Relation to Organic Carbon, Barium, and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at p ≤ *0.01, depending on sample size in the given year. Variables were* log_{10}*-transformed for correlations.*

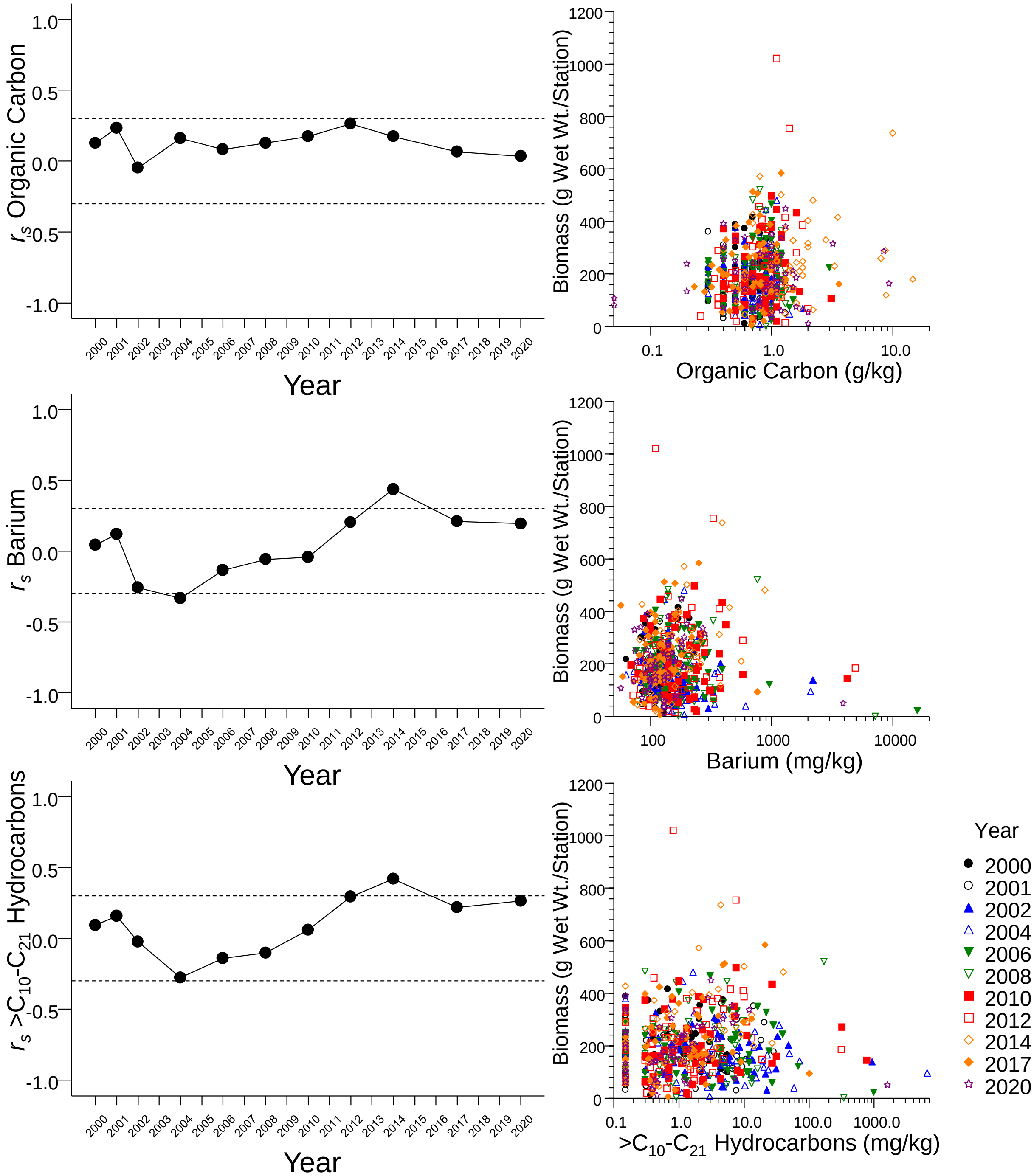


Figure 5-69 Spearman Rank Correlations Over Time and Scatterplots of Biomass in Relation to Organic Carbon, Barium, and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at p ≤ 0.01, depending on sample size in the given year. Variables were log_{10}-transformed for correlations.

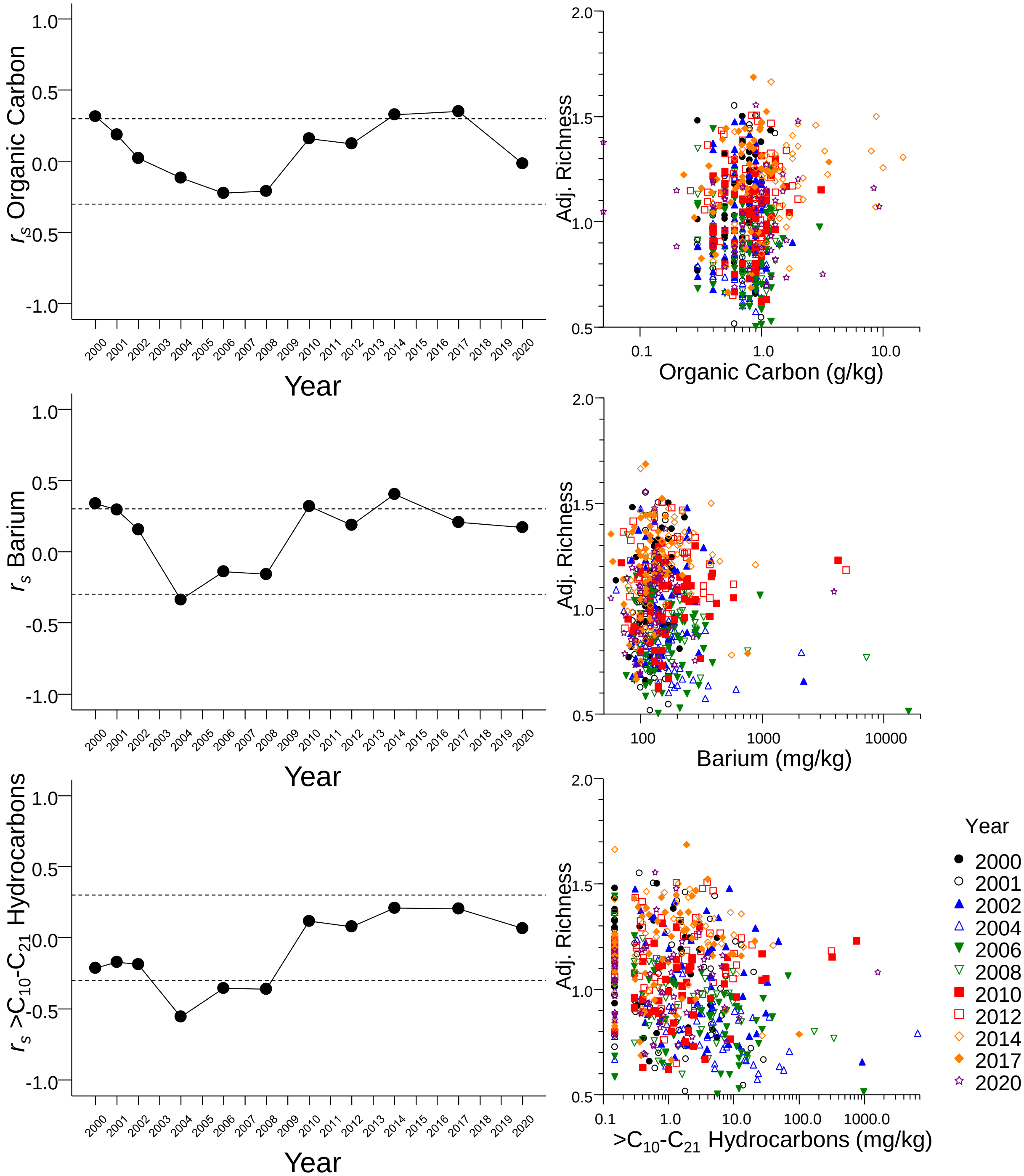


Figure 5-70 Spearman Rank Correlations Over Time and Scatterplots of Adjusted Richness in Relation to Organic Carbon, Barium, and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at p ≤ 0.01, depending on sample size in the given year. Variables were log_{10}-transformed for correlations.

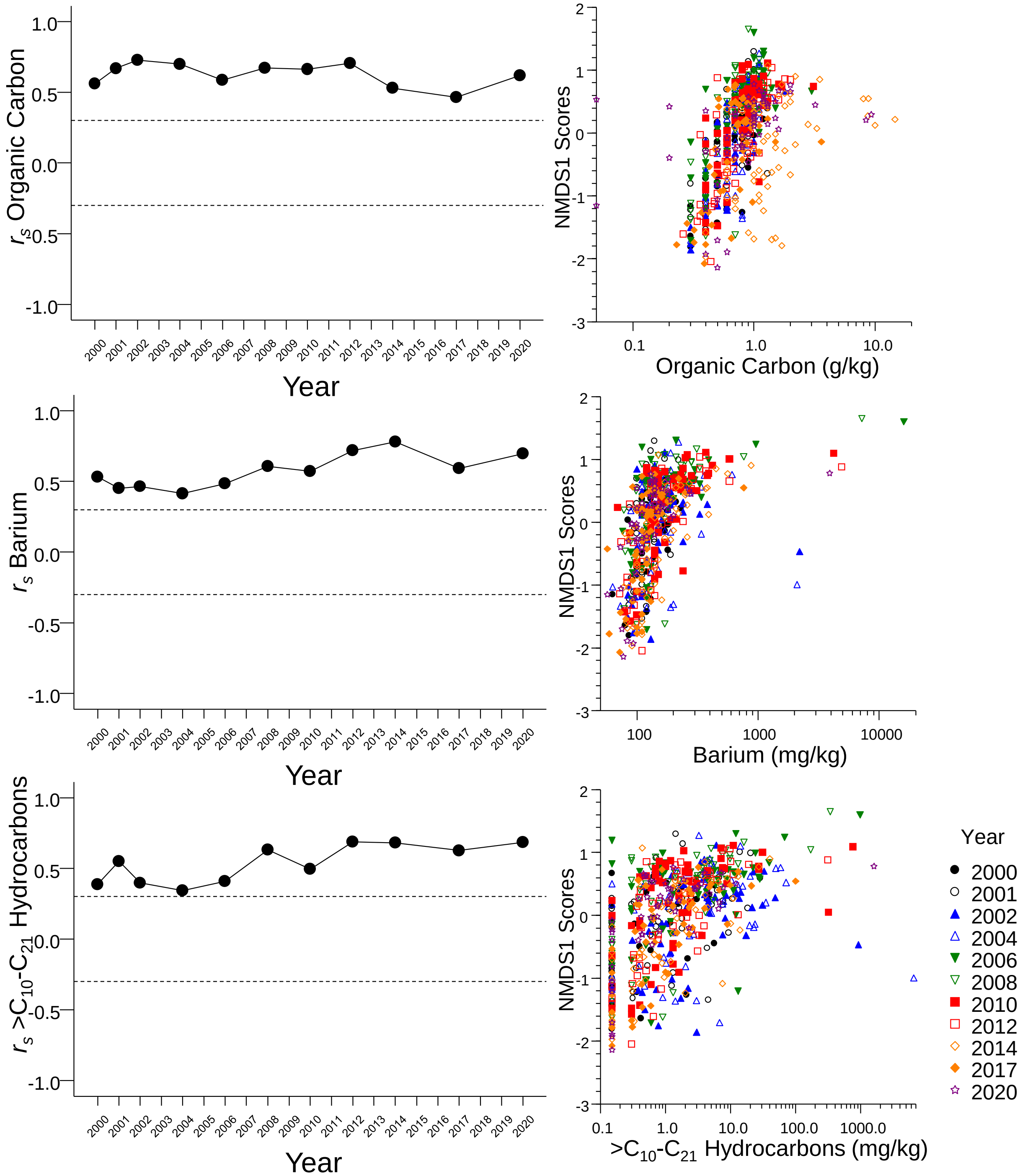


Figure 5-71 Spearman Rank Correlations Over Time and Scatterplots of NMDS1 Scores in Relation to Organic Carbon, Barium, and $>C_{10}$-C_{21} Hydrocarbons

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at p ≤ 0.01, depending on sample size in the given year. Variables were log_{10}-transformed for correlations.

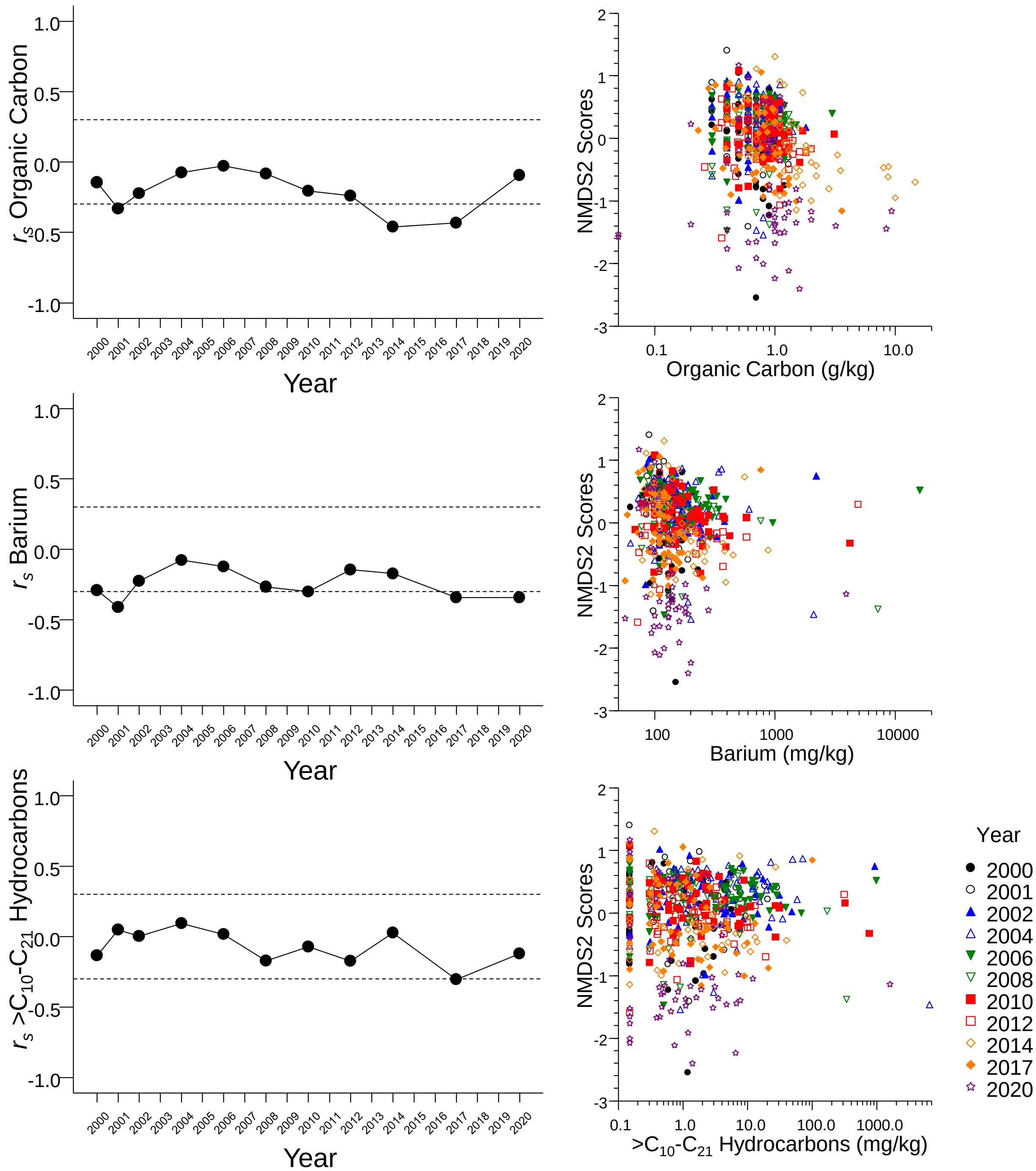


Figure 5-72 Spearman Rank Correlations Over Time and Scatterplots of NMDS2 Scores in Relation to Organic Carbon, Barium, and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values greater than |0.3| were generally significant at p ≤ *0.01, depending on sample size in the given year. Variables were log_{10}-transformed for correlations.*

5.4 SUMMARY OF RESULTS

5.4.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

>C_{10}-C_{21} hydrocarbon concentrations in sediments increased from 2000 to 2006 and have since decreased. Median >C_{10}-C_{21} hydrocarbon concentrations increased from 0.67 mg/kg in 2000 to 4.30 mg/kg in 2006, then decreased to concentrations ranging from 0.7 to 1.4 mg/kg from 2008 to 2020. The highest >C_{10}-C_{21} hydrocarbon concentration (6,550 mg/kg) over all years occurred in 2004 at Station 30(FE), located 0.14 km from the FE Drill Centre. The highest concentration in 2020 (1,600 mg/kg) also occurred at Station 30(FE).

Median barium concentrations increased from 120 mg/kg in baseline (1997) to concentrations ranging from 130 to 170 mg/kg from 2000 to 2020. Median concentrations in EEM years have been below the 95th percentile concentration noted in baseline (200 mg/kg). The maximum barium concentration over all years (16,000 mg/kg) occurred in 2006 at Station 30(FE). The highest concentration in 2020 (3,900 mg/kg) also occurred at Station 30(FE).

In 2020, as in previous years, >C_{10}-C_{21} hydrocarbons and barium concentrations decreased significantly with distance from drill centres. Sediment concentrations of >C_{10}-C_{21} hydrocarbons decreased to low levels (near the detection level of 0.3 mg/kg) within approximately 2 km from drill centres. Estimated distances at which low concentrations were reached (i.e., threshold distances) for >C_{10}-C_{21} hydrocarbons were in the range of 4 to 5 km in 2004, 2006 and 2014; threshold distances were approximately 2 to 3 km other years. Since confidence intervals (a measure of error about estimates) overlapped, the 2020 threshold is not statistically different from the threshold distances that were computed from 2008 to 2017. However, the threshold distance in 2020 is smaller than threshold distances computed in 2004 and 2006.

Concentrations of barium decreased to background levels within approximately 1 km of drill centres in 2020. Threshold distances for barium have been between 1 and 2 km in most previous years, except in 2014, when the threshold was approximately 3 km. Confidence intervals for the 2020 estimate did not overlap with confidence intervals for threshold estimates from 2002, 2010 and 2014. The threshold was lower in 2020 than in those three years, and similar to thresholds noted in remaining EEM years.

Statistical comparison among years through repeated-measures regression indicated that the slope of the relationship between sediment concentrations of >C_{10}-C_{21} hydrocarbons and distance from the FEZ drill centres varied among EEM years, with a general but slight decrease in strength over time. The slope of the relationships for sediment barium and distance from the FEZ drill centres also changed over time, with slopes generally decreasing in strength over time. The slope of the relationship between >C_{10}-C_{21} hydrocarbons and barium sediment concentrations and distance from the FE Drill Centre changed after drilling began at that drill centre. In both cases, concentrations increased with distance from the FE Drill Centre before drilling (i.e., increased toward the centre of the development and the FEZ). After drilling at the FE Drill Centre, that relationship was obscured, predominantly by higher concentrations at the two stations nearest the FE Drill Centre (30(FE) and 31(FE)). Distance relationships for >C_{10}-C_{21} hydrocarbons and barium generally decreased with distance from the FE Drill Centre after drilling began at the drill centre (i.e., a reversal of regression slopes from positive to negative).

Fines content in 2020 ranged from 0.7% to 3.4% (median = 1.4%). Fines content during baseline (1997) ranged from 0.7% to 3.4% (median = 1.0%). Fines content decreased with distance from drill centres in every year, including baseline (1997). These distance correlations were significant in 2000, 2006, 2010 and 2017, and weaker in remaining years (including 2020). Repeated-measures regression indicated no change in the slope of the relationship between sediment fines content and distance from the FEZ or FE drill centres in EEM years.

Organic carbon content has generally decreased with increasing distance from FEZ drill centres and increased with distance from the FE Drill Centre in both baseline and EEM years (a relationship largely driven by increases in organic carbon content, and many other variables, toward the centre of the development). Repeated-measured regression indicated no change in the relationship between sediment organic carbon content and distance from the FEZ or FE drill centres in EEM years; and baseline distance correlations were generally as strong or stronger than in EEM years.

Sediment metals concentrations (as assessed by Metals PC1) were somewhat higher in baseline and 2010 and somewhat lower in 2020. Metals PC1 can be considered a summary measure for sediment concentrations of aluminum, chromium, iron, lead, manganese, and vanadium. Metals PC2 scores have remained similar across years. Metals PC2 scores can be considered a summary measure for sediment concentrations of strontium relative to concentrations of manganese. Metals PC1 scores generally decreased from the centre of the development in all years (including baseline). That relationship was significant in 2020. However, repeated measures regression indicated with no change in the slopes of the relationships over time. Metals PC2 scores were unrelated to any distance measure with no change in distance relationships over time.

Sediment ammonia concentrations were highest in 2001 (when ammonia was first measured) and have decreased since then. Ammonia concentrations decreased with distance from the FEZ drill centres and increased with distance from the FE Drill Centre in all years. The negative distance slope from the FEZ drill centres was somewhat weaker in 2001 than in subsequent years. There was no change over time in distance slopes from the FE Drill Centre.

Sediment sulphur concentrations were generally less than 0.10 mg/kg since sulphur was first measured (in 2001). Sulphur concentrations decreased with distance from the FEZ drill centres in most EEM years. Negative distance relationships were modestly strong in earlier EEM years, with higher concentrations near drill centres. The relationship weakened in 2017 and results indicated a positive rather than negative relationship in 2020 (i.e., lower sulphur concentration near the FEZ drill centres). Sulphur concentrations have generally not been related to distance from the FE Drill Centre.

Sediment sulphide concentrations have been measured at a consistent laboratory detection limit since 2006. Overall sulphide levels were highest in 2008 and lowest in 2014. Levels in all years have generally been below 10 mg/kg. Sulphide concentrations decreased with distance from drill centres in 2020, 2014 and 2008; three of the seven years it was measured. In 2020 and 2014, the distance correlation from the FEZ drill centres was stronger than the correlation from the FE Drill Centre. In 2008, the distance correlation from the FE Drill Centre was stronger.

Sediment redox potential has varied over time, with lower levels in 2004 and 2008. Redox potential generally increased with distance from the FEZ drill centres in EEM years (i.e., lower redox potential near FEZ drill centres), with stronger relationships in 2002, 2014 and 2020. Distance relationships from the FE Drill Centre have been highly variables, sometimes positive, sometimes negative. The 2020 relationship between redox and distance from the FE Drill Centre was significant and negative, indicating higher redox potential near the FE Drill Centre. In spite of relationships with distance from the FEZ and FE drill centres, redox values in 2020 were similar to redox values noted since 2010, as well as in baseline, and all sediments were oxic (>100 mV).

For $>C_{10}$-C_{21} hydrocarbons, barium, fines, metals other than barium, organic carbon, sulphur, and redox, distance relationships from the FEZ drill centres (i.e., the centre of the development) have been stronger than relationships from the FE Drill Centre. Some of these relationships relate to natural distance gradients from the centre of the development observed in baseline. The accentuation of the relationship for barium and the presence of distance gradients for $>C_{10}$-C_{21} hydrocarbons relate to project effects. Changes in distance gradients after drilling at the FE Drill Centre for $>C_{10}$-C_{21} hydrocarbons and barium also relate to project effects.

5.4.2 TOXICITY

There has been little evidence for project effects on laboratory amphipods in EEM years and more than 97% of samples have been non-toxic. In 2020, amphipod survival ranged from 80% to 100%, and no samples were classified as toxic following Environment and Climate Change Canada (1998) interpretative guidance for sediments.

Polychaete toxicity tests were not performed in years prior 2020. In 2020, polychaete survival ranged from 47% to 100%, with a median of 90%, and one sample (from Station 46(FEZ) was considered toxic. Polychaete growth was not reduced to below 30% of growth in control sediment in sediments from any station. However, polychaete growth was reduced to below 20% of growth in reference sediment in sediments from 6 of the 41 stations tested (Stations 5(SW), 21 (NW), 29(FE), 31(FE), 37(FEZ), and 49(FEZ)).

There were no correlations between the three toxicity variables in 2020, and all correlations between each variable and sediment physical and chemical characteristics were weak and non-significant. The toxicity variables were also uncorrelated with distance to drill centres.

5.4.3 BENTHIC COMMUNITY STRUCTURE

In 2020, total abundance, richness and NMDS1 scores (Spionidae dominance) decreased with distance from the nearest drill centre (i.e., were higher near drill centres), with distance relationships from the FEZ drill centres stronger than relationships from the FE Drill Centre. Biomass was unrelated to distance to the nearest drill centre. However, biomass was negatively related (i.e., decreased with) distance from the FEZ drill centres and increased with distance from the FE Drill Centre. These opposing relationships explain the lack of relationship between biomass and distance to the nearest drill centre (which aggregates both distance measures). Adjusted richness and NMDS2 scores (Cirratulidae dominance) were not significantly correlated with distances to the nearest drill centre in 2020; nor were they significantly correlated with distance to the FEZ or FE drill centres.

Gradients observed in 2020 were similar to those observed in previous EEM years. Statistical comparison among years through repeated-measures regression indicated that there was a decrease in abundance with distance from the FEZ drill centres across all years, consistent with 2020 results. The strength of this gradient changed over time, with the relationship weakening from 2004 to 2010 and strengthening from 2012 to 2020. There was no gradient in total abundance with distance from the FE Drill Centre across all years and no changes over time. Overall total abundance (i.e., at all or most stations) generally increased to 2008, decreased to 2012 and subsequently increased. Total abundance in 2020 was higher than in any previous year, and this predominantly because of an increase in the overall abundance of Balanidae (i.e., across all or most stations).

There was a decrease in biomass with distance from the FEZ drill centres across all years and this gradient became stronger over time. There was also an increase in biomass with distance from the FE Drill Centre across all years, but with no change over time and no change in the gradient from before to after drilling began at the FE Drill Centre. Overall biomass (i.e., at all or most stations) increased to 2012, and subsequently decrease.

There was no overall relationship between richness and distance from the FEZ drill centres across all years. However, the relationships changed over time from near zero in most years to stronger and negative since 2012 (i.e., a decrease in richness with distance from the FEZ drill centres). There was no relationship between richness and distance from the FE Drill Centre across all years, and no change over time. Overall richness has increased over time, with the highest richness values noted in 2020.

There were no significant relationships between adjusted richness and distance from either the FEZ or FE drill centres across all years. However, there were changes in the relationship from the FEZ drill centres over time; the positive relationship between adjusted richness and distance from the FEZ drill centres weakened in 2008 and became negative in 2014 and 2017. The relationship was again positive in 2020 (results from the within year analysis above indicate that this positive relationship is not significant). There was no relationship between adjusted richness and distance from the FE Drill Centre across all years, and no change over time. Overall adjusted richness was marginally lower from 2004 to 2010 than in other years.

The overall relationship between NMDS1 scores and distance from the FEZ drill centres across all year was strong and negative indicating a decrease in NMDS1 scores with distance from the FEZ drill centres. The negative relationship between NMDS1 scores and distance to the FEZ drill centres decreased in strength over time, indicating that Spionidae dominance noted near drill centres in earlier EEM years was less pronounced in later EEM years (2001 to 2012 versus 2014 to 2020). The overall relationships between NMDS1 scores and distance from the FE Drill Centre was not significant. However, FE slopes changed over time and have gradually decreased from positive in 2001 to negative since 2014, indicating Spionidae dominance near the FE Drill Centre since 2014.

There were no overall relationships between NMDS2 scores and distance from either the FEZ or FE drill centres across all years and no change over time.

Changes over time in the above indices with distance to drill centres were generally subtle and/or not associated with the onset of drilling; although observed gradients for abundance, biomass and richness were stronger in 2020 than noted previously, and abundance and richness were higher. In 2020, the strongest distance gradients occurred with total abundance. Of the taxa examined individually in this report, stations nearer drill centres tended to have higher numbers of Spionidae, Cirratulidae, Phyllodocidae, Sabellidae, Balanidae, and Tellinidae, and lower numbers of Paraonidae in 2020. No trends with distance to the nearest drill centres were noted in 2020 for Orbiniidae, Sigalionidae, Syllidae, Amphipoda, or Echinodermata. As in previous years, threshold relationships were not apparent for summary measures of benthic community or for individual taxa (as they have been for $>C_{10}$-C_{21} hydrocarbon and barium concentrations), but effects on the most affected taxa were apparent within approximately 1 to 2 km of drill centres.

5.4.3.1 Integrated Assessment

Correlations between total abundance, richness and NMDS1 scores and sediment organic carbon content, barium and $>C_{10}$-C_{21} hydrocarbon concentrations have been significant in most years and positive, indicating higher total abundance, richness and NMDS1 scores in sediments with higher organic content and barium and $>C_{10}$-C_{21} hydrocarbon concentrations. Since organic carbon content was not visibly affected by project activity, the consistent association between it and total abundance, richness, and NMDS1 may be partly natural and could indicate that, like organic carbon, natural distance gradients existed for benthos during baseline.

Correlations between biomass, adjusted richness and NMDS2 scores and sediment organic carbon content and barium and >C_{10}-C_{21} hydrocarbon concentrations have generally been weak and/or inconsistent. Correlations between biomass and organic carbon and barium were not significant in 2020. Biomass was weakly correlated to >C_{10}-C_{21} hydrocarbon concentrations, as in 2014. As in most previous years, adjusted richness was not correlated with organic carbon, barium or >C_{10}-C_{21} hydrocarbon concentrations. In 2020, NMDS2 scores were significantly and negatively correlated with barium concentration, as in 2001, 2008, 2010, and 2017.

6.0 COMMERCIAL FISH COMPONENT

6.1 FIELD COLLECTION

American plaice (“plaice”) were collected on board the commercial fishing vessel *M/V Atlantic Champion.* Reference Area fish were collected from October 7 to 12, 2020. Study Area fish were collected from October 19 to 20. 2020. Collection dates for the baseline program and EEM programs are shown in Table 6-1.

Table 6-1 Field Trips Dates

Trip	Date
Baseline Program	November 16 to 17, 1997
EEM Program Year 1	July 7 to 8, 2000
EEM Program Year 2	June 27 to July 2, 2001
EEM Program Year 3	June 24 to 30, 2002
EEM Program Year 4	July 10 to 18, 2004
EEM Program Year 5	July 11 to July 21, 2006
EEM Program Year 6	May 26 to June 2, 2008
EEM Program Year 7	June 29 to July 2, 2010
EEM Program Year 8	July 7 to 8, 2012
EEM Program Year 9	June 21 to 26, 2014
EEM Program Year 10	July 12 to 17, 2017
EEM Program Year 11	October 7 to 12 and October 19 to 20, 2020

Notes: -White Rose Reference Area fish collected earlier than Terra Nova Study Area fish are used for Study / Reference comparisons for the 2020 (Year 11) EEM program. See below for further details.

Field collection methods in 2020 were consistent with previous surveys. Details on the collection and processing of samples from the baseline program and from previous EEM programs are presented in Suncor Energy (1998a, 2001, 2002, 2003, 2005, 2007, 2009, 2011, 2013, 2017, 2019). Because of sampling difficulties in 2020, plaice from White Rose Reference Areas 1 and 2 (the two Reference Areas nearest to Terra Nova) are used in this report as Reference Area plaice for Terra Nova[28]. Samples from these two areas are combined in this report for consistency with previous years as the Terra Nova EEM program normally has a single reference area. White Rose Reference Areas 1 and 2 will be referred to as the Reference Area in subsequent instances in this report.

Sampling for the 2020 program was conducted under experimental fishing license NL-6018-20, issued by DFO. Location of sampling transects are provided in Figure 1-20 (Section 1) and in Appendix C-1. Plaice were collected using a

[28] Sufficient plaice were collected in White Rose Reference Areas 1 and 2 to accomodate both the Terra Nova and the White Rose EEM programs.

commercial fishing trawl towed at 3 knots for 15 minutes per transect. A total of 66 plaice were collected in the Terra Nova Study Area in 2020; a total of 90 plaice were collected in the Reference Area.

Preliminary processing of samples was done on board the ship. Plaice that had suffered obvious trawl damage were discarded. Only those plaice larger than 300 mm in length were retained for analysis. Top fillets were frozen at -20°C for subsequent taste analysis. Bottom fillets and liver (left half only) were frozen at -20°C for body burden analysis.

For fish health assessment, fish were euthanized by severing the spinal cord. Each plaice was assessed visually for parasites and/or abnormalities on the skin and fins or internal organs (liver, gonads, digestive track, musculature, and spleen) under the general framework of autopsy-based condition assessment described by Goede and Barton (1990). The entire liver was excised and bisected. A 4- to 5-mm thick slice was cut from the centre portion of the right half of the liver (along the longitudinal axis) and placed in Dietrich's fixative for histological processing. The rest of the right half of the liver was frozen on dry ice until return to port, when it was placed in a -65°C freezer for MFO analysis. The first gill arch on the right/top side of the fish was removed and placed in 10% buffered formalin for histological processing. Otoliths were removed for ageing. Throughout the dissection process, any internal parasites and/or abnormal tissues were preserved in Dietrich's fixative for subsequent identification. Measurements of biological characteristics (fish length, weight (whole and gutted), sex and maturity stage, liver and gonad weight) were performed to support the overall fish health assessment.

The following QA/QC protocols were implemented. The upper and lower fishing decks of the survey vessel were washed with degreaser and disinfectant then flushed with seawater at the beginning of the survey. Flushing of the fishing decks and transfer baskets was continuous throughout 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 were supplied with new latex gloves prior to each transect. Gloves were washed with distilled water after processing each sample within a transect. With the exception of some liver samples used for MFO analysis (see paragraph above), processed samples to be frozen were transferred within one hour of collection to a -20°C freezer. Samples were transferred to testing laboratories within specified sample holding times, as applicable.

6.2 LABORATORY ANALYSIS

6.2.1 ALLOCATION OF SAMPLES

Plaice from five transects in the Study Area and six transects in the Reference Area were used for body burden analysis, taste tests, and fish health analyses (see Table 6-2). Bottom fillet and liver from plaice in each of these transects were composited to generate five body burden samples each for fillet and liver for the Study Area and six such samples for the Reference Area. Top fillets from fish used in body burden analysis were used in taste analyses. Individual fish were examined for fish health (Table 6-2).

Table 6-2 Plaice Selected for Body Burden, Taste and Health Analyses (2020)

Transect	Area	Total No. Fish	Body Burden Composites	Taste Analysis (grams of Top Fillets)	Health Analysis (No. of Fish)
TN1	Study	14	Composite 1 (14 fish)	814	10
TN2	Study	7	Composite 2 (7 fish)	311	3
TN3	Study	15	Composite 3 (15 fish)	306	10
TN4	Study	15	Composite 4 (15 fish)	296	7
TN5	Study	15	Composite 5 (15 fish)	999	10
Total	**Study**	**66**	**5**	**2,726**	**40***
WR-1	Reference	15	Composite 11 (15 fish)	770	10
WR-2	Reference	15	Composite 12 (15 fish)	763	10
WR-3	Reference	15	Composite 13 (15 fish)	771	10
WR-26	Reference	15	Composite 14 (15 fish)	853	10
WR-27	Reference	15	Composite 15 (15 fish)	718	10
WR-28	Reference	15	Composite 16 (15 fish)	752	10
Total	**Reference**	**90**	**5**	**4,627**	**60****

Notes:
- This table identifies composite number for plaice liver and fillet tissue both. Appendix C-2 reports the chemistry results for each tissue type and composite numbers are preceded by 'Liver' or 'Fillet', as appropriate.
- *40 rather than the usual 50 fish were collected from the Study Area for Health Analysis in 2020 because of sampling difficulties due to time of year.
- **60 rather than the usual 50 fish from the Reference Area were examined in Health Analyses because 30 fish from each of Reference Areas 1 and 2 are examined for Health at White Rose. Exclusion of 10 of those fish for Terra Nova was not warranted.

6.2.2 BODY BURDEN

Samples were delivered frozen to Bureau Veritas in Nova Scotia and processed for the variables listed in Table 6-3. Analytical methods and QA/QC procedures for these tests are provided in Appendix C-2.

Table 6-3 Body Burden Variables (1997 to 2020)

Variables	Method	Laboratory Detection Limit							Units
		1997	2000	2001	2002	2004/06	2008/10	2012/14/17/20	
>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
1-Chloronaphthalene	GC/MS	NA	NA	NA	NA	0.05	0.05	0.05	mg/kg
2-Chloronaphthalene	GC/MS	NA	NA	NA	NA	0.05	0.05	0.05	mg/kg
1-Methylnaphthalene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
2-Methylnaphthalene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Acenaphthene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Acenaphthylene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Anthracene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benz[*a*]anthracene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*a*]pyrene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*b*]fluoranthene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo[*ghi*]perylene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Benzo(j)fluoranthene*	GC/MS	NA	NA	NA	NA	NA	NA	0.05	mg/kg
Benzo[*k*]fluoranthene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Chrysene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Dibenz[*a,h*]anthracene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Fluoranthene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Fluorene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Indeno[1,2,3-*cd*]pyrene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Naphthalene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Perylene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Phenanthrene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Pyrene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
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	0.5	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	1.5	1.5	0.5	0.5	0.5	mg/kg
Boron	ICP-MS	1.5	1.5	1.5	1.5	1.5	1.5	1.5	mg/kg
Cadmium	ICP-MS	0.08	0.08	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	5	5	15	15	15	mg/kg
Lead	ICP-MS	0.18	0.18	0.18	0.18	0.18	0.18	0.18	mg/kg
Lithium	ICP-MS	0.5	0.5	0.5	0.5	0.5	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	0.5	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	0.12	0.12	mg/kg

Variables	Method	Laboratory Detection Limit							Units
		1997	2000	2001	2002	2004/06	2008/10	2012/14/17/20	
Strontium	ICP-MS	1.5	1.5	1.5	1.5	1.5	1.5	1.5	mg/kg
Thallium	ICP-MS	0.02	0.02	0.02	0.02	0.02	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	0.02	0.02	mg/kg
Vanadium	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Zinc	ICP-MS	0.5	0.5	0.5	0.5	0.5	1.5	1.5	mg/kg
Lipids	AOAC922.06	0.1	0.1	0.1	0.5	0.5	0.5	0.5	%
Moisture	Gravimetry	0.1	0.1	0.1	0.1	0.1	1	1	%

Notes:
- The laboratory detection limit is the lowest concentration that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions. Laboratory detection limits may vary from year to year because instruments are checked for precision and accuracy every year as part of QA/QC procedures[29].
- NA = Not Analyzed.
- *Benzo(*j*)fluoranthene was not reported by the analytical laboratory until 2012.

6.2.3 TASTE TESTS

Plaice samples were delivered frozen to the Marine Institute of Memorial University for sensory evaluation using taste panels. Frozen samples were thawed for 24 hours at 2°C. Tissue from either the Reference or Study Area was homogenized and then allocated to either the triangle taste test or the hedonic scaling test. Samples were enclosed in individual aluminum foil packets (shiny side in), labelled with a predetermined random three-digit code, cooked in a convection oven at 175°C for 15 minutes and then served at 35°C in glass cups.

Each panel included 24 untrained panellists who were provided with score sheets (Figures 6-1 and 6-2) and briefed on the presentation of samples prior to taste tests. Panellists were instructed not to communicate with each other and to leave the panel room immediately upon completion of the taste tests.

[29] Typically, Bureau Veritas set the laboratory detection limit at 2 to 10 times the Method Detection Limit calculated using the US Environmental Protection Agency protocol. The 2 to 10 times Method Detection Limit factor for laboratory detection limits established by Bureau Veritas is based on a number of considerations, including details of the analytical method, and known or anticipated matrix effects.

QUESTIONNAIRE FOR TRIANGLE TEST

Name: ______________________ Date/Time: ______________

Product: **American Plaice**

Two of these samples are identical, the third is different.

1. Taste the samples in the order indicated and identify the odd sample. You must choose one of the samples.

Code	**Check Odd Sample**
993	______________
508	______________
910	______________

2. Comments: ____

Figure 6-1 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.

	584		873
____	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 6-2 Questionnaire for Taste Evaluation by Hedonic Scaling

6.2.4 FISH HEALTH INDICATORS

Fish health indicators for plaice included examination of external and internal lesions, MFO enzymes, and a variety of liver and gill tissue (histological) indices. Analysis of plaice biological characteristics (sex, size, maturity, and condition indices) was performed to support the overall fish health assessment.

MFO induction was assessed in liver samples of plaice as 7-ethoxyresorufin O-deethylase (EROD) activity according to the method of Pohl and Fouts (1980) as modified by Porter et al. (1989).

Fixed liver and gill tissue samples were processed by standard histological methods (Lynch et al. 1969).

Details on these methods are provided in Appendix C-3.

6.3 DATA ANALYSIS

6.3.1 BODY BURDEN

Summary statistics were calculated for Reference Area and Study Area metal, hydrocarbon, and fat concentrations in plaice fillet and liver samples. Comparable data for plaice were available from 2001 to 2020. In 2000, fillet and liver samples from individual fish, rather than composite samples, were analyzed. In 1997, no plaice samples were collected for body burden analysis.

Three metals (arsenic, mercury, and zinc) were detected in all fillet samples. Fat concentration and concentrations of these three metals were compared among years and between Areas in two-way Analysis of Variance (ANOVA). One fat concentration in 2010, one in 2012, five in 2017 and one in 2020 were less than recent laboratory detection limit of 0.5% and were set at 0.4% for analyses.

Eight metals (arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc) were detected in most composite liver samples from 2001 to 2020. In 2008, manganese and selenium concentrations in Reference Area Composite 7 were less than the laboratory detection limit of 5 mg/kg. These detection limits were elevated because of matrix interference and were greater than all manganese and selenium concentrations in the other composite samples. Therefore, Reference Area Composite 7 from 2008 was excluded from metals analyses. In 2012, iron was below the detection limit in one sample, and manganese and mercury were each below their detection limits in two samples. Those sample concentrations were set to ½ the detection limit for subsequent statistical analyses and plotting of data.

PCA was used to provide summary measures (PCs) of concentrations of the eight metals detected in liver samples. Metals PC scores and fat concentration were compared among years and between Areas in two-way ANOVA. Analyses of fat concentration examined variations from 2004 to 2020 because low sample volume restricted laboratory analyses of fat concentration to only one composite per Area in 2001 and 2002.

Concentrations of hydrocarbons in plaice fillet were qualitatively compared among years and Areas because hydrocarbons were seldomly detected in fillet. Concentrations of hydrocarbons in plaice liver were compared among years and between Areas in two-way ANOVA. This analysis included data from 2006 to 2020 only because of elevated detection limits for many samples prior to 2006.

Analyses were performed with Systat (Version 13.1). Data were $\log_{10}$ transformed before analysis.

6.3.2 TASTE TESTS

The triangle test datum is the number of correct sample identifications over the number of panellists. This value was calculated and compared to values in Appendix C-4 (after Larmond 1977) to determine statistical significance. For a panel size of 24, a statistically significant discrimination between Areas (at $\alpha = 0.05$) would require that 13 panellists correctly identify samples.

Hedonic scaling results were assessed in ANOVA and presented graphically in a frequency histogram.

Ancillary comments from panellists were tabulated and assessed for both tests.

6.3.3 FISH HEALTH INDICATORS

Fish condition was assessed by calculating the following condition indices (Dutil et al. 1995): a) Fulton's condition factor, calculated as 100 x body weight/length^3 based on gutted weight; b) hepatosomatic index, calculated as 100 x liver weight/total body weight; and c) gonadosomatic index calculated as 100 x gonad weight/total body weight. Since these condition indices are commonly used, they are presented for general interest and compared between the two Areas for female fish using the Unpaired t-test. However, since use of these indices assumes that body weight is proportional to the cube of length, and liver and gonad weights are linearly related to body weight (which is not always the case), $\log_{10}$ regressions of total body weight on length, and liver and gonad weight on total body weight for female fish, were also tested by analysis of covariance (ANCOVA).

Remaining differences between the Study and Reference Areas were assessed using the Unpaired t-test or Fisher's exact test. When male and female plaice were considered separately in analyses (biological characteristics and MFO analysis), no statistical tests were performed for males because of the low number of males

(n = 8) caught. Comparisons of results for biological characteristics and MFO were made for all female plaice (all maturity stages combined) and spent females.

Details on these analysis methods are provided in Appendix C-3.

6.4 RESULTS

6.4.1 BODY BURDEN

Arsenic, mercury, and zinc were detected in all plaice fillet samples from 2001 to 2020[30] (Appendix C-2).

Arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc were detected in most plaice liver composite samples from 2001 to 2020 (Appendix C-2). In 2008, manganese and selenium were detected in all but one Reference Area sample. That one sample had elevated laboratory detection limits (5 mg/kg) and was excluded from further analyses.

>C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons were rarely detected in plaice fillet samples. Hydrocarbons in the >C_{10}-C_{21} and >C_{21}-C_{32} ranges were frequently detected in plaice liver samples from both the Reference and Study Areas from 2002 to 2020 (see below for further discussion). Barium was never detected in plaice liver and fillet samples at the laboratory detection limit of 1.5 mg/kg.

Average fat concentration in fillet composite samples collected from 2001 to 2020 ranged from approximately 0.5% to 2%. Average fat concentration in composite liver samples was higher (approximately 5% to 20%) (Appendix C-2).

PAHs were never detected in plaice fillet. PAHs were not detected in plaice liver from 2001 to 2010, nor in 2014 and 2020. Low levels of PAHs were detected in two liver samples in 2012, likely as a result of onboard sample contamination (see Suncor Energy 2013 for details). Low levels of PAHs were detected in four Study Area and four Reference Area liver samples in 2017.

[30] Samples from individual fish were analyzed in 2000 and these data are not comparable to data collected subsequently.

Metals and Fat

Concentrations of mercury, zinc and fat in plaice fillets varied significantly among EEM years (all Year Terms $p < 0.001$, Table 6-4)[31], with no difference between Areas (all Area Terms $p > 0.05$). Variations in fillet arsenic concentration differed between Areas in some EEM years (Year*Area Term $p = 0.045$). This difference resulted predominantly from the difference in arsenic concentration between Areas in 2020 (the Year*Area Term was not significant when 2020 data were excluded). In 2020, arsenic concentrations were lower in the Study Area than in the Reference Area (Figure 6-3). Arsenic concentrations have been increasing over time (EEM Linear Term $p < 0.001$). However, there was no difference between the Study and Reference Area in these increases (EEM Linear*Area Term $p > 0.05$). The trend was driven by increasing arsenic concentrations from 2008 to 2017, with arsenic concentrations in 2020 similar to concentrations noted in earlier EEM years (Figure 6-3). Finally, there has been a general decrease in fat concentration in fillet over time in both Areas (EEM Linear $p < 0.001$; Figure 6-3).

Table 6-4 Results of Two-Way ANOVA Comparing Metal and Fat Concentrations in Plaice Fillets among Years and Between Areas (2001 to 2020)

Source	df	*p*			
		Log of Arsenic	**Log of Mercury**	**Log of Zinc**	**Log of Fat**
Year	9	**<0.001**	**<0.001**	**<0.001**	**<0.001**
EEM Linear	1	**<0.001**	0.306	0.280	**<0.001**
Area	1	0.320	0.431	0.439	0.120
Year*Area	9	0.045*	0.158	0.751	0.052
EEM Linear*Area	1	0.979	0.432	0.516	0.995

Notes: -*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
-n = 101 composite samples.
-df is numeratory df.
-The Year term tests for differences among years, overall.
-The EEM Linear contrast tests for a monotonic (progressive) increase or decrease (simple trend) in body burden variable values over EEM years.
-The Area term tests for differences among Areas, overall.
-The Year*Area contrast provides a test of changes in differences between the two Areas over time.
-The EEM Linear*Area contrast tests for a difference in monotonic trends between Areas in EEM years.
-Two statistical outliers (Studentized residual > |4|) were noted for zinc in the Study Area in 2004 and 2014 (8.2 and 7.6 mg/kg, respectively). Removal of these outliers did not change the significance of any term from significant to non-significant, or vice versa. Results presented are those with the outliers retained.

[31] The Year term was also significant for arsenic. This is discussed in the context of the significant Year*Area interaction.

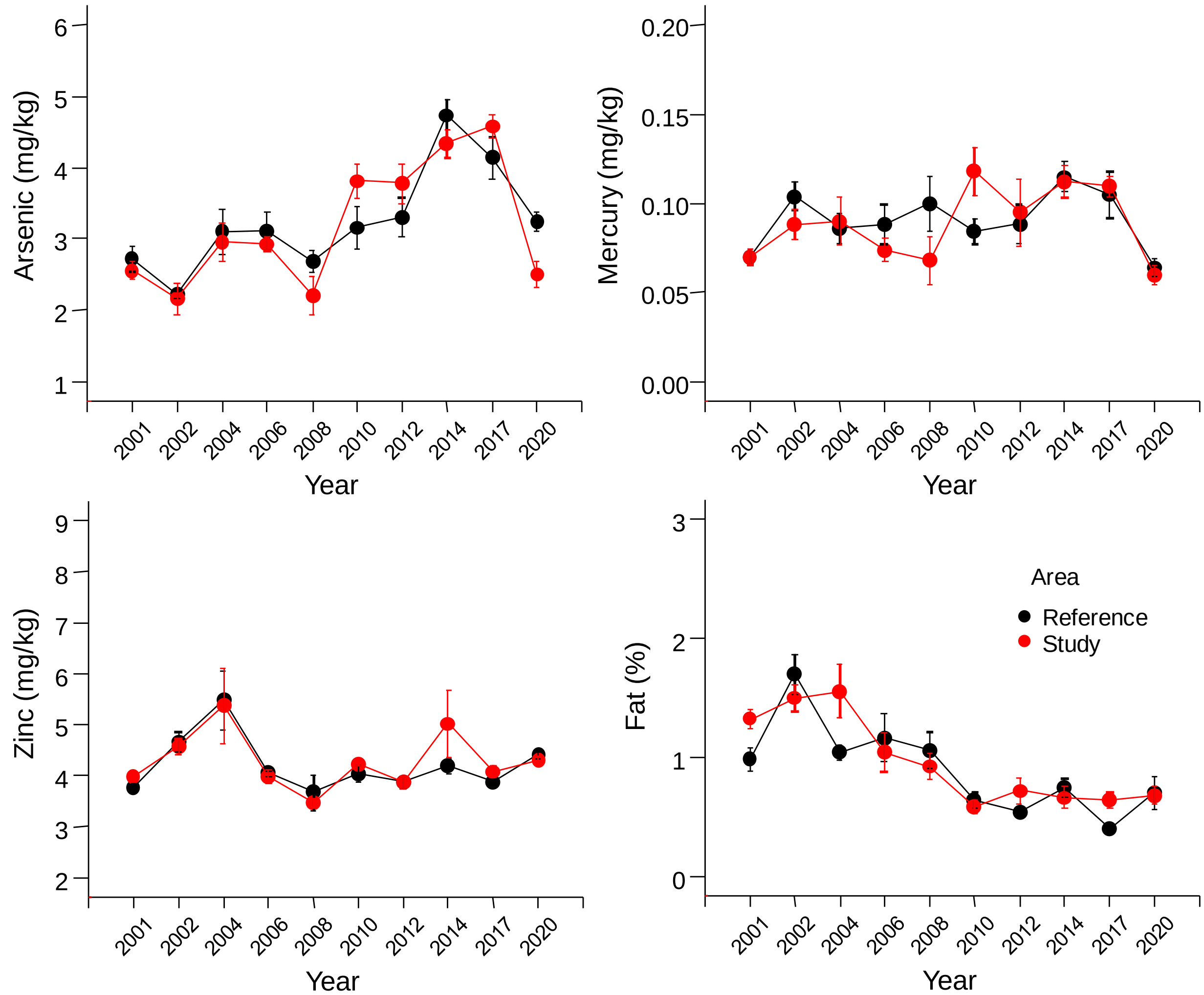


Figure 6-3 Area Mean (± 1 SE) Metal and Fat Concentrations in Plaice Fillets (2001 to 2020)

Note: Area means for zinc include two statistical outliers noted in 2004 and 2014 (see text Table 6-4 footnote).

Mean concentrations of arsenic, mercury, and zinc in fillet samples from individual plaice in 2000 generally were similar to means in subsequent years and did not differ substantially between Areas (Table 6-5). Fat concentration was not measured in 2000 fillet samples.

Table 6-5 Metal Concentrations in Plaice Fillets Sampled in 2000

Metal	Area Mean ± SE (mg/kg)	
	Reference Area (*n* = 11 fish)	Study Area (*n* = 10 fish)
Arsenic	1.89 ± 0.15	2.01 ± 0.19
Mercury	0.044 ± 0.004	0.063 ± 0.009
Zinc	3.99 ± 0.13	4.18 ± 0.21

PCA of plaice liver metals produced two PC axes with eigenvalues greater than 1 (i.e., they probably explained non-random variation in liver metals concentration; Jackson 1993). Combined, the two axes explained approximately 80% of the variation in plaice liver metals concentrations. Concentrations of the 8 metals detected in all 100 plaice liver composites included in the PCA were positively correlated with the first axis (Table 6-6). Therefore, plaice liver PC1 can be considered to be a summary measure of total metal concentrations. Plaice liver PC2 was positively correlated with manganese concentrations. Therefore, the second liver PC primarily reflected variations in concentrations of manganese that were independent of variations in concentration of the other metals. The PCA justifies further analysis of PC1 as a measure of overall metals concentrations, and of manganese because it varied independently of the other metals.

Table 6-6 Correlations (r_p) Between Concentrations of Metals in Plaice Liver and Principal Components Derived from those Concentrations (2001 to 2020)

Variable	Correlation (r_P) with	
	PC1	PC2
Log of Arsenic	**0.86**	-0.24
Log of Cadmium	**0.87**	-0.11
Log of Copper	**0.88**	-0.25
Log of Iron	**0.93**	-0.07
Log of Manganese	0.37	**0.91**
Log of Mercury	**0.78**	0.18
Log of Selenium	**0.88**	0.03
Log of Zinc	**0.80**	0.09
Percent of Variance Explained	66.0	12.6

Notes: - $|r| \geq 0.6$ in **bold.**
- *n* =100 composite samples, excluding Composite 7 from the 2008 EEM program (see Section 7.3.2 for details).

Plaice liver fat concentrations varied over time (Year Term $p < 0.001$; Table 6-7)[32] and decreased significantly in EEM years (EEM linear Term $p < 0.001$; Figure 6-4; the increase in fat in 2020 was insufficient to obscure the overall decreasing trend in fat over all EEM years). There was no difference in variations in fat concentrations between Areas (Area and EEM Linear*Area Terms $p > 0.05$; Figure 6-4).

[32] The Year term was also significant for metals PC1 scores and manganese. This is discussed in the context of the Year*Area interaction.

Table 6-7 Results of Two-Way ANOVA Comparing Metal Concentrations in Plaice Liver among Years and Between Areas (2001 to 2020)

Source	PC1		Log of Manganese		Log of Fat	
	df	***p***	**df**	***p***	**df**	***p***
Year	9	**<0.001**	9	**<0.001**	7	**<0.001**
EEM Linear	1	**<0.001**	1	0.093	1	**<0.001**
Area	1	0.394	1	0.016*	1	0.503
Year*Area	9	0.032*	9	0.024*	7	0.756
EEM Linear*Area	1	0.356	1	0.709	1	0.943

Notes: -*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
-*n = 100* composite samples from 2001 to 2020 for metals.
-*n = 7*9 composite samples from 2004 to 2020 for fat.
-df is numeratory df.
-The Year term tests for differences among years, overall.
-The EEM Linear contrast tests for a monotonic (progressive) increase or decrease (simple trend) in body burden variable values over EEM years.
-The Area term tests for differences among Areas, overall.
-The Year*Area contrast provides a test of changes in differences between the two Areas over time.
-The EEM Linear*Area contrast tests for a difference in monotonic trends between Areas after the onset of project activity.
-Two statistical outliers (Studentized residual > |4|) from EEM year 2012 were noted for PC1. Removal of the outliers changed the Year*Area term from not significant to significant. Results presented are with the outliers removed.
-Two statistical outliers from EEM year 2012 were noted for manganese. Removal of the outliers changed the Area term from not significant to significant. Results presented are with the outliers removed.

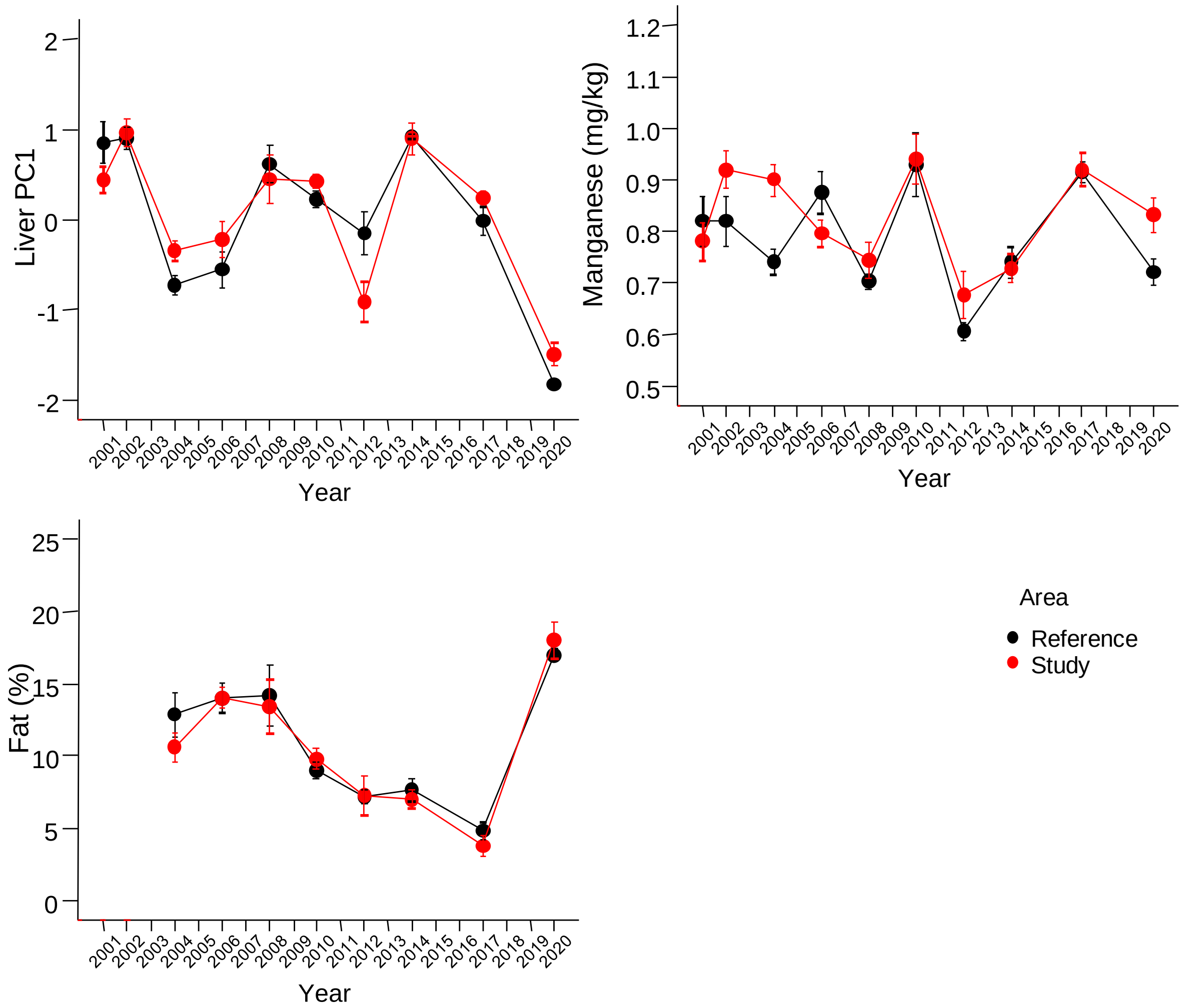


Figure 6-4 Area Mean (± 1 SE) Metal (2001 to 2017) and Fat (2004 to 2020) Concentrations in Plaice Livers

Note: Area means for PC1 and manganese exclude two statistical outliers noted in 2012 samples (see text Table 6-7 footnote).

With two statistical outliers removed (see footnote to Table 6-7), analyses indicated differences between Areas in variations over time for PC1 scores (Year*Area term $p = 0.032$). Liver PC1 scores generally were higher in the Study Area in 2004, 2006, and 2020; and they were lower in the Study Area in 2001 and 2012 (Figure 6-4). Scores were generally similar in remaining years. The largest difference occurred in 2012, with lower liver PC1 scores in the Study Area (Figure 6-4). PC1 liver scores also decreased over time (EEM linear Term $p < 0.001$; Figure 6-4), with no difference between Areas in these variations (EEM Linear*Area Term $p > 0.05$).

With the two outliers removed, results also indicated differences between Areas in variations over time for manganese (Year*Area term p = 0.024)[33]. Manganese concentrations generally were higher in the Study Area in 2002, 2004, and 2020. Concentrations generally were lower in the Study Area in 2006 and 2012, and similar in other years (Figure 6-4).

Fat concentrations for the single Area composites analyzed in 2001 and 2002 were generally similar to means in subsequent years and did not differ substantially between Areas (Table 6-8).

Table 6-8 Fat Concentration in Plaice Liver in 2001 and 2002

Year	Fat (%)	
	Reference Area	Study Area
2001 (1 composite/Area)	7.21	5.47
2002 (1 composite/Area)	10	11

Hydrocarbons

Hydrocarbons generally were not detected in fillet samples. >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons were only detected in a fillet from one (of ten) Study Area plaice in 2000, at concentrations of 44 and 21 mg/kg, respectively. >C_{21}-C_{32} hydrocarbons were also detected at a concentration of 21 mg/kg in one fillet composite sample in 2008. However, the hydrocarbon profiles for these samples did not match that of PureDrill IA35-LV or petroleum compounds. >C_{21}-C_{32} hydrocarbons were detected in one composite Study Area fillet sample in 2006, at a concentration of 17 mg/kg. However, >C_{21}-C_{32} hydrocarbons were not detected in a duplicate analysis of this sample, and it was judged that the first analysis was performed with a contaminated syringe (Suncor Energy 2007). >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons were not detected in any of the other individual and composite fillet samples analyzed since 2000.

In 2000, >C_{10}-C_{21} hydrocarbons resembling the drill mud PureDrill IA35-LV were detected in one of five Study Area individual liver samples at a concentration of 31 mg/kg; >C_{21}-C_{32} hydrocarbons were not detected. Laboratory detection limits varied from 15 to 26 mg/kg and Reference Area liver samples were not analyzed in 2000. In 2001, >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons were not detected in plaice liver composite samples (laboratory detection limit: 15 mg/kg).

[33] The Area term was also significant for manganese. This is discussed in the context of the Year*Area interaction.

In 2002 and 2004, compounds in the $>C_{10}$-C_{21} hydrocarbon range were detected in plaice liver composites when the laboratory detection limit was 15 mg/kg, but not in some samples with higher detection limits (Table 6-9). Compounds in the $>C_{21}$-C_{32} range were detected in all composites in those two years. From 2006 to 2020, compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon range were detected in all liver composites.

Table 6-9 Hydrocarbon Concentrations in Plaice Liver (2002 to 2020)

Carbon Range	Year	Reference Area			Study Area		
		No. >LDL	Median (mg/kg)	Maximum (mg/kg)	No. >LDL	Median (mg/kg)	Maximum (mg/kg)
$>C_{10}$-C_{21}	2002[a]	2	<70	28	2	<80	39
	2004[b]	5	34	41	3	37	50
	2006	5	25	32	5	28	34
	2008	5	58	100	5	45	60
	2010	5	33	37	5	34	41
	2012	5	42	59	5	58	66
	2014	5	34	43	5	29	31
	2017	5	71	71	5	56	72
	2020	6	315	580	5	270	380
$>C_{21}$-C_{32}	2002	5	140	240	5	150	230
	2004	5	50	100	5	63	78
	2006	5	49	62	5	70	78
	2008	5	220	520	5	220	230
	2010	5	98	120	5	110	120
	2012	5	200	220	5	240	260
	2014	5	130	150	5	120	140
	2017	5	83	100	5	110	120
	2020	6	420	940	5	570	760

Notes:
- [a] $>C_{10}$-C_{21} hydrocarbons were only detected in two Reference Area and two Study Area samples at a laboratory detection limit of 15 mg/kg. Detection limits were elevated to between 70 and 80 mg/kg in the other samples, and concentrations in those samples were all below detection limit.
- [b] $>C_{10}$-C_{21} hydrocarbons were detected in three Study Area samples at a laboratory detection limit of 15 mg/kg. Detection limits were elevated to between 38 and 48 mg/kg in other samples, and concentrations in those samples were all below the laboratory detection limit. The median and maximum were based on the three samples with concentrations greater than the laboratory detection limit.
- In 2020, six fish were collected from the Reference Area and five fish were collected from the Study Area. In remaining years, five fish were collected from each of the Study and Reference Areas.
- LDL = Laboratory Detection Limit.

Since 2002, hydrocarbons in liver have showed no resemblance to drill mud hydrocarbons. Based on examination of chromatograms, one Reference Area sample from the 2008 EEM program and one Study Area sample from the 2012 EEM program showed contamination with petrogenic material (J. Kiceniuk, 2011, pers. comm.)[34]. Otherwise, hydrocarbon peaks observed on chromatograms for liver (Appendix C-2; also see Suncor Energy 2003, 2005, 2007, 2009, 2011, 2013, 2017, and 2019 for chromatograms for 2002, 2004, 2006, 2008, 2010, 2012, 2014 and 2017 samples, respectively) were consistent with those expected for natural compounds (J. Kiceniuk, 2015, pers. comm.) and similar compounds have consistently been observed in plaice liver at the nearby White Rose site (Husky Energy 2019). In 2020, as in previous years, liver samples from the Terra Nova Study and Reference Areas were analyzed further by mass spectroscopy. Based on these additional analyses, Bureau Veritas reported that there was no apparent indication of petrogenic hydrocarbons in any sample and that the material was likely of natural or biological origin (see Appendix C-2 for results of additional analysis on liver).

Table 6-10 provides results of ANOVA comparing liver $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon concentrations from 2006 to 2020, when concentrations were above detection limits in all samples. Concentrations of both hydrocarbons varied significantly among years (Year Term $p < 0.001$, Table 6-10). Concentrations increased over time (EEM Linear Term $p < 0.001$), with concentrations in 2020 higher than in previous years (Figure 6-5). However, there was no significant difference between the Study and Reference Areas in these trends (Table 6-10, Figure 6-5). Higher concentrations in 2020 potentially were a result of differences in sampling time between 2020 and remaining years[35]. This is further discussed in Section 7.

[34] The noted contamination in 2012 likely occurred on board the vessel (see Suncor Energy 2013 for details).

[35] Plaice have normally been sampled in the Spring but were sampled in the Fall in 2020 because of COVID-19 restrictions on sampling earlier in the year.

Table 6-10 Results of Two-Way ANOVA Comparing Hydrocarbon Concentrations in Plaice Liver among Years and Between Areas (2006 to 2020)

Source	>C_{10}-C_{21} Hydrocarbons		>C_{21}-C_{32} Hydrocarbons	
	df	*p*	df	*p*
Year	6	**<0.001**	6	**<0.001**
EEM Linear	1	**<0.001**	1	**<0.001**
Area	1	0.571	1	0.337
Year*Area	6	0.320	6	0.348
EEM Linear*Area	1	0.739	1	0.502

Notes: -*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
-n = *71* composite samples from 2006 to 2020 for metals.
-df is numeratory df.
-The Year term tests for differences among years, overall.
-The EEM Linear contrast tests for a monotonic (progressive) increase or decrease (simple trend) in body burden variable values over EEM years.
-The Area term tests for differences among Areas, overall.
-The Year*Area contrast provides a test of changes in differences between the two Areas over time.
-The EEM Linear*Area contrast tests for a difference in monotonic trends between Areas after the onset of project activity.

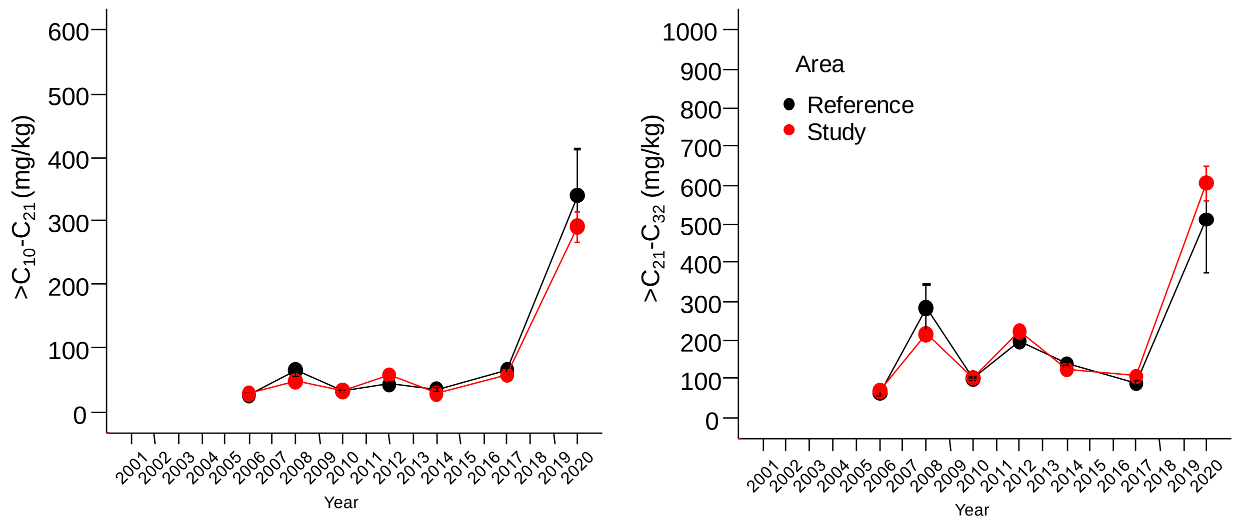


Figure 6-5 Area Mean (± 1 SE) >C_{10}-C_{21} and >C_{21}-C_{32} Hydrocarbon Concentration in Plaice Liver (2006 to 2020)

6.4.2 TASTE TESTS

No significant difference in taste was noted between plaice collected in the Study and Reference Areas in the triangle test. Panellists were successful in discriminating 10 out of 24 samples. These results are not significant at α = 0.05 (Appendix C-4).

ANOVA statistics for the hedonic scaling test are provided in Table 6-11 and a frequency histogram of results is provided in Figure 6-5. These results show no significant taste difference between Areas.

Table 6-11 ANOVA Statistics for the 2020 Taste Evaluation by Hedonic Scaling of Plaice

Source of Variation	**SS**	**df**	**MS**	**F**	***p***
Area	1.69	1	1.69	0.86	0.36
Error	90.63	46	1.97		

Note -MS = Mean Square
-SS = Sum of Squares
-df is numeratory df

From ancillary comments (Tables 6-12 and 6-13; Appendix C-4), there were no consistent comments about Study Area plaice identifying abnormal or foreign odour or taste.

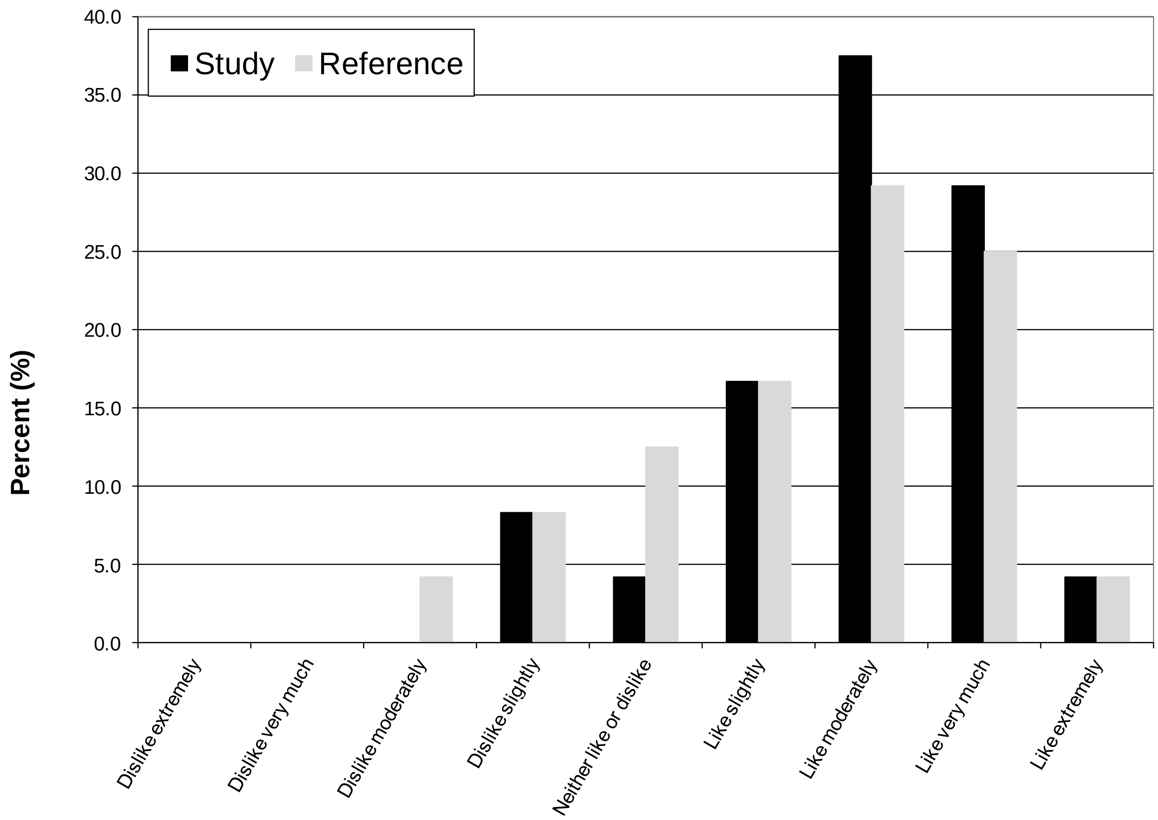


Figure 6-6 Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2020)

Table 6-12 Summary of Comments from the Triangle Test for Plaice (2020)

Reference Area [RA]	Study Area [SA]
Correctly identified as odd sample	**Correctly identified as odd sample**
All 3 pretty bland; not a significance in taste	The other 2 samples have more preferred flavour
249 [SA] and 269 [SA] had a stronger taste	742 [SA] tastes "burnt"
Had a lighter flavour / taste; other 2 were bland	
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
257 [RA] was better tasting (more sweet) than the others	Hard to tell, but milder taste in 269 [SA]
Stronger fish flavour	All samples were very similar
427 [RA] and 742 [SA] had an industrial aftertaste	Too much of a fishy taste for me
No real discernable difference	
Not much difference. Hard to tell. 216 [RA] maybe stronger "fishy" taste	
216 [RA] is good. 784 [SA] and 869 [RA] had an off taste, but only slightly	

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 6-13 Summary of Comments from the Hedonic Scaling Test for Plaice (2020)

Preferred Reference Area [RA]	Preferred Study Area [SA]
297 [SA] I found too bland	The flavour of sample 244 [SA] was preferred
Not a lot of difference in taste or texture	939 [RA] bland flavour; both samples are acceptable
466 [SA] is bland and tough; 591 [RA] has a lighter taste and not tough	234 [RA] had a strange aftertaste; 297 [SA] was bland
Tasted the same to me	Tasted the same to me
These both taste the same. Not as good as many of the samples I rated in the past, kind of bland.	These both taste the same. Not as good as many of the samples I rated in the past, kind of bland.
	466 [SA] great flavour, texture; 591 [RA] good flavour
	591 [RA] had an off taste. Not fishy, but not right

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 samples were ranked equally, comments are indicated in both columns.

6.4.3 FISH HEALTH INDICATORS

6.4.3.1 Biological Characteristics

Sex Ratios and Maturity Stages

Fifty-five (55) females and 5 males were collected in the Reference Area for fish health assessment, and 37 females and 3 males were collected in the Study Area. Females outnumbered males in both Areas, and female to male ratios (F:M) were not significantly different between the two Areas (p = 1.0; Fisher's exact test).

Since the number of males collected was low, statistical tests of differences in maturity stages between Areas were not conducted for males. For females, there were no significant differences between the Study and Reference Areas in the frequencies (i.e., percentages) of any of the maturity stages observed ($p > 0.05$) (Table 6-14).

Table 6-14 Frequencies (%) of Maturity Stages of Female Plaice (2020)

	No.	Immature F-500 [a]	Spent in the previous year F-510 [a]	Maturing to spawn this year F-520 to F-540 [a]	Partly spent F-550 [a]	Spent this year F-560+F-570[a]
Reference Area	55	27.272	70.909	1.818	0	0
Study Area	37	27.027	72.973	0	0	0
p Value [b]		1.000	1.000	-	-	-

Notes: -[a]Maturity stages were defined according to procedures used by DFO (Appendix C-3, Annex A).
-[b]*p* value obtained with the Fisher's exact test; $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in **bold**).

Size, Age and Condition

Males

Information on biological characteristics and condition indices of male fish (all maturity stages pooled) from the Reference and Study Areas are summarized in Table 6-15. The complete data set is provided in Appendix C-3, Annex B.

Table 6-15 Mean (± 1SD) Biological Characteristics and Condition Indices of Male Plaice (2020)

Variable	Reference Area	Study Area
Number of fish	5	3
Length (cm)	40.90 ± 7.99	34.17 ± 3.82
Total body weight (g)	714.00 ± 508.68	353.33 ± 99.73
Gutted weight (g)	621.00 ± 442.21	296 ± 100.54
Liver weight (g)	22.40 ± 13.22	11.33 ± 5.03
Gonad weight (g)	5.00 ± 2.58	6.67 ± 4.62
Age (year)	7.2 ± 2.28	6.67 ± 0.58
Fulton's condition factor [a]	0.821± 0.078	0.724 ± 0.054
Hepatosomatic index [b]	3.84 ± 1.60	3.86 ± 1.53
Gonadosomatic index [c]	1.19 ± 0.68	2.12 ± 0.80

Notes: -All data are expressed as mean of raw values ± standard deviation.
-[a]Calculated as 100 x gutted body weight/length^3.
-[b]Calculated as 100 x liver weight/gutted body weight.
-[c]Calculated as 100 x gonad weight/gutted body weight.

Females

Information on biological characteristics and condition of female fish (all maturity stages pooled) from the Reference and Study Areas are summarized in Table 6-16. The complete data set is provided in Appendix C-3, Annex B. Significant differences were detected between the two areas for length, total body weight, gutted body weight and liver weight ($p < 0.05$). Fish from the Reference Area were generally larger than fish from the Study Area.

Table 6-16 Mean (± 1 SD) Biological Characteristics and Condition Indices of Female (All Maturity Stages Pooled) (2020)

Variable	Reference Area	Study Area	*p* [d]
Number of fish	55	37	
Length (cm)	40.791 ± 3.666	38.135 ± 4.522	0.003**
Total body weight (g)	673.40 ± 222.38	548.54 ± 187.39	0.010*
Gutted body weight (g)	576.76 ± 181.36	478.03 ± 169.76	0.020*
Liver weight (g)	23.89 ± 10.63	18.43 ± 7.88	0.009**
Gonad weight (g)	21.31 ± 15.15	19.13 ± 14.06	0.449
Age (year)	8.491 ± 1.245	8.838 ± 1.323	0.215
Fulton's condition factor [a,e]	0.823 ± 0.072	0.814 ± 0.057	-
Hepatosomatic index [b,e]	4.057 ± 1.085	3.798 ± 0.862	-
Gonadosomatic index [c,e]	3.400 ± 1.647	3.591 ± 1.827	-

Notes: -All data are expressed as mean of raw values ± standard deviation.
-[a]Calculated as 100 x gutted body weight/length^3.
-[b]Calculated as 100 x liver weight/gutted body weight.
-[c]Calculated as 100 x gonad weight/gutted body weight.
-[d]*p*-value obtained with the Unpaired t-test; $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in **bold**).
-[e]*p*-values for Fulton's Condition Factor and the Hepatic and Gonadosomatic indices are not reported because these conditions are tested via ANCOVA (below).

No differences between Areas were observed when comparing adjusted means for gutted body weight on the covariate length, and liver on the covariate gutted body weight (Table 6-17). However, a significant difference was detected for gonad weight on the covariate gutted weight ($p = 0.021$), with larger gonads relative to gutted weight for Study Area females.

Table 6-17 Adjusted Means of ANCOVA on Gutted Weight, Liver Weight and Gonad Weight for Female Plaice (All Maturity Stages Pooled) (2020)

Variable	Covariate	Adjusted Means		*p* Value [a]
		Reference Area	Study Area	
Gutted weight	Length	498.88	508.16	0.347
Liver weight	Gutted weight	19.14	19.05	0.940
Gonad weight	Gutted weight	13.52	17.62	0.021*

Notes: -ANCOVA were based on log-transformed values of Y and X variables. Displayed data was obtained using the anti-log equation on adjusted means obtained from the ANCOVA analysis.
-[a]*p*-values were obtained using log_{10}-transformed data; $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in **bold**).

Comparison of size, age, and condition between the Study and the Reference Areas were also carried out for the female maturity stage that was most prevalent (Stage F-510 - Spent females), because this stage was also examined separately in MFO analyses. There were significant differences in length, body weight, gutted body weight, and liver weight between spent females from the Reference and Study Areas (Table 6-18). As was the case for all females, spent females from the Reference Area were generally larger.

Table 6-18 Mean (± 1 SD) Biological Characteristics and Condition Indices of Female for Spent Female Plaice (F-510) (2020)

Variable	Reference Area	Study Area	*p* Value [d]
Fish number	39	27	
Length (cm)	41.86 ± 3.45	39.76 ± 3.29	0.015*
Total body weight (g)	741.6 ± 217.3	601.9 ± 159.7	0.004**
Gutted body weight (g)	631.8 ± 174.8	528.3 ± 141.8	0.013*
Liver weight (g)	27.64 ± 9.47	20.74 ± 6.91	0.002**
Gonad weight (g)	26.51 ± 14.54	23.63 ± 12.96	0.357
Age (year)	8.67 ± 1.30	9.26 ± 1.26	0.054
Fulton's condition factor [a,e]	0.842 ± 0.066	0.824 ± 0.052	-
Hepatosomatic index [b,e]	4.374 ± 0.885	3.922 ± 0.828	-
Gonadosomatic index [c,e]	4.016 ± 1.395	4.263 ± 1.515	-

Notes: -All data are expressed as mean of raw values ± standard deviation.
-[a]Calculated as 100 x gutted body weight/length ^{3}.
-[b]Calculated as 100 x liver weight/gutted body weight.
-[c]Calculated as 100 x gonad weight/gutted body weight.
-[d]*p* Value obtained with the Unpaired t-test; $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in **bold**).
-[e]*p*-values for Fulton's Condition Factor and the Hepatic and Gonadosomatic indices are not reported because these conditions are tested via ANCOVA (below).

No differences between Areas were observed when comparing adjusted means of spent females for gutted body weight on the covariate length, and liver on the covariate gutted body weight (Table 6-19). However, as was the case for all females, a significant difference was detected for gonad weight on the covariate gutted weight ($p = 0.042$), with larger gonads relative to gutted weight for Study Area females.

Table 6-19 Adjusted Means of ANCOVA on Gutted Weight, Liver Weight and Gonad Weight for Spent Female Plaice (F-510) (2020)

Variable	Covariate	Adjusted Means		*p* Value [a]
		Reference Area	Study Area	
Gutted weight	Length	570.16	561.05	0.412
Liver weight	Gutted weight	24.32	21.83	0.086
Gonad weight	Gutted weight	20.37	24.66	0.042*

Notes: -ANCOVA were based on $\log_{10}$-transformed values of Y and X variables. Displayed data was obtained using the anti-log equation on adjusted means obtained from the ANCOVA analysis.
-$*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in **bold**).

More details on results of biological characteristics are provided in Appendix C-3.

6.4.3.2 Gross Pathology

With the exception of a parasite observed in the gill of one fish from the Study Area, there were no other visible abnormalities observed upon necropsy on the skin or fins of fish or on the external surface of the gonad, digestive tract, liver, body-cavity, or spleen (Appendix C-3, Annex B).

6.4.3.3 Mixed Function Oxygenase Activity

MFO enzyme activities, measured as EROD, in the liver of male and female plaice from the Reference and Study Areas, are provided in Appendix C-3, Annex C. The results for males are summarized in Table 6-20. Results for females (all maturity stages pooled) and spent females are summarized in Figures 6-7 and 6-8, respectively. There were no significant differences in MFO activity between Areas for all females (Figure 6-7) or spent females (Figure 6-8).

Table 6-20 MFO Activity in the Liver of Male Plaice (2020)

Sampling Area	n	EROD Activity (pmol/min/mg protein)
Reference	5	36.98 ± 13.24
Study	3	32.42 ± 6.90

Notes: -Data are means ± standard deviation.

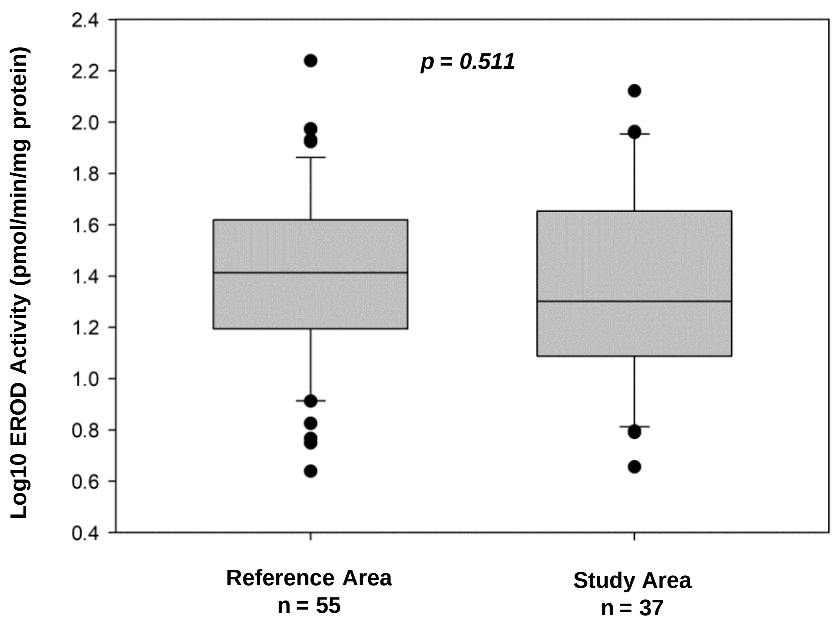


Figure 6-7 MFO Activity in the Liver of Female Plaice (All Maturity Stages Combined) (2020)

Notes: Data plotted are median (horizontal line in middle of box), 25th and 75th percentiles are the bottom and top edges of the box, and the whiskers are the lowest and highest values of the data set excluding the outliers. p value obtained with Unpaired t-test on log_{10}-transformed data.

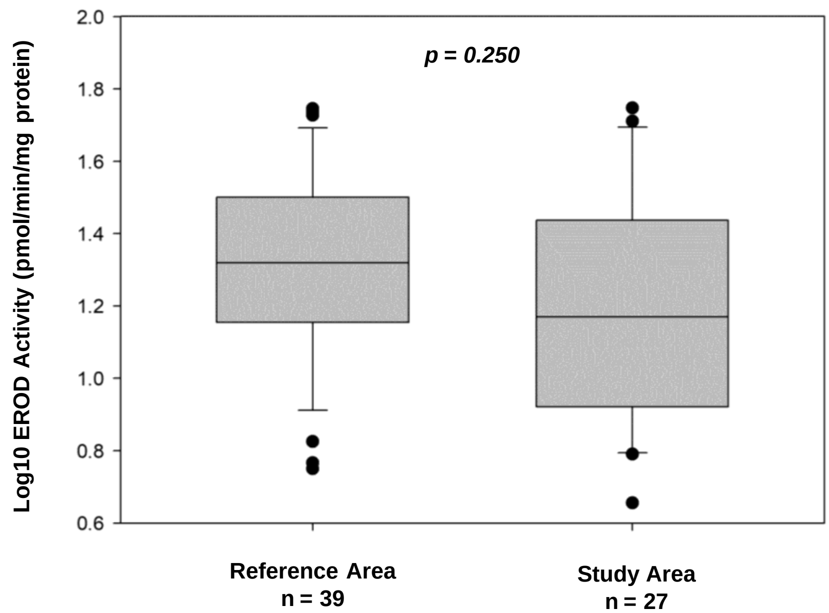


Figure 6-8 MFO Activity in the Liver of Spent Female Plaice (F-510) (2020)

Notes: Data plotted are median (horizontal line in middle of box), 25th and 75th percentiles are the bottom and top edges of the box, and the whiskers are the lowest and highest values of the data set excluding the outliers. p value obtained with the Unpaired t-test on log_{10}-transformed data.

6.4.3.4 Histopathology

Liver Histopathology

Liver histopathology was examined on a total of 100 livers, 40 from the Study Area and 60 from the Reference Area. Results were expressed as percentage of fish affected by different types of hepatic lesion/observation (or prevalence of lesion, %) in each Area (Table 6-21). The complete data set is provided in Appendix C-3, Annex D. Representative photographs of normal liver as well as a number of histological changes are included in Appendix C-3, Annex F.

Table 6-21 Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions (2020)

Variable	Reference Area (n = 60)		Study Area (n = 40)		p [d]
	Fish Affected	Prevalence % [a]	Fish Affected	Prevalence % [a]	
Nuclear pleomorphism	11	18.33	23	57.50	**<0.001*** **
Megalocytic hepatosis	1	1.67	4	10.00	0.154
Focus of cellular alteration	0	0.00	0	0.00	-
Fibrillar inclusions	0	0.00	0	0.00	-
Proliferation of macrophage aggregation [b]	15	25.00	8	20.00	0.633
Inflammatory response [c]	28	46.67	23	57.50	0.314
Hepatocellular vacuolation	7	11.67	11	27.50	0.062
Parasitic infestation of biliary system	32	53.33	22	55.00	1.000
Golden rings	0	0.00	0	0.00	-

Notes: -[a]Percentage of fish affected.
-[b]Defined as scores greater than 3 on a 0-7 relative scale.
-[c]Inflammatory response including mild, moderate, and severe scores.
-[d]p value obtained with Fisher's exact test; *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).

Nuclear pleomorphism was observed in 18.33% of fish from the Reference Area and 57.50% of fish from the Study Area and the difference between Areas was significant (Table 6-21). Remaining differences between Areas were not significant or low prevalence precluded statistical comparison. Megalocityc hepatosis was detected in 1.67% of fish from the Reference Area and 10% of fish from the Study Area. Inflammatory response was observed in 46.67% of fish from the Reference Area and 57.50% of fish from the Study Area. The response was rated as mild in all fish (Appendix C-3, Annex F, Photo 3). Hepatocellular vacuolation was observed in 11.67% of fish from the Reference Area and 27.50% of fish from the Study Area. The presence of a myxosporean parasite and possibly trematodes in liver tissue was observed in 53.33% of fish from the Reference Area and in 55.00% of fish from the Study Area. The presence of these parasites did not appear to result in any other pathological changes in hepatic tissues (Appendix C-3, Annex F, Photo 2). No cases of focus of cellular alteration, fibrillar inclusions or golden rings were detected in any of the fish.

Gill Histopathology

Gill histopathology results, expressed as means ± standard deviations of percentage of secondary lamellae affected by each type of lesion, are summarized in Table 6-22, with details provided in Appendix C-3.

Table 6-22 Occurrence of Lesions in the Gill Tissues of Plaice (2020)

Variable	Reference Area n = 60	Study Area n = 39 [d]
Basal hyperplasia 1 [a b]	0.0745 ± 0.0014	0.0581 ± 0.0014
Basal hyperplasia 2 [a c]	0.0428 ± 0.0013	0.0253 ± 0.0011
Distal hyperplasia [a]	0.1322 ± 0.0030	0.0178 ± 0.0009
Tip hyperplasia [a]	0.1405 ± 0.0027	0.0433 ± 0.0010
Fusion [a]	0.0205 ± 0.0009	0.0133 ± 0.0005
Telangiectasis [a]	0	0
Parasites	0.0097 ± 0.0004	0.0044 ± 0.0003

Notes: -For each fish, lamellar counts were performed on four filaments and are presented as the percentage of secondary lamellae affected by each type of lesion in relation to the total number of secondary lamellae counted (see Appendix C-3 for details).
-All data are means ± standard deviations.
-[a]Mean percentage of lamellae presenting the lesion.
-**[b]**Basal hyperplasia 1: increase in thickness of the epithelium reaching 1/3 to 2/3 of total lamellar length.
-**[c]**Basal hyperplasia 2: increase in thickness of the epithelium reaching more than 2/3 of total lamellar length.
-[d]n = 39 because one slide was unreadable due to damage and necrosis of the tissue.

Statistical comparisons between the Study and Reference Areas on the number of fish exhibiting lesions are presented in Table 6-23. With the exception of distal hyperplasia, none of the gill lesions occurred either more or less frequently in Study Area fish compared to Reference Area fish. Distal hyperplasia was present in more fish from the Reference Area ($p = 0.002$, Table 6-23).

Table 6-23 Number of Plaice with Specific Types of Gill Lesions and Percentages of Fish Exhibiting the Lesions (2020)

Gill Lesions	Measure	Reference Area	Study Area	*p*[d]
Total Number of Fish	Number	60	39	
Distal Hyperplasia	Number	19	2	0.002**
	%	31.67	5.13	
Tip Hyperplasia	Number	23	8	0.077
	%	38.33	20.51	
Basal Hyperplasia 1[a]	Number	16	7	0.343
	%	26.67	17.95	
Basal Hyperplasia 2[b]	Number	8	3	0.519
	%	13.33	7.69	
Fusion	Number	5	3	1.000
	%	8.33	7.69	
Telangiectasis	Number	0	0	-
	%	0.00	0.00	
Parasites	Number	3	1	1.000
	%	5.00	2.56	

Notes: -Hyperplasia and fusion were considered “present” if those conditions occurred on any of the lamellae examined for each fish.
-**[a]**Basal hyperplasia 1: increase in thickness of the epithelium reaching 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.
-[c]n = 39 because one slide was unreadable due to damage and necrosis of the tissue.
-[d]*p* value obtained with Fisher’s exact test; $*p \leq 0.05$; $**p \leq 0.01$; $***p \leq 0.001$ (in **bold**).

6.5 SUMMARY OF RESULTS

6.5.1 BODY BURDEN

Arsenic, mercury, and zinc were detected in all plaice fillet composites since 2001. Arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc were detected in most plaice liver composites since 2001. The concentration of these metals in each tissue was analyzed quantitatively.

Concentrations of mercury, zinc, and fat in plaice fillets varied among EEM years, with no difference between Areas. Variations in fillet arsenic concentration differed between Areas in some EEM years, with arsenic concentrations lower in the Study Area than in the Reference Area in 2020. Arsenic concentrations were also marginally lower in the Study Area in 2008; and they were marginally higher in the Study Area in 2010, 2012, and 2017. Over time, arsenic concentrations in fillets have ranged from approximately 2 to 4 mg/kg, and any differences between or across Areas were subtle. In addition to these differences, there was a general increase over time in fillet arsenic concentrations in both Areas and a general decrease over time in fat, again in both Areas.

Overall metals concentrations (PC1 scores), fat, and manganese concentrations were examined in plaice liver. Manganese concentrations were examined separately because variations in its concentrations differed from variations in other metals. Fat concentrations varied among EEM years, with no difference between Areas. Variations in liver PC1 scores differed in some EEM years; scores generally were higher in the Study Area in 2004, 2006, and 2020; and they were lower in the Study Area in 2001 and 2012. There were also differences between Areas in variations over time for manganese, with concentrations generally higher in the Study Area in 2002, 2004, and 2020, and generally lower in 2006 and 2012. In addition to these differences, there has been a general decrease over time in fat concentrations and liver PC1 scores in both Areas, with no difference between Areas.

$>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons were detected in one Study Area plaice fillet in 2000 and $>C_{21}$-C_{32} hydrocarbons were detected in one Study Area plaice fillet composite in 2008, but the hydrocarbon profiles for these samples did not match that of the synthetic-based drill mud used at Terra Nova or petroleum compounds. $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons were not detected in any of the other individual and composite fillet samples analyzed since 2000.

>C_{10}-C_{21} hydrocarbons resembling PureDrill IA35-LV were detected in one Study Area liver sample in 2000. Hydrocarbons were not detected in plaice liver in 2001. Compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbon range were detected in most liver samples from both the Study and Reference Areas from 2002 to 2020. With the exception of one Reference Area sample in 2008 and one Study Area sample in 2012, none of these compounds had profiles that matched that of petrogenic material[36]. As in previous years, additional mass spectroscopy tests on liver samples in 2020 indicated that compounds were not petrogenic in origin and that the material was likely of natural or biological origin.

Analyses of liver >C_{10}-C_{21} and C_{21}-C_{32} hydrocarbon concentrations from 2006 to 2020[37] indicated no difference between Areas. There was an increase in concentrations of both compounds in both Areas in 2020, possibly related to a change in sampling time in 2020 versus previous sampling years. This is further discussed in Section 7.

Barium, a component of drilling mud, has not been detected in plaice fillet or liver samples.

6.5.2 TASTE TESTS

There was no evidence of taint for plaice. No difference in taste was noted between the Study and the Reference Areas in the triangle and hedonic scaling tests. For all tests, there were no consistent comments from panellists about Study Area plaice identifying an abnormal or foreign odour or taste that would suggest taint.

6.5.3 FISH HEALTH INDICATORS

Female plaice from the Reference Area were generally larger than females from the Study Area, with higher values for fish length, total body weight, gutted body weight, and liver weight. However, female plaice from the Study Area had larger gonads relative to gutted weight than did females from the Reference Area. These differences occurred when either all females or only spent females were considered. No statistical comparisons were carried out for males because too few were caught (five in the Reference Area and three in the Study Area).

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[36] The noted contamination in 2012 likely occurred on board the vessel (see Suncor Energy 2013 for details).
[37] Data prior to 2006 were excluded from analyses because of elevated laboratory detection limit for many samples.

With the exception of a parasite observed in the gill of one fish from the Study Area, there were no other visible abnormalities observed upon necropsy of n the skin or fins of fish or on the external surface of the gonad, digestive tract, liver, body-cavity, or spleen.

There was no significant difference in MFO activity between sampling Areas when either all females or only spent females were considered.

There were no significant differences between Areas for most liver histopathology indices. However, nuclear pleomorphism occurred more frequently in the Study Area, with 57.5% of plaice affected in the Study Area and 18.3% affected in the Reference Area.

Similarly, there were no significant differences between Areas for most gill histopathology indices. However, distal hyperplasia occurred more frequently in the Reference Area, with 23% of plaice affected in the Reference Area and 8% of plaice affected in the Study Area.

7.0 DISCUSSION

7.1 SEDIMENT COMPONENT

7.1.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

Sediments in the Terra Nova area are predominantly sand, with median sand content greater than 90% in 2020 and all previous years. Gravel content varied from 0% to approximately 30% in 2020. Fines (silt + clay) content was low (median and maximum fines content were 1.4% and 3.4% in 2020, respectively).

Barium is a major constituent of water-based and synthetic-based drill muds, and >C_{10}-C_{21} hydrocarbons are major constituents of synthetic-based drill muds. >C_{10}-C_{21} hydrocarbons in synthetic-based drill muds are synthetic organic compounds and background concentrations for these compounds in sediment samples can be considered near or below the laboratory detection limit of 0.3 mg/kg. Therefore, >C_{10}-C_{21} hydrocarbon concentrations greater than 0.3 mg/kg are evidence of contamination and distance gradients (decreases in concentration with increasing distance from drill centres) for these hydrocarbons are project-related, not naturally occurring. In contrast, barium occurs naturally in Terra Nova sediments at concentrations of approximately 100 to 200 mg/kg, and there have always been natural distance gradients for barium and many other variables from the centre of the development. Consequently, it is difficult to distinguish low-level barium contamination from variance in natural background concentrations.

In 2020, as in previous EEM years, concentrations of >C_{10}-C_{21} hydrocarbons and barium were elevated above background levels near drill centres and decreased rapidly with increasing distance from the drill centres. Decreases in concentration with distance from active drill centres were evident for >C_{10}-C_{21} hydrocarbons and barium in 2000, the first EEM sampling year after drilling began. For barium, the natural distance gradient observed in baseline (1997) became stronger, but similar natural gradients for other metals generally did not increase in strength.

The threshold distance at which >C_{10}-C_{21} hydrocarbon concentrations approached background levels in 2020 (i.e., the estimated zone of influence) was approximately 2 km, which is within the range of threshold distances noted from 2008 to 2017 (i.e., confidence intervals for threshold estimates overlapped). However, the threshold distance in 2020 was smaller than threshold distances computed in 2004 and 2006 (4.6 and 5.2 km, respectively). Barium concentrations decreased to background levels within approximately 1 km from drill centres in 2020. Based on confidence intervals, the threshold distance for barium was lower than those noted in 2002, 2010, and 2014 (1.8, 2.0, and 2.7, respectively), and similar to estimates from other EEM years.

In general, there has been a decrease in sediment >C_{10}-C_{21} hydrocarbon and barium concentrations since the 2006 EEM program, and these decreases coincided with a decrease in drilling activity at Terra Nova[38]. The highest >C_{10}-C_{21} hydrocarbon (6,550 mg/kg) and barium (16,000 mg/kg) concentrations over all EEM years were noted at Station 30(FE) in 2004 and 2006, respectively. Station 30(FE) is the nearest to a drill centre and is located 0.14 km from the FE Drill Centre. In 2020, maximum >C_{10}-C_{21} hydrocarbon and barium concentrations also occurred at Station 30(FE) and were 1,600 and 3,900 mg/kg, respectively. Highest median levels, over the whole field, were noted in 2006 for both >C_{10}-C_{21} hydrocarbons and barium (4.3 and 170 mg/kg, respectively). Median levels in 2020 were 0.74 and 130 mg/kg, respectively. Median barium concentrations in EEM years have been below the 95th percentile concentration noted in baseline (200 mg/kg).

In 2020, sediment sulphide concentrations decreased, and sediment redox potential increased with distance from the FEZ drill centres; indicating higher sulphide levels and lower redox potential at some stations near the FEZ drill centres. These results are potentially indicative of a project effect. Sulphide concentration was also elevated at Station 30(FE), the station nearest the FE Drill Centre in 2020. However, the relationship between sulphide concentration and distance from the FE Drill Centre was weak and not significant, indicating little influence from the FE Drill Centre other than at Station 30(FE). For redox potential, the relationship with distance from the FE Drill Centre was negative, indicating higher redox potential (more oxic sediments) near the FE Drill Centre, including at Station 30(FE).

A decrease in sediment sulphide concentration with distance from the FEZ drill centres was also noted in 2014. An increase in sulphide concentration with distance from the FE Drill Centre was noted in 2006 and 2008. In remaining EEM years, the relationships between sediment sulphide concentration and distance to drill centres (either the FEZ or FE drill centres) has been weak and not significant. Redox potential has generally increased with increasing distance from the FEZ drill centres

[38] A total of 671 tonnes of synthetic-based mud--on-cuttings and 6,696 m^3 of water-based muds were discharged at Terra Nova from 2007 to November 2020, when collections for the 2020 EEM program took place. Prior to this, 5,424 tonnes of synthetic-based mud-on-cuttings and 54,622 m^3 of water-based muds were discharged.

across EEM years. The relationship between redox potential and distance from the FE Drill Centre has been highly variable - sometimes positive, sometimes negative.

Overall, results for sulphides and redox potential indicate potential project effects at a few stations, primarily around the FEZ drill centres, in some years, including 2020. In years when this occurs, it may indicate some level of decomposition of natural or anthropogenic organic carbon. In 2020, as in most previous years, all sediment were oxic (>100 mV). Anoxic conditions have only been noted at three stations over all EEM years (Station 30(FE) in 2004 and 2008; and Stations 16(NE) and 37(FEZ) in 2004). Maximum sediment sulphide concentrations in 2004 and 2008 were 24 and 44 mg/kg, respectively. The maximum in 2020 was 4.9 mg/kg.

There has been evidence of project effects on sulphur in some EEM years, with elevated levels at a few stations near drill centres. Maximum sulphur concentration in 2020 (0.27%) occurred at Station 30(FE), providing evidence of contamination at that station. However, there were no other stations near the FE Drill Centre with elevated sulphur concentrations. In general, concentrations in 2020 were lower than in many previous EEM years and the distance relationship from the FEZ drill centres was positive, rather than negative - indicating lower sulphur concentrations near drill those centres. Overall, there was little evidence of effects on sulphur in 2020, except at Station 30(FE).

There has been evidence of project effects on sediments fines, with elevated levels at some stations in some EEM years. In 2020 that evidence was weak. Sediment fines content in 2020 was similar to that noted in baseline (range of 0.7% to 3.4% in both baseline and 2020). The relationship between fines and distance to drill centres noted in every year, including baseline, was also weak and not significant in 2020. Over all years, including baseline, decreases in fines content with distance from drill centres was more evident with increasing distance from the FEZ drill centres. There was no significant change in distance relationships from the FEZ drill centres for fines in EEM years, indicating this reflects a predominantly natural gradient.

Sediment metals concentrations, ammonia, and organic carbon content decreased from the centre of the development (i.e., FEZ drill centres) in 2020. For metals and organic carbon, these gradients were apparent in all EEM years and were present and also strong in baseline (1997). Ammonia was not measured in baseline and has shown a consistent negative gradient from the centre of the development since it was first measured in 2001. Distance relationships for metals and organic carbon have not changed over time. Distance relationships for ammonia were somewhat weaker in 2001 and 2002 than in subsequent EEM years. However, sediment ammonia concentrations were highest in 2001 and have decreased since then.

There has never been any evidence of project effects on sediment gravel content, and distance gradients from drill centres have never been significant.

In summary, project effects on >C_{10}-C_{21} hydrocarbons and barium were clear and consistent across EEM years. There has been some evidence of project effects on sediment sulphur, sulphide, and fines content and redox potential in some EEM years. In 2020, there was evidence of effects on sediment sulphides content and redox potential, but there was little evidence of effects on sulphur and fines. Other physical and chemical characteristics have been largely unaffected by project activities. Baseline distance gradients (usually decreases in values with distance from the centre of development) for other variables have persisted through EEM years, often with little, or no consistent, change in strength.

Terra Nova data indicate a decrease in sediment >C_{10}-C_{21} hydrocarbon and barium contamination since a reduction in drilling intensity in 2006. In the long term, post-drilling reductions in contamination should occur because of re-suspension and transport of sediment and biodegradation of hydrocarbons (OGP 2003). Re-suspension and transport of sediment may have accounted for most of the observed decreases in >C_{10}-C_{21} hydrocarbon and barium concentrations. DeBlois et al. (2014) note that current speeds on the Grand Banks are large enough to cause re-suspension and transport of contaminated sediments away from drill centres, with potential transport of clean sediments to the drill centres. Given that both barium (which cannot biodegrade) and hydrocarbon concentrations decreased at Terra Nova, storm events coupled with a reduction in cuttings discharge can explain the decrease in hydrocarbon and barium concentrations at Terra Nova in recent years.

7.1.2 TOXICITY

There has been little evidence for project effects on laboratory amphipods in EEM years and more than 97% of samples have been non-toxic. In 2020, amphipod survival ranged from 80% to 100%, and no samples were classified as toxic following Environment and Climate Change Canada (1998) interpretative guidance for sediments.

Polychaete toxicity tests were not performed in years prior 2020. In 2020, polychaete survival ranged from 47% to 100%, with a median of 90%, and one sample (from Station 46(FEZ)) was considered toxic. Station 46(FEZ) is located 0.78 km from the

SW Drill Centre. Barium and >C_{10}-C_{21} hydrocarbon concentrations were relatively high at that station, but there were many other stations with higher concentrations that were not toxic to polychaetes. Most remaining physical and chemical characteristics values were in the mid-range at Station 46(FEZ). Sediment organic carbon concentration and redox potential were relatively low at Station 46(FEZ) but there were other stations with lower values were not toxic to polychaetes.

Polychaete growth was not reduced to below 30% of growth in control sediment in sediments from any station[39]. However, polychaete growth was reduced to below 20% of growth in reference sediment in sediments from 6 of the 41 stations tested (Stations 5(SW), 21 (NW), 29(FE), 31(FE), 37(FEZ), and 49(FEZ)). On a station-by-station examination, there was no obvious link between sediment physical characteristics at these stations and the polychaete growth response, with sediment physical and chemical characteristics covering the range of observed values.

There were no significant correlations between the three toxicity variables and sediment physical and chemical characteristics. The toxicity variables were also uncorrelated with distance to drill centres, and they were uncorrelated with each other.

Overall, there was little evidence of project effects on amphipod toxicity, or polychaete survival and growth in 2020.

7.1.3 BENTHIC INVERTEBRATE COMMUNITY STRUCTURE

In 2020, total abundance, richness, and NMDS1 scores (Spionidae dominance) decreased with distance to the nearest drill centre (i.e., were higher near drill centres), with distance relationships from the FEZ drill centres stronger than relationships from the FE Drill Centre. Distance gradients from the FEZ drill centres for total abundance and NMDS1 scores were relatively strong; the distance gradient for richness was weaker. Biomass was unrelated to distance to the nearest drill centre. However, biomass was negatively related (i.e., decreased with) distance from the FEZ drill centres and increased with distance from the FE Drill Centre. These opposing relationships explain the lack of relationship between biomass and distance to the nearest drill centre (which aggregates both distance measures).

[39] Polychaete growth was not reduced in the sample from Station 46(FEZ) that was considered toxic for survival. Although no guidance is provided in PSEP (1995), we caution against examining sublethal effects in samples for which there is a significant difference in survival because there can be density-dependent effects on the sublethal endpoint given that organisms are fed during the tests and no adjustments are made based on the number of polychaetes present.

Adjusted richness and NMDS2 scores (Cirratulidae dominance) were not significantly correlated with distance to the nearest drill centre in 2020; nor were they significantly correlated with distance to the FEZ or FE drill centres.

Gradients observed in 2020 were similar to those observed in previous EEM years. Statistical comparison among years indicated that there was a decrease in total abundance with distance from the FEZ drill centres across all years, consistent with 2020 results. The strength of this gradient changed over time, with the relationship weakening from 2004 to 2010 and strengthening from 2012 to 2020. There was no gradient in total abundance with distance from the FE Drill Centre across all years and no changes over time. In 2020, overall total abundance (i.e., at most or all stations) was higher than in any previous year, and this predominantly because of an increase in the overall abundance of Balanidae. The increase in Balanidae abundance is discussed in Section 7.1.3.1.

There was also a decrease in NMDS1 scores and biomass with distance from the FEZ drill centres across all years. Although still relatively strong in 2020, the gradient for NMDS1 scores became weaker, indicating that Spionidae dominance noted near FEZ drill centres in earlier EEM years was less pronounced in later EEM years (2001 to 2012 versus 2014 to 2020). The gradient for biomass with distance from the FEZ drill centres became stronger over time. The overall relationships between NMDS1 scores and distance from the FE Drill Centre was not significant. However, this gradient changed over time and has gradually decreased from positive in 2001 to negative since 2014, indicating Spionidae dominance near the FE Drill Centre since 2014. There was an increase in biomass with distance from the FE Drill Centre across all years, but with no change over time and no change in the gradient from before to after drilling began at the FE Drill Centre.

There was no overall relationship between richness, adjusted richness and NMDS2 scores and distance from the FEZ or FE drill centres across all years, although there were changes in some of these relationships over time. The relationship between richness and distance from the FEZ drill centres changed from near zero (i.e., uncorrelated with distance) to stronger and negative since 2012 (i.e., a decrease with distance from the FEZ drill centres). The positive relationship between adjusted richness and distance from the FEZ drill centres (i.e., an increase in adjusted richness with distance from the FEZ drill centres) became negative in 2014 and 2017 and was again positive in 2020.

Correlations between total abundance, richness, and NMDS1 scores and sediment organic carbon content, barium, and $>C_{10}$-C_{21} hydrocarbon concentrations have been significant in most years and positive, indicating higher total abundance, richness, and NMDS1 scores in sediments with higher organic content and barium and $>C_{10}$-C_{21} hydrocarbon concentrations. Since organic carbon content was not visibly affected by project activity, the consistent association between it and total abundance, richness, and NMDS1 scores may be partly natural and could indicate that, like organic carbon, natural distance gradients existed for benthos during baseline[40]. Correlations between biomass, adjusted richness, and NMDS2 scores and sediment organic carbon content and barium and $>C_{10}$-C_{21} hydrocarbon concentrations have generally been weak and/or inconsistent.

Overall, the benthic invertebrate community results in 2020 provide evidence of effects on total abundance and NMDS1 scores and weak evidence of potential effects on biomass and richness. Effects continue to be difficult to decouple from natural distance gradients that may have existed during baseline, but enrichment of the benthic community was noted in the vicinity of drill centres. Effects on total abundance were somewhat stronger in 2020 than in previous years. This result could be due in part to the increased abundance of Balanidae in samples in 2020, since the abundance of this taxon was related to distance from drill centres[41]. In other words, although the abundances of some taxa continued to decrease with distance to drill centres (and predominantly the centre of the development), and the abundance of some other taxa continued to increase with distance, the relative abundance of a taxon that had a negative distance gradient was substantially greater than in previous EEM years, thereby strengthening the usual negative distance gradient for total abundance. Effects on NMDS1 scores have been strong in all EEM years, but weaker since 2014. Effects from the FEZ drill centres generally were stronger than effects from the FE Drill Centre for total abundance and NMDS1 scores. Distance relationships for biomass and richness were weak relative to those for total abundance and NMDS1 scores. As in previous years, threshold relationships were not apparent for any summary measure of benthic community (as they have been for $>C_{10}$-C_{21} hydrocarbon and barium concentrations), but effects on the most affected taxa were apparent within approximately 1 to 2 km of drill centres.

Effects on benthic invertebrates in response to offshore oil and gas activities have been noted elsewhere (Paine et al. 2014 and references therein). Total abundance

[40] Baseline data for Terra Nova can not be compared to subsequent years because a different sieving method was used in baseline, as well as for some samples collected in 2000.
[41] Of the taxa examined individually in this report, stations nearer drill centres tended to have higher numbers of Spionidae, Cirratulidae, Phyllodocidae, Sabellidae, Balanidae, and Tellinidae, and lower numbers of Paraonidae in 2020. No significant trends with distance to the nearest drill centres were noted in 2020 for Orbiniidae, Sigalionidae, Syllidae, Amphipoda, or Echinodermata.

increased near oil platforms in the Gulf of Mexico and the North Sea (Olsgård and Gray 1995; Montagna and Harper 1996; Peterson et al. 1996; Bakke and Nilssen 2005). Richness and/or diversity have also been reduced near platforms in the North Sea (Olsgård and Gray 1995; Bakke and Nilssen 2005). These authors (see also Warwick and Clarke 1991, 1993; Kilgour et al. 2004; Newman and Clements 2008) also concluded that multivariate analyses of community composition are usually more sensitive at identifying effects of drill cuttings discharges or other anthropogenic stressors than abundance, richness, or biomass. In the Terra Nova EEM program, a multivariate measure of community composition (NMDS1) has been relatively strongly correlated with distance to drill centres and sediment concentrations of barium and >C_{10}-C_{21} hydrocarbons. In 2020, total abundance was also relatively strongly correlated with distance to drill centres. In general, effects on richness, adjusted richness, and biomass have been more subtle or absent.

7.1.3.1 Balanidae Abundance in 2020

In 2020, there was a large difference in the abundance of barnacles (Balanidae, and specifically, *Balanus crenatus*) in samples relative to previous years. *B. crenatus* numbers in 2020 reached a maximum of 1,468 organisms and a total of 23,344 organisms across all stations, versus a maximum of 60 organisms and a total number of 457 organisms across all stations in 2017. Although there was a relationship between barnicle abundance and distance to drill centres in 2020, abundances higher than in previous years occurred at most stations. Therefore, it is unlikely that the increase in barnicle abundance in 2020 was the result of project activity.

Several other factors could have contributed to the higher number of barnacles noted this year. Sampling was conducted in late November/early December in 2020, later than in previous years. This could have allowed a greater number of juvenile barnacles from the 2020 spawning period to settle out on substrates, begin growth and be large enough to be collected on a 500-micron sieve and counted. Also, barnacle reproduction and larval release can be variable depending on several factors. For example, reduced water temperatures can delay spawning in some years, and higher water temperatures can promote early or prolonged spawning events (J. Keene, pers. comm.). *B. crenatus* is also unique among the subtidal barnacles in that it can sometimes have a second spawning event in the fall, in addition to the normal spring spawning event if water temperature and food availability allow (Salman 1982). Also, barnacles require solid substrate upon which to settle, whether it be exposed rocks, gravel, shell material or other organisms, such as crabs. The inherent patchiness of these solid substrates within the sand-dominated Terra Nova study area will affect barnacle densities from season to season. Finally, there was a change in benthic taxonomist in 2020, which could influence the identification outcome. However, given all the other more likely causes of interannual variability, minor variations in sample processing and elutriation techniques in 2020[42] are considered to be a less likely cause of the increase in barnacle abundance observed in 2020.

7.2 COMMERCIAL FISH COMPONENT

7.2.1 BODY BURDEN

>C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons were detected in one Study Area plaice fillet in 2000 and >C_{21}-C_{32} hydrocarbons were detected in one Study Area plaice fillet composite in 2008, but the chromatogram profiles for these samples did not match that of the synthetic-based drill mud used at Terra Nova or any other petroleum compounds. >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons were not detected in any of the other individual and composite fillet samples analyzed since 2000.

>C_{10}-C_{21} hydrocarbons resembling the drill mud used at Terra Nova were detected in one Study Area liver sample in 2000. Hydrocarbons were not detected in plaice liver in 2001. Compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbon range were detected in most liver samples from both the Study and Reference Areas from 2002 to 2020, but none of these compounds had chromatogram profiles that matched that of the synthetic-based drill mud used at Terra Nova. As in previous years, additional mass spectroscopy tests on liver samples indicated that compounds were not petrogenic in origin. Instead, hydrocarbon peaks observed on chromatograms for liver were consistent with those expected for natural compounds, and similar compounds have consistently been observed in plaice liver at the nearby White Rose site (Husky Energy 2019).

Analyses of liver >C_{10}-C_{21} and C_{21}-C_{32} hydrocarbon concentrations from 2006 to 2020[43] indicated no difference between Areas. There was an increase in concentrations of both compounds in both Areas in 2020, possibly related to a change in sampling time in 2020 versus previous sampling years. From 2000 to

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[42] The main difference in sample processing between 2020 and most prior EEM years (i.e., 2001 to 2017) was the used of shallow pan floatation to elutriate samples in 2020. Bucket floatation was used in most prior EEM years.

[43] Data prior to 2006 were excluded from analyses because of elevated laboratory detection limit for many samples.

2017, fish sampling was conducted in May, June, or July. COVID-19 restrictions prevented sampling in these months in 2020 and samples were collected in mid-October. Since hydrocarbon compounds in liver likely are natural, possibly related to diet or reproductive status, a seasonal change in their concentration in liver is not unexpected.

Barium, a constituent of drill muds, has never been detected in plaice fillet or liver samples. Several other metals were detected frequently in plaice tissue, particularly livers (the major site of chemical accumulation, elimination, and transformation). Arsenic, mercury, and zinc have been detected in all plaice fillet samples since 2001[44]. Arsenic, cadmium, copper, iron, manganese, mercury, selenium, and zinc have been detected in most plaice liver composites since 2001. Metals concentrations have generally been low (less than 10 times the laboratory detection limit), with no consistent differences in concentrations across all EEM years. There were differences in metals concentrations in plaice tissue between Areas in some EEM years. Fillet arsenic concentrations generally were lower in the Study Area in 2020 and 2008; and they generally were higher in the Study Area in 2010, 2012, and 2017. Metals concentrations in livers (as represented by liver PC1 scores) generally were higher in the Study Area in 2004, 2006, and 2020; and they were lower in the Study Area in 2001 and 2012. Manganese concentrations generally were higher in the Study Area in 2002, 2004, and 2020, and they generally were lower in 2006 and 2012.

For all metals, differences among years were significant and much greater than differences between Areas. In general, metals other than barium in plaice tissue should be regarded as naturally occurring and as essential elements rather than contaminants.

7.2.2 TASTE TESTS

There was no evidence of taint for plaice fillets. No difference in taste was noted between the Study and the Reference Areas in the triangle or hedonic scaling tests. For both tests, there were no consistent comments about Study Area plaice from panellists identifying an abnormal or foreign odour or taste that would suggest taint.

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[44] Individual fish, rather than composite samples, were analyzed in 2000. Plaice tissue was not sampled for chemistry in 1997.

7.2.3 FISH HEALTH INDICATORS

An extensive discussion of results of the fish health indicators assessment is provided in Appendix C-3 and is summarized below.

7.2.3.1 Biological Characteristics

A total of 100 plaice were collected for fish health assessment in 2020; 60 from the Reference Area; and 40 from the Study Area. Female plaice outnumbered males in both Areas, with no difference in sex ratios between Areas. The number of males collected in the Reference and Study Areas was low; five males were collected in the Reference Area and three males were collected in the Study Area. These low numbers restricted statistical analysis for males. For females, there was no difference in the frequency of maturity stages between Areas. Female plaice from the Reference Area were generally larger than females from the Study Area, with higher values of total length, total and gutted weight, and liver weight. However, females from the Study Area had heavier gonads relative to body weight.

Inter-area differences in biological characteristics have been observed for plaice in previous EEM programs for Terra Nova. Heterogeneity in biological characteristics of fish can often be attributed to normal inter-site variability linked to such factors as feeding or reproductive status (e.g., Barton et al. 2002; Morgan 2003) rather than exposure to contaminants.

7.2.3.2 Gross Pathology

Except for one parasite on the gill of one fish from the Study Area, there were no visible abnormalities on the skin or fins of plaice or on the external surface of the gonad, digestive tract, liver, body cavity or spleen.

7.2.3.3 Mixed Function Oxygenase Activity

MFO activity was compared between Areas for spent females and all females (all maturity stages pooled). There was no difference in MFO activity between Areas in both cases.

7.2.3.4 Histopathology

There were no differences between the Study and Reference Areas for most liver histopathology indices. However, nuclear pleomorphism was observed in 18.35% of plaice from the Reference Area and 57.50% of plaice from the Study Area, and this difference was statistically significant. The levels of nuclear pleomorphism detected in both the Study and Reference Areas at Terra Nova were higher than in previous years. One case of nuclear pleomorphism was detected in the Study Area in baseline (1997) and in the first EEM program (2000). The lesion was not detected in any program from 2001 to 2014. In 2017, the prevalence of the lesion was 8% in the Reference Area and 2% in the Study Area. Nuclear pleomorphism is a lesion that is commonly associated with the effects of contaminants including PAHs (Myers et al. 2008; Wolf and Wheeler 2018). However, it has also been associated with the effects of toxic algae (Feist et al. 2015) and has been found in fish at low levels in apparently unpolluted waters (Malins et al. 1984; Myers et al. 1991).

There were no differences between the Study and Reference Areas for most gill histopathology indices. However, distal hyperplasia was observed more frequently in plaice from the Reference Area. Epithelial cell hyperplasia is a common, nonspecific response of the gill to damage due to a variety of irritants including bacterial and parasite infections, poor water quality, and environmental toxins (Ferguson 1989; Roberts 1989; Nowak and Bryan 1998; Noga 2011; Wolf et. al. 2015).

7.2.3.5 Overall Fish Health

Overall, the results of the 2020 fish health survey indicated that the health of American plaice is similar between the Reference Area and the Terra Nova Study Area. The differences noted in biological characteristics can reasonably be attributed to natural variability. Of particular interest was the virtual absence of inter-area variability with respect to most health effect indicators commonly associated with chemical toxicity such as hepatic EROD activity and a wide range of liver and gill lesions. However, the prevalence of nuclear pleomorphism was generally higher in 2020 than in previous EEM years, in both Areas, with higher prevalence in the Study Area than in the Reference Area. This should continue to be examined in future programs to assess if a pattern emerges.

7.3 SUMMARY OF EFFECTS AND MONITORING HYPOTHESES

As discussed in Section 1, monitoring hypotheses (reiterated in Table 7-1) were developed as part of EEM program design for Terra Nova to guide interpretation of results. As noted in Section 1, the “null” hypotheses (H_o) always state that no effects will be observed, even though effects might have been predicted in the Terra Nova EIS.

Table 7-1 Monitoring Hypotheses

Sediment Quality
H_0: There will be no attenuation of physical or chemical alterations or biological effects with distance from project discharge points.
Water Quality
H_0: Project discharges will not result in changes to physical and chemical characteristics of the water column, or to phytoplankton densities near discharge points in the Terra Nova Project area.
Commercial Fish
H_0: Project discharges will not result in taint of fish resources within the Terra Nova Project area, as measured using taste panels. H_0: Project discharges will not result in adverse effects to fish health within the Terra Nova Project area, as measured using histopathology and MFO induction.

Given results observed in the 2020 EEM program, the null hypothesis is rejected for the sediment component of the program, but the null hypothesis is not rejected for the commercial fish component of the EEM program. The water quality program for Terra Nova was not executed in 2020 because produced water was not being released at the site. Rejection of the null hypothesis for sediment quality was expected, since drill cuttings modelling and EIS predictions indicated that there should be changes in sediment physical and chemical characteristics and benthic community structure with distance from a discharge point.

As in previous years, there was clear evidence that sediment $>C_{10}$-C_{21} hydrocarbon and barium concentrations were elevated near drill centres in 2020. There has been some evidence of project effects on sediment sulphur, sulphide, and fines concentration in some EEM years. In 2020, there was evidence of project effects on sediment sulphide concentration and redox potential but little evidence of effects on sulphur and fines.

Sediment contamination did not extend beyond the zone of influence predicted by Seaconsult (1998) (Section 1). The model predicted that, on completion of drilling, drill cuttings could be dispersed to 15 km from source, with the heaviest deposition occurring within approximately 5 to 10 km from drill centres. Consistent with these results, concentrations of $>C_{10}$-C_{21} hydrocarbons decreased to levels near the laboratory detection limit (0.3 mg/kg) within approximately 2 km from drill centres; concentrations of barium decreased to background levels within approximately 1 km from drill centres.

There was evidence that project activities altered community composition near drill centres in 2020, with abundances of some taxa increasing and abundances of other taxa decreasing near drill centres and at higher barium and $>C_{10}$-C_{21} hydrocarbon concentrations. Total abundance was also higher near drill centres, potentially as a result of the increased abundance of Balanidae in 2020 (see further discussion in

Section 7.1.3.1 above). There was weaker evidence of potential increases in biomass and richness near drill centres in 2020. As in previous years, the distance gradient for these changes was too weak to provide robust estimates of the spatial extent of effects, but 2020 results suggest effects on the most affected taxa to approximately 1 to 2 km of drill centres.

Effects of drill cuttings on benthic invertebrates were expected to be fairly large in the immediate vicinity of drill centres and mild within a few hundred metres of the drill centres (Suncor Energy 1996). Large effects on benthic invertebrates at Terra Nova were only noted in 2008 at Station 30(FE) located nearest to (within 0.15 km of) a drill centre. In that year, total abundance, biomass, and richness were substantially lower at Station 30(FE) than at other stations. Otherwise, the predominant effect at Terra Nova has been a change in community composition, with enrichment of the benthic community near drill centres. These results are consistent with EIS predictions.

No effects were noted on plaice. No tissue contamination was noted; no tainting of this resource was observed; and overall plaice health, as measured through various health indicators, was similar between the Terra Nova Study Area and the more distant Reference Area.

7.4 CONSIDERATION FOR FUTURE EEM PROGRAMS

To reduce seasonal effects, sampling should be performed at a consistent time of year for each component.

7.4.1 SEDIMENT COMPONENT

In its response to regulator comments on the 2014 EEM program, Suncor committed to replacing the Microtox toxicity test with the juvenile polychaete test. This commitment was fulfilled in the 2020 EEM program. Suncor also committed to evaluating the usefulness of the polychaete test relative to information gained from examination of benthic community structure. In 2020, the examination of benthic community structure provided substantially more information on potential project effects than did the polychaete test. Project effects were noted for benthos; there was little evidence of project effects from juvenile polychaete test results. We therefore recommend that the juvenile polychaete test be discontinued in future EEM programs. Given the long-term data set established using the laboratory amphipod toxicity test, we recommend that this test be retained.

At present, all organisms within each benthos sample are weighed together to obtain a single measure of biomass. In order to better assess potential project effects on biomass, individual taxa within the echinoderms and barnacles (which are larger and may have an undue influence on biomass in any given sample) should be separated out from samples before any subsampling and weighed separately. A biomass measure with and without echinoderms and barnacles would then be available to best quantify potential influences.

The before-after drilling at the FE Drill Centre contrast in repeated-measures regression (i.e., a comparison between years 2000 and 2001 and subsequent years) has ceased to provide much new information. As the number of EEM sampling years increase, testing for linear and quadratic trends over time becomes more relevant. The before-after drilling at the FE Drill Centre contrast should be discontinued. Linear and quadratic contrasts from the FEZ and FE drill centres should examine data back to the earliest available EEM year (2000 for sediment physical and chemical characteristics; and 2001 for benthos).

7.4.2 COMMERCIAL FISH COMPONENT

Because of the increased in nuclear pleomorphism noted in plaice liver at Terra Nova in 2020 and, to a lesser extent, in 2017, the presence of this liver lesion should continue to be examined closely in future programs to determine if a pattern emerges.

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