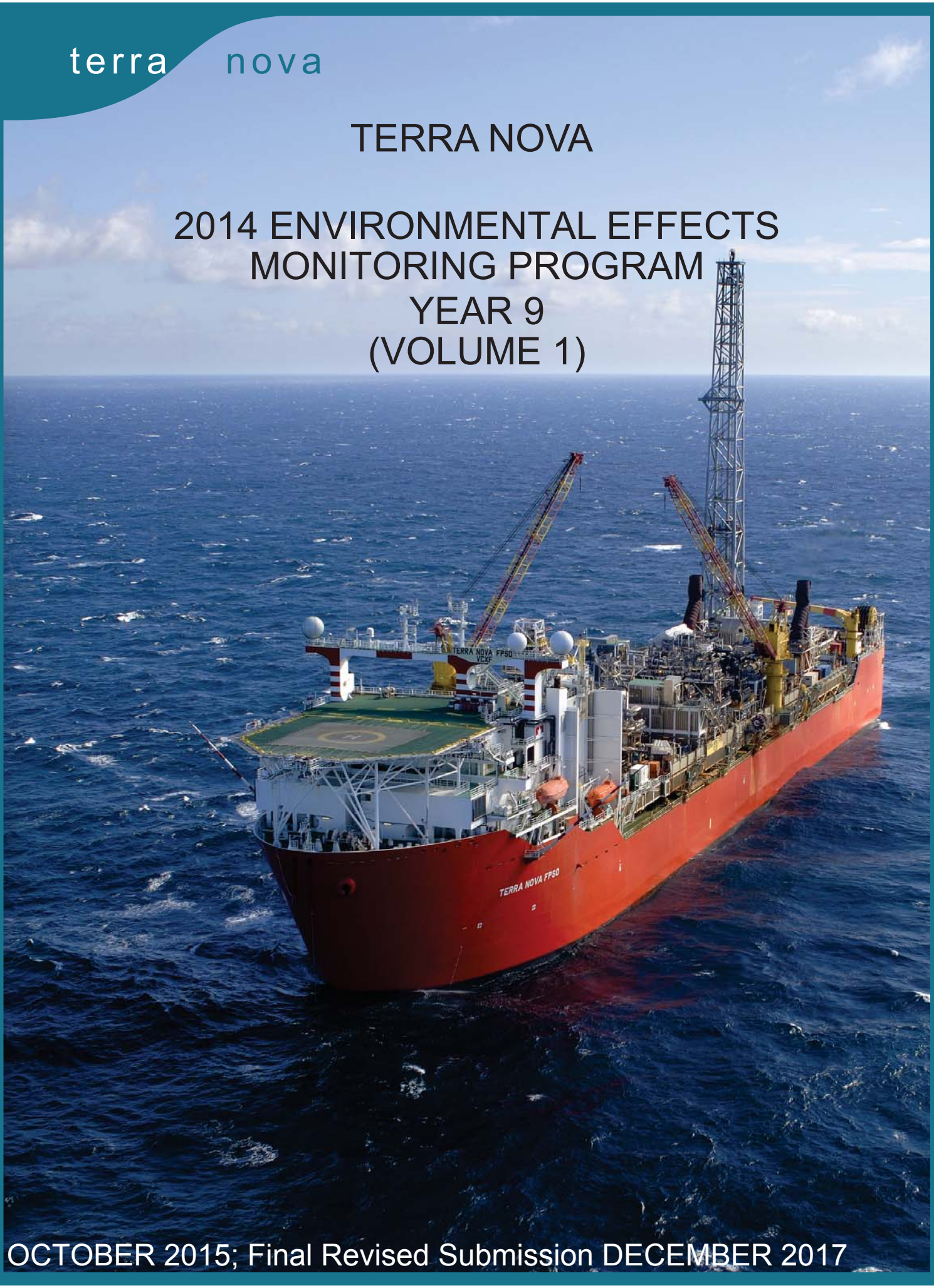
terra nova

TERRA NOVA

2014 ENVIRONMENTAL EFFECTS MONITORING PROGRAM YEAR 9 (VOLUME 1)



OCTOBER 2015; Final Revised Submission DECEMBER 2017

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 (2012) control document TN-IM-EV02-X00-001 and submitted to the Canada-Newfoundland and Labrador Offshore Petroleum Board on December 3, 2012. 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 eighth EEM Programs were conducted in 2000, 2001, 2002, 2004, 2006, 2008, 2010 and 2012. This report discusses the results of the ninth EEM Program, conducted in the summer and fall 2014, and relates these to findings of previous EEM years (Suncor Energy 2001, 2002, 2003, 2005, 2007, 2009, 2011, 2013) and to the baseline (1997) program (Suncor Energy 1998a).

In 2014, 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 luminescent bacteria (Microtox) and a marine amphipod species were performed, and benthic invertebrate infaunal species were identified and enumerated and community structure was analyzed.

Water samples and conductivity, temperature, depth data were collected at 16 stations in a Study Area. Eight of these stations were located 0.3 km from the FPSO and eight were located approximately 3 km from the FPSO, in the vicinity of drill centres. An additional eight stations were located in two Reference Areas approximately 20 km to the southeast and southwest of the Terra Nova site. Water

[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).

samples were analyzed for physical and chemical characteristics, as well as for phytoplankton pigment concentration as a measure of phytoplankton productivity.

Samples of a commercial bivalve species (Iceland scallop) and a flatfish species (American plaice) were collected in the Study Area and in the Southeast Reference Area. These samples were analyzed for chemical body burden and taste. Analyses were also performed on Iceland scallop and American plaice size, shape, fecundity and maturity status (morphometric and life history characteristics), and American plaice health indices.

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 near drill centres in 2014. 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 2014, maximum barium and $>C_{10}$-C_{21} hydrocarbon concentrations (880 and 40 mg/kg, respectively) occurred at station 31(FE), located 0.37 km from the Far East (FE) drill centre. 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 2014. Higher sulphide and lower redox levels at some stations near drill centres indicate that decomposition of synthetic-based drill fluid or natually occurring organic carbon may be occurring.

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 results, concentrations of barium decreased to background levels within approximately 3 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 4.5 km from drill centres. Higher sulphides and lower redox occurred at a few stations within 1 to 2 km of drill centres. As in most previous years, all sediments were oxic.

There was little to no evidence of project-related sediment toxicity, as measured through laboratory tests with luminescent bacteria (Microtox) and amphipods.

There was evidence of project effects on *in-situ* benthic invertebrates near drill centres, 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. Effects on the most affected taxa were apparent within 1 to 2 km of drill centres. More general summary measures of community composition (total abundance, biomass, richness and diversity) were predominantly unaffected by project activities in 2014. Overall, these results are consistent with EIS predictions.

Analyses of water samples indicated that seawater physical and chemical characteristics at Study Area stations and Reference Area stations were similar. In some previous EEM years, polycyclic aromatic hydrocarbons (PAHs) were detected sporadically and in trace amounts in seawater samples. The occurrence of trace amounts of PAHs in seawater samples was reduced in 2014 (and 2012), and it was similar to that noted in the baseline year (1997). The evidence that produced water was detected in seawater samples was weak, consistent with dispersion modelling results that indicate rapid dilution of produced water in the marine environment.

Sediment contamination and effects on benthic invertebrates were not coupled with biological effects on commercial fish. Iceland scallop resources were not tainted. Results of body burden analysis on Iceland scallop tissue have indicated Iceland scallop viscera contamination with >C_{10}-C_{21} hydrocarbons and barium. Viscera >C_{10}-C_{21} hydrocarbon contamination has decreased since 2004; barium levels in viscera in 2014 (and 2012) were similar to baseline levels. There was no evidence of muscle tissue contamination in 2014 (and 2012).

No contamination or tainting was noted for American plaice and American plaice health, as measured through a combination of 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. 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. There was little indication of project effects on water quality. Although contamination of Iceland scallop tissue was noted, no effects on Iceland scallop taste were noted. No tissue contamination or effects on taste were noted for American plaice and American plaice heath was similar between the Terra Nova Study Area and the Reference Area.

ACKNOWLEDGEMENTS

The Terra Nova EEM program (2014) was led by Stantec Consulting Ltd. (St. John's, NL) under contract to Suncor Energy and under the direction of Greg Janes (Suncor Energy). Stantec Consulting Ltd. led data collection. Participants in the commercial fish survey included Doug Rimmer and Melinda Watts (Stantec Consulting Ltd., St. John's, NL), and Adam Templeton and Joseph Woodford (Oceans Ltd., St. John's, NL). Participants in the sediment and water survey included Doug Rimmer, Scott Finlay, Kristian Greenham, Alexandra Eaves, Justin Bath and Jim Harrison from Stantec Consulting Ltd. Fugro Jacques Geosurveys Inc. (Rob Boland and Shane Sullivan) provided geopositional services for sediment and water collections. Benthic invertebrate sorting, identification and enumeration were led by Patricia Pocklington (Arenicola Marine, Wolfville, NS). Chemical analyses of sediment were conducted by Maxxam Analytics (Halifax, NS and St. John's, NL) and petroforma inc. (St. John's, NL). Chemical analyses of tissues were conducted by Maxxam Analytics. Chemical analyses of water were conducted by Maxxam Analytics and RPC (Fredericton, New Brunswick). Chromatograms were interpreted by Dr. Joe Kiceniuk. Particle size analysis was conducted by Stantec Consulting Ltd. Sediment toxicity tests were conducted by petroforma inc. Fish and shellfish taste tests were performed at the Marine Institute of Memorial University. Fish health indicator analyses were supervised by Dr. Juan Perez Casanova (Oceans Ltd.). Sediment chemistry, toxicity and benthic invertebrate data, as well as body burden data, were analyzed by Dr. Bruce Kilgour (Kilgour & Associates, Ottawa, Ontario). Water chemistry data were analyzes by Dr. Elisabeth DeBlois (Elisabeth DeBlois Inc., St. John's, NL). Drs. Elisabeth DeBlois, Bruce Kilgour and Juan Perez Casanova wrote sections of the report. Technical review and consolidation of text within each report section was done by Dr. Elisabeth DeBlois. Editing and report consolidation was performed by Ellen Tracy (Stantec Consulting Ltd). Lois Strangemore and Ryan Melanson (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 and Greg Janes (Suncor Energy) and Dr. Joe Kiceniuk provided final review of the document before final production.

The original EEM report was submitted in October 2015, this document reflects the final, revised document as accepted by the C-NLOPB.

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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 acts 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.).

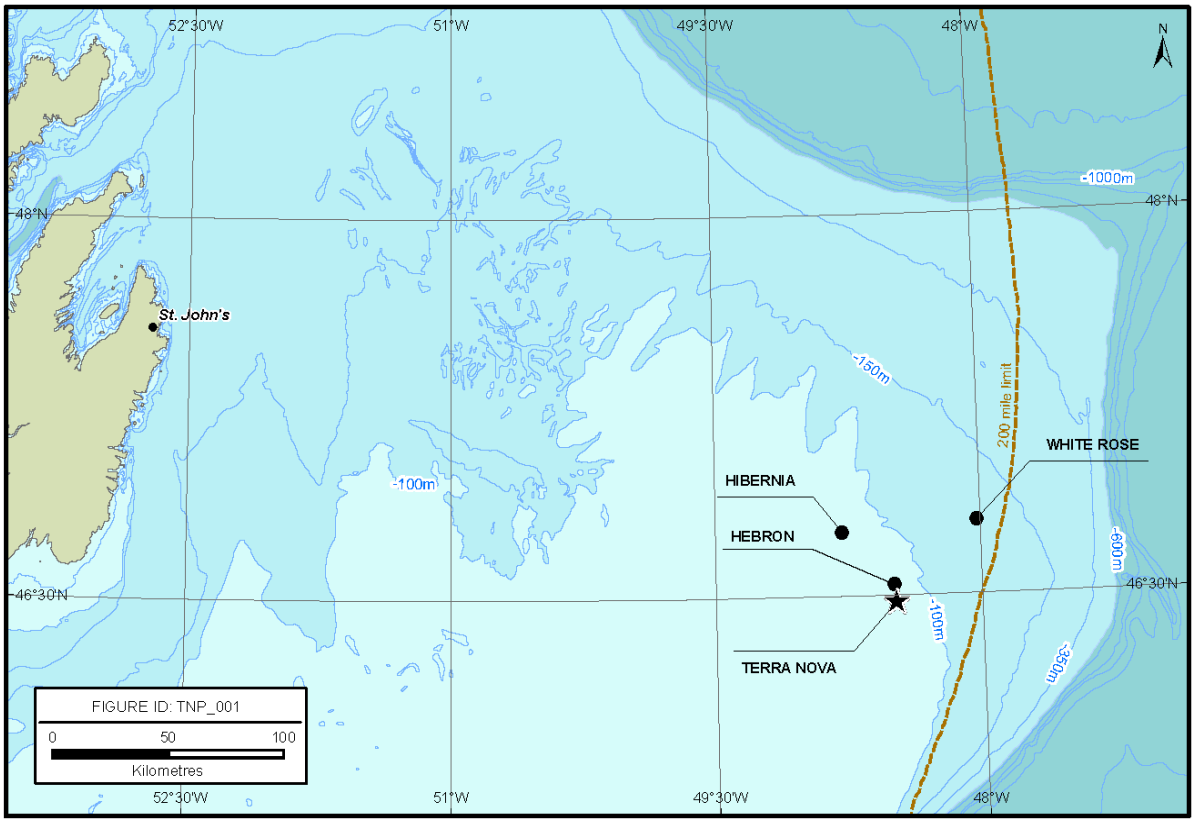


Figure 1-1 Terra Nova and Other Oil Field Locations on the Grand Banks

The oil field is being developed using a floating production, storage and offloading (FPSO) facility and a semi-submersible drilling rig (Figure 1-2). Wells were drilled through seven subsea templates, located in five glory holes to protect them from iceberg impact (Figure 1-3). Trenched and bermed flowlines connected to flexible risers link the subsea installations to the FPSO.

Figure 1-2 Terra Nova Oil Field Schematic

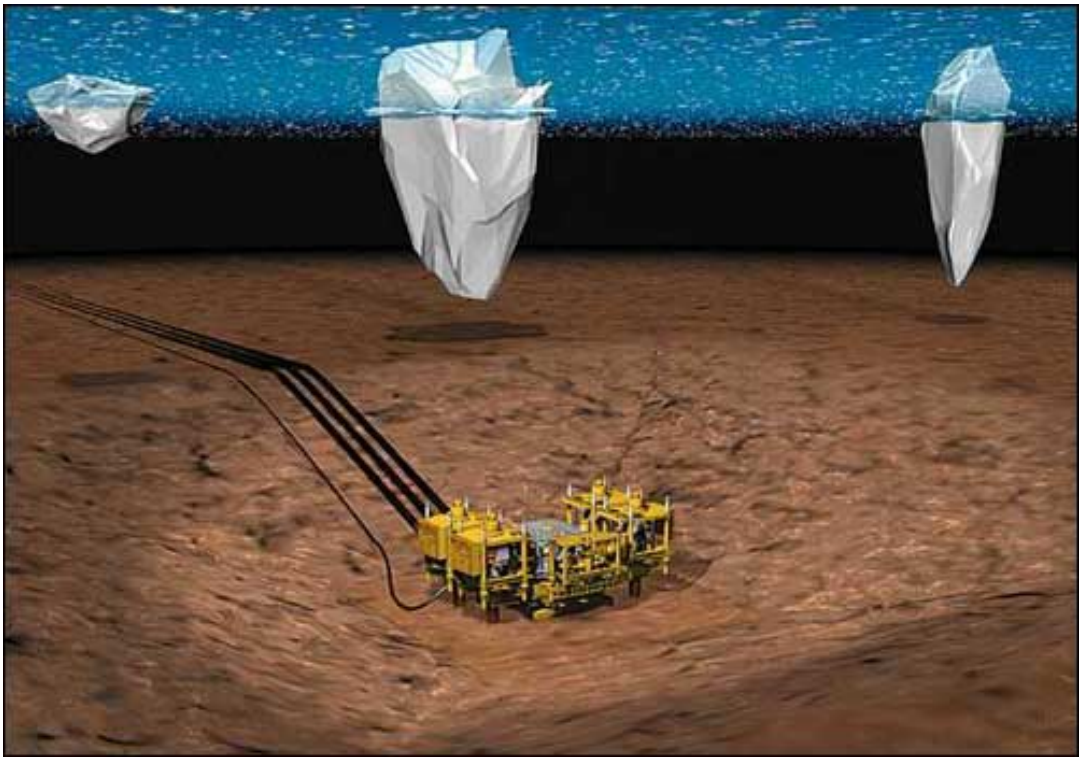


Figure 1-3 Typical Glory Hole Configuration

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 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

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

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 nine times, in 2000, 2001, 2002, 2004, 2006, 2008, 2010, 2012 and 2014. 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 (2012) control document TN-IM-EV02-X00-001 and submitted to the Canada-Newfoundland and Labrador Offshore Petroleum Board December 3, 2012.

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.

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.

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

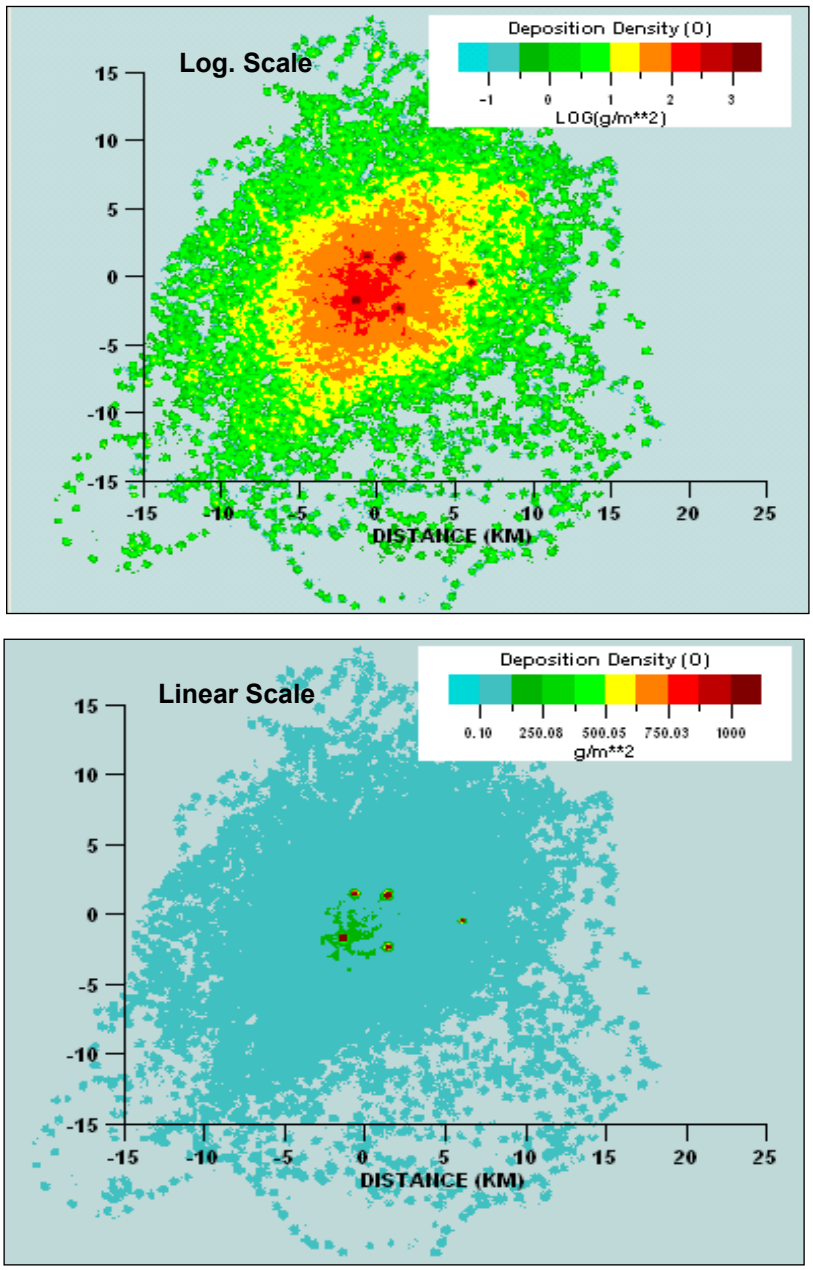


Figure 1-4 Zone of Influence for Drill Cuttings After Completion of Drilling

(Seaconsult 1998)

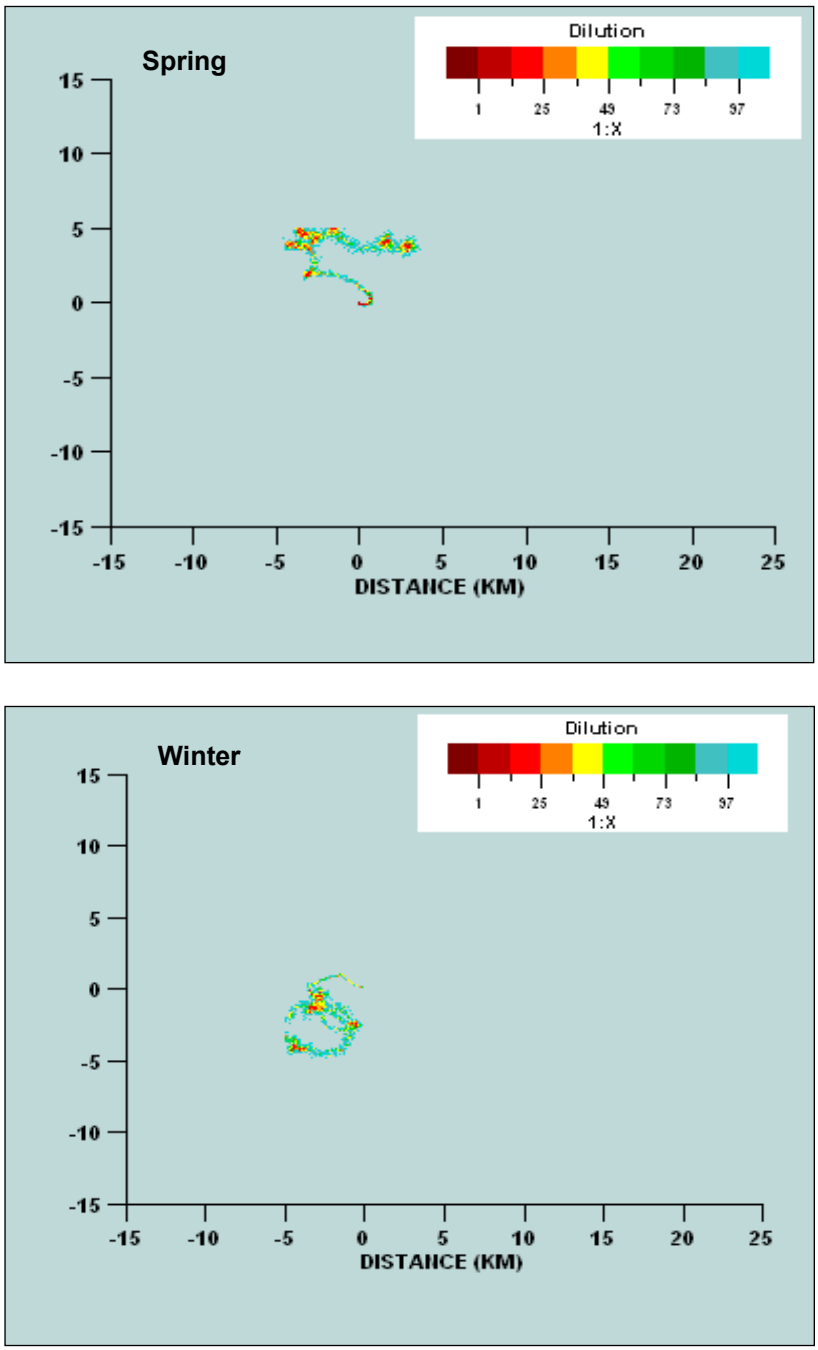


Figure 1-5 Snap-Shot of the Distribution of Produced Water

(Seaconsult 1998)

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 draw 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) and American plaice (plaice). 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 (2012) control document TN-IM-EV02-X00-001, submitted to the Canada-Newfoundland and Labrador Offshore Petroleum Board December 3, 2012), as well as the Baseline program report (Suncor Energy 1998a).

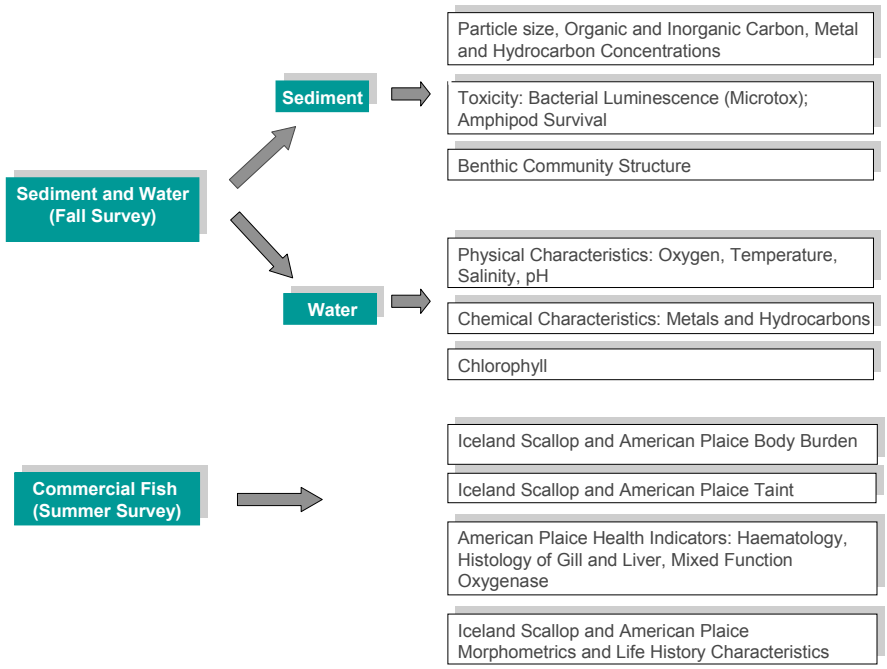


Figure 1-6 EEM Components

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, haematology 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.

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, while water has been 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 (2012) control document TN-IM-EV02-X00-001 for details).

[6] MFO: Mixed Function Oxygenase.

The general spatial distribution of sampling sites was established during the design phase of the Terra Nova EEM program. The distribution of sampling sites then underwent some modifications to accommodate changes in drill centre location (proposed versus actual) and a Fisheries Exclusion Zone (FEZ) around construction activities.

The FEZ was not yet established and therefore posed no restrictions for the Baseline program in 1997 and for collection of scallop and plaice in Spring of 2000. However, sediment and water could not be collected inside the FEZ in the Fall of 2000. Scallop, plaice, sediment and water could not be collected inside the FEZ in 2001. 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. In 2012 and 2014, the revised water quality monitoring program was implemented and water stations were sampled inside the FEZ, near the FPSO, and outside the FEZ, near drill centres.

Station locations for sediment and water 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 locations for water for the 2000 to 2010 EEM programs are shown in Figure 1-9. Station locations for water for the 2012 and 2014 programs are shown in Figure 1-10. Transect locations for scallop and plaice for the Baseline program and the EEM programs are shown in Figures 1-11 to 1-20. In 2014, the SW corner of the FEZ was expanded for the fish survey to accomodate drilling activity. Station name changes that have occurred since the Baseline program are identified in Table 1-2.

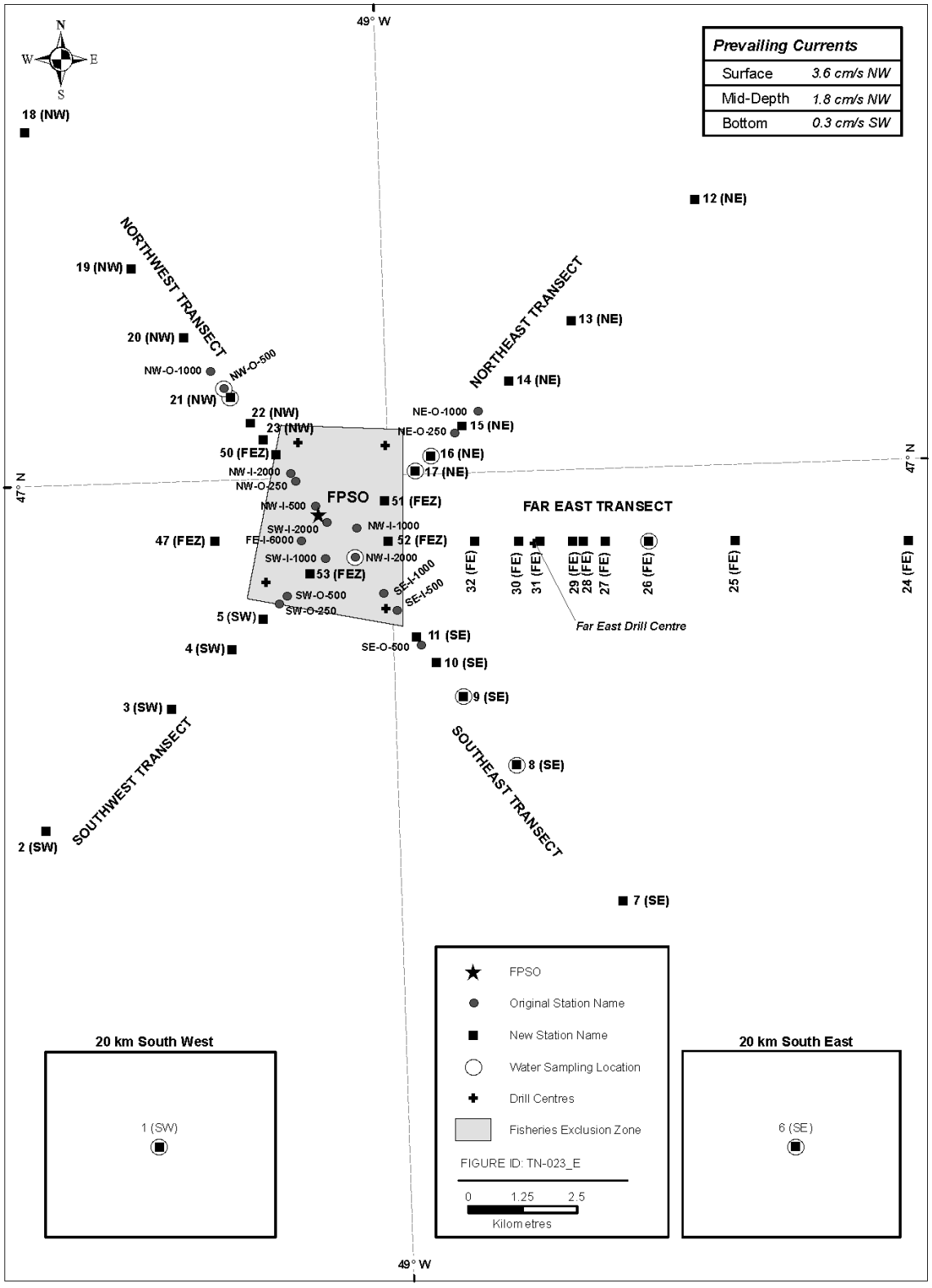


Figure 1-7 Station Locations for the Baseline Program (1997) Sediment and Water Collections

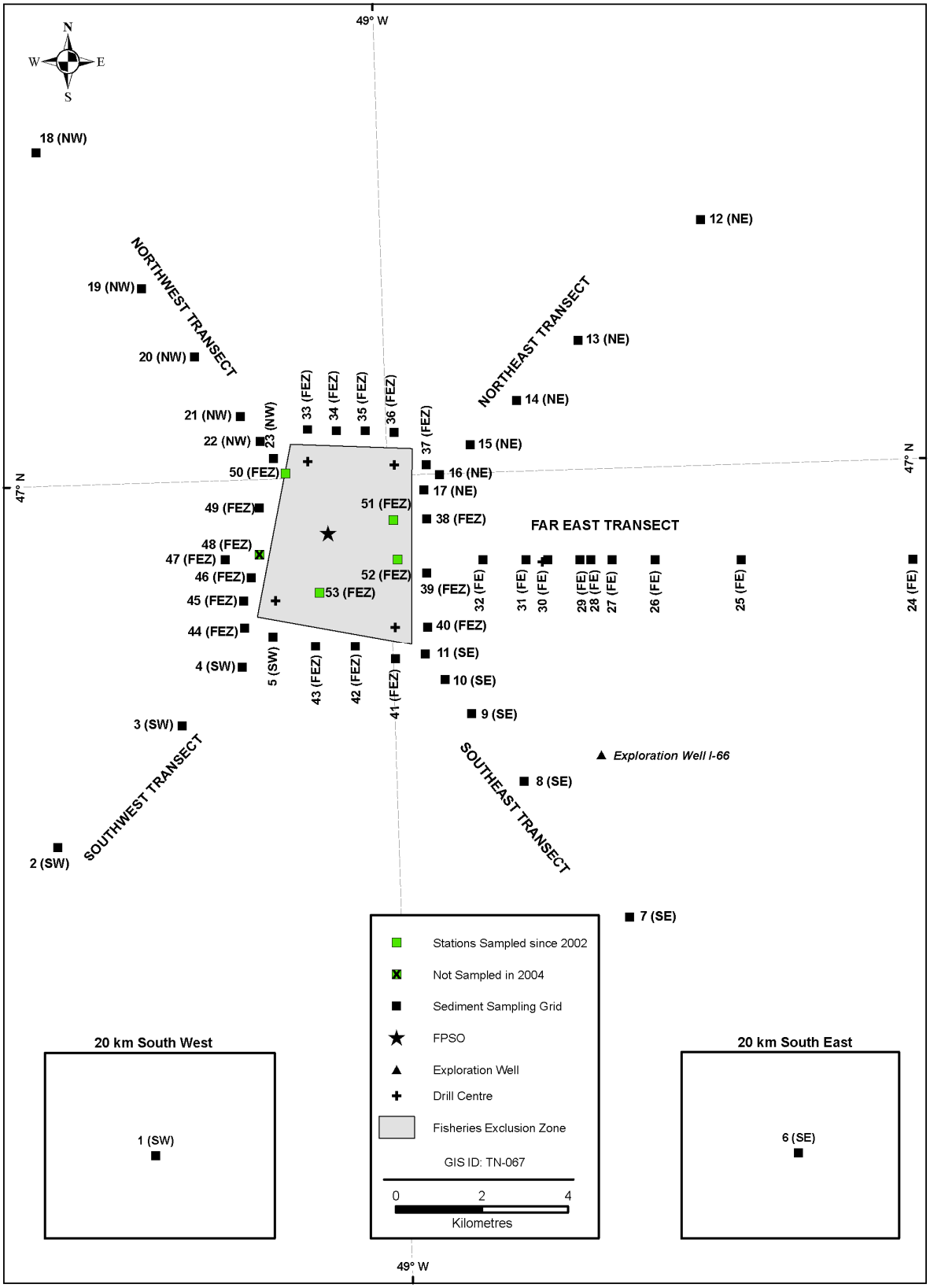


Figure 1-8 Station Locations for the EEM Program Sediment

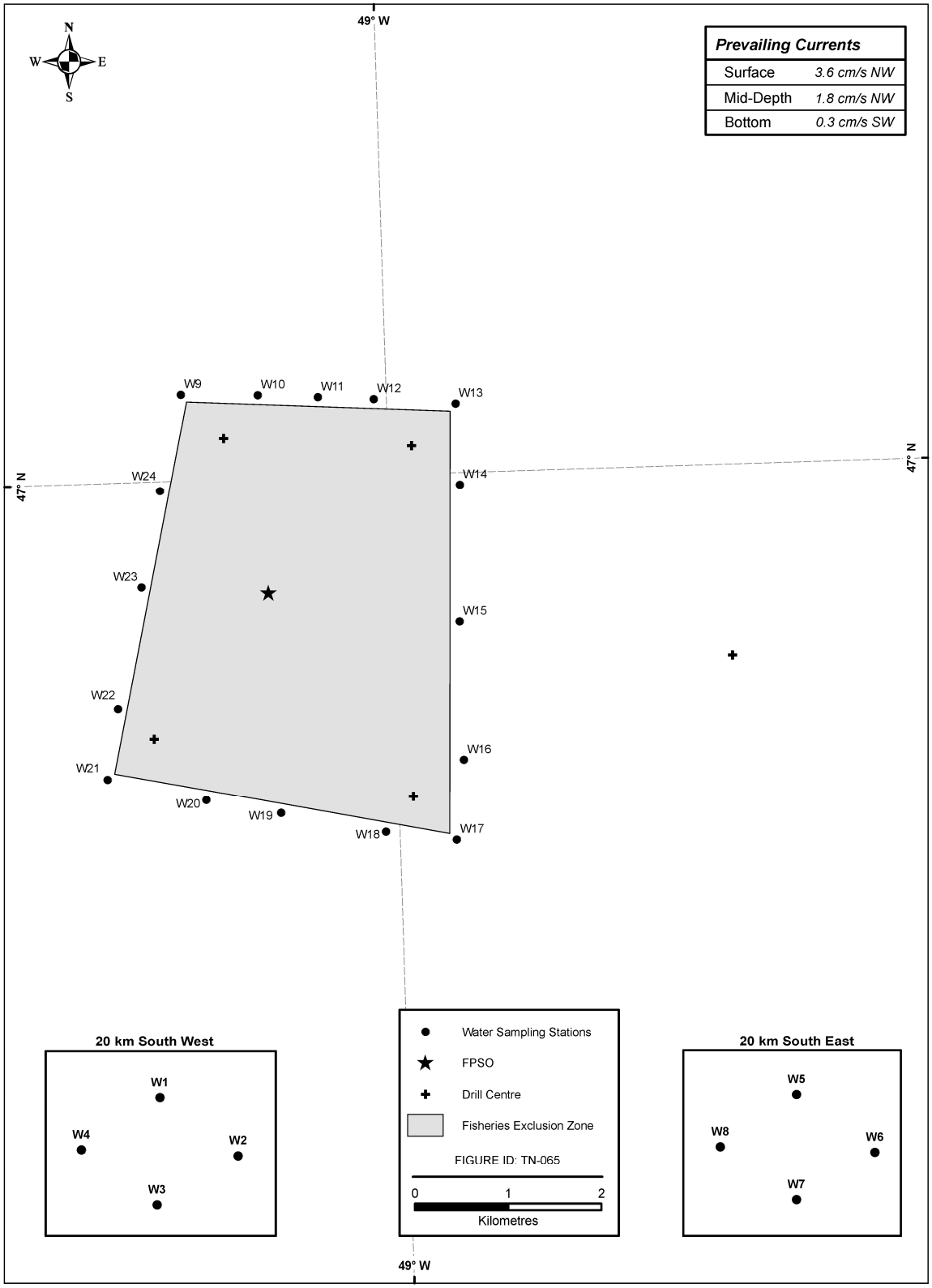


Figure 1-9 Station Locations for the EEM Program Water Collections (2000 to 2010)

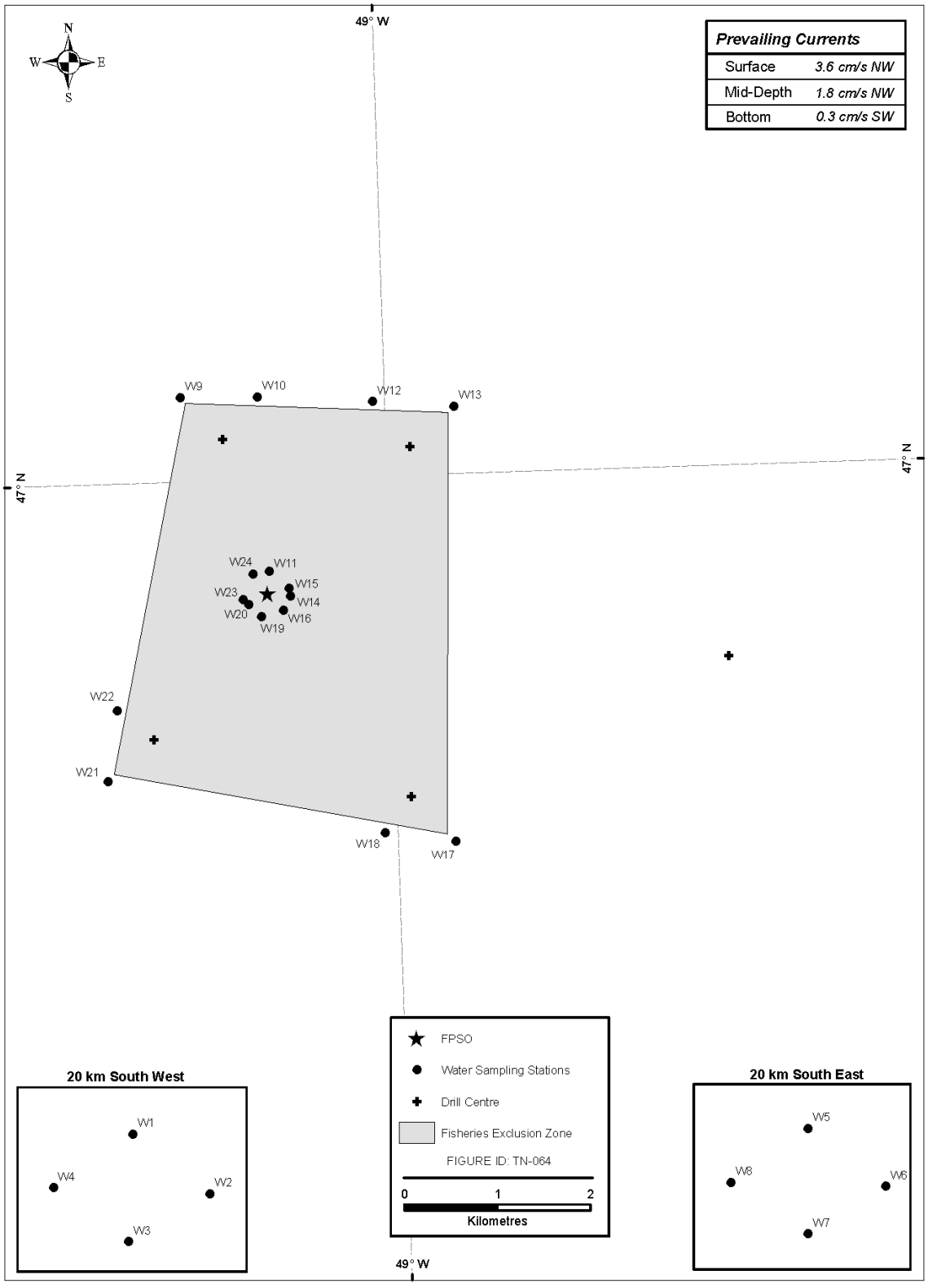


Figure 1-10 Station Locations for the EEM Program Water Collections (2012 and 2014)

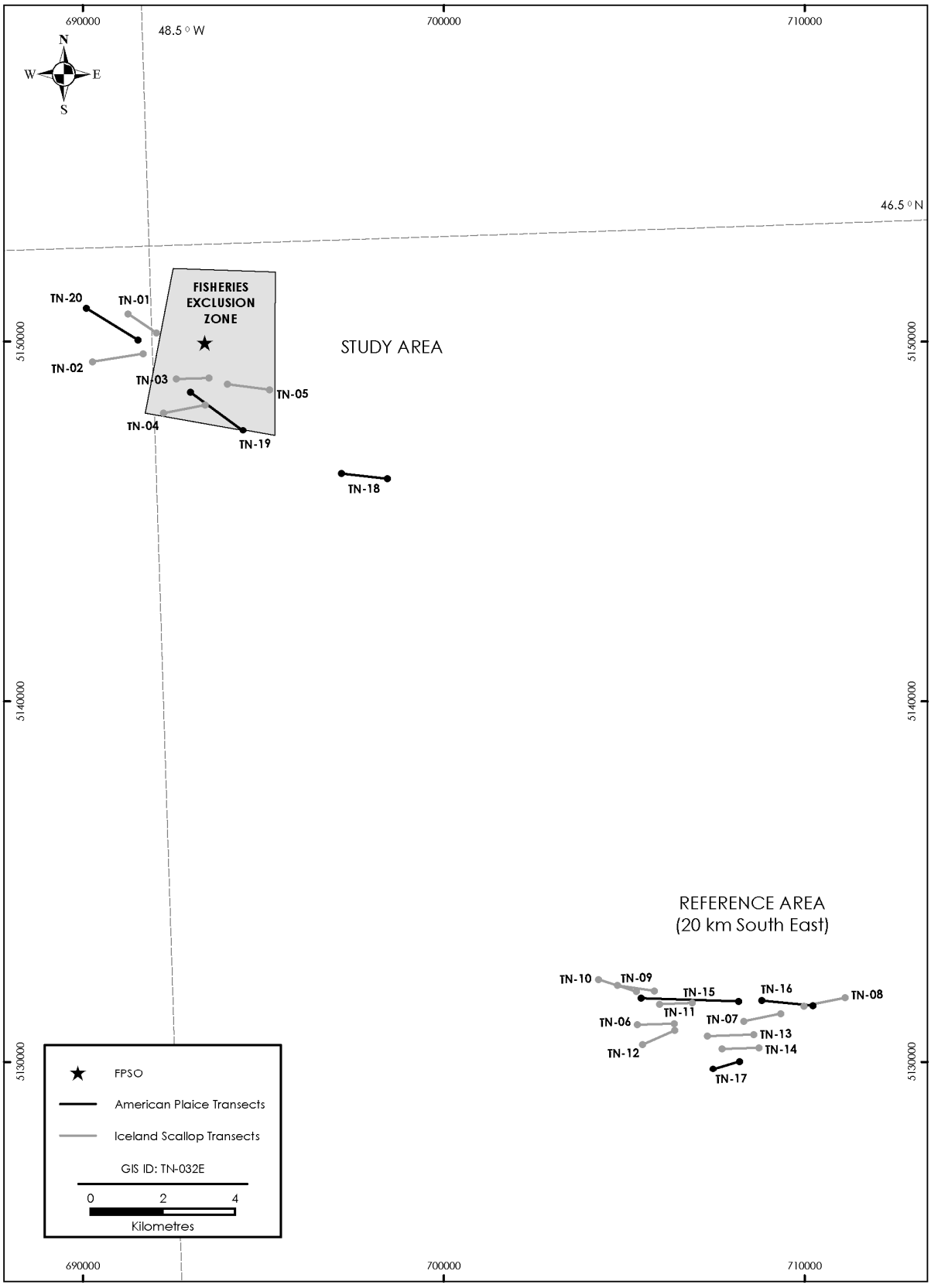


Figure 1-11 Transect Locations for Scallop and Plaice (1997)

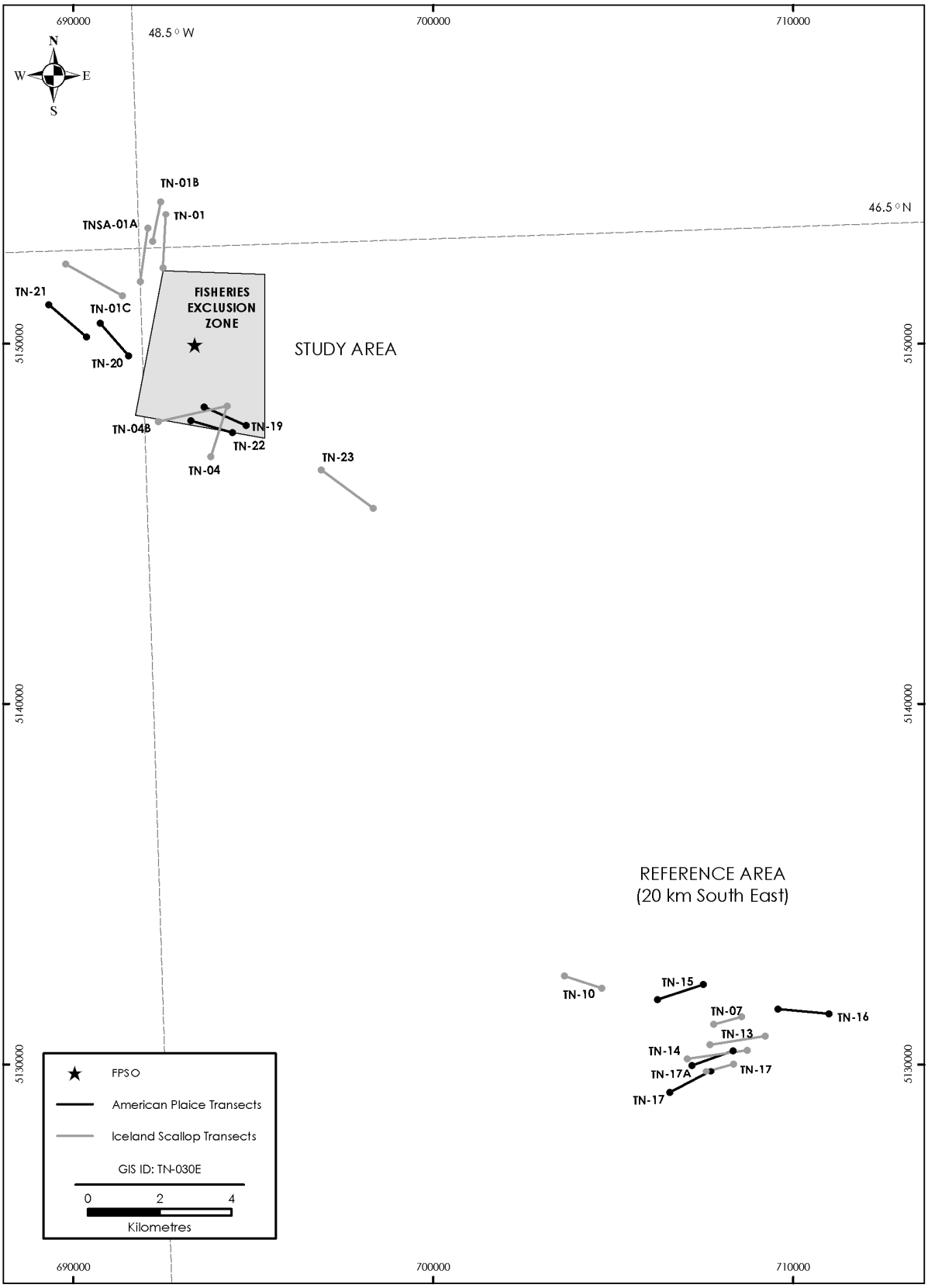


Figure 1-12 Transect Locations for Scallop and Plaice (2000)

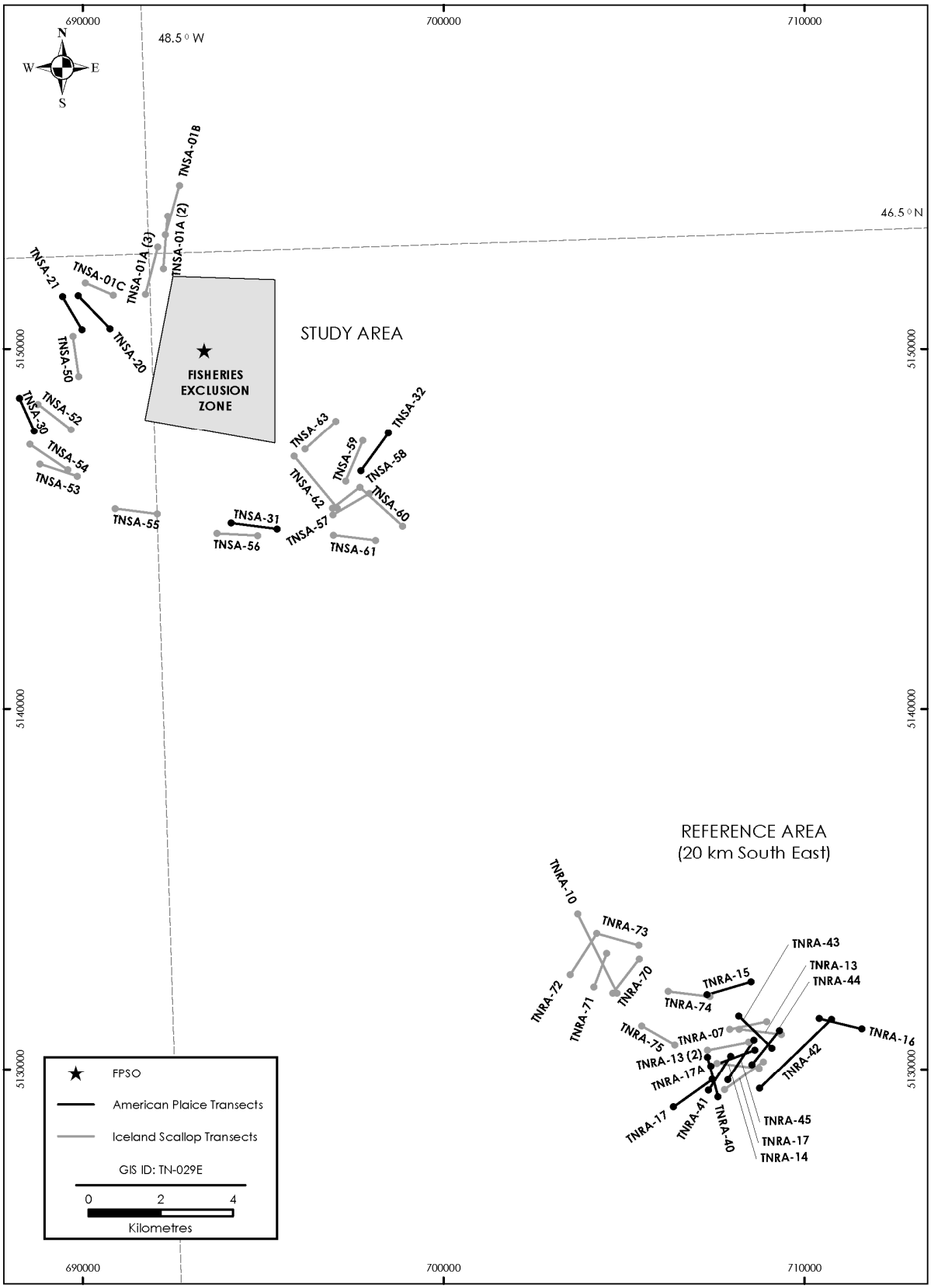


Figure 1-13 Transect Locations for Scallop and Plaice (2001)

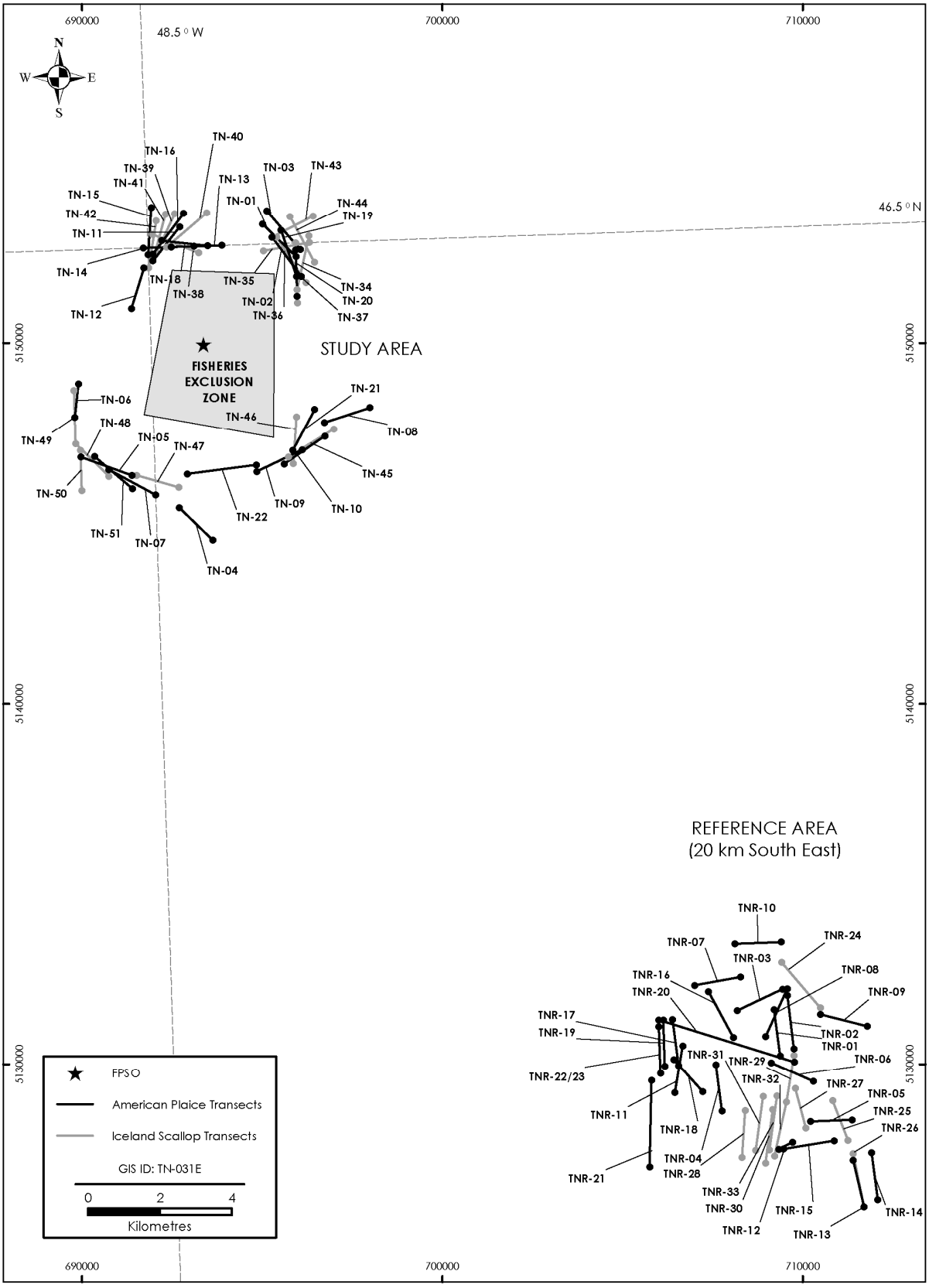


Figure 1-14 Transect Locations for Scallop and Plaice (2002)

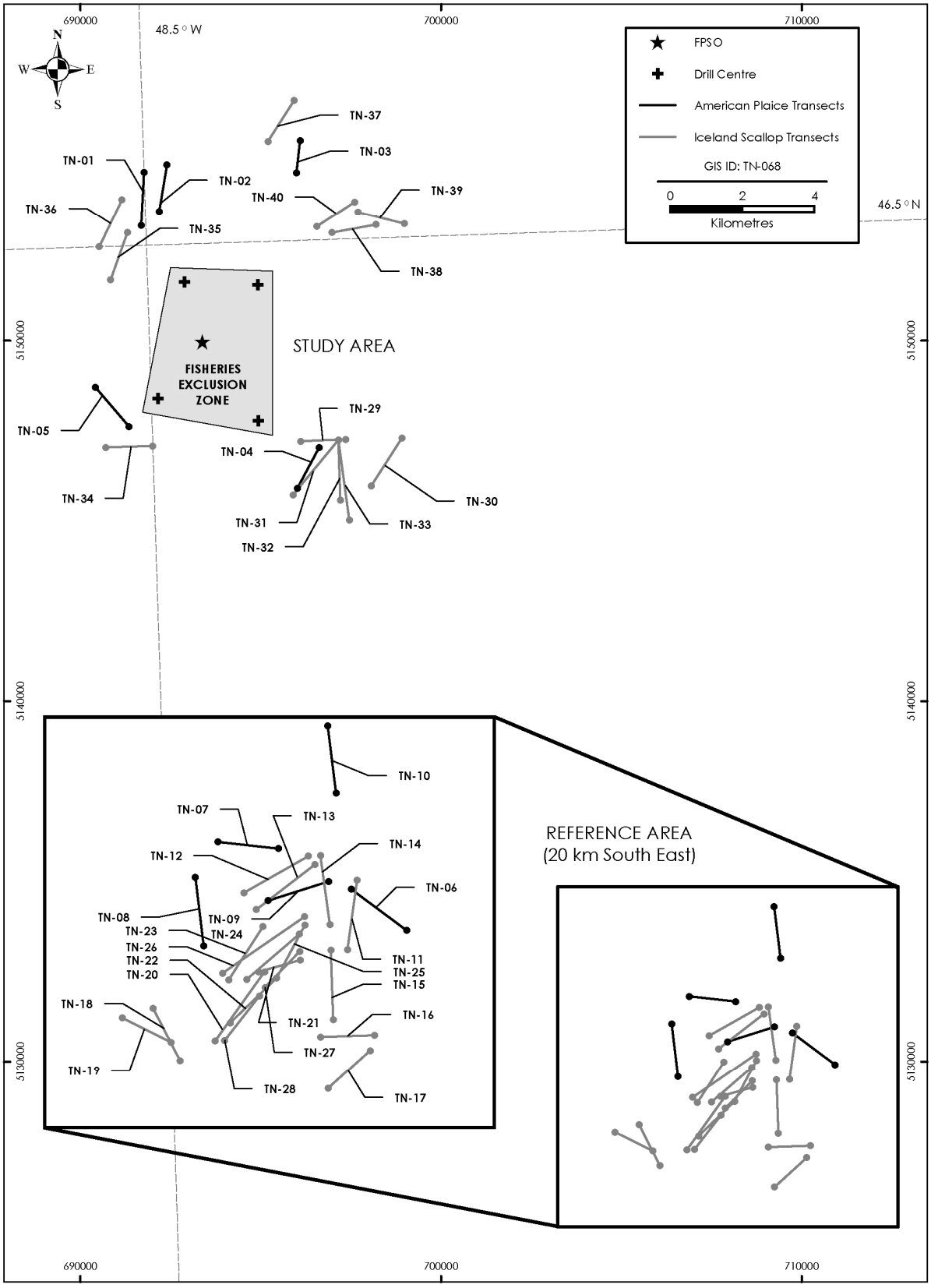


Figure 1-15 Transect Locations for Scallop and Plaice (2004)

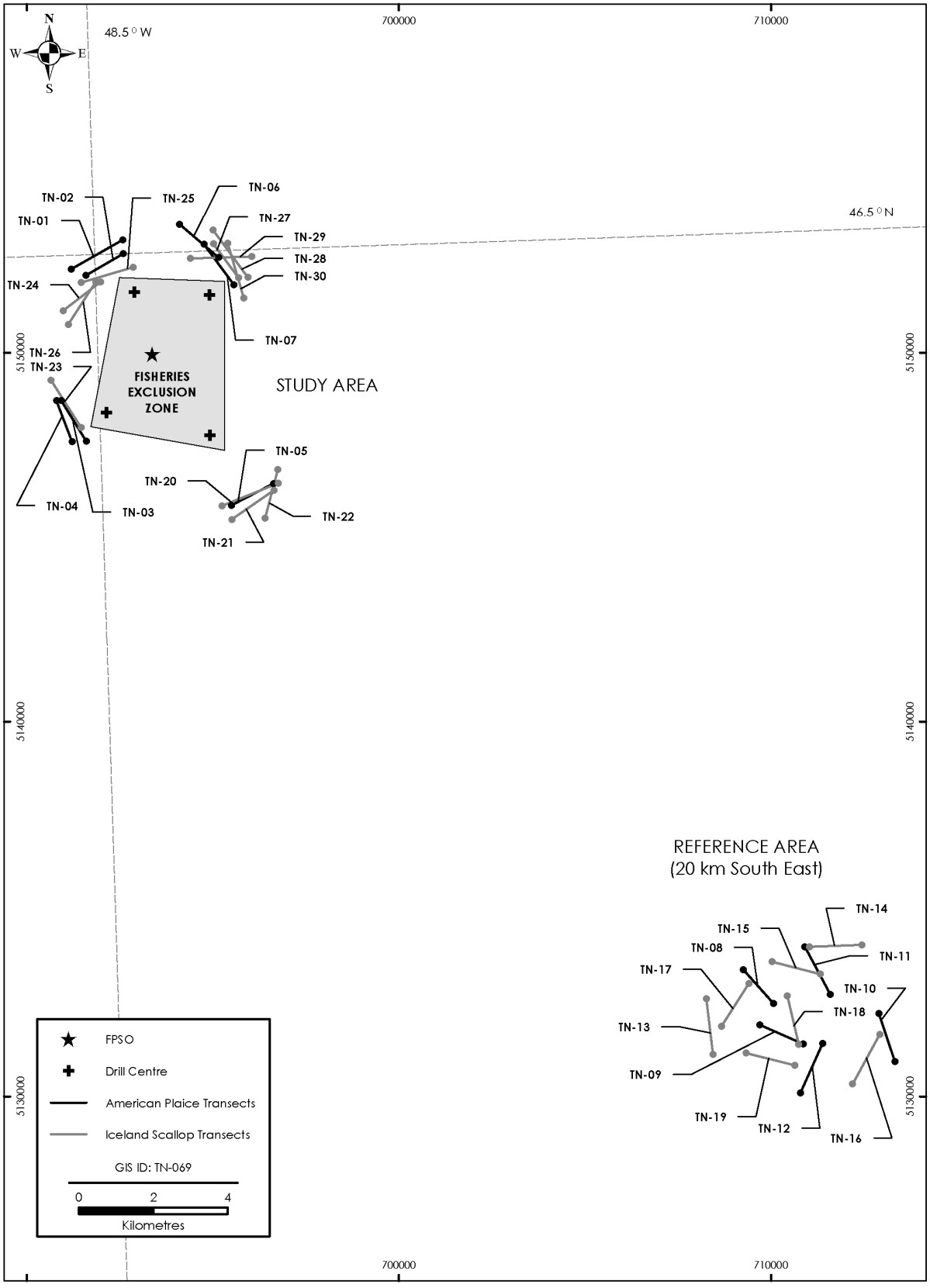


Figure 1-16 Transect Locations for Scallop and Plaice (2006)

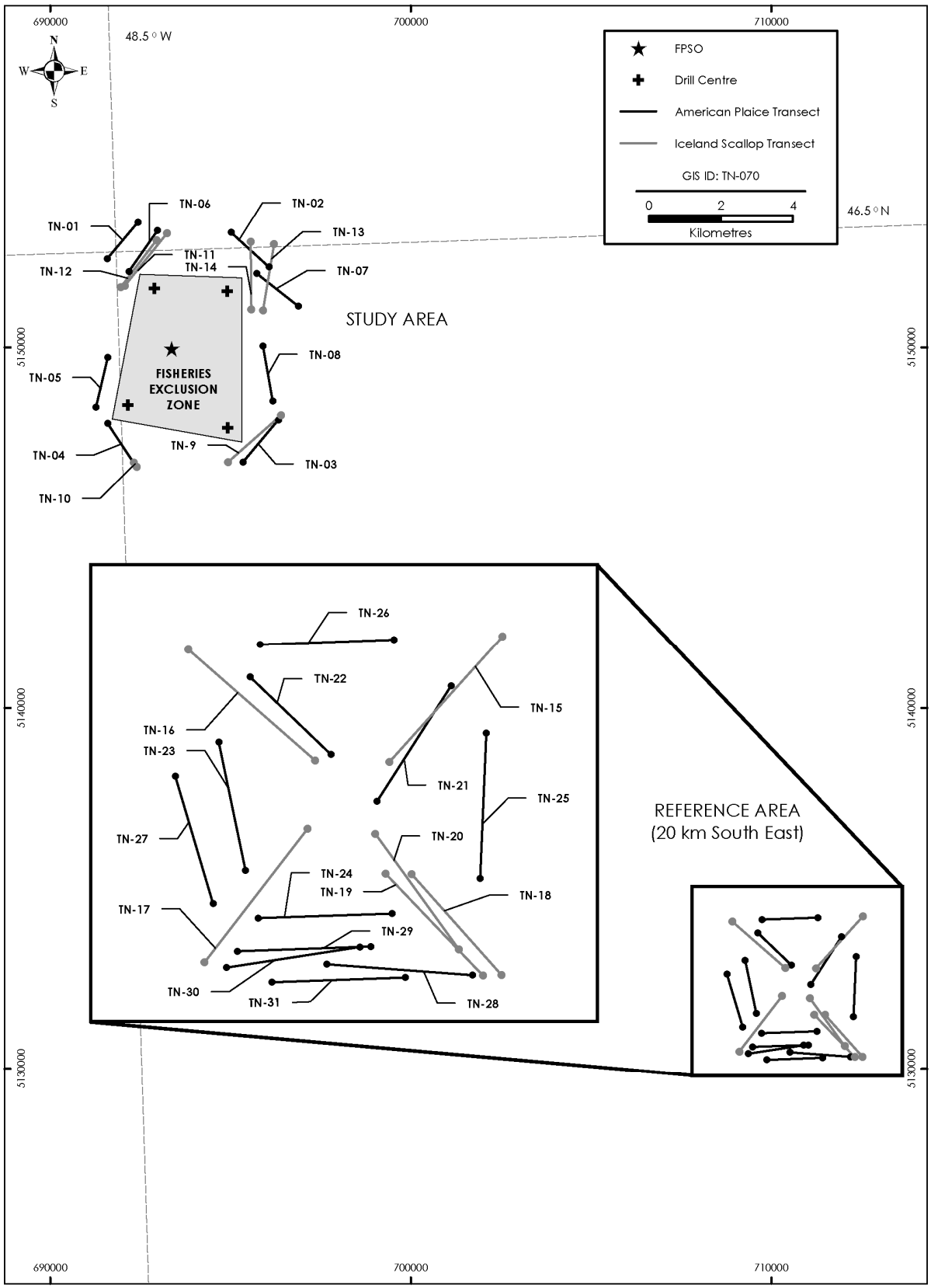


Figure 1-17 Transect Locations for Scallop and Plaice (2008)

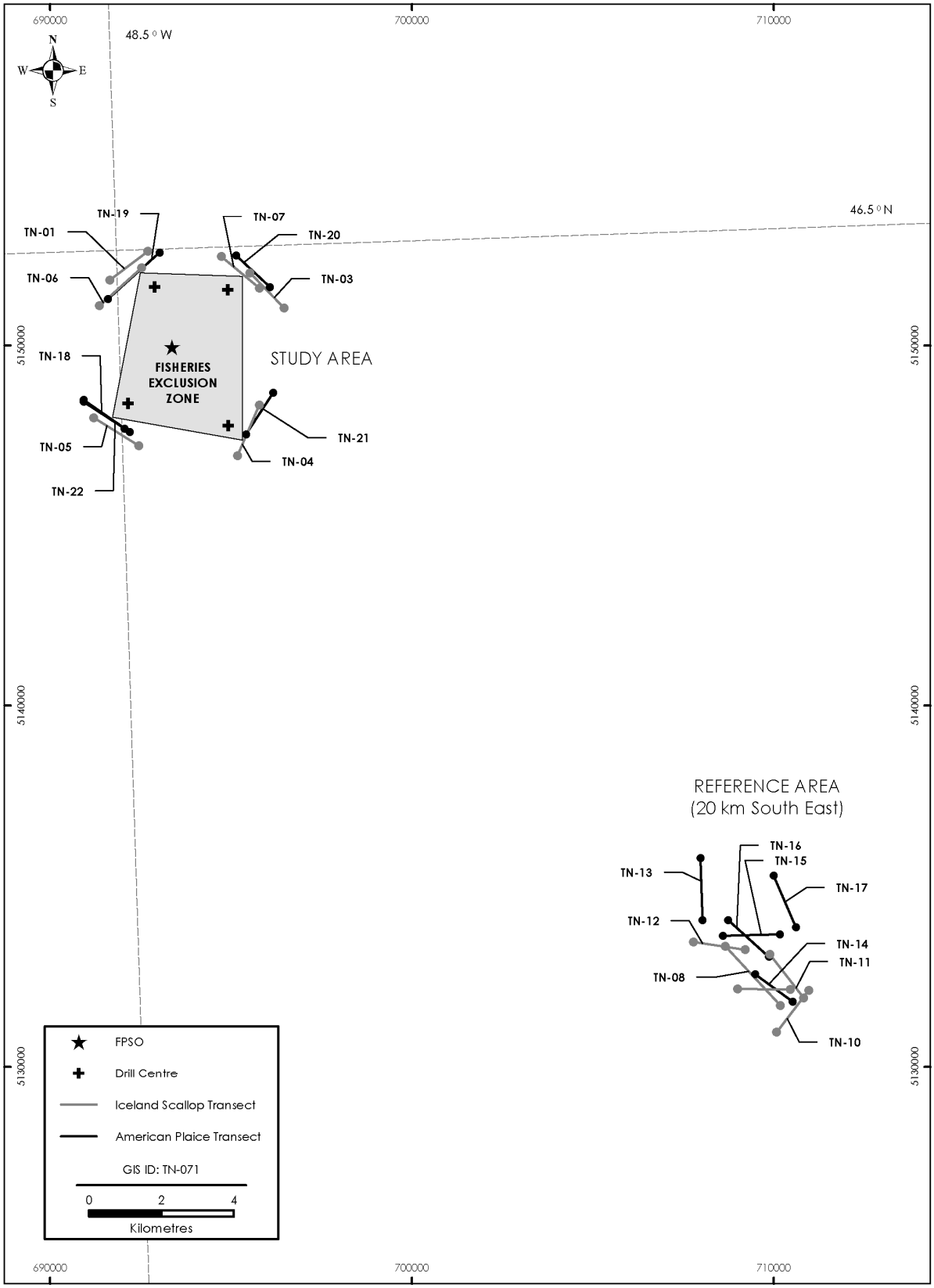


Figure 1-18 Transect Locations for Scallop and Plaice (2010)

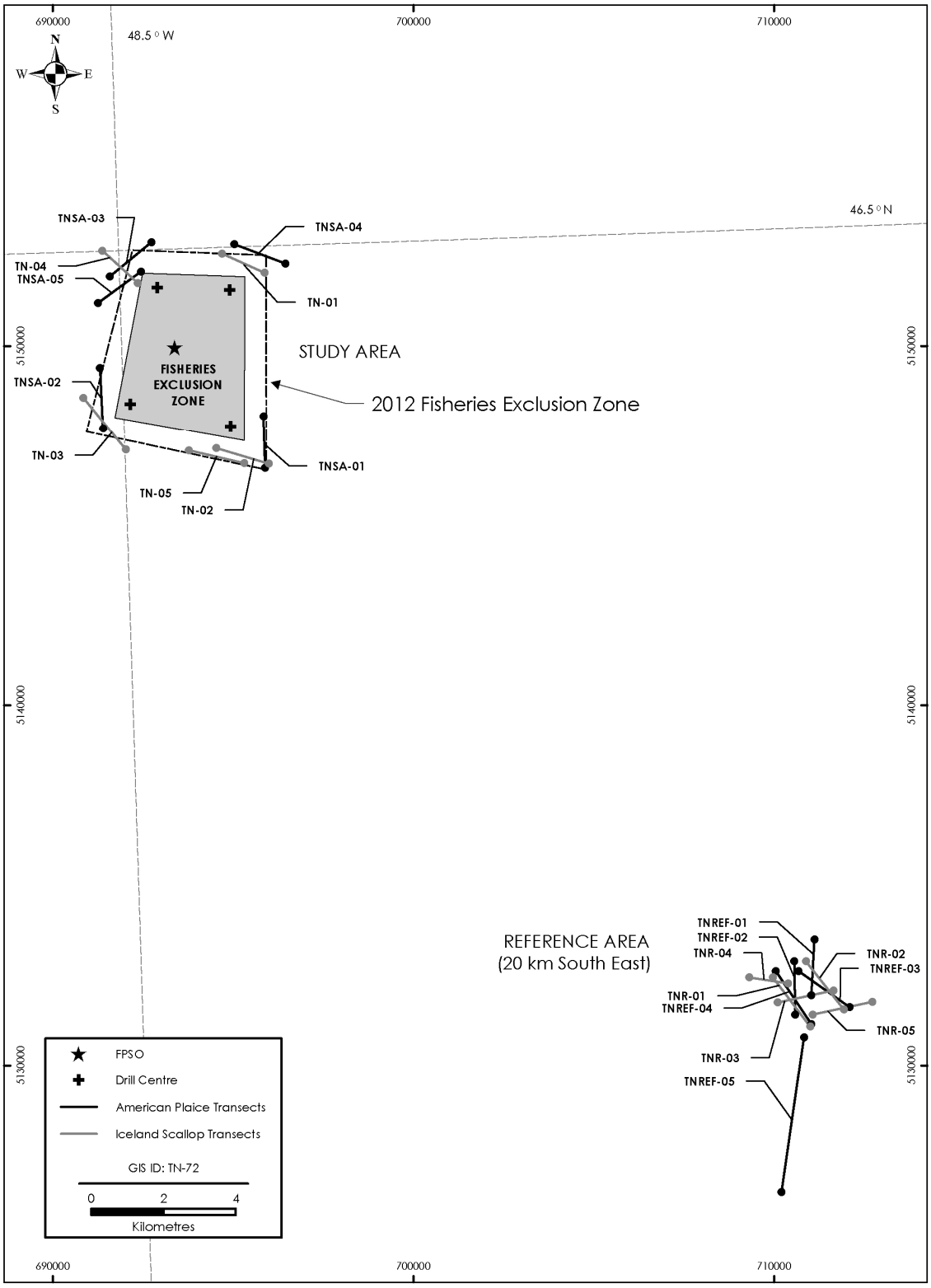


Figure 1-19 Transect Locations for Scallop and Plaice (2012)[7]

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

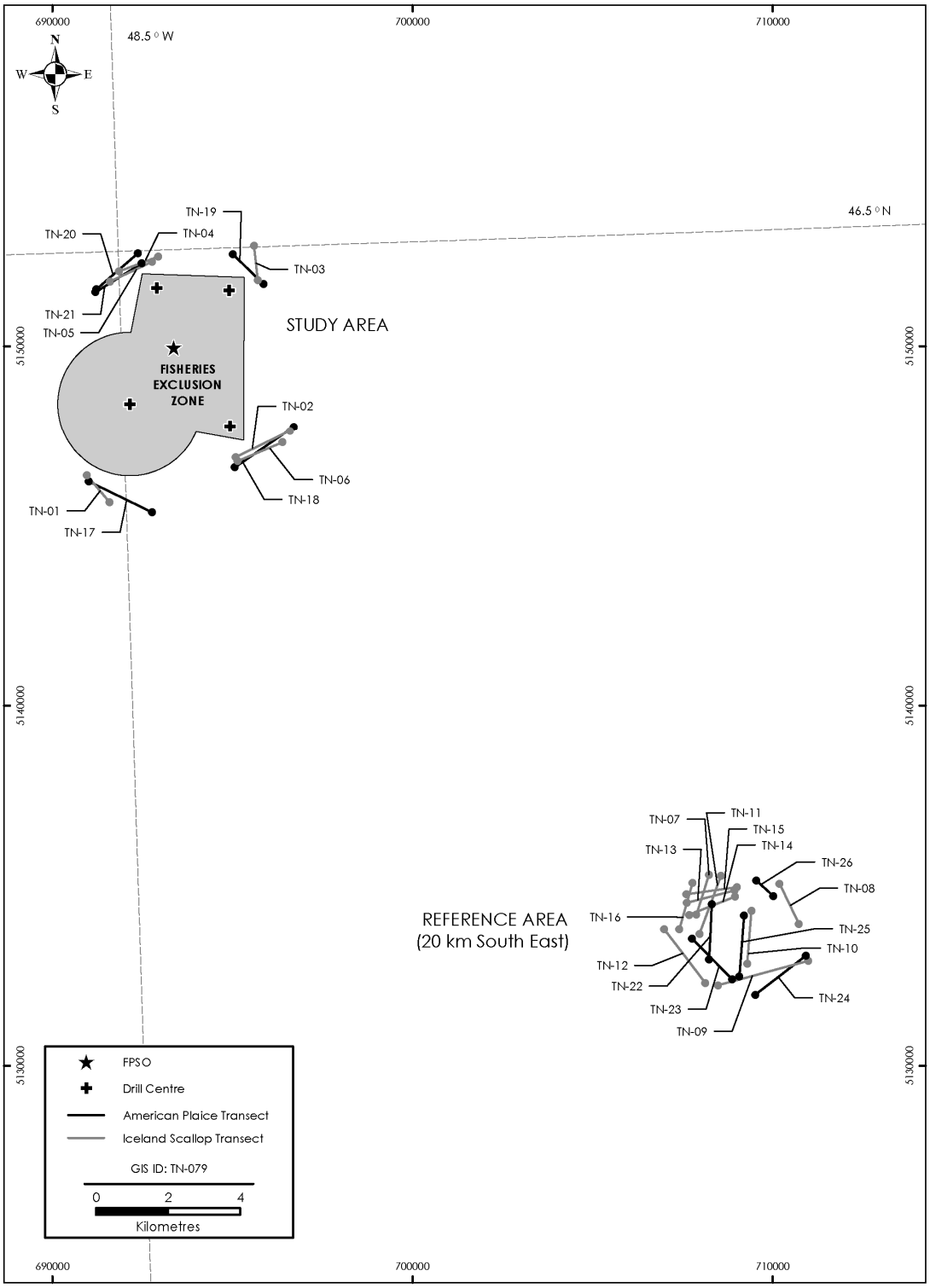


Figure 1-20 Transect Locations for Scallop and Plaice (2014)[8]

[8] The SW corner of the FEZ was expanded in 2014 to accommodate the drill rig anchors at the SW drill centre.

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

Sample type	EEM Station Name	Baseline Station Name
	46(FEZ)	NW-SW-3
	47(FEZ)	FE-I-8000
	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
Water	W1	SW-20000-1
	W2	SW-20000-2
	W3	SW-20000-3
	W4	SW-20000-4
	W5	SE-20000-1
	W6	SE-20000-2
	W7	SE-20000-3
	W8	SE-20000-4
	W9	NW-2
	W10	NW-3
	W11	NW-4
	W12	NE-1
	W13	NE-2
	W14	NE-3
	W15	NE-4
	W16	SE-1
	W17	SE-2
	W18	SE-3
	W19	SE-4
	W20	SW-1
	W21	SW-2
	W22	SW-3
	W23	SW-4
	W24	NW-1

2.0 SCOPE AND REPORT STRUCTURE

This document, *Terra Nova Environmental Effects Monitoring Program 2014 (Volume 1)*, provides summary results, analysis and interpretation for the Terra Nova 2014 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, water 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 2014.

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 2014 (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
CTD	Conductivity Temperature Depth
CV	Coefficients of Variations
DFO	Department of Fisheries and Oceans
EEM	Environmental Effects Monitoring
EIS	Environmental Impact Statement
EROD	7-ethoxyresorufin O-deethylase
FE	Far East
FE *d*	Distance to the FE drill centre
FEZ	Fisheries Exclusion Zone
FEZ *d*	Distance to the nearest FEZ drill centre
FPSO	Floating Production Offloading and Storage
g	Gram
g/kg	Gram per Kilogram
IC50	50% inhibitory concentration); molar concentration of an agonist which produces 50% of the maximum possible inhibitory response to that agonist
km	Kilometre
L	Litre
L/s	Litres per Second
m²	Square Metre
MFO	Mixed Function Oxygenase
mg	Milligram
mg/kg	Milligram per Kilogram
Min *d*	Distance to the nearest drill centre
ml	Millilitre

Acronym	Meaning
mm	Millimetre
mV	milliVolt
NE	North East (Drill Centre)
NMDS	Non-metric Multidimensional Scaling
NW	North West (Drill Centre)
PAH	Polycyclic Aromatic Hydrocarbons
PC	Principal Component
PCA	Principal Component Analysis
QA/QC	Quality Assurance/Quality Control
SD	Significant Difference
SE	South East (Drill Centre)
SW	South West (Drill Centre)
TIC	Total Inorganic Carbon
TOC	Total Organic Carbon

4.0 PROJECT-RELATED ACTIVITIES AND DISCHARGES

A number of site development activities occurred between 1997, when baseline field collection took place, and October 2014, when the collections for the ninth sampling year of the EEM program were performed. These activities were related to site development and operation, as described in the following sections[9].

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.

[9] Please note that the statistics present within this section pertain only to those operational activities that occurred prior to and including October 2014, when EEM sampling was performed. The discharge statistics do not reflect the production and drilling activities conducted beyond this period.

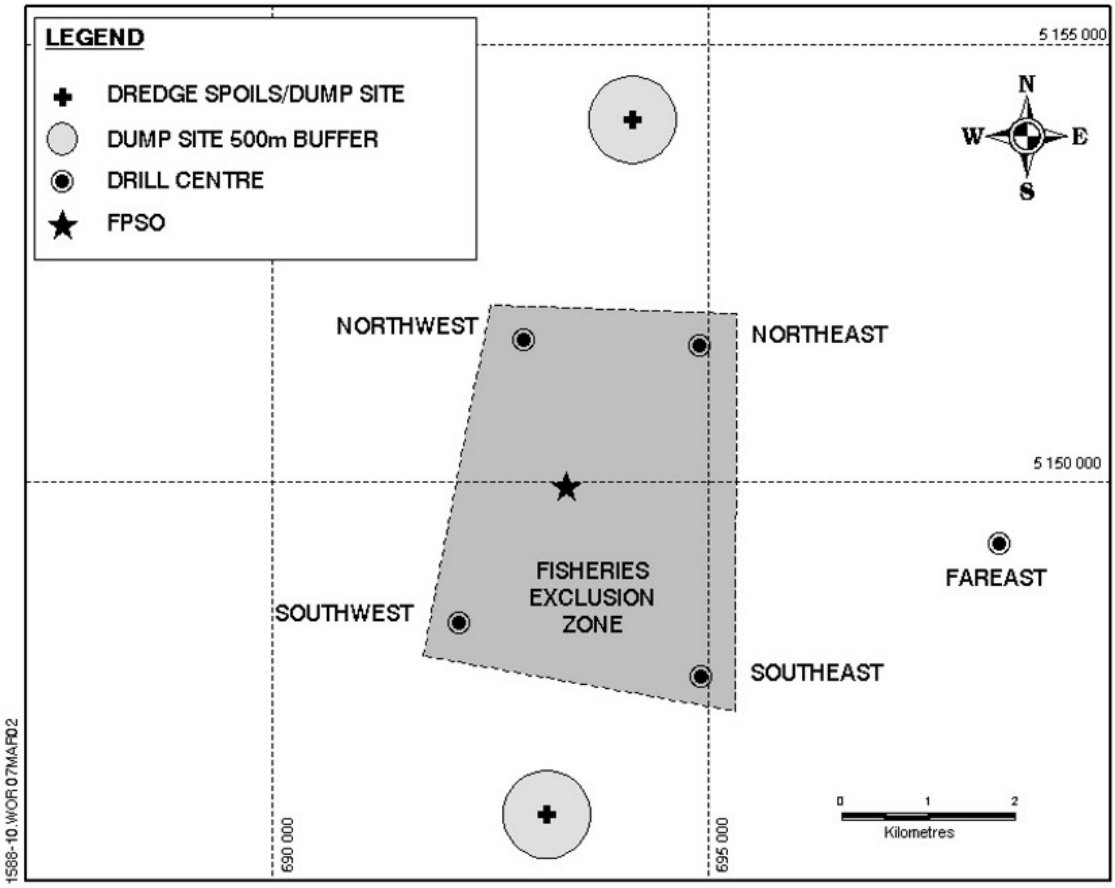


Figure 4-1 Drill Centre Locations and Dump Sites for Dredge Spoils

In 2000 and 2001, flowline and riser installation was carried out at the Terra Nova field prior to the FPSO coming on-station in Q4 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 2014 were limited primarily to maintenance and repair activities for subsea equipment components, including 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 drilling in October 2014, 38 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, four were gas injectors and eleven were water injectors. One of the oil producers, one of the gas injectors and one 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 not used for drilling activities conducted during the period of August 2012, after completion of the 2012 EEM program, to October 2014.

From the beginning of drilling to October 2014, Suncor reported cumulative water-based discharges of 52,238 m^3 at development drill centres. Of these, 21,555 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 drill centre, and 3,865 m^3 were discharged at the Far East (FE) drill 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 mud drilling activities were conducted at the Terra Nova development drill centres during the period of August 2012 to October 2014 (as detailed in Table 4-1).

Table 4-1 PureDrill IA35-LV Base Oil Fluid on Cuttings Discharged at Development Drill Centres from August 2012 to October 2014

Year	Month	Well	Drill Centre	Discharge to Sea		
				Oil Volume (m^3)	Oil Weight (tonne)	Cuttings Weight (tonne)
2013	April	L98-12Z	SW	76.06	62.75	967.26
2013	May	L98-12Z	SW	26.93	22.22	271.85
2014	March	L98-13	SW	39.05	32.22	433.48
2014	April	L98-13	SW	54.18	44.69	699.12
2014	May	L98-13	SW	47.18	38.93	502.00
2014	July	L98-1Y	NE	16.34	13.48	377.79
2014	August	L98-1Y	NE	53.66	44.27	680.01
August 2012 to Ocober 2014 Total (rounded)				**313**	**259**	**3,932**

Note: - Drilling discharge statistics refer only to discharges from since the last (2012) EEM program to the 2014 EEM program.

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 were 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).

From August 2012 to October 2014, Suncor reported cumulative synthetic-based mud-on-cuttings discharges of 259 tonnes at development drill centres.

Since the beginning of drilling to October 2014, Suncor reported cumulative SBM-on-cuttings discharges of 6,437 tonnes at those drill centres: 1,988 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, 515 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 2012 to October 2014 (as detailed in Table 4-2).

Table 4-1 Completion Fluids Discharged at Development Drill Centres from August 2012 to October 2014

Year	Month	Well	Drill Centre	Completion Fluids Discharged to Sea Volume(m^3)
2014	March	L98-13	SW	91.1
2014	May	L98-13	SW	414.5
2014	June	L98-13	SW	50.6
2014	July	L98-1Y	NE	498.6
2014	September	L98-1Y	NE	160.5
2014	October	L98-1Y	NE	237.1
August 2012 to Ocober 2014 Total				**1,452.4**

Note: -Drilling discharge statistics refer only to discharges from since the last (2012) EEM program to the 2014 EEM program.

From the beginning of drilling to October 2014, Suncor reported cumulative water-based completion fluid discharges of 44,937 m³: 12,400 m³ were discharged at the SW drill centre; 25,176 m³ were discharged at the NE drill centre; 2,636 m³ were discharged at the SE drill centre; and 4,725 m³ 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 five times between August 2012 and October 2014. Shut-down periods are listed in Table 4-3.

Table 4-2 Production Shut-Down Periods from August 2012 to October 2014

Year	Shut-Down Interval
2012	June 9 - December 8
2013	April 25 - 30
	September 26 - December 5
2014	February 7
	August 7 - 30

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 August 2012 to October 2014 are provided in Table 4-4.

Table 4-3 Produced Water Discharges from August 2012 to October 2014

Period	Monthly Average Effluent Oil Concentration (mg/L)	Total Monthly Effluent Flow (m^3/month)
August 2012	2012 Turnaround/ Off Station Program	
September 2012		
October 2012		
November 2012		
December 2012	19.1	50,332
January 2013	22.7	74,687
February 2013	22.4	342,785
March 2013	21.4	417,820
April 2013	17.7	224,430
May 2013	11.0	441,425
June 2013	14.7	536,254
July 2013	15.0	650,597
August 2013	10.5	616,558
September 2013	10.0	494,495
October 2013	2013 Turnaround	
November 2013		
December 2013	22.8	306,252
January 2014	17.4	528,474
February 2014	14.0	429,564
March 2014	13.3	583,165
April 2014	17.9	448,440
May 2014	13.6	486,338
June 2014	13.9	416,967
July 2014	23.1	260,535
August 2014	15.7	70,252
September 2014	15.8	495,503
October 2014	24.8	173,793

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 program on the *Henry Goodrich* and the production on the FPSO.

The *Henry Goodrich* (drilling) effluent streams and their compliance limits were:

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

Bilge water for the *Henry Goodrich* passes through the oily water separator system before discharge to the marine environment. The total volume of bilge water discharged for the *Henry Goodrich* in the Terra Nova field from April 2013 to August 2013 and March 2014 to October 2014 was 391 m^3. Deck/drilling area drainage for the *Henry Goodrich* was transported to shore for treatment and disposal.

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 target chlorinated seawater discharge during the period from from August 2012 to October 2014.

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 August 2012 to October 2014 was 12,034 m^3. Suncor met the oil-in-water compliance limit 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 2014 EEM program was conducted from October 23 to 30, 2014, using the offshore supply vessel *M/V Atlantic Raven.* 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). Sediment collection stations for the 2014 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

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).

Sediment oxidation/reduction potential (redox) was measured on each sediment core before sample collection. Sediment physical and chemical characteristics included measurement of sediment particle size, total petroleum hydrocarbons (benzene, toluene, ethylbenzene and xylenes (BTEX), and $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons), polycyclic aromatic hydrocarbons (PAHs), total inorganic and total organic carbon (TIC and TOC), metals, sulphur, sulphides, ammonia and moisture.

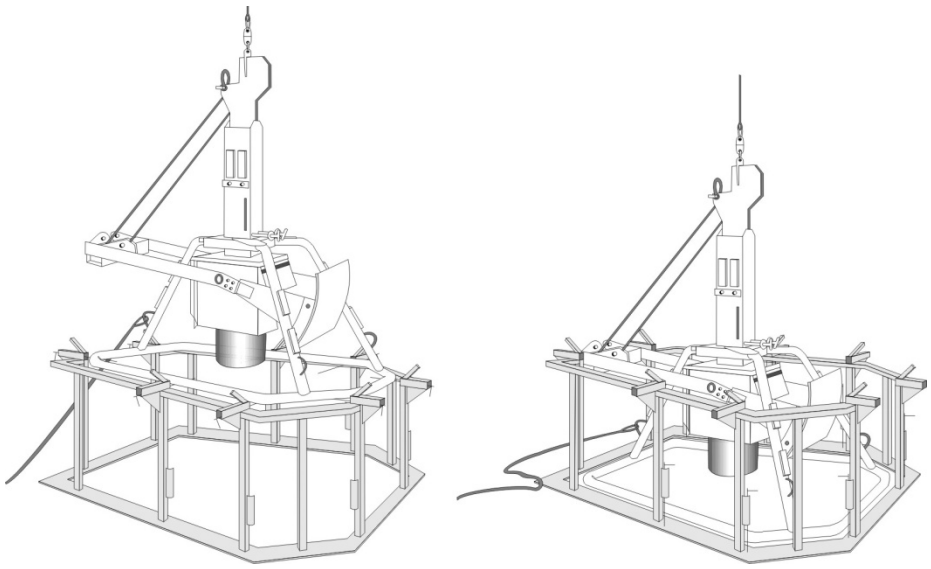
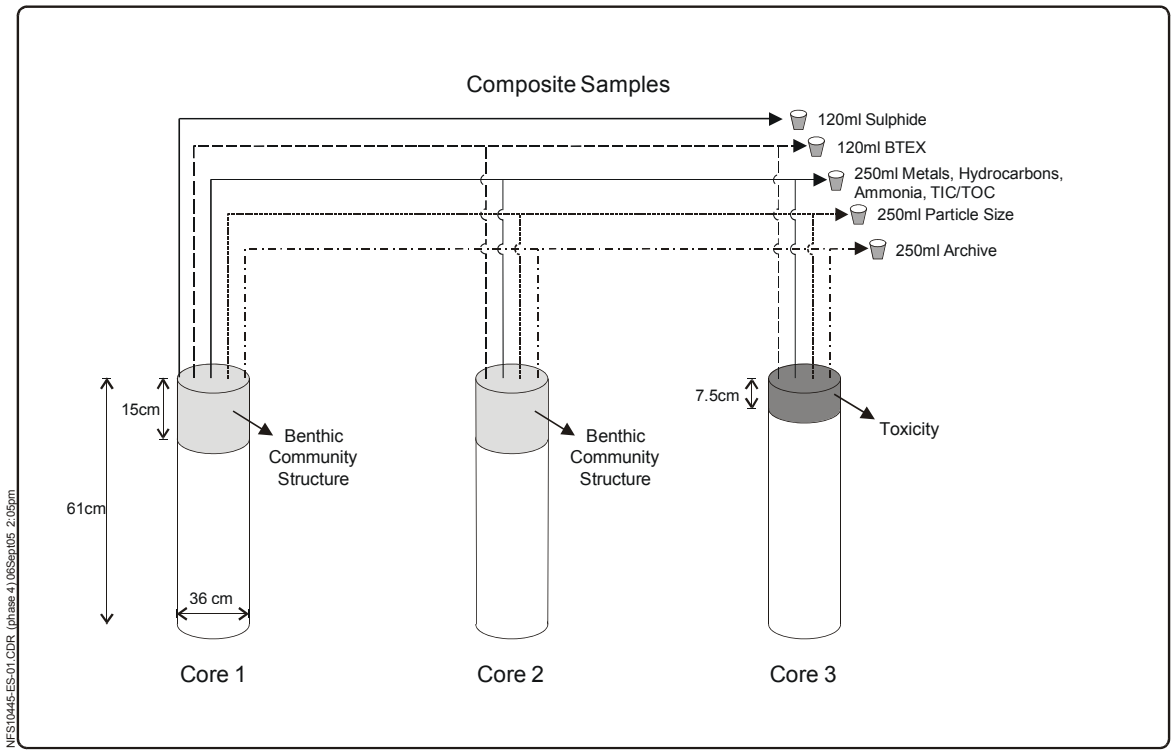


Figure 5-1 Sediment Corer Diagram

Figure 5-2 Sediment Corer

Sediment samples collected for physical and chemical analysis, 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 250-ml glass jars at -20°C. Sediment samples collected for toxicity 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 (amphipod toxicity) and a sterile 200 ml Whirl-Pak (bacterial luminescence; Microtox). 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.



Source: Modified from Petro-Canada

Figure 5-3 Allocation of Samples from Cores

The following quality control (QC) samples were collected. Sediment chemistry field blanks, composed of clean sediment, were obtained from the analytical laboratory and were “collected” (i.e., handled) at stations 23(NW), 42(FEZ) and 49(FEZ). Blank vials were opened as soon 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), 9(SE), 40(FEZ) and 46(FEZ). Blanks and duplicates were collected

for analysis of BTEX, PAHs, ammonia, sulphur, sulphides, TIC and TOC[10]. Both blanks and duplicates were assigned randomly to stations.

Quality Assurance/Quality Control (QA/QC) protocols were followed for collection of samples for sample integrity and to prevent onboard contamination. 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.

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. in St. John's, Newfoundland and Labrador. Metals and >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbon concentrations were assessed at Maxxam Analytics, in Halifax, Nova Scotia. Remaining analyses were conducted at petroforma inc. in St. John's, Newfoundland and Labrador. Sample hold-time (the recommended time interval before analysis) was exceeded for TIC, TOC, sulphides, ammonia, >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons. More details on exceedances and their implications are provided in Appendix B-2. Methods summaries from the three laboratories are also 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".

[10] Because of difficulties with sample hold-time (see Section 5.1.2), archive samples were used for assessment of >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons and metals. Field blanks and field duplicates were not available for archive samples. Archive samples consist of one additional sample collected at each station and held in storage at -20°C as back-up (also see Figure 5-3).

Table 5-3 Sediment Chemistry Variables (1997 to 2014)

Variable	Method	Laboratory Detection Limit									Units
		1997	2000	2001	2002	2004	2006	2008	2010&2012	2014	
Hydrocarbons											
Benzene	Calculated	0.025	0.025	0.025	0.025	0.025	0.03	0.03	0.03	0.03	mg/kg
Toluene	Calculated	0.025	0.025	0.025	0.025	0.025	0.03	0.03	0.03	0.04	mg/kg
Ethylbenzene	Calculated	0.025	0.025	0.025	0.025	0.025	0.03	0.03	0.03	0.03	mg/kg
Xylenes	Calculated	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
C_6-C_{10}	Calculated	2.5	2.5	2.5	2.5	2.5	3	3	3	3	mg/kg
>C_{10}-C_{21}	GC/FID	15	0.25	0.25	0.25	0.25	0.3	0.3	0.3	0.3	mg/kg
>C_{21}-C_{32}	GC/FID	15	0.25	0.25	0.25	0.25	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	mg/kg
2-Chloronaphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	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	mg/kg
2-Methylnaphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	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	mg/kg
Acenaphthylene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	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	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	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	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	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	mg/kg
Benzo(j)fluoranthene	GC-MS	NA	NA	NA	NA	NA	NA	NA	NA/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	mg/kg
Chrysene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	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	mg/kg
Fluoranthene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	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	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	mg/kg
Naphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	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	mg/kg
Phenanthrene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.05	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	mg/kg
Carbon											
Total Carbon	LECO	NA	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	g/kg

Variable	Method	Laboratory Detection Limit									Units
		1997	2000	2001	2002	2004	2006	2008	2010&2012	2014	
TOC	LECO	NA	0.1	0.1	0.1	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	g/kg
Metals (total)											
Aluminum	ICP-MS	10	10	10	10	10	10	10	10	10	mg/kg
Antimony	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Arsenic	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Barium	ICP-MS	5	5	5	5	5	5	5	5	5	mg/kg
Beryllium	ICP-MS	5	5	5	5	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	mg/kg
Chromium	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Cobalt	ICP-MS	1	1	1	1	1	1	1	1	1	mg/kg
Copper	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Iron	ICP-MS	20	20	20	20	50	50	50	50	50	mg/kg
Lead	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Lithium	ICP-MS	5	5	5	2	2	2	2	2	2	mg/kg
Manganese	ICP-MS	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	mg/kg
Molybdenum	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Nickel	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Selenium	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Strontium	ICP-MS	5	5	5	5	5	5	5	5	5	mg/kg
Thallium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	mg/kg
Tin	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Uranium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	mg/kg
Vanadium	ICP-MS	2	2	2	2	2	2	2	2	2	mg/kg
Zinc	ICP-MS	2	2	2	2	5	5	5	5	5	mg/kg
Other											
Ammonia (as N)	COBAS	NA	NA	0.3	0.25	0.25	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	%
Sulphide	COBAS(SM4500-S2-D)	NA	NA	NA	20	2	0.2	0.2	0.2	0.2	mg/kg
Moisture	Gravimetry	0.1	0.1	0.1	0.1	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.

Within the hydrocarbons, BTEX are aromatic organic compounds that are detected in the C_6-C_{10} range, commonly referred to as the gasoline range. The >C_{10}-C_{21} range is 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). When complex hydrocarbon mixtures are separated by chromatography, the more unique compounds such as the n-alkanes separate as individual peaks. Isoalkanes, on the other hand, are such a diverse group with so little difference in physical characteristics that they tend not to separate into distinct peaks in the chromatogram but, rather, form a “hump” in the chromatogram. This hump is often referred to as the “Unresolved Complex Mixture”. 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). Most of the components of PureDrill IA35-LV form an Unresolved Complex Mixture that starts around the retention time of C_{11} n-alkane (2.25 min) and ends around the same time as C_{21} n-alkanes (approximately 7.4 min) (Figure 5-4). The highest peaks in a chromatogram of PureDrill IA35-LV have retention times similar to those of n-alkanes of C_{17}-C_{18} size.

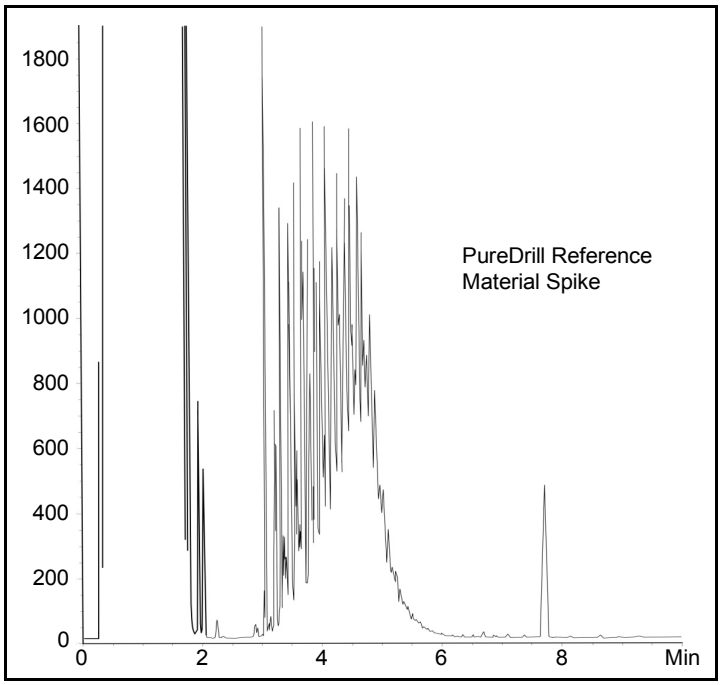


Figure 5-4 Gas Chromatogram Trace for PureDrill IA35-LV

5.1.2.2 Toxicity

petroforma inc. in St. John's, Newfoundland and Labrador, conducted the sediment toxicity analyses. All sediment samples were examined using the amphipod survival bioassay and the bacterial luminescence assay (Microtox). Both bioassays used whole sediment as the test matrix. Tests with lethal endpoints, in this case amphipod survival, measure survival over a defined exposure period. Tests with sublethal endpoints measure physiological functions of the test organism, such as metabolism, fertilization and growth, over a defined exposure period. Bacterial luminescence, in this case, was used as a measure of metabolism. Tests that rely on sublethal endpoints are a potential gauge of the long-term effects.

Amphipod survival tests were conducted according to the Environment Canada (1998) Reference Method using the marine amphipod *Rhepoxynius abronius* obtained from West Beach, Whidbey Island, Washington State (USA). 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). In 2014, one of the five test vessels for station 3(SW) was excluded because the chamber experienced an interruption in aeration.

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 in aqueous solution was tested for each batch of test organisms received. Positive controls provide a measure of precision for a particular test, monitor seasonal and batch resistance to a specific toxicant, as well as standardize results to which the results for other samples may be tentatively compared. Ancillary testing of total ammonia and sulphides in overlying water was conducted with an ammonia ion selective probe and by colorimetric determination, respectively.

The bacterial luminescence test was performed with *Vibrio fischeri*. This bacterium emits light as a result of normal metabolic activities. The Microtox assay was conducted according to the Environment Canada (2002) Reference Method using the large volume solid phase assay. Analysis was conducted on a Model 500 Photometer with a computer interface. A geometric series of sediment

concentrations was set up using solid phase diluent. The actual number of concentrations was dependent on the degree of reduction in bioluminescence observed. Negative (clean) and positive (toxic) controls were run concurrently with the test samples. Reduction of light after 15 minutes was used to measure toxicity. Data interpretation for 2004, 2006, 2008, 2010, 2012 and 2014 was conducted as outlined in Environment Canada's 2002 Reference Method. Data from the 1997, 2000, 2001 and 2002 programs were re-examined using the criteria outlined in Environment Canada (2002) because these analyses were originally conducted using 1992 Environment Canada guidance (small volume solid phase assay; Environment Canada 1992). Reinterpretation of data using Environmental Canada (2002) did not alter any of the interpretations.

All samples for the Microtox test were processed within six weeks of sample collection, meeting the storage time requirement recommended by Environment Canada guidance (Environment Canada 1998, 2002). However, due to a failure during a quality control check, some samples were retested just beyond the six week storage period[11].

When possible, amphipod tests were initiated within six weeks of sample collection. Samples from some stations were initiated outside the recommended six week storage period recommended by Environment Canada (1998) due to lack of amphipods from the supplier[12].

Interpretation of Results

The statistical endpoint for the amphipod toxicity test is the determination of whether the biological endpoint (percent survival) differs statistically from the control or reference sample, calculated using the Dunnett's Test with the CETIS computer program (Tidepool Scientific Software). The statistical endpoint for the bacterial luminescence toxicity test is the determination of whether the biological endpoint (inhibition of bioluminescence) for the sample is significantly different from the negative control (0%), calculated as the IC50[13] value.

Sample toxicity was assessed using standard toxicity testing statistical programs. The amphipod survival test results for sediments were considered toxic if either of

[11]Samples from stations 6(SE) and 44(FEZ) were retested one to two days outside the six week storage period.
[12] Samples from stations 1(SW), 2(SW), 3(SW), 4(SW), 5(SW), 6(SE), 7(SE), 41(FEZ), 42(FEZ), 43(FEZ), 44(FEZ), 45(FEZ), 46(FEZ), 47(FEZ), 48(FEZ), 49(FEZ) and 53(FEZ) 9 to 12 days outside the six week storage period.
[13]An IC50 (50% inhibitory concentration) is the molar concentration of an agonist that produces 50% of the maximum possible inhibitory response to that agonist.

the following two conditions applied. Sediment were considered toxic if the endpoint (mortality) exhibited a greater than a 30% reduction in survival as compared to negative control sediment; and the result was statistically significantly different from mortality in the negative control sediment. Amphipod survival was also compared to Reference Station sediment (stations 1(SW) and 6(SE)). In this case, the amphipod survival test results for sediments were considered toxic if the endpoint (mortality) exhibited a greater than 20% reduction in survival when compared to Reference Station sediment; and the result was statistically significantly different from mortality in the reference sediment.

For the bacterial luminescence assay, as noted in above, Environment Canada published a revised reference method for Solid Phase Microtox Testing in 2002. Sediments with levels of silt/clay greater than 20% are considered to have failed the sediment toxicity test (are toxic) if the IC50 is less than 1,000 mg/L as dry solids. For any test sediment from a particular station that is comprised of less than 20% fines and that has an IC50 (dry weight) of ≥1,000 mg/L (dry weight), the IC50 of this sediment must be compared against a sample of "clean" reference sediment or negative control sediment (artificial or natural), with a percent fines content that does not differ by more than 30% from that of the test sediment. Based on this comparison, the test sediment is judged to have failed the sediment toxicity test if, and only if, both of the following two conditions apply:

1. the IC50 is more than 50% lower than that determined for the sample reference sediment or negative control sediment; and
2. the IC50s for the test sediment and reference sediment or negative control sediment differ significantly.

There are some limitations for calculations of dry weights using the Microtox computer program (Microtox Omni™ Software for Windows 95/98/NT (April 1999)). These limitations are both related, and unrelated, to the use of new interpretation methods for Microtox. The Microtox program does not calculate dry weights for samples that do not exhibit a reduction in bioluminescence below 197,000 mg/kg (i.e., responses >197,000 mg/kg); and the program does not calculate dry weights or IC50s for samples that exhibit a quadratic dose-response relationship (hormetic response[14]). When this occurs, wet weight IC50s are calculated by hand using probit graphs.

[14]The hormetic response (or hormesis) is a dose-response relationship in which there is a stimulatory (or inhibitory) effect at low doses and an inhibitory (or stimulatory) response at high doses, resulting in a U or inverted U-shaped dose response (Calabrese and Baldwin 2001).

5.1.2.3 Benthic Community Structure

All 2014 benthos samples were provided whole to Arenicola Marine Limited (Wolfville, Nova Scotia). Sandy samples were washed through a 0.5-mm sieve. Samples with larger proportions of coarse material (gravel and shell) were elutriated and sieved by directing a high volume (1 L/s) flow of freshwater into the sample, tilting the sample bucket and catching the overflow on a 0.5-mm sieve. This washing removed the silt/clay and finer sand fractions from the samples. The procedure was adjusted to leave coarser sediment fractions in the pail. The flow suspended the less dense organisms (e.g., polychaetes) and separated small gastropods and clams, which, with a suitable balance of flow in and out of the bucket, could be separated as well. Elutriation was continued until the water leaving the pail was free of organisms and when no additional heavier organisms could be seen after close examination of the sediment. Usually, larger organisms such as scallop and propeller clams were separated manually as they were found. Barnacles and sponges were scraped off rocks. With coarser sediments such as gravels, which were occasionally encountered, a 1.2-cm mesh in combination with the 0.5-mm screen was used to aid in separating the organisms.

All sieved samples were sorted under a stereomicroscope at 6.4x magnification, with a final scan at 16x. After sorting, 10% of the sieved samples were re-examined by a different sorter to determine sorting efficiency. Efficiency levels of 99% or better were achieved (i.e., the first sorter recovered 99 to 100% of the organisms recovered by both sorters combined). Wet weight biomass (g/sample) was estimated by weighing animals to the nearest milligram at the time of sorting after blotting to remove surface water. None of the samples were sub-sampled.

Organisms were identified to the lowest practical taxonomic level, typically to species, using conventional literature for the groups involved (Appendix B-3). All organisms were identified by Patricia Pocklington, a specialist in marine benthic invertebrate taxonomy.

Benthic invertebrate samples collected in 2001 and 2002 were processed (sieved and identified) by Pat Stewart of Envirosphere Ltd. Identification of invertebrates was performed by Pat Stewart of Envirosphere Ltd in 2000. Arenicola Marine Limited identified invertebrates in 1997 and sieved and identified samples in 2004, 2006, 2008, 2010, 2012 and 2014. Both Arenicola Marine Limited and Envirosphere Ltd. use similar sieving and identification methods and results from these two laboratories are comparable. However, 11 of the 49 samples collected in 2000 and all samples collected in 1997 were sieved using the Wash 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

This 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:

1. Were temporal and spatial variations in sediment quality variables indicative of effects from project activities?
2. 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 2014 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. These variables were analyzed separately because they are "markers" for drilling activity, or because they could directly or indirectly reflect physical impact to benthic habitats.

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

>C_{10}-C_{21} hydrocarbons are major constituents of synthetic-based drilling muds. Barium is a major constituent of water-based drilling muds 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 TOC 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-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, but would also occur wherever natural decomposition of organic materials occurs. Decomposition of organic materials would reduce 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 the 2014 data in order 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-4 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 2014. Data from all (n = 53) stations in this analysis were used in this analysis.

A scatterplot of the relationship between the response (sediment) variable and Min *d* was generated for visual inspection in **Step 3**. For $>C_{10}$-C_{21} hydrocarbons and barium, maps 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-4) were used in **Step 4** to compute the threshold distances for $>C_{10}$-C_{21} hydrocarbons and barium for the 2014 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-4 for details) (whereas the Spearman rank correlations used in Step 3 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)[15]. The analysis was carried out using ranks of concentration variables and of distances to allow the analysis to detect correlations even if there were hockey-stick-type relationships for some variables (i.e., hydrocarbons and barium). Annual variations in FE and FEZ regression slopes (multiple regression on ranks, again see Appendix

[15] 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.

B-4) were inspected visually (graphically) to assist in the interpretation of the repeated-measures regression results.

Values below Laboratory Detection Limit

The following approach to values below laboratory detection limit was used.

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[16] for analyses and plots.

Of the metals, aluminum, barium, iron, lead, manganese, strontium and vanadium were detected in all samples in every year. All these metals were included in a PCA[17]. Chromium concentrations were below the laboratory detection limit in two samples in 2006, and in three samples in 2014. Concentrations below detection limit were set to 1 mg/kg (or ½ the detection limit).

Three ammonia concentrations less than the laboratory detection limit in 2002 were set to ½ the laboratory detection limit of 0.3 mg/kg[18] for analysis and plots.

Sulphur has been measured since 2001, but laboratory detection limits have varied over time. For plotting, sulphur concentrations less than the highest laboratory detection limit of 0.03% (Table 5-3) were set to ½ the laboratory detection limit, even if they were greater than the lower laboratory detection limits achieved from 2004 to 2008 (0.002% to 0.02%).

Sulphide values less than the laboratory detection limit were set to ½ the laboratory detection limit of 0.2 mg/kg. Sulphide measurements for 2002 and 2004, when laboratory detection limit ranged from 2 to 20 mg/kg, were excluded from analysis. Sulphides were not measured prior to 2002.

Repeated-measure 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 (20 mg/kg) to 2004 (2 mg/kg), and then again in 2006 (0.2 mg/kg).

[16] 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.
[17] Uranium was also detected in all but three samples from 1997 to 2014, but at concentrations at or barely above the laboratory detection limit (i.e., variance was minimal). Therefore, uranium was excluded from PCA.
[18] The reported laboratory detection limit for ammonia 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 Microtox IC50 and laboratory amphipod survival (%).

Two benchmarks were used for qualitative comparisons of Microtox IC50s among years because classification of samples as toxic based on Environment Canada (2002) interpretative guidance is sample-specific. No single IC50 value can be used to separate toxic from non-toxic samples because definitions of toxicity depend on the highest concentrations tested and Reference values (which varied among years), and on confidence intervals (CI) for sample IC50s (which varied among samples within years). Therefore, IC50s less than 98,500 mg wet/L were considered to be evidence of some negative response (although not necessarily due to project activities or toxicants). The benchmark of 98,500 mg wet/L was approximately equal to the highest concentration tested (98,684 mg wet/L) prior to 2004 and was one-half of the highest concentration tested (197,000 mg wet/L) from 2004 to 2014[19]. Samples with IC50s less than 50,000 mg wet/L were classified as "toxic" in this assessment of the data, since most samples with IC50s less than 50,000 mg wet/L would be also classified as toxic based on Environment Canada (2002) interpretative guidance.

For all analyses, Microtox IC50s based on wet weight were used because dry weight IC50s were not always available (see Section 5.1.2.2 for details). In 2008, an IC50 value could not be estimated for the sample from station 5(SW) beyond noting that the IC50 was between 98,500 and 197,000 mg wet/L (the two highest concentrations tested). Therefore, the IC50 used for analyses and plotting was the average of the four IC50s between 98,500 and 197,000 mg wet/L from other samples (or 139,325 mg wet/L). In 2010, the IC50 for station 32(FE) was reported as 3,078 to 6,156 mg wet/L, since a more precise value could not be calculated. The mid-point of that range (4,617 mg wet/L) was used for analyses and plotting.

5.2.3.2 Statistical Analysis

Amphipod survival and Microtox IC50s were analyzed using methods similar to those applied to sediment chemistry.

[19] It would be impossible to determine if earlier IC50s of ">98,684 mg wet/L" were greater or less than later IC50s between 98,684 and 197,000 mg wet/L. In later years, samples also would not be classified as toxic unless IC50s were less than ½ the highest concentration (i.e., less than 98,500 mg wet/L).

In **Step 1**, the Spearman rank correlation between Microtox and amphipod survival was computed using the 2014 data, as a general indication of the redundancy of the two data sets.

In **Step 2**, Spearman rank correlations between the two toxicity variables and all sediment physical and chemical variables identified above were computed to identify factors that were potentially influencing toxicity. Strontium was included separately in the correlation analysis because it covaried with Microtox toxicity in prior years.

In **Step 3**, bivariate Spearman rank correlations between toxicity and Min *d* were computed for the 2014 data in order to understand the degree of the association with drilling activity in the current year; and multiple rank regression was (see Appendix B-4 for details) to determine the relative influence of the FE and FEZ drill centres on toxicity.

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

The influence of drilling activity on toxicity could be anticipated to change over time. In **Step 5**, annual variations in Spearman rank correlations for Microtox with Min *d* were illustrated graphically. Amphipod survival was not compared among years because survival has been uniformly high.

In **Step 6**, repeated-measures regression on rank-transformed values was used to analyze the data from the 48 stations that had been repeatedly sampled during EEM years, to explore variations in the nature, strength and temporal variations in FE and FEZ distance gradients for Microtox. Multiple regression distance slopes for FE and FEZ drill centres were computed and plotted over time for a visual inspection of the temporal variations in distance gradients.

5.2.4 BENTHIC COMMUNITY STRUCTURE

The assessment of benthic community data involved the identification of key summary variables, then the 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 2014 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-log regression are back-transformed, they will represent 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) 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 2014. Abundances of each taxon were expressed as a percentage of total abundance (relative abundance) 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 (%) abundances of individual taxa. 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 (Orbiinidae, Paraonidae and Phyllodocidae);
- the most abundant bivalve (Bivalvia) family, Tellinidae;
- amphipods (Amphipoda), the most abundant crustaceans (Crustacea); 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 the 2014 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-4 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-4 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*). The analysis was carried out using ranks of variables and of distances to be consistent with what was done with sediment chemistry. 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. The 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.

5.3 RESULTS

5.3.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

Summary statistics and raw data for sediment physical and chemical characteristics from 1997 to 2014 are provided in Appendix B-2. No PAHs were detected in sediments in 2014 (Appendix B-2). C_6-C_{10} (less BTEX) was detected at six stations. All values except one ranged from 3 to 4 mg/kg (i.e., near the laboratory detection limit of 3 mg/kg). A value of 46 mg/kg was noted at station 13(NE). Sediments from that station were retested and indicated C_6-C_{10} (less BTEX) levels below the laboratory detection limit (Appendix B-2).

Compounds in the >C_{21}-<C_{32} hydrocarbon range were listed as above the laboratory detection limit in 29 samples (Appendix B-2). As noted in prior years, this results primarily from a laboratory artifact called 'tailing', where high levels of hydrocarbons in the >C_{10}-C_{21} hydrocarbon range results in measurable levels in the >C_{21}-<C_{32} range, even if levels of the latter are not elevated (Suncor Energy 2011). Examination of chromatograms indicated that >C_{21}-<C_{32} hydrocarbons were present in only 19 samples (J. Kiceniuk, pers. comm.). Levels were low, with a median of

0.34 mg/kg (i.e., near detection limit) and a maximum of 1 mg/kg at station 36(FEZ) located 0.75 km from the NE drill centre[20].

Table 5-4 provides summary statistics for more commonly detected compounds in 2014. As in prior years, sediments collected in 2014 were predominantly sand, organic carbon content was low, and all detectable metals for which there is a sediment quality guideline were at 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 (2014)

Variable	Units	n	n < LDL*	Minimum	Median	Maximum	ISQG**
>C_{10}-C_{21}	mg/kg	53	10	<0.25	1.2	40	
Aluminum	mg/kg	53	0	3800	6200	11000	
Barium	mg/kg	53	0	78	150	880	
Chromium	mg/kg	53	3	<2	3.1	4.8	52.3
Iron	mg/kg	53	0	680	1400	3100	
Lead	mg/kg	53	0	1.3	2.1	4.7	30.2
Manganese	mg/kg	53	0	15	39	110	
Strontium	mg/kg	53	0	21	40	230	
Uranium	mg/kg	53	1	<0.1	0.15	0.25	
Vanadium	mg/kg	53	0	3.1	5	8.3	
Total Carbon	g/kg	53	0	0.4	1.5	31.3	
TOC	g/kg	53	0	0.4	1.3	14.6	
% Clay	mg/kg	53	0	0.35	0.71	1.32	
% Gravel	mg/kg	53	0	0	4.8	30.6	
% Sand	mg/kg	53	0	68.1	94.18	99.21	
% Silt***	mg/kg	53	0	0	0.43	1.49	
Ammonia	mg/kg	53	0	0.533	1.93	5.03	
Sulphide	mg/kg	53	14	<0.2	0.35	1.41	
Sulphur	%	53	12	<0.02	0.03	0.09	
Redox	mV	53	0	190	266	331	
Moisture	%	53	0	11	16	19	

Note: - * LDL = Laboratory Detection Limit.
- ** ISQG = Interim Sediment Quality Guideline.
- *** One value for silt was reported at -0.5. That value was set to 0 in this table and in analyses that follow.

[20] Elevated levels of >C_{21}-<C_{32} hydrocarbons could have resulted from the drilling that occurred at the NE drill centre shortly before sampling, as all stations with elevated >C_{21}-C_{32} hydrocarbons were near the NE drill centre.

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 5-6). 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). 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 1.40 mg/kg in 2008, to 1.30 mg/kg in both 2010 and 2012, and to 1.20 mg/kg in 2014 (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). The highest concentration in 2014 (40 mg/kg) was observed at station 31(FE), located 0.37 km from the FE drill centre. All chromatograms for stations with >C_{10}-C_{21} hydrocarbon concentrations above the laboratory detection limit (43 of 53 stations in 2014) 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). In 2014, as in previous years, concentrations decreased rapidly with distance from drill centres (Figure 5-7).

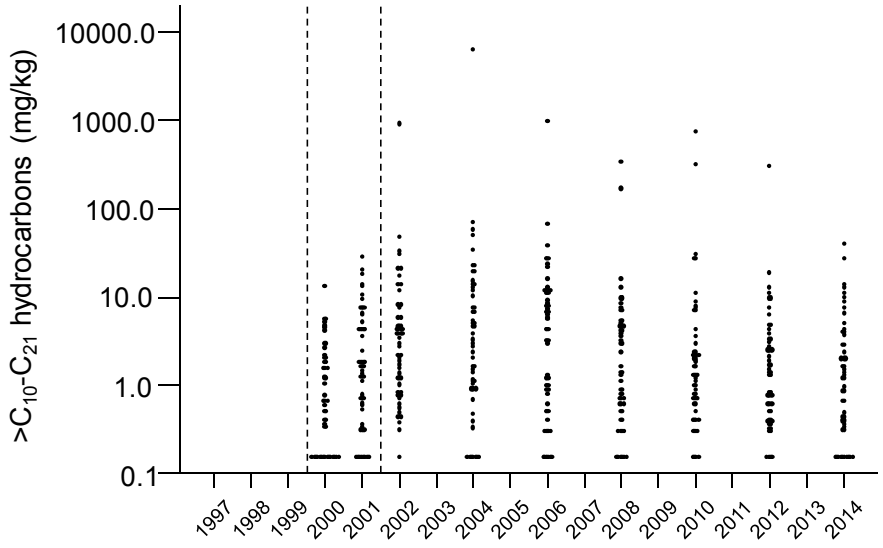


Figure 5-6 Annual Distributions for >C_{10}-C_{21} Hydrocarbon Concentrations (2000 to 2014)

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).

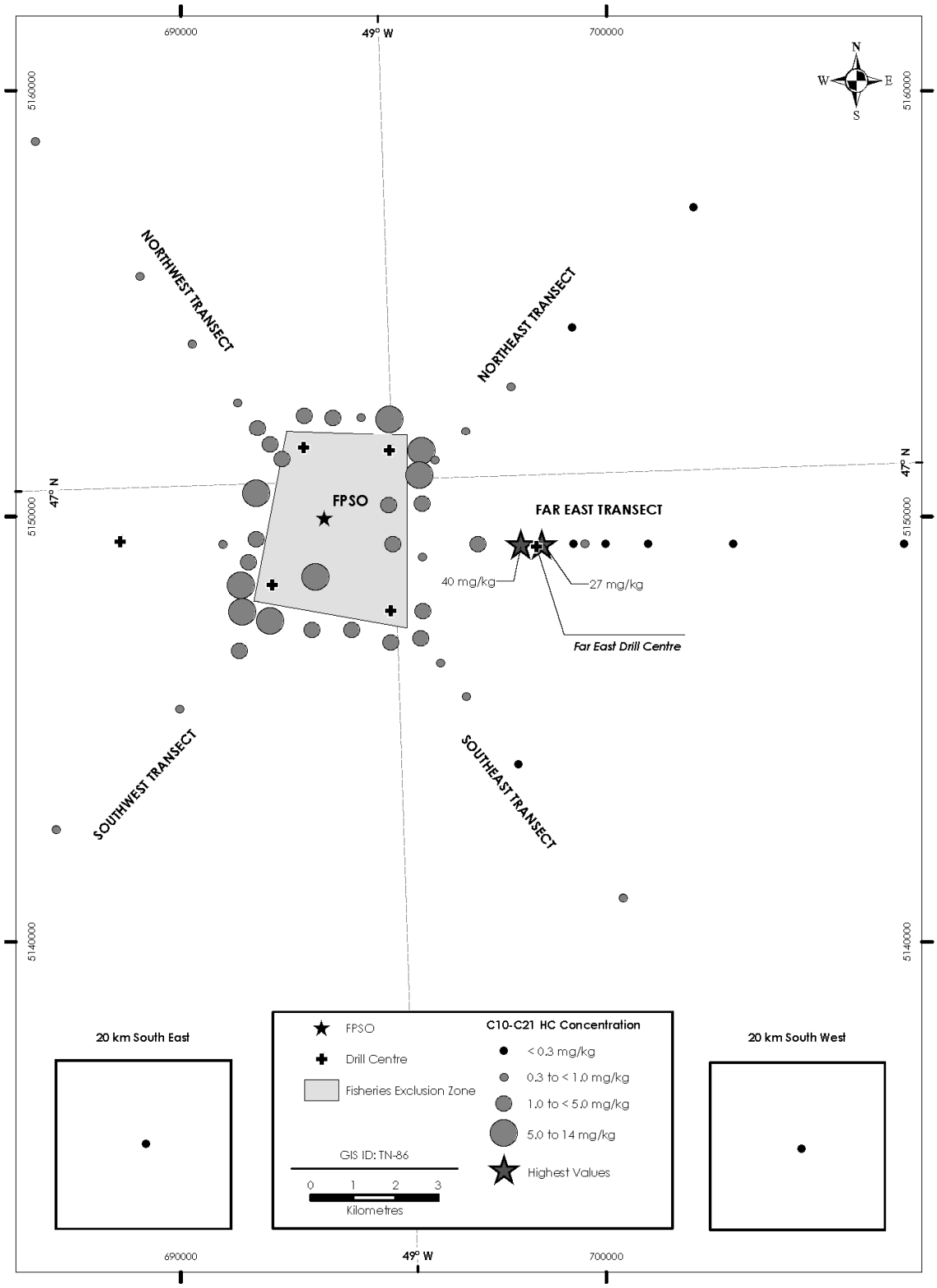


Figure 5-7 Spatial Distribution of >C_{10}-C_{21} Hydrocarbon Concentrations (2014)

Decreases of >C_{10}-C_{21} hydrocarbons with distance from the nearest drill centre (Min *d*) were significant in 2014 (Spearman rank: r_s = -0.78, p< 0.001, Table 5-5), as in previous years (Figure 5-8). In 2014 (as in 2012), the Spearman rank value for Min *d* was greater than multiple correlation for 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, or for the partial correlations of >C_{10}-C_{21} hydrocarbon ranks on ranks of distances to the FEZ or FE drill centres (Table 5-5). Therefore, a single distance measure (Min *d*) was the best predictor of >C_{10}-C_{21} hydrocarbons concentrations.

Table 5-5 Results of Rank-Rank Regression of >C_{10}-C_{21} Hydrocarbons on Distance Variables (2014)

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* **	**-0.72*** **	-0.04	**-0.78*** **

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

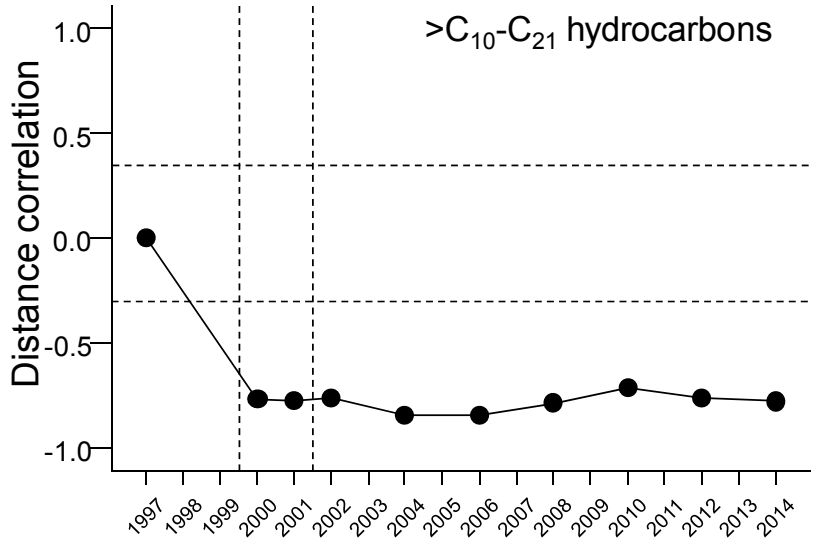


Figure 5-8 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for >C_{10}-C_{21} Hydrocarbons (1997 to 2014)

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 2014. Distance correlations in 1997 are assumed to be zero.

Adding a threshold in a hockey-stick model of $\log_{10}$ >C_{10}-C_{21} hydrocarbon concentrations versus $\log_{10}$ Min *d* in 2014 reduced error variance relative to a bivariate regression (Table 5-6). The fitted line in Figure 5-9 shows the hockey-stick

model for 2014. In 2014, the estimated threshold distance (zone of influence) for >C_{10}-C_{21} hydrocarbons was 4.5 km, with a 95% CI of 2.4 to 8.4 km. Since CIs overlapped, the 2014 threshold is not statistically different from threshold distances that were computed for previous years (Table 5-6).

Table 5-6 Distance Relationships and Thresholds for >C_{10}-C_{21} Hydrocarbons (2000 to 2014)

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

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (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 2014.
- 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 in 2006, 2008, 2010, 2012 and 2014.
- Not estimated = threshold was not estimated because $p > 0.05$ for adding the threshold.

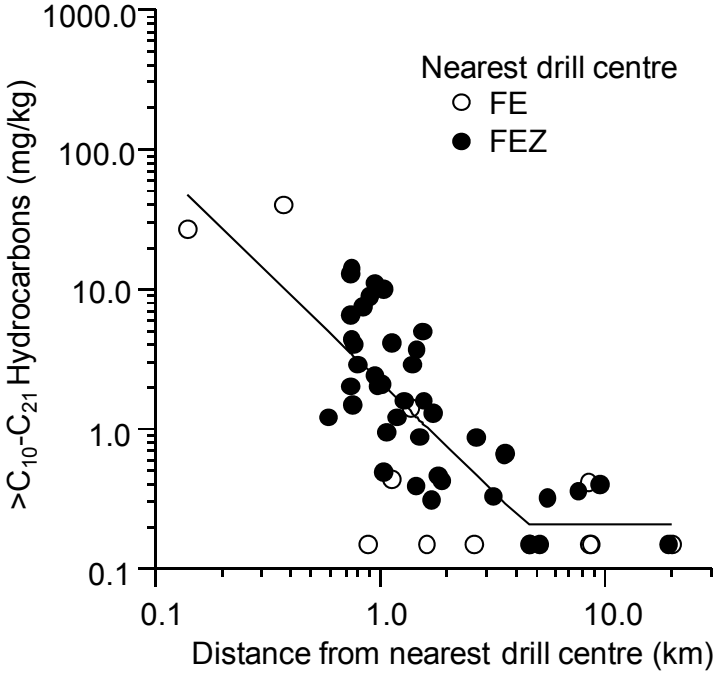


Figure 5-9 Distance Gradient for >C_{10}-C_{21} Hydrocarbons (2014)

The relationship between >C_{10}-C_{21} hydrocarbons and distance to the FE drill centre was visually apparent in Figure 5-9, but this was largely because of high concentrations at stations 30(FE) and 31(FE). The influence of stations 30 (FE) and 31(FE) was reduced in rank-rank regressions (partial r_s of 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 = -0.72 (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 5-9).

Results of repeated-measures regression for >C_{10}-C_{21} hydrocarbons are provided in Table 5-7. Appendix B-4 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 Error 1 term tests for carry-over effects (persistent differences among stations unrelated to distance). The Within-Stations terms test for variations in distance regression intercepts (Year terms) or slopes (Year $\times$ 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 in particular, while the within-stations terms are discussed if the specific contrasts are not significant.

Carry-over effects were highly significant for >C_{10}-C_{21} hydrocarbons (F = 10.0, $p \leq$ 0.001, Table 5-7), indicating persistent spatial patterns. >C_{10}-C_{21} hydrocarbons were at non-detectable levels in baseline. Therefore, carry-over effects should be considered persistent small-scale project-related effects unrelated to distance.

Table 5-7 Results (F Values) of Repeated-Measures Regressions Comparing >C_{10}-C_{21} Hydrocarbon Concentrations Among EEM Years (2000 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	**99.7*** **				
FE *d*	<0.1				
Error 1 (Carry-over)	**10.0*** **				
Year		1.6	1.3	4.4*	0.8
Year x FEZ *d*		3.0**	<0.1	7.2*	0.3
Year x FE *d*		**4.5*** **	9.3**	<0.1	0.7

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.
- Distance variables (*X*) and *Y* variables were rank-transformed.
- See Appendix B-4 for description and interpretation of terms in the repeated-measures regression models.

The overall distance slope from the nearest FEZ drill centre was highly significant ($F = 99.7$, $p \leq 0.001$, Table 5-7), and negative (Figure 5-10). 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 ($F = 3.0$, $p \leq 0.01$), with slopes generally decreasing in strength over time ($F = 7.2$, $p \leq 0.05$; Figure 5-10). The overall distance slope from the FE drill centre was not significant, suggesting a stronger influence from the FEZ drill centres. Distance slopes from the FE drill centre varied over time ($F = 4.5$, $p < 0.001$), with slopes negative after drilling began at the FE drill centre ($F = 9.3$, $p \leq 0.01$; 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 ($F = 4.4$, $p < 0.05$; Figure 5-6).

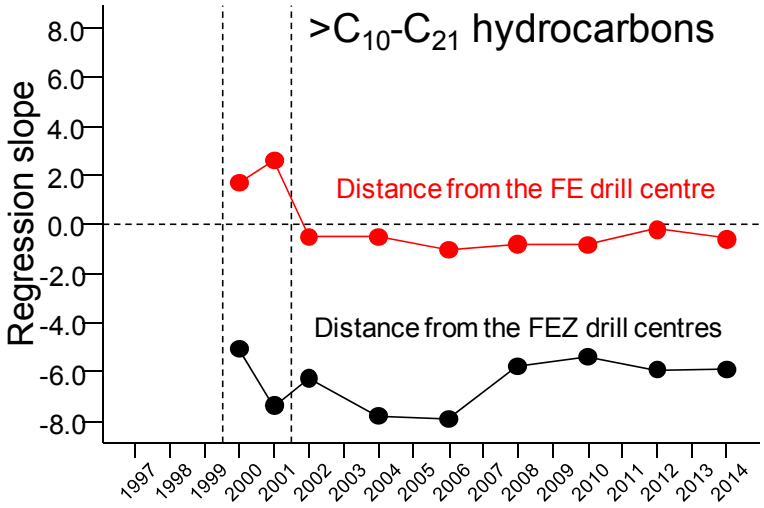


Figure 5-10 Annual Multiple Regression Distance Slopes for >C_{10}-C_{21} Hydrocarbons (2000 to 2014)

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). Here and elsewhere, the reader may note that regression slopes illustrated in this report for years 2000 to 2012 differ from what was presented in the 2012 report. Regression slopes depend on the values of the ranks, and there was a change in the way ranks were computed in this 2014 report compared to the 2012 report. The change and the rationale for the change is explained in Appendix B-4.

5.3.1.2 Barium

Annual variations in barium concentrations among years are shown in Figure 5-11. Median barium concentrations increased from 120 mg/kg in the baseline year (1997) to between 130 and 170 mg/kg between 2000 and 2014 (Appendix B-2). Maximum concentrations from 2002 to 2012 (all greater than 2,000 mg/kg) occurred at station 30(FE), located 0.14 km from the FE drill centre. The maximum barium concentration (880 mg/kg) in 2014 occurred at station 31(FE).

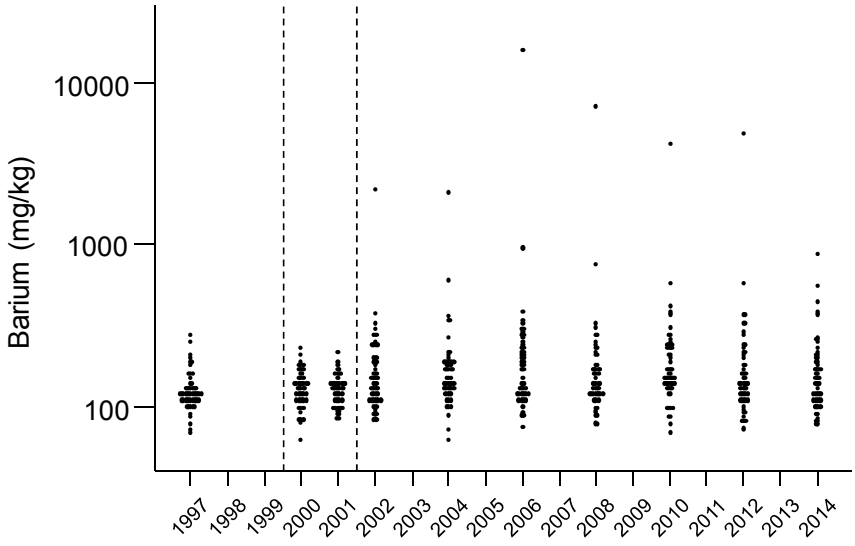


Figure 5-11 Annual Distributions for Barium Concentrations (1997 to 2014)

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 (Figure 5-12). For interpretation of results for 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 1997. Concentrations above 300 mg/kg can be considered outside the background range and evidence of contamination from drill cuttings discharges.

[21]The 95% percentile for baseline values was 208 mg/kg rounded to 200 mg/kg for Figure 5-12.

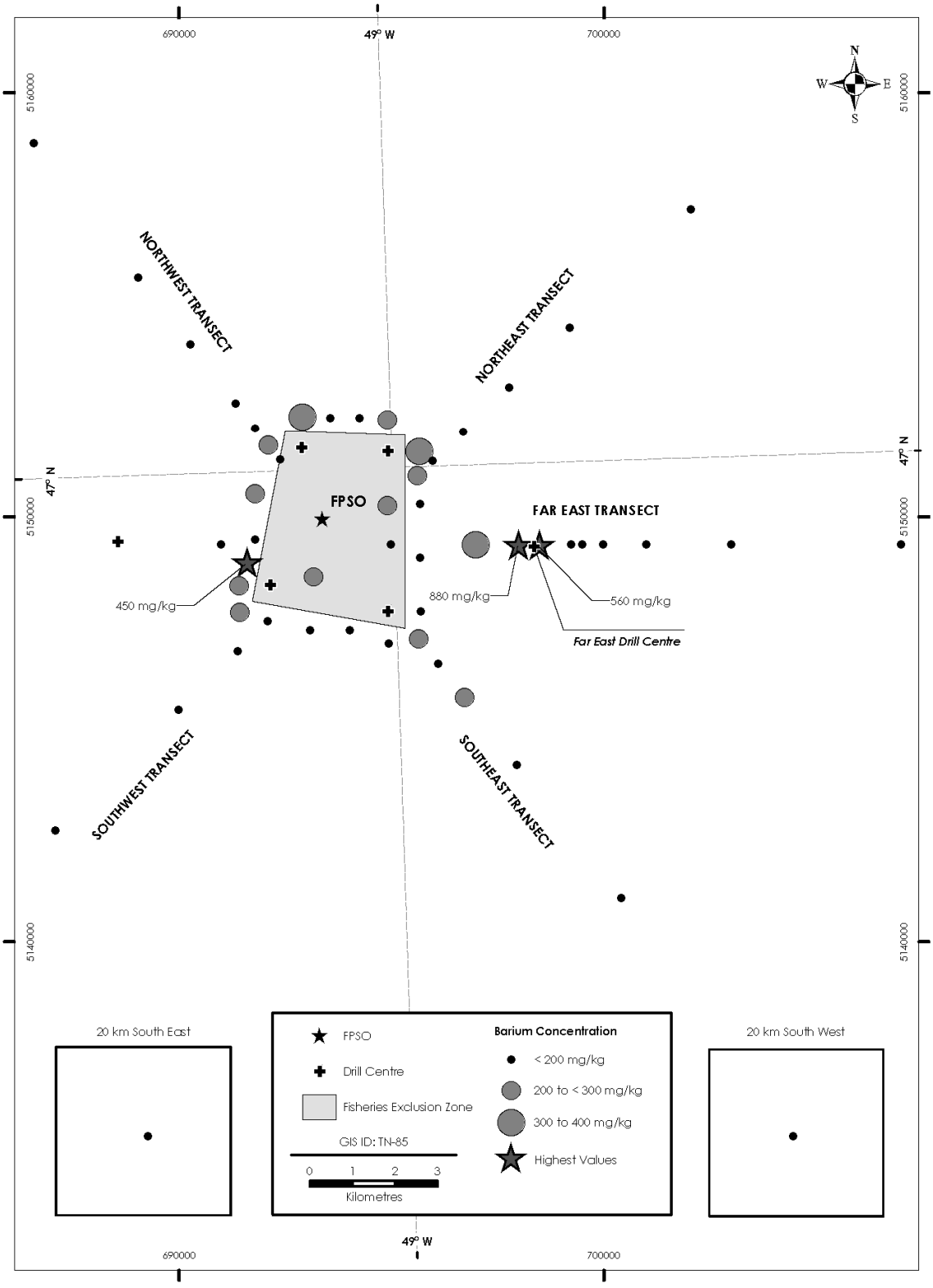


Figure 5-12 Spatial Distribution of Barium Concentrations (2014)

Barium concentrations decreased significantly with Min *d* in 2014 (r_s = -0.67, $p \leq 0.001$; 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, or for the partial correlations of barium on distances to the FEZ or FE drill centres (Table 5-8). Therefore, a single distance measure (Min *d*) was the best predictor of barium concentrations.

Table 5-8 Results of Rank-Rank Regression of Barium on Distance Variables (2014)

Multiple R	Regression on distance from nearest FEZ and FE Drill Centres(Partial *r*)		Min *d*
	FEZ *d* (FE *d* constant)	FE *d* (FEZ *d* constant)	(r_s)
0.58* **	**-0.51*** **	-0.11	**-0.67*** **

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

In 1997, 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 5-13).

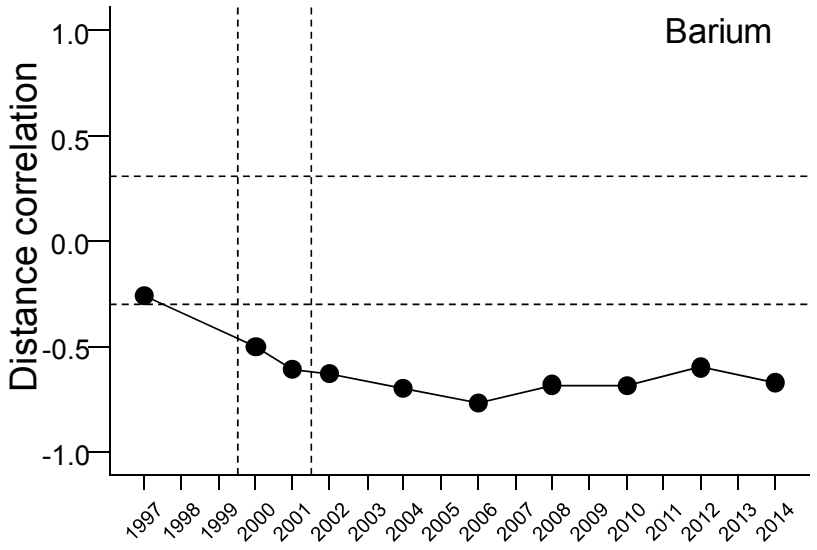


Figure 5-13 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Barium (1997 to 2014)

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 2014. The NE and SW drill centres were considered active for 1997 (baseline).

The addition of a threshold to the relationship between barium concentration and Min *d* in 2014 significantly reduced error variance (p = 0.008, Table 5-9). The estimated threshold distance for barium in 2014 was 2.7 km, with a 95% CI of 1.6 to 4.7 km. The threshold distance in 2014 was significantly higher than it was in 2004, 2006, 2008 and 2012, but the 2014 estimate was not statistically different from what was estimated in 2002 and 2010.

Table 5-9 Distance Relationships and Thresholds for Barium (1997 to 2014)

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*** **	**0.480*** **	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

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 2014. 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 in 2006, 2008, 2010, 2012 and 2014.
- Not estimated = threshold was not estimated because $p > 0.05$ for adding the threshold.

As in previous years, barium concentrations at Stations 30(FE) and 31(FE) were largely responsible for the relationship between barium and distance from the FE drill centre in 2014 (Figure 5-14). Like >C_{10}-C_{21} hydrocarbons, the influence of those two stations was statistically reduced in rank-rank regressions (r_s = -0.11, Table 5-8). In contrast, there were elevated barium concentrations at several stations within approximately 1 km from drill centres, and a more continuous distance gradient for stations nearest the FEZ (Figure 5-14).

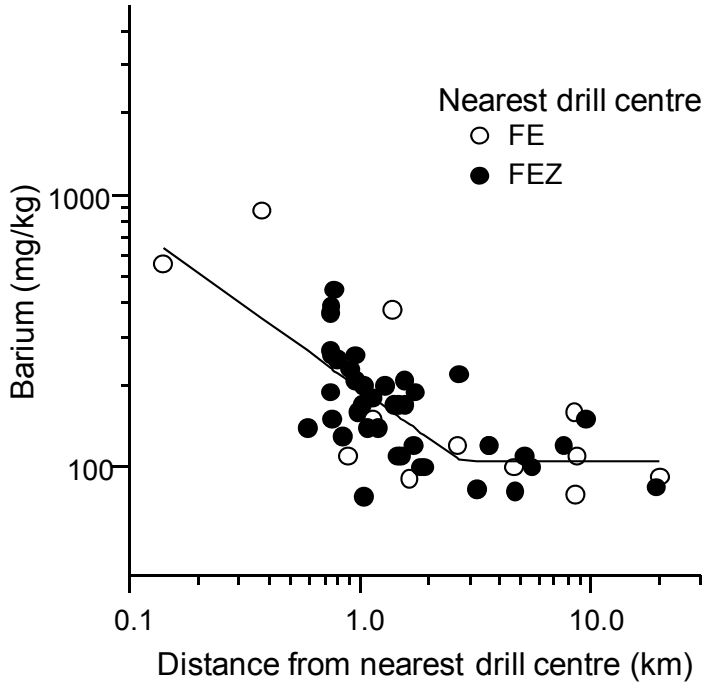


Figure 5-14 Distance Gradient for Barium (2014)

Results of repeated-measures regression for barium are provided in Table 5-10. Carry-over effects were highly significant for barium ($F = 19.3$; $p \leq 0.001$, Table 5-10). Carry-over effects for barium were stronger than carry-over effects for >C_{10}-C_{21} hydrocarbons because barium was at measurable concentrations in the baseline period (i.e., carry-over effects incorporated both natural and project-related persistent small-scale variance).

Table 5-10 Results (F Values) of Repeated-Measures Regressions Comparing Barium Concentrations Among EEM Years (2000 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	**30.7*** **				
FE *d*	0.6				
Error 1 (Carry-over)	**19.3*** **				
Year		0.7	0.1	<0.1	1.4
Year x FEZ *d*		0.5	1.8	0.1	0.7
Year x FE *d*		2.0*	6.0*	0.3	0.8

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.

Across years, the overall multiple regression slope for barium was stronger for the FEZ drill centres ($F = 30.7$, $p \leq 0.001$) than it was for the FE drill centre ($F = 0.6$; Table 5-10; also see Figure 5-15), again suggesting a stronger influence from the FEZ drill centres. Similar to what was seen for >C_{10}-C_{21} hydrocarbons, there were variations in FE distance slopes among EEM years ($F = 2.0$, $p \leq 0.05$), with slopes generally more negative after drilling started at the FE drill centre ($F = 6.0$, $p \leq 0.05$, Table 5-10; Figure 5-15).

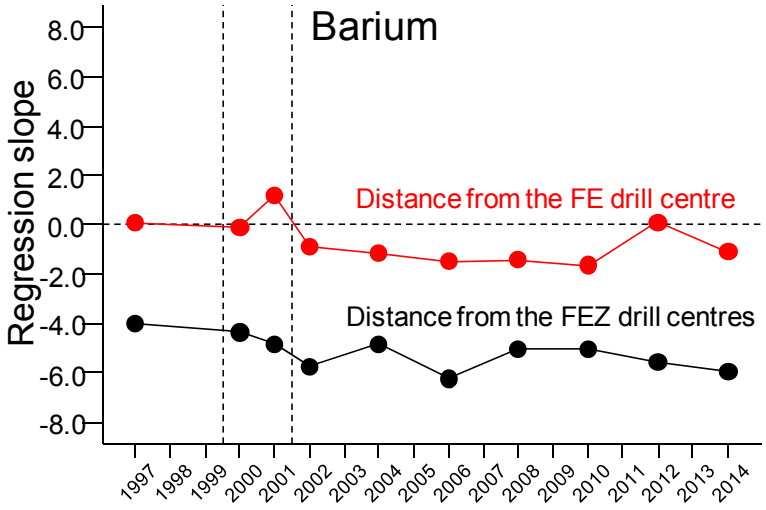


Figure 5-15 Annual Multiple Regression Distance Slopes for Barium (1997 to 2014)

Notes: 1997 regression slopes were based on the 33 stations sampled in both 1997 and in EEM years. 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 2014 were predominantly sand, with median sand content of approximately 94% (Appendix B-2; Figure 5-16). Fines (silt + clay) content was low (0.6% to 2.7%; median = 1.1%). Gravel content varied widely, from 0% to approximately 31%, with a median of 4.8% (Appendix B-2; Figure 5-16).

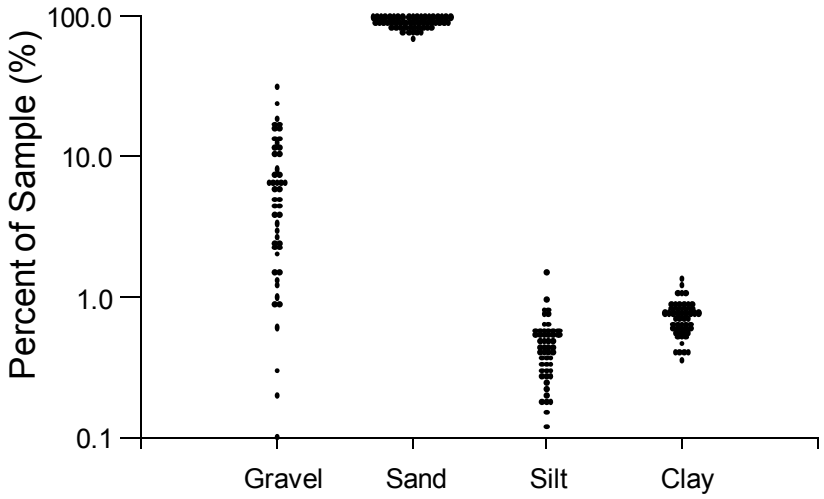


Figure 5-16 Distribution of Values for Four Particle Size Categories (2014)

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 (2014)

	% fines	**% sand**
% sand	**-0.584*****	
% gravel	0.543***	**-0.996*****

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 2% of sediments, while gravel content has varied between trace amounts and to upwards of approximately 10% to 30% of sediment grains (Figure 5-17).

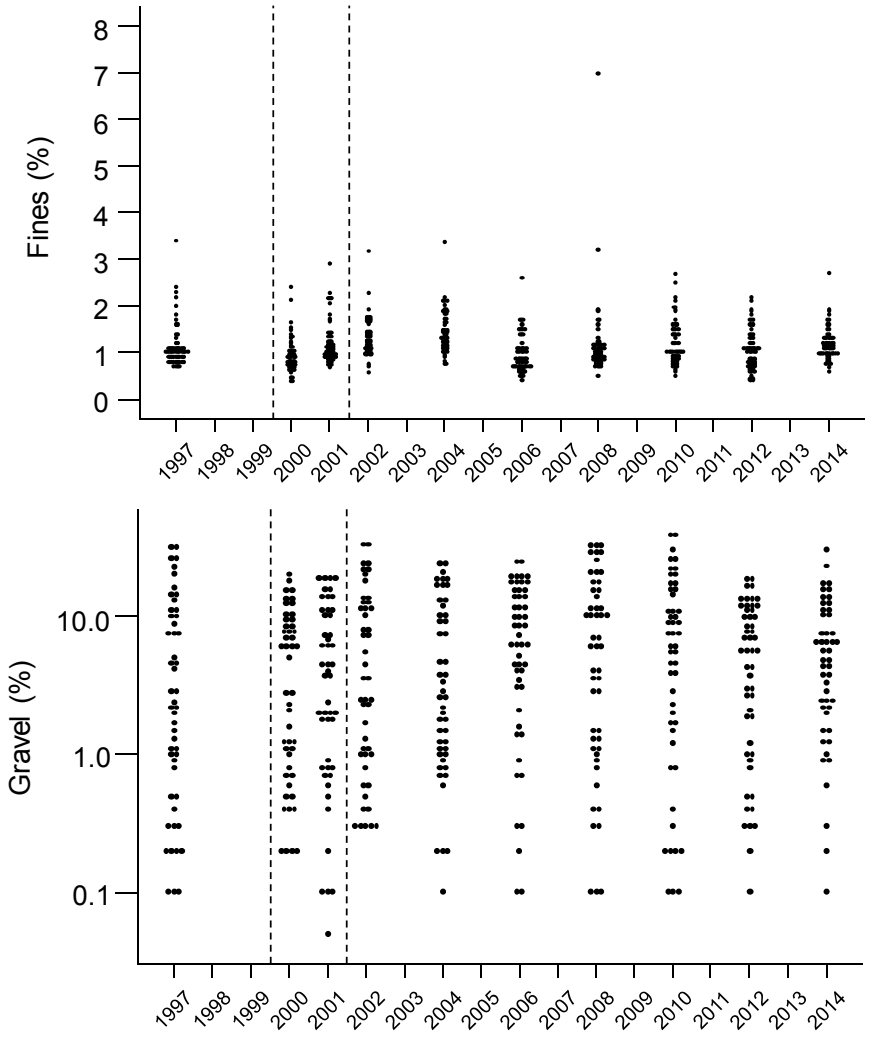


Figure 5-17 Annual Distributions for Fines and Gravel Content (1997 to 2014)

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).

In 2014, the Spearman rank correlation between Min *d* and % fines was significant and negative (r_s= -0.34, $p \leq 0.01$, Table 5-12), indicating a decrease in fines with distance from drill centres. Distance from the FEZ drill centres explained significant variation in % fines (partial r = -0.36, $p \leq 0.01$); distance to the FE drill centre did not, after controlling (partialling out) the effect of the distance to the FEZ drill centres (partial r = 0.01). Maximum fines concentrations in 2014 occurred at station 33(FEZ) located 0.75 km from the NW drill centre (Figure 5-18). % fines have generally decreased with distance from drill centres in all years, including baseline, and distance correlations were significant in 2000, 2001, 2006, 2010 and 2014 (Figure 5-19).

Table 5-12 Results of Rank-Rank Regression of Fines and Gravel on Distance Variables (2014)

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	0.34***	-0.36**	0.01	-0.34**
Gravel	0.24	-0.22	-0.07	-0.26*

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

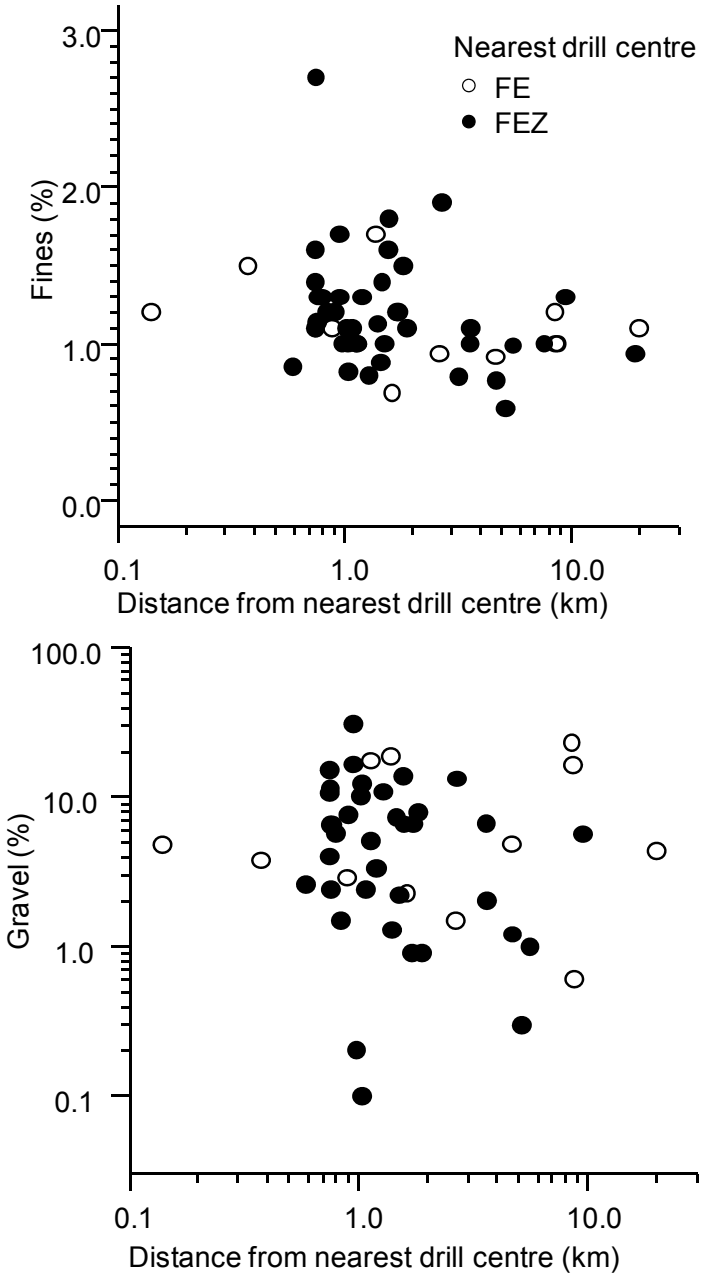


Figure 5-18 Distance Gradients for Fines and Gravel Content (2014)

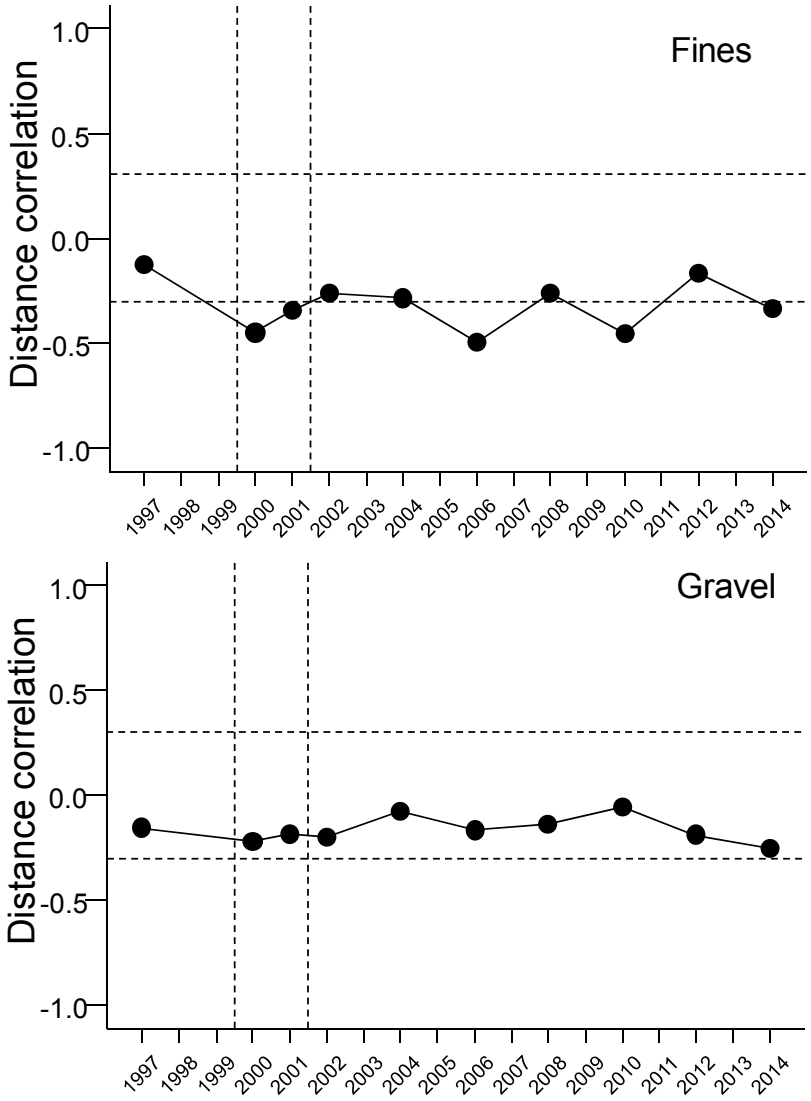


Figure 5-19 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Fines and Gravel Content (1997 to 2014)

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 2014. The NE and SW drill centres were considered active for 1997 (baseline).

The Spearman rank correlation between % gravel and Min *d* was weakly negative in 2014 (r_s = -0.26, $p \leq 0.05$, Table 5-12). The overall multiple correlation was not significant (R = 0.24, $p > 0.05$), and distances to the FE and FEZ drill centres were also individually not significantly associated with % gravel (partial r values of -0.07 and -0.22 respectively, Table 5-12). The relationship between % gravel and Min *d* in 2014 and across years is illustrated in Figures 5-18 and 5-19, 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. Carry-over effects for fines were large (F = 7.9, $p \leq 0.001$), indicating persistent spatial pattern among years. The overall FEZ distance slope for fines content was also significant (F = 11.0, $p \leq 0.01$), with fines content decreasing with increasing distance from the FEZ drill centres in every year including baseline (1997) (note negative regression slopes in Figure 5-20). The FEZ distance slopes did not vary significantly among 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 2014. 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 2014. There was a change in overall fines levels over EEM years (F = 6.3, $p \leq$ 0.001), with fine levels somewhat higher in earlier and later EEM years, and somewhat lower in 2006 and 2008 (F = 18.2, $p \leq 0.001$; also see Figure 5.17).

Table 5-13 Results (F Values) of Repeated-Measures Regressions Comparing Fines and Gravel Among EEM Years (2000 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
Fines					
FEZ *d*	11.0**				
FE *d*	0.8				
Error 1 (Carry-over)	**7.9*** **				
Year		**6.3*** **	5.6*	3.8	**18.2*** **
Year x FEZ *d*		0.6	0.1	0.4	<0.1
Year x FE *d*		0.9	0.1	<0.1	3.3
Gravel					
FEZ *d*	1.3				
FE *d*	0.6				
Error 1 (Carry-over)	**18.6*** **				
Year		1.3	2.3	0.8	10.8**
Year x FEZ *d*		0.2	0.1	0.4	1.0
Year x FE *d*		0.4	0.1	0.5	0.8

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.

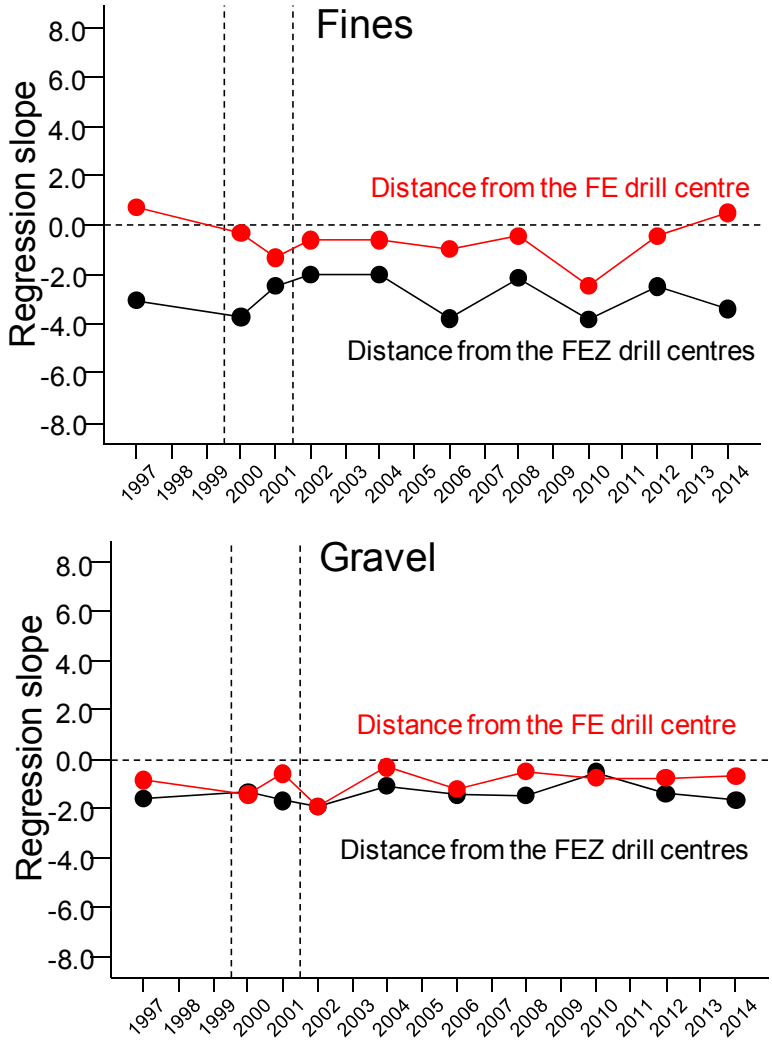


Figure 5-20 Annual Multiple Regression Distance Slopes for Fines and Gravel Content (1997 to 2014)

Note: 1997 regression slopes were based on the 33 stations sampled in both 1997 and in EEM years. 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).

Carry-over effects for % gravel were also large (F = 18.6, $p \leq 0.001$, Table 5-13), indicating a persistent spatial patterns in gravel content among years. 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 2014. The lack of strong distance gradients is illustrated in Figure 5-20, with regression slopes near or less than -1 in magnitude. There were changes in overall sediment gravel content over time, with gravel content lower in 2001/2002, increasing in 2006 through to 2010, and decreasing in 2012 and 2014 (F = 10.8, $p \leq 0.05$; Figure 5-17).

5.3.1.4 Organic Carbon Content

TOC content of sediments was more variable in 2014 than in previous years. TOC ranged between 0.4% and 14.6% in 2014 (Appendix B-2; Figure 5-21). In previous years, TOC values were limited to a range of between approximately 0.2% and 3% (Figure 5-21). Differences in the acid used to extract carbonates from sediment between 2014 and previous years (*o*-phosphoric acid in 2014 versus hydrochloric acid in previous years[22]) would explain the observed difference in results (J, Kiceniuk, pers. comm., 2015)[23]. TOC values in excess of 3% in 2014 occurred at seven stations (Table 5-14). There was no consistent spatial pattern in the distribution of these stations. Maxima for indicators of drill muds in sediments (>C_{10}-C_{21} and barium) did not coincide with high TOC values. However, maxima for sediment sulphur, sulphide, % gravel and % fines did, and medians for these variables were higher at the seven stations than they were over all stations.

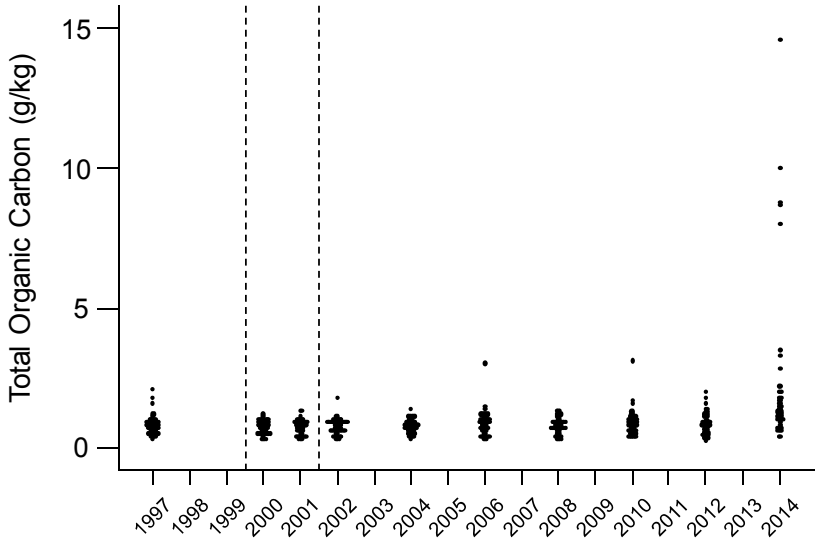


Figure 5-21 Annual Distributions for Total Organic Content (1997 to 2014)

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).

22 A different analytical laboratory was used in 2014.
23 Hydrochloric acid will dissolve some organic compounds, resulting in underestimation of TOC in samples having these compounds (J. Kiceniuk, pers. comm., 2015).

Table 5-14 Values for Selected Variables at Stations with Sediment Total Organic Carbon (2014)

Variable	22(NW)	46(FEZ)	49(FEZ)	44(FEZ)	32(FE)	33(FEZ)	11(SE)	Max	Median	Overall Max	Overall Median
TOC	3.3	3.5	8	8.7	8.8	10	14.6	14.6	8.7	14.6	1.3
Ammonia	3.38	1.7	0.894	1.97	0.658	2.93	0.913	3.38	1.7	5.03	1.93
Sulfide	0.82	0.54	0.55	0.57	0.45	1.41	0.43	1.41	0.55	1.41	0.35
Sulfur	0.03	0.06	0.08	0.08	0.07	0.09	0.08	0.09	0.08	0.09	0.03
Barium	140	450	210	260	380	390	210	450	260	880	150
$>C_{10}$-C_{21}	1.2	4	5	11	1.4	4.4	2.4	11	4	40	1.2
% Gravel	3.3	6.5	13.9	16.7	18.7	11.3	30.6	30.6	13.9	30.6	4.8
Fines	1.3	1.3	1.6	1.7	1.7	2.7	1.3	2.7	1.6	2.7	1.1
Redox	241	275	282	264	239	255	310	310	264	331	266

Using the entire dataset, the relationship between organic content and Min *d* was not significant in 2014 (r_S = -0.19, Table 5-15; Figure 5-22), although the multiple correlation was (R = 0.24, $p \leq 0.05$). 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 $r = -0.15$ versus $r = 0.05$, Table 5-15). 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 5-15 Results of Rank-Rank Regression of Total Organic Carbon Content on Distance Variables (2014)

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)	
TOC	0.24*	-0.15	0.05	-0.19

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

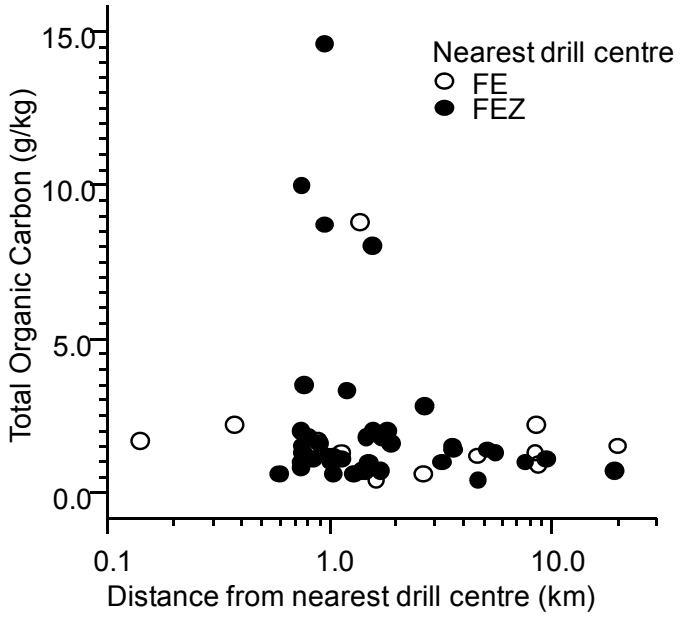


Figure 5-22 Distance Gradient for Total Organic Carbon Content (2014)

The relationships between Min *d* and TOC were statistically significant in 1997 (baseline), 2000, 2001, 2006 and 2008 (Figure 5-23). The baseline (1997) correlation between Min *d* and TOC of approximately $r_s = -0.4$ was among the strongest distance correlation observed for those two variables.

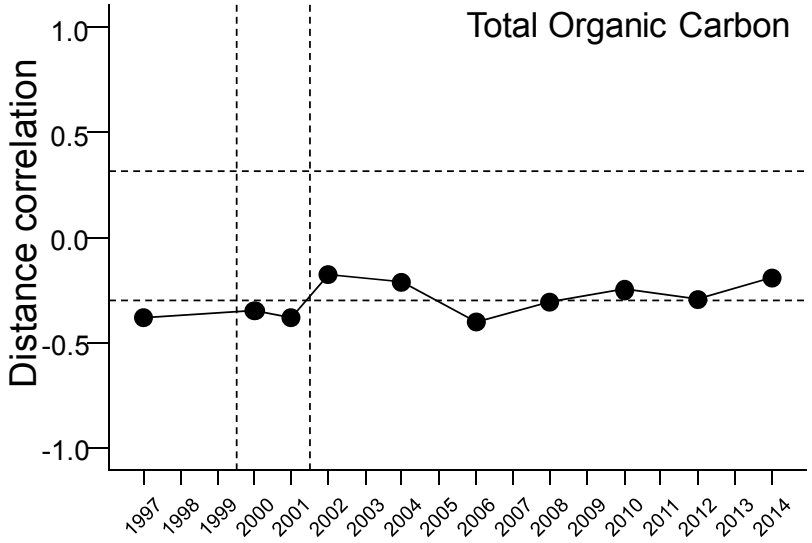


Figure 5-23 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) Total Organic Carbon Content (1997 to 2014)

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 2014. The NE and SW drill centres were considered active for 1997 (baseline).

Results of repeated-measures regression for TOC are provided in Table 5-16. Carry-over effects were highly significant for organic carbon content (F = 19.2, $p \leq 0.001$, Table 5-16), indicating persistent spatial variations over time. The overall FEZ regression slope for TOC in EEM years was also highly significant (F = 19.0, $p \leq 0.001$), because organic carbon decreased with distance from the FEZ drill centres in all years, including baseline (Figure 5-24). FEZ distance slopes varied among years (F = 3.3, $p \leq 0.01$), generally increasing in strength from 2002 to 2012, and then decreasing in strength (F = 7.2, $p \leq 0.01$; Figure 5-24). FE regression slopes did not vary over time. There were significant variations in overall organic carbon levels over time (F = 7.9 and F = 19.9, $p \leq 0.001$), reflecting higher organic carbon levels in early and later EEM years, notably in 2014 (Figure 5-21).

Table 5-16 Results (F Values) of Repeated-Measures Regressions Comparing Total Organic Carbon Content Among EEM Years (2000 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	**19.0*** **				
FE *d*	8.3**				
Error 1 (Carry-over)	**19.2*** **				
Year		**7.9*** **	2.5	11.7**	**19.9*** **
Year x FEZ *d*		3.3**	<0.1	0.4	7.2**
Year x FE *d*		1.7	0.6	1.3	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.
- Distance variables (X) and Y variables were rank-transformed.

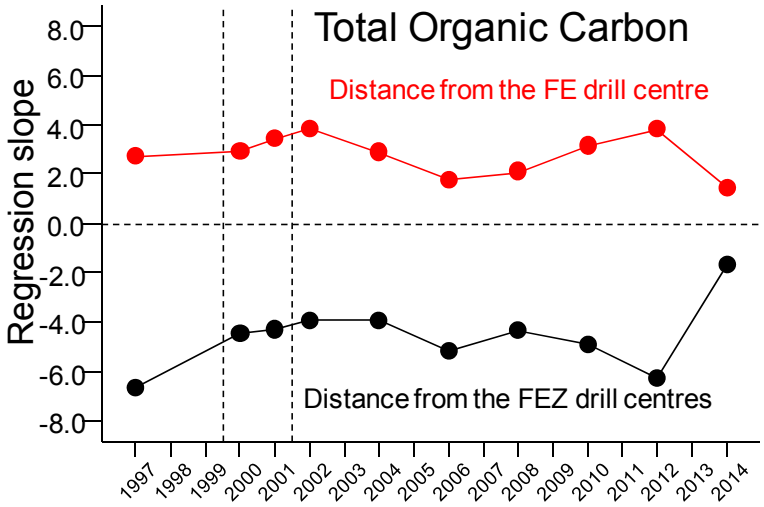


Figure 5-24 Annual Multiple Regression Distance Slopes for Total Organic Content (1997 to 2014)

Note: 1997 regression slopes were based on the 33 stations sampled in both 1997 and in EEM years. 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., metals PC1 and 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 and in three samples in 2014. 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 first Principal Component (Metals PC1) derived from those concentrations (Table 5-17). Strontium was also weakly positively associated with Metals PC1 ($r_p = 0.57$). Metals PC1 accounted for 63% of the total variance and served as a summary measure of “total metals”. Principal Component 2 (Metals PC2) accounted for 18.5% of the total variance, and was strongly negatively correlated with strontium concentration ($r_p = -0.64$), weakly negatively correlated with aluminum and lead concentrations, and weakly positively correlated with manganese and iron concentrations. Metals PC2 scores reflected variations in metals concentrations independent of the general increase-decrease in overall metals concentrations. Lower Metals PC2 scores indicated higher strontium (and to a lesser extent, aluminum and lead) levels relative to manganese and iron levels.

Table 5-17 Pearson Correlations (r_p) Between Metal Concentrations and Principal Components Derived from those Concentrations (1997 to 2014)

Variable	Correlation (r_p) with Axis	
	Metals PC1	**Metals PC2**
Aluminum	**0.80**	-0.41
Chromium	**0.78**	0.20
Iron	**0.87**	0.41
Lead	**0.80**	-0.40
Manganese	**0.75**	0.59
Strontium	0.57	**-0.64**
Vanadium	**0.93**	0.05
Percent of Variance Explained	62.6	18.5

Notes:
- $|r_p| \geq 0.6$ in **bold.**
- Concentrations were log-transformed prior to deriving PC.
- n = 522 stations; 54 in 1997, 49 in 2000 and 2001, 53 in 2002, 52 in 2004, and 53 in 2006, 2008, 2010, 2012 and 2014.
- PCs were retained if they produced an eigenvalue >1.

Variations in metals concentrations as illustrated by Metals PC1 and Metals PC2 had similar ranges across all years of study (Figure 5-25).

Distance relationships with Min d for Metals PC1 and PC2 were not statistically significant in 2014 (r_s > |0.19|, Table 5-18). Partial correlations of FE distances with Metals PC1 or PC2 in 2014 were not significant (Table 5-18). Partial correlations of FEZ distances were significant and negative for Metals PC1 (partial r = -0.38, $p \leq$ 0.05), indicating a general decrease in Metals PC1 scores with distance from the centre of the development (Figure 5-26).

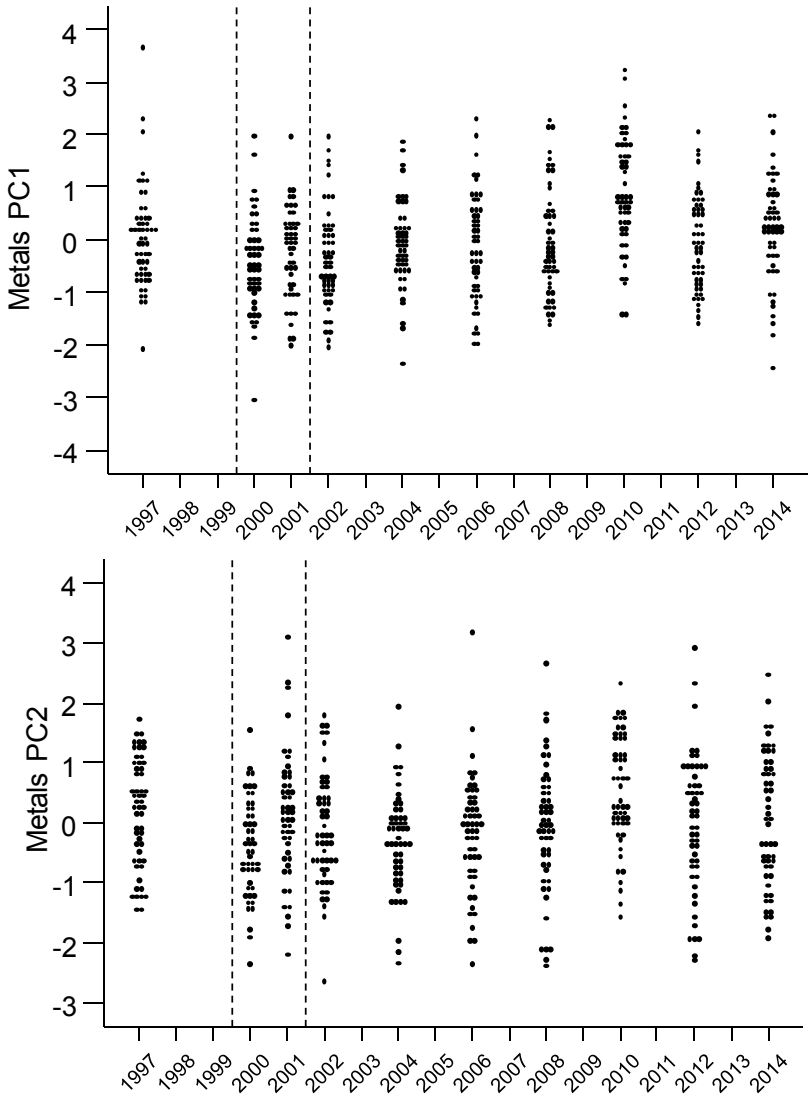


Figure 5-25 Annual Distributions for Metals PC1 and Metals PC2 (1997 to 2014)

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).

Table 5-18 Results of Rank-Rank Regression of Metals PC1 and PC2 on Distance Variables (2014)

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	0.35**	-0.38*	0.07	-0.19
Metals PC2	0.21	0.08	0.20	0.19

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

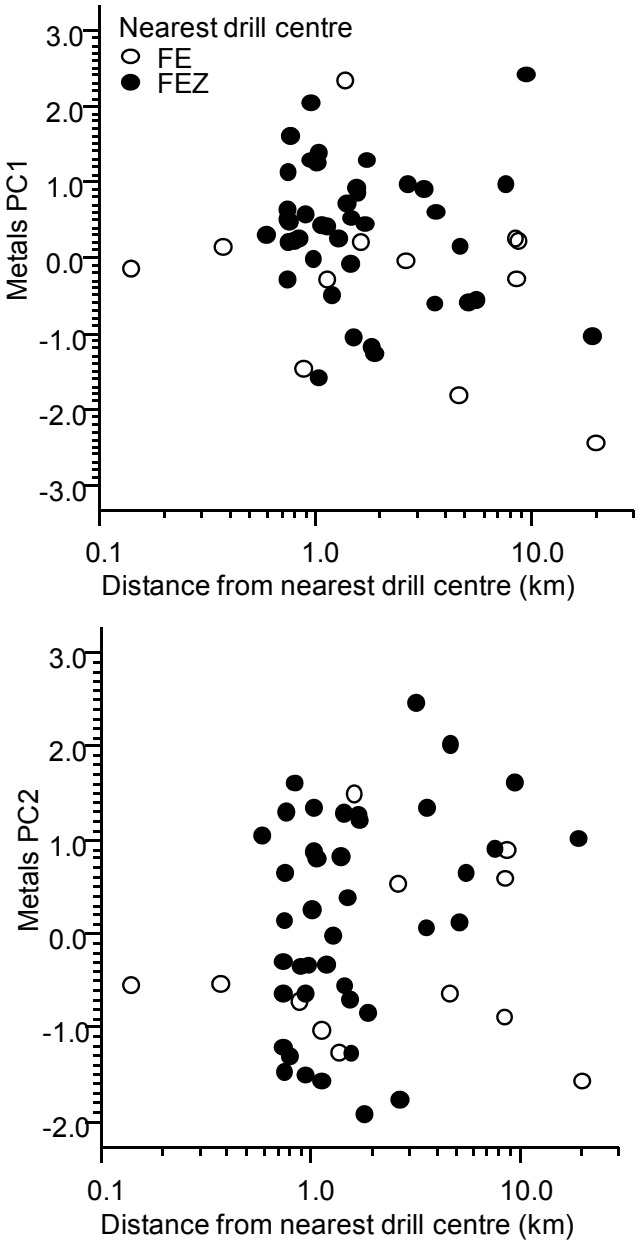


Figure 5-26 Distance Gradients for Metals PC1 and Metals PC2 (2014)

Metals PC1 scores generally decreased with Min *d* in every year, including baseline (Figure 5-27). The strongest distance correlation occurred in 2001 (r_s ~-0.6; $p \leq 0.001$). Correlations in other EEM years varied between approximately r_s = -0.2 and -0.3. Distance correlations for Metals PC2 scores (strontium concentrations relative to manganese and iron concentrations) were strong and positive between 2004 and 2008, and weaker (but still positive) from 1997 to 2002 and from 2010 to 2014 (Figure 5-27).

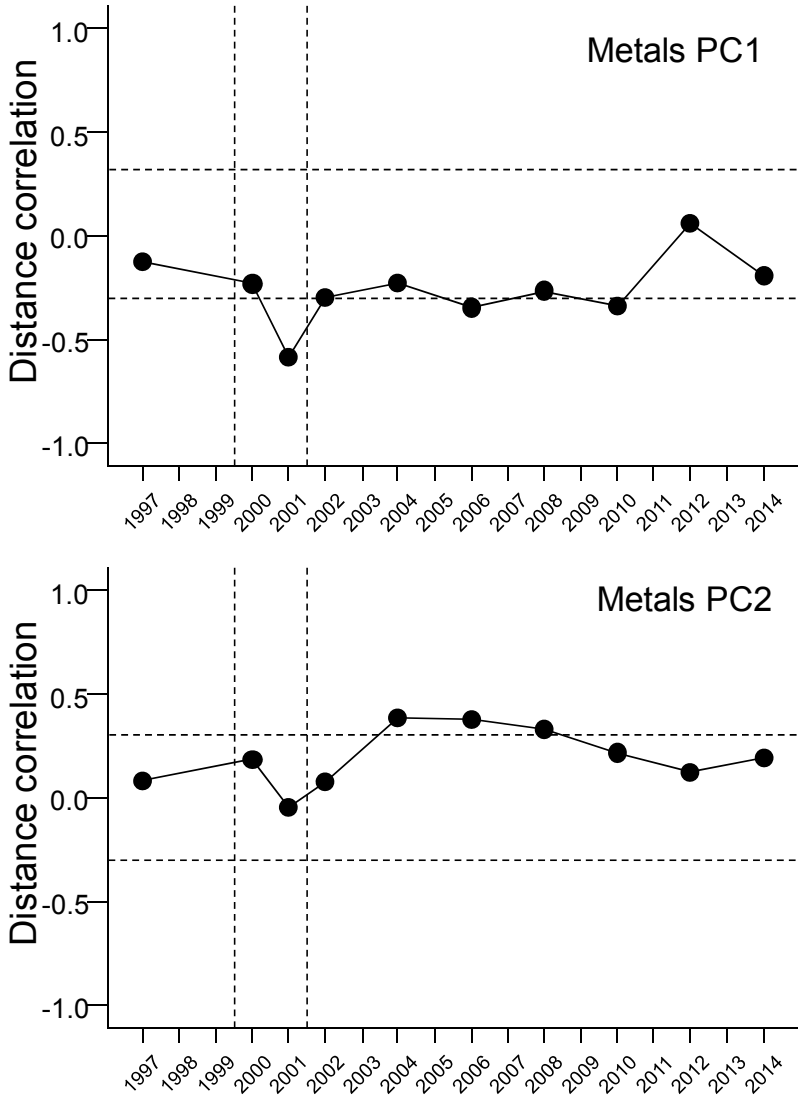


Figure 5-27 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Metals PC1 and Metals PC2 (1997 to 2014)

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 2014. The NE and SW drill centres were considered active for 1997 (baseline).

Results from repeated-measured regression on metals are provided in Table 5-19. Carry-over effects were strong for Metals PC1 ($F = 7.8$, $p \leq 0.001$), indicating persistent spatial variations. Overall FEZ regression slopes were significant ($F = 7.9$, $p \leq 0.01$), consistent with results noted for 2014 alone. Overall FE regression slopes for Metals PC1 were not significant. There were variations in overall Metals PC1 scores across years ($F = 12.4$, $p \leq 0.01$ and $F = 5$, $p \leq 0.05$), with Metals PC1 scores increasing over time in EEM years (although levels in EEM years have generally been lower than in baseline (Figure 5-25).

Table 5-19 Results (F Values) of Repeated-Measures Regressions Comparing Metals PC1 and Metals PC2 Among EEM Years (2000 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
Metals PC1					
FEZ *d*	7.9**				
FE *d*	1.6				
Error 1 (Carry-over)	**7.8*** **				
Year		3.9	12.4**	5.0*	1.6
Year x FEZ *d*		1.6	3.9	0.9	0.1
Year x FE *d*		0.6	0.3	1.6	<0.1
Metals PC2					
FEZ *d*	1.9				
FE *d*	1.6				
Error 1 (Carry-over)	**12.6*** **				
Year		1.8	6.1*	2.8	2.7
Year x FEZ *d*		1.2	1.4	<0.1	<0.1
Year x FE *d*		1.3	1.1	<0.1	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.

Carry-over effects were also strong for Metals PC2 scores ($F = 12.6$, $p \leq 0.001$; Table 5-19). Overall FE and FEZ gradients were not significant. Variations in FE and FEZ regression slopes among years were not significant (also see Figure 5-28). There was a change in overall Metals PC2 scores from 2000 and 2001 to later years ($F = 6.1$, $p \leq 0.05$), with scores generally lower in 2000 and 2001 (Figure 5-25).

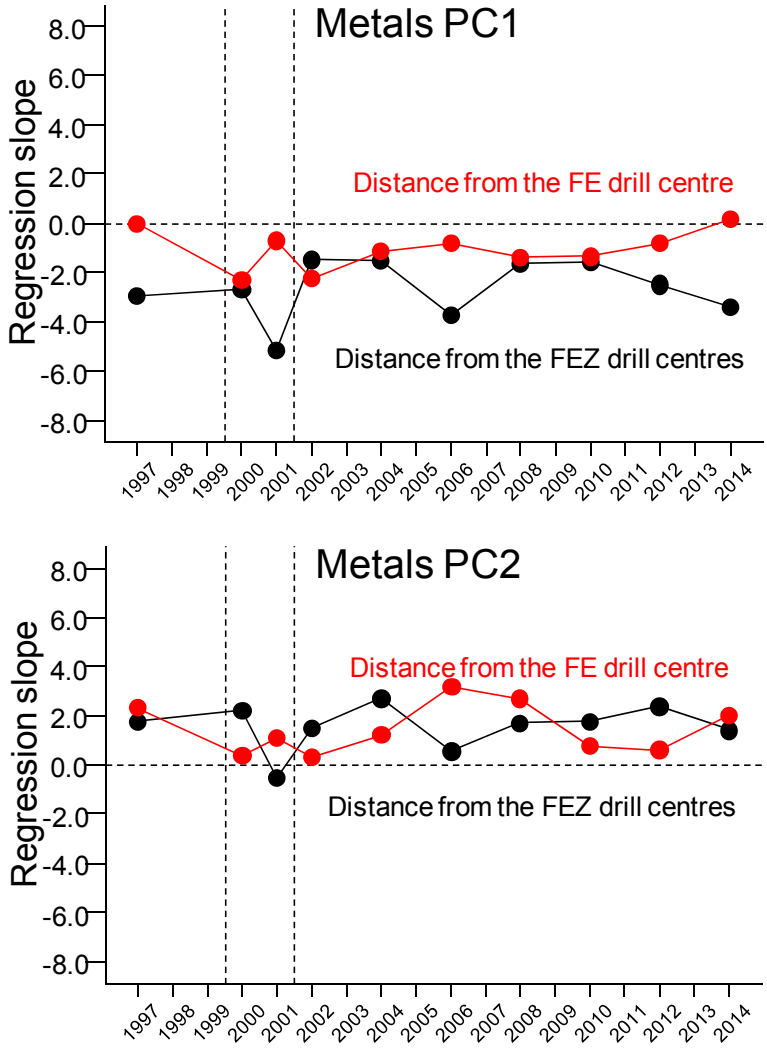


Figure 5-28 Annual Multiple Regression Distance Slopes for Metals PC1 and Metals PC2 (1997 to 2014)

Note: 1997 regression slopes were based on the 33 stations sampled in both 1997 and in EEM years. 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 2001 than in subsequent years, and concentrations were generally lowest in (Figure 5-29). In 2014, exceedances in sample holding time may have contributed to lower observed ammonia levels. The stated holding time for ammonia is 28 days at -20˚C. In 2014, samples were processed approximately 160 days after collection. The risks that may contribute to loss of ammonia include volatilization and microbial degradation. However, while stored at -20˚C, the potential

for diminished recovery was minimized as much as possible (see Appendix B-2 for details).

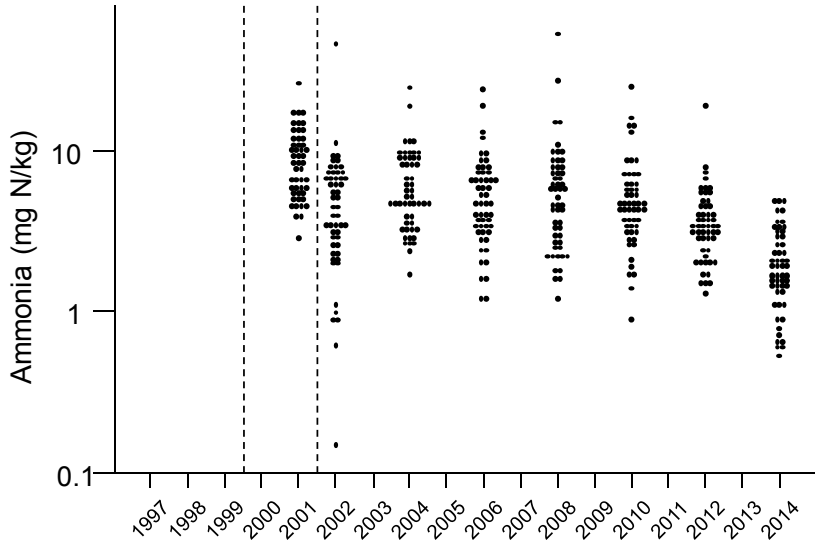


Figure 5-29 Annual Distributions for Ammonia Concentrations (2001 to 2014)

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).

Ammonia concentrations were not correlated with Min *d* in 2014 (r_s = -0.15, Table 5-20; Figure 5-30), similar to what was observed in all previous years except 2010 (Figure 5-31). Multiple regression analysis results indicated that FE and FEZ distances significantly correlated with ammonia concentrations (Multiple R = 0.48, $p \leq 0.001$; Table 5-20), with ammonia decreasing (partial r = -0.47, $p \leq 0.001$) with distance from the FEZ drill centres, and increasing (partial r = 0.38, $p \leq 0.01$) with distance from the FE drill centre. The difference in the sign (increasing versus decreasing) of these two relationships likely explains the lack of association between ammonia and the overall distance measure (Min *d*).

Table 5-20 Results of Rank-Rank Regression of Ammonia on Distance Variables (2014)

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	0.48***	-0.47***	0.38**	-0.15

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

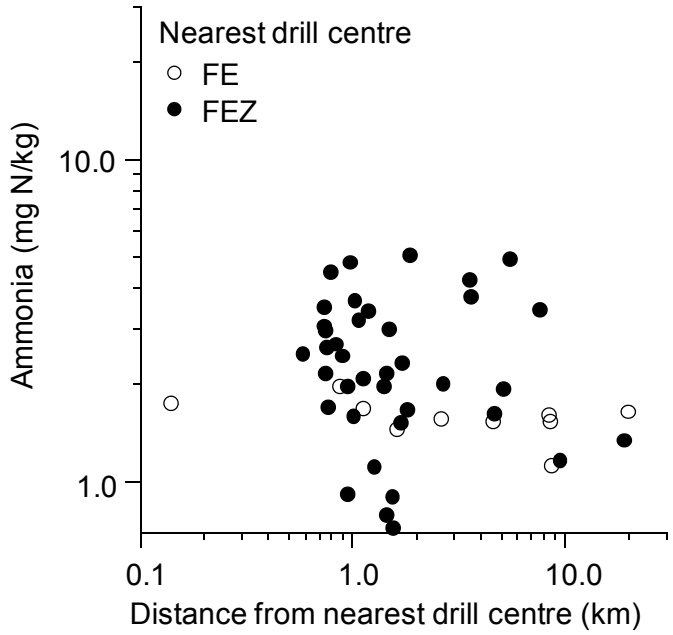


Figure 5-30 Distance Gradient for Ammonia (2014)

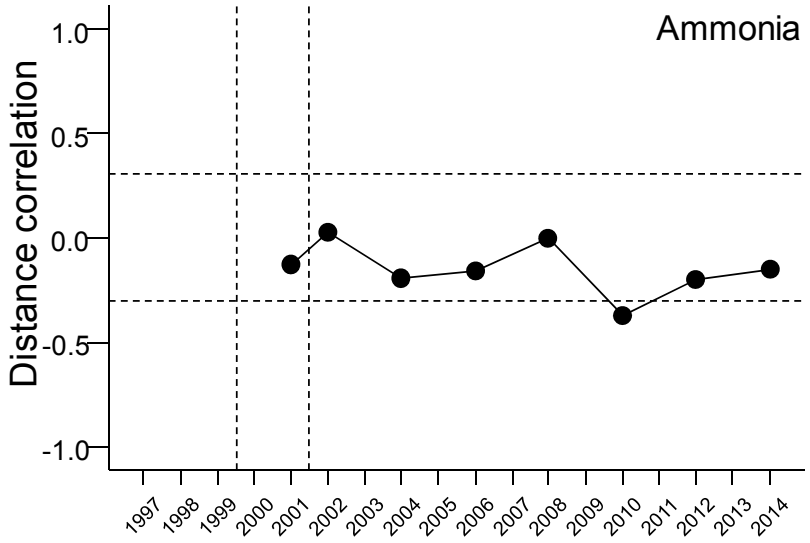


Figure 5-31 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Ammonia (1997 to 2014)

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 2014.

Results from repeated-measured regression for ammonia are provided in Table 5-21. Carry-over effects for ammonia were significant ($F = 2.3$, $p \leq 0.001$). Overall FE and FEZ regression slopes were also significant ($F = 4.3$ and 12.5, $p \leq 0.05$ and 0.001, respectively), with ammonia generally increasing with distance from the FE, and decreasing with distance from the FEZ drill centres (Figure 5-32), as noted for 2014 data. FE and FEZ regression slopes did not vary among years. Overall ammonia levels varied over time (all Year terms significant in Table 5-21). Ammonia levels were higher in 2001, decreased in 2002, increased to 2008, and have been decreasing since (Figure 5-29).

Table 5-21 Results (F Values) of Repeated-Measures Regressions Comparing Ammonia Among EEM Years (2000 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	12.5**				
FE *d*	4.3*				
Error 1 (Carry-over)	**2.3*** **				
Year		**5.0*** **	**39.1*** **	7.5**	4.7*
Year x FEZ *d*		0.8	2.6	<0.1	0.2
Year x FE *d*		0.6	<0.1	1.3	<0.1

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.

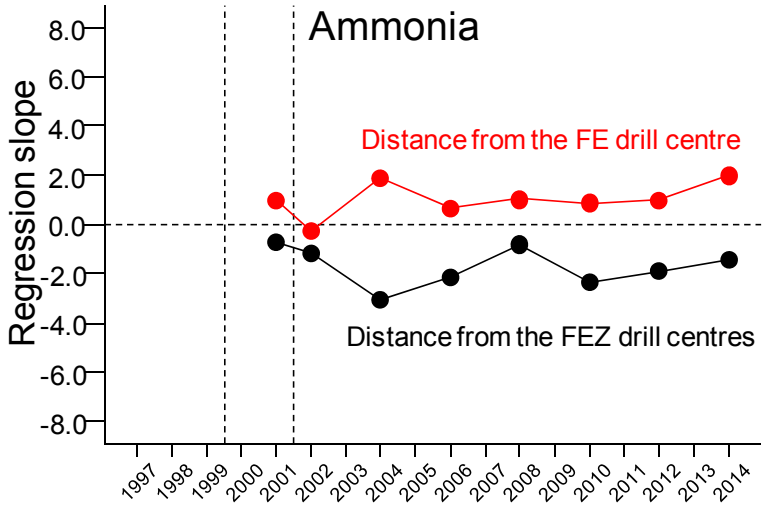


Figure 5-32 Annual Multiple Regression Distance Slopes for Ammonia (2001 to 2014)

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 2001 to 2004, increased in 2006, decreased in 2008, then increased in 2010. The range of redox values in 2014 was similar to that noted in 2010 and 2012 (Figure 5-33). 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.

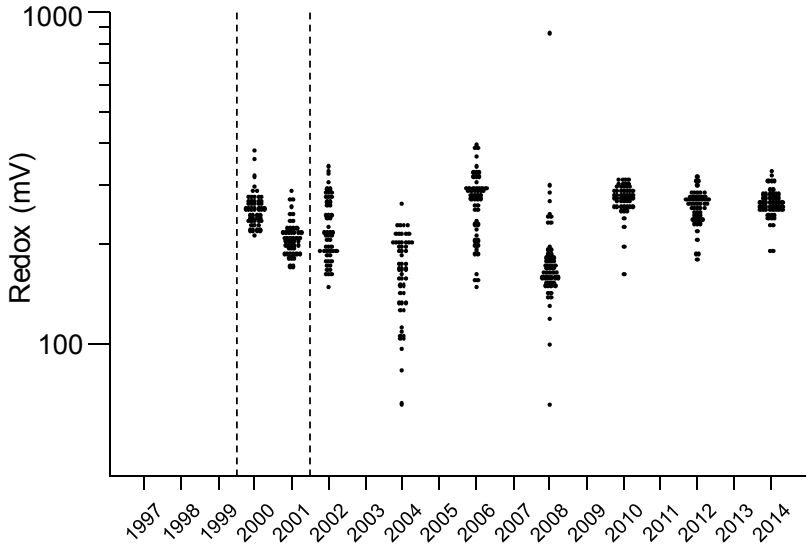


Figure 5-33 Annual Distributions for Redox (1997 to 2014)

Redox was positively correlated with Min *d* in 2014 (r_s = 0.48, $p \leq 0.001$, Table 5-22; Figures 5-34). The positive relationship indicates an increase in redox potential of sediments with increasing distance from drill centres. Multiple regression indicated that distances to both the FE and FEZ drill centres explained significant variation in redox potential in 2014 (Table 5-22). Partial correlations for the FE (partial r = 0.35, $p \leq 0.05$) and the FEZ (partial r = 0.54, $p \leq 0.001$) were both positive and significant.

Table 5-22 Results of Rank-Rank Regression of Redox on Distance Variables (2014)

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	**0.52*****	**0.54*****	0.35*	**0.48*****

Note: -*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 53
- see Appendix B-4 for results for n = 48 repeated-measures stations

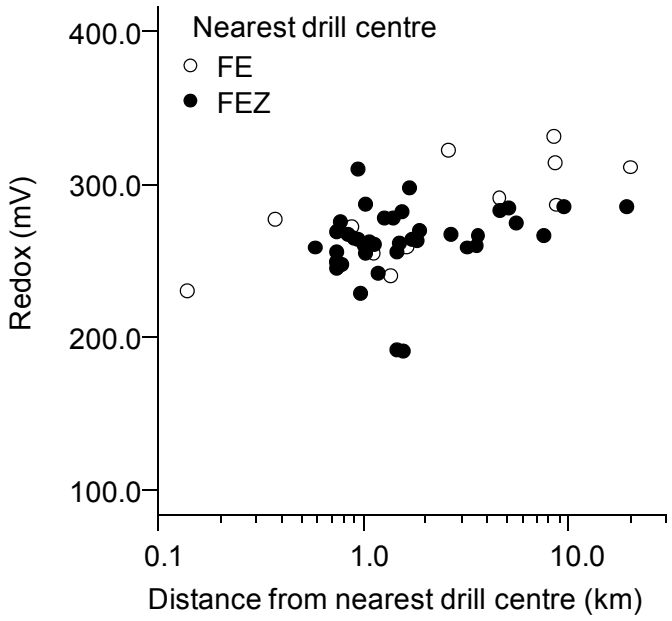


Figure 5-34 Distance Gradient for Redox (2014)

Strong positive correlations between redox and Min *d* have also occurred in 2000, 2002, and 2004 (Figure 5-35). In 2014, as in most previous years, all sediments were oxic (i.e., redox >100 mV; Figure 5-33).

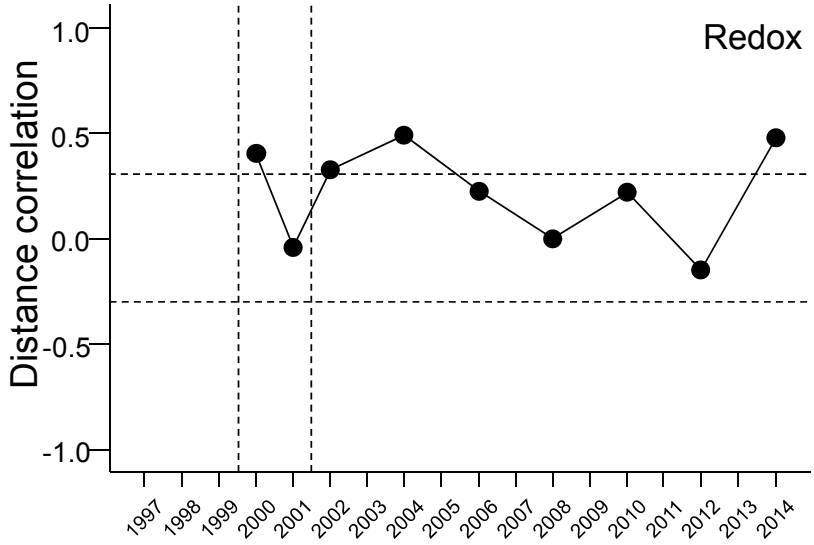


Figure 5-35 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Redox (2000 to 2014)

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 2014.

Results of repeated-measured regression for redox are provided in Table 5-23. Carry-over effects for redox were not significant ($F = 0.6$). The overall regression slopes for redox from the FEZ drill centres was significant (positive; $F = 43.3$, $p \leq 0.001$), 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 significant in Table 5-23). The predominant change over time for redox was a decrease in FEZ regression slopes from 2002 to 2014 ($F = 25.4$, $p \leq 0.001$, Figure 5-36), although the slope in 2014 was greater than it was from 2008 to 2012 (Figure 5-36; and the significant quadratic term in Table 5-23).

Table 5-23 Results (F Values) of Repeated-Measures Regressions Comparing Redox Among EEM Years (2000 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	**43.3*** **				
FE *d*	0.2				
Error 1 (Carry-over)	0.6				
Year		**13.0*** **	3.5	11.4**	3.4
Year x FEZ *d*		**7.1*** **	2.2	**25.4*** **	12.7**
Year x FE *d*		3.5**	0.2	4.7*	4.7*

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.
- Distance variables (X) and Y variables were rank-transformed.

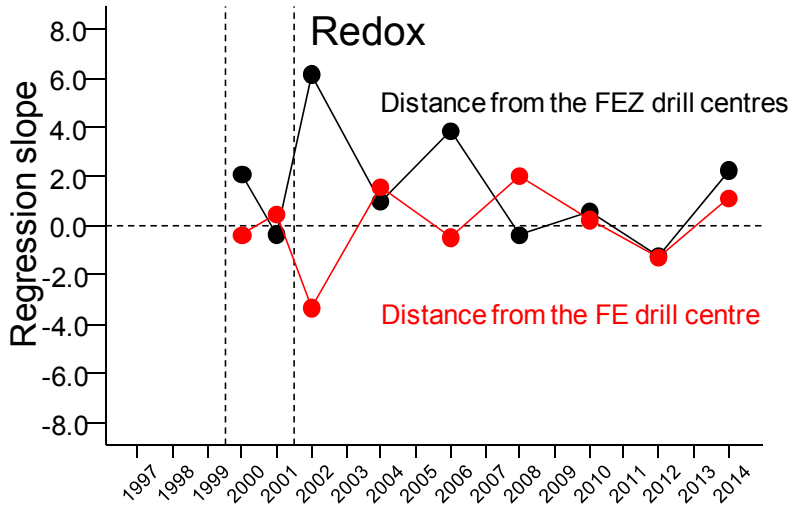


Figure 5-36 Annual Multiple Regression Distance Slopes for Redox (2000 to 2014)

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. Regression slopes varied among years (three of four Year x FE *d* terms significant in Table 5-23). However, the FE regression slopes did not vary from before to after drilling started at the FE drill centre. Generally, the relationship between redox levels and distance from the FE drill centre has been highly variable across years, and relatively weak in most years (Figure 5-36). As noted above, overall redox levels have varied over time ($F = 13.0$, $p \leq 0.001$ and $F = 11.4$, $p \leq 0.01$; Figure 5-33).

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 have generally been below 0.1% since 2001. Sulphide generally has been below 10 mg/kg since 2006 (Figure 5-37).

Percent sediment as sulphur was not significantly correlated with Min *d* in 2014 ($r_s = -0.25$, Table 5-24; Figure 5-38). Multiple regression results also indicated no relationship between FE and FEZ distances and sulphur in 2014.

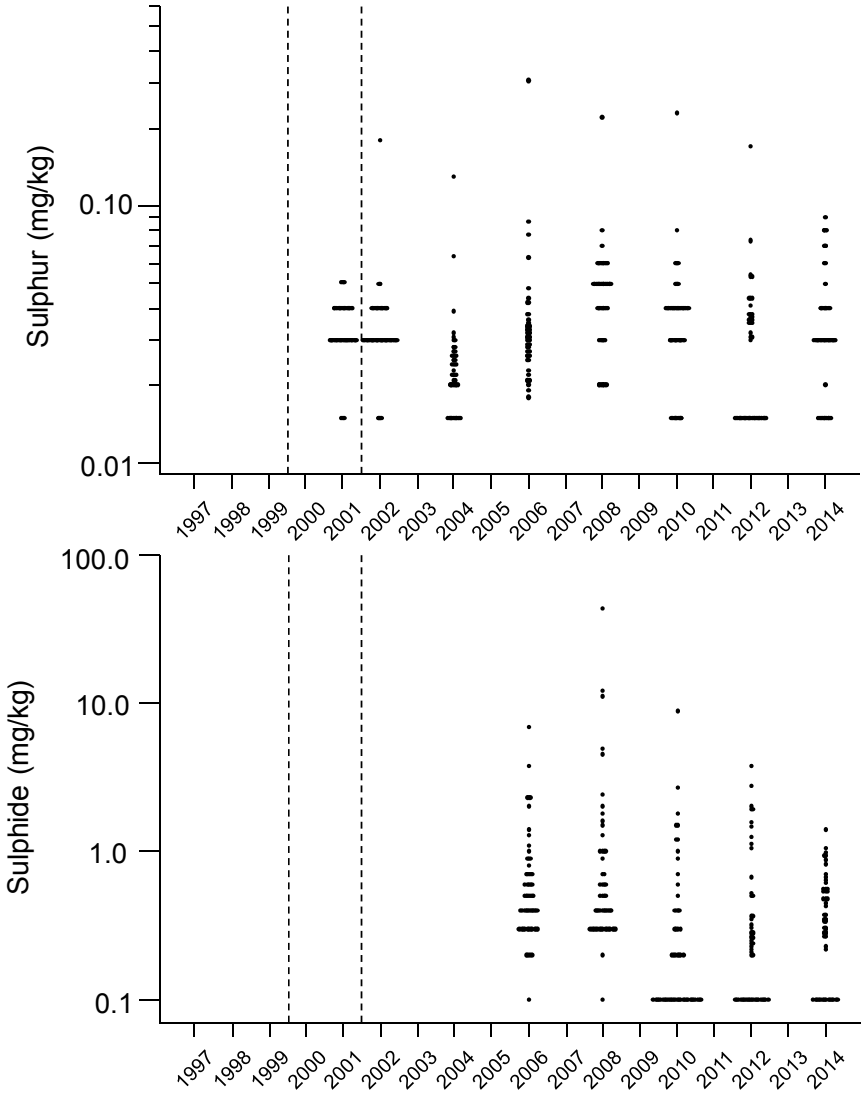


Figure 5-37 Annual Distributions of Concentrations for Sulphur (2001 to 2014) and Sulphide (2006 to 2014)

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 5-24 Results of Rank-Rank Regression of Sulphur and Sulphide on Distance Variables (2014)

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	0.21	-0.21	-0.04	-0.25
Sulphide	**0.56*****	**-0.63*****	0.15	**-0.52*****

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

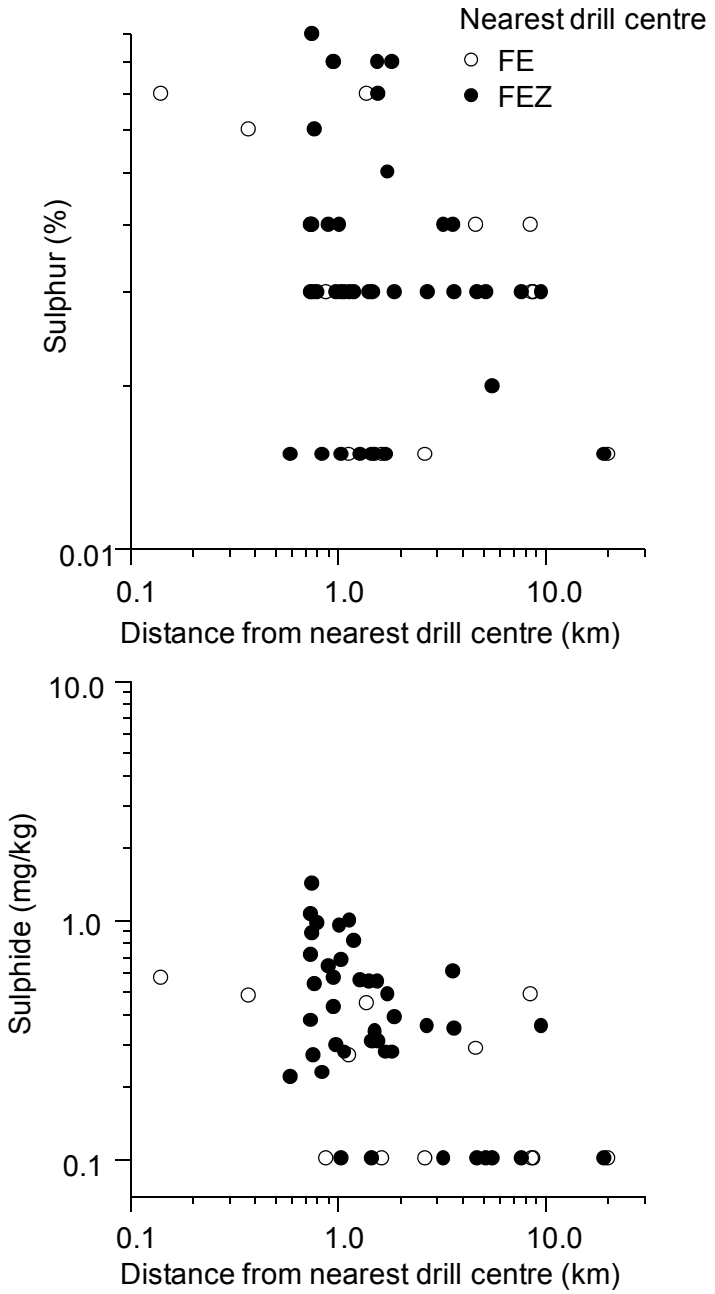


Figure 5-38 Distance Gradients for Sulphur and Sulphide (2014)

Sulphur has had modestly strong distance relationships in most years since it was first measured (Figure 5-39), with higher concentrations near drill centres. The relationship observed in 2014 was weaker than in all other years except 2008.

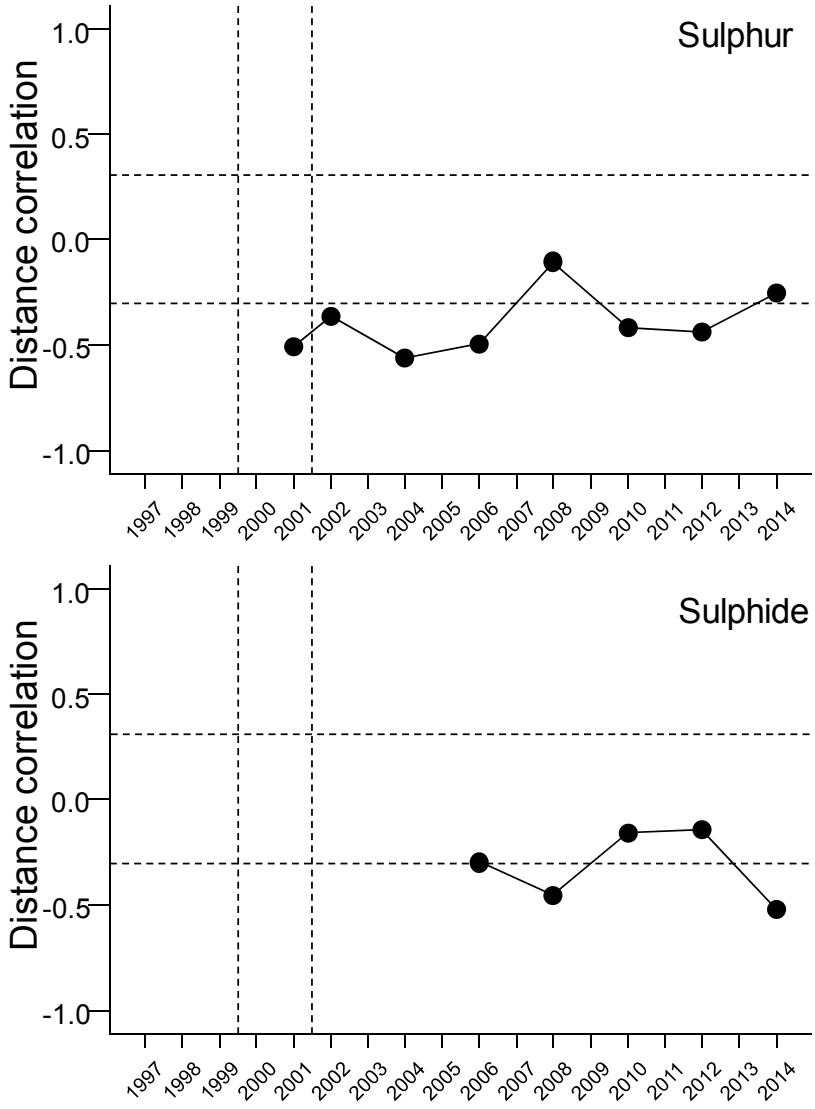


Figure 5-39 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Sulphur (2001 to 2014) and Sulphide (2006 to 2014)

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 2014.

Sulphide concentrations were significantly and negatively associated with Min *d* in 2014 (r_s = -0.52, $p \leq 0.001$; Table 5-24; Figure 5-38). Distance to the FEZ drill

centres was a stronger predictor of sulphide concentration (partial r = -0.63, $p \leq 0.001$) than was distance to the FE drill centre (partial r = 0.15, $p > 0.05$).

Results from repeated-measures regression for sulphur are provided in Table 5-25. Carry-over effects were significant ($F = 4.3$, $p \leq 0.001$). There was a significant overall FEZ regression slope (F = 15.7, $p \leq 0.001$). However, there were no significant variations in the FEZ regression slopes over time, with regression slopes typically in the range of -2.0 and -4.0 (Figure 5-40).

Table 5-25 Results (F Values) of Repeated-Measures Regressions Comparing Concentrations Among EEM Years for Sulphur (2001 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	**15.7*** **				
FE *d*	<0.1				
Error 1 (Carry-over)	**4.3*** **				
Year		**7.8*** **	0.5	0.2	1.1
Year x FEZ *d*		0.9	<0.1	3.0	0.4
Year x FE *d*		2.7*	1.0	1.6	2.6

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.
- Distance variables (X) and Y variables were rank-transformed.

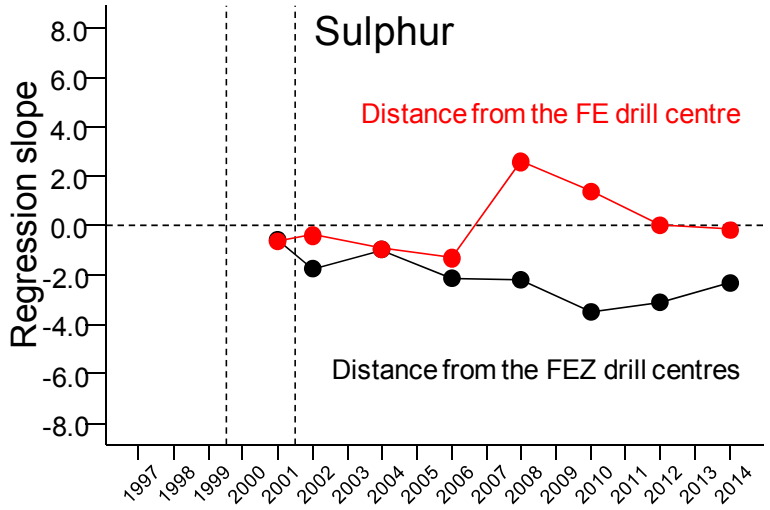


Figure 5-40 Annual Multiple Regression Distance Slopes for Sulphur (2001 to 2014)

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).

The overall FE regression slope for sulphur was not significant. There were significant variations in FE regression slopes, but the variations were not consistent

with the start of drilling at the FE drill centre (F = 1.0). FE regression slopes were negative from 2001 to 2006, positive in 2008 and 2010, and have been near zero since (Figure 5-40). There were significant variations in overall sulphur levels (F = 7.8, $p \leq 0.001$; Figure 5-37), but there were no linear or quadratic trends of over time.

There was no repeated-measures regression analysis of the sulphides concentration data because comparable sulphide data were only available from 2006 to present.

5.3.2 TOXICITY

5.3.2.1 Analysis of 2014 Data

Appendix B-5 provides Microtox IC50s and amphipod survival results from 1997 to 2014. In 2014, Microtox IC50s ranged from 6,129 to >197,000 mg wet/L. IC50s were less than 197,000 mg wet/L (the highest concentration tested) in 14 (of 53) samples. IC50s less than 50,000 mg wet/L (the benchmark used here for a toxic response) occurred in 11 samples, two fewer than in 2012. Two samples had IC50s less than 98,500 mg/kg (the benchmark used here for a negative response). The last of the 14 samples had an IC50 of 191,300 mg wet/L.

Amphipod survival ranged from 8% to 100%, with a median survival of 90%. Three samples were classified as toxic in 2014 following Environment Canada's (1998) interpretative guidance for sediments: samples from stations 22(NW); 39(FEZ); and 9(SE).

Relationships with Sediment Physical and Chemical Characteristics

Microtox IC50s and amphipod survival were uncorrelated (r_s = 0.121; $p > 0.05$) over all 53 samples tested in 2014. Microtox toxicity did not occur in two of the three samples classified as toxic to amphipods. Sediments from station 9(SE) were classified as toxic to both Microtox and amphipods.

Microtox IC50s were negatively correlated with most sediment physical and chemical variables (Table 5-26), indicating that sediment toxicity increased as values of those variables increased. Correlations in Table 5-26 are not necessarily indicative of direct negative effects of sediment physical and chemical characteristics on Microtox test organisms. IC50s were significantly but weakly correlated with >C_{10}-C_{21} hydrocarbons and barium, and those correlations were weaker than correlations between Microtox and many other variables. In 2014, as in prior years, strontium and fines were the strongest correlate of Microtox IC50s, with little

indication of project effects on either of these variables (Section 5.3.1, for fines, and Appendix B-4, for strontium).

Table 5-26 Spearman Rank Correlations (r_s) Between Toxicity Test Responses and Sediment Physical and Chemical Characteristics (2014)

Physical / Chemical Variable	Microtox IC50 (wet weight)	Amphipod Survival
$>C_{10}$-C_{21}	-0.236*	0.046
Barium	-0.389**	-0.062
Fines	**-0.656*** **	-0.092
Adjusted Fines	**-0.659*** **	-0.161
Gravel	**-0.434*** **	-0.220
TOC	**-0.609*** **	-0.115
Metals PC1	0.312**	0.110
Strontium	**-0.674*** **	-0.049
Sulphur	**-0.531*** **	-0.003
Sulphide	-0.150	-0.081
Ammonia	-0.345**	0.168
Redox	0.034	0.173

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

All correlations between amphipod survival and sediment physical and chemical variables were weak and non-significant (Table 5-26). Sediment barium and $>C_{10}$-C_{21} hydrocarbon concentrations were not remarkably high in the three samples toxic to amphipods (barium levels were 220 mg/kg or less; $>C_{10}$-C_{21} hydrocarbon levels were 1.2 mg/kg or less). However, two of the three samples (stations 9(SE) and 22(NW)) had relatively high levels of TOC (2.8 and 3.3 mg/kg, respectively) (Appendix B-5).

Distance Relationships

In 2014, Microtox IC50s were uncorrelated with distances from drill centres (r_s = 0.21, Table 5-27). As in previous years, the lowest values (greatest toxicity) generally occurred at intermediate distances of approximately 1 to 2 km from nearest drill centres (Figure 5-41).

Table 5-27 Results of Rank-Rank Regressions of Toxicity Test Responses on Distance Variables (2014)

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)	
Microtox IC50	0.24	0.22	0.23	0.21
Amphipod survival	0.12	0.09	0.12	0.06

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

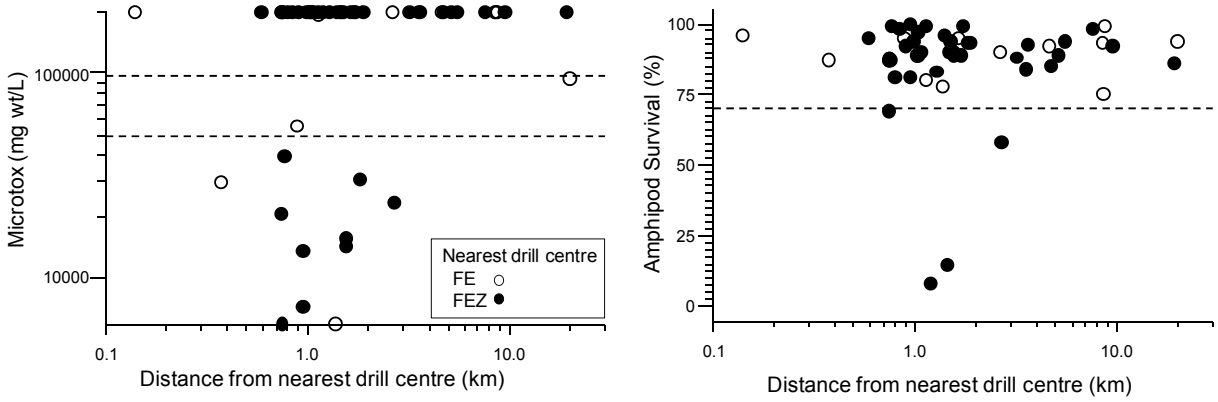


Figure 5-41 Distance Gradients for Toxicity Test Responses (2014)

Notes: The horizontal dashed lines in the left panel are the benchmarks of 50,000 and 98,500 mg wet/L, used in this report to define Microtox toxicity and negative responses, respectively. The horizontal dashed line in the right panel is the benchmark, 70% survival, used in this report to define toxicity to laboratory amphipods.

Amphipod survival also was uncorrelated with distances from drill centres in 2014 (r_s = 0.06; Table 5-27; Figure 5-41).

Microtox toxicity has not been significantly correlated with distance to drill centres in most years (Figure 5-42). Positive distance correlations were only statistically significant in 2000, although the NW and SE drill centres were inactive then and drilling has occurred at all four FEZ drill centres since 2001. Correlations with Min *d* have not increased in strength after drilling began at the FE drill centre.

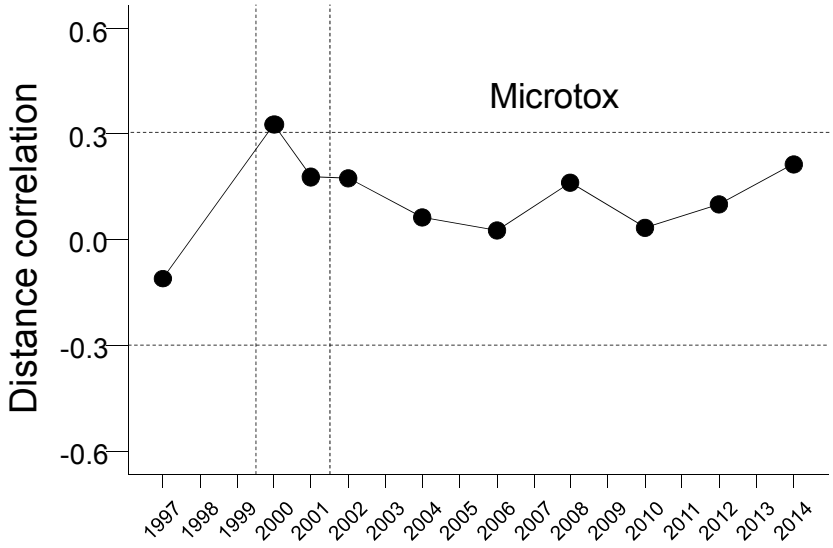


Figure 5-42 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Microtox (1997 to 2014)

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values below -0.3 or above 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 2014. The NE and SW drill centres were considered active for 1997 (baseline).

Results from repeated-measures regression for Microtox toxicity are provided in Table 5-28. Carry-over effects were highly significant for Microtox ($F = 10.8$, $p \leq 0.001$). Overall FEZ and FE regression slopes were not significant, and there were no significant variations among EEM years. There were no annual variations in regression slopes among years, and no variations in regression slopes that were consistent with drilling-related activities.

Table 5-28 Results (F Values) of Repeated-Measures Regressions Comparing Microtox Toxicity Among EEM Years (2000 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	2.0				
FE *d*	1.2				
Error 1 (Carry-over)	**10.8*** **				
Year		0.8	<0.1	<0.1	<0.1
Year x FEZ *d*		0.6	1.8	0.2	0.3
Year x FE *d*		0.4	0.1	<0.1	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.

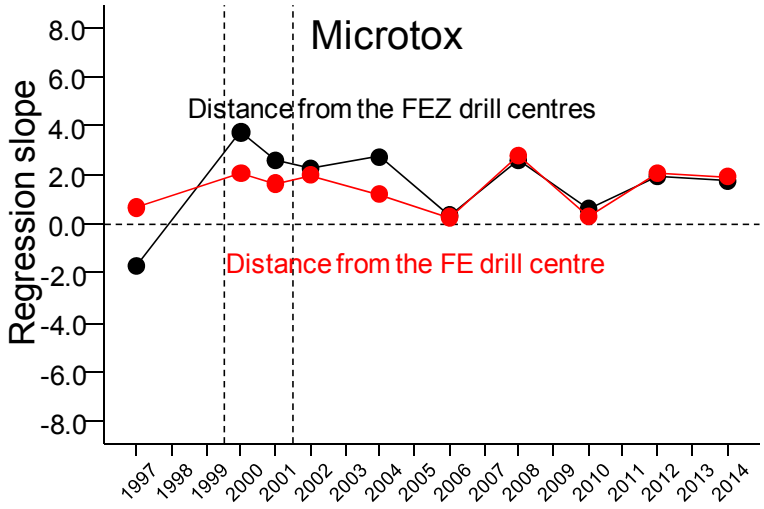


Figure 5-43 Annual Multiple Regression Distance Slopes for Microtox (1997 to 2014)

Note: 1997 regression slopes were based on the 33 stations sampled in both 1997 and in EEM years. 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).

Multi-year comparisons are not provided for amphipod survival because survival has been uniformly high.

5.3.3 BENTHIC COMMUNITY STRUCTURE

5.3.3.1 Overview

Over the ten sample years (from 1997 to 2014), more than 700 individual kinds of invertebrates from over 185 families (excluding meiofauna such as oligochaetes, protodrilids, copepods, ostracods, nematodes, nemerteans) have been collected, sorted from sediments, and identified (Table 5-29).

In 2014, over 34,000 individual benthic macro-invertebrates were collected in 106 samples from 53 stations (Table 5-29). Samples were dominated by polychaetes, which accounted for approximately 84% of total abundance in previous years, and 72% in 2014. Molluscs and crustaceans were the only other phyla accounting for more than 1% of total abundance in 2014 samples. Bivalves were the most abundant molluscs. Amphipods were the most abundant crustaceans.

Table 5-29 Abundant Taxa (Families) in Benthic Invertebrate Elutriate Samples (2000 to 2014)

Taxon			2000 to 2012		2014	
Phylum or Subphylum	**Class or Order**	**Family**	**% of organisms**	**% of samples**	**% of organisms**	**% of samples**
Annelida	Polychaeta	Sub-total	84.4	100	71.6	100
		Ampharetidae	0.7	55	2.5	77
		Capitellidae	1.3	89	0.9	83
		Cirratulidae	14.1	100	10.7	100
		Glyceridae	0.8	62	1.4	68
		Maldanidae	1.4	72	1.6	77
		Opheliidae	0.7	62	1.2	60
		Orbiniidae	1.3	72	1.4	91
		Paraonidae	3.0	88	3.8	87
		Pholoidae	3.4	87	2.9	91
		Phyllodocidae	3.5	99	1.5	98
		Sabellidae	2.8	87	5.5	83
		Spionidae	36.3	100	21.0	100
		Syllidae	11.8	100	12.3	100
	Bivalvia	Sub-total	2.5	100	4.8	100
		Hiatellidae	0.6	91	1.3	94
		Tellinidae	1.2	76	2.2	85
	Gastropoda	Sub-total	1.5	80	3.6	92
		Lepetidae	1.1	48	3.0	62
Crustacea	Amphipoda	Sub-total	4.3	98	8.3	100
		Oedicerotidae	0.6	75	1.1	92
		Phoxocephalidae	1.4	76	2.1	60
		Stenothoidae	0.1	10	1.6	68
	Cirripedia	Balanidae	2.2	58	2.1	62
	Cumacea	Sub-total	0.6	75	2.3	94
		Leuconidae	0.4	64	1.5	92
	Tanaidacea	Sub-total	2.1	79	3.1	77
		Paratanaidae	1.8	61	3.1	77
Echinodermata		Sub-total	1.0	87	1.4	87
Hemichordata			0.3	24	1.4	57
Grand Total Count			298,436		34,144	

Note: Only those taxa that accounted for >1% of total numbers in 2014 or in the years prior to 2014 are listed.

In 2014, as in previous years, invertebrate communities were dominated by three polychaete families: Spionidae (21% of total numbers); Syllidae (12%); and Cirratulidae (11). These three families were collected at every station in every year and accounted for just under 50% of the total number of invertebrates collected in EEM samples in 2014. Most of the other common families were also polychaetes. Tellinidae (mostly *Macoma*) and Hiatellidae (*Cyrtodaria* and *Hiatella*) were the dominant bivalve families. Lepetidae (*Lepeta*) was the dominant gastropod family. Tanaidacea (Order) was the most abundant crustacean. Oedicerotidae was the dominant amphipod family. Echinarachnidae was the dominant echinoderm family.

In 2014, total abundance varied by more than 10-fold among stations (from 160 to 1,873 individuals per station), with the standard deviations (SD) of abundances more than 50% of the mean (i.e., the coefficient of variation (CV)) for all major groups (Table 5-30). CVs were approximately 100% for Spionidae and Cirratulidae abundances, which together accounted for more than half of total abundance. Except for Syllidae and Phyllodocidae, CVs for abundances of other taxa were greater than 100%.

Table 5-30 Summary Statistics for Invertebrate Community Variables (2014)

Variable	Unit/Interpretation	Min	Max	Median	Mean	SD	CV (%)
Summary Measures							
Total abundance (N)	No. organisms/station	160	1,873	507	644	421	65
Biomass (B)	g wet/station	22	737	224	243	138	57
Richness (S)	No. taxa/station	20	58	40	38	12	32
Adjusted Richness (S2)	Observed:Expected S	0.8	1.7	1.3	1.2	0.2	17
NMDS1	Spionidae dominance*	-2.14	0.98	-0.42	-0.43	0.81	NA
NMDS2	Cirratulidae	-1.43	1.56	-0.37	-0.19	0.73	NA
Taxon Abundance							
Spionidae	No. organisms/station	2	573	93	135.3	143.2	106
Cirratulidae	No. organisms/station	4	295	50	69.0	65.6	95
Syllidae	No. organisms/station	7	225	72	79.1	45.6	58
Paraonidae	No. organisms/station	0	190	7	24.5	38.0	155
Orbiniidae	No. organisms/station	0	41	5	9.1	9.8	108
Phyllodocidae	No. organisms/station	0	32	9	10.0	6.5	65
Tellinidae	No. organisms/station	0	75	4	14.2	18.2	128
Amphipoda	No. organisms/station	3	191	38	53.6	50.6	94
Echinodermata	No. organisms/station	0	83	4	9.2	15.4	167

Notes: - *n* = 53 stations.
- S2 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). These were not computed for NMDS axis scores because CVs on variables scaled to a mean of zero are not relevant.
-*See Section 5.3.3.6 for correlations between taxa abundances and NMDS scores.

Biomass varied over 70-fold (approximately 22 to 737 g wet/station) among stations, with a CV of 57% (Table 5-30).

Richness and adjusted richness varied less (i.e., had lower CVs) among stations than abundances and biomass (Table 5-30). In 2014, 20 to 58 taxa were collected per station. Average (i.e., mean and median) adjusted richness values were approximately 1 (as they should be given the construct of the index; see Section 5.2.4).

Correlations Among Community Variables

Table 5-31 provides rank correlations among benthic invertebrate community summary measures for 2014 stations. Richness adjusted for abundance (adjusted richness) removed most of the positive correlation between raw richness and

abundance. Biomass in 2014 was weakly positively correlated with richness (r_s = 0.306, $p \leq 0.05$) and abundance (r_s = 0.309, $p \leq 0.05$).

Table 5-31 Spearman Rank Correlations (r_s) Among Primary Benthic Invertebrate Community Variables (2014)

Parameter	Total Abundance (N)	Biomass (B)	Richness (S)
Biomass (B)	0.309*		
Richness (S)	**0.908*** **	0.306*	
Adjusted Richness (S2)	**0.441*** **	0.222	**0.734*** **

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

Correlations (all positive) between abundances of the three dominant polychaete families (Spionidae, Cirratulidae, Syllidae) and total abundance were significant (Table 5-32). Abundances of Tellinidae, Phyllodocidae, Amphipoda and Echinodermata were also significantly positively correlated with total abundance. Orbiniidae abundances were weakly negatively correlated with total abundance.

Table 5-32 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Summary Measures versus Taxon Abundances (2014)

Taxon Abundance	Total Abundance (N)	Biomass (B)	Richness (S)	Adjusted Richness (S2)
Spionidae	**0.893*** **	0.294*	**0.821*** **	**0.435*** **
Cirratulidae	**0.445*** **	0.397**	0.363**	0.109
Syllidae	0.410**	-0.063	0.353**	0.042
Paraonidae	0.210	-0.258*	0.111	-0.118
Orbiniidae	-0.239*	-0.173	-0.250*	-0.180
Phyllodocidae	**0.598*** **	0.369**	**0.492*** **	0.334**
Tellinidae	**0.560*** **	0.320**	**0.517*** **	0.364**
Amphipoda	**0.543*** **	0.190	**0.646*** **	**0.545*** **
Echinodermata	**0.500*** **	0.099	**0.548*** **	0.271*

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

Biomass was positively correlated with abundances of Spionidae, Cirratulidae and Phyllodocidae polychaetes, as well as that of Tellinidae bivalves, and negatively correlated with abundances of Paraonidae polychaetes (Table 5-32).

Taxa correlations with richness were the same as those for total abundances. Adjusting richness for total abundance generally reduced the strength of the correlation between adjusted richness and the dominant groups. However, correlations between adjusted richness and Spionidae, Phyllodocidae, Tellinidae, Amphipoda and Echinodermata abundances remained significant despite adjusting for total abundance.

5.3.3.2 Abundance

Total abundance generally increased from 2000 to 2014 (Figure 5-44). Approximately 200 to 1,000 organisms per station were noted in 2000, whereas 160 to 1,873 organisms per station were noted in 2014. The high range in values of total abundance increased from 2002 to 2008, and then decreased in 2010 through 2014. Annual variations in abundances of Spionidae, Phyllodocidae and Tellinidae were generally similar to those of total abundance, with more organisms present in 2008 (Figure 5-45).

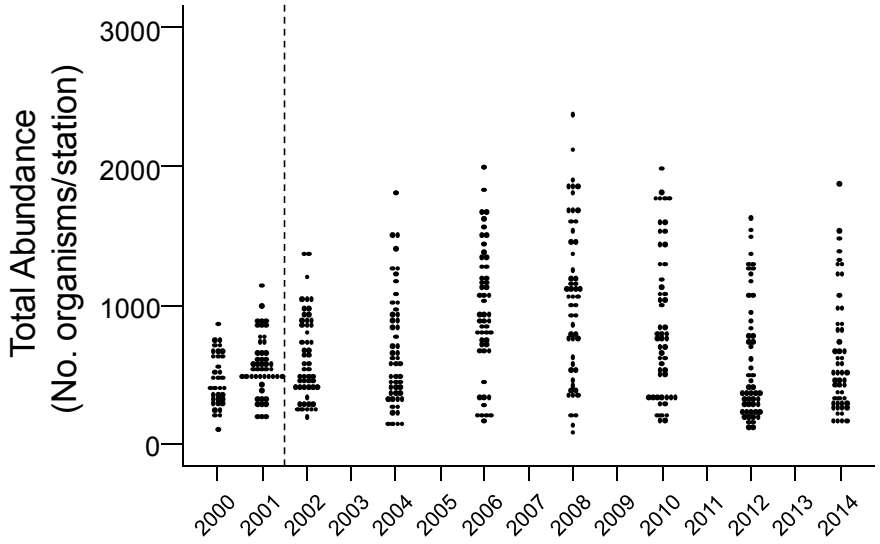


Figure 5-44 Annual Distributions for Total Abundance (2000 to 2014)

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

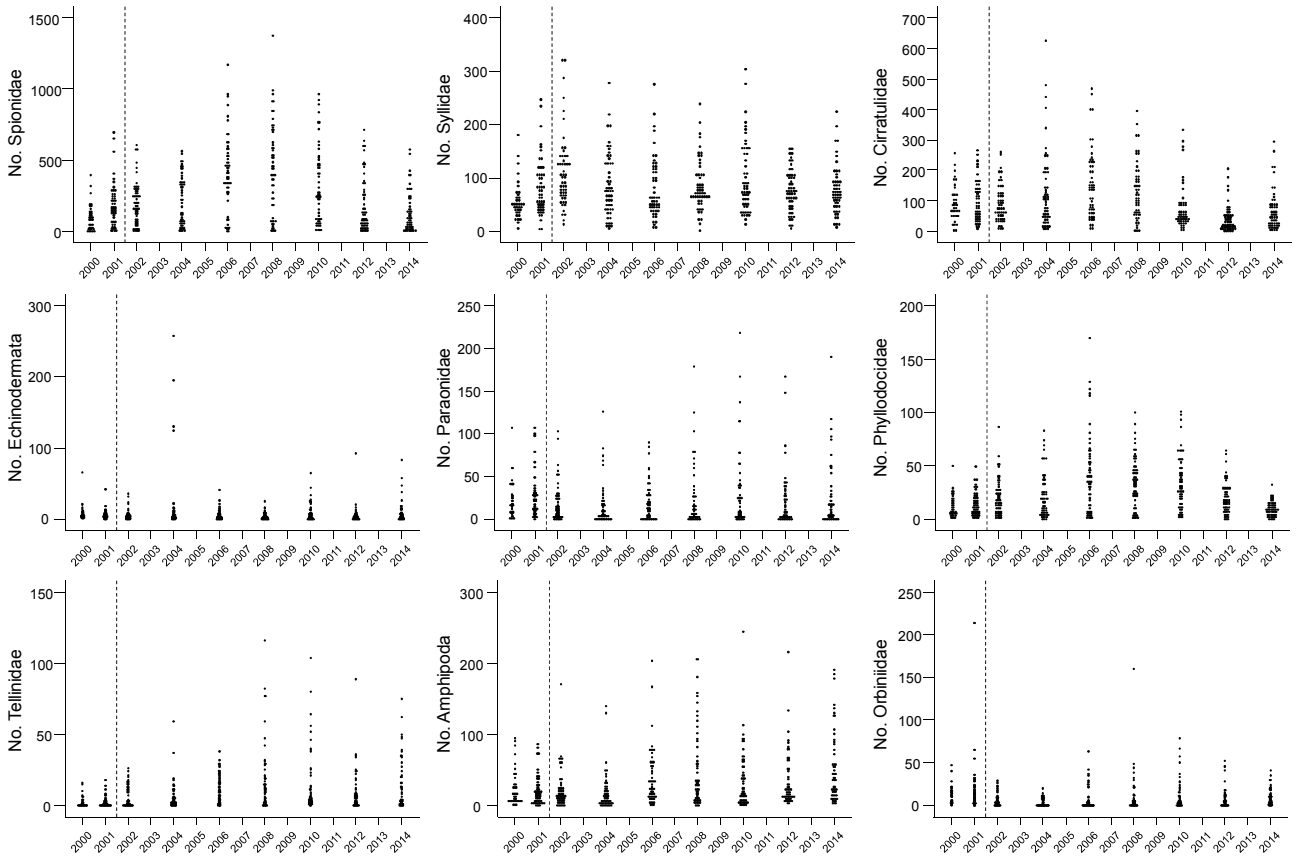


Figure 5-45 Annual Variations in Abundances of Major Taxonomic Groups (2000 to 2014)

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 distances to drill centres in 2014 (r_s = -0.32, $p \leq 0.05$, Table 5-33; Figure 5-46). Partial correlations with distance to the nearest FEZ drill centre and distance to the FE drill centre were not significant. (Table 5-33), indicating that Min *d* was the best overall predictor of total abundance.

Table 5-33 Results of Rank-Rank Regression of Total Abundance on Distance Variables (2014)

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	0.29*	-0.20	-0.16	-0.32*

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

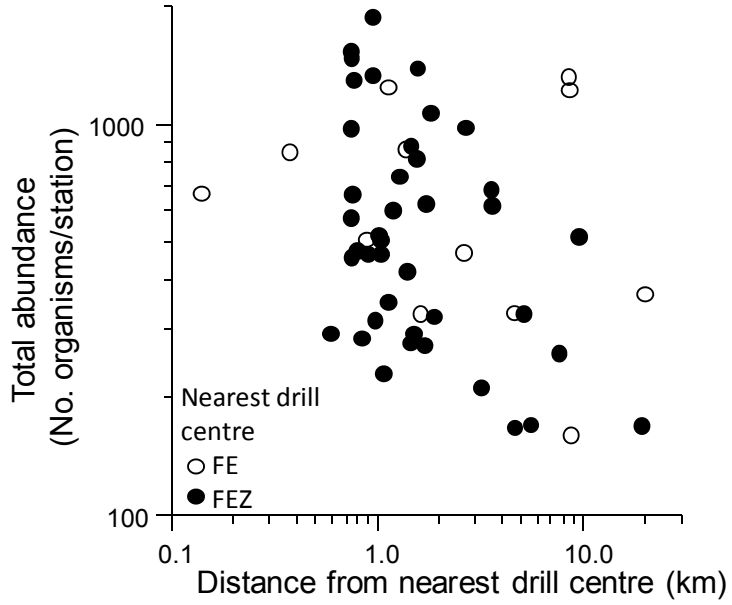


Figure 5-46 Distance Gradient for Total Abundance (2014)

Distance correlations for total abundance have been weakly negative in all years, with correlations significant in 2004 and 2014 (Figure 5-47).

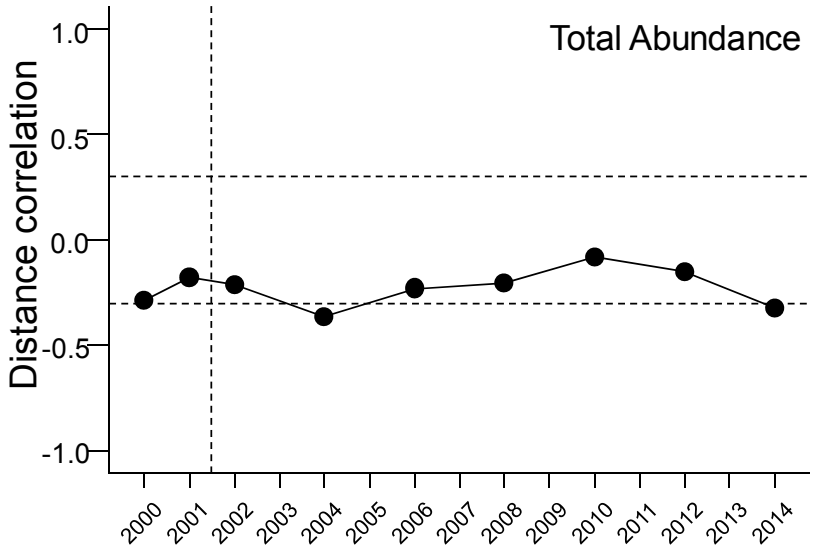


Figure 5-47 Annual Distance Correlations (r_s) for Total Abundance (2000 to 2014)

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 2014.

Results of repeated-measures regression for total abundance are provided in Table 5-34. Carry-over effects were highly significant for total abundance (F = 12.2, $p \leq 0.001$), indicating persistent spatial variations over time. The overall FEZ regression slope was weakly significant (F = 5.2, $p \leq 0.05$). There were no significant variations among years in FEZ regression slopes, and slopes were generally negative (Figure 5-48), indicating a decrease in abundance with distance from the FEZ drill centres. There was no strong overall FE regression slope, although FE slopes generally increased from near zero in 2002 and 2004, to positive, and then to negative in 2014 (F = 4.3, $p \leq 0.05$, Figure 5-48). As noted above, there were changes in overall abundance over time (F = 21.6, $p \leq 0.001$, Figure 5-44).

Table 5-34 Results (F Values) of Repeated-Measures Regressions Comparing Total Abundance Among EEM Years (2001 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	5.2*				
FE *d*	<0.1				
Error 1 (Carry-over)	**12.2*** **				
Year		**5.2*** **	0.7	<0.1	**21.6*** **
Year x FEZ *d*		1.1	2.2	1.0	<0.1
Year x FE *d*		1.5	1.4	0.1	4.3*

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.
- 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.

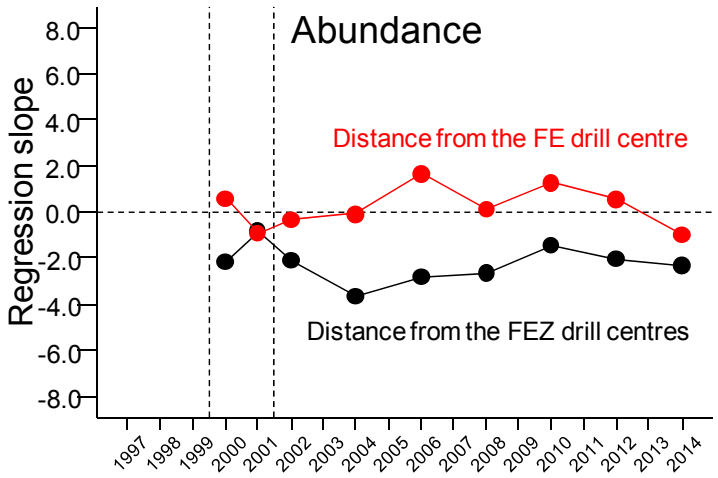


Figure 5-48 Annual Multiple Regression Distance Slopes for Total Abundance (2000 to 2014)

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).

5.3.3.3 Biomass

Total benthic biomass has remained relatively consistent since year 2000, ranging between approximately 50 and 400 g wet/station (Figure 5-49), with a median biomass in 2014 of just over 200 g wet/station. Variations in biomass in 2014 were similar to variations observed in prior years.

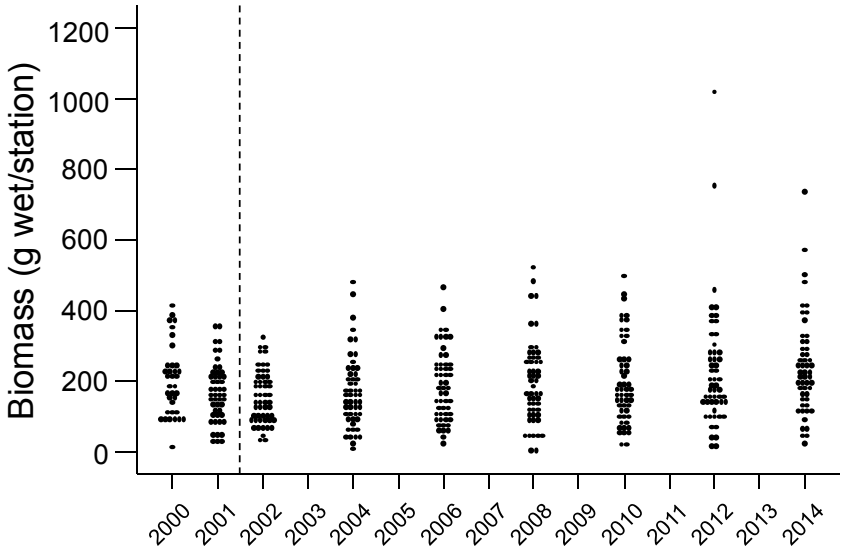


Figure 5-49 Annual Distributions for Biomass (2000 to 2014)

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 2014 (r_s = -0.15, Table 5-35; Figure 5-50). Partial correlations with FE and FEZ distances indicated that distance to the nearest FEZ drill centres explained significant variation in total biomass (r_s = -0.32, $p \leq 0.05$, Table 5-35), with biomass decreasing with distance from the FEZ drill centres. With station 33(FEZ) (highest observed biomass of >730 g/sample) removed from the analysis, none of the associations between biomass and proximity to drill centres was significant.

Table 5-35 Results of Rank-Rank Regression of Biomass on Distance Variables (2014)

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 (all stations)	0.30*	-0.32*	0.20	-0.15
Biomass (Station 33 (FEZ) removed)	0.27	-0.19	0.14	-0.16

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

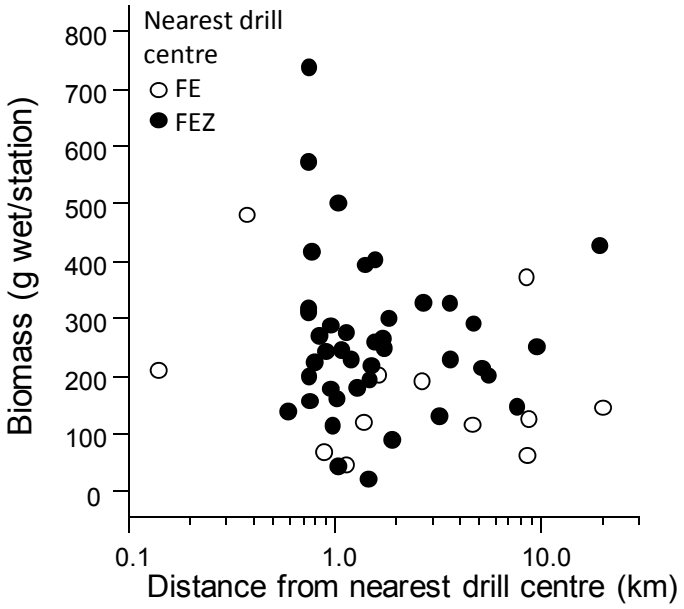


Figure 5-50 Distance Gradient for Biomass (2014)

Biomass has only been correlated with Min *d* in 2004 (Figure 5-51), when the relationship was significant and positive, indicating increasing biomass with increasing distance from drill centres.

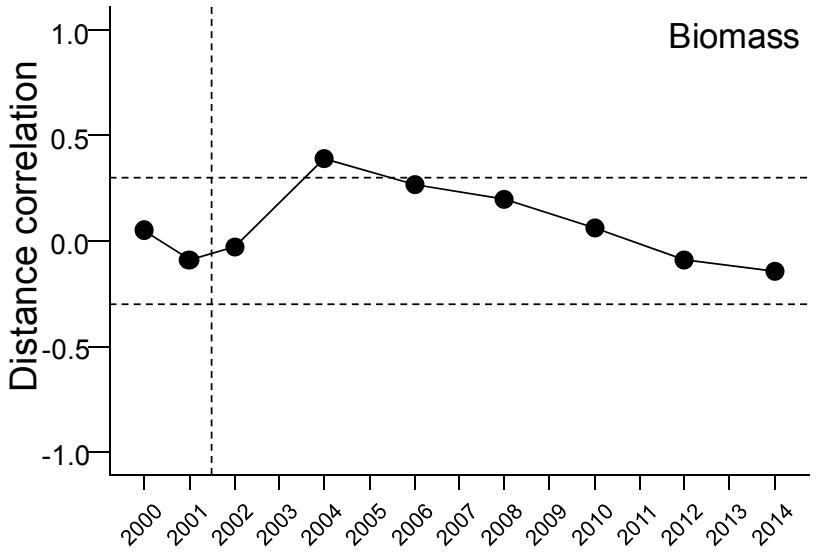


Figure 5-51 Annual Distance Correlations (r_s) for Biomass (2000 to 2014)

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 2014.

Results of repeated-measures regression for biomass are provided in Table 5-36. Carry-over effects were significant (F = 1.94, $p \leq 0.001$). The overall FEZ regression slope was not significant and slopes did not vary among years. The overall FE regression slope was significant (F = 34.5, $p \leq 0.001$), with slopes positive indicating an increase in biomass with distance from the FE drill centre in most years (Figure 5-52). Annual variations in FE regression slopes varied in a quadratic fashion (F = 7.9, $p \leq 0.01$) from 2002 to 2014, with stronger positive slopes in 2004 and 2006 (Figure 5-52). Overall biomass values were modestly lower in 2000, and from 2010 to 2014, producing a modest quadratic effect (F = 8.6, $p \leq 0.01$).

Table 5-36 Results (F Values) of Repeated-Measures Regressions Comparing Biomass Among EEM Years (2001 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	4.3				
FE *d*	**34.5*****				
Error 1 (Carry-over)	**1.94*****				
Year		2.0	0.8	<0.1	8.7**
Year x FEZ *d*		1.6	0.2	3.8	1.0
Year x FE *d*		1.9	<0.1	<0.1	7.9**

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.

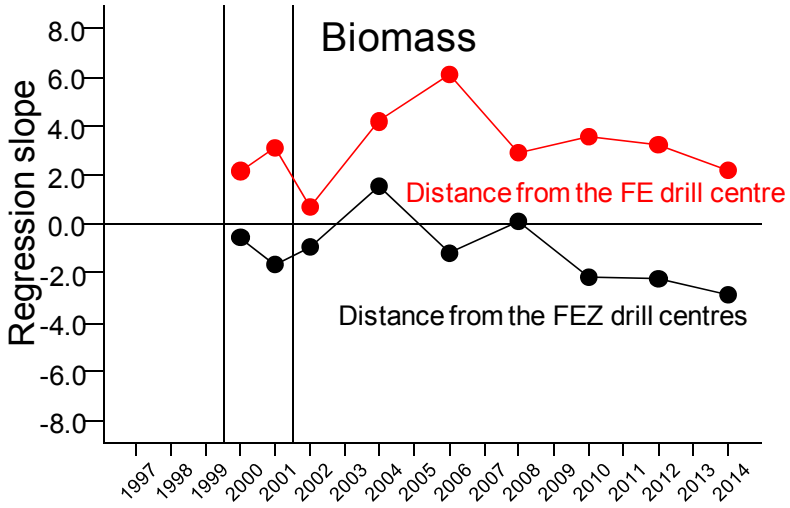


Figure 5-52 Annual Multiple Regression Distance Slopes for Biomass (2000 to 2014)

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).

5.3.3.4 Richness

Approximately 15 to 60 taxa per station have been noted since sampling began in 2000 (Figure 5-53).

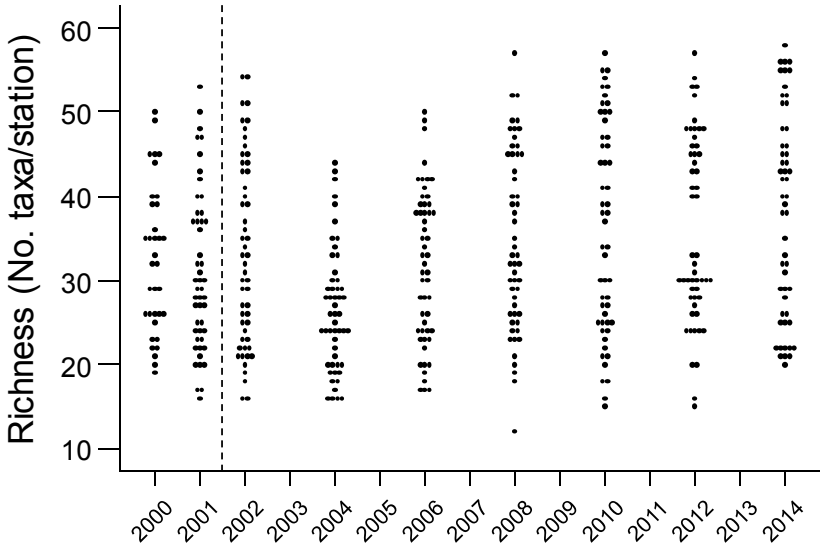


Figure 5-53 Annual Distributions for Richness (2000 to 2014)

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

Richness in 2014 did not vary significantly with Min *d* (r_s = -0.24, Table 5-37; Figure 5-54), similar to what was observed in prior years (Figure 5-55). Multiple regression likewise failed to demonstrate an influence of distance to the FE (r_s = -0.18) or FEZ (r_s = -0.22) drill centres individually, but the combined effect of FE and FEZ distances did explain significant variation in taxa richness (Multiple *R* = 0.33; Table 5-37). Negative correlation coefficients in Table 5-37 indicate higher richness near drill centres.

Table 5-37 Results of Rank-Rank Regression of Richness on Distance Variables (2014)

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	0.33*	-0.22	-0.18	-0.24

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

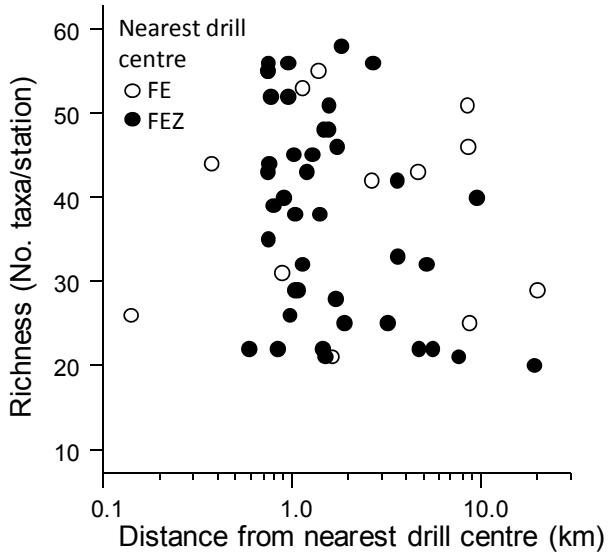


Figure 5-54 Distance Gradient for Richness (2014)

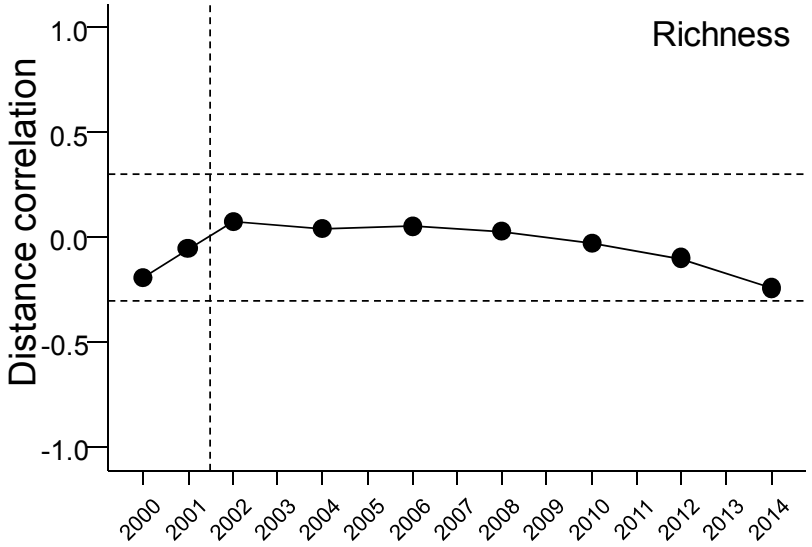


Figure 5-55 Annual Distance Correlations (r_s) for Richness (2000 to 2014)

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 2014.

Results of repeated-measures regression for richness are provided in Table 5-38. Carry-over effects were highly significant for richness ($F = 24.7$, $p \leq 0.001$). Although there was no significant overall FEZ regression slope, FEZ regression slopes varied in quadratic fashion from 2002 to 2014 ($F = 6.9$, $p \leq 0.05$) with more negative values in 2000, and since 2010 (Figure 5-56) (i.e., higher richness near FEZ drill centres

relative to richness at greater distances in those years). There was no significant overall FE regression slope, and no significant variations over time. There were significant variations in overall richness over time, with richness generally higher since 2008 (Figure 5-53).

Table 5-38 Results (F Values) of Repeated-Measures Regressions Comparing Richness Among EEM Years (2001 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	0.2				
FE *d*	0.2				
Error 1 (Carry-over)	**24.7*** **				
Year		2.3*	4.9*	<0.1	1.8
Year x FEZ *d*		3.0**	0.3	11.4	6.9*
Year x FE *d*		0.9	2.0	1.7	<0.1

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.

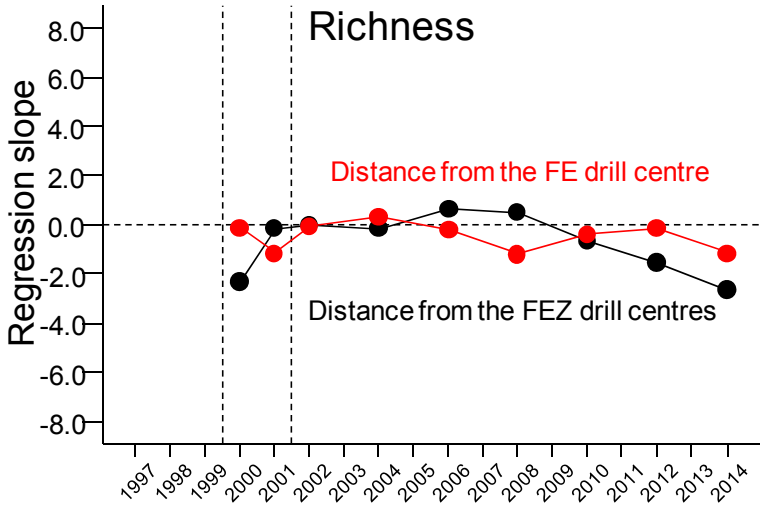


Figure 5-56 Annual Multiple Regression Distance Slopes for Richness (2000 to 2014)

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).

5.3.3.5 Adjusted Richness

Adjusted richness values ranged between approximately 0.7 and 1.7 in 2014, similar to what was observed in 2000 (Figure 5-57). Adjusted richness values had a somewhat lower range of values in 2004 through 2010 than in years before or after.

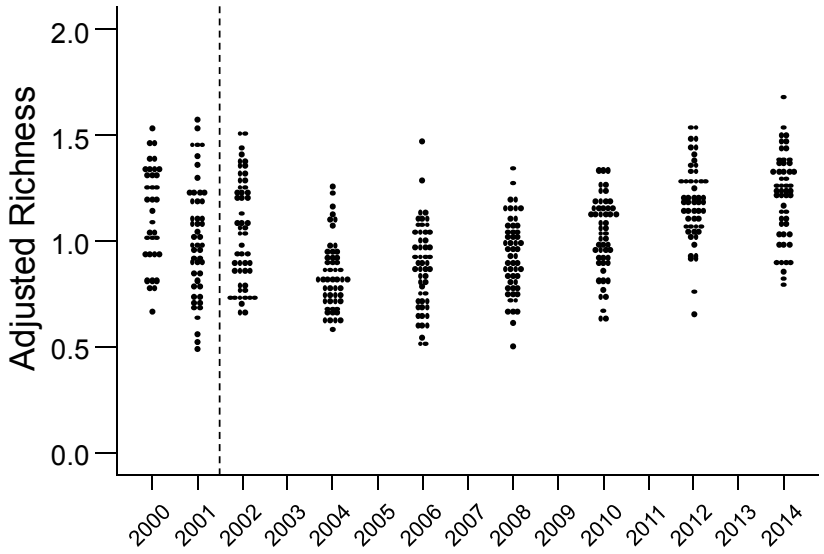


Figure 5-57 Annual Distributions for Adjusted Richness (2000 to 2014)

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 (r_s = -0.08, Table 5-39; Figure 5-58). Partial correlations with FE and FEZ distances and adjusted richness, and the overall multiple correlation coefficient, were not significant in 2014.

Table 5-39 Results of Rank-Rank Regression of Adjusted Richness on Distance Variables (2014)

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	0.25	-0.15	-0.17	-0.08

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

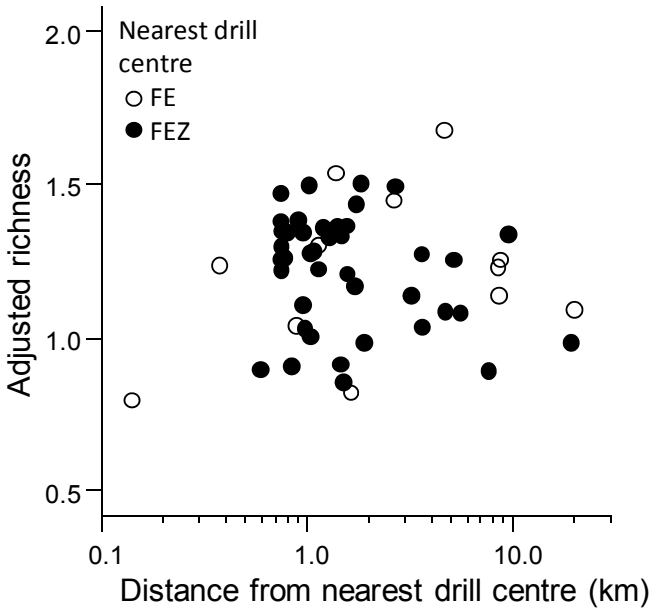


Figure 5-58 Distance Gradient for Adjusted Richness (2014)

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 5-59).

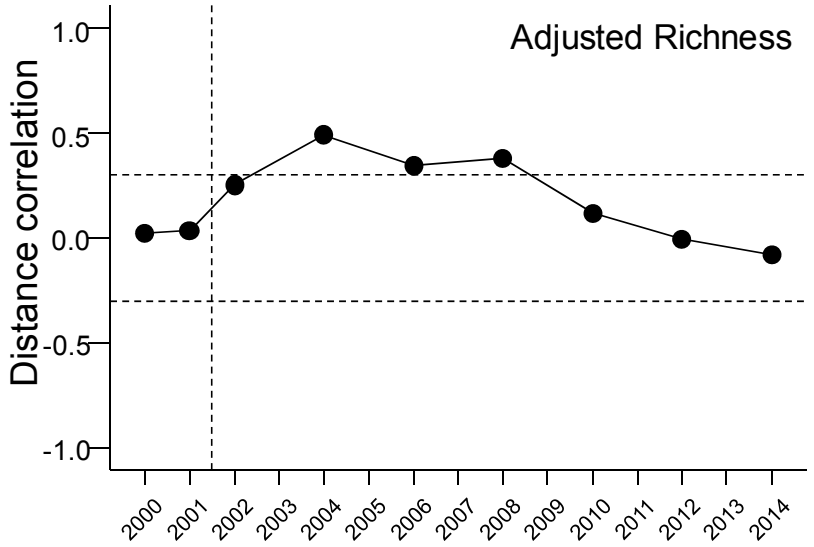


Figure 5-59 Annual Distance Correlations (r_s) for Adjusted Richness (2000 to 2014)

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 2014.

Results of repeated-measures regression for adjusted richness are provided in Table 5-40. Carry-over effects were highly significant ($F = 7.9$, $p \leq 0.001$). There were no significant overall FE and FEZ regression slopes for adjusted richness. There were variations in FEZ regression slopes, with slopes varying in a quadratic fashion ($F = 9.9$, $p \leq 0.05$) (Figure 5-60). Negative slopes in recent years indicate marginally higher adjusted richness near FEZ drill centres, relative to values at greater distances. There were no variations in FE regression slopes. Overall adjusted richness was marginally lower from 2004 to 2010 than in other years ($F = 6.4$, $p \leq 0.05$; Figure 5-57).

Table 5-40 Results (F Values) of Repeated-Measures Regressions Comparing Adjusted Richness Among EEM Years (2001 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (200 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
FEZ *d*	3.5				
FE *d*	0.8				
Error 1 (Carry-over)	**7.9*** **				
Year		2.0	1.0	0.2	6.4*
Year x FEZ *d*		**5.0*** **	1.7	**17.3*** **	9.9**
Year x FE *d*		1.1	<0.1	1.6	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.
- 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.

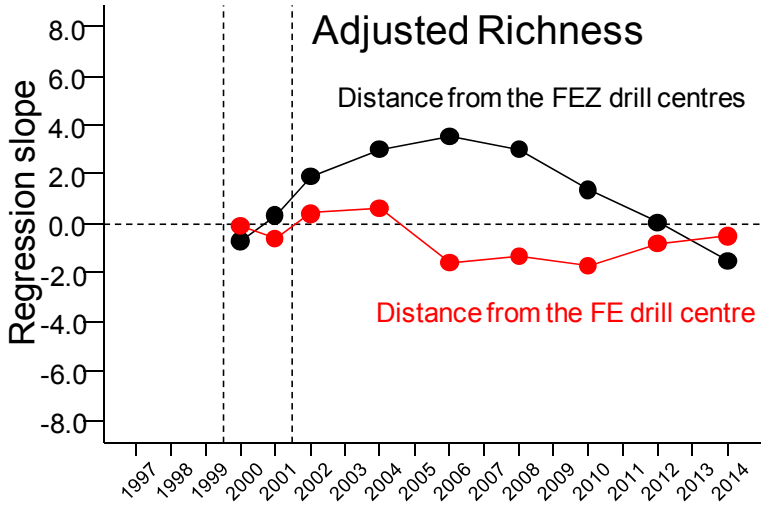


Figure 5-60 Annual Multiple Regression Distance Slopes for Adjusted Richness (2000 to 2014)

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).

5.3.3.6 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 0.18. Stress values can range from 0 (perfect fit) to 1 (no fit). A stress coefficient of 0.18 indicates a reasonable two-dimensional fit to the pair-wise Bray-Curtis distances among the 454 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. In Figure 5-61, 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 5-61 show a shift in community composition over time along the NMDS1 axis for communities located within 1 km from drill centres.

Figure 5-62 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 5-61 onto Figure 5-62 would indicate approximately the associations between stations and taxa. For example, stations in the lower left quadrant of Figure 5-61 (negative NMDS1 and NMDS2 scores) would have greater relative abundances of taxa in the lower left quadrant of Figure 5-62 (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)).

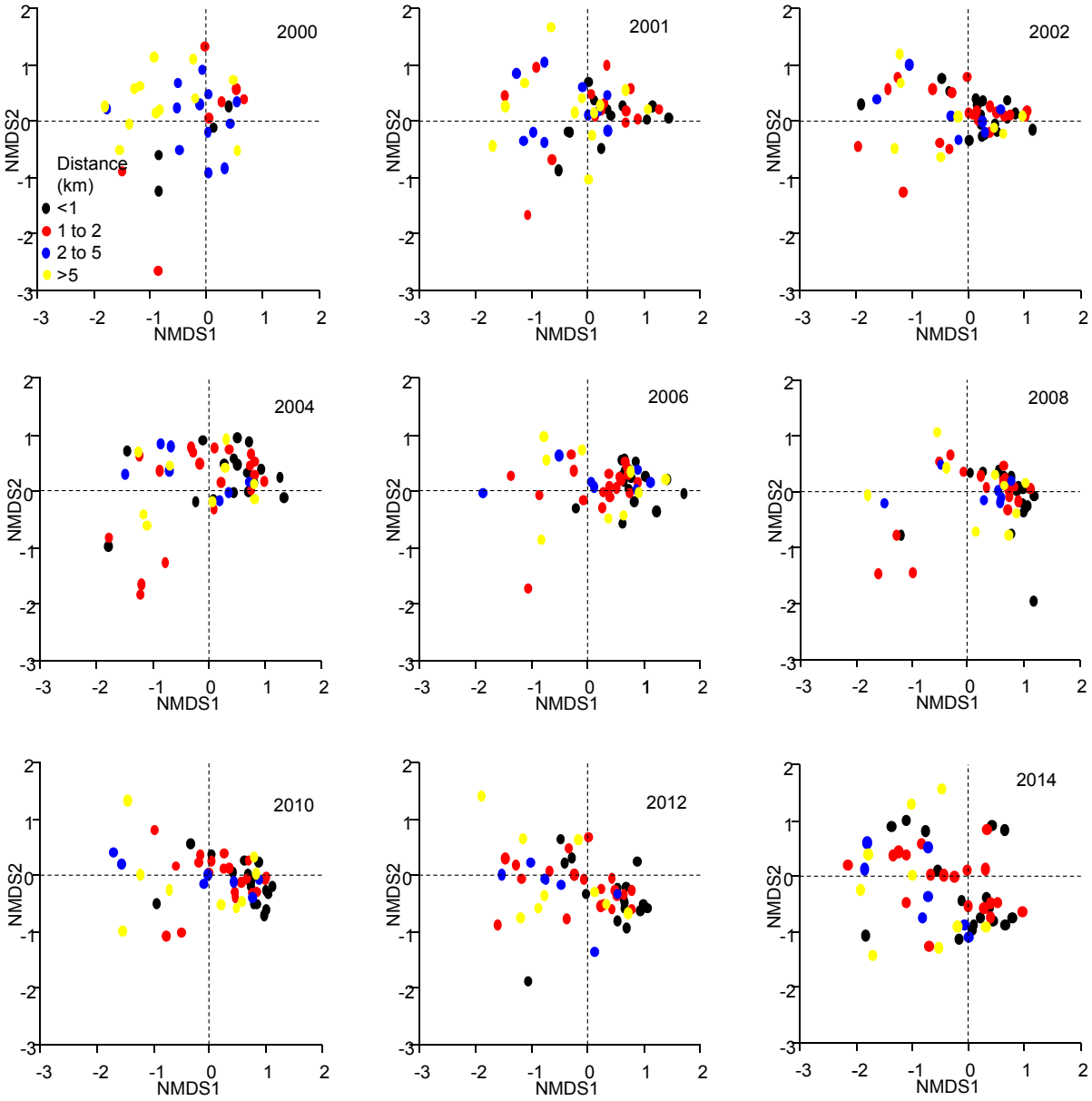


Figure 5-61 Non-Metric Multidimensional Scaling Plots Based on Relative Abundances of Invertebrate Taxa (2000 to 2014)

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 2014).

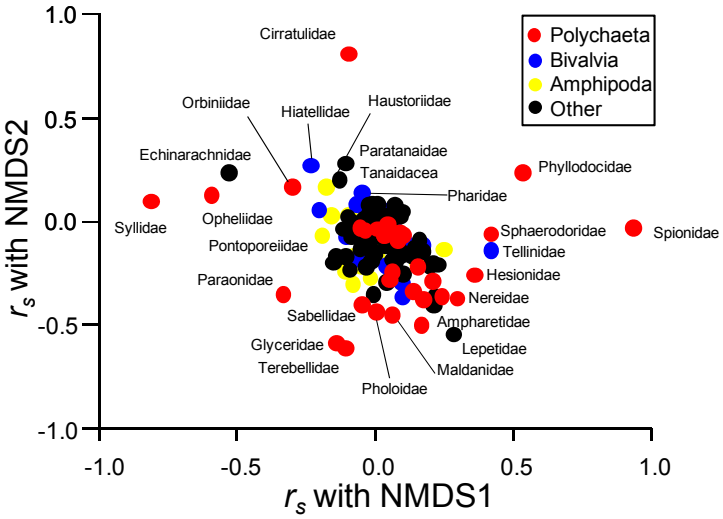


Figure 5-62 Spearman Rank Correlations (r_s) Between Family Relative (%) Abundances and Non-Metric Multidimensional Scaling Axes (2000 to 2014)

The three dominant polychaete families (Spionidae, Syllidae and Cirratulidae) largely defined overall community differences along the NMDS axes among stations in Figure 5-61, and differences among taxa or groups of taxa in Figure 5-62. The first NMDS axis (NMDS1) was strongly positively correlated with the relative abundance of Spionidae, Phyllodocidae and Tellinidae and strongly negatively correlated with the relative abundance of Syllidae, Orbiniidae and Paraonidae (Figure 5-62). In other words, NMDS1 scores represent a Spionidae-Phyllodocidae-Tellinidae versus Syllidae-Orbiniidae-Paraonidae contrast. Abundances of the polychaete family Sphaerodoridae were strongly positively associated, and abundance of the echinoderm family were strongly negatively associated, with NMDS1 scores, but each accounted for a minor fraction of the total numbers in 2014 (approximately 0.2% for both).

NMDS2 scores were strongly positively correlated with the relative (%) abundances of the dominant Cirratulidae, uncorrelated with relative abundances of Spionidae and Syllidae, and strongly negatively correlated with abundances of several sub-dominant taxa (particularly Terebellidae, Lepetidae and Glyceridae). Therefore, NMDS2 represented a contrast between Cirratulidae versus most other taxa (i.e., Cirratulidae dominance).

NMDS1 and NMDS2 were correlated with more general measures of benthic invertebrate community composition (Table 5-41). Larger positive NMDS1 scores occurred in communities that had higher abundance (r_s = 0.73, $p \leq 0.001$), heavier total biomass (r_s = 0.36, $p \leq 0.01$) and a greater richness of fauna (r_s = 0.67 and 0.44

for richness and adjusted richness, respectively, $p \leq 0.001$). Larger negative NMDS2 scores occurred in communities with higher abundance (r_s = -0.66, $p \leq 0.001$) and greater richness of fauna (r_s = -0.69 and -0.45 for richness and adjusted richness, respectively, $p \leq 0.001$).

Table 5-41 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Summary Measures and NMDS Axis Scores (2014)

Summary Measure	NMDS1	NMDS2
Abundance	**0.73*** **	**-0.66*** **
Biomass	0.36**	-0.11
Richness	**0.67*** **	**-0.69*** **
Adjusted Richness	**0.44*** **	**-0.45*** **

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

NMDS1 scores were strongly negatively associated with Min *d* in 2014 (r_s = -0.44, $p \leq 0.001$, Table 5-42; Figure 5-63), reflecting higher abundances of Spionidae, Phyllodocidae and Tellinidae, and lower abundances of Orbiniidae and Paraonidae, as well as Echinodermata, nearer drill centres. Variations in abundances of selected taxa in relation to Min *d* in 2014 are illustrated in Figure 5-64, showing that stations nearer drill centres tended to have higher numbers of Spionidae, Phylodocidae and Tellinidae, and lower numbers of Orbiniidae, Paraonidae and Echinodermata. Cirratulidae also had higher abundances near drill centres (Figure 5-63), despite abundances of this group not correlating strongly with NMDS axis 1 scores (Figure 5-62). As in previous years, threshold relationships were not apparent for NMDS1, but effects were apparent within approximately 1 to 2 km of drill centres (Figure 5-63). Distance to the FEZ drill centres was a stronger predictor of NMDS1 than distance from the FE drill centre (Table 5-42).

NMDS1 scores were relatively high at stations 30(FE) and 31(FE), the two stations nearest a drill centre (Figure 5-63). Those high scores reflected relatively high abundances of Spionidae, Phyllodocidae and Tellinidae, lower abundances of Orbinidae and Paraonidae, as well as Echinodermata (Figure 5-64).

NMDS2 scores were uncorrelated with any distance measure in 2014 (r_s = -0.02, Table 5-42; Figure 5-63). Partial correlations with distances from the FEZ and FE drill centres, as well as the multiple correlation coefficient, were not significant for NMDS2.

Table 5-42 Results of Rank-Rank Regression of NMDS 1 and 2 on Distance Variables (2014)

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	0.34*	-0.31*	-0.10	**-0.44*** **
NMDS2	0.15	-0.11	0.14	-0.02

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

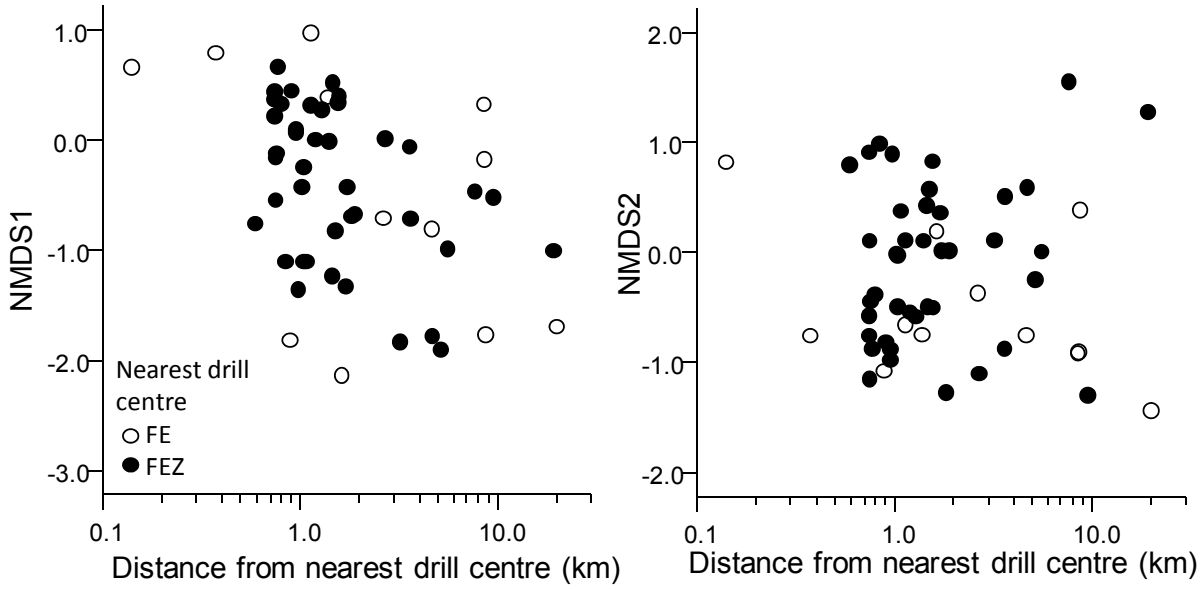


Figure 5-63 Distance Gradient for NMDS 1 and 2 (2014)

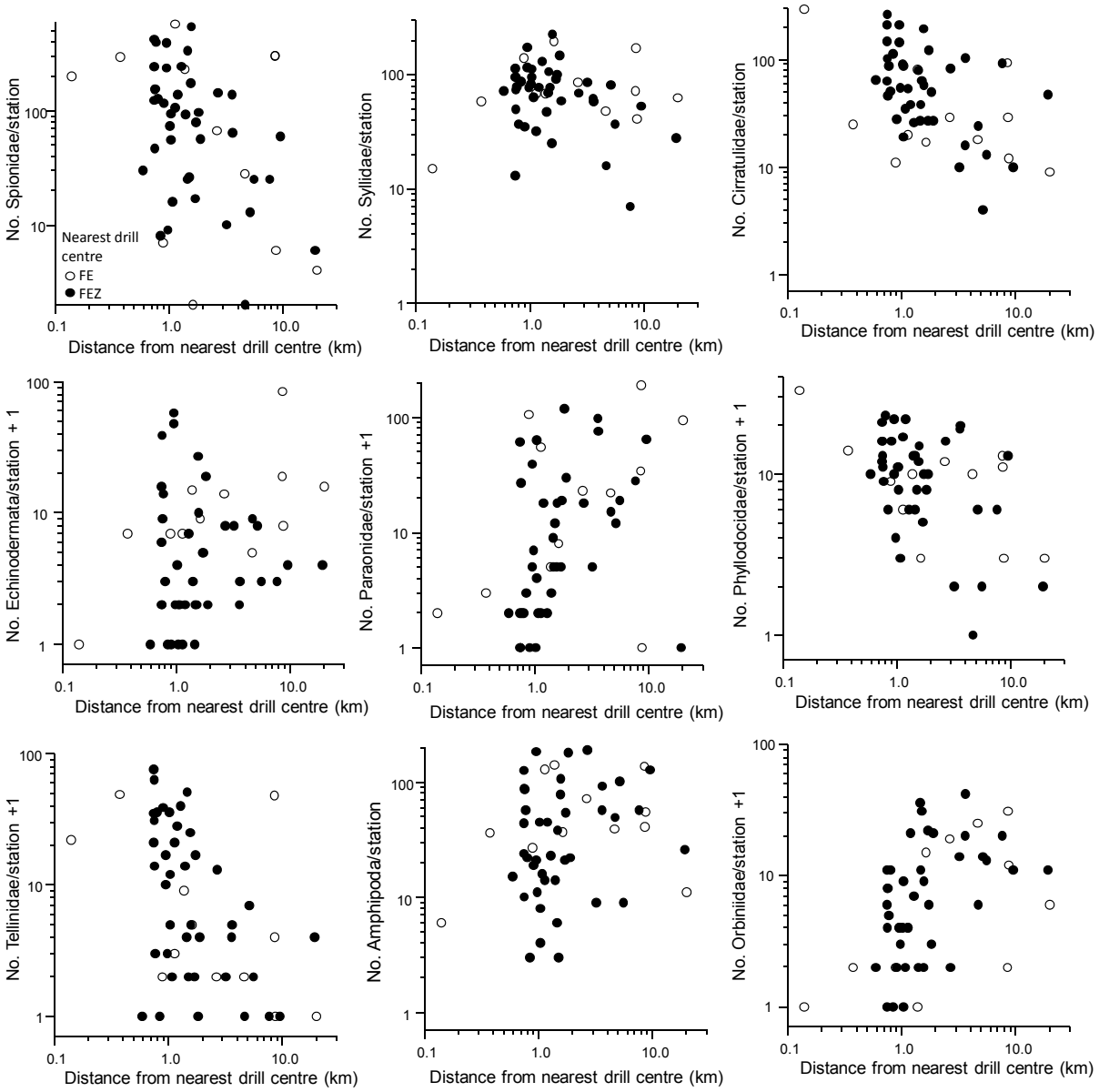


Figure 5-64 Distance Gradient for Major and Numerically Dominant Benthic Taxa (2014)

Across years, NMDS1 score correlations with Min *d* have generally been negative (Figure 5-65). Numbers of Spionidae, Phyllodocidae and Tellinidae have typically decreased with distance from drill centres across all sampling years, while numbers of Orbiniidae, Paraonidae and Echinodermata have increased with distance across all sampling years (Figure 5-66). NMDS2 scores have generally never correlated significantly with Min *d*, except in year 2000, when the relationship was positive (Figure 5-66).

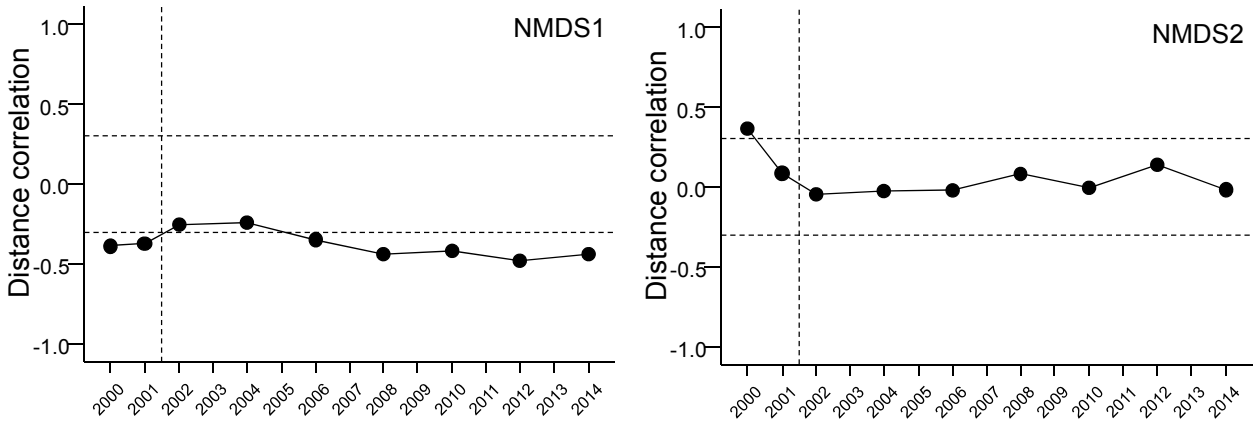


Figure 5-65 Annual Distance Correlations (r_s) for NMDS 1 and 2 (2000 to 2014)

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 2014.

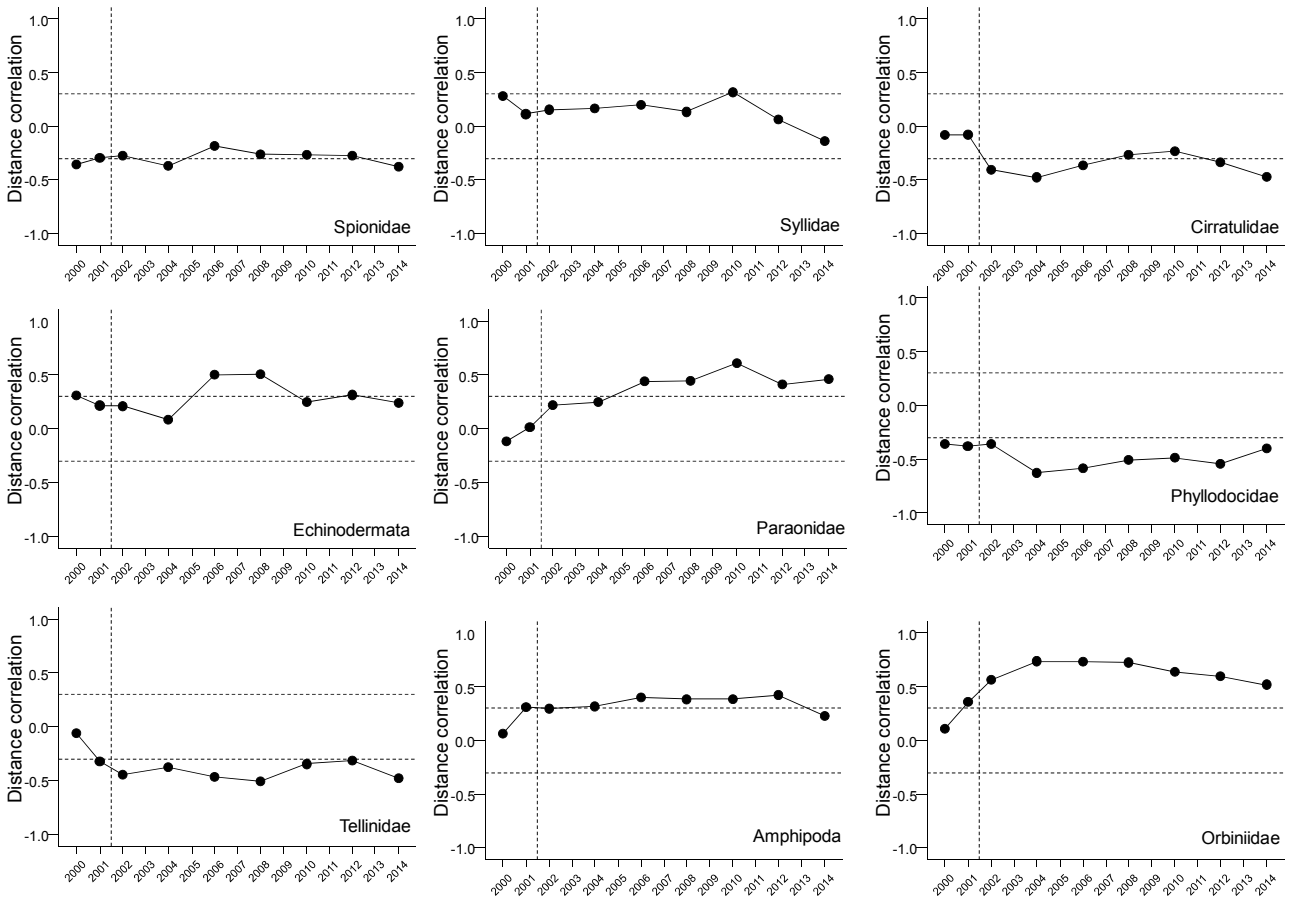


Figure 5-66 Annual Distance Correlations (r_s) for Major and Numerically Dominant Benthic Taxa (2000 to 2014)

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 2014.

Results of repeated-measures regression for NMDS scores are provided in Table 5-43. Carry-over effects were highly significant for NMDS1 (F = 13.6, $p \leq 0.001$). There was a significant overall FEZ regression slope (F = 15.5, $p \leq 0.01$), but slopes did not vary significantly among years. There was no significant overall FE regression slope. FE slopes changed over time (F = 10.0, $p \leq 0.01$), but these changes did not coincide with the start of drilling at the FE drill centre. FE regression slopes have generally been decreasing from positive to a negative slope in 2014 (Figure 5-67). Overall NMDS1 scores have varied over time (F = 31.6, $p \leq 0.001$; also see Figure 5-61), with scores generally lower in 2000 and 2014 and higher in the intervening years.

Table 5-43 Results (F Values) of Repeated-Measures Regressions Comparing NMDS 1 and 2 Among EEM Years (2001 to 2014)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After (2000 and 2001 vs 2002 to 2014)**	**Linear Trend 2002 to 2014**	**Quadratic Trend 2002 to 2014**
NMDS1					
FEZ *d*	**15.5*** **				
FE *d*	2.9				
Error 1 (Carry-over)	**13.6*** **				
Year		5.5	0.6	6.6*	**31.6*** **
Year x FEZ *d*		1.3	<0.1	1.4	3.3
Year x FE *d*		**4.8*** **	3.9	10.0**	2.0
NMDS2					
FEZ *d*	0.2				
FE *d*	0.6				
Error 1 (Carry-over)	**12.7*** **				
Year		1.5	4.6*	1.5	0.2
Year x FEZ *d*		2.1*	1.7	1.6	1.6
Year x FE *d*		1.0	0.2	0.4	0.7

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.

Carry-over effects also were highly significant for NMDS2 ($F = 12.7$, $p \leq 0.001$; Table 5-43). There were no significant overall FEZ or FE regression slopes for NMDS2. There were significant annual variations in FEZ regression slopes ($F = 2.1$, $p \leq 0.05$), with slopes more negative from 2004 to 2010 (Figure 5-67). There were no significant annual variations in FE regression slopes. Overall NMDS scores changed from 2000 and 2002 to later years ($F = 4.6$, $p \leq 0.05$), with scores marginally lower in later years.

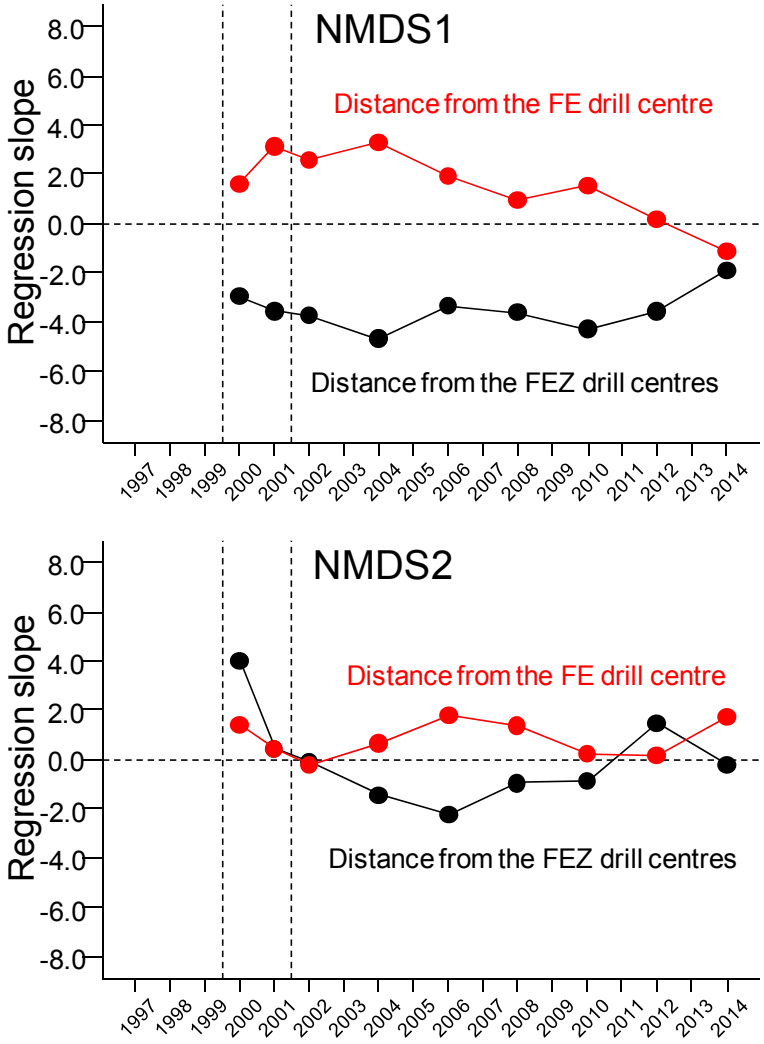


Figure 5-67 Annual Multiple Regression Distance Slopes for NMDS 1 and 2 (2000 to 2014)

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).

5.3.3.7 Integrated Assessment

Various analyses were used in the sections above to describe the bivariate 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 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 drilling muds.
- Metals PC1 was selected because it described the principal metals gradient.
- Sediment physical condition: Percent fines, gravel and TOC were selected because they collectively described the physical configuration and organic content of the sediments, factors that fundamentally influence benthic community composition.
- Microtox IC50 and laboratory amphipod survival were both selected to represent toxic and non-toxic sediments.
- 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 (logarithms for abundance, richness, biomass, Microtox toxicity, laboratory amphipod survival, barium, $>C_{10}$-C_{21} hydrocarbons, TOC, fines, gravel). The PCA was carried using all the data from 2000 to 2014 (i.e., 454 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 5-44. Correlations of magnitude >|0.6| were considered strongly associated with a PCA axis and are used to interpret the axes.

Table 5-44 Correlations (r_p) Between Core Sediment Variables and Principal Component Axis Station Scores (2000 to 2014)

Variable	Correlation with Principal Component Axis		
	1	2	3
Min *d*	-0.41	-0.45	-0.01
Abundance	**0.79**	-0.21	-0.12
Biomass	0.21	0.03	**0.66**
Richness	**0.82**	-0.48	0.06
Adjusted Richness	0.47	-0.56	0.26
NMDS1	**0.74**	0.30	0.08
NMDS2	-0.50	0.56	-0.08
Microtox	-0.50	0.16	0.41
Amphipod Survival	-0.05	0.14	0.54
Barium	**0.69**	0.50	0.09
>C10-C21 Hydrocarbons	**0.62**	**0.61**	0.23
Metals PC1	0.51	0.45	-0.26
TOC	**0.65**	-0.05	-0.19
Fines	**0.69**	0.14	-0.20
Gravel	**0.72**	-0.31	0.15
Variance Explained	35.50	15.54	8.15

The first PCA axis scores were strongly positively correlated with total abundance, taxa richness, NMDS1, barium concentrations, $>C_{10}$-C_{21} hydrocarbon concentrations, metals PC1, TOC content, % fines and % gravel.

The second PCA axis scores were strongly associated with $>C_{10}$-C_{21} hydrocarbon concentrations; the third PCA axis scores were strongly correlated with biomass. No other biological, physical, or chemical variables were strongly correlated with the second or third axes.

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 drilling muds. Percent of the sediment as gravel and fines are somewhat redundant with TOC. Therefore, gravel and fines were excluded and TOC was retained. Min *d* was excluded from this second step because it is redundant with barium and $>C_{10}$-C_{21} hydrocarbons. Metals PC1, amphipod survival and Microtox toxicity were not included because they did not indicate strong associations with any benthic measures.

In 2014, total benthic abundances and taxa richness were significantly positively correlated with barium, >C_{10}-C_{21} hydrocarbons and TOC (Figures 5-68 and 5-69). The positive relationships for abundance and richness with barium, >C_{10}-C_{21} hydrocarbons and TOC reflects that sediments with high concentrations of these compounds had high abundances and high taxa richness.

Biomass was positively associated with barium and >C_{10}-C_{21} hydrocarbons concentrations in 2014 (Figure 5-70). Like abundance and richness, higher biomass tended to co-occur in sediments with high concentrations of barium and >C_{10}-C_{21} hydrocarbons.

In 2014, adjusted richness values were correlated with TOC and barium concentrations (Figure 5-71).

Scatterplots of total abundance, richness (which is correlated with abundance) and biomass indicate a potential threshold at barium and >C_{10}-C_{21} hydrocarbon concentrations in excess of 2,000 and 400 mg/kg, respectively. However, there were very few observations where sediments contained these high concentrations (generally only station 30(FE) in some years).

NMDS1 scores were significantly positively associated with TOC, barium and >C_{10}-C_{21} hydrocarbon concentrations across all years (Figure 5-72). The relationship between NMDS1 scores and TOC, barium and hydrocarbons reflects higher abundances of Spionidae and Phyllodocidae polychaetes, Tellinidae bivalves, and lower abundances or Orbiniidae and Paraonidae polychaetes and other more minor taxa (e.g., Sphaerodoridae, Hesionidae, Nereidae, see Figure 5-62) in sediments with higher concentrations of those three analytes. The association between NMDS1 scores and TOC has generally been stronger than the association with the two drill mud indicators (Figure 5-72). However, since organic carbon was not visibly affected by project activity, the association may be natural and could indicate that like organic carbon, sediment fines content and many other variables, natural distance gradients existed for NMDS1 during baseline[24].

In 2014, NMDS2 scores (reflecting Cirratulidae dominance) were significantly and negatively correlated with sediment TOC contents, and uncorrelated with sediment barium and >C_{10}-C_{21} hydrocarbons concentrations (Figure 5-73).

[24]Baseline data are unavailable for benthic invertebrates.

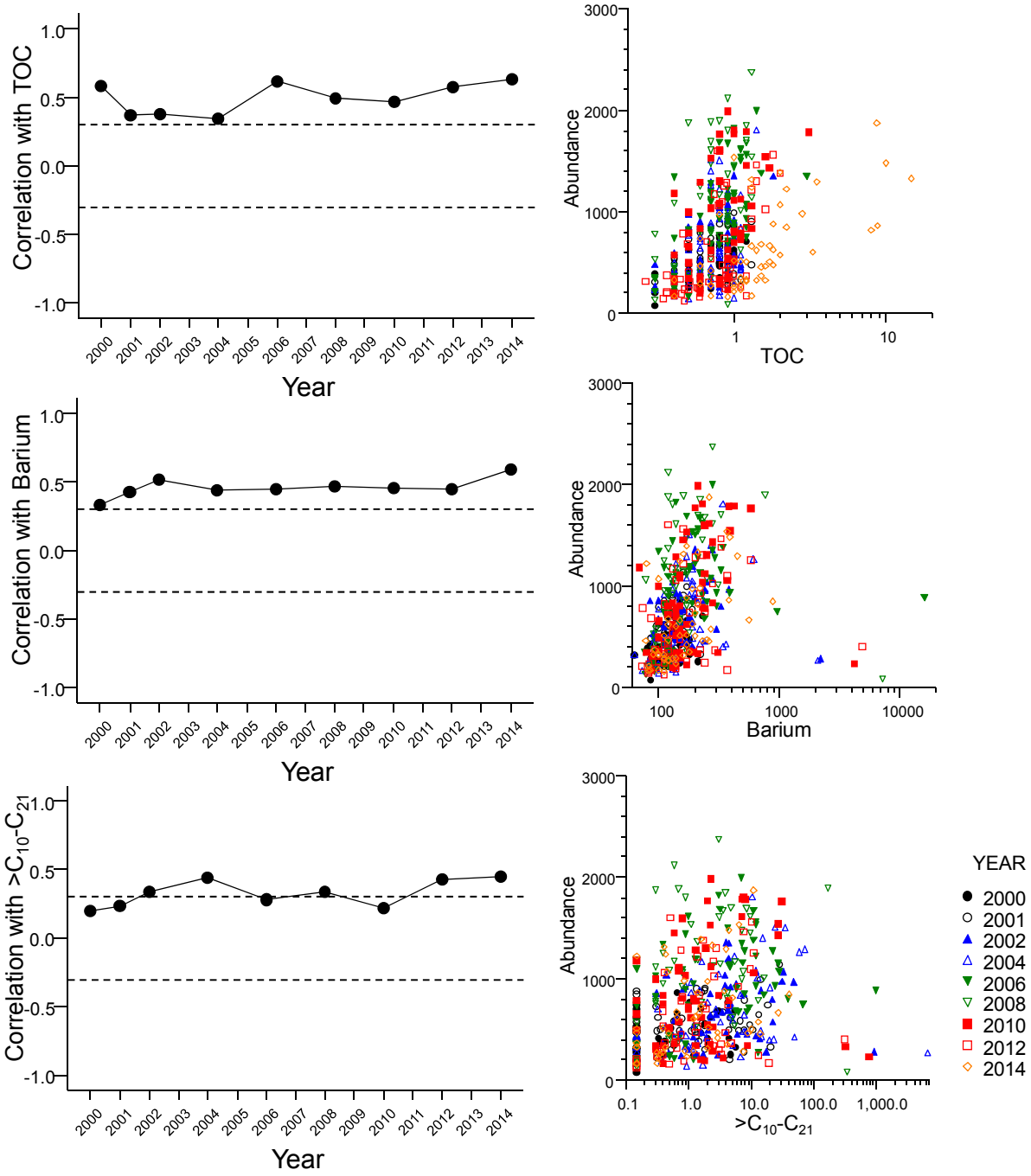


Figure 5-68 Correlations (r_s) Over Time and Scatterplots of Total Abundance in Relation to Total Organic Carbon, Barium and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dashed lines indicates $|r_s| = 0.3$, which is a significant correlation at $0.01 \leq p \leq 0.05$.

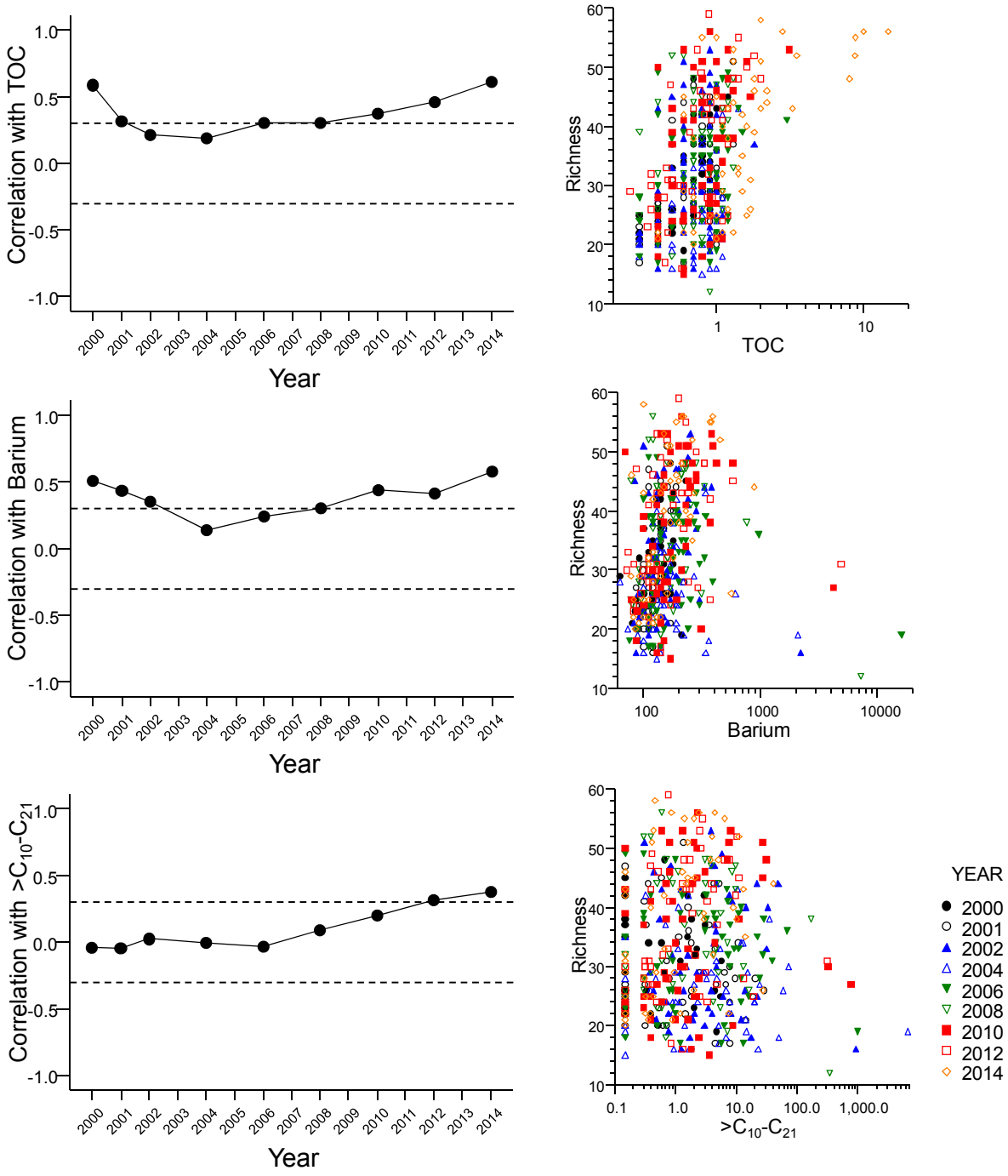


Figure 5-69 Correlations (r_s) Over Time and Scatterplots of Richness in Relation to Total Organic Carbon, Barium and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dashed lines indicates $|r_s| = 0.3$, which is a significant correlation at $0.01 \leq p \leq 0.05$.

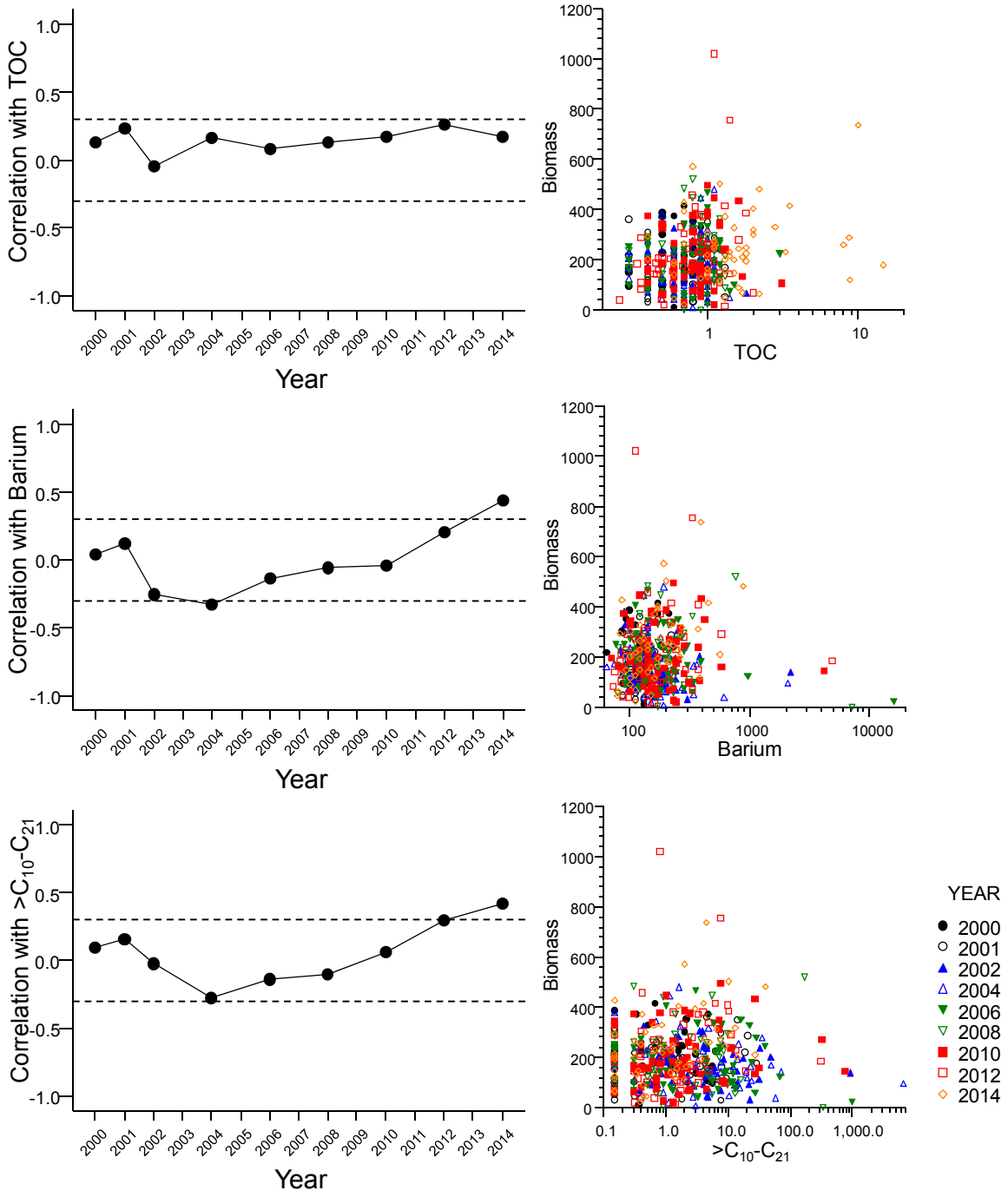


Figure 5-70 Correlations (r_s) Over Time and Scatterplots of Biomass in Relation to Total Organic Carbon, Barium and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dashed lines indicates $|r_s| = 0.3$, which is a significant correlation at $0.01 \leq p \leq 0.05$.

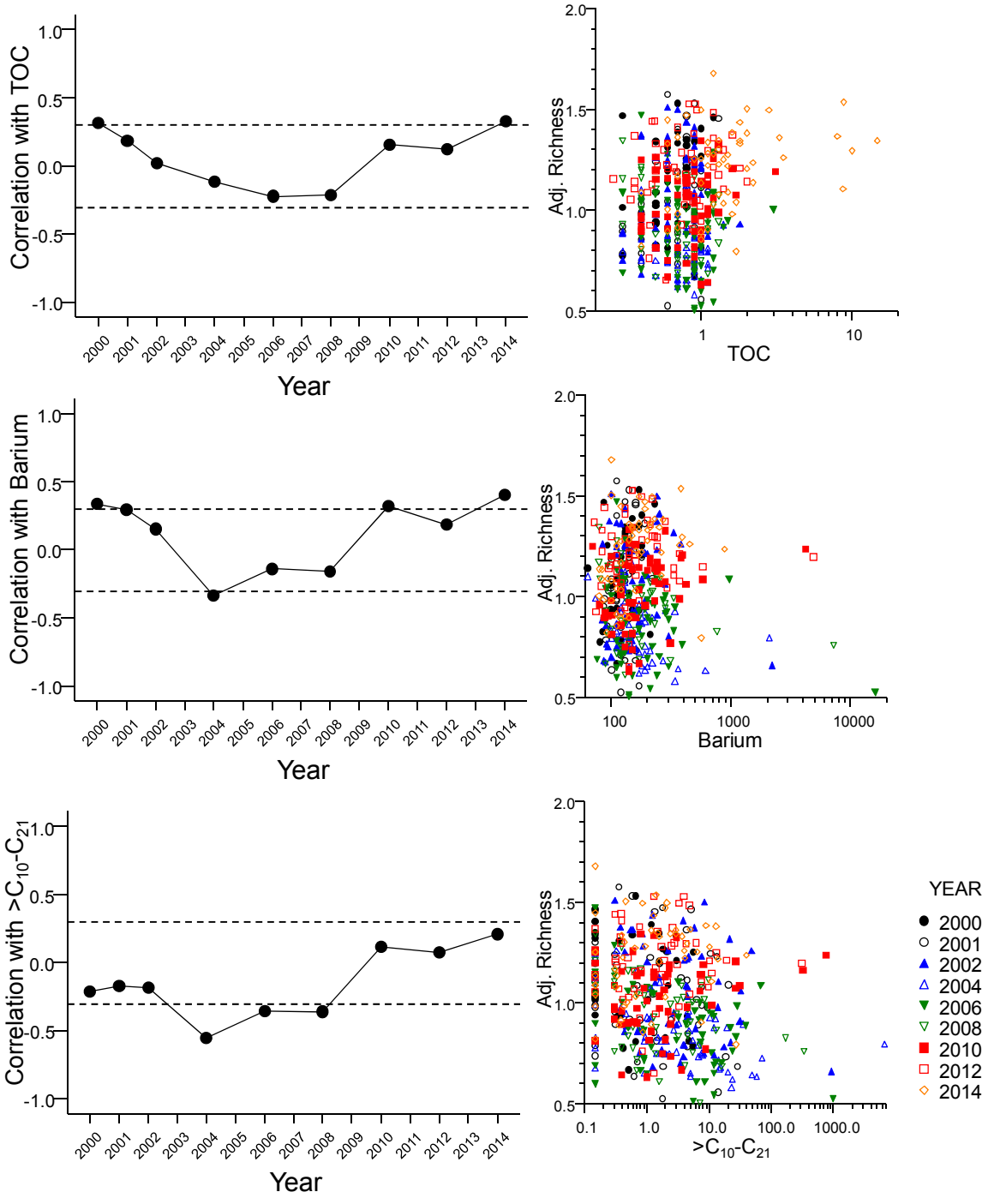


Figure 5-71 Correlations (r_s) Over Time and Scatterplots of Adjusted Richness in Relation to Total Organic Carbon, Barium and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dashed lines indicates $|r_s| = 0.3$, which is a significant correlation at $0.01 \leq p \leq 0.05$.

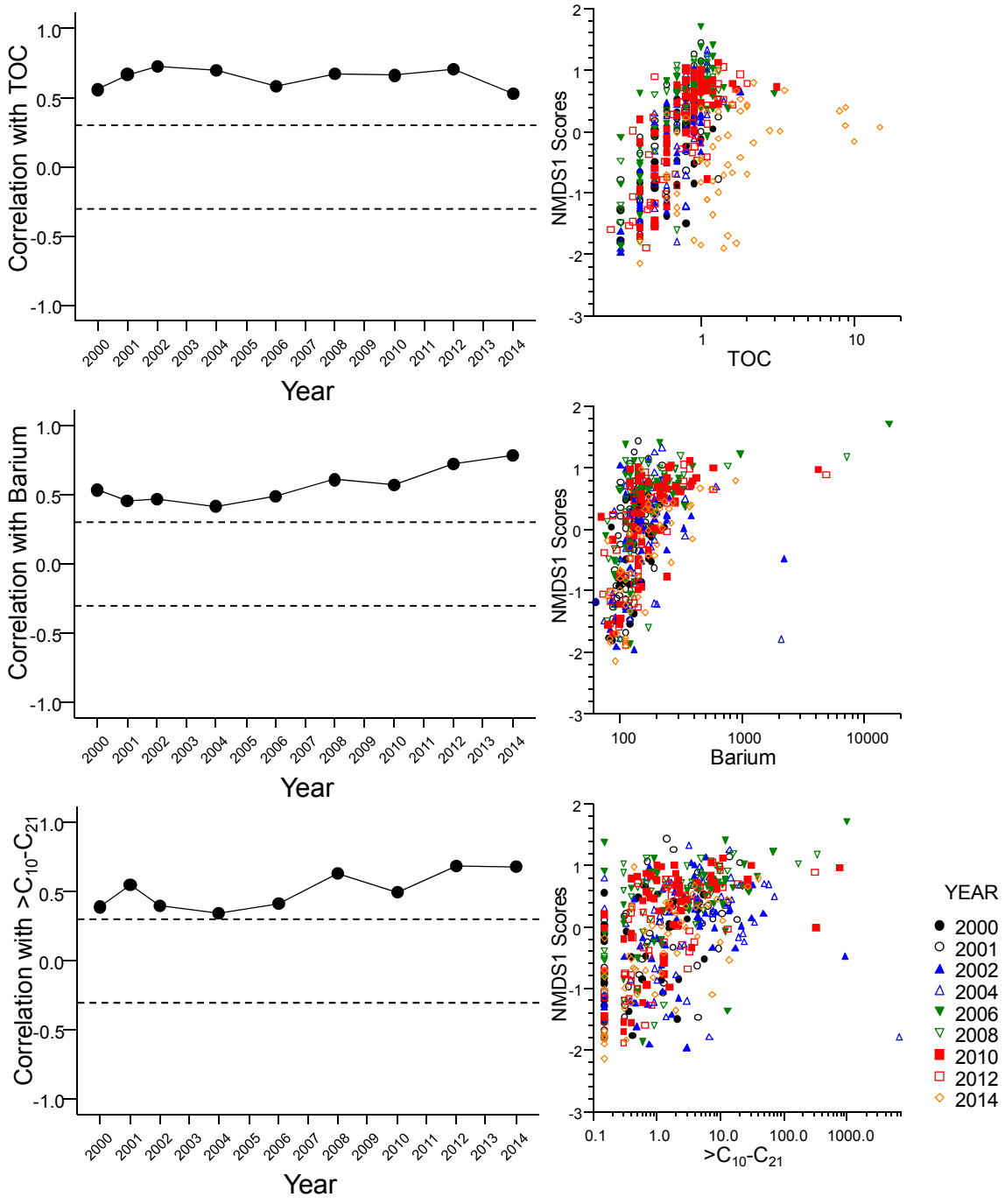


Figure 5-72 Correlations (r_s) Over Time and Scatterplots of NMDS1 Scores in Relation to Total Organic Carbon, Barium and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dashed lines indicates $|r_s| = 0.3$, which is a significant correlation at $0.01 \leq p \leq 0.05$.

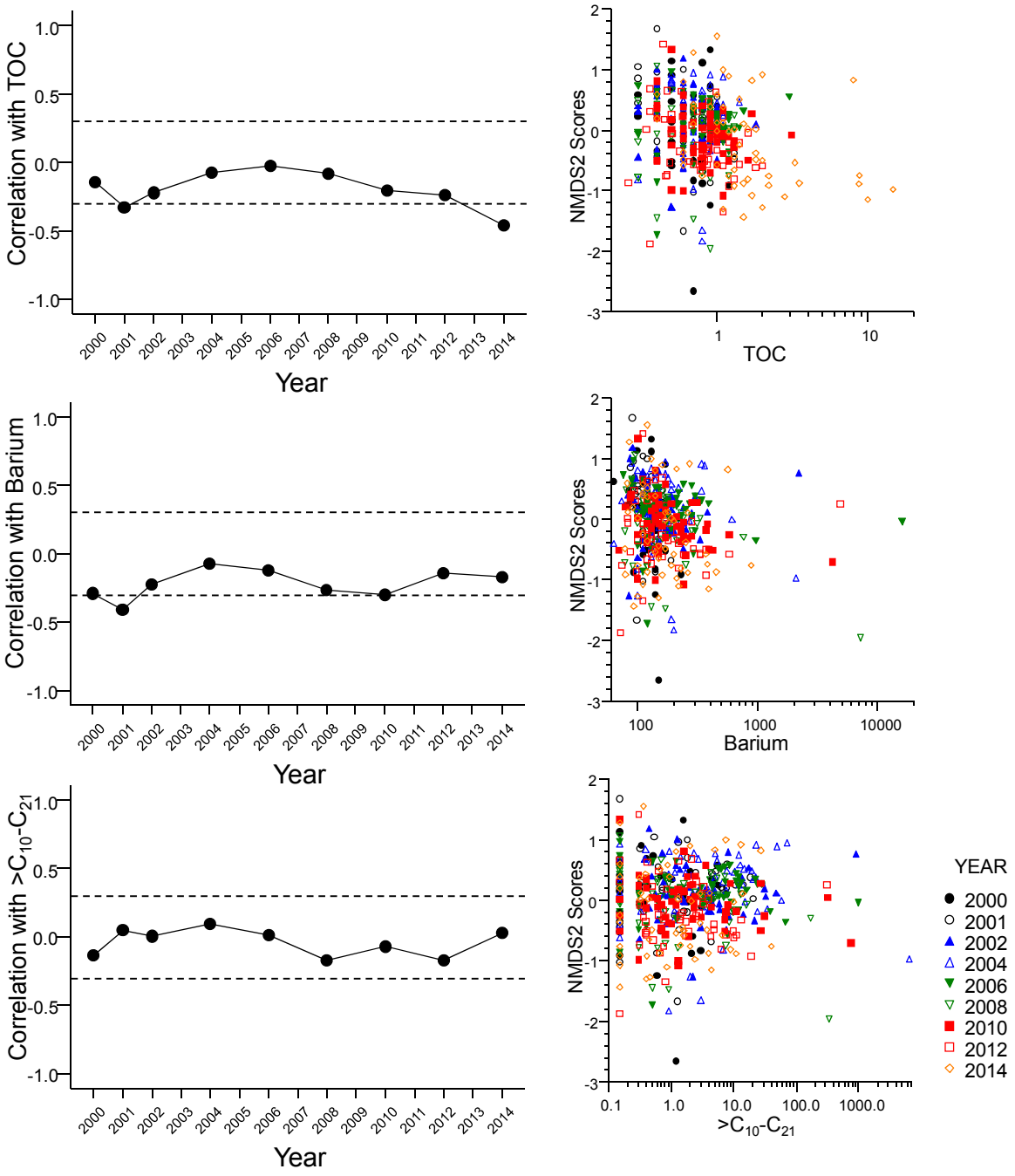


Figure 5-73 Correlations (r_s) Over Time and Scatterplots of NMDS2 Scores in Relation to Total Organic Carbon, Barium and >C_{10}-C_{21} Hydrocarbons

Note: The horizontal dashed lines indicates |rs| = 0.3, which is a significant correlation at 0.01 ≤ p ≤ 0.05.

5.4 SUMMARY OF RESULTS

5.4.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

>C_{10}-C_{21} hydrocarbon concentrations 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 1.40 mg/kg in 2008, to 1.30 mg/kg in 2010 and 2012, and to 1.20 mg/kg in 2014. 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. In 2014, the highest >C_{10}-C_{21} hydrocarbon concentrations (40 mg/kg) occurred at station 31(FE), located 0.37 km from the FE drill centre.

Median barium concentrations increased from 120 mg/kg in baseline (1997) to concentrations ranging from 130 to 170 mg/kg from 2000 to 2014. Median concentrations in EEM years have been below the 95th percentile concentration noted in baseline (200 mg/kg). Maximum barium concentrations from 2002 to 2012 (all greater than 2,000 mg/kg) occurred at station 30(FE). In 2014, the maximum barium concentration (880 mg/kg) occurred at station 31(FE).

In 2014, 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 (0.3 mg/kg) within approximately 4.5 km from drill centres. Concentrations of barium decreased to background levels within approximately 3 km of 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 for >C_{10}-C_{21} hydrocarbons were approximately 3 km from 2008 to 2012. The estimated threshold distance for barium was 3 km in 2014. Threshold distances of 1 to 2 km were noted for barium in most previous 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 generally decreased over time in EEM years. The slope of the relationships for sediment barium and distance from the FEZ drill centres did not change 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 (i.e., a reversal of regression slopes from positive to negative).

Fines content in 2014 ranged from 0.6% to 2.7% (median = 1.1%). Fines content during baseline (1997) ranged from 0.7% to 3.4% (median = 1.0%). The highest fines content in 2014 occurred at station 33(FEZ). The highest fines content (7.0%) over all EEM years occurred at station 44(FEZ) in 2008. Fines content decreased with distance from drill centres in every year, including baseline (1997). 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.

Sediment organic carbon concentration was higher than noted in previous years at seven stations in 2014, most likely because of a change in laboratory methods. There was no consistent spatial pattern in the distribution of these stations. Maxima for sediment sulphur, sulphide, % gravel and % fines also occurred at these stations. Over all stations, organic carbon content has generally decreased with increasing distance from drill centres (a relationship largely driven by increases in organic carbon content, and many other variables, toward the centre of the development). Looking at years individually (i.e., Spearman rank correlations by year), the negative relationship between sediment organic carbon content and distance from drill centres was strongest in baseline and in 2006. Across years, repeated-measures regression indicated that the negative relationship between sediment organic carbon content and distance from the FEZ drill centres weakly increased in strength from 2002 to 2012, and then decreased in strength in 2014. Repeated-measured regression indicated no change in the relationship between sediment organic carbon concentration and distance from the FE drill centre.

Sediment metals concentrations have been similar across years. Overall metals concentrations (i.e., metals PC1) generally decreased from the centre of the development in all years, with no change in the relationship over time.

Sediment ammonia concentrations were highest in 2000 (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, with no change in the slope of the relationships over time.

Sediment sulphur concentrations were generally less than 0.10 mg/kg since sulphur was first measured (in 2001). Sulphur has decreased with distance from drill centres with relationships weaker (and not significant) in 2008 and 2014.

Sediment sulphide concentrations have been measured at a consistent laboratory detection limit since 2006. Sulphide levels were highest in 2008 and lowest in 2014. Sulphides decreased significantly with distance from drill centres in both those years.

Sediment redox potential has varied over time, with lower levels in 2004 and 2008. Sediment redox potential increased with distance from drill centres in 2000 and 2014. In 2014, as in most previous years, all sediments were oxic (i.e., redox >100 mV). For most variables (fines, metals other than barium, organic carbon, sulphur, sulphide, redox), distance relationships from the FEZ drill centres (i.e., the centre of the development) were stronger than relationships from the FE drill centre.

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 2014, three samples were toxic to laboratory amphipods. Amphipod survival in 2014 was uncorrelated with distance from drill centres and all sediment physical and chemical characteristics. Sediment barium and $>C_{10}$-C_{21} hydrocarbon concentrations were not remarkably high in the three samples toxic to amphipods (barium levels were 220 mg/kg or less; $>C_{10}$-C_{21} hydrocarbon levels were 1.2 mg/kg or less). However, two of the three samples (stations 9(SE) and 22(NW)) had relatively high levels of TOC (2.8 and 3.3 mg/kg, respectively).

Sediments from 11 stations were toxic to Microtox in 2014. As in previous years, Microtox IC50s were not correlated with distance to drill centres. Microtox IC50s were negatively correlated with most sediment physical and chemical variables; and strontium and fines were the strongest correlates, as in previous years. There continues to be little indication of project effects on sediment strontium and fines concentrations.

5.4.3 BENTHIC COMMUNITY STRUCTURE

Total abundance decreased with distance from the nearest drill centre (i.e., was higher near drill centres) in 2014. This occurred in all previous years, and the relationship was also significant in 2004. Biomass was uncorrelated to distance to

the nearest drill centre in 2014, with data from station 33(FEZ) removed from analysis. The greatest biomass (more than 730 g/sample) occurred at station 33(FEZ). The barnacle *Balanus* and the mussel *Macoma*, both heavy shelled organisms, were both relatively abundant at that station. Biomass was correlated with distance to the nearest drill centre in 2004, with biomass increasing with distance from drill centres. Richness, adjusted richness and NMDS2 scores (Cirratulidae dominance) were uncorrelated with distances to the nearest drill centre in 2014, as in most previous years.

There was an overall decrease in abundance with distance from the FEZ drill centres in EEM years, but that gradient did not change over time. There was an overall increase in biomass with distance from the FE drill centre. That gradient changed over time, but those changes did not coincide with the onset of drilling at the FE drill centre. Distance gradients from the FE drill centre for biomass were strong in 2006 and have decreased in strength since then (i.e., distance effects are now weaker than in 2006). Distance gradients from the FEZ drill centres for richness and adjusted richness changed over time; with marginally higher richness near FEZ drill centres in 2000, 2012 and 2014. Distance gradients from the FEZ drill centres also changed over time for NMDS2 scores with slopes more negative from 2004 to 2010 (i.e., more pronounced Cirratulidae dominance near the FEZ drill centres in those years).

Any change in the above indices with distance to drill centres was subtle and/or not associated with the onset of drilling. The strongest correlations with distance measures were seen with NMDS1 scores. In a general sense, NMDS1 scores represent a contrast between the abundances of Spionidae, Phyllodocidae and Tellinidae versus the abundance of Syllidae, Orbiniidae and Paraonidae. The abundances of additional, less abundant, taxa (specifically - echinoderms) were also correlated with NMDS1 scores.

NMDS1 scores were strongly negatively associated with distance to the nearest drill centre in 2014, reflecting higher abundances of Spionidae, Phyllodocidae and Tellinidae, and lower abundances of Orbiniidae, Paraonidae and echinoderms nearer drill centres. NMDS1 scores were also relatively high at stations 30(FE) and 31(FE), the two stations nearest a drill centre. Most of the other indices were not visibly affected at stations 30(FE) and 31(FE) in 2014. However, adjusted richness was lowest at station 30(FE).

Across years, NMDS1 scores have generally been negatively correlated with distance to the nearest drill centre. The overall distance gradient from the FEZ drill

centre has been strong; the overall distance gradient from the FE drill centre has been weak (and not significant). Repeated-measures regression indicates no change in distance gradients from the FEZ drill centres over time. However, there was a change in distance gradients from the FE drill centre, with positive slopes decreasing in strength and becoming negative in 2014. As in previous years, threshold relationships were not apparent for NMDS1 (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 and richness and sediment TOC and barium and, in most years, $>C_{10}$-C_{21} hydrocarbon concentrations have been significant and positive, indicating higher total abundance and richness in sediments with higher TOC, barium and $>C_{10}$-C_{21} hydrocarbon concentrations.

NMDS1 scores were significantly positively associated with TOC, barium and $>C_{10}$-C_{21} hydrocarbon concentrations in all years. The relationship between NMDS1 scores and barium and $>C_{10}$-C_{21} hydrocarbons reflects higher abundances of Spionidae and Phyllodocidae polychaetes and Tellinidae bivalves, and lower abundances of Orbiniidae and Paraonidae polychaetes and other more minor taxa in sediments with higher concentrations of organic carbon, barium and $>C_{10}$-C_{21} hydrocarbons.

Since TOC 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 TOC, barium and $>C_{10}$-C_{21} hydrocarbons have generally been weak and inconsistent. Nevertheless, correlations between biomass and sediment barium and $>C_{10}$-C_{21} hydrocarbons were significant in 2014; correlations between adjusted richness and sediment TOC and barium concentrations were significant. These correlations indicate that higher biomass co-occurred with higher concentrations of sediment barium and $>C_{10}$-C_{21} hydrocarbons; and higher values of adjusted richness co-occurred with higher concentrations of TOC and barium in 2014.

Scatter plots of data for all years indicated potential negative effects on total abundance, richness, biomass and adjusted richness at barium concentrations in excess of approximately 2,000 mg/kg and >C_{10}-C_{21} concentrations in excess of approximately 400 mg/kg. These high concentrations have only ever occurred at one station (station 30(FE), located 0.14 km from the FE drill centre).

6.0 WATER COMPONENT

6.1 FIELD COLLECTION

The water sampling component of the 2014 EEM Program was conducted in conjunction with the sediment sampling component of the program. Details on collections dates are provided in Section 5.1. Water collection stations for the 2014 program are shown in Figure 1-10 (Section 1). Geographic coordinates, distance to drill centres and distance to the FPSO are provided in Appendix C-1.

Water samples were collected at 10 m below surface, at 40 m and at 10 m above bottom using a string of three Teflon-lined, 10 L Niskin-X water samplers (Figure 6-1). All stations were sampled for physical and chemical characteristics and phytoplankton pigment concentrations. Groups or specific compounds analyzed included PAHs and alkyl PAHs, total petroleum hydrocarbons, trace metals, total suspended solids and chlorophyll *a* and phaeophytin *a* pigments. Samples were stored at 4°C or frozen as detailed in Table 6-1.

Figure 6-1 Niskin Bottle Water Samplers

Table 6-1 Water Sample Storage Containers

Analysis	Storage Container	Preservative Description and Comments	Storage Temperature	Holding Time
PAHs and Alkyl PAHs	1 – 1L amber glass bottle	Fill to the neck and cap	4°C	7 days
Total Petroleum Hydrocarbons	2 - 250 ml clear glass bottles 2 - 40 ml glass vials	Sodium bisulphate (both containers) – fill to neck of bottle and cap	4°C	28 days
Mercury	1 - 100 ml amber glass	$K_2Cr_2O_7$ in 17% HNO_3. Be careful not to overfill	4°C	28 days
Trace Metals	250 ml plastic bottles	No preservative	4°C	6 months
Total Suspended Solids	1 L plastic bottles	No preservative required, fill to top	4°C	7 days
Chlorophyll *a* and Phaeophytin*a*	GF/F filters (1L samples)	Each filter pad is fixed with 20 ml magnesium carbonate, wrapped in foil, placed in a petri-dish and stored in a dark area	-20°C	unlimited

A Conductivity Temperature Depth (CTD) recorder cast was performed at each water quality stations to obtain depth, pH, temperature, conductivity, salinity, dissolved oxygen and chlorophyll *a* profiles.

The following QA/QC protocols were implemented for collection of samples. Field blanks for PAHs and alkyl PAHs, total petroleum hydrocarbons and metals made up of distilled water were collected at stations W2 (Surface), W2 (Bottom), W16 (Bottom) and W24 (Surface). Blank vials were opened as soon as water samples from these locations were brought onboard and remained opened until chemistry samples from these locations were processed. Blank vials were then sealed and stored with the remainder of chemistry samples. Field replicates were collected at stations W1 (Surface), W2 (Surface), W5 (Surface), W9 (Bottom) and W14 (Middle).

All instruments and work surfaces used for sampling were cleaned between stations prior to collecting samples. The cleaning process consisted of first washing with mild soap and water, then disinfecting with isopropyl alcohol, and finally rinsing with distilled water. Sampling personnel were supplied with new latex gloves for each station. Processed samples were transferred to cold storage within one hour of collection and then shipped to the analytical laboratory within one week of collection.

6.2 LABORATORY ANALYSIS

Organic constituents in water samples were processed by RPC in New Brunswick. Remaining constituents were processed by Maxxam Analytics in Nova Scotia. In accordance with Suncor Energy's revised water quality program (Suncor Energy 2012), seawater samples were processed for additional constituents in 2012 and 2014. A list of specific constituents in 2014 and in previous years is provided in Table 6-2. Details on analytical methods in 2014 are provided in Appendix C-2.

6.3 DATA ANALYSIS

6.3.1 PHYSICAL AND CHEMICAL CHARACTERISTICS FROM NISKIN BOTTLES

Analysis of 2014 physical and chemical characteristics from Niskin bottle samples included quantitative analysis of analytes that were frequently detected (analytes detected in 60% or more of samples) and qualitative examination of analytes that occurred infrequently (in 20% to 59% of samples). Remaining analytes are briefly discussed. The 2014 assessment also includes an examination of extreme high or low values in individual seawater samples relative to concentration of produced water constituents.

Comparisons across years were made for arsenic, iron and total suspended solids, the only three analytes that have been frequently detected in all years.

In 2014, as in 2012, the Study Area for water sampling at Terra Nova included sample collection inside the FEZ, within approximately 0.3 km of the FPSO, and at stations located outside the FEZ, near drill centres. Therefore, the Terra Nova Study Area was divided into two Study Areas, within and outside the FEZ (see Figure 1-10, Section 1 and Appendix C-1). The Southwest (SW) and Southeast (SE) Reference Areas sampled in previous years were again sampled in 2014.

Boxplots of analytes that occurred above laboratory detection limit in 60% or more of samples were generated for each Area. Values below detection limit were set to ½ detection limit for plotting.

Table 6-2 Water Chemistry Analytes (1997 to 2014)

Analytes	Method	Detection Limit									Units
		1997	2000	2001	2002	2004	2006 & 2008	2010	2012	2014	
Benzene	P&T GC/MS	NA	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	mg/L
Toluene	P&T GC/MS	NA	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	mg/L
Ethylbenzene	P&T GC/MS	NA	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	mg/L
Xylenes	P&T GC/MS	NA	0.002	0.002	0.002	0.002	0.002	0.002	0.001	0.001	mg/L
C_6-C_{10}(Less BTEX)	Calculated	NA	0.25	0.25	0.01	0.01	0.01	0.01	0.01	0.01	mg/L
>C_{10}-C_{21}	GC/FID	NA	0.05	0.05	NA	0.05	0.05	0.05	NA	NA	mg/L
>C_{10}-C_{13}	GC/FID	NA	NA	NA	0.05	NA	NA	NA	NA	NA	mg/L
>C_{13}-C_{21}	GC/FID	NA	NA	NA	0.05	NA	NA	NA	NA	NA	mg/L
>C_{10}-C_{16}	GC/FID	NA	NA	NA	0.05	NA	NA	NA	0.05	0.05	mg/L
>C_{16}-C_{21}	GC/FIC	NA	NA	NA	0.05	NA	NA	NA	0.05	0.05	mg/L
>C_{21}-C_{32}	GC/FID	NA	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	mg/L
C_6-C_{32}	Calculated	NA	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	mg/L
Oil & Grease	IR, FTIR	1	0.1	0.2	0.2	0.5	0.5	2	NA	NA	mg/L
Vegetable Oil & Grease	IR	1	NA	NA	NA	NA	NA	NA	NA	NA	mg/L
Mineral Oil & Grease	IR	1	NA	NA	NA	NA	NA	NA	NA	NA	mg/L
1-Chloronaphthalene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.05	0.05	0.05	0.05	µg/L
2-Chloronaphthalene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.05	0.05	0.05	0.05	µg/L
1-Methylnaphthalene	GC/FID	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	µg/L
2-Methylnaphthalene	GC/FID	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	µg/L
Acenaphthene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Acenaphthylene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Anthracene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Benz[*a*]anthracene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Benzo[*a*]pyrene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Benzo[e]pyrene	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.01	0.01	µg/L
Benzo[*b*]fluoranthene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Benzo[*ghi*]perylene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Benzo[*k*]fluoranthene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Chrysene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Dibenz[*a,h*]anthracene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Fluoranthene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Fluorene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Indeno[1,2,3-*cd*]pyrene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Naphthalene	GC/FID	0.05	0.2	0.2	0.2	0.2	0.2	0.2	0.05	0.05	µg/L
Perylene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L

Analytes	Method	Detection Limit									Units
		1997	2000	2001	2002	2004	2006 & 2008	2010	2012	2014	
Phenanthrene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Pyrene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Biphenyl	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.05	0.05	µg/L
C1-Naphthalenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	µg/L
C2-Naphthalenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	µg/L
C3-Naphthalenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	µg/L
C1-Phenanthrenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	µg/L
C2-Phenanthrenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	µg/L
C3-Phenanthrenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	µg/L
Dibenzothiophene	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	µg/L
C1-Dibenzothiophenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	µg/L
C2-Dibenzothiophenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	µg/L
C3-Dibenzothiophenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	0.1	µg/L
Aluminum	ICP-MS	NA	NA	NA	NA	NA	NA	NA	10	10	µg/L
Antimony	ICP-MS	NA	NA	NA	NA	NA	NA	NA	0.5	0.5	µg/L
Arsenic	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.5	µg/L
Barium	ICP-MS	NA	NA	50	NA	NA	NA	NA	1	1	µg/L
Beryllium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	1	µg/L
Bismuth	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	1	µg/L
Boron	ICP-MS	NA	NA	NA	NA	NA	NA	NA	50	50	µg/L
Cadmium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.05	µg/L
Calcium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	1	mg/L
Chromium	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	µg/L
Cobalt	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	µg/L
Copper	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.5	µg/L
Iron	ICP-MS	1	1	1	1	1	1	1	2	2	µg/L
Lead	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	µg/L
Lithium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	20	20	µg/L
Magnesium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	1	mg/L
Manganese	ICP-MS	1	1	1	1	1	1	1	0.5	0.5	µg/L
Mercury	CVAAS	0.05	0.05	0.05	0.05	0.05	0.01	0.013	0.013	0.013	µg/L
Molybdenum	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	1	µg/L
Nickel	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.2	0.2	µg/L
Phosphorous	ICP-MS	NA	NA	NA	NA	NA	NA	NA	50	50	µg/L

Analytes	Method	Detection Limit									Units
		1997	2000	2001	2002	2004	2006 & 2008	2010	2012	2014	
Potassium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	1	mg/L
Selenium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	0.5	0.5	µg/L
Silicon	ICP-MS	NA	NA	NA	NA	NA	NA	NA	100	100	µg/L
Silver	ICP-MS	NA	NA	NA	NA	NA	NA	NA	0.05	0.05	µg/L
Sodium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	1	mg/L
Strontium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	10	10	µg/L
Sulphur	ICP-MS	NA	NA	NA	NA	NA	NA	NA	20	20	mg/L
Thallium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	0.10	0.10	µg/L
Tin	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1.0	1.0	µg/L
Titanium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	10	10	µg/L
Uranium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	0.05	0.05	µg/L
Vanadium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	10	10	µg/L
Zinc	ICP-MS	1	1	1	1	1	1	1	1	1	µg/L
Phaeophytin *a*	Fluorescence	NA	0.1	0.1	0.1	0.1	0.005	0.005	0.0004	0.5	µg/L
Chlorophyll *a*	Fluorescence	NA	0.1	0.1	0.1	0.1	0.01	0.01	0.0004	0.5	µg/L
Total suspended solids	Grav.	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/L

Notes:
- The detection limit is the lowest concentration that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions. Detection limits may vary from year to year because instruments are regularly checked for precision and accuracy as part of QA/QC procedures.
- NA = Not Analyzed.
- Phaeophytin and chlorophyll detection limits are for Niskin bottle samples.

Analysis of variance (ANOVA), with depth as a covariable, was used to test for significant differences in concentrations of frequently detected analytes among Areas. Areas were (1) Inside the FEZ; (2) outside the FEZ; (3) SE Reference Area; and (4) SW Reference Area. If variations among Areas were significant then the following contrasts were evaluated:

- Differences in concentration between the mean of the Study Areas (Inside the FEZ, Outsize the FEZ) and the mean of the Reference Areas (SE Reference, SW Reference) (i.e., SR);
- Differences in concentration between the two Reference Areas (BR);
- Differences in concentration between the mean inside the FEZ and the mean of the Reference Areas (i.e., IFEZ *vs* R);
- Differences in concentration between the mean outside the FEZ and the mean of the Reference Areas (i.e., OFEZ *vs* R).

In each of the contrasts, variations among stations within areas were used to judge the significance of variations among Areas.

Analytes that had values less than the laboratory detection limit were rank transformed before ANOVA. Rank transformation treats values below detection limit as tied for the lowest rank. Remaining variables were $\log_{10}$ transformed.

For variables that occurred in 20% to 59% of samples, frequencies of detection (percent occurrence) at stations inside the FEZ, at stations outside the FEZ and in the combined Reference Areas were qualitatively compared.

Finally, the concentrations of produced water constituents were compared to chemical concentrations in seawater from Reference Area stations to generate an estimate of expected enrichment, or depletion, of specific produced water compounds in seawater. Individual stations were then examined for produced water constituents with expected concentrations on release of more than, or less than, 10 times seawater concentrations (i.e., those constituents that could act as markers for produced water in seawater samples). The concentration of produced water constituents was obtained from a produced water chemical characterization performed on samples collected on October 18, 2014.

Arsenic, iron and total suspended solids were the only analytes detected in all years. Variations over time in concentration of these analytes were examined graphically. The comparisons across years were made between the depth averaged values for the combined Study Areas (as there was just one Study Area in previous years) and

depth averaged values for the combined Reference Areas. For 1997, because samples were not collected in defined Study and Reference Areas, the 24 stations sampled nearer the centre of the development were considered to be in the Study Area, and the six remaining stations were considered to be in the Reference Areas.

6.3.2 PIGMENTS AND TEMPERATURE PROFILES

The majority of the pigment concentrations from the Niskin bottle samplers were below the laboratory detection limit of 0.5 µg/L (see Appendix C-2), and data analysis was not warranted.

Temperature and chlorophyll *a* concentration versus depth obtained from the CTD recorder in 2014 were plotted for a visual inspection of the data. Chlorophyll *a* values were then grouped into the following depth classes: 5 to 30 m (surface); 31 to 60 m (middle); and 61 to 100 m (bottom). Data from the first 5 m of the water column were excluded because erroneous results are common at those shallow depths. Data from station W10 were excluded because of erroneous results.

Boxplots of chlorophyll *a* values by depth class were generated for stations inside the FEZ, outside the FEZ and in the two Reference Areas. Data were then compared quantitatively in ANOVA as described in Section 6.3.1.

Multi-year comparisons examined changes in median temperature and chlorophyll *a* concentrations in the three depth classes across years in the combined Study Areas and the combined Reference Areas. Data from 1997 were excluded from these multi-year comparisons because few (5 versus the current 24) CTD casts were performed at stations that have been retained in the EEM program.

6.4 RESULTS

6.4.1 PHYSICAL AND CHEMICAL CHARACTERISTICS FROM NISKIN BOTTLES

Summary statistics for physical and chemical characteristics of water samples collected with Niskin bottles from 1997 to 2014 are provided in Appendix C-2. Arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, nickel, potassium, sodium, strontium, sulphur and uranium were detected in all samples. Suspended solids and iron were detected in 93% and 64% of samples, respectively. These variables were analyzed quantitatively. Manganese, silicon and zinc were detected in approximately 20% to 45% of samples and were examined qualitatively.

Remaining constituents were rarely or never detected. Chromium was detected in 15% of samples; in 10 (of 48) samples from the Study Areas and one (of 24) sample from the Reference Areas. Mercury was detected in 13% of samples; in two samples from the Study Areas and five samples from the Reference Areas. Cadmium was detected in 10% of samples; in three samples from the Study Areas and four samples from the Reference Areas. Lead was detected in 8% of samples; in one sample from the Study Areas and five samples from the Reference Areas. Cobalt was detected in 6% of samples; in one sample from the Study Areas and three samples from the Reference Areas. Copper was detected in 3% of samples; in two samples from the Study Areas. Phosphorous was detected in 1% of samples; in one sample from the Study Areas. Hydrocarbons, BTEX and PAHs were not detected in water samples.

6.4.1.1 Frequently Detected Variables

Arsenic, barium, potassium, strontium and sulphur varied across depths, in both Areas (Figure 6-2, Table 6-3). Concentrations of boron, iron, nickel, potassium, sodium and strontium differed among Areas (Table 6-3). However, none of the contrasts tested for strontium showed a significant difference. The Area difference for strontium was most likely between the stations inside the FEZ and the SW Reference Area (see Figure 6-2). That contrast is not tested because it does not fully take into account background variability (i.e., both Reference Areas). Study versus Reference contrasts were significant for remaining analytes (boron, iron, nickel, potassium and sodium). Median iron, nickel[25], potassium and sodium levels were 45%, 81%, 4% and 8% lower, respectively, in the Study Areas than in the Reference Areas; and the median boron level was 12% lower in the Reference Areas than in the Study Areas.

[25] Calculation of medians for nickel excluded a statistical outlier noted in the bottom sample at station W16. This sample is discussed in greater detail below.

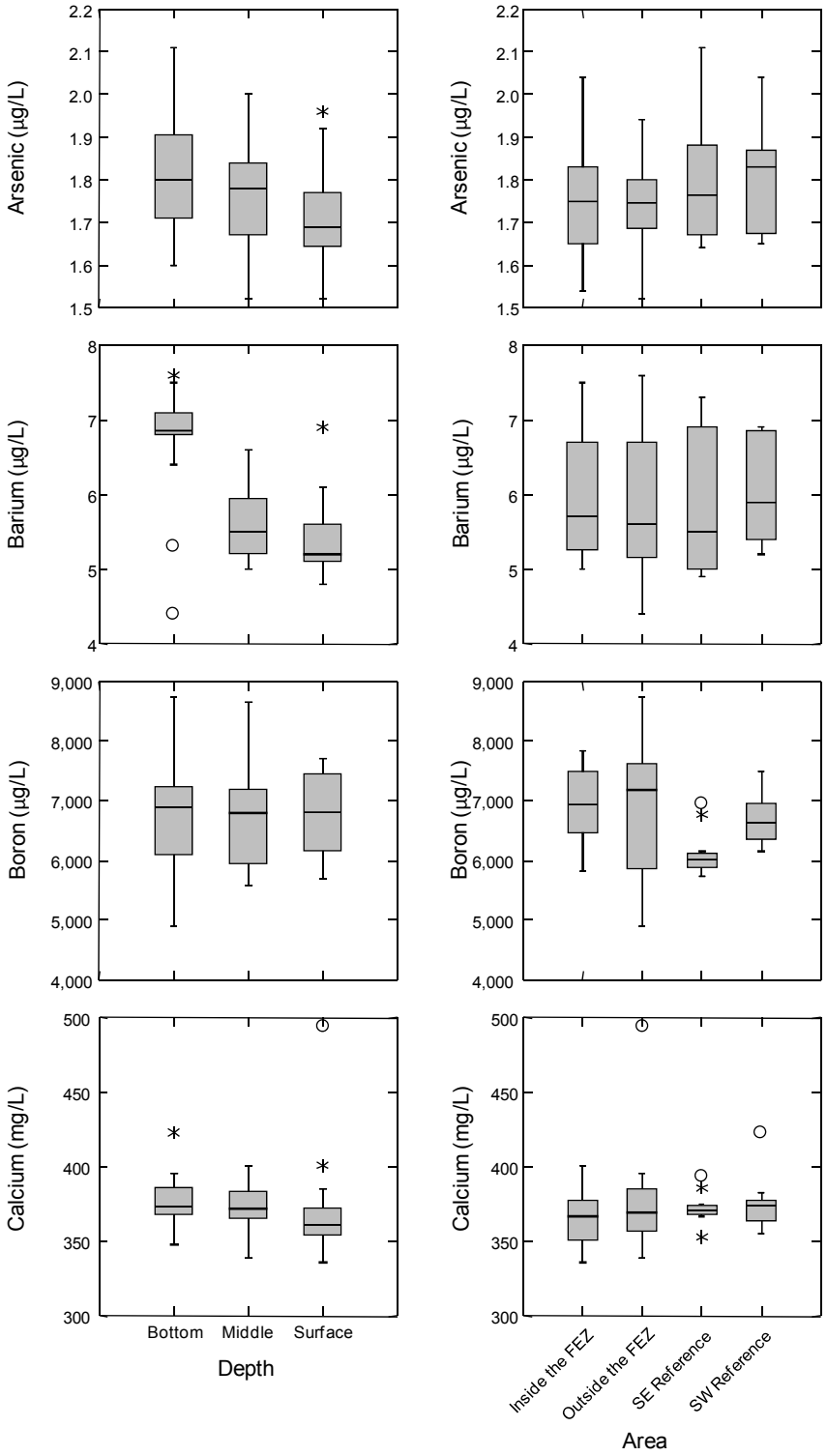


Figure 6-2 Boxplots of Frequently Detected Variables (2014)

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

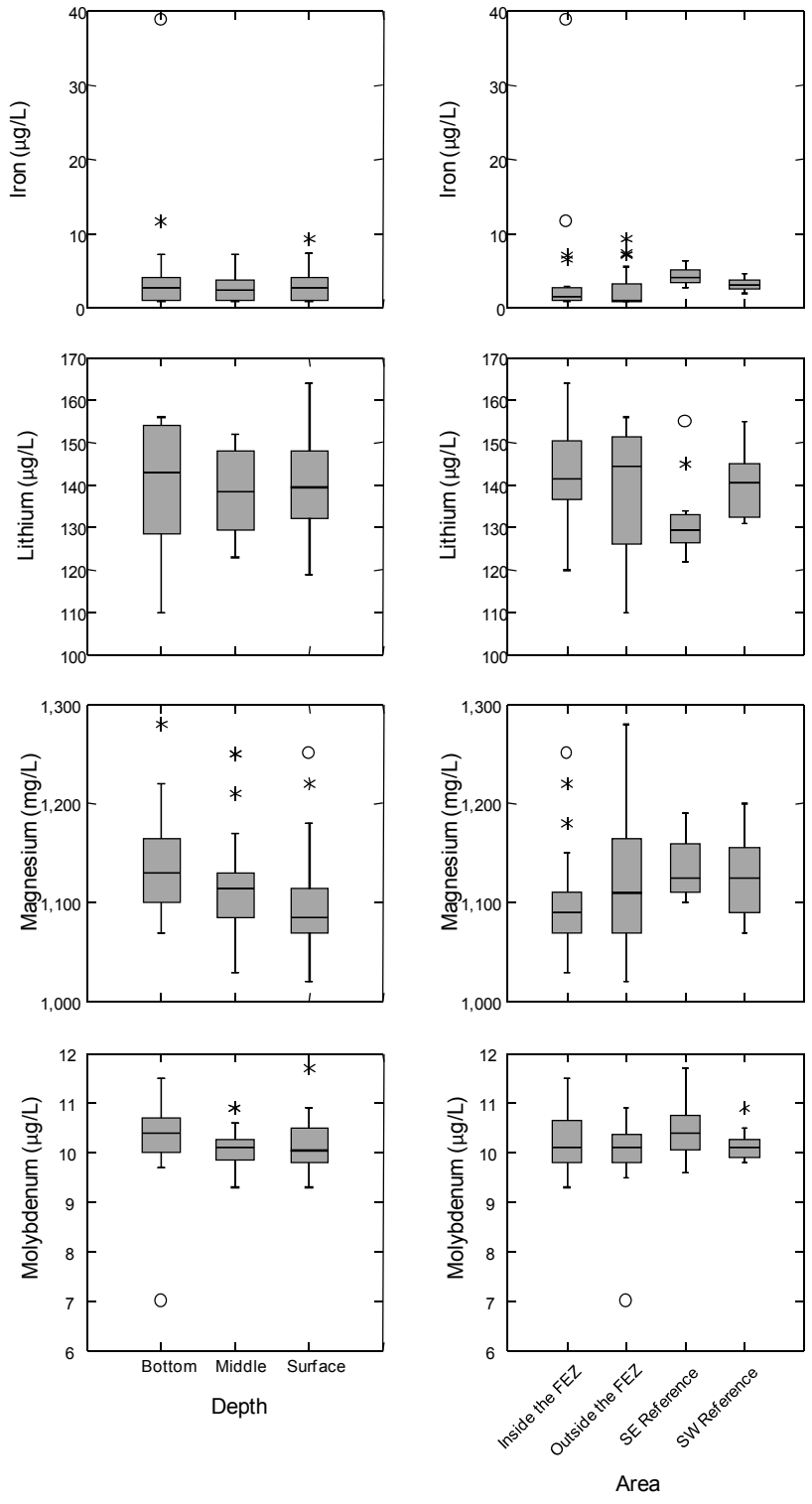


Figure 6-2 (cont.) Boxplots of Frequently Detected Variables (2014)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ±1.5 x interquartile spread. Asterisks indicate values falling within the quartile ±3 x interquartile spread. Open circles indicate values falling outside the quartile ±3 x interquartile spread. Values below detection limit for iron were set to ½ detection limit for plotting purposes only.

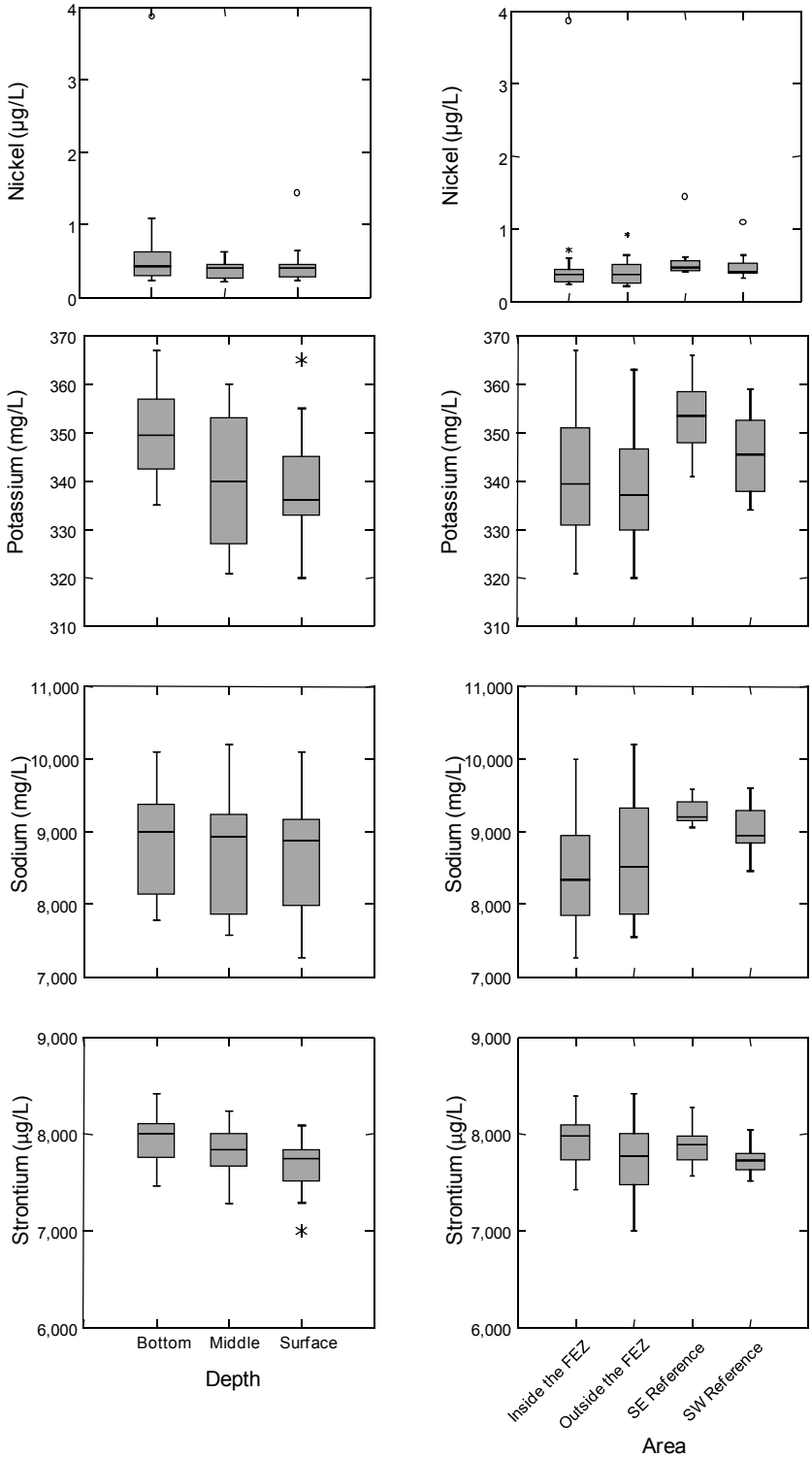


Figure 6-2 (cont.) Boxplots of Frequently Detected Variables (2014)

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

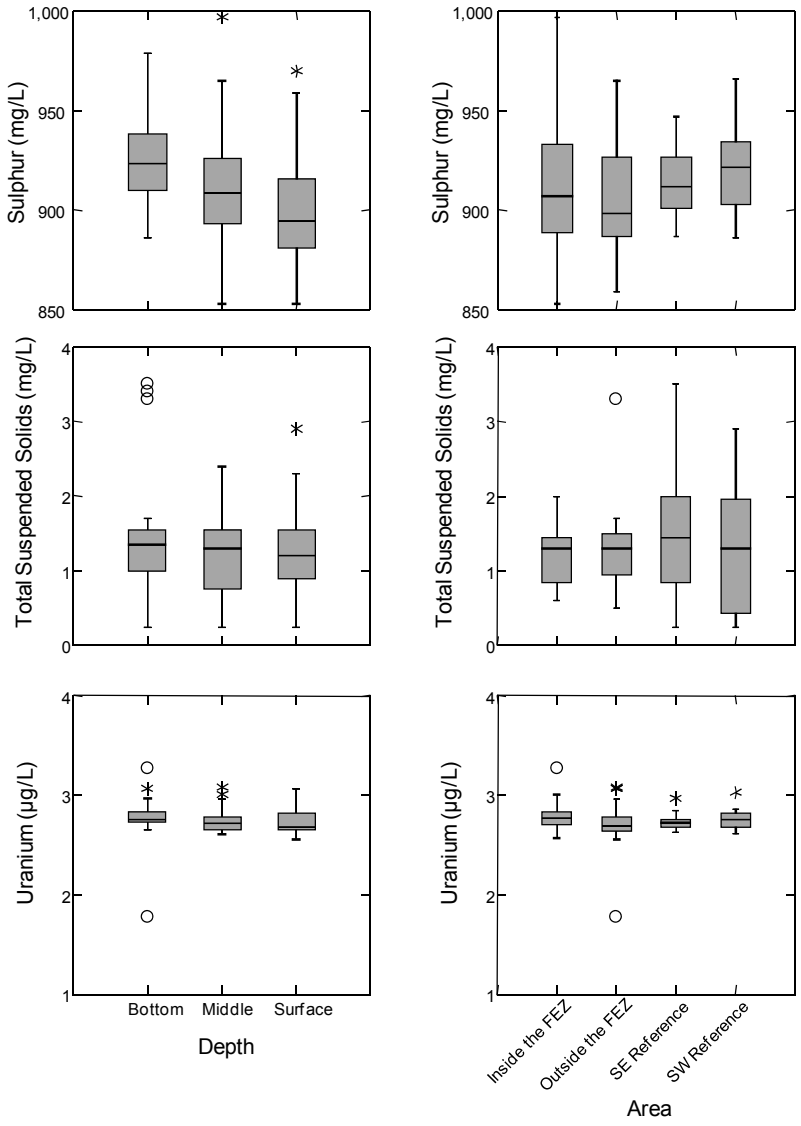


Figure 6-2 (cont.) Boxplots of Frequently Detected Variables (2014)

Notes: The centre line is the median. Ends of the box indicate the lower and upper quartiles. Ends of the whiskers indicate the quartile ±1.5 x interquartile spread. Asterisks indicate values falling within the quartile ±3 x interquartile spread. Open circles indicate values falling outside the quartile ±3 x interquartile spread. Values below detection limit for total suspended solids were set to ½ detection limit for plotting only.

Table 6-3 Results of ANOVA (p-values) Testing Differences Between Areas (2014)

Variable	*p*-values						
	Area	**Depth**	**AxD**	**SR**	**BR**	**IFEZ vs R**	**OFEX vs R**
Arsenic	0.355	0.016	0.945				
Barium	0.641	**<0.001**	0.333				
Boron	0.016	0.977	0.963	0.008	0.050	0.019	0.024
Calcium	0.439	0.350	0.982				
Iron	0.001	0.835	0.967	**<0.001**	0.170	**<0.001**	0.001
Lithium	0.094	0.917	0.948				
Magnesium	0.203	0.059	1.000				
Molybdenum	0.320	0.715	0.606				
Nickel	0.007	0.346	0.868	0.001	0.369	0.002	0.006
Potassium	0.001	0.001	0.942	0.001	0.094	0.005	0.002
Sodium	0.009	0.632	0.999	0.001	0.422	0.001	0.016
Strontium	0.032	0.001	0.907	0.725	0.159	0.141	0.383
Sulfur	0.487	0.013	0.963				
Total suspended solids	0.804	0.865	0.418				
Uranium	0.460	0.918	0.789				

Notes:
- Total suspended solids and iron were rank transformed. Remaining variables were $\log_{10}$ transformed.
- Statistical outliers (samples with studentized residual values greater than 4.0) were identified for barium, boron, calcium, molybdenum, nickel and uranium. Exclusion of outliers did not change results from significant to non-significant, or vice versa, for all variables except nickel. For nickel, reported statistics exclude results from the bottom sample at station W16. The nickel value in that sample is discussed in detail below.
- 'Area' tests for differences among the four areas, overall.
- 'Depth' tests for depth differences, overall.
- 'SR' tests for differences between the two Reference Areas and the two Study Areas.
- 'BR' tests for differences between the two Reference Areas.
- 'IFEZ vs R' tests for a difference between Study Area stations inside the FEZ and the combined Reference Areas.
- 'OFEZ vs R' tests for a difference between Study Area stations outside the FEZ and the combined Reference Areas.
- 'AxD' tests for differences in depth gradients among Areas.
- Shaded cells indicate that the test was not performed, because no Area differences were noted
- When AxD was statistically significant, additional tests were performed for each depth.
- Reported p-values for Area, Depth, BR, SR, IFEZ vs R, and OFEZ vs R were from models with the interaction term (AxD) removed when the interaction term was not significant.
- $p \leq 0.001$ **in bold**.

6.4.1.2 Infrequently Detected Variables

Figure 6-3 provides percent occurrence of infrequently detected variables (variables that occurred in 20% to 59% of samples) for stations inside the FEZ, stations outside the FEZ and the two Reference Areas (combined). In all cases, differences among Areas were not large or percent occurrence was higher in the Reference Areas.

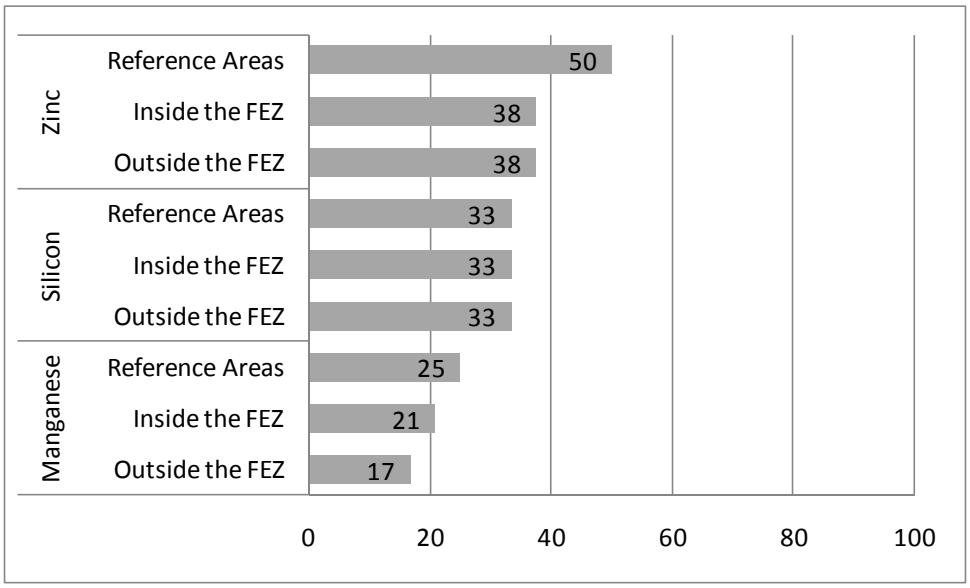


Figure 6-3 Percent Occurrence for Infrequently Detected Variables (2014)

Note: Percent occurrence represents occurrence at any depth.

6.4.1.3 Produced Water Constituents

Concentrations of seawater constituents at Reference Area stations in 2014 and concentration of these constituents in a produced water sample are provided in Table 6-4. Only those constituents detected in seawater samples and with produced water concentrations more than, or less than, 10 times that of seawater (i.e., potential enrichment or depletion) at Reference Area stations are shown.

Table 6-4 indicates that barium, iron, lithium, manganese, nickel and silicon could have been enriched in seawater samples as a result of produced water input, and uranium could have been depleted.

Maximum iron, manganese and nickel concentrations occurred in the bottom depth sample at station W16, inside the FEZ. The second highest concentrations of iron and manganese occurred in the bottom sample for station W11, inside the FEZ. There was no notable pattern in the distribution of high values for remaining constituents listed in Table 6-4, and low uranium concentration did not coincide with iron, manganese and nickel maxima (Appendix C-2). Given that iron, manganese and nickel are all elevated in produced water, it is possible that produced water was detected at stations W16 and W11.

Table 6-4 Concentration of Seawater Constituents at Reference Area Stations and in Produced Water (2014), and Analytes that Could Potentially be Enriched or Depleted in Seawater Samples

Variable	Reference Area Station Results				Concentration (µg/L) in Produced Water	Potential Enrichment[2]	Potential Depletion[3]
	n> DL	Min (µg/L)	Max (µg/L)	Median (µg/L)[1]			
Barium	24	4.9	7.3	5.7	239	42	0
Iron	24	2	6.4	3.65	3150	863	0
Lithium	24	122	155	132.5	1750	13	0
Manganese	6	<0.5	0.66	0.25	107	428	0
Nickel	23	0.32	1.44	0.45	8	18	0
Silicon	8	<100	310	50	25400	508	0
Uranium	24	2.62	3.03	2.73	0.05	0	55

Notes: - Analytes that could potentially be enriched in seawater samples are shown in yellow; analytes that could potentially be depleted are shown in green.
- Collection dates for seawater samples were October 28 to 30, 2014. The collection date for the produced water sample was October 18, 2014.
- [1]When the median of values was below the laboratory detection limit, the median was set to ½-detection limit for calculations of enrichment or depletion.
- [2]Potential enrichment = concentration in produced water/median concentration at Reference Area stations.
- [3]Potential depletion = concentration at Reference Area stations/concentration in produced water.
- Only those constituents detected in seawater samples and showing produced water concentrations more than, or less than, 10 times that of seawater at Reference Area stations are shown.

Overall, evidence that produced water constituents were detected in seawater samples at Terra Nova in 2014 is weak given that only two stations showed elevated concentrations of some of the constituents present in produced water.

6.4.1.4 Comparison Among Years

Arsenic concentrations have varied in each Area across years. However, median Study Area concentrations have not been consistently higher or lower than median Reference Area concentrations (Figure 6-4). Median arsenic concentration was higher in 2012 and 2014 than in previous years, in both the Study and Reference Areas.

Median iron concentration was higher in the Study Area than in the Reference Areas in 2002 and 2012; and median concentration was higher in the Reference Areas than in the Study Area in 2008 and 2014.

Within years, total suspended solids concentrations in the Study and Reference Areas have generally been similar.

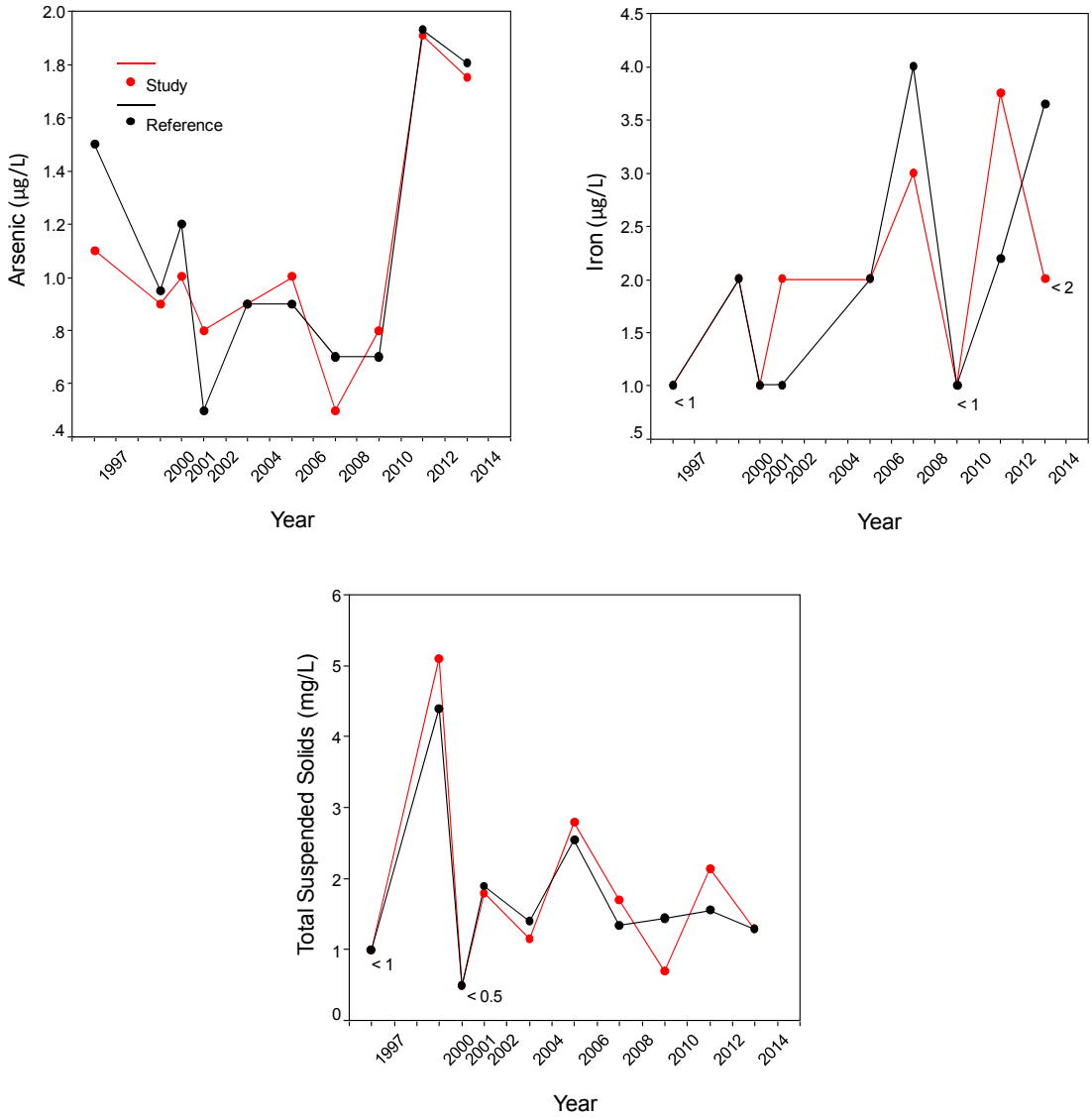


Figure 6-4 Median Arsenic, Iron and Total Suspended Solids Concentrations in Niskin Bottle Water Samples from the Reference and Study Areas (2000 to 2014)

Notes: When the Study Area and Reference Area values and lines completely overlap, only the Reference Area values and lines (black) appear in the plots. Iron concentrations in 2004 were excluded because the laboratory detection limit in that year was 10 µg/L and many values were below that level.

6.4.2 Pigments and Temperature Profiles

Summary statistics for water column temperature, pH, salinity, oxygen and chlorophyll *a* from the CTD recorder for 1997 to 2014, and depth profiles for individual water stations in 2014, are provided in Appendix C-3.

Temperature at water stations sampled in 2014 ranged from a low of -1°C near bottom to close to 10°C near the surface. Thermoclines extended from approximately 20 to 50 m at stations inside and outside the FEZ, from 20 to 40 m at stations in the SW Reference Area, and from near surface to 60 m at stations in the SE Reference Area (Figure 6-5). There were no obvious differences in temperature profiles at stations W11 and W16 (two stations where produced water constituent might have been detected; Section 6.4.1) relative to other FEZ stations (Appendix C-3)[26].

In 2014, chlorophyll *a* concentrations at water quality stations varied between approximately 1.0 and 3.5 μg/L, with concentrations higher at approximately 20 to 30 m depth (Figure 6-6).

Boxplots of chlorophyll *a* concentrations from CTD casts grouped into 5 to 30 m (surface), 31 to 60 m (middle) and 61 to 100 m (bottom) depth classes are provided in Figure 6-7; ANOVA results testing for differences among Areas for chlorophyll *a* over these depth classes are provided in Table 6-5.

Chlorophyll *a* concentrations differed among depth classes, and depth gradients varied among Areas (Table 6-5). Overall, differences in chlorophyll *a* concentrations were greater between the two Reference Areas than between the Study Areas and SE Reference Area (Figure 6-7) (i.e., the SW Reference Area stood out as dissimilar from the remaining Areas). The thermocline extended over a narrower depth range in the SW Reference Area, and that difference was mirrored in the distribution of chlorophyll *a* over depth (see Figures 6-5 and 6-6).

[26] Produced water is being released at temperatures ranged from approximately 75°C to 85°C at a depth of approximately 15 m. Although unlikely, this input could have altered temperature profiles at stations potentially under the influence of produced water.

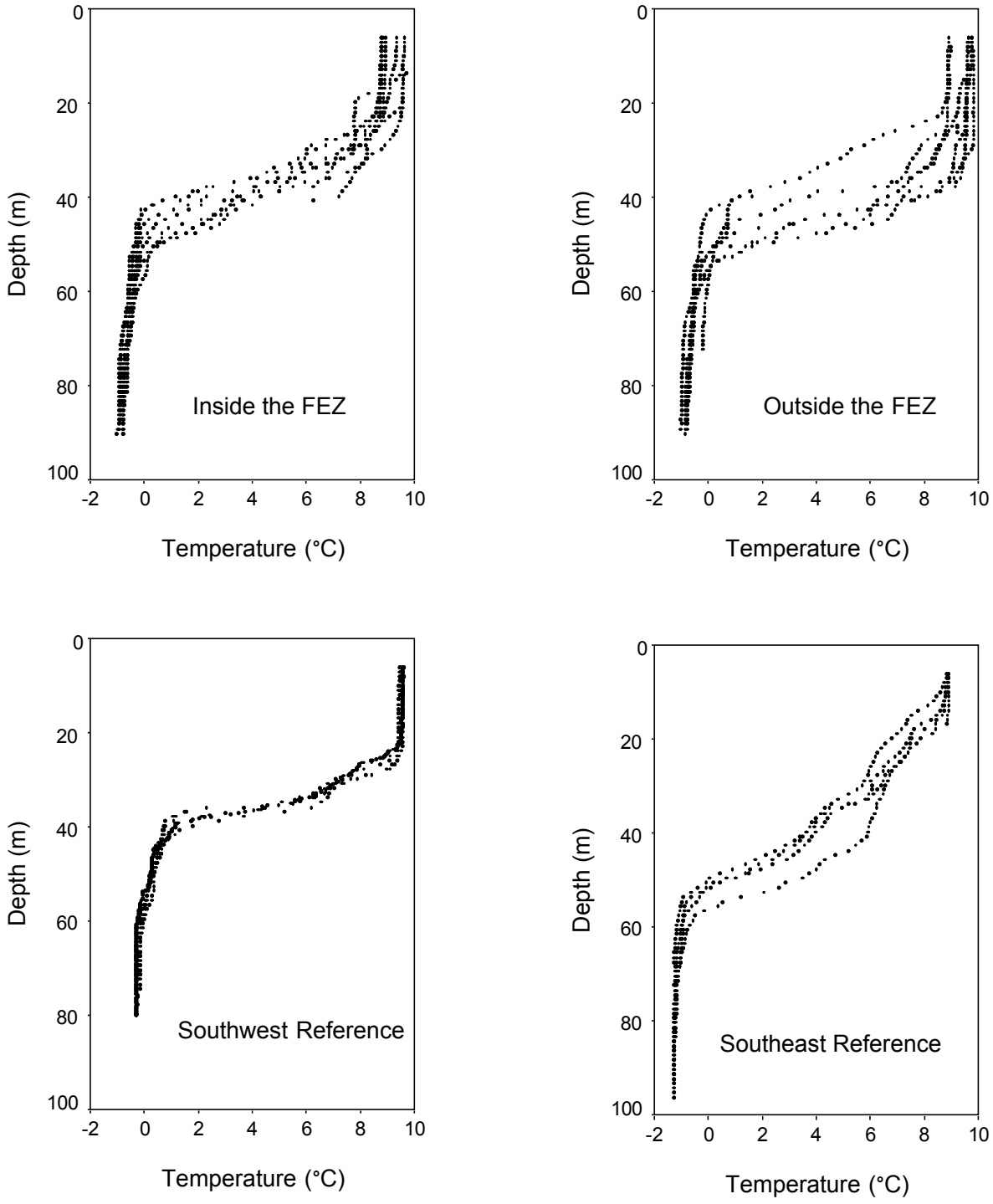


Figure 6-5 Temperature from CTD Casts versus Depth for Each Area (2014)

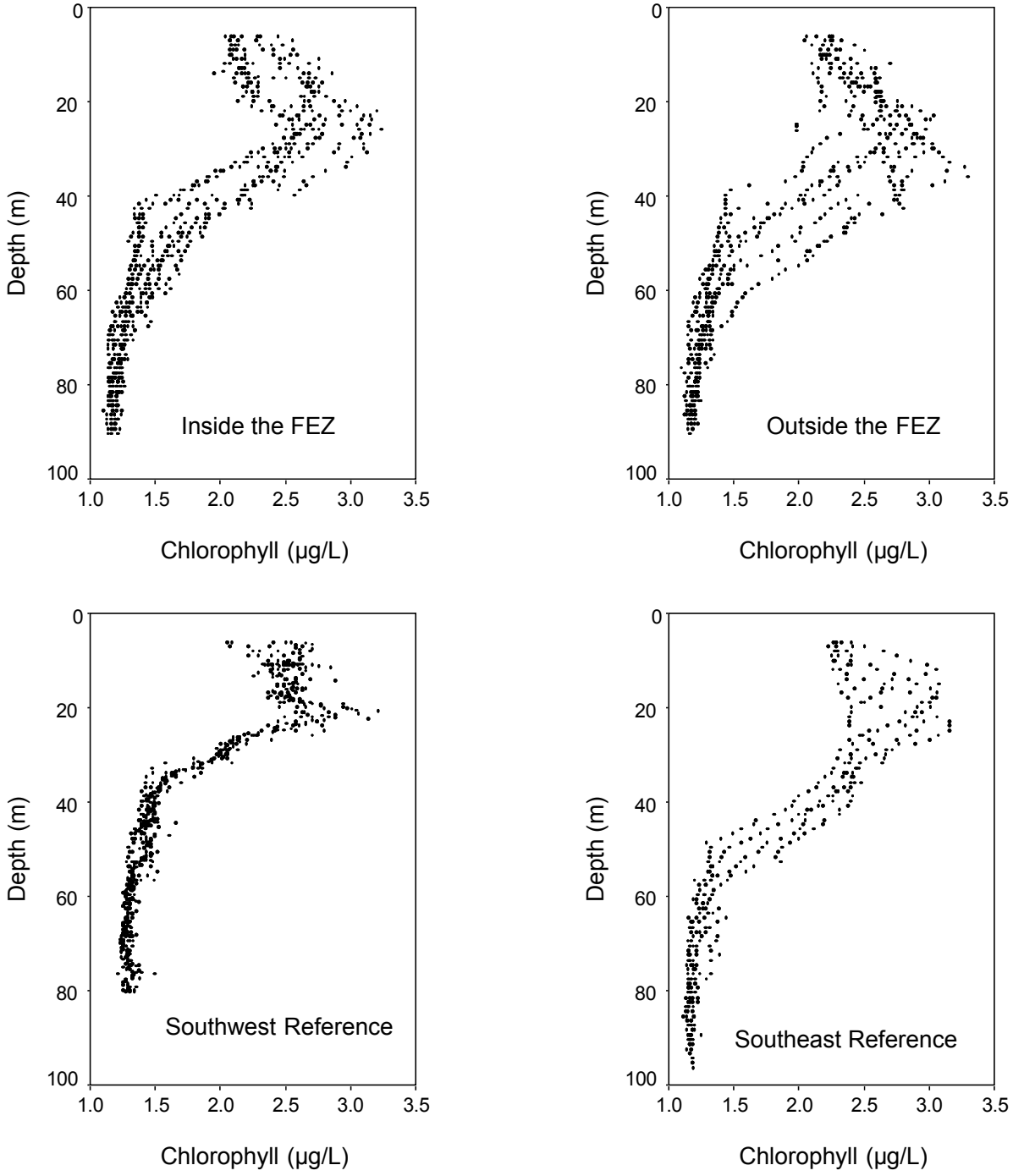


Figure 6-6 Chlorophyll a Concentrations from CTD Casts versus Depth for Each Area (2014)

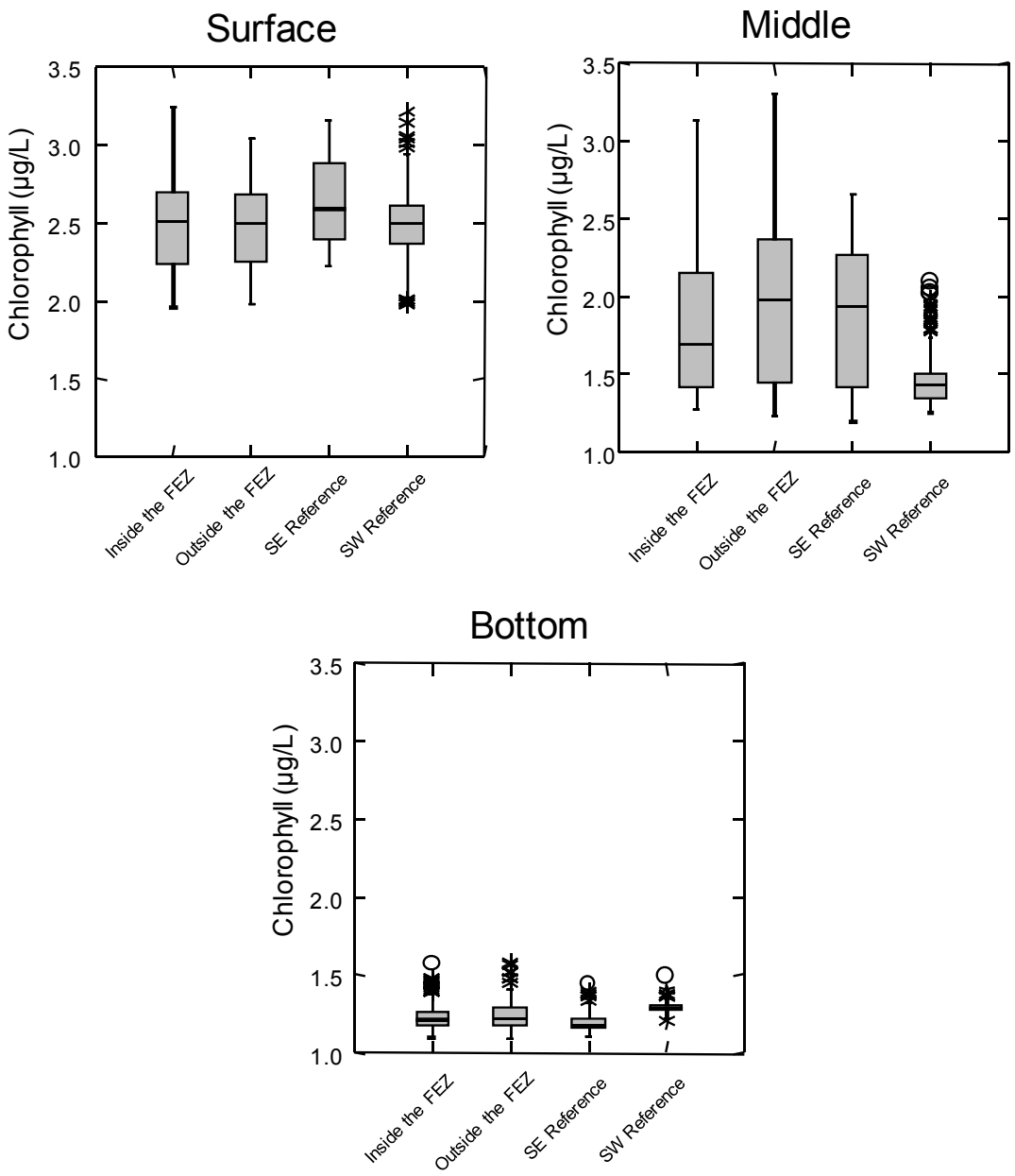


Figure 6-7 Boxplot of Chlorophyll a Concentrations from CTD Casts (2014)

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

Table 6-5 Results of ANOVA (p-values) Testing Differences in Chlorophyll a concentrations Between Areas (2014)

Variable	*p*-values						
	Area	**Depth**	**AxD**	**SR**	**BR**	**IFEZ vs R**	**OFEZ vs R**
Chlorophyll *a*	**<0.001**	**<0.001**	**<0.001**				
	<0.001	B		0.036	**<0.001**	0.028	0.178
	<0.001	M		**<0.001**	**<0.001**	**<0.001**	**<0.001**
	<0.001	S		0.03	**<0.001**	0.091	0.05

Notes:
- 'Area' tests for differences among the four areas, overall.
- 'Depth' tests for depth differences, overall.
- 'SR' tests for differences between the two Reference Areas and the two Study Areas.
- 'BR' tests for differences between the two Reference Areas.
- 'IFEZ*vs* R' tests for a difference between Study Area stations inside the FEZ and the combined Reference Areas.
- 'OFEZ*vs* R' tests for a difference between Study Area stations outside the FEZ and the combined Reference Areas.
- 'AxD' tests for differences in depth gradients among Areas.
- If AxD was statistically significant, additional tests were performed for each depth.
- Reported *p*-values for Area, Depth, BR, SR, IFEZ*vs* R, and OFEZ*vs* R were from models with the interaction term removed when the interaction term was not significant.
- $p \leq 0.001$ **in bold**.

6.4.2.1 Comparison Among Years

Median temperature from CTD casts at the surface (5 to 30 m), mid-depth (31 to 60 m) and at the bottom (61 to 100 m) has been similar in the Study and Reference Areas in most years (Figure 6-8). The largest difference between Areas occurred in 2002, when median Study Area temperature at mid depth was approximately 2°C higher than median Reference Area temperature.

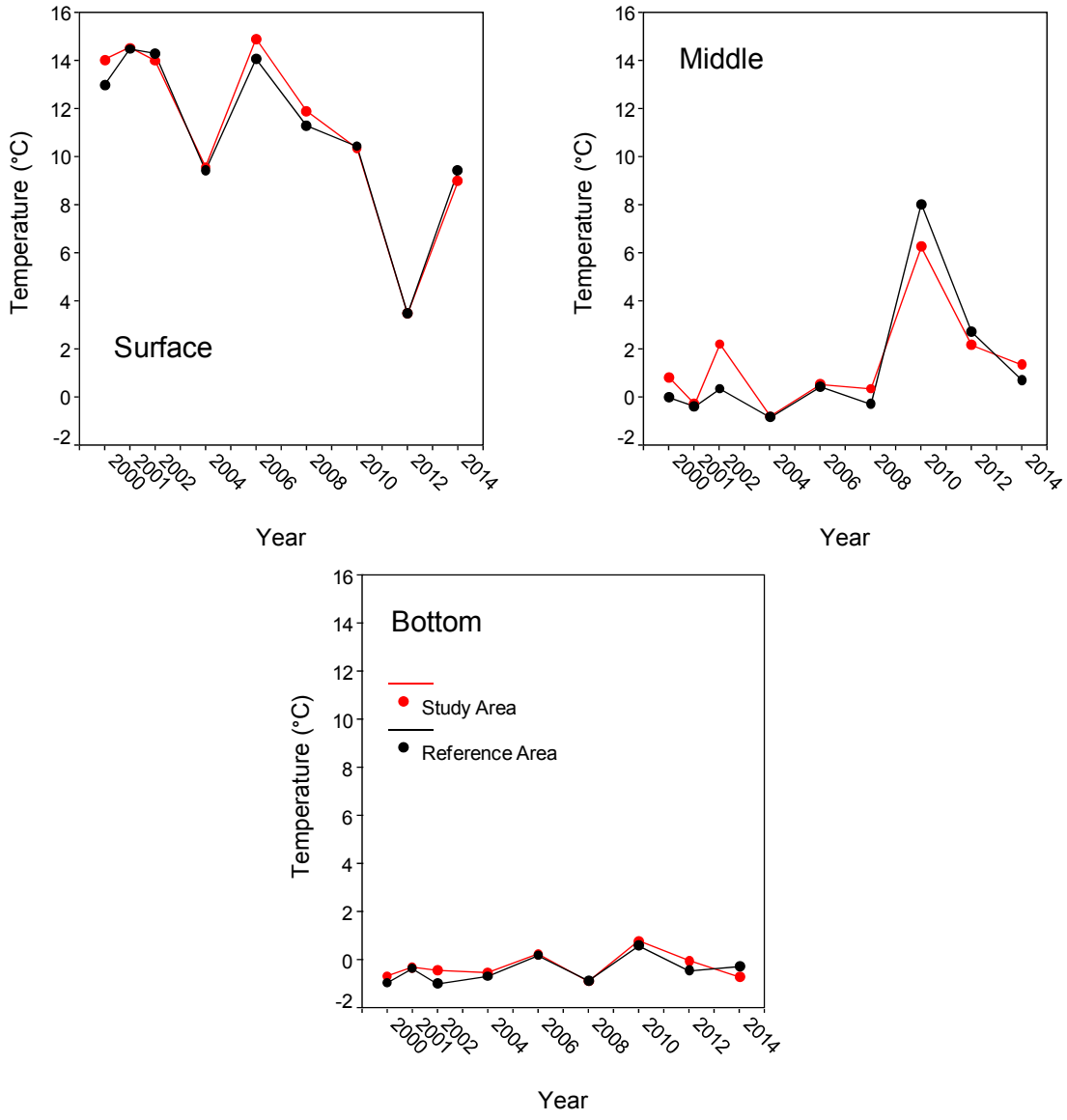


Figure 6-8 Median Temperature from CTD Casts in the Study and Reference Areas (2000 to 2014)

Note: When the Study Area and Reference Area values and lines completely overlap, only the Reference Area values and lines (black) appear in the plots.

Median chlorophyll *a* concentration has generally followed the same pattern in the Study and Reference Areas, with concentrations slightly more variable across years at the surface in the Reference Areas (Figure 6-9).

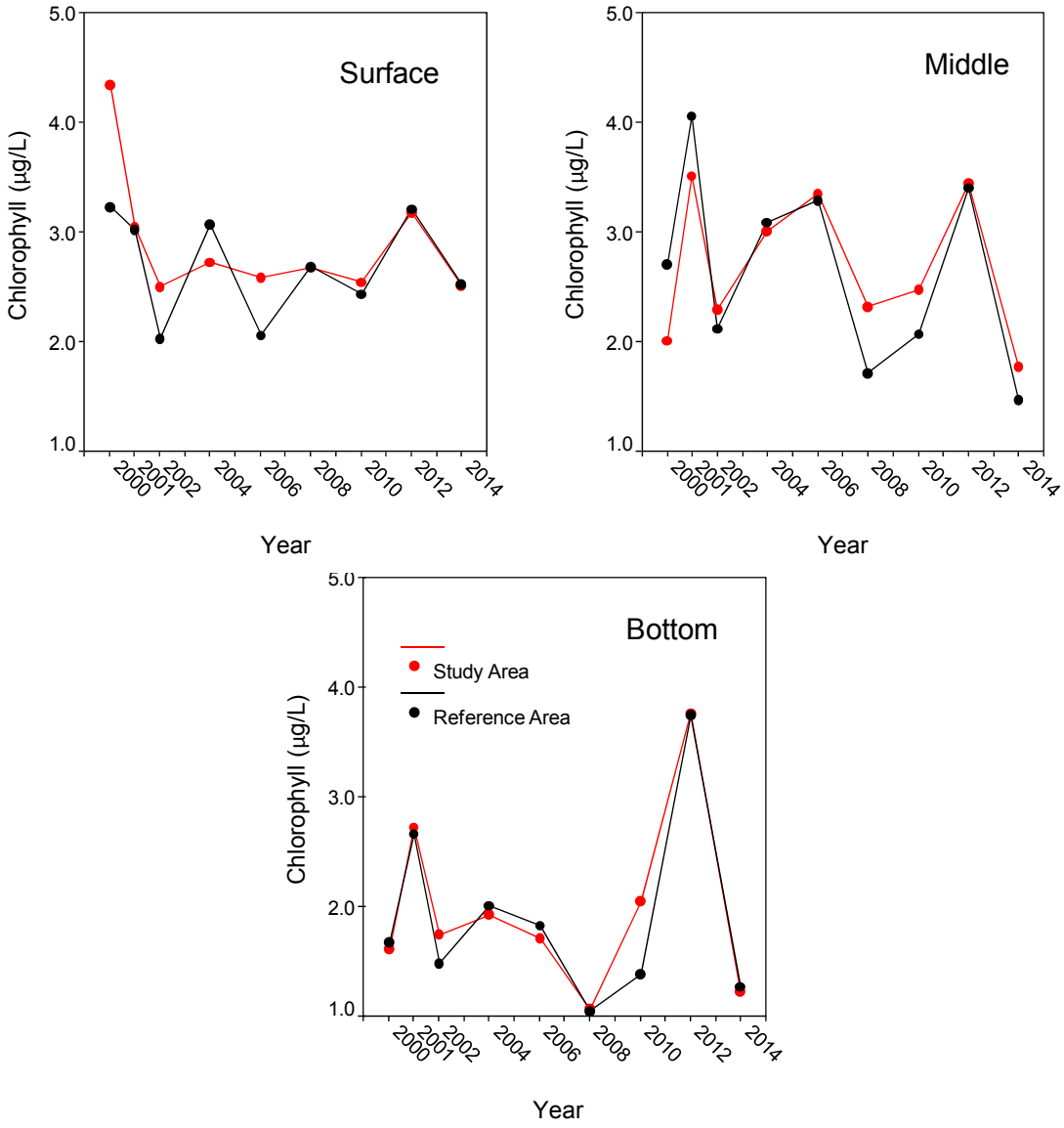


Figure 6-9 Median Chlorophyll a Concentration from CTD Casts in the Study and Reference Areas (2000 to 2014)

Note: When the Study Area and Reference Area values and lines completely overlap, only the Reference Area values and lines (black) appear in the plots.

6.5 SUMMARY OF RESULTS

In 2014, BTEX, >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons and PAHs were not detected in any sample. Arsenic, barium, boron, calcium, lithium, magnesium, molybdenum, nickel, potassium, sodium, strontium, sulphur and uranium were detected in all samples. Suspended solids and iron were detected in 93% and 64% of samples, respectively. These variables were analyzed quantitatively.

Concentrations of boron, iron, nickel, potassium and sodium differed between the Study Areas and the Reference Areas, with concentrations of most metals lower in the Study Areas than in the Reference Areas. Median iron, nickel, potassium and sodium levels were 45%, 81%, 4% and 8% lower, respectively, in the Study Areas than in the Reference Areas; and the median boron level was 12% lower in the Reference Areas than in the Study Areas.

Manganese, silicon and zinc were detected in 20% to 59% of samples and the frequency of occurrence (percent occurrence) of these metals in each Area was examined qualitatively. In all cases, differences among Areas were not large or percent occurrence was higher in the Reference Areas.

The occurrence of extreme values (i.e., statistical outliers) of known produced water constituents was examined at individual stations to determine if there could be an association between these extremes and release of produced water. Maximum iron, manganese and nickel concentrations occurred in the bottom depth sample at station W16, inside the FEZ. The second highest concentrations of iron and manganese occurred in the bottom sample for station W11, inside the FEZ. Given that iron, manganese and nickel are all elevated in produced water, it is possible that evidence of produced water was detected at stations W16 and W11. Concentrations of arsenic, iron and total suspended solids were examined across years. These were the only variables that were detected frequently in samples in all years. Over time, median arsenic concentrations have not been consistently higher or lower than median Reference Area concentrations. Median iron concentration was higher in the Study Area than in the Reference Areas in 2002 and 2012; and median concentration was higher in the Reference Areas in 2008 and 2014. Total suspended solids in the Study and Reference Areas have generally been similar.

In 2014, chlorophyll *a* concentrations from CTD casts varied between approximately 1 and 3.5 µg/L, with concentrations higher at approximately 20 to 30 m depth. Chlorophyll *a* depth gradients varied among Areas. However, differences in chlorophyll *a* concentrations were greater between the two Reference Areas than

between the Study Areas and SE Reference Area (i.e., the SW Reference Area stood out as dissimilar from remaining Areas). The thermocline extended over a narrower depth range in the SW Reference Area, and that difference was mirrored in the distribution of chlorophyll *a* over depth.

Across years, median chlorophyll *a* concentrations from CTD casts have generally followed the same pattern in the Study and Reference Areas, with concentrations slightly more variable at the surface in the Reference Areas.

7.0 COMMERCIAL FISH COMPONENT

7.1 FIELD COLLECTION

American plaice ("plaice") and Iceland scallop ("scallop") were collected on board the commercial trawler *M/V Kinguk* from June 21 to 26, 2014. Collection dates for the baseline program and EEM programs are shown in Table 7-1.

Table 7-1 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

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). Sampling for the 2014 program was conducted under experimental fishing license NL-2361-14, issued by Fisheries and Oceans Canada (DFO). A total of 50 plaice and 377 scallop were collected in the Terra Nova Study Area in 2014. A total of 50 plaice and 383 scallop were collected in the Reference Area. Location of sampling transects are provided in Figure 1-20 (Section 1) and in Appendix D-1. Plaice were collected using a commercial fishing trawl towed at 3 knots for 15 minutes per transect. Scallop were collected by towing an 8-foot dredge at 3 knots for 15 minutes.

Preliminary processing of samples was done on board the ship. Plaice and scallop that had suffered obvious trawl or dredge damage were discarded. Only those plaice larger than 300 mm in length were retained for analysis. Tissue samples, top fillet for plaice and adductor muscle for scallop, were frozen at -20°C for subsequent taste analysis. Bottom fillets and liver (left half only) for plaice and adductor muscle and viscera for scallop were frozen at -20°C for body burden analysis. Measurements on plaice included fish length, weight (whole and gutted), sex and maturity stage, liver weight and gonad weight. For scallop, measurements included total weight, sex, tissue weight, shell length, width and height.

Blood from plaice used in fish health analysis was drawn from a dorsal vessel near the tail with a syringe coated with an anticoagulant (EDTA) and carefully dispensed into a tube containing EDTA and gently mixed. Two blood smears were prepared for each fish within one hour of blood collection according to standard haematological methods (Platt 1969). After collection of blood samples, fish were killed by severing the spinal cord. Each fish was assessed visually for any parasites and/or abnormalities on the skin and fins under the general framework of autopsy-based condition assessment described by Goede and Barton (1990). Fish were dissected and sex and maturity stage were determined by visual examination according to procedures used by DFO in the Newfoundland Region.

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 and the rest was frozen on dry ice until return to port, when it was placed in a -65°C freezer for Mixed Function Oxygenase (MFO) analysis. However, due to a sampling error, only 55 of the 100 livers collected were processed for MFO analysis in this way. Liver samples from the other 45 fish were stored at -20°C[27]. Liver from these fish was collected for MFO analysis by cutting a piece of the frozen sample and storing at -65°C until processing. 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.

The following QA/QC protocols were implemented. The fishing deck of the survey vessel was washed with degreaser then flushed with seawater at the beginning of the survey. Flushing of the fishing deck and the chute leading to the processing facility 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.

[27] Statistical analyses were conducted to determine if the MFO results differed between liver samples that were stored on ship on dry ice versus at -20°C (see Section 7.3.4).

7.2 LABORATORY ANALYSIS

7.2.1 ALLOCATION OF SAMPLES

Scallop from five transects in the Study Area and five transects in the Reference Area were used for body burden analysis. All remaining scallop were used in taste analyses (Table 7-2). Scallop tissue selected from each of the Study and Reference Areas were allocated to the triangle test and the hedonic scaling taste test (see Section 7.2.3 for details on taste tests) and randomly assigned to panellists.

Table 7-2 Scallop Selected for Body Burden and Taste Analysis (2014)

Transect	Area	No. of Scallop	Body Burden Composites	Taste (Wt. g. of Scallop)*
TN01	Study (SW corner of FEZ)	60	TN-01 (20 scallop)	239
TN02	Study (SE corner of FEZ)	43	TN-02 (20 scallop)	137
TN03	Study (NE corner of FEZ)	59	TN-03 (20 scallop)	233
TN04	Study (NW corner of FEZ)	60	TN-04 (20 scallop)	239
TN05	Study (NW corner of FEZ)	118	TN-05 (20 scallop)	585
TN06	Study (SE corner of FEZ)	37		221
Total	**Study**	**377**	**5**	**1,655**
TN7	Reference	57	TN-07 (20 scallop)	238
TN8	Reference	19		122
TN9	Reference	77	TN-9 (20 scallop)	367
TN10	Reference	80	TN-10 (20 scallop)	386
TN11	Reference	20		129
TN12	Reference	20		129
TN13	Reference	34	TN-13 (20 scallop)	97
TN14	Reference	40	TN-14 (20 scallop)	129
TN15	Reference	16		103
TN16	Reference	20		129
Total	**Reference**	**383**	**5**	**1,828**

Note: * Weights used for each transect were estimated from total weight for the Area, number of scallop remaining for taste tests and average weight of a scallop adductor muscle in 2014 (6.19 g).

Plaice from five transects in the Study Area and five transects in the Reference Area were used for body burden analysis, taste tests and fish health analyses (see Table 7-3). Bottom fillet and liver from plaice in each of these transects were composited to generate five body burden samples for fillet and liver for each Area. Top fillets from fish used in body burden analysis were used in taste analyses. In taste analyses, fish fillet selected from the Study Area and the Reference Area were allocated to the triangle test and the hedonic scaling test (see Section 7.2.3 for details on taste tests) and randomly assigned to panellists. Fish health analyses focussed on individual fish rather than on composite or randomly assigned samples (Table 7-3).

Table 7-3 Plaice Selected for Body Burden, Taste and Health Analyses (2014)

Transect	Area	Total No. Fish	Body Burden Composites	Taste (Wt. g. of Top Fillets)	Health (No. of Fish)*
TN17	Study (SW corner of FEZ)	10	TN17 (10 fish)	794	10/10
TN18	Study (SE corner of FEZ)	10	TN18 (10 fish)	829	10/5
TN19	Study (NE corner of FEZ)	10	TN19 (10 fish)	825	10/5
TN20	Study (NW corner of FEZ)	10	TN20 (10 fish)	436	10/5
TN21	Study (NW corner of FEZ)	10	TN21 (10 fish)	405	10/5
Total	**Study**	**50**	**5**	**3,289**	50/30
TN22	Reference	10	TN22 (10 fish)	814	10/5
TN23	Reference	10	TN23 (10 fish)	804	10/5
TN24	Reference	10	TN24 (10 fish)	800	10/5
TN25	Reference	10	TN25 (10 fish)	799	10/5
TN26	Reference	10	TN26 (10 fish)	828	10/5
Total	**Reference**	**50**	**5**	**4,045**	50/25

Notes: * For fish health, 10 fish per transect were used for assessment of sex ratios, maturity, age, size, condition, gross pathology and MFO analysis. Remaining analyses used fewer fish, as indicated in the above Table (see Sections 7.1 and 7.4 for details).
- Study Area fish tissue for taste analyses was selected to generate relatively equal weights of fish from the four corners of the FEZ.

7.2.2 BODY BURDEN

Samples were delivered frozen to Maxxam Analytics in Nova Scotia, and processed for the analytes listed in Table 7-4. Analytical methods and QA/QC procedures for these tests are provided in Appendix D-2.

Table 7-4 Body Burden Variables (1997 to 2014)

Variables	Method	Laboratory Detection Limit							Units
		1997	2000	2001	2002	2004/06	2008/10	2012/14	
$>C_{10}$-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

Variables	Method	Laboratory Detection Limit							Units
		1997	2000	2001	2002	2004/06	2008/10	2012/14	
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
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[28].
- NA = Not Analyzed.
- * Benzo(*j*)fluoranthene was not reported by the analytical laboratory until 2012.

7.2.3 TASTE TESTS

Plaice and scallop 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. All 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

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

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 7-1 and 7-2) and briefed on the presentation of samples prior to taste tests. Panellists were instructed that samples were being tested for uncharacteristic odour or taste and that grit, cartilage and texture should not be considered in their assessment. Panellists were also instructed not to communicate with each other and to leave the panel room immediately upon completion of the taste tests.

QUESTIONNAIRE FOR TRIANGLE TEST

Name: _____ Date/Time: _____

Product: American Plaice

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

Code	**Check Odd Sample**
214	_____
594	_____
733	_____

2. Comments:

_____
_____
_____
_____
_____
_____
_____
_____

Figure 7-1 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.

619		835	
_____	like extremely	_____	like extremely
_____	like very much	_____	like very much
_____	like moderately	_____	like moderately
_____	like slightly	_____	like slightly
_____	neither like nor	_____	neither like nor
_____	dislike	_____	dislike
_____	dislike slightly	_____	dislike slightly
_____	dislike moderately	_____	dislike moderately
_____	dislike very much	_____	dislike very much
_____	dislike extremely	_____	dislike extremely

2. Comments:

_____
_____
_____
_____
_____
_____
_____

Figure 7-2 Questionnaire for Taste Evaluation by Hedonic Scaling

7.2.4 FISH HEALTH INDICATORS

Fish health indicators for American plaice included external and internal lesions, condition indices, haematology, MFO enzymes, and a variety of liver and gill tissue (histological) indices.

Blood smears were stained with Giemsa stain and examined with a Wild Leitz Aristoplan bright field microscope to identify different types of cells based on their general form and affinity to the dye, after methods in Ellis (1976).

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 D-3.

7.3 DATA ANALYSIS

7.3.1 BIOLOGICAL CHARACTERISTICS

Biological characteristics (size and other variables) of scallop and plaice were analyzed because difference in biological characteristics of the two species in the Study and the Reference Areas might affect results for body burden, taste and health analyses. For scallop, analyses also examined if the 200 scallop selected for body burden analysis were representative of the larger subset of the 760 scallop sampled.

7.3.1.1 Scallop

Quantitative analyses of biological characteristics for scallop were performed on 2014 samples. Summary statistics from previous years are provided in Appendix D-4 for qualitative comparisons with 2014 data. Analyses of scallop biological characteristics in 2014 included comparisons of sex ratios, size and shape among transects within Areas and between Areas. These analyses on size and shape included all 760 scallop from the 16 transects sampled in 2014.

Sex ratios (frequencies of the two sexes) were compared among transects within Areas and between Areas, using log-likelihood ratio or *G* tests[29] (Sokal and Rohlf 1981).

Size variables included shell length, width and height (one-dimensional measures), tissue weight (adductor muscle weight + viscera weight + gonad weight) and shell weight (total weight – tissue weight) (three-dimensional measures). PCA[30] was used to derive summary size and shape measures from $\log_{10}$ transformations of these five size variables.

[29] *G* is similar to χ^2, but is strictly additive for multiple independent tests, whereas χ^2 is not.

[30] PCA identifies the major axis of covariance (Principal Component or PC1) among the original variables (i.e., the five size variables) and also variance among samples (i.e., individual scallop). For analyses of size and shape, PC1 is usually positively correlated with all variables and is an overall size measure. Positions of individuals along PC1 are called scores, which are weighted sums of the original variables. PCA then identifies lesser (minor) axes of variance, each perpendicular to, and uncorrelated with, PC1 and each other. PC2 will account for more variance than PC3, PC3 will account for more variance than PC4, and so on. PC2 and other secondary axes usually reflect differences in shape (e.g., shell length relative to width) or condition (e.g., tissue weight relative to shell weight). In this report, axes were considered 'significant', if they produced an eigenvalue greater than 1.0 (i.e., a result that generally occurs when a PC explains/accounts for non-random variation in the raw data) (Jackson 1993).

PC axis scores were compared among transects within Areas and between Areas in nested ANOVA[31]. The nested ANOVA were conducted on each sex separately.

7.3.1.2 Plaice

Fisher's Exact Test was used to compare sex ratios and maturity stages between the Study Area and Reference Area. Statistical analyses of maturity stages for male fish between the Study Area and Reference Area was not conducted as the limited number of males captured violated the assumptions of contingency test analyses (Quinn and Keough 2002).

Size and age for each sex were compared among Areas via Unpaired t-test or the Mann-Whitney Rank Sum test when the data violated the assumptions of equality of variances and normality.

Fish condition was assessed by calculating different 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 they were compared between the two Areas by the Unpaired t-test or the Mann-Whitney Rank Sum 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-log regressions of total body weight on length, and liver and gonad weight on total body weight, were also tested by analysis of covariance (ANCOVA). When ANCOVA revealed parallel slopes between sites, comparisons were made on adjusted means to detect any inter-site differences.

7.3.2 BODY BURDEN

7.3.2.1 Scallop

Summary statistics were calculated for Reference Area and Study Area metal, hydrocarbon and fat concentrations in scallop adductor muscle and viscera composites.

[31] In the nested ANOVA, variance among transects within Areas, rather than variance among scallop within transects, is the appropriate error term for testing differences between Areas. The test of Area differences in nested ANOVA is equivalent to a *t* test comparing Areas with transect means as replicate values and those means weighted by sample size. Variance among transects within Areas is tested against variance among scallops within transects and the test is equivalent to a one-way ANOVA comparing transects with any overall Area differences removed.

From 1997 to 2002, laboratory detection limits for fat content were 0.1% and there were eight (of 40) values for adductor muscle less than 0.5%. From 2004 to 2014, detection limits were increased to 0.5% and there were 22 (of 60) values for adductor muscle less than 0.5%. For subsequent statistical analyses (PCA, ANOVA), all fat concentrations less than 0.5% were set to 0.4%. Fat levels in viscera were never below recent detection limits of 0.5%. Mercury was not detected in one Study Area viscera sample in 2010, and in two Reference Area viscera samples in 2014. Those non-detect mercury concentrations were set to 0.005 mg/kg (½ the laboratory detection limit) for subsequent analyses. Strontium concentrations were below detection in one Reference Area muscle sample in 2012, in three Study Area samples in 2012, in two Study Area samples in 2014 and in four Reference Area samples in 2014. Those non-detect values were set to 0.75 mg/L (i.e., ½ the laboratory detection limit) for subsequent analyses.

PCA was used to derive summary measures of metal concentrations in muscle and viscera samples collected in baseline (1997) and EEM years (2000, 2001, 2002, 2004, 2006, 2008, 2010, 2012 and 2014). The PCA for muscle included six metals detected in most muscle samples. The PCA for viscera include 12 metals detected in most viscera samples. Concentrations were $\log_{10}$-transformed prior to conducting the PCA.

Metals PC scores, fat concentrations and concentrations of individual metals if PCA analysis indicated that these varied differently from other metals were compared among the 10 sample years and between the two Areas in two-way Year x Area ANOVA. Two time (Year) contrasts were tested. The Before-After (BA) contrast compared baseline (Before project activity) values to EEM (After onset of project activity) values. The EEM Linear contrast tested for a monotonic (progressive) increase or decrease (simple trend) in body burden variable values over the nine EEM years.

When applied to the Year term, the contrasts test for time changes common to both the Reference and Study Areas. When applied to the Year x Area interaction, the contrasts provide tests of potential project effects and other changes in differences between the two Areas over time. The BA x Area contrast is the classical Before-After Control-Impact (BACI) contrast (Green 1979), testing for a change in the difference between Reference (Control) and Study (Impact) Areas between 1997 and EEM years. The EEM Linear x Area contrast tests for a difference in monotonic trends between Areas after the onset of project activity. For example, body burdens might progressively increase in the Study Area but not in the Reference Area. The

BACI and EEM Linear x Area are the truest tests of drilling-related effects, and are the focus of the interpretations. If these interaction-based terms are significant, then interpretation of main effects (i.e., Year and Area, be they statistically significant or not) become more challenging and require consideration of the interaction terms.

Qualitative comparisons among years and between Areas were conducted for concentrations of $>C_{10}$-C_{21} hydrocarbons and barium, two important constituents of drill muds. More quantitative analyses of these substances were not conducted because concentrations were often below the laboratory detection limit.

7.3.2.2 Plaice

Summary statistics were calculated for Reference Area and Study Area metal, hydrocarbon and fat concentrations in plaice fillet and liver samples. Statistical analyses of body burdens were similar to those for scallop, except that comparable data for plaice were only available for 2001, 2002, 2004, 2006, 2008, 2010, 2012 and 2014. 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 content and concentrations of these three metals were compared among years and between Areas in two-way ANOVA. The Year BA and Year x Area BACI contrasts could not be tested because there were no baseline data. One fat concentration in 2010, and one in 2012 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 samples from 2001 to 2014. 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 was excluded from further 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 content were

compared among years and between Areas in two-way ANOVA. Analyses of fat content were restricted to 2004, 2006, 2008, 2010, 2012 and 2014 because low sample volume restricted fat content analyses to only one composite per Area in 2001 and 2002.

Concentrations of hydrocarbons in plaice fillet and liver were qualitatively compared among years and Areas.

7.3.3 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 D-5 (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 processed in ANOVA and presented graphically in a frequency histogram.

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

7.3.4 FISH HEALTH INDICATORS

Because of the difference in storage temperature in liver samples for MFO activity assays, an analysis comparing MFO activity between the two storage temperatures within each sampling area was conducted (Mann-Whitney Rank Sum test). If differences in MFO activity between samples stored at different temperatures were detected, "storage temperature" was introduced as a variable in factorial ANOVA (with Temperature and Area as factors). If data did not meet the equality of variance and the normality assumptions for ANOVA, individual non-parametric analysis for each temperature was also used (Mann-Whitney Rank Sum test).

Fisher's Exact Test was used to compare presence versus absence of biliary parasites between the Study and Reference Areas. Other liver abnormalities were rare or absent and were not statistically analysed. Fisher's Exact Test also was used to compare frequencies of fish with at least one gill lamella affected by the different lesions between the Study and Reference Areas.

7.4 RESULTS

7.4.1 BIOLOGICAL CHARACTERISTICS

7.4.1.1 Scallop

In 2014, a total of 760 scallop were collected from 10 Reference Area transects and six Study Area transects. Tissues from 200 of the scallop were analyzed for body burden. Table 7-5 summarizes numbers and sizes of female and male scallop collected in each Area. Summary statistics per transect are provided in Appendix D-4, as are overall summary statistics for previous years.

Table 7-5 Summary Statistics of Scallop Shell Dimensions and Weights (2014)

Sex	Area	Statistic	Dimensions (mm)			Weights (g)				
			Length	Width	Height	Total	Shell	Muscle	Viscera	Gonad
Female	Reference	*n*	201	201	201	201	201	201	201	201
		Mean	73.6	68.7	23.3	57.5	31.9	5.6	20.0	3.6
		SD	6.0	6.9	2.8	14.7	10.9	2.3	4.9	1.5
	Study	*n*	221	221	221	221	221	221	221	221
		Mean	74.6	69.6	23.9	61.0	33.6	6.2	21.3	2.9
		SD	5.6	5.4	3.6	12.1	9.8	2.7	5.4	0.4
Male	Reference	*n*	182	182	182	182	182	182	182	182
		Mean	72.3	68.1	22.9	54.0	29.3	5.2	19.6	3.6
		SD	5.6	6.2	2.7	13.3	9.7	2.0	4.3	1.3
	Study	*n*	156	156	156	156	156	156	156	156
		Mean	73.8	69.3	23.7	59.2	33.2	5.1	20.9	3.0
		SD	5.6	5.6	2.5	15.4	10.8	2.6	5.7	0.4

Sex Ratios

In 2014, female scallop generally outnumbered males in catches from both the Reference and Study Areas (Table 7-6). Variations in sex ratios between the Reference and Study Area were not significant ($p = 0.088$ for the whole data set; $p = 0.478$ for the body burden data set). There were stronger variations in sex ratio within both the Study and Reference Areas ($p < 0.05$; Table 7-7; also see Table 7-6).

Table 7-6 Sex Ratios of Scallop in Transects (2014)

Area	Tow	Gender			
		Female		Male	
		No.	%	No.	%
Reference	7	22	38.6	35	61.4
	8	8	42.1	11	57.9
	9	45	58.4	32	41.6
	10	38	48.1	41	51.9
	11	15	71.4	6	28.6
	12	12	60.0	8	40.0
	13	21	61.8	13	38.2
	14	18	45.0	22	55.0
	15	10	62.5	6	37.5
	16	12	60.0	8	40.0
	Total	201	52.5	182	47.5
Study	1	51	85.0	9	15.0
	2	25	58.1	18	41.9
	3	16	40.0	24	60.0
	4	54	68.4	25	31.6
	5	55	46.6	63	53.4
	6	20	54.1	17	45.9
	Total	221	58.6	156	41.4

Table 7-7 Results of G Tests Comparing Scallop Sex Ratios Among Transects (2014)

Source	df	Whole Data Set		Body Burden Data Set	
		G	*p*	G	*p*
Among Transects	15	52.28	<0.001	31.49	<0.001
Between Reference and Study	1	2.90	0.088	0.50	0.478
Among Transects Within Study	5	35.63	<0.001	16.16	0.003
Among Transects Within Reference	9	13.75	0.132	14.83	0.005

Note: - *G* = log-likelihood ratio, similar to χ^2.

Size and Shape

Scallops ranged from approximately 50 to 100 mm in length, and from approximately 25 to 150 g in weight. Those variations were similar for male and female scallop from both Reference and Study Areas (Figure 7-3).

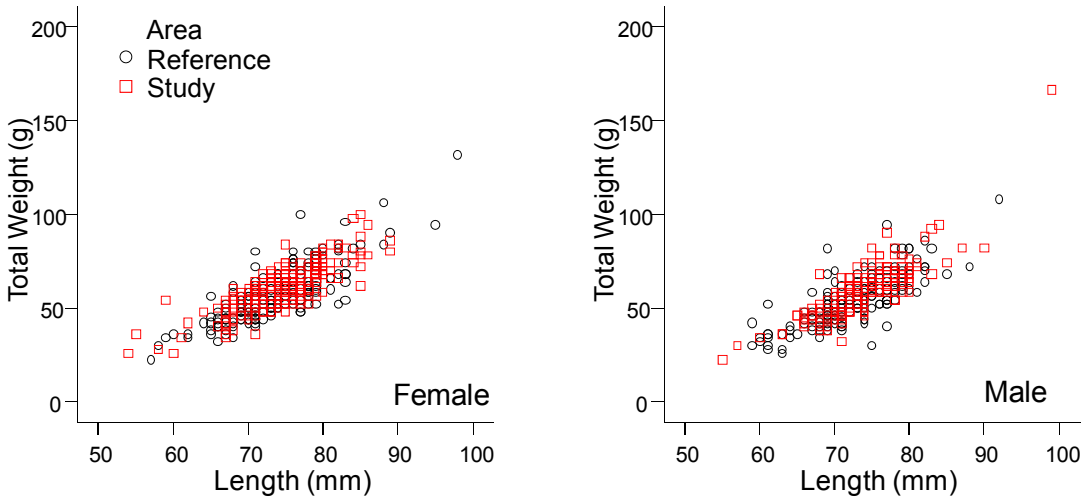


Figure 7-3 Scatterplots of Weight and Length for Male and Female Scallop (2014)

The PCA of shell size variables produced three PC axes that each had eigenvalues greater than 1 (i.e., they probably explained non-random variation (Jackson 1993). As expected, all five size variables were positively correlated with each other and with PC1 (Table 7-8). PC1 can be considered a summary size measure, with higher PC1 scores reflecting greater size. Most of the variation in size and shape variables was expressed in PC1 (i.e., approximately 64% of the total size variation). The subsequent two PC axes explained much less of the total variation (11 to 15%), and none of the size variables was strongly correlated with either of the axes (i.e., all r_p values were < |0.6|). Most of the size-related variation, therefore, can be considered to be described by PC1.

Table 7-8 Correlations (r_p) Between Scallop Size Variables and Principal Components (PCs) Derived from those Variables (2014)

Variable	Correlation (r_P) with:		
	PC1	PC2	PC3
Log of Length	**0.92**	0.08	0.15
Log of Width	**0.84**	0.19	0.35
Log of Height	**0.73**	-0.38	-0.53
Log of Tissue Weight	**0.71**	0.58	-0.30
Log of Shell Weight	**0.77**	-0.49	0.22
Percent of Variance Explained	63.5	15.3	11.2

Notes: - |r| ≥ 0.6 in bold.
- n = 960 scallop.
- r_P = Pearson correlation.

There were no differences in size of male or female scallop between the Reference and Study Areas (Area Term p > 0.4 for both male and female scallop, Table 7-9; also see Figure 7-4). Results were similar for the subset of scallops used for body

burden analysis (i.e., there were no differences in sizes of scallop between the Reference Area and the Study Area, for either males or females (Table 7-9)).

Table 7-9 Results of Nested ANOVA Comparing Scallop Size and Shape Principal Components (PCs) Among Transects Within Areas and Between Areas (2014)

Variable	Source	*Females*		*Males*	
		df	***p***	**df**	***p***
Whole Data Set					
PC Axis 1	Area	1	0.498	1	0.460
	Transect within Area	14	0.001	14	0.007
	Error	406		322	
Body Burden Data Set					
PC Axis 1	Area	1	0.453	1	0.907
	Transect within Area	8	0.013	8	0.028
	Error	97		83	

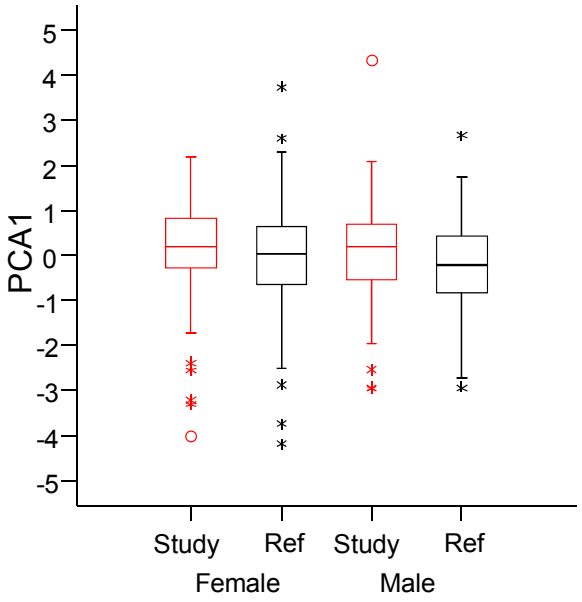


Figure 7-4 Box Plot of Size PCA1 Scores per Area for Male and Female Scallop (2014)

7.4.1.2 Plaice

Sex Ratios and Maturity Stages

Forty seven (47) females and three males were collected in the Reference Area, and 46 females and four 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 = 1.000; Fisher's exact test).

The number of males collected in either Area was low. Therefore, significance tests comparing prevalence of maturity stages in the Reference and Study Areas were not conducted.

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 7-10).

Table 7-10 Frequencies (%) of Maturity Stages of Female Plaice (2014)

	N	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	47	6.383	72.340	19.149	0.000	2.128
Study	46	6.522	71.739	13.043	2.174	6.522
p [b]		1.000	1.000	0.574	0.495	0.361

Notes: [a] Maturity stages were defined according to procedures used by DFO (Appendix D-3, Annex A).
[b] *p* value obtained with the Fisher's exact test.

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 7-11. Data are expressed as mean ± standard deviations. The complete data set is provided in Appendix D-3, Annex B. As mentioned above, few males were collected. Therefore, no statistical comparisons are provided between Areas for males.

Table 7-11 Biological Characteristics and Condition Indices of Male Plaice (2014)

Variable	Reference Area	Study Area
Fish number	3	4
Length (cm)	41.33 ± 1.53	44.87 ± 5.78
Total body weight (g)	730.67 ± 179.83	855.00 ± 361.41
Gutted weight (g)	666.00 ± 157.09	750.00 ± 288.92
Liver weight (g)	11.33 ± 6.43	21.50 ± 33.68
Gonad weight (g)	10.00 ± 10.39	22.50 ± 21.81
Age (year)	11.33 ± 1.53	11.75 ± 1.71
Fulton's condition factor [a]	0.932 ± 0.113	0.804 ± 0.115
Hepatosomatic index [b]	1.67 ± 0.93	2.25 ± 2.85
Gonadosomatic index [c]	1.33 ± 1.11	2.48 ± 2.05

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 7-12. Data are expressed as mean ± standard deviation. The complete data set is provided in Appendix D-3, Annex B.

Table 7-12 Biological Characteristics and Condition Indices of Female (All Maturity Stages Pooled) (2014)

Variable	Reference Area	Study Area	*p* [d]
Fish number	47	46	
Length (cm)	44.82 ± 3.68	44.65 ± 3.16	0.820
Total body weight (g)	872.98 ± 250.11	861.11 ± 221.65	0.927
Gutted body weight (g)	767.30 ± 215.92	751.13 ± 187.96	0.872
Liver weight (g)	11.87 ± 5.57	13.78 ± 7.62	0.140
Gonad weight (g)	43.47 ± 35.24	32.06 ± 13.78	0.153
Age (year)	11.39 ± 1.39	12.00 ± 1.63	**0.040**
Fulton's condition factor [a]	0.837 ± 0.083	0.831 ± 0.078	0.656
Hepatosomatic index [b]	1.56 ± 0.64	1.84 ± 1.02	**0.044**
Gonadosomatic index [c]	5.70 ± 4.48	4.39 ± 1.76	0.331

Notes: - All data are expressed as mean of raw values ± standard deviation.
[a] Calculated as 100 x gutted body weight/length³.
[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 or Mann-Whitney Rank Sum test.

No significant differences in female size, Fulton's condition factor and gonadosomatic index were found between the Reference and Study Areas (Table 7-12). However, female age and the hepatosomatic index were significantly different between Areas (p = 0.040 and 0.044, respectively). Females from the Study Area were older and had a higher mean hepatosomatic index.

No significant differences between Areas were observed when comparing adjusted means for gutted body weight on the covariate length, and liver and gonad weight on the covariate gutted body weight (Table 7-13).

Table 7-13 Adjusted Means of ANCOVA on Gutted Weight, Liver Weight and Gonad Weight for Female Plaice (All Maturity Stages Pooled) (2014)

Variable	Covariate	Adjusted Means		*p* [a]
		Reference Area	Study Area	
Gutted weight	Length	739.60	734.51	0.734
Liver weight	Gutted weight	1.03	1.09	0.105
Gonad weight	Gutted weight	34.99	29.99	0.134

Note: - ANCOVA were based on $\log_{10}$-transformed values of Y and X variables. Displayed data were obtained using the anti-log equation on adjusted means obtained from the ANCOVA analysis.
[a] *p* value were obtained using $\log_{10}$-transformed data.

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; Table 7-10), because this stage was also examined separately in MFO analyses. Results are provided in Appendix D-3. There were no significant differences between Areas for F-510 females in any of the parameters that were investigated.

7.4.2 BODY BURDEN

7.4.2.1 Scallop

In 2014, as in prior years, arsenic, boron, cadmium, mercury and zinc were detected in all scallop adductor muscle samples (Appendix D-2). Strontium concentration was below detection limit (1.5 mg/kg) in four Reference Area and two Study Area muscle samples (Appendix D-2). Other metals were rarely or never detected in the body burden samples. Fat content in muscle samples was near or below the recent laboratory detection limit of 0.5%.

Aluminum, arsenic, boron, cadmium, copper, iron, manganese, mercury nickel, selenium, strontium, uranium and zinc were detected in most scallop viscera samples in 2014. Barium was detected in all Study Area samples and in one Reference Area sample. Other metals were rarely or never detected in the body burden samples. Fat content in viscera was 1% to 2%, and was greater than the laboratory detection limit in all samples.

In 2014, $>C_{10}$-C_{21} hydrocarbons were detected in two Study Area samples and $>C_{21}$-C_{32} hydrocarbons were detected in one Study Area sample. Hydrocarbons were not detected in any Reference Area samples (Appendix D-2).

PAHs were never detected in scallop muscle or viscera.

Metals and Fat

Two adductor muscle PCs had an eigenvalue greater than 1 (i.e., they probably explained non-random variation in metals concentrations in scallop muscle; Jackson 1993), and they each accounted for more than 20% of the total variance in metals concentration (Table 7-14). Concentrations of all metals in muscle correlated positively with muscle PC1. Therefore, muscle PC1 can be considered a summary measure of total metal concentrations in muscle. Muscle PC2 was strongly negatively correlated with concentrations of boron (Table 7-14), indicating that concentrations of boron tended to vary independently of concentrations of other

metals. The PCA analysis justifies further examination of muscle PC1 scores, as a measure of total metals concentrations in muscle, and of muscle boron concentrations.

Table 7-14 Correlations (r_p) Between Concentrations of Metals in Scallop Tissues (Adductor Muscle and Viscera) and Principal Components Derived from those Concentrations (1997 to 2014)

Variable	Correlation (r_P) with:					
	Adductor Muscle		Viscera			
	PC1	PC2	PC1	PC2	PC3	PC4
Log of Aluminum			0.22	**-0.91**	0.20	0.00
Log of Arsenic	0.56	-0.53	**0.70**	0.10	-0.23	-0.29
Log of Boron	0.18	**-0.82**	0.26	0.26	0.50	0.44
Log of Cadmium	**0.71**	0.33	**0.62**	0.17	0.00	0.52
Log of Copper			0.58	0.31	0.28	-0.51
Log of Iron			0.48	**-0.80**	0.16	0.06
Log of Manganese			0.54	-0.35	0.33	-0.25
Log of Mercury	0.46	0.51	0.53	0.05	-0.48	-0.27
Log of Nickel			0.20	0.42	**0.68**	-0.33
Log of Selenium			0.83	0.21	-0.04	0.20
Log of Strontium	**0.79**	0.08	0.23	-0.30	0.29	0.19
Log of Uranium			**0.73**	-0.26	-0.39	0.00
Log of Zinc	**0.85**	-0.10	0.68	0.47	-0.09	0.23
Percent of Variance Explained	40.0	22.3	30.0	18.3	11.5	9.2

Notes: - $|r| \geq 0.6$ in **bold.**
- n = 100 composite samples for each tissue.

Four viscera PC axes produced an eigenvalue greater than 1 (i.e., they probably explained non-random variation in viscera metals concentrations; Jackson 1993). The first three axes accounted for more than 10% of the total variance in metals concentrations (Table 7-14). Concentrations of all metals in viscera were positively correlated with the viscera PC1. Therefore, viscera PC1 scores can be considered a summary measure of total metal concentrations in viscera. Viscera PC2 was strongly negatively correlated with concentrations of aluminum and iron. Lower viscera PC2 scores indicate higher concentrations of these metals in viscera, independent of concentrations of other metals. Both aluminum and iron are found in very high concentration in sediments (Appendix B-2). Therefore, viscera PC2 could be considered a measure of natural metals concentration in ingested sediments. Viscera PC3 and PC4 explained lesser amounts of variation in viscera metal concentrations. Nickel correlated moderately strongly (r_P = 0.68) with PC3, and is carried forward for further analysis. No other metals covaried strongly ($|r| \geq 0.6$) with PC4. Therefore, no other metal is carried forward for analysis.

Scallop adductor muscle PC1 (i.e., metals concentrations) varied significantly over time (Year Term $p < 0.001$; Table 7-15), with metals concentrations generally higher from 2000 to 2010, and lower in 1997, and in 2012 and 2014, in both the Study and Reference Areas (Figure 7-5). The BA (before to after) Term was significant ($p = 0.001$), but this difference as well as change over time in EEM years (EEM Linear Term $p < 0.001$) occurred in both Areas (BACI Term $p = 0.720$, EEM Linear x Area Term $p = 0.221$, also see Figure 7-5).

Table 7-15 Results of Two-Way ANOVA Comparing Metal and Fat Concentrations in Scallop Adductor Muscle Among Years and Between Areas (1997 to 2014)

Source	df	*p*		
		PC1	**Log of Boron**	**Log of Fat**
Year	9	**<0.001**	**<0.001**	**<0.001**
BA	1	0.001	0.980	0.029
EEM Linear	1	**<0.001**	0.095	**<0.001**
Area (CI)	1	0.132	**<0.001**	0.062
Year * Area	9	0.080	0.048	0.001
BACI	1	0.720	0.985	0.027
EEM Linear*Area	1	0.221	0.101	0.921
Error	80			

Notes: - $p \leq 0.001$ in **bold.**
- $n = 100$ composite samples.

Muscle boron concentrations varied between approximately 4.5 and 6 mg/kg from 1997 to 2014. Like adductor muscle PC1, boron concentrations varied significantly among years (Year Term $p < 0.001$, Table 7-15; Figure 7-5). Boron concentrations have generally been lower in the Study Area than in the Reference Area (Area Term $p < 0.001$; Figure 7-5), and the difference between the Reference and Study Areas has varied somewhat among years (Year x Area Term $p = 0.048$). The BACI and EEM Linear x Area Terms were not significant ($p > 0.05$), indicating no difference in time trends between the Reference and Study Areas.

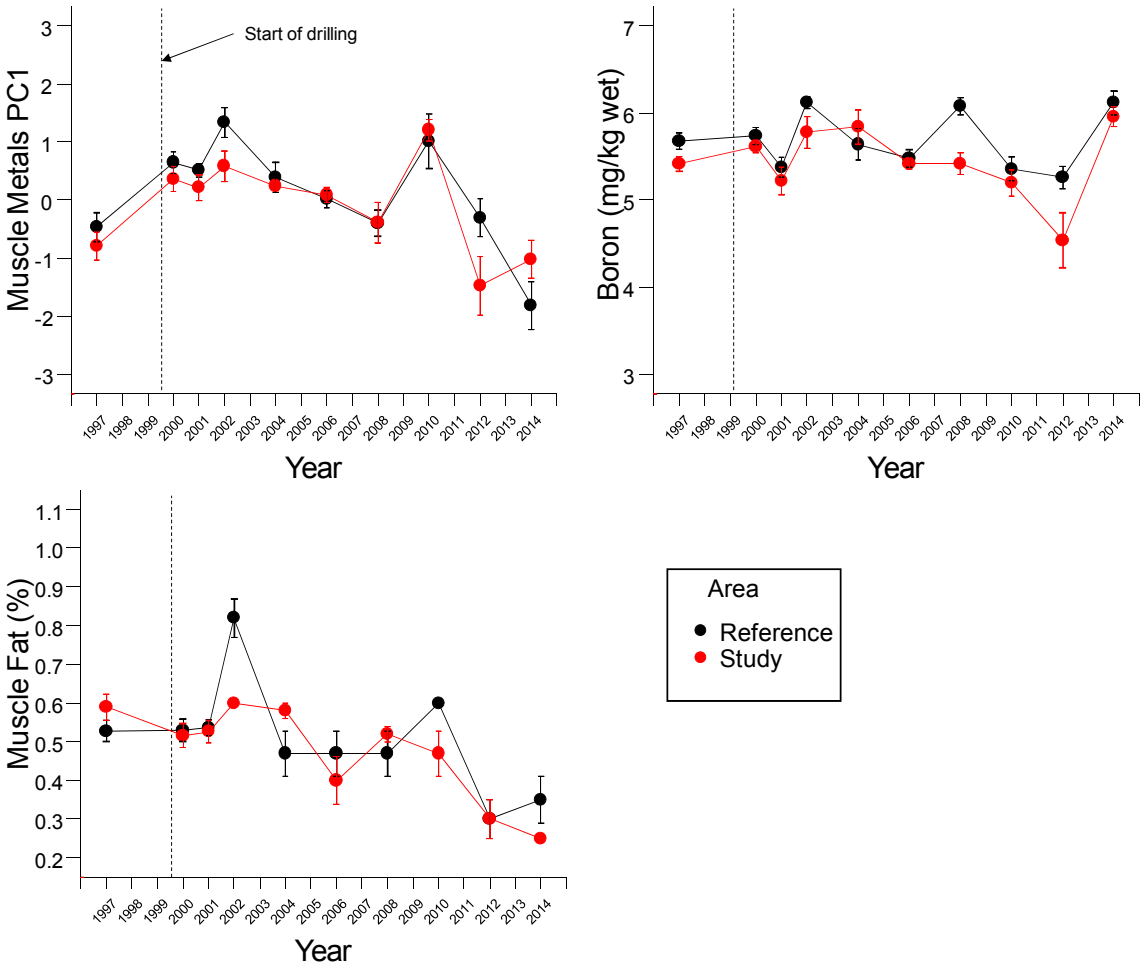


Figure 7-5 Area Mean (± 1 Standard Error (SE)) Metal and Fat Concentrations in Scallop Adductor Muscle (1997 to 2014)

Fat content in scallop muscle has varied between approximately 0.4% and 0.9%. Annual variations in fat content were significant (Year Term $p < 0.001$; Table 7-15). Fat content was generally higher during baseline than in EEM years (BA Term $p = 0.029$); although fat content was high in the Reference Area in 2002 (Figure 7-5). There has been a decrease in fat content of scallop muscle in EEM years (EEM Linear term $p < 0.001$), in both Areas (Area Term $p = 0.062$). The BACI Term was weakly significant ($p = 0.027$), suggesting a small change in the Reference vs Study Area difference from baseline to EEM years. Fat concentrations were modestly lower in Reference Area scallop during the baseline sample period (1997), in contrast to seven of nine years during the drilling period (not including 2004, 2008), when fat concentrations in Reference scallop were the same or higher than concentrations in Study Area scallop.

Viscera metals PC1 scores differed among years (Year Term $p < 0.001$, Table 7-16) and between the Study and Reference Areas (Area Term $p < 0.001$, Table 7-16), but with no difference between Areas from before to after drilling (BACI Term $p = 0.242$, Table 7-16). Viscera metals PC1 scores were greater in the Study Area than in the Reference Area in every year including baseline, except for 2008 (Figure 7-6). Annual Reference Area means were relatively constant over time, whereas Study Area means were more variable (Year x Area Term $p = 0.028$, Figure 7-6). Differences between the two Areas decreased over time in EEM years, with Study Area PC1 scores similar to Reference Area scores since 2008 (EEM Linear x Area Term $p = 0.011$, Figure 7-6).

Table 7-16 Results of Two-Way ANOVA Comparing Metal and Fat Concentrations in Scallop Viscera among Years and Between Areas (1997 to 2014)

Source	df	*p*			
		PC1	PC2	Log of Nickel	Log of Fat
Year	9	**<0.001**	**<0.001**	**<0.001**	**<0.001**
BA	1	0.934	0.349	0.084	**<0.001**
EEM Linear	1	**<0.001**	0.124	0.033	0.159
Area (CI)	1	**<0.001**	0.892	0.660	0.144
Year * Area	9	0.028	0.021	0.001	**<0.001**
BACI	1	0.242	0.010	0.459	0.528
EEM Linear*Area	1	0.011	0.731	0.093	0.142
Error	80				

Notes: - $p \leq 0.001$ in **bold.**
- *n = 100* composite samples.

Viscera PC2 scores (negatively correlated with aluminum and iron concentrations in viscera) also differed significantly over time (Year Term $p < 0.001$, Table 7-16; Figure 7-6), with some differences in changes over time between Areas (Year * Area Term $p = 0.021$, Table 7-16). Viscera PC2 scores were higher in the Study Area than in the Reference Area in 1997 and 2006, and scores were lower in the Study Area in 2010 (Figure 7-6). The BACI Term was significant ($p = 0.010$), again because viscera PC2 scores were higher in the Study Area in 1997 and, with the exception of 2006, scores in the Study Area were similar or lower than Reference Area scores in EEM years (Figure 7-6). There was no difference in the linear time trend between the Reference and Study Areas in EEM years (EEM Linear x Area term $p = 0.731$). Metals PC2 scores were similar in the Study and Reference Areas in 2014, as they were in 2012 (Figure 7-6).

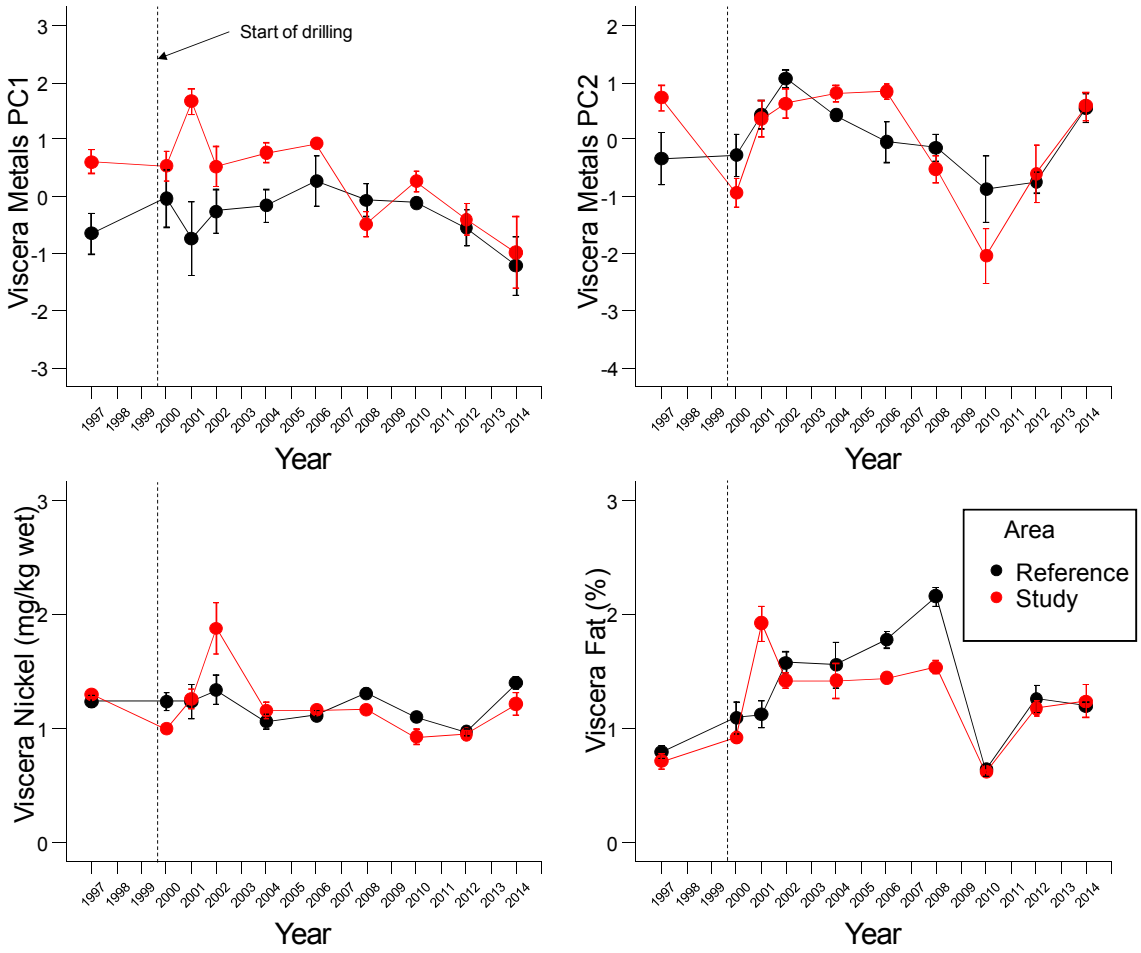


Figure 7-6 Area Mean (± 1 SE) Metal and Fat Concentrations in Scallop Viscera (1997 to 2014)

Viscera nickel concentrations varied over time (Year Term $p < 0.001$), with significant differences over time between Areas (Year * Area Term $p = 0.001$); nickel levels were higher in the Study Area in 2002 (Figure 7-6). The EEM linear term was significant ($p = 0.033$); on average nickel concentrations decreased in EEM years (particularly between 2002 and 2012; Figure 7-6).

Fat content varied over time (Year Term $p < 0.001$), between Areas (BA Term $p < 0.001$), and there were changes in Area differences over time (Year * Area Term $p < 0.001$). Fat content has been lower in Study Area viscera in most years (Figure 7-6), but fat content was higher in the Study Area in 2001. As was the case for metals PC1 and PC2, fat content was similar between Areas in recent years (Figure 7-6). Neither the BACI nor the EEM Linear x Area Terms was significant (both $p > 0.1$, Table 7-16).

Hydrocarbons and Barium

>C_{10}-C_{21} hydrocarbons have never been detected at concentrations above the laboratory detection limit of 15 mg/kg in Reference Area adductor muscle samples (Figure 7-7). >C_{10}-C_{21} hydrocarbons were not detected in the Study Area in baseline (1997). In 2000, 2001, 2002 and 2004, >C_{10}-C_{21} hydrocarbons were detected in three to five of the five Study Area composite muscle samples analyzed in each year. Chromatograms for those hydrocarbons have generally resembled the profile of PureDrill IA35-LV, the drill mud used at Terra Nova. In 2008, >C_{10}-C_{21} hydrocarbons were detected in one sample, but this result was assigned to integration error (Suncor Energy 2009). >C_{10}-C_{21} hydrocarbons were not detected in scallop adductor muscle samples in 2006, 2010, 2012 or 2014.

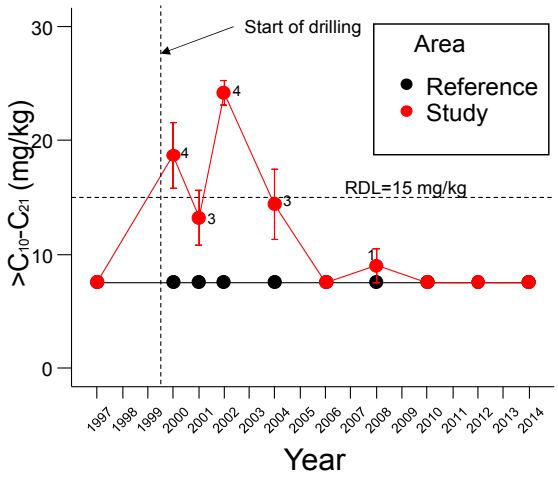


Figure 7-7 Frequencies of Detection and Area Means for >C_{10}-C_{21} Hydrocarbon Concentrations in Scallop Adductor Muscle (1997 to 2014)

Notes: Points are means ± 1 SE. Numeric values beside points indicate the number of detectable concentrations out of five samples. Values below detection were set to half the laboratory detection limit for the purpose of estimating means and SEs.

Barium, a constituent of both synthetic- and water-based drill muds, was detected (laboratory detection limit of 1.5 mg/kg) in two adductor muscles samples from the Reference Area in 2000 and 2004, in three samples from the Study Area in 2010, and in one sample from the Study Area in 2012. Barium was not found in scallop adductor muscle in 2014.

Concentrations of >C_{10}-C_{21} hydrocarbons in all baseline (1997) viscera samples and in most Reference Area samples collected in EEM years were less than the laboratory detection limit of 15 mg/kg (Figure 7-8). >C_{10}-C_{21} hydrocarbons were detected in all 30 Study Area viscera samples collected from 2000 to 2008 but were not detected in any 2010 samples. >C_{10}-C_{21} hydrocarbons were detected in four of five Study Area samples in 2012 and in two of five Study Area samples in 2014. Study Area means were well above the laboratory detection limit in earlier EEM years, and decreased to near or below the laboratory detection limit from 2008 to 2014. Chromatograms from Study Area samples with detectable hydrocarbon concentrations have resembled the profile of PureDrill IA35-LV[32]. Therefore, contamination of scallop viscera from hydrocarbons in synthetic-based drill muds occurred but has been decreasing over time.

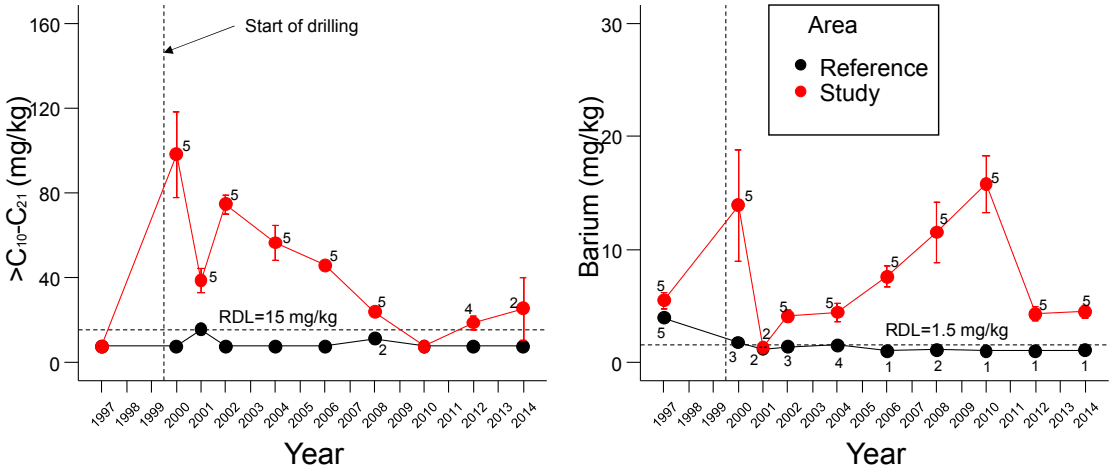


Figure 7-8 Frequencies of Detection and Area Means of >C_{10}-C_{21} Hydrocarbon and Barium Concentrations in Scallop Viscera (1997 to 2014)

Notes: Points are means ± 1 SE. Numeric values beside points indicate the number of detectable concentrations out of five samples. Values below detection were set to half the laboratory detection limit for the purpose of estimating means and SEs.

[32] In addition to PureDrill IA35-LV, the viscera sample from transect TN04 also contained biogenic hydrocarbons (J. Kiceniuk, 2015, pers. comm.).

Barium has been detected more frequently and at higher concentrations in Study Area viscera samples than in Reference Area samples in EEM years (Figure 7-8). In 1997, barium was detected in all five Reference and Study Area samples. Frequencies of detection and median concentrations subsequently decreased in Reference Area scallop. Barium was detected in every Study Area sample in every year except 2001, when it was detected in only two of five samples. From 2001 to 2010, median barium concentrations in viscera of Study Area scallop progressively increased, then decreased in 2012 and 2014 (Figure 7-8). The higher frequencies of detection and median barium concentrations in Study Area samples versus Reference Area samples in EEM years may be evidence of barium contamination from drill muds. Barium in viscera, regardless of source, probably originated from ingested sediment that was later egested, since barium was rarely incorporated into muscle tissue at detectable concentrations.

7.4.2.2 Plaice

Arsenic, mercury and zinc were detected in all plaice fillet samples from 2000 to 2014 (Appendix D-2).

Arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc were detected in most plaice liver composite samples in 2001, 2002, 2004, 2006 and 2010, 2012 and 2014[33] (Appendix D-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 2014 (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.

Fat content in fillet composite samples collected from 2001 to 2014 was approximately 1%. Fat content in composite liver samples was higher (approximately 10%) (Appendix D-2).

[33] Liver samples from individual fish were analyzed in 2000 and these data are not comparable to data collected subsequently.

PAHs were never detected in plaice fillet. PAHs were not detected in plaice liver from 2001 to 2010. 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). PAHs were not detected in liver samples in 2014.

Metals and Fat

Concentrations of arsenic, mercury, zinc and fat in plaice fillets varied significantly among EEM years (all Year Terms $p < 0.01$, Table 7-17). However, those differences were similar in both Areas (all Area Terms and Year x Area Terms $p > 0.05$). Over EEM years, there has been a general increase in concentrations of arsenic and mercury, and a decrease in % fat (EEM Linear $p < 0.01$ for each analyte; Figure 7-9). The changes were common to both Areas (EEM Linear x Area Terms $p > 0.05$).

Table 7-17 Results of Two-Way ANOVA Comparing Metal and Fat Concentrations in Plaice Fillets among Years and Between Areas (2001 to 2014)

Source	df	p			
		Log of Arsenic	Log of Mercury	Log of Zinc	Log of Fat
Year	7	**<0.001**	0.005	**<0.001**	**<0.001**
EEM Linear	1	**<0.001**	0.003	0.222	**<0.001**
Area	1	0.582	0.391	0.520	0.462
Year x Area	7	0.201	0.116	0.741	0.091
EEM Linear x Area	1	0.376	0.474	0.352	0.199
Error	64				

Notes: - $p \leq 0.001$ in **bold.**
- n = 80 composite samples.

Mean concentrations of arsenic, mercury and zinc in fillet samples from individual place in 2000 were similar to means in subsequent years, and did not differ substantially between Areas (Table 7-18). Fat content was not measured in 2000 fillet samples.

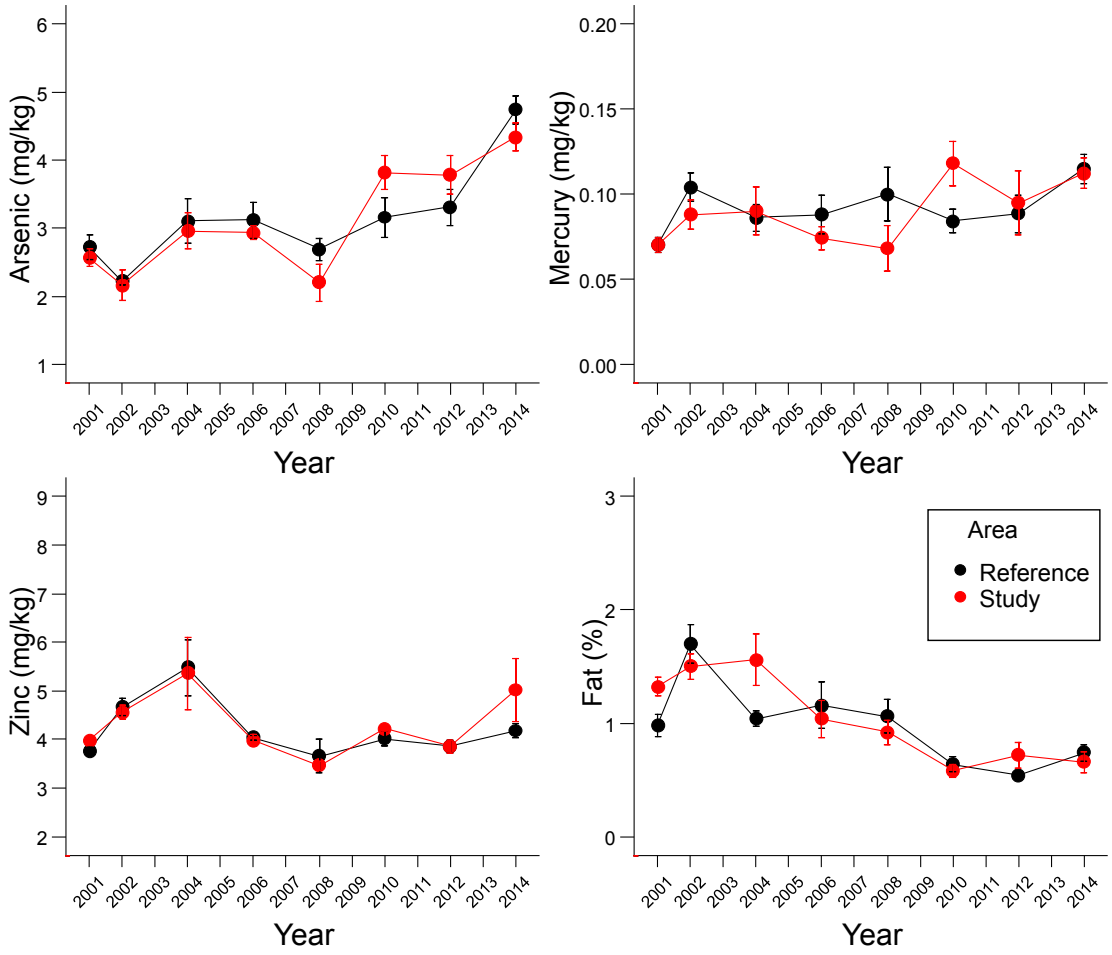


Figure 7-9 Area Mean (± 1 SE) Metal and Fat Concentrations in Plaice Fillets (2001 to 2014)

Table 7-18 Metal Concentrations in Plaice Fillets Sampled in 2000

Metal	Area Mean ± SD (mg/kg)	
	Reference Area (*n* = 11 fish)	Study Area (*n* = 10 fish)
Arsenic	1.89 ± 0.48	2.01 ± 0.59
Mercury	0.044 ± 0.014	0.063 ± 0.028
Zinc	3.99 ± 0.43	4.18 ± 0.65

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). Those two axes each explained more than 10% of the variation in plaice liver metals concentrations. Concentrations of the eight metals detected in all 79 plaice liver composites included in the PCA were positively correlated with the first axis (Table 7-19). Therefore, plaice liver PC1 can be considered to be a summary measure of total metal concentrations. Plaice liver PC2 was negatively

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 7-19 Correlations (r_P) Between Concentrations of Metals in Plaice Liver and Principal Components Derived from those Concentrations (2001 to 2014)

Variable	Correlation (r_P) with	
	PC1	**PC2**
Log of Arsenic	**0.80**	0.35
Log of Cadmium	**0.81**	0.20
Log of Copper	**0.85**	0.27
Log of Iron	**0.91**	0.01
Log of Manganese	0.48	**-0.77**
Log of Mercury	**0.69**	-0.40
Log of Selenium	**0.82**	-0.18
Log of Zinc	**0.90**	0.12
Percent of Variance Explained	62.8	12.9

Notes: - $|r| \geq 0.6$ in **bold.**
- n =79 composite samples.

Plaice liver PC1 scores, manganese concentrations and % fat all varied over time (Year Term $p < 0.001$; Table 7-20). Manganese and % fat decreased significantly in EEM years (EEM linear Term $p < 0.001$; Figure 7-10; although the relationship for % fat was more parabolic than linear). There were changes in differences between Areas over time for manganese (Year x Area Term $p < 0.001$); manganese concentrations were higher in Study Area plaice liver in 2002 and 2004, and concentrations were lower or similar to those in the Reference Area in other years (Figure 7-10).

Table 7-20 Results of Two-Way ANOVA Comparing Metal Concentrations in Plaice Liver among Years and Between Areas (2001 to 2014)

Source	PC1		Log of Manganese		Log of Fat	
	df	***p***	**df**	***p***	**df**	***p***
Year	7	**<0.001**	7	**<0.001**	5	**<0.001**
EEM Linear	1	0.300	1	**<0.001**	1	**<0.001**
Area	1	0.873	1	0.832	1	0.797
Year x Area	7	0.164	7	<0.001	5	0.855
EEM Linear x Area	1	0.440	1	0.114	1	0.507
Error	63		63		48	

Notes: - $p \leq 0.001$ in **bold.**
- n = 79 composite samples from 2001 to 2014 for metals.
- n = 60 composite samples from 2004 to 2014 for fat.

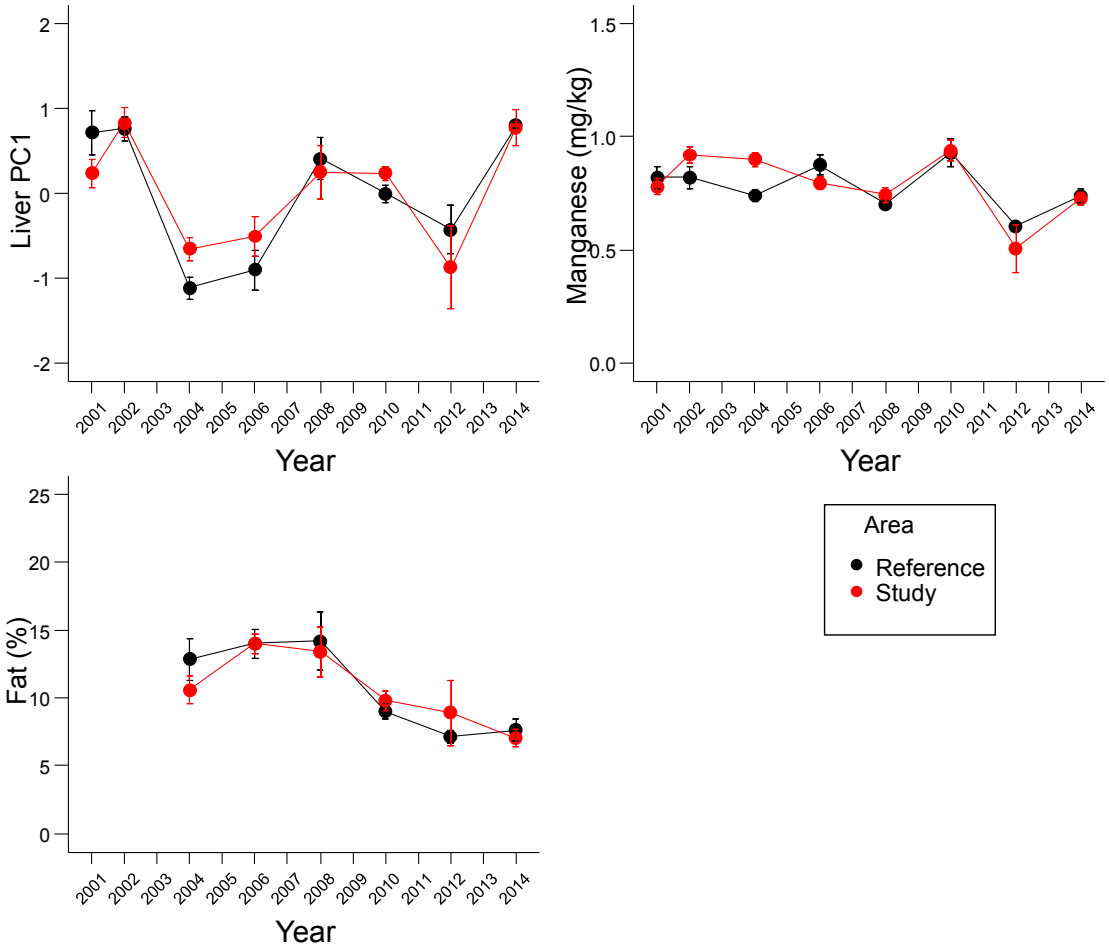


Figure 7-10 Area Mean (± 1 SE) Metal (2001 to 2014) and Fat (2004 to 2014) Concentrations in Plaice Livers

Annual means for % fat in both Areas from 2004 to 2014 were approximately 7 to 15%, similar to values for the single Area composites analyzed in 2001 and 2002 (Table 7-21).

Table 7-21 Fat Content 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

>C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons were detected in a fillet from one (of 10) 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).

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 7-22). Compounds in the >C_{21}-C_{32} range were detected in all composites in those two years. In 2006, 2008, 2010, 2012 and 2014, compounds in the >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbon range were detected in all liver composites. Median and maximum hydrocarbon concentrations were generally similar in the Reference and Study Areas (Table 7-22).

Table 7-22 Hydrocarbon Concentrations in Plaice Liver (2002 to 2014)

Carbon Range	Year	Reference Area			Study Area		
		No. (of 5) >LDL	Median (mg/kg)	Maximum (mg/kg)	No. (of 5) >LDL	Median (mg/kg)	Maximum (mg/kg)
$>C_{10}$-C_{21}	2002[a]	2	<70	28	2	<80	39
	2004	5	34	41	3[b]	37[b]	50[b]
	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
$>C_{21}$-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

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 the 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.

- LDL = Laboratory Detection Limit.

Since 2002, hydrocarbons in liver have showed no resemblance to drill mud hydrocarbons. One sample in 2008, from a Reference Area composite, showed potential $>C_{21}$-C_{32} contamination (J. Kiceniuk, 2011, pers. comm.). Based on examination of chromatograms, only one liver sample in 2012 was contaminated with petrogenic material, and that contamination likely occurred onboard vessel (see Suncor Energy 2013 for details). Otherwise, hydrocarbon peaks observed on chromatograms for liver (Appendix D-2; also see Suncor Energy 2003, 2005, 2007, 2009, 2011 and 2013 for chromatograms for 2002, 2004, 2006, 2008, 2010 and 2012 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 2013). In 2014, liver samples from the Terra Nova Study and Reference Areas were analyzed further by mass spectroscopy. Based on these additional analyses, Maxxam Analytics reports that there was no indication of petrogenic hydrocarbons in any sample (see Appendix D-2 for results of additional analysis on liver).

7.4.3 TASTE TESTS

7.4.3.1 Scallop

No significant difference in taste was noted between scallop collected in the Study and Reference Areas in the triangle test. Panellists were successful in discriminating 8 out of 24 samples. These results are not significant at $\alpha = 0.05$ (Appendix D-5).

ANOVA statistics for the hedonic scaling test are provided in Table 7-23 and a frequency histogram of results is provided in Figure 7-11. These results show no significant taste difference between Areas.

Table 7-23 ANOVA Statistics for the 2014 Taste Evaluation by Hedonic Scaling of Scallop

Source of Variation	SS	df	MS	F	*p*
Area	0.0	1	0.0	0.0	1.0
Residual	96.67	46	2.10		
Total	96.67	47			

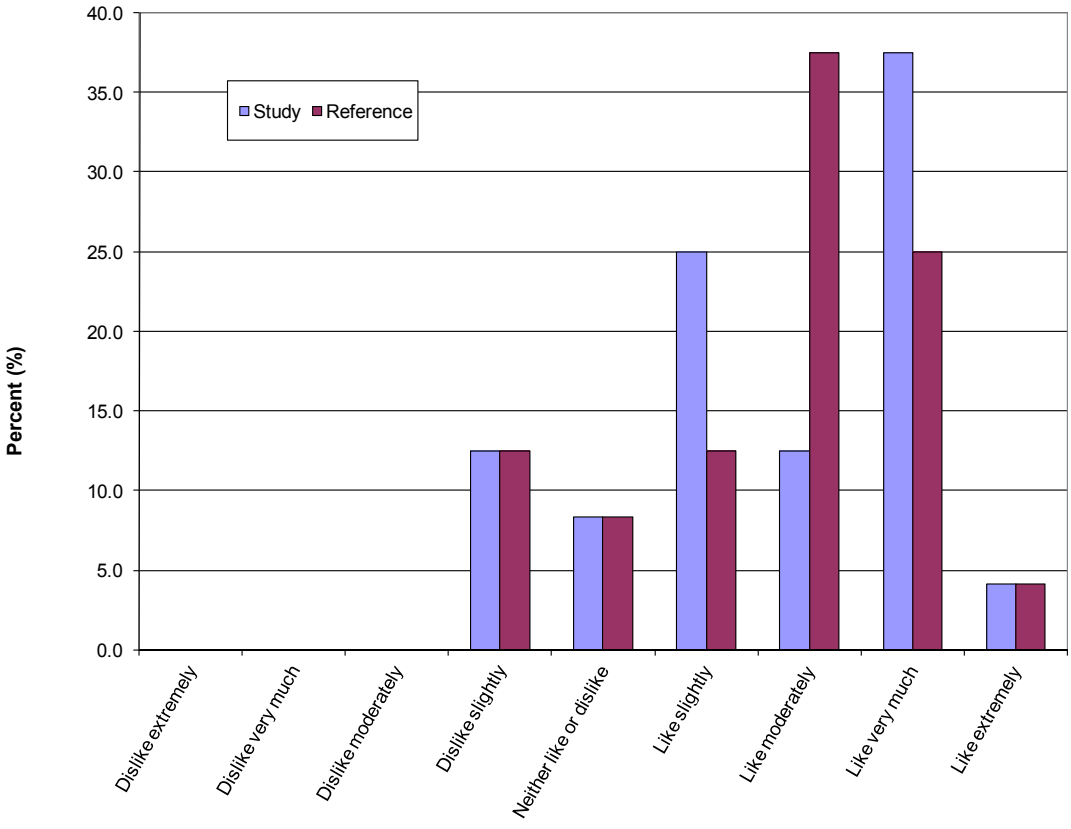


Figure 7-11 Scallops Frequency Histogram for Hedonic Scaling Taste Evaluation (2014)

From ancillary comments (Tables 7-24 and 7-25; Appendix D-5), one panelist noted a foreign 'alcohol' taste and smell (Table 7-24). Overall, there were no consistent comments identifying abnormal or foreign odour or taste.

Table 7-24 Summary of Comments from the Triangle Test for Scallop (2014)

Reference Area (RA)	Study Area (SA)
Correctly identified as odd sample	**Correctly identified as odd sample**
510 (SA) and 953 (SA) taste and smell like they have alcohol or something similar in them	Difficult. They tasted all the same
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
305 (RA) slightly browned	798 (RA) and 953 (SA) had a slight aftertaste that seemed different than 510 (SA)
305 (RA) and 143 (SA) had a sweeter flavour	All tasted the same. Just a guess
362 (SA) and 939 (RA) have a sweeter scallop taste. 561 (RA) is pretty tasteless	218 (SA) had a lighter taste
	More flavour, sweeter

Table 7-25 Summary of Comments from the Hedonic Scaling Test for Scallop (2014)

Preferred Reference Area	Preferred Study Area
947 (reference) lots of sand; bland. 967 (study) gritty; bland	947 (reference) lots of sand; bland. 967 (study) gritty; bland
Very good except for the grit	Very good except for the grit
Both taste similar	The first one tastes like scallops, the second one like a scallop imitation. It is lacking in taste. An analogy: crabs and crabsticks
Both samples were good	Both samples were good
992 (reference) more flavour. 322 (study) very bland	800 (study) more flavourful/sweeter
Odd aftertaste on both samples. Both seemed same	992 (reference) had an off aftertaste
Sample 102 (reference) has a preferred intense sweet flavour	Odd aftertaste on both samples. Both seemed same
102 (reference) was browned on the bottom. I think that changed the taste a bit. Both samples are very sweet	701 (study) seems a little sweeter with more pronounced characteristic odour and flavour of scallop
	102 (reference) was browned on the bottom. I think that changed the taste a bit. Both samples are very sweet
	701 (study) had a nice sweet scallop flavour. 102 (reference) was a little bit blander

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

7.4.3.2 Plaice

No significant difference in taste was noted between plaice collected in the Study and Reference Areas in the triangle test. Panellists for the triangle test were successful in discriminating 10 out of 24 samples. These results were not significant at $\alpha = 0.05$ (Appendix D-5).

ANOVA statistics for the hedonic scaling test are provided in Table 7-26 and a frequency histogram of results is provided in Figure 7-12. These results show no significant taste difference between Areas.

Table 7-26 ANOVA Statistics for 2014 Taste Evaluation by Hedonic Scaling of Plaice

Source of Variation	SS	df	MS	F	*p*
Area	0.52	1	0.52	0.29	0.60
Residual	83.86	46	1.83		
Total	84.48	47			

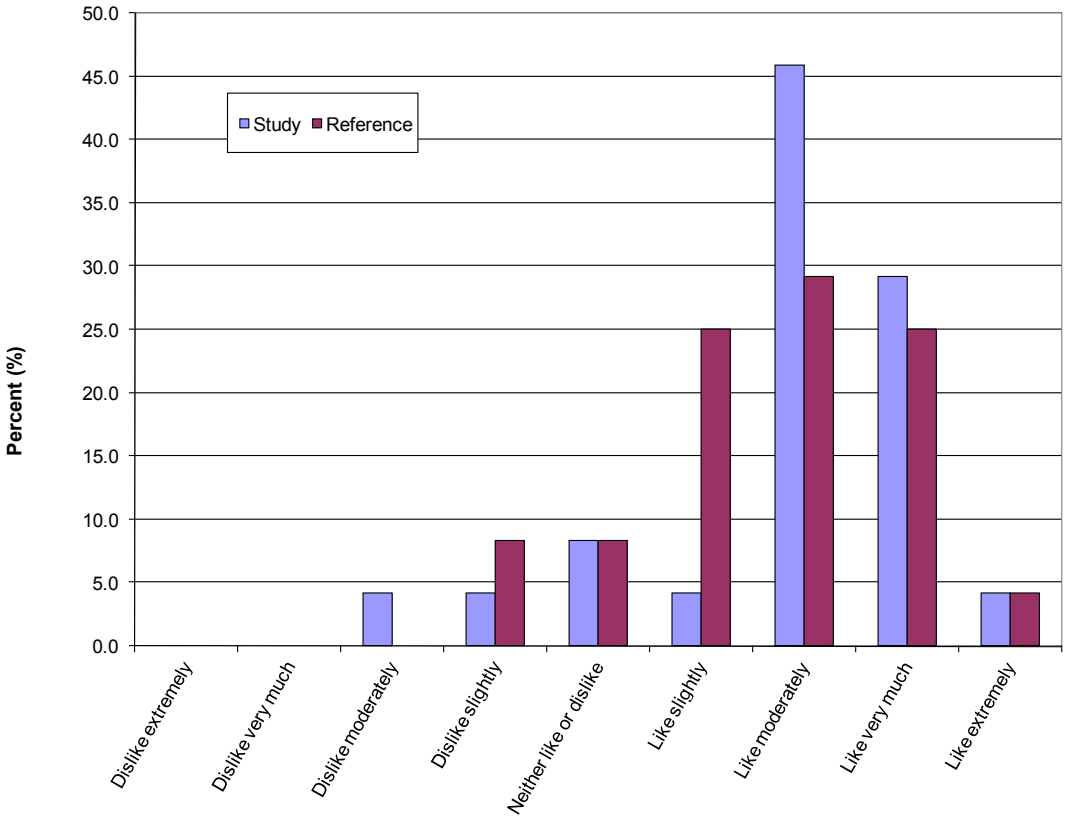


Figure 7-12 Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2014)

Ancillary comments from panellists for both tests are summarized in Tables 7-27 and 7-28 and presented in full in Appendix D-5. There were no consistent comments identifying abnormal or foreign odour or taste.

Table 7-27 Summary of Comments from the Triangle Test for Plaice (2014)

Reference Area (RA)	Study Area (SA)
Correctly identified as odd sample	**Correctly identified as odd sample**
Checking because I was told I must. Not sure at all, however. Very difficult to tell	not much difference noted
Very little difference but 817 (RA) taste slightly fishier than the other two samples	
257 (RA) tastes better	
difference very subtle, so much so, I actually guessed a result	
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
slightly off flavour	I could not distinguish the odd sample. 688 (SA) is a guess
No difference	based on taste and odour. Did not enjoy
Sample 930 (RA) has a less preferred flavour as compared with the other two	little stronger flavour profile
867 (RA) has a much lighter taste than 505 (SA) and 197 (RA)	786 (SA) was a little different
Sweeter flavour. All samples were acceptable	

Table 7-28 Summary of Comments from Hedonic Scaling Tests for Plaice (2014)

Preferred Reference Area	Preferred Study Area
Both samples were very "plain". Nothing to really like or dislike about them. They were "OK".	They are very similar in taste and odour
Found very little difference in the samples. 249 (Study) slightly bland	322 (Reference) smells more "fishy". 249 (Study) slightly sweeter tasting
It's all good!!!	Both samples were very "plain". Nothing to really like or dislike about them. They were "OK".
No real difference	Found very little difference in the samples. 249 (Study) slightly bland
844 (Reference) light tasting flavour, nice, moisture on fish. 510 (Study) tasted very "fishy"	It's all good!!!
Both were OK, but 720 (Reference) tasted better	384 (Reference) slightly sweet flavour while 161 (Study) was a little saltier
Number 737 (Study) tasted a little blander than the number 720 (Reference). Although both were good	No real difference
	Strong flavour on sample 384 (Reference)
	Liked the taste of sample 510 (Study) a little more
	737 (Study) more flavourful, sweeter. 720 (Reference) bland to slight stale.
	737 (Study) and 720 (Reference) were very similar. Liked 737 (Study) slightly more. Slight aftertaste with 720 (Reference)
	Both samples were very similar. 737 (Study) little more pronounced taste

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

7.4.4 FISH HEALTH INDICATORS

7.4.4.1 Gross Pathology

With the exception of one worm observed on the liver 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 D-3, Annex B).

7.4.4.2 Haematology

Blood smears collected during the 2014 survey displayed signs of clotting, water micro-droplets and lack of uniformity. Therefore, they were considered not suitable for carrying out reliable differential cell counts. Preliminary screening of the smears indicated that counts could vary by more than 20% upon examination of different regions of a slide. In human haematology, when 200 cells are counted, the variability is normally in the ± 7 to 10% range (Lynch et al. 1969). Oceans Ltd. considered the quality of smears poor and the variability too high in the 2014 fish for carrying out haematological analysis.

7.4.4.3 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 D-3, Annex C. The results for each sex (all maturity stages pooled) and for spent females are summarized in Tables 7-29 to 7-31, and Figures 7-13 to 7-16. Due to an error in sampling, some of the liver samples were stored at -20°C, instead of -65°C, and MFO activity was higher for samples stored at the lower temperature ($p < 0.001$, Mann-Whitney Rank Sum test; see appendix D-3 for details). Because of this difference, storage temperature was used as an additional variable in analysis of MFO results and/or MFO results were examined separately for each storage temperature.

Table 7-29 MFO Activity in the Liver of Male Plaice (2014)

Sampling Area	Storage Temperature	n	EROD Activity (pmol/min/mg protein)
Reference	-65 °C	1	18.013
Reference	-20 °C	2	4.52 ± 1.44
Study	-65 °C	2	12.40 ± 11.09
Study	-20 °C	2	9.40 ± 9.40

Note: Data are means ± standard deviation.

Table 7-30 Factorial ANOVA Results on Log_{10} MFO Activity for Female Plaice (All Maturity Stages Combined) (2014)

Source of Variation	SS	df	MS	F	*p*
Area	0.0004	1	0.0004	0.0026	0.959
Storage Temperature	5.830	1	5.830	40.801	<0.001
Area X Temperature	0.0338	1	0.0338	0.237	0.628
Residual	12.575	88	0.143		
Total	18.534	91	0.204		

Table 7-31 Factorial ANOVA Results on Log_{10} MFO Activity for F-510 Female Plaice (2014)

Source of Variation	SS	df	MS	F	*p*
Area	0.0302	1	0.0302	0.275	0.602
Storage Temperature	5.376	1	5.376	48.888	<0.001
Area X Temperature	0.0165	1	0.0165	0.150	0.700
Residual	6.9127	63	0.110		
Total	12.306	66	0.186		

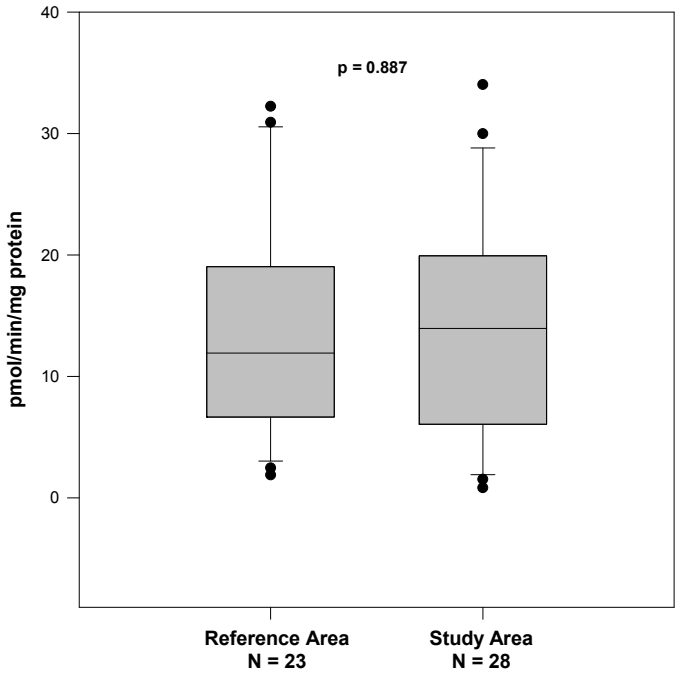


Figure 7-13 MFO Activity in the Liver of Female Plaice (All Maturity Stages Combined) Stored at -65°C (2014)

Notes: Data plotted are median (horizontal line in middle of box), 25th and 75th 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 Mann-Whitney Rank Sum test.

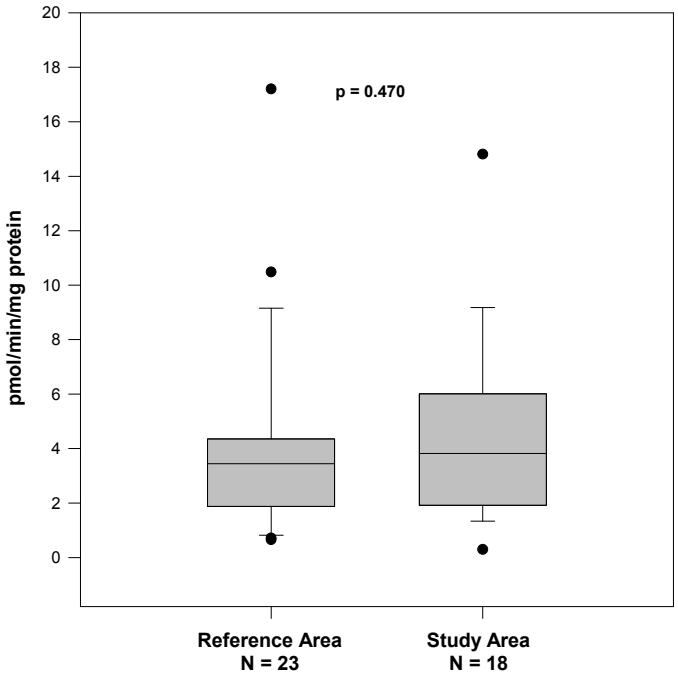


Figure 7-14 MFO Activity in the Liver of Female American Plaice (All Maturity Stages Combined) Stored at -20°C (2014)

Notes: Data plotted are median (horizontal line in middle of box), 25th and 75th 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 Mann-Whitney Rank Sum test.

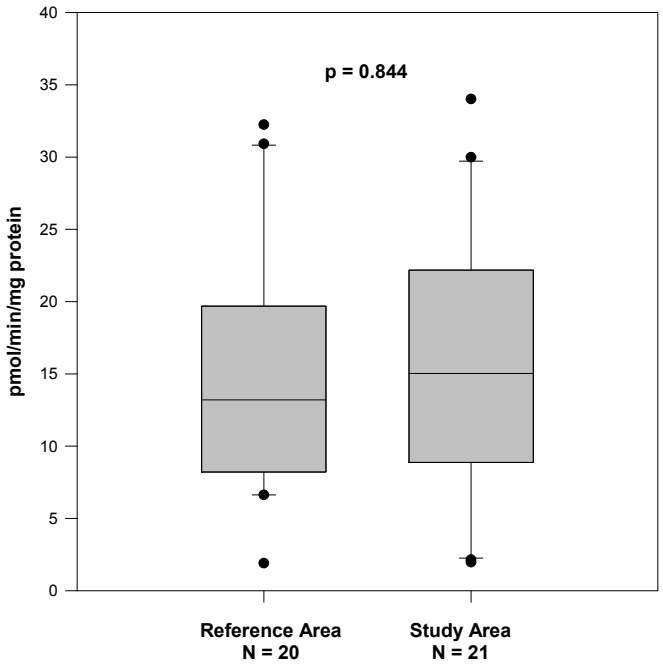


Figure 7-15 MFO Activity in the Liver of F-510 Female American Plaice Stored at -65°C (2014)

Notes: Data plotted are median (horizontal line in middle of box), 25th and 75th 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.

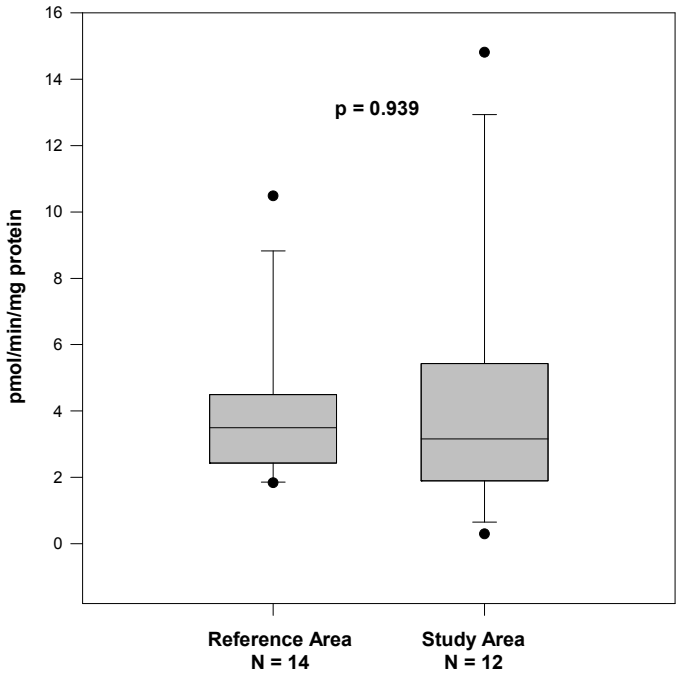


Figure 7-16 MFO Activity in the Liver of F-510 Female American Plaice Stored at -20°C (2014)

Notes: Data plotted are median (horizontal line in middle of box), 25th and 75th 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 Mann-Whitney Rank Sum test.

The low number of male fish captured prevented the statistical analysis of liver MFO activity. However, MFO activity for each Area is provided for informational purposes in Table 7-29.

For females, and because MFO data deviated from assumptions of normality (but not equality of variance), both parametric and non-parametric statistics were used to assess differences between Areas. Factorial ANOVA on $\log_{10}$ values indicated differences in storage temperature (as noted above), but no difference between Areas, and no Area X Temperature interaction (Table 7-30). From non-parametric tests for each temperature, no significant differences between Areas were detected for samples stored at -65°C (p = 0.887; Mann-Whitney Rank Sum test; Figure 7-12) or for samples stored at -20°C (p = 0.470; Mann-Whitney Rank Sum test; Figure 7-13).

Since maturity stage can result in some loss of sensitivity for resolving contaminant mediated differences in females during spawning, a comparison of enzyme activity was also carried out on spent female fish (DFO maturity stages F-510; see Annex A

for maturity stage classification). No significant differences were detected between the Reference and Study Areas in liver EROD activity of F-510 females in parametric comparisons on $\log_{10}$ values (Table 7-31) or for samples stored at -65°C (p = 0.884; Mann-Whitney Rank Sum test; Figure 7-13) or at -20°C (p = 0.939; Mann-Whitney Rank Sum test; Figure 7-14).

7.4.4.4 Histopathology

Liver Histopathology

Liver histopathology was examined on a total of 55 livers, 30 from the Study Area and 25 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 7-32). The complete data set is provided in Appendix D-3, Annex D. Representative photographs of normal liver as well as a number of histological changes are included in Appendix, D-3, Annex F.

Table 7-32 Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions (2014)

Variable	Reference Area (N = 25)		Study Area (N = 30)	
	Fish affected	Prevalence % [a]	Fish affected	Prevalence % [a]
Nuclear pleomorphism	0	0	0	0
Megalocytic hepatosis	0	0	0	0
Focus of cellular alteration	0	0	0	0
Fibrillar inclusions	0	0	0	0
Proliferation of macrophage aggregation [b]	0	0	0	0
Inflammatory response [c]	1	4	2	6.67
Hepatocellular vacuolation	1	4	5	16.67
Parasitic infestation of biliary system	16	64	23	76.67
Golden rings	0	0	2	6.67

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.

No cases of nuclear pleomorphism, megalocytic hepatosis, focus of cellular alteration, fibrillar inclusions or macrophage aggregation were detected in any of the fish. The frequency of other lesions generally not associated with chemical pollutants is provided in Appendix D-3. There were no significant differences (Fisher exact test, $p > 0.05$ in all cases) in any of the hepatic indices examined between fish from the Study and Reference Areas.

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 7-33, with details provided in Appendix D-3. In all cases, the percentages of lamellae affected by the lesions were all less than 1.4%.

Table 7-33 Occurrence of Lesions in the Gill Tissues of Plaice (2014)

Variable	Reference Area N = 24	Study Area N = 30
Basal hyperplasia 1 [a b]	0.0016 ± 0.0042	0.0011 ± 0.0019
Basal hyperplasia 2 [a c]	0.0001 ± 0.0006	0
Distal hyperplasia [a]	0.0001 ± 0.0004	0.0006 ± 0.0019
Tip hyperplasia [a]	0.0006 ± 0.0014	0.0006 ± 0.0019
Fusion [a]	0.0004 ± 0.0014	0.0002 ± 0.0008
Telangiectasis [a]	0	0

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 D-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.

Statistical comparisons between the Study and Reference Areas on the number of fish exhibiting lesions are presented in Table 7-34. None of the gill lesions occurred either more or less frequently in Study Area fish compared to Reference Area fish (Fisher Exact test, $p > 0.05$ in all cases).

Table 7-34 Number of Plaice with Specific Types of Gill Lesions and Percentages of Fish Exhibiting the Lesions (2014)

Gill Lesions	Measure	Reference Area	Study Area
Total Number of Fish	Number	24	30
Distal Hyperplasia	Number	1	6
	%	4.17	20
Tip Hyperplasia	Number	5	5
	%	20.83	16.67
Basal Hyperplasia 1[a]	Number	4	8
	%	16.67	26.67
Basal Hyperplasia 2[b]	Number	1	0
	%	4.17	0
Fusion	Number	2	2
	%	8.33	6.67
Telangiectasis	Number	0	0
	%	0	0

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

7.5 SUMMARY OF RESULTS

7.5.1 BIOLOGICAL CHARACTERISTICS

In 2014, a total of 760 scallop were collected in Reference and Study Areas. Overall female to male ratios were approximately 60:40 and females outnumbered males in most transects, with no difference in sex ratio between the Study and Reference Areas. Females and males were similar in size, and there were no differences in the size or shape of scallop between the Reference and Study Areas for either females or males. Those results held for the subset (n = 200) of scallop used in body burden analysis.

A total of 100 female plaice were collected in the Reference and Study Areas. Overall female to male ratios were approximately 90:10 and females outnumbered males in all transects, with no difference in sex ratios between the Study and Reference Areas. The number of males collected in either the Reference or Study Area was low (four males in the Study Area; three males in the Reference Area) and statistical analysis on the frequency of maturity stages and other variables requiring analysis by sex were not performed. For females, there was no difference between Areas in the frequency of maturity stages.

Size and condition for female plaice were similar between Areas in most cases. Females from the Study Area were older and had a higher mean hepatosomatic index. However, there was no statistical difference between Areas for adjusted means of liver weight on the covariate of gutted body weight (a comparable and more appropriate measure of variability in liver weight).

7.5.2 BODY BURDEN

7.5.2.1 Scallop

Arsenic, boron, cadmium, mercury, strontium and zinc were detected in most scallop adductor muscle samples analyzed from 1997 to 2014. Aluminum, arsenic, boron, cadmium, copper, iron, manganese, mercury, nickel, selenium, strontium, uranium and zinc were detected in most viscera samples from 1997 to 2014. Other metals were rarely or never detected.

Overall metal concentrations in scallop adductor muscle (based on muscle PC1 scores) differed significantly among years. In both Areas, concentrations of most metals were greater from 2000 to 2010, than in 1997 (baseline), 2012 and 2014.

Boron concentration in muscle (examined separately from other metals because it varied somewhat independently from other metals) also differed significantly among years, with concentrations generally lower in the Study Area than in the Reference Area in most years, including baseline (1997).

Fat content in muscle varied among years, with concentrations lower in Reference Area versus Study Area scallop during baseline. In EEM years, fat content in scallop muscle was most often the same or higher in the Reference Area compared to the Study Area. Differences were slight, with fat content approximately 0.05% lower in Reference Area scallop muscle during baseline. When fat content was higher in Reference Area scallop in EEM years, it usually differed by approximately 0.1% to 0.2%.

Overall metals concentration in scallop viscera (viscera PC1 scores) differed among years and concentrations have been higher in the Study Area than in the Reference Area in most years, including baseline. Differences between the two Areas have decreased over time, with similar levels in both Areas since 2008. In 2014, metals concentrations in both the Study and Reference Areas were lower than concentrations measured during baseline.

Viscera PC2 scores (negatively correlated with concentrations of aluminum and iron) also differed significantly among years; scores were higher in the Study Area than in the Reference Area in 1997 and 2006, and scores were lower in the Study Area in 2010. Otherwise, viscera PC2 scores have been similar between the Study and Reference Areas, especially in 2012 and 2014.

Nickel concentrations in viscera were generally similar between the Study and Reference Areas, except in 2002, when concentrations were higher in the Study Area. In 2014, nickel concentrations in both the Study and Reference Areas were similar, and these were similar to baseline concentrations.

Fat content has been lower in Study Area viscera in most years, but fat content was higher in the Study Area in 2001. As was the case for metals PC1 and PC2, fat content was similar between Areas in recent years

>C_{10}-C_{21} hydrocarbons, important constituents of synthetic-based drill muds, were detected in Study Area scallop adductor muscle after drilling began, and chromatogram profiles have indicated the presence of the drill mud PureDrill IA35-LV. However, hydrocarbon concentrations in Study Area muscle decreased to

near or below the laboratory detection limit in recent years and >C_{10}-C_{21} hydrocarbons were not detected in muscle tissue in 2006, 2010, 2012 and 2014.

>C_{10}-C_{21} hydrocarbons resembling the drill mud PureDrill IA35-LV have been noted in Study Area scallop viscera since drilling began. Study Area means were well above the laboratory detection limit in earlier EEM years and have decreased to near or below the laboratory detection limit from 2008 to 2014.

Barium has been detected more frequently and at higher concentrations in Study Area viscera samples than in Reference Area samples. From 2001 to 2010, median barium concentrations in viscera of Study Area scallop progressively increased. The concentration of barium decreased in 2012 and 2014 to levels similar to baseline levels. Barium in viscera, regardless of source, probably originated from ingested sediment that was later egested, since barium was rarely incorporated into muscle tissue at detectable concentrations.

7.5.2.2 Plaice

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.

Concentrations of arsenic, mercury, zinc and fat in plaice fillets varied among years, but not between Areas. There was a general increase in arsenic and mercury concentration in plaice fillets, and a decrease in fat content. These changes were common to both Areas.

Overall metals concentrations in plaice liver (liver PC1 scores) differed among years, but not between Areas. Manganese concentration in liver (examined separately from other metals), as well as fat concentration, varied among years and decreased linearly over time, in both the Reference and Study Areas. Manganese concentrations were higher in Study Area plaice liver in 2002 and 2004, and concentrations were lower or similar to Reference Area concentrations in other years.

>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 2014, but none of these compounds had profiles that matched that of PureDrill IA35-LV. As in previous years, additional mass spectroscopy tests on liver samples indicated that compounds were not petrogenic in origin.

Barium has not been detected in plaice fillet and liver samples.

7.5.3 TASTE TESTS

There was no evidence of taint for scallop or plaice. No difference in taste was noted between the Study and the Reference Areas for either tissue types in the triangle and hedonic scaling tests, and there were no consistent comments from panellists identifying abnormal or foreign odour or taste.

7.5.4 FISH HEALTH INDICATORS

With the exception of one worm observed on the liver of one fish from the Study Area, there were no 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.

No difference between Areas in MFO activity was noted for female plaice with all maturity stages pooled, or spent females.

There were no cases of liver lesions that have been commonly associated with chemical toxicity; and there was no difference in the number of fish exhibiting gill lesions between the Study and Reference Areas.

8.0 DISCUSSION

8.1 SEDIMENT COMPONENT

8.1.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

Sediments in the Terra Nova area are predominantly sand, with median sand content greater than 90% in 2014 and all previous years. Gravel content varied from 0% to approximately 30%. Fines (silt + clay) content was low (median and maximum fines content were 1.1% and 2.7% in 2014, respectively).

Barium is a major constituent of water-based drill muds 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 can be considered near or below the laboratory detection limit of 0.3 mg/kg. Therefore, concentrations greater than 0.3 mg/kg are evidence of contamination and distance gradients (decreases in concentration with increasing distance from drill centres) for >C_{10}-C_{21} 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 from the centre of the development. Consequently, it is difficult to distinguish low-level barium contamination from variance in natural background concentrations.

In 2014, 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 2014 (i.e., the estimated zone of influence) was approximately 4.5 km, which is within the threshold distance for previous years. Threshold distances of approximately 4 to 5 km for >C_{10}-C_{21} hydrocarbons were noted in 2004 and 2006. Barium concentrations decreased to background levels within approximately 3 km from drill centres in 2014. Both threshold estimates were higher in 2014 than those noted in recent years. However, given overlapping confidence intervals for the estimates, the threshold for >C_{10}-C_{21} hydrocarbons was not

statistically different than in past years; the threshold for barium was not statistically different than in 2002 and 2010.

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[34]. 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 2014, maximum >C_{10}-C_{21} hydrocarbon and barium concentrations were low compared to these previous maxima (40 and 880 mg/kg, respectively) and occurred at station 31(FE), located 0.37 km from the FE drill centre. 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 2014 were 1.2 and 150 mg/kg, respectively.

There has been evidence of project effects on sulphur in some EEM years, with elevated levels at a few stations near drill centres. That evidence was weaker in 2014 and the relationship between sulphur and distance to drill centres was not significant. Sulphur (barium sulphate) is an important component of drill muds. Therefore, sulphur contamination would be expected where barium contamination occurs[35]. A decrease in project effects on sulphur in 2014 is consistent with the noted decrease in project effects on barium.

Distance gradients for sulphides and redox were significant in 2014, with sulphides decreasing and redox increasing with distance to drill centres. In both cases, relationships were stronger with distance from the FEZ drill centres than from the FE drill centre. Combined, these results could indicate some level of decomposition of natural or anthropogenic organic carbon. Distance gradients for both variables were weak, with higher sulphides and lower redox at a few stations within 1 to 2 km of drill centres. As in most previous years, all sediments were oxic.

[34] A total of 400 tonnes of oil-on-cuttings and 3,944 m^3 of water-based muds were discharged at Terra Nova from 2007 to October 2014, when collections for the 2014 EEM program took place (Suncor Energy 2013 and Section 4). Prior to this, 5,424 tonnes of oil-on-cuttings and 54,622 m^3 of water-based muds were discharges (Suncor Energy 2013). Also see DeBlois et al. (2014a) for discharge statistics by drill centre to 2010.

[35] Elemental sulphur accounts for only 15% of the weight of barium sulphate, whereas barium accounts for 60%. Therefore, contamination by sulphur, a lesser constituent of barium sulphate, should be of lesser magnitude than barium contamination.

There has been weak evidence of project effects on sediment fines in some EEM years, with fines elevated in the immediate vicinity of drill centre. Sediment fines content in 2014 decreased with distance from the FEZ drill centres, as in previous years, with no change in distance relationships among EEM years. Sediment fines content also decrease with distance from the centre of the development (i.e., FEZ drill centres) in baseline. Fines content in 2014 ranged from 0.6% to 2.7% (median = 1.1%). Fines content during baseline (1997) ranged from 0.7% to 3.4% (median = 1.0%). These data indicate that any project effects on sediment fines content have been minor.

Sediment metals concentrations, ammonia and organic carbon content decreased from the centre of the development (i.e., FEZ drill centres) in 2014. For metals and organic carbon, these gradients were apparent in all EEM years and were present and strong in baseline (1997), although the gradient for organic carbon with distance from the centre of the development decreased in strength in 2014. Ammonia was not measured in baseline and has shown a consistent gradient from the centre of the development since it was first measured in 2001.

In summary, project effects on $>C_{10}$-C_{21} hydrocarbons and barium were clear and consistent. 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 2014. Higher sulphide and lower redox levels at some stations near drill centre indicate that decomposition of drill fluid may be occurring. However, higher sulphide and lower redox levels could also be related to decomposition of naturally occurring organic carbon, given the distance gradients noted for this variable since baseline. Other physical and chemical characteristics have been largely unaffected by project activities. Evidence for effects ranged from none to equivocal (i.e., with elevated levels observed at only a few stations near drill centres and/or in a few years). Baseline distance gradients (usually decreases in values with distance from the centre of development) for variables measured in 1997 persisted through EEM years, often with little or no 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). Given higher levels of sulphides and lower redox levels near source in 2014 some degradation of hydrocarbons may be occurring. However, 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. (2014b) 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. The shift in the maximum >C_{10}-C_{21} and barium concentrations from stations 30(FE), nearest the FE drill centre, to station 31(FE), also supports the concept of cuttings redistribution.

8.1.2 TOXICITY

Sediments from 11 stations were toxic to Microtox in 2014. Microtox IC50s were not correlated with distance to drill centres. As in previous years, strontium and fines were the strongest correlates with Microtox IC50s. Strontium has not been affected by Terra Nova activity and evidence that fines have been affected has only been conclusive at station 30(FE) and that station has never been toxic to Microtox.

Results from 2014 are consistent with prior results and indicate that variations in Microtox responses are more likely natural. Whiteway et al. (2014) reviewed Terra Nova Microtox and amphipod toxicity results from baseline to 2010, and concluded that toxicity to Microtox was more likely driven by natural differences in sediment types. Toxicity has never been related to distance from drill centres and has more frequently occurred at approxmately 1 to 2 km from drill centres (Figure 8-1). Figure 8-1 shows that the toxicity response at station 30(FE), historically with the highest sediment >C_{10}-C_{21} hydrocarbon and barium concentrations, has been similar to that at references stations.

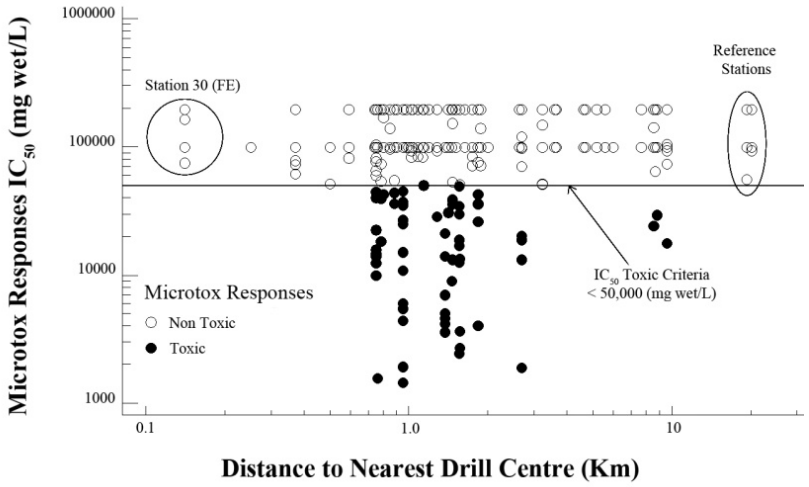


Figure 8-1 Microtox IC50 Responses at Terra Nova EEM Stations (2000 to 2010)

Source: Whiteway et al. 2014

An examination of the particle size composition between stations with toxic and non-toxic responses indicated that non-toxic stations (the dominant station type) were composed predominantly of sand, whereas sediments from toxic stations (the secondary station type) contained more gravel and fines, and were richer in benthic invertebrates (Figure 8-2). Elevated strontium levels are common in areas that have a high content of shell hash fragments (Ueda et al. 1973). Therefore, this potentially explains the link between Microtox results and strontium.

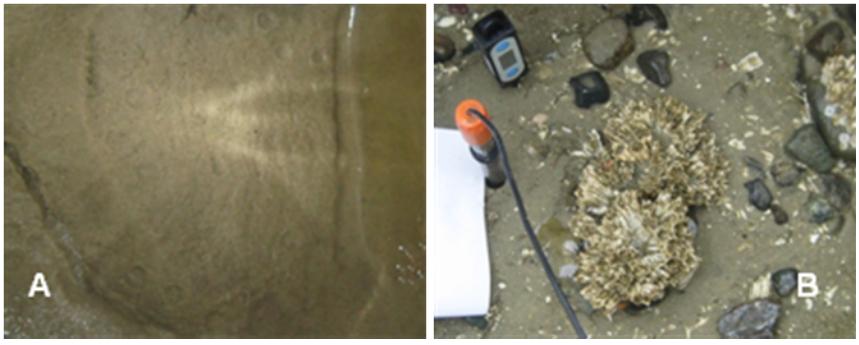


Figure 8-2 Examples of Primary Sediment Type (A) and Secondary Sediment Type (B) at Terra Nova

Source: Whitway et al. 2014.

Based on an extensive examination of the data, Whiteway et al. (2014) concluded that the usefullness of Microtox toxicity tests needs to be questioned within the context of environmental monitoring for Terra Nova and, potentially, other offshore oil operations.

Evidence of project effects on laboratory amphipods has been limited; more than 97% of samples have been non-toxic. Nevertheless and in contrast to Microtox results, Whiteway et al. (2014) linked amphipod toxicity results to project activity in some instances. Unlike Microtox results, sediments from station 30(FE) were toxic to laboratory amphipods in 2004, 2006 and 2008, when sediment barium and $>C_{10}$-C_{21} hydrocarbon concentrations and sulphide levels were higher at that station. Whiteway et al. (2014) also noted that the association between the remaining toxic samples and project-activity was not clear.

In 2014, samples from three stations were toxic to laboratory amphipods. Amphipod survival was uncorrelated with distance from drill centres and all sediment physical and chemical characteristics. Sediment barium and $>C_{10}$-C_{21} hydrocarbon concentrations were not remarkably high in the three samples toxic to amphipods (barium levels were 220 mg/kg or less; $>C_{10}$-C_{21} hydrocarbon levels were 1.2 mg/kg or less). Therefore, in 2014, the link between amphipod toxicity and project activities was also unclear. Sediments from two of the three toxic stations (stations 9(SE) and 22(NW)) had relatively high levels of organic carbon (2.8 and 3.3 mg/kg, respectively, versus a median level of 1.3 mg/kg over all stations); and sulphide levels were relatively high at station 22(NW) (0.82 mg/kg vs a median level of 0.35 mg/kg). Therefore, toxicity to amphipods in 2014 could have resulted in part from degradation of naturally occurring organic carbon.

8.1.3 BENTHIC INVERTEBRATE COMMUNITY STRUCTURE

Total abundance of benthic invertebrates was higher near drill centres and decreased with distance from the nearest drill centre in 2014. This same pattern occurred in all previous years, and the relationship was also significant in 2004. Biomass was uncorrelated to distance to the nearest drill centre in 2014, after data from station 33(FEZ) were removed from analysis. The greatest biomass (more than 730 g/sample versus a median of 224 g/sample) occurred at station 33(FEZ) due to the relative abundance of the heavy-shelled barnacle *Balanus* and mussel *Macoma*. Biomass was correlated with distance to the nearest drill centre in 2004, with biomass increasing with distance from drill centres. Richness, adjusted richness and

NMDS2 scores (Cirratulidae dominance) were uncorrelated with distance to the nearest drill centre in 2014, as in most previous years.

Examining the FEZ and the FE drill centres seperately, there was an overall decrease in abundance with distance from the FEZ drill centres from 2001[36] to 2014, but that gradient did not change over time. There was an overall increase in biomass with distance from the FE drill centre. That gradient changed over time, but changes did not coincide with the onset of drilling at the FE drill centre. Distance gradients from the FEZ drill centres for richness and adjusted richness changed over time, with marginally higher richness near FEZ drill centres in 2000, 2012 and 2014. Distance gradients from the FEZ drill centres also changed over time for NMDS2 scores, with slopes more negative from 2004 to 2010 (i.e., more pronounced Cirratulidae dominance near the FEZ drill centres in those years).

Any change in the above indices with distance to drill centres was subtle and/or not associated with the onset of drilling. The strongest correlations with distance measures were seen with NMDS1 scores. NMDS1 scores represent a contrast between the abundances of Spionidae, Phyllodocidae and Tellinidae versus the abundance of Syllidae, Orbiniidae and Paraonidae. The abundances of additional, less abundant taxa (e.g., echinoderms) were also correlated with NMDS1 scores.

NMDS1 scores were strongly negatively associated with distance to the nearest drill centre in 2014, reflecting higher abundances of Spionidae, Phyllodocidae and Tellinidae, and lower abundances of Orbiniidae and Paraonidae, as well as echinoderms, nearer drill centres. NMDS1 scores were also relatively high at stations 30(FE) and 31(FE), the two stations nearest a drill centre. Most of the other indices were not visibly affected at stations 30(FE) and 31(FE) in 2014. However, adjusted richness was lowest at station 30(FE).

Across years, NMDS1 scores have generally been negatively correlated with distance to the nearest drill centre. There has also been a gradual shift in community composition over time along the NMDS1 axis for communities within 1 km of drill centres. The overall distance gradient from the FEZ drill centre has been strong; the overall distance gradient from the FE drill centre has been weak (and not significant), indicating a greater influence from the FEZ drill centres. Repeated-measures regression indicates no change in distance gradients from the FEZ drill centres over time. As in previous years, threshold relationships were not apparent

[36] 1997 data are unavailable for benthic community indices and 2000 data were excluded from repeated-measures regression because many samples were sieved using a different method.

for NMDS1 in 2014 (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.

Correlations between biomass, adjusted richness and NMDS2 scores and sediment organic carbon (as an index of sediment texture), >C_{10}-C_{21} hydrocarbon and barium concentrations (as indices of drilling discharges) were weak or absent, or not consistent across years. Correlations between total abundance and richness and sediment organic carbon content and barium have generally been significant and positive, indicating higher total abundance and richness in sediments with higher organic carbon and barium concentrations. Correlations between abundance and richness and sediment >C_{10}-C_{21} hydrocarbon concentrations have been weaker than relationships between those indices and organic carbon and barium.

NMDS1 scores were significantly positively associated with sediment organic carbon, barium and >C_{10}-C_{21} hydrocarbon concentrations in all years. The relationship reflects higher abundances of Spionidae and Phyllodocidae polychaetes and Tellinidae bivalves, and lower abundances of Orbiniidae and Paraonidae polychaetes and other more minor taxa in sediments with higher concentrations of organic carbon, barium and >C_{10}-C_{21} hydrocarbons.

Since organic carbon was not visibly affected by project activity, the consistent association between it and total abundance, richness and NMDS1 scores may be natural and could indicate that, like organic carbon, natural distance gradients existed for benthos during baseline. For NMDS1 scores, the relationship with organic carbon has generally been stronger than the relationship with sediment barium and >C_{10}-C_{21} hydrocarbon concentrations, again suggesting a natural association with sediment type.

The lines of evidence to indicate benthic invertebrates have been affected by project activity over and above any natural distance gradients that may have existed in baseline are a shift in community composition over time along the NMDS1 axis for communities within 1 km of drill centres and relatively high values of NMDS1 at the at station 30(FE) (located 0.14 km from the FE drill centre) and station 31(FE) (located 0.37 km from the FE drill centre). In some EEM years, but generally not in 2014, other summary measures of benthic community structure have been affected at station 30(FE). At this one station, results indicate a potential threshold for effects at barium concentrations in excess of approximately 2,000 mg/kg and >C_{10}-C_{21} concentrations in excess of approximately 400 mg/kg. However, since these high

levels have only occurred in a few years, any conclusion about a threshold concentration needs to be made with caution.

In addition, elevated levels of barium and >C_{10}-C_{21} hydrocarbons in sediment may not be the direct cause of variations in benthic invertebrates. Barium and barite are toxicologically inert and are largely present in water-based drill muds and sediments as insoluble and biologically unavailable metal sulphides (Neff 2008; Smit et al. 2008). Suspended solids (e.g., barite particles) at high concentrations in the water column near the sediment-water interface can irritate gills and have other physical effects on benthic invertebrates (Barlow and Kingston 2001; Armsworthy et al. 2005; Smit et al. 2008). At the suspended solids levels observed in Terra Nova water column samples (usually less than 5 mg/L; Section 6), any effects should be restricted to plankton and filter-feeding bivalves (Smit et al. 2008). However, abundances of Tellinidae (*Macoma)*, the dominant bivalve at Terra Nova, increased rather than decreased near drill centres. Sediment burial and particle size alterations refer to physical effects of deposited rather than suspended solids. Neither would be of concern in the Terra Nova area, where sediment fines content remains low, with only minor evidence of increases in fines levels associated with drilling discharges in some years.

>C_{10}-C_{21} hydrocarbons could have both enrichment (increases in abundance) and toxic (decreases in abundance) effects on benthic invertebrates. Enrichment effects could be direct, with increases in abundances of organisms (e.g., polychaetes) feeding on bacteria breaking down hydrocarbons released in drilling discharges (Kennicutt et al. 1996).

Finally, both “positive” or “negative” effects of the Terra Nova and other offshore oil developments (and many other anthropogenic activities) on benthic invertebrate communities could be a result of indirect rather than direct enrichment or toxic effects of drill cuttings discharges (Peterson et al. 1996; Newman and Clements 2008). For example, abundances of some opportunistic or tolerant taxa may increase near drill centres or at high hydrocarbon concentrations, not because of any direct enrichment effects on those taxa but because abundances of competitors or predators of those taxa decrease as a result of more direct toxic effects. Similarly, project effects, direct or indirect, may be attributable to unmeasured correlates of barium and hydrocarbons, rather than the two indicator substances themselves.

In summary, evidence of effects on the principle indicators of benthic community structure (total abundance, biomass, richness and adjusted richness (diversity)) at Terra Nova remains weak. There was evidence that project activities altered

community composition near drill centres, with abundances of some taxa increasing and abundances of other taxa decreasing near drill centres and at higher barium or >C_{10}-C_{21} hydrocarbon concentrations. As in previous years, the distance gradient for these changes in community composition was too weak to provide robust estimates of the spatial extent of effects. In 2014, when Orbiniidae, Paraonidae and echinoderms were not found in samples, these samples generally were collected within 1 to 2 km of drill centres. NMDS1 scores also shifted to the right along the NMDS1 axis for stations within 1 km of drill centres. These results, and results from previous years, suggest effects within 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 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 to drill cuttings discharges or other anthropogenic stressors than abundance, richness or biomass; and Kilgour et al. (2005) concluded that effects that are manifest on multivariate measures may be considered subtle if there are not also strong effects on the principal indicators of community structure. In the Terra Nova EEM program, a multivariate community composition measure (NMDS1) has been relatively strongly correlated with distance to drill centres and sediment concentrations of barium and >C_{10}-C_{21} hydrocarbons. In general, effects on total benthic abundance, richness, adjusted richness and biomass have been subtle or absent.

8.2 WATER COMPONENT

8.2.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

PAHs were not detected in seawater samples in 2014. From 2002 to 2010, PAHs were generally detected more frequently, although sporadically and in trace amounts, in seawater samples from the Study Area than in samples from the Reference Areas. In 2012, trace levels of naphthalene were detected in one sample collected at Study Area stations. The 2012 and 2014 data compare to the baseline year, when only one occurrence of a PAH was noted in water samples.

Arsenic has been detected in all seawater samples from 1997 to 2014. Total suspended solids and iron were detected in most samples over those years. In accordance with Suncor Energy's revised water quality program (Suncor Energy 2012), seawater samples have been processed for additional constituents since 2012. As a result, barium, boron, calcium, lithium, magnesium, molybdenum, nickel, potassium, sodium, strontium, sulphur and uranium were frequently detected in 2014 samples. Concentrations of boron, iron, nickel, potassium and sodium differed between the Study Areas and the Reference Areas, with concentrations of most metals lower in the Study Areas than in the Reference Areas. Median iron, nickel, potassium and sodium levels were approximtaely 45%, 81%, 4% and 8% lower, respectively, in the Study Areas than in the Reference Areas; and the median boron level was approximately 12% lower in the Reference Areas than in the Study Areas (or 6,210 μg/L in the combined Reference Areas versus 7,070 μg/L in the combined Study Areas).

Concentrations of arsenic, iron and total suspended solids were examined across years. Over time, median Study Area arsenic concentrations have not been consistently higher or lower than median Reference Area concentrations. Median iron concentration was higher in the Study Area[37] than in the Reference Areas in 2002 and 2012; and median iron concentration was higher in the Reference Areas in 2008 and 2014. Total suspended solids in the Study and Reference Areas have generally been similar. These, and the within year analysis of a larger suite of metals, likely indicate natural variability.

In 2014, the occurrence of elevated values of known produced water constituents was examined for individual Study Area samples to determine if there could be an association between elevated values and release of produced water. Maximum iron, manganese and nickel concentrations occurred in the bottom depth sample at station W16, inside the FEZ (approximately 0.3 km from source). The second highest concentrations of iron and manganese occurred in the bottom depth sample at Station W11, inside the FEZ (approximately 0.3 km from source). Given that iron, manganese and nickel are all elevated in produced water, it is possible that evidence of produced water was detected at stations W16 and W11. In general, and given the sporadic occurrence of relatively high values for these constituents (in 2 of 48 Study Area samples), the evidence that these were related to release of produced water was weak, consistent with dispersion modelling results that indicate

[37] In years prior to 2012, there was only one Study Area. For comparisons across years, data for the two Study Areas in 2012 and 2014 were combined.

rapid dilution of produced water in the marine environment (Neff et al. 2011 and references therein).

In summary, analyses indicate that seawater physical and chemical characteristics at Study Area stations and Reference Area stations are similar. In most cases in 2014, differences between Study and Reference Area stations were not significant. Where they were significantly different, concentrations were usually higher in the Reference Areas than in the Study Areas (i.e, in four out of five instances). These results better indicate natural variability. No PAHs were detected in seawater in 2014. Across years, concentrations of arsenic, iron and total suspended solids were not consistently higher or lower in the Study versus Reference Areas. The evidence that produced water constituents were detected in seawater samples was weak.

8.2.2 PHYTOPLANKTON PIGMENTS

Chlorophyll *a* concentration from CTD casts is used as an indicator of algal biomass in the Terra Nova EEM program. These data are supplemented with measurement of chlorophyll and pheophytin *a* concentrations from Niskin bottles when these are available. In 2014, chlorophyll and pheophytin *a* were not detected in most seawater samples because of elevated laboratory detection limits.

In 2014, chlorophyll *a* concentrations from CTD casts varied between approximately 1 and 3.5 µg/L, with concentrations higher at approximately 20 to 30 m depth. Chlorophyll depth gradients varied among Areas. However, differences in chlorophyll *a* concentrations were greater between the two Reference Areas than between the Study Areas and Southeast Reference Area (i.e., the Southwest Reference Area stood out as dissimilar from remaining Areas). The thermocline extended over a narrower depth range in the Southwest Reference Area, and that difference was mirrored in the distribution of chlorophyll *a* over depth.

Across years, median chlorophyll *a* concentrations from CTD casts have generally followed the same pattern in the Study and Reference Areas, with concentrations slightly more variable at the surface in the Reference Areas. In 2012, sampling was performed in the spring of the year, with chlorophyll maxima occurring at the greatest depth sampled (i.e., the bottom depth) in both the Study and Reference Areas. In 2014, chlorophyll was lower in bottom samples, generally consistent with results from previous years when sampling was performed in late summer/fall.

Overall, there is little indication that Terra Nova is affecting chlorophyll *a* concentration near the development. Any nutrient enrichment from produced water

(Rivkin et al. 2000) would be expected to increase phytoplankton production near the FPSO. In 2014, the largest variation in chlorophyll *a* concentraion occurred between the two Reference Areas, rather than between the Study Areas and the Reference Areas. Based on these data, variations in chlorophyll *a* noted in the Study and Reference Areas were likely natural.

8.3 COMMERCIAL FISH COMPONENT

8.3.1 BIOLOGICAL CHARACTERISTICS

8.3.1.1 Scallop

A total of 760 scallop were retained from the Reference and Study Areas in 2014. The overall female to male sex ratio was approximately 60:40, with no difference in sex ratio between the Study and Reference Areas. There also were no differences in the size or shape of scallop between the Reference and Study Areas for either females or males. These results held for the subset (n = 200) of scallop used in body burden analysis.

8.3.1.2 Plaice

A total of 100 plaice 30 cm or larger were retained from the Reference and Study Areas in 2014. The overall female to male sex ratio was approximately 90:10 and females outnumbered males in all transects, with no difference in sex ratios between the Study and Reference Areas. For females, there was no difference between Areas in the frequency of maturity stages. The number of males collected was low (four males in the Study Area; three males in the Reference Area) and statistical analysis on the frequency of maturity stages and other variables requiring analysis by sex were not performed.

Size and condition for female plaice were similar between Areas in most cases. Females from the Study Area were older and had a higher mean hepatosomatic index. However, there was no statistical difference between Areas for adjusted means of liver weight on the covariate of gutted body weight (a comparable and more appropriate measure of variability in liver weight).

Inter-area differences in fish condition have been observed in both male and female plaice since the beginning of the Terra Nova EEM program. Overall, heterogeneity in biological characteristics and condition of fish, including plaice, can often be attributed to normal inter-site variability linked to such factors as feeding or reproductive status (e.g., Barton et al. 2002; Morgan 2003).

8.3.2 BODY BURDEN

8.3.2.1 Scallop

>C_{10}-C_{21} hydrocarbons were detected in Study Area scallop adductor muscle in earlier EEM years. However, hydrocarbon concentrations in Study Area muscle decreased to near or below the laboratory detection limit of 15 mg/kg since 2006.

>C_{10}-C_{21} hydrocarbons have been noted in Study Area scallop viscera since drilling began. Study Area means were well above the laboratory detection limit in earlier EEM years (with a maximum area mean of 100 mg/kg noted in 2000). Concentrations decreased to near the detection limit since 2008.

Barium was detected in one adductor muscles sample from the Reference Area in 2000 and in 2004. Barium was detected in three muscle samples from the Study Area in 2010, and in one sample from the Study Area in 2012. Barium was not detected in adductor muscle in 2014. Over the years, the Reference Area maximum for barium was 2 mg/kg (in 2000) and the Study Area maximum was 5.8 mg/kg (in 2010).

Barium has been detected more frequently and at higher concentrations in Study Area viscera samples than in Reference Area samples. From 2001 to 2010, median barium concentrations in Study Area viscera samples progressively increased to approximately 15 mg/kg. The concentration of barium in Study Area viscera samples decreased in 2012 and 2014 to levels similar to baseline levels (approximately 5 mg/kg).

Arsenic, boron, cadmium, strontium and zinc were detected in most scallop adductor muscle samples from 1997 to 2014. Concentrations of these metals were examined using principal components analysis, which provided an aggregate proxy variable (metals PC1) of the concentration of most metals. Changes in metals concentration over time in EEM years were similar between Areas, and metals concentrations in 2014 were lower than levels noted in baseline (1997). Boron concentration in muscle was examined separately from other metals because it varied somewhat independently from other metals. Boron was generally lower in the Study Area than in the Reference Area in most years, including baseline (1997).

Aluminum, arsenic, boron, cadmium, copper, iron, manganese, mercury, nickel, selenium, strontium, uranium and zinc were detected in most scallop viscera samples from 1997 to 2014. Two aggregate proxy measures (Metals PC1 and

Metals PC2) were generated to summarize variability in metals concentration among years. Metals PC1 provided a summary measure of most metals concentration in viscera. Metals PC2 provided a summary measure of aluminum and iron concentration in viscera. Aluminum and iron are found in very high concentration in sediments. Therefore, metals PC2 can be considered a measure of metals concentration in ingested sediments. Nickel, which varied somewhat independently from other metals, was examined seperately.

The concentration of most metals (Metals PC1) in scallop viscera has been higher in the Study Area than in the Reference Area in most years, including baseline. Differences between the two Areas have decreased over time, with similar levels in both Areas since 2008. In 2014, metals concentrations in both the Study and Reference Areas were lower than concentraitons during baseline. Concentrations of aluminum and iron, as determined by Metals PC2, were similar between Areas in most years, especially in 2012 and 2014. Concentrations were higher in the Study Area in a few years (1997 and 2006); and concentrations were higher in the Reference Area in 2010. Nickel concentrations in viscera were generally similar between the Study and Reference Areas, except in 2002, when concentrations were higher in the Study Area. In 2014, nickel concentrations in both the Study and Reference Areas were similar, and these were similar to baseline concentrations.

As in previous years, results of body burden analysis on scallop tissue indicate contamination with $>C_{10}$-C_{21} hydrocarbons and barium, two important constituents of drill muds (Section 4 and DeBlois et al., 2014a provide information on the composition of drill muds). Hydrocarbon contamination occurred in viscera and to a lesser extent, muscle tissue. Barium contamination occurred predominantly in viscera; evidence of barium contamination in muscle was weak given low concentrations in both the Reference and Study Areas. Data from recent EEM years indicate a decrease in $>C_{10}$-C_{21} hydrocarbon contamination in muscle since 2006, a decrease in $>C_{10}$-C_{21} hydrocarbon contamination in viscera since 2008, and a decrease in barium contamination in viscera since 2012. There continues to be little evidence of tissue contamination with metals other than barium. Changes in the concentration of metals other than barium generally either have been common to both the Study and Reference Areas (muscle Metals PC1, viscera Metals PC2, viscera nickel concentraitons), or differences have remained consistent since baseline (muscle boron concentration, viscera Metals PC1).

>C_{10}-C_{21} hydrocarbons in scallop tissue would originate from the synthetic-based drill mud used at Terra Nova. Bivalves in general have been used extensively to study bioaccumulation of chemicals in coastal estuarine and marine waters because of their limited ability to metabolize organic chemicals (DeBlois et al. 2014c). Neff et al. (2000) describes two studies where bivalves were exposed to synthetic-based drill muds under laboratory conditions. In both cases, bivalves rapidly accumulated the drill mud hydrocarbons in tissue, but equally rapidly released the chemicals when returned to clean water, suggesting retention of the chemical in gills and digestive tract, but no accumulation in other tissues. In later studies, Armsworthy et al. (2005) and Cranford et al. (2005) noted that the digestive gland was the primary site for accumulation of hydrocarbons for sea scallop (*Placopecten magellanicus*) and Iceland scallop following exposure to synthetic-based fluids. Most of the hydrocarbons detected in scallop at Terra Nova were in viscera tissue, again suggesting that contamination occurred through ingestion of drill mud. Also, tissue contamination has decreased in recent years, potentially related to a decrease in drilling and sediment >C_{10}-C_{21} hydrocarbon concentations (Section 8.1), again supporting the concept that synthetic hydrocarbons are ingested and egested, rather than bioaccumulated. For fish, Rushing et al. (1991) hypothesized that the greater molecular size of hydrocarbons in synthetic-based drill muds restricts uptake by gill and digestive structures. In agreement, Neff et al. (2000) states that olefins and paraffins of the sizes found in synthetic-based drill muds are relatively large linear chains that do not permeate membranes efficiently. Results at Terra Nova are consistent with expectations about the bioaccumulation potential of synthetic-based drill muds.

Barium is a major constituent of both the synthetic and water-base drill muds used at Terra Nova, and scallop viscera contamination was higher in EEM years, consistent with higher sediment barium contamination near drill centres after drilling began (Section 8.1). The effect of barium on scallop would be primarily physical rather than chemical (Barlow and Kingston 2001; Armsworthy et al. 2005; Smit et al. 2008). At high concentrations, barite interferes with ciliary activity in gills and other epithelial tissues (Cranford and Gordon 1992) or physically damages gills. Laboratory studies conducted with sea scallop indicate that physical interference by bentonite and barite particles in drill muds can affect growth and reproduction (Cranford et al. 2005). These physical effects are not specific to barite but can occur whenever concentrations of fine particles (e.g., clay) from drill cuttings are elevated. Uptake of barium in scallop viscera at Terra Nova was limited, suggesting that any effects on gills would be limited.

8.3.2.2 Plaice

>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.

>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 2014, 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 2013).

Barium 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 were detected in all plaice fillet samples since 2001[38]. Arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc were detected in most plaice liver composites since 2001. Concentrations have generally been low (less than 10 times the laboratory detection limit), there were no significant differences in concentrations between Areas for either tissue, and differences among years were often significant and much greater than differences between Areas. For plaice, as well as for scallop, metals other than barium in tissue should be regarded as naturally occurring and often essential elements rather than contaminants.

8.3.3 TASTE TESTS

No significant difference in taste was noted between the Study and the Reference Areas for scallop or plaice in both the triangle and hedonic scaling test, and there

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

were no consistent comments from panellists identifying abnormal or foreign odour or taste for either tissue type. There is no indication of taint in either scallop or plaice from these results.

8.3.4 FISH HEALTH INDICATORS

8.3.4.1 Gross Pathology

There were no visible lesions on the skin or fins or on internal organs (gonad, digestive tract, liver, body cavity and spleen) of any fish, with the exception of one fish from that Study Area that had a worm in the liver.

8.3.4.2 Haematology

As has been the case in previous years, blood smears collected in 2014 displayed signs of clotting and were considered of insufficient uniformity for carrying out reliable differential cell count (see Section 8.5.3 for further discussion).

8.3.4.3 Mixed Function Oxygenase Activity

No significant differences between the Study and Reference Areas were noted in female hepatic EROD activity with all female maturity stages grouped. Since maturity stage can result in some loss of sensitivity for resolving contaminant-mediated differences in females during spawning, a comparison of enzyme activity was also carried out on spent female fish. No significant differences were detected between the Reference and Study Areas in hepatic EROD activity of spent females.

8.3.4.4 Histopathology

There were no cases of liver lesions commonly associated with chemical toxicity, including nuclear pleomorphism, megalocytic hepatosis, focus of cellular alteration, fibrillar inclusions or macrophage aggregation. The frequency of other lessions generally not associated with chemical toxicity did not differ significantly between the Study and Reference Areas.

Similarly, no significant differences between the Study and Reference Areas were found in the frequency of gill lessions.

As in previous years, the results of the fish health survey carried out in 2014 indicated that the overall health of American plaice is similar at the Reference Area and the Study Area.

8.4 SUMMARY OF EFFECTS AND MONITORING HYPOTHESES

As discussed in Section 1, monitoring hypotheses (reiterated in Table 8-1) 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 8-1 Monitoring Hypotheses

Sediment Quality
H_o: There will be no attenuation of physical or chemical alterations or biological effects with distance from project discharge points.
Water Quality
H_o: 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_o: Project discharges will not result in taint of fish resources within the Terra Nova Project area, as measured using taste panels. H_o: Project discharges will not result in adverse effects to fish health within the Terra Nova Project area, as measured using histopathology, haematology and MFO induction.

Given results observed in the 2014 EEM program, the null hypothesis is rejected for the sediment quality component of the program, but the null hypotheses are not rejected for the water quality or commercial fish components of the EEM program. 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 the discharge point.

There was clear evidence that sediment $>C_{10}$-C_{21} hydrocarbon and barium concentrations were elevated near drill centres in 2014, as in previous EEM years. There was weak evidence of project effects on sulphide and redox levels, although results could also indicate natural variation. Sediment contamination with $>C_{10}$-C_{21} and barium was reduced in 2014 compared to previous EEM years. Minor effects noted previously on sediment sulphur and fine content were not apparent in 2014.

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 4.5 km from drill centres; concentrations of barium decreased to background levels within approximately 3 km

from drill centres. Higher sulphide and lower redox levels occurred at a few stations within 1 to 2 km from drill centres.

There was evidence that project activities altered community composition near drill centres, 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. The distance gradient for these changes in community composition was too weak to provide robust estimates of the spatial extent of effects, but from results in 2014 and previous years, effects on the most affected taxa were apparent within 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). As noted above, evidence that summary measures of community composition (total abundance, biomass, richness and diversity) were affected by project activity was weak, but some taxa did respond more strongly. These results are consistent with EIS predictions.

Seawater physical and chemical characteristics at Study Area stations and Reference Area stations were similar in 2014. In some previous EEM years, PAHs were detected sporadically and in trace amounts in seawater samples. The occurrence of trace amounts of PAHs in seawater samples was reduced in 2014 (and 2012), and it was similar to that noted in the baseline year (1997). The evidence that produced water was detected in seawater samples was weak, consistent with dispersion modelling results that indicate rapid dilution of produced water in the marine environment.

Sediment contamination and effects on benthic invertebrates were not coupled with effects on commercial fish. Although contamination of scallop tissue was noted, this did not translate into tainting of the resource. No contamination was noted for plaice; 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.

8.5 CONSIDERATION FOR FUTURE EEM PROGRAMS

8.5.1 SEDIMENT COMPONENT

In 2014, some sediment samples were processed after their recommended hold-time period. Although this does not invalidate the data, these would have a higher uncertainty level than usual (see Appendix B-2 on hold-time for further discussion). Because of this, every effort should be made to process samples within their designated hold-time.

Microtox toxicity results from 2014 and previous EEM programs, as well as an extensive examination of these data by Whiteway et al. (2014), indicate that the usefullness of Microtox toxicity tests within the context of environmental monitoring for Terra Nova needs to be questionned. Amphipod toxicity test results have been of value in some years. Microtox toxicity testing should be discontinued in future EEM programs; amphipod toxicity testing should be retained.

Although multivariate analyses of community composition often provide a more complete picture, some analyses of selected dominant and sub-dominant taxa should continue because these analyses provide insight into the more general multivariate analyses.

8.5.2 WATER COMPONENT

CTD data on chlorophyll *a* concentrations are used preferentially over the Niskin bottle dataset on chlorophyll *a* at Terra Nova because the former dataset is much more extensive. In previous years, estimates of chlorophyll *a* concentrations from Niksin bottles have been qualitatively similar to estimates from CTD casts and have been used to support conclusions based on examination of CTD data. In 2014, and because of higher laboratory detection limits, all chlorophyll *a* values from Niskin bottles were below the laboratory detection limit. If estimates of chlorophyll *a* are to continue in the Terra Nova EEM program, a minimum detection limit of 0.1 μg/L should be used (if available). However, given the small contribution that pigment measurement from Niskin bottles make to the overall examination of chlorophyll *a*, the recommendation is to discontinue those measurements. The assessment of other variables (hydrocarbons, metals and total suspended solids) from Niskin bottle data should continue.

In 2014, the depth distribution of chlorophyll *a* was similar to what it was in prior years when sampling was performed in late summer/early fall. Differences in the depth distribution of chlorophyll *a* were noted in 2012, when sampling was performed in spring. In order to minimize seasonal effects on pigment concentrations, sampling should be performed in late summer/early fall. This recommendation can be generalized to all components of the EEM program: as much as feasible, sampling should be performed at a consistent time of year for each component.

8.5.3 COMMERCIAL FISH COMPONENT

Blood smears collected in 2014, and many previous years, displayed signs of clotting and were considered of insufficient uniformity for carrying out reliable differential cell count. As recommended in the 2012 report, EDTA tubes were tested prior to the survey to confirm that they displayed adequate anti-clotting properties. Syringes used to draw blood were also coated with EDTA prior to blood collections. Additional issues with the smears in 2014 included droplets of water on the slides as a result of the high humidity onboard the vessel; and damage to the slides as a result of ship movement. After many attempts to remedy these problems, the difficulties in obtaining adequate haematology smears offshore makes this test unsuitable for use in the EEM program. Because of this, and because the remaining health indices are sufficient to provide an overall assessment of fish health, haematological analysis should be discontinued.

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