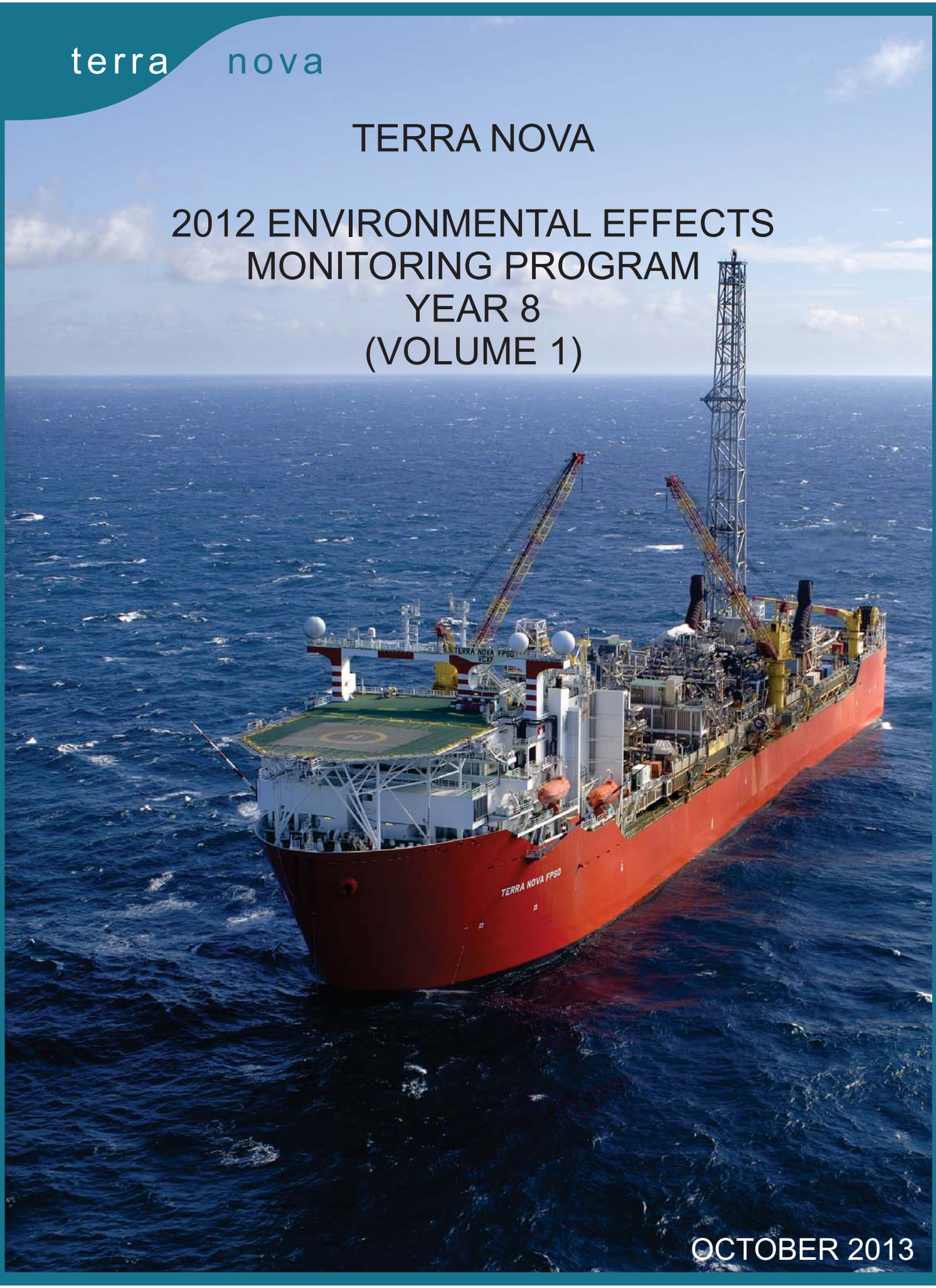
terra nova

TERRA NOVA

2012 ENVIRONMENTAL EFFECTS MONITORING PROGRAM YEAR 8 (VOLUME 1)



OCTOBER 2013

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 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 seventh EEM Programs were conducted in 2000, 2001, 2002, 2004, 2006, 2008 and 2010. This report discusses the results of the eighth EEM Program, conducted in the spring and summer of 2012, and relates these to findings of previous EEM years (Suncor Energy 2001, 2002, 2003, 2005, 2007, 2009, 2011) and to the baseline (1997) program (Suncor Energy 1998a).

In 2012, 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 bacteria (Microtox) and a marine amphipod species were performed, and benthic invertebrate infaunal species were identified and enumerated.

Water samples and conductivity, temperature, depth (CTD) 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 the document.
[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.

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 2012. Although contamination has increased in EEM years overall, contamination in 2012 (and 2008 and 2010) was reduced compared to levels observed in 2004 and 2006. Reduction in contamination coincided with reduced drilling activities in the field after 2006. In 2012, maximum barium and $>C_{10}$-C_{21} hydrocarbon concentrations (4,900 and 310 mg/kg, respectively) occurred at station 30(FE), located 0.14 km from the Far East (FE) drill centre. As in previous years, there was also some indication in 2012 that sulphur and, perhaps, sediment fines content were elevated by drilling activity. Evidence of effects on sediment fines content was weaker in 2012 than in previous years.

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 1 km from drill centres; concentrations of $>C_{10}$-C_{21} hydrocarbons decreased to levels near the laboratory detection limit (0.3 mg/kg) within approximately 2.5 km from drill centres. Elevated concentrations of sulphur occurred within 1 to 2 km of drill centres. Evidence of project effects on fines was weak and elevated concentrations occurred only in the immediate vicinity of drill centres.

There was little to no evidence of project-related sediment toxicity, as measured through laboratory tests with 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. 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 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. Scallop resources were not tainted. In 2012, as in previous years, results of body burden analysis on scallop tissue indicated scallop viscera contamination with >C_{10}-C_{21} hydrocarbons and barium. Data from 2012 indicate a decrease in barium and >C_{10}-C_{21} contamination in viscera. There was no evidence of muscle tissue contamination in 2012.

No contamination or tainting was noted for American plaice and 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 scallop tissue was noted, no effects on scallop taste were noted. No tissue contamination or effects on taste were noted for American plaice and plaice heath was similar between the Terra Nova Study Area and the Reference Area.

ACKNOWLEDGEMENTS

The Terra Nova EEM program (2012) 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.), and Wynnan Melvin and Adam Templeton (Oceans Ltd., St. John's, NL). Participants in the sediment and water survey included Doug Rimmer, Matt Steeves, Kristian Greenham, Melinda Watts, Scott Finlay and Sean Wilson from Stantec Consulting Ltd. Fugro Jacques Geosurveys Inc. (Robyn Clements and Dion Cox) 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 and tissues were conducted by Maxxam Analytics (Halifax, NS and St. John's, NL). 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 supervised by Dianne Hunt-Hall (Stantec Consulting Ltd. – Environmental Laboratory Division). Fish and shellfish taste tests were performed at the Marine Institute of Memorial University. Fish health indicator analyses were supervised by Dr. Anne Mathieu (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 Drs. Elisabeth DeBlois (Elisabeth DeBlois Inc.) and Bruce Kilgour. Drs. Elisabeth DeBlois, Bruce Kilgour and Anne Mathieu 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 Stangemore and Amber Frickleton/ Anna Marie Buchheit (Stantec Consulting Ltd.) provided administrative and graphics support, respectively. Trudy Wells and Greg Janes (Suncor Energy) and Dr. Joe Kiceniuk reviewed the document before final printing.

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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 and 35 km southeast of the Hibernia oil field (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.).

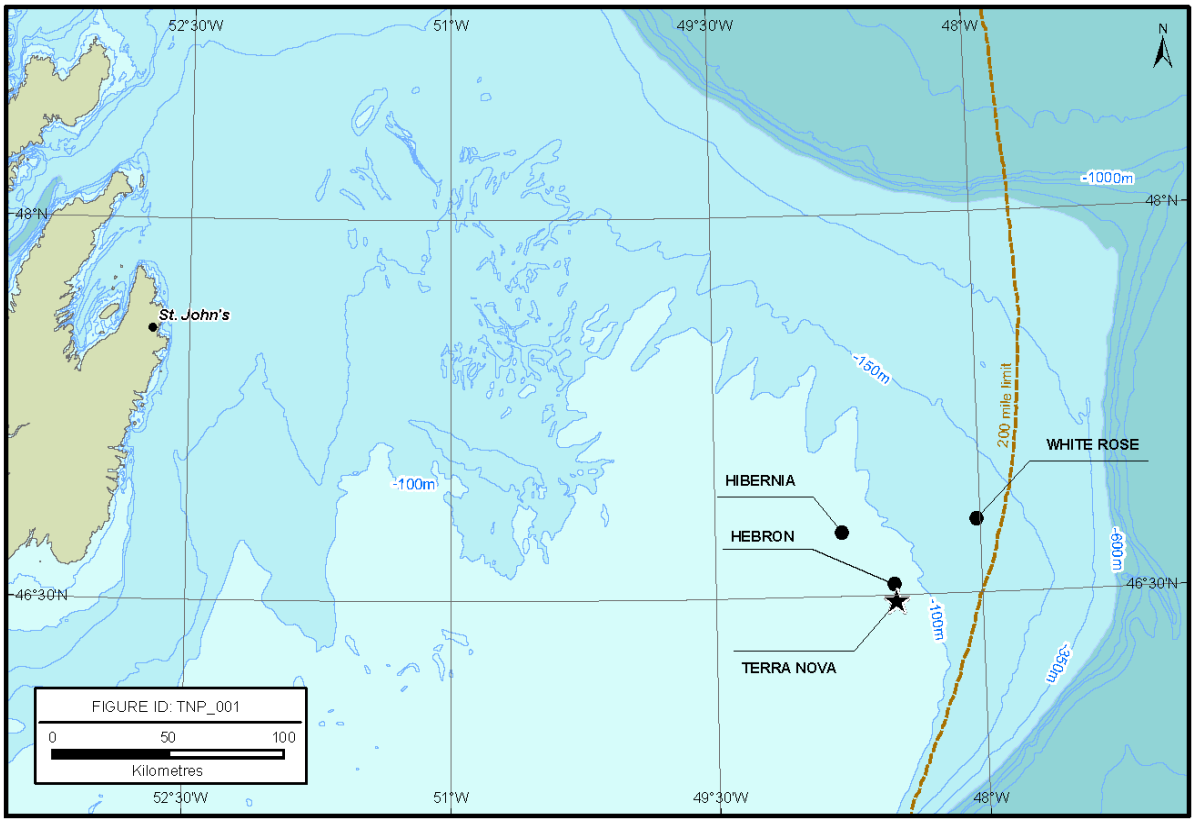


Figure 1-1 Terra Nova and Other Field Locations on the Grand Banks

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

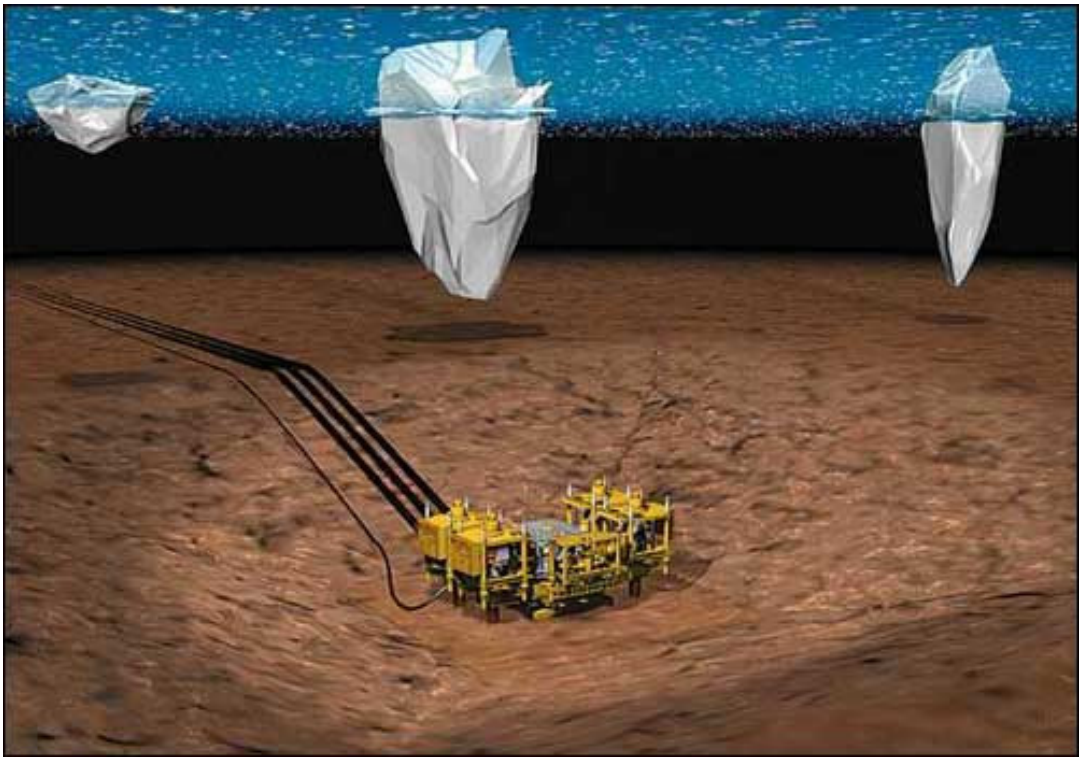


Figure 1-3 Typical Glory Hole Configuration

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 strong 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 eight times, in 2000, 2001, 2002, 2004, 2006, 2008, 2010 and 2012. 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 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, while regular operations were expected to have the greatest effect on physical and chemical characteristics of water, through release of produced water. The zone of influence[5] for these waste streams was not expected to extend beyond approximately 15 km from source for drill cuttings, with the heaviest deposition occurring in the immediate vicinity of drill centres (Figure 1-4). The zone of influence for produced water was not expected to extend beyond approximately 5 km from source (Figure 1-5). Most other waste streams (see Section 4 for details) were expected to have negligible effects on sediment and water, as well as biota. However, deck drainage was expected to have minor effects, as described below.

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

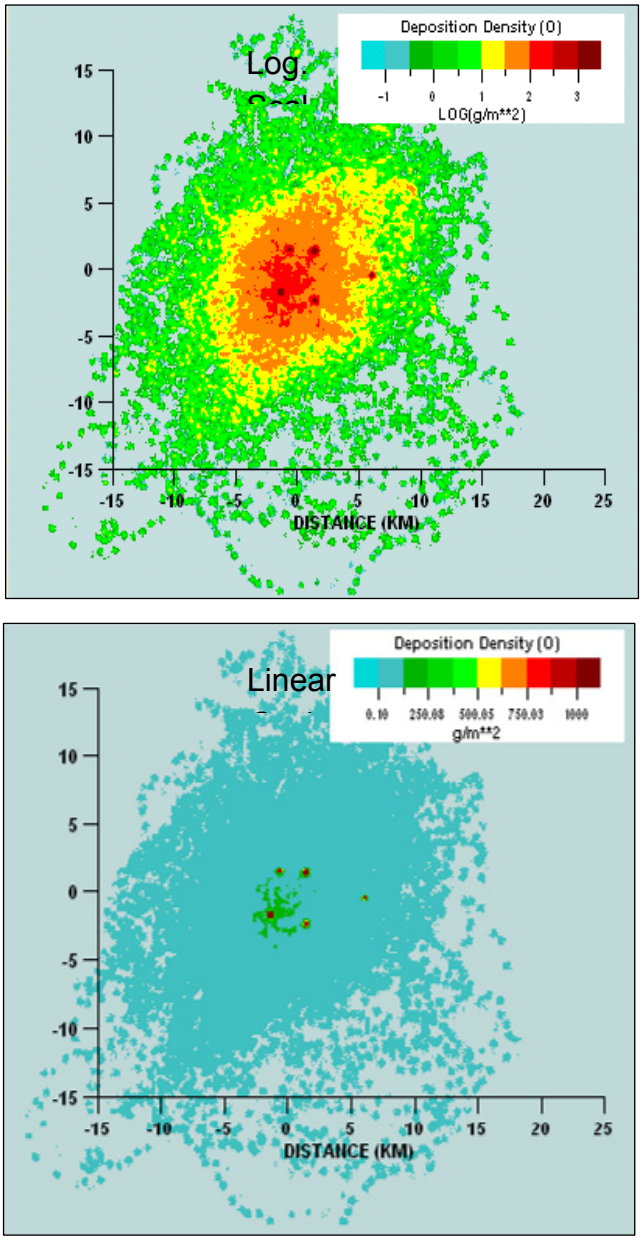


Figure 1-4 Zone of Influence for Drill Cuttings After Completion of Drilling (Seaconsult 1998)

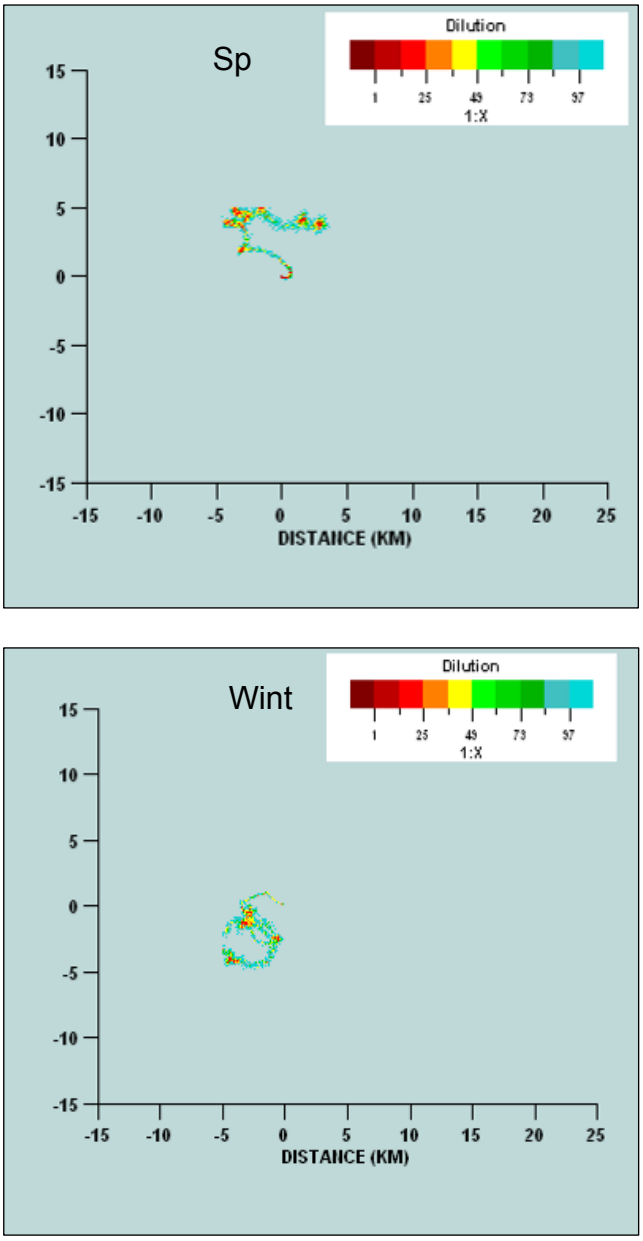


Figure 1-5 Snap-Shot of the Distribution of Produced Water (Seaconsult 1998)

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

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

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

Further details on effects and effects assessment methodologies can be obtained from the Terra Nova EIS (Suncor Energy 1996). For the purpose of the EEM program, testable hypotheses that 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 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).

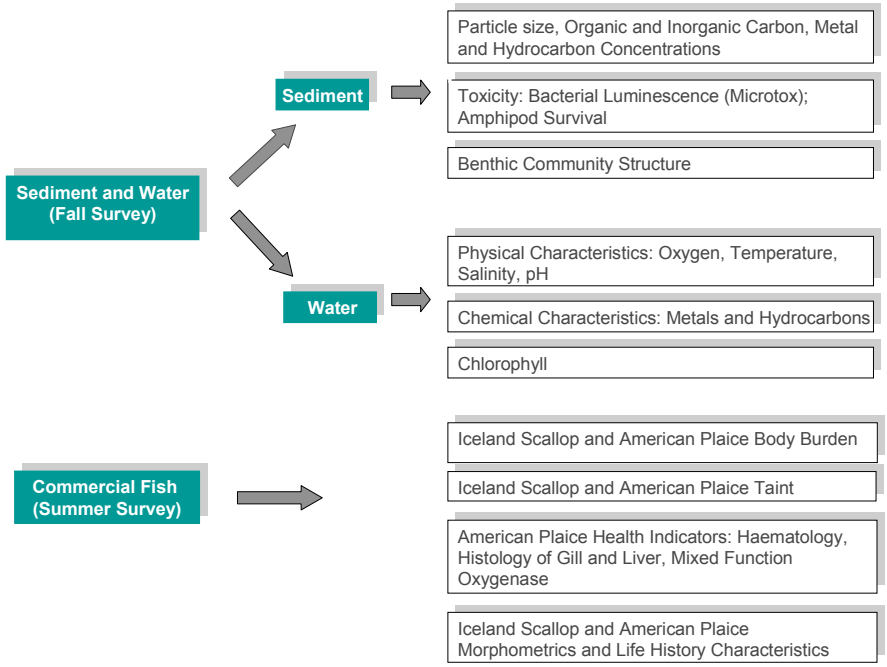


Figure 1-6 EEM Components

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.

[6] MFO: Mixed Function Oxygenase.

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 control document TN-IM-EV02-X00-001 (submitted to the Canada-Newfoundland and Labrador Offshore Petroleum Board December 3, 2012) for details).

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 have been usually collected at four stations inside the FEZ, but station 48(FEZ) could not be sampled in 2004 because of drilling activity. In 2012, the revised water quality monitoring program was implemented and water stations were samples 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 program 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 1-19. Station name changes that have occurred since the Baseline program are identified in Table 1-2.

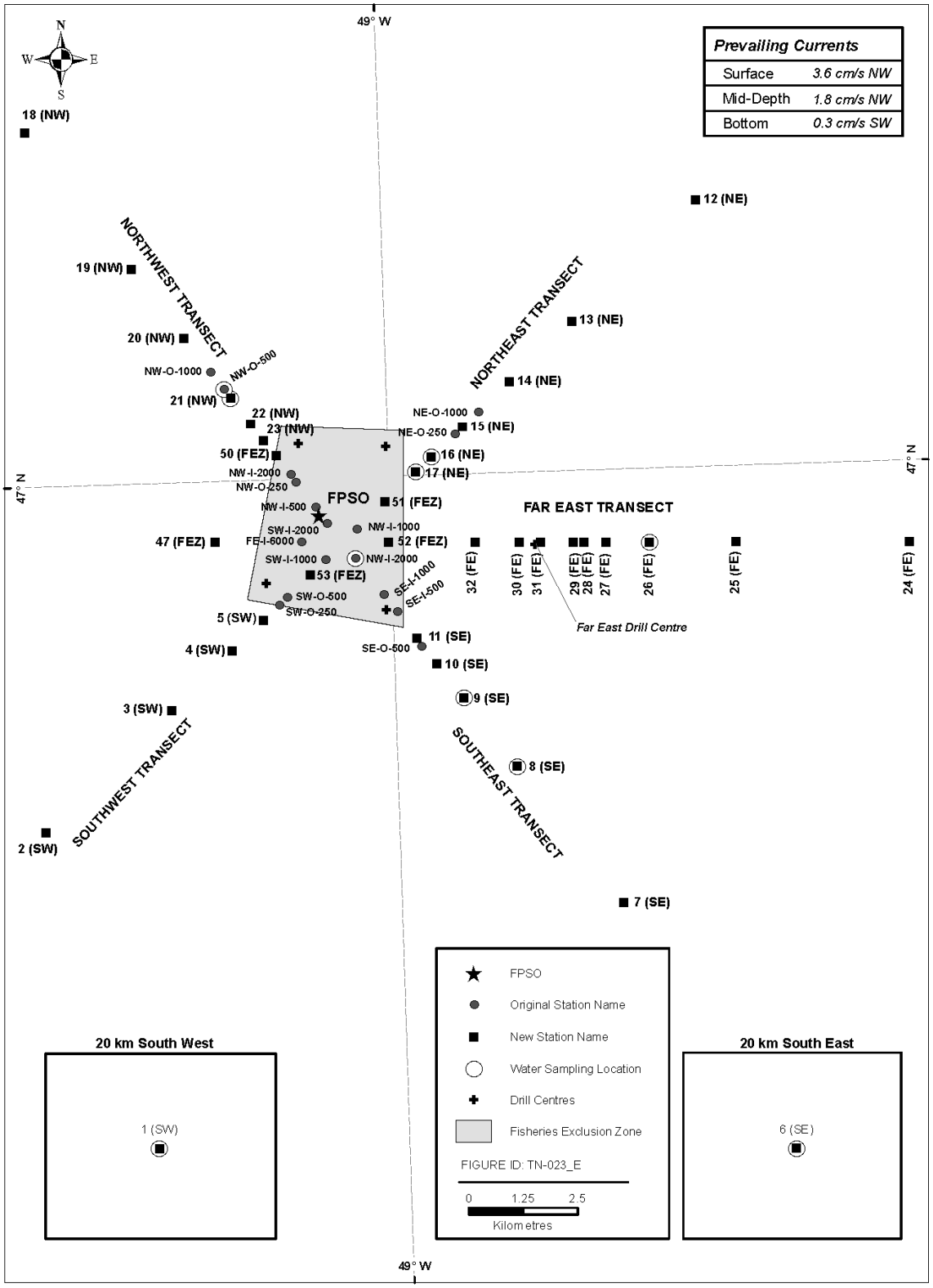


Figure 1-7 Station Locations for the Baseline Program (1997) Sediment and Water Collections

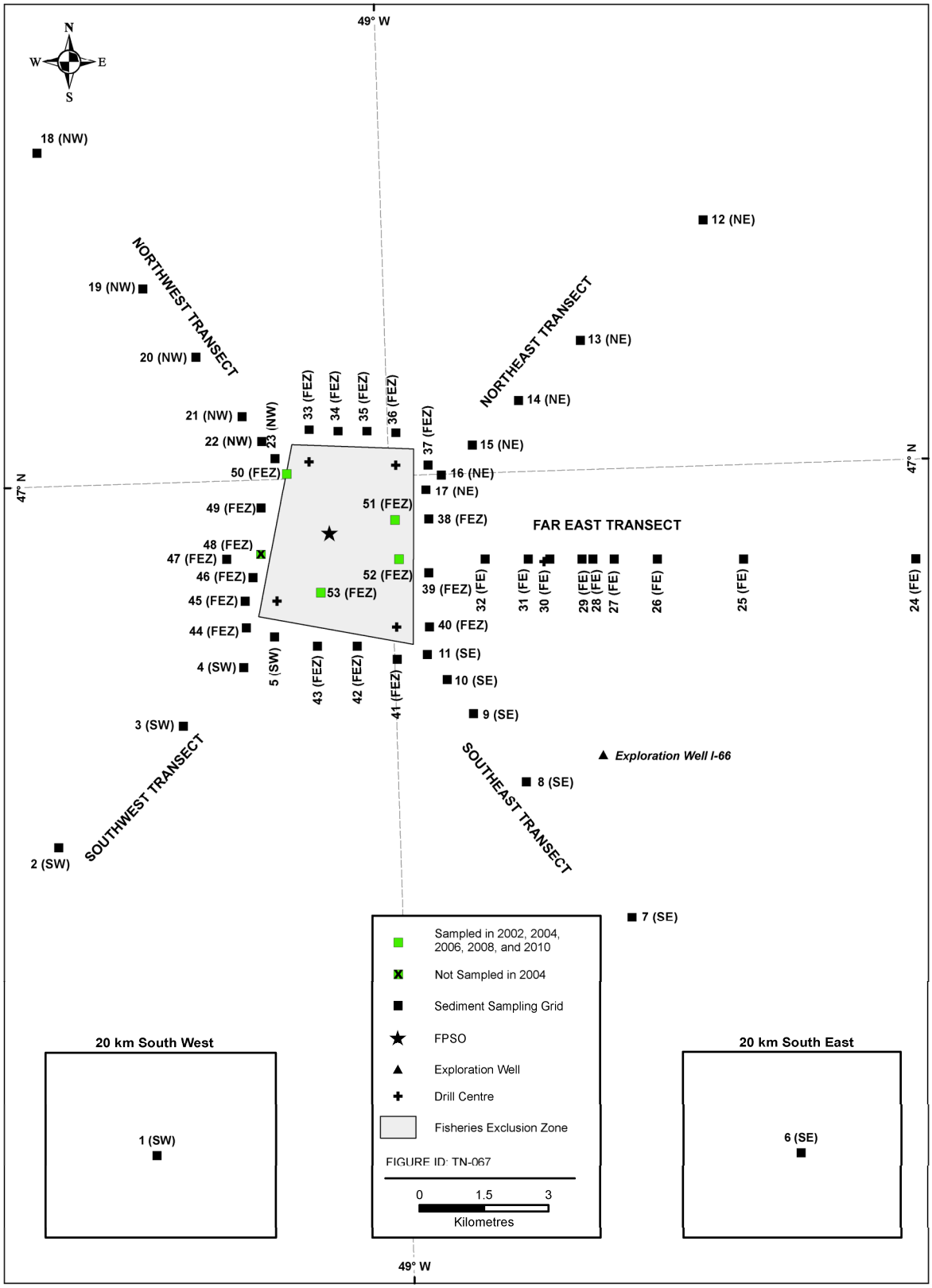


Figure 1-8 Station Locations for the EEM Program Sediment

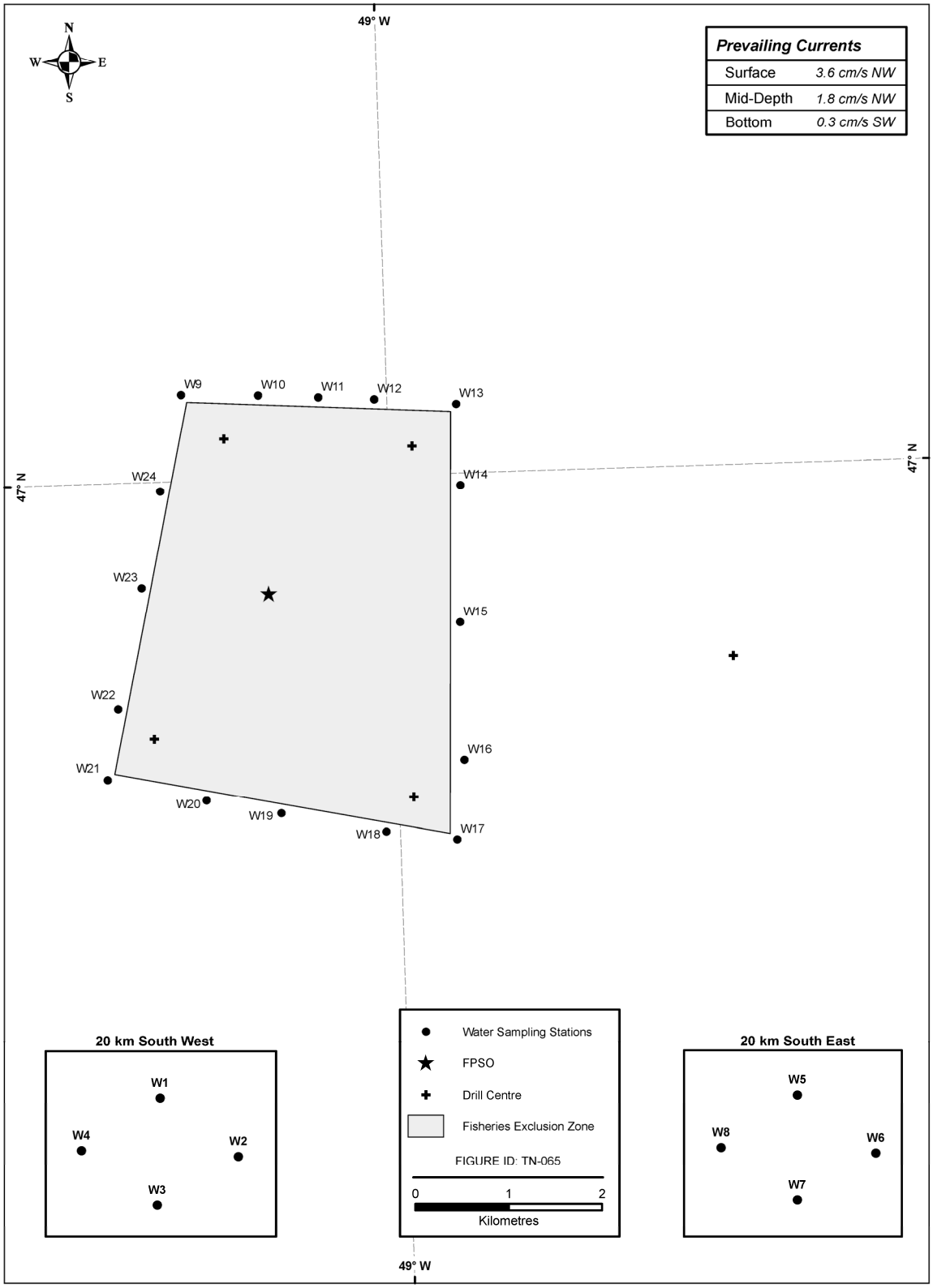


Figure 1-9 Station Locations for the EEM Program Water Collections (2000 to 2010)

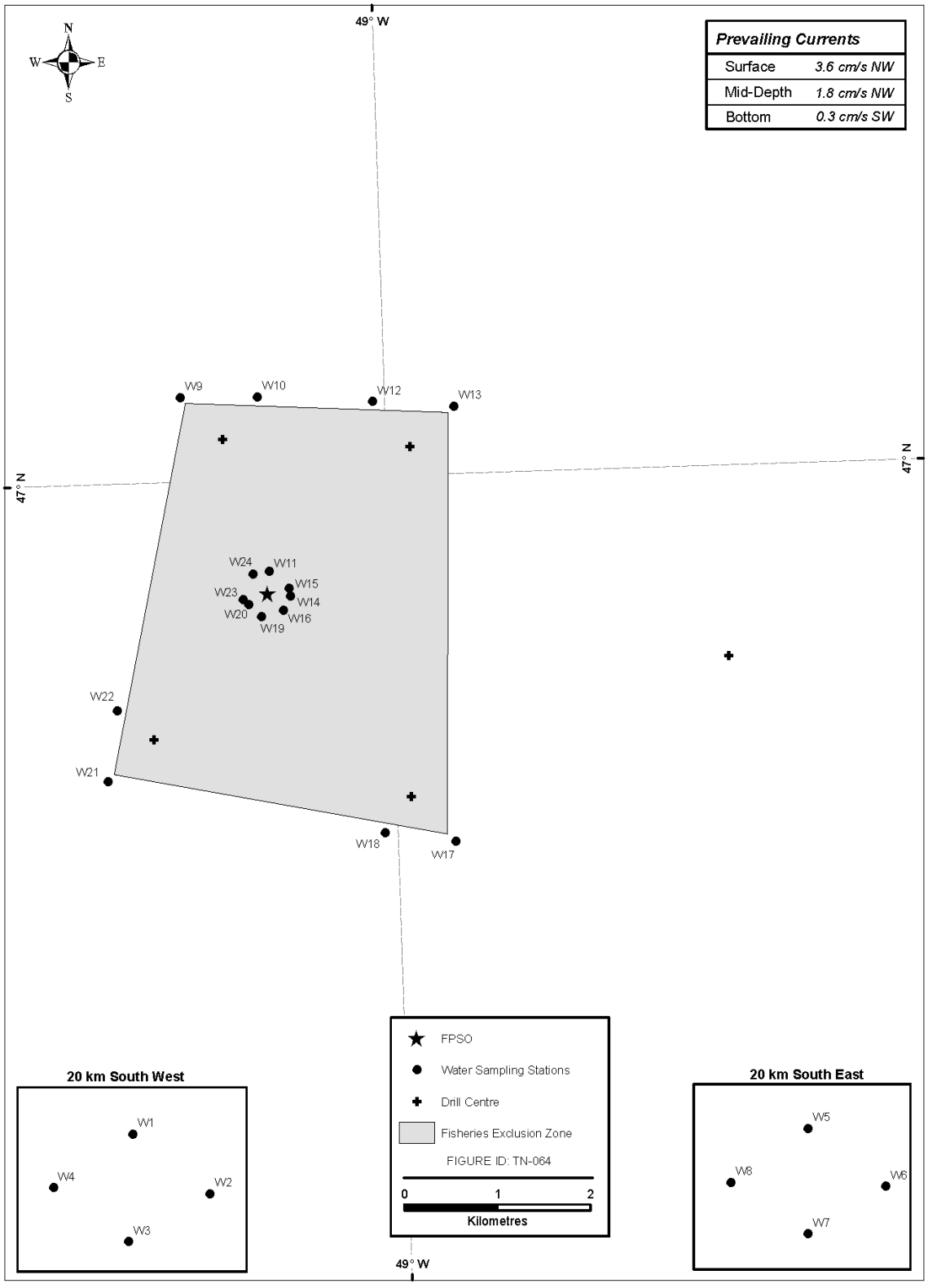


Figure 1-10 Station Locations for the EEM Program Water Collections (2012)

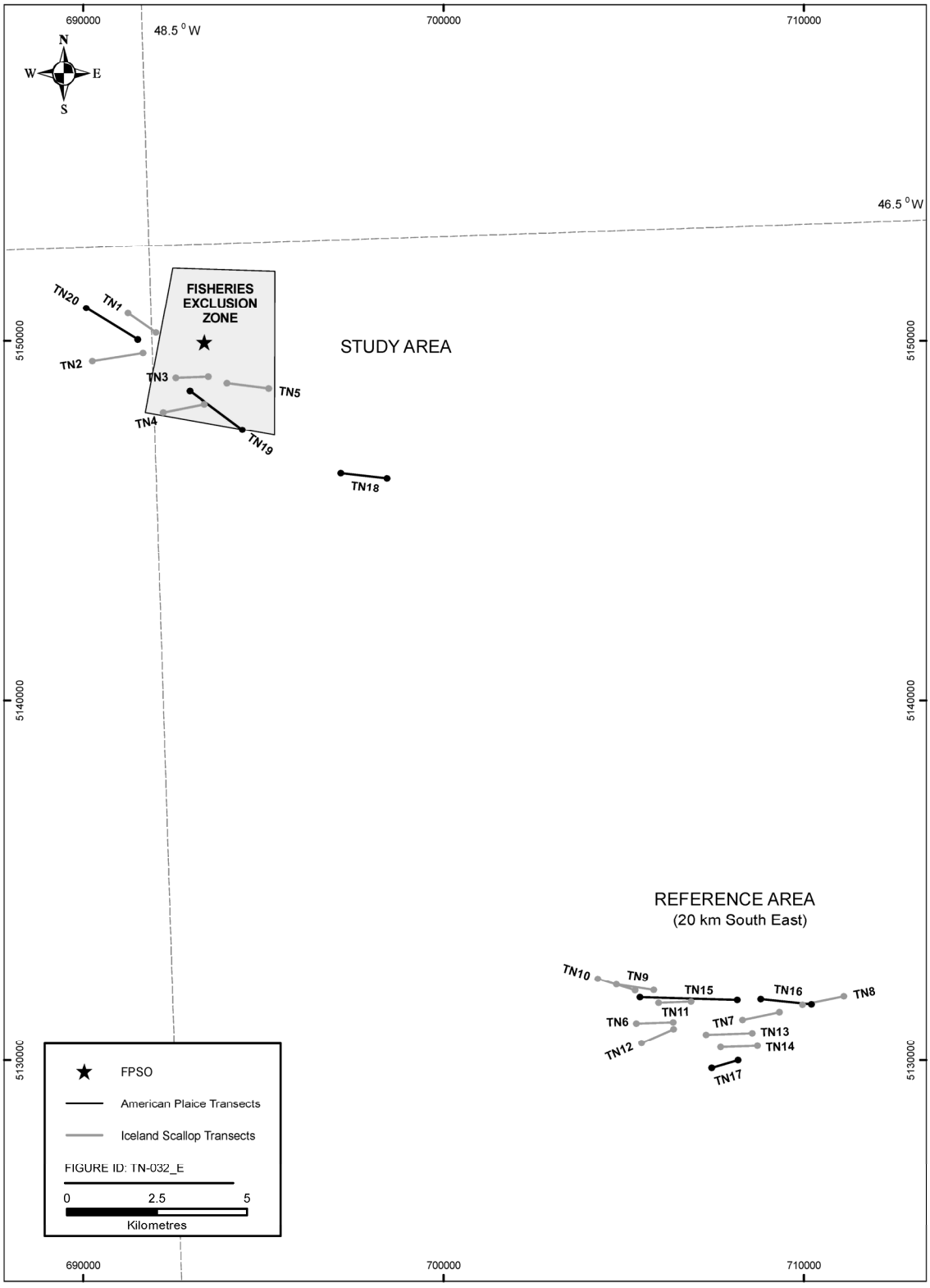


Figure 1-11 Transect Locations for Scallop and Plaice (1997)

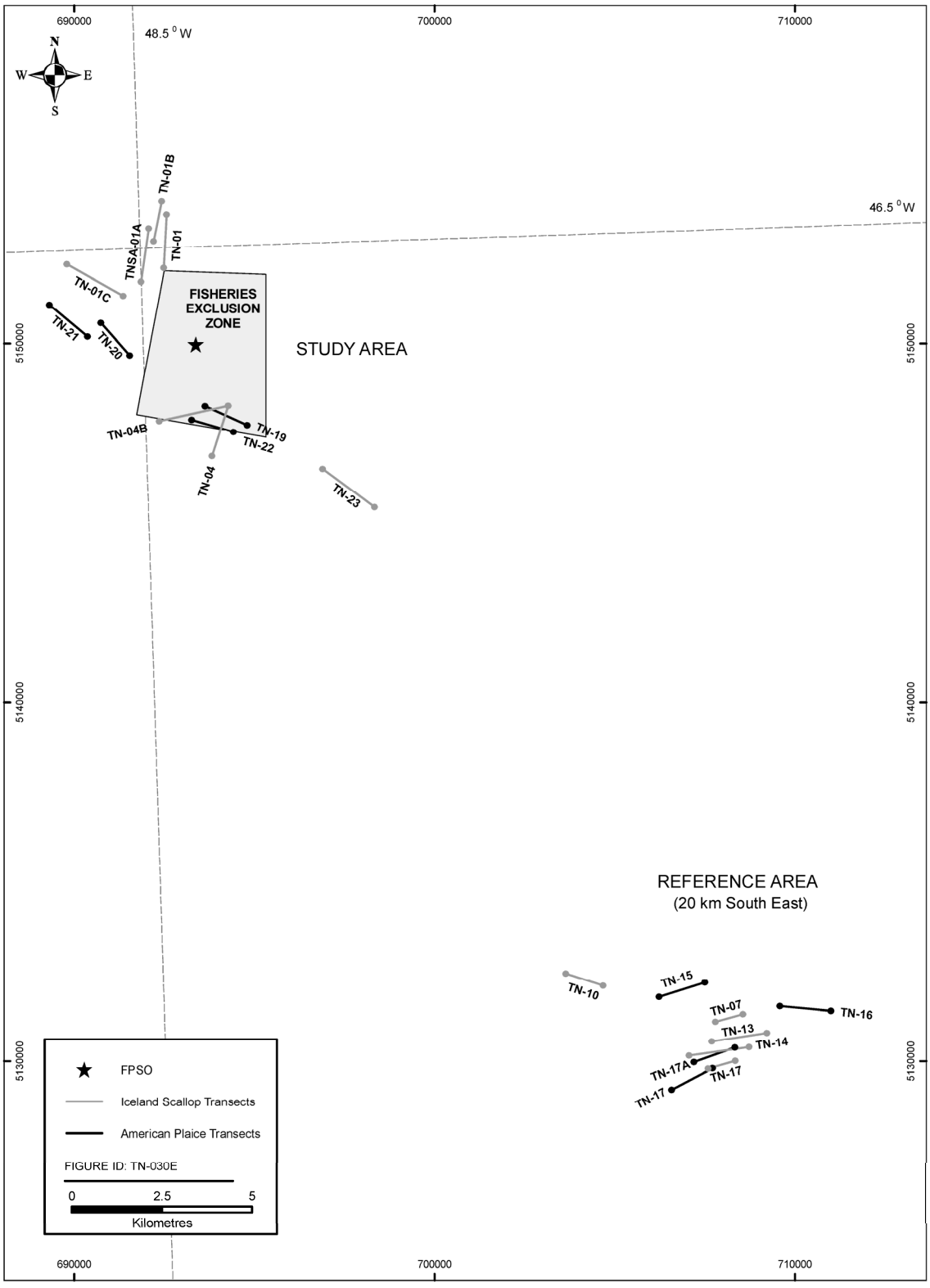


Figure 1-12 Transect Locations for Scallop and Plaice (2000)

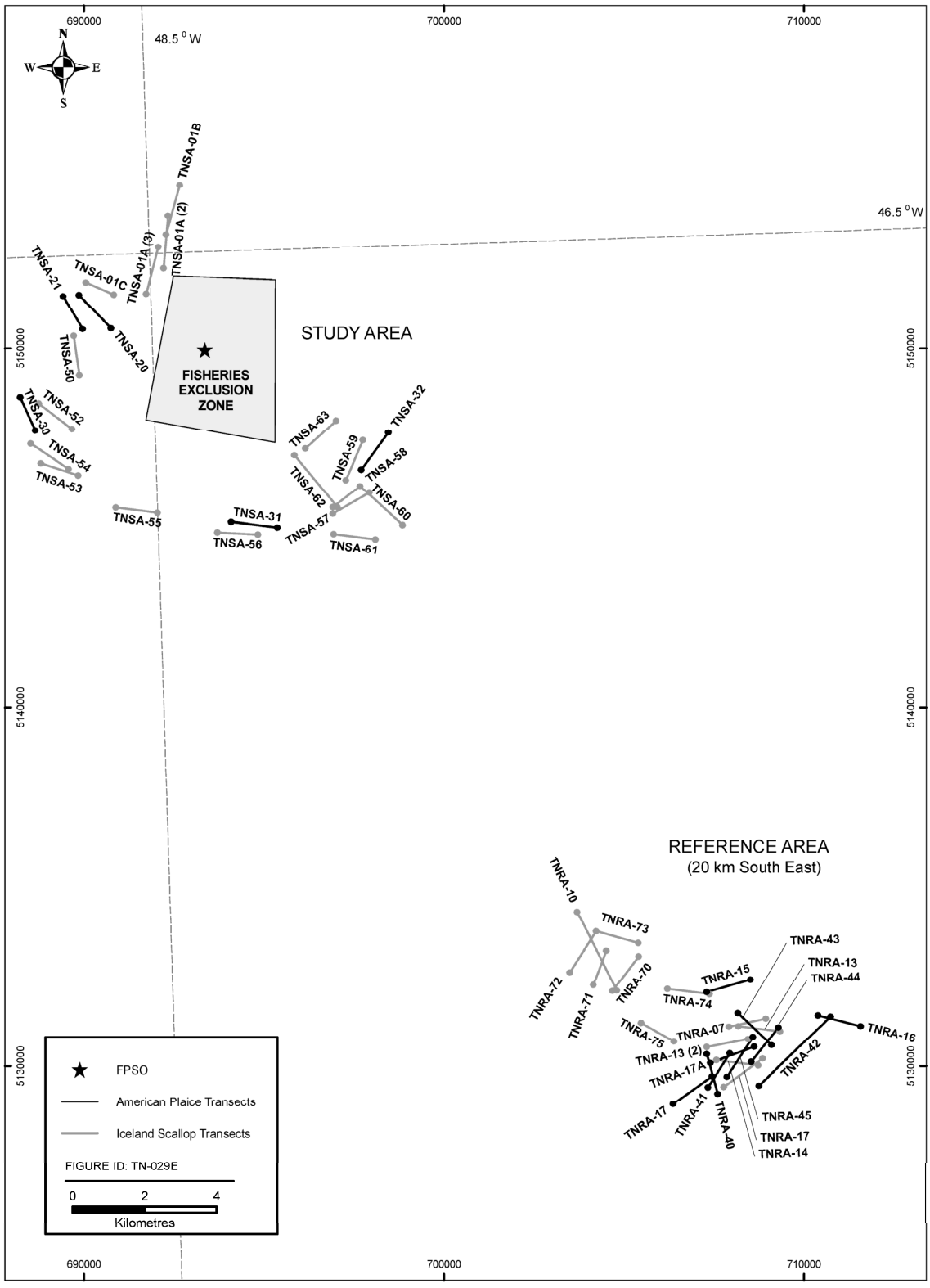


Figure 1-13 Transect Locations for Scallop and Plaice (2001)

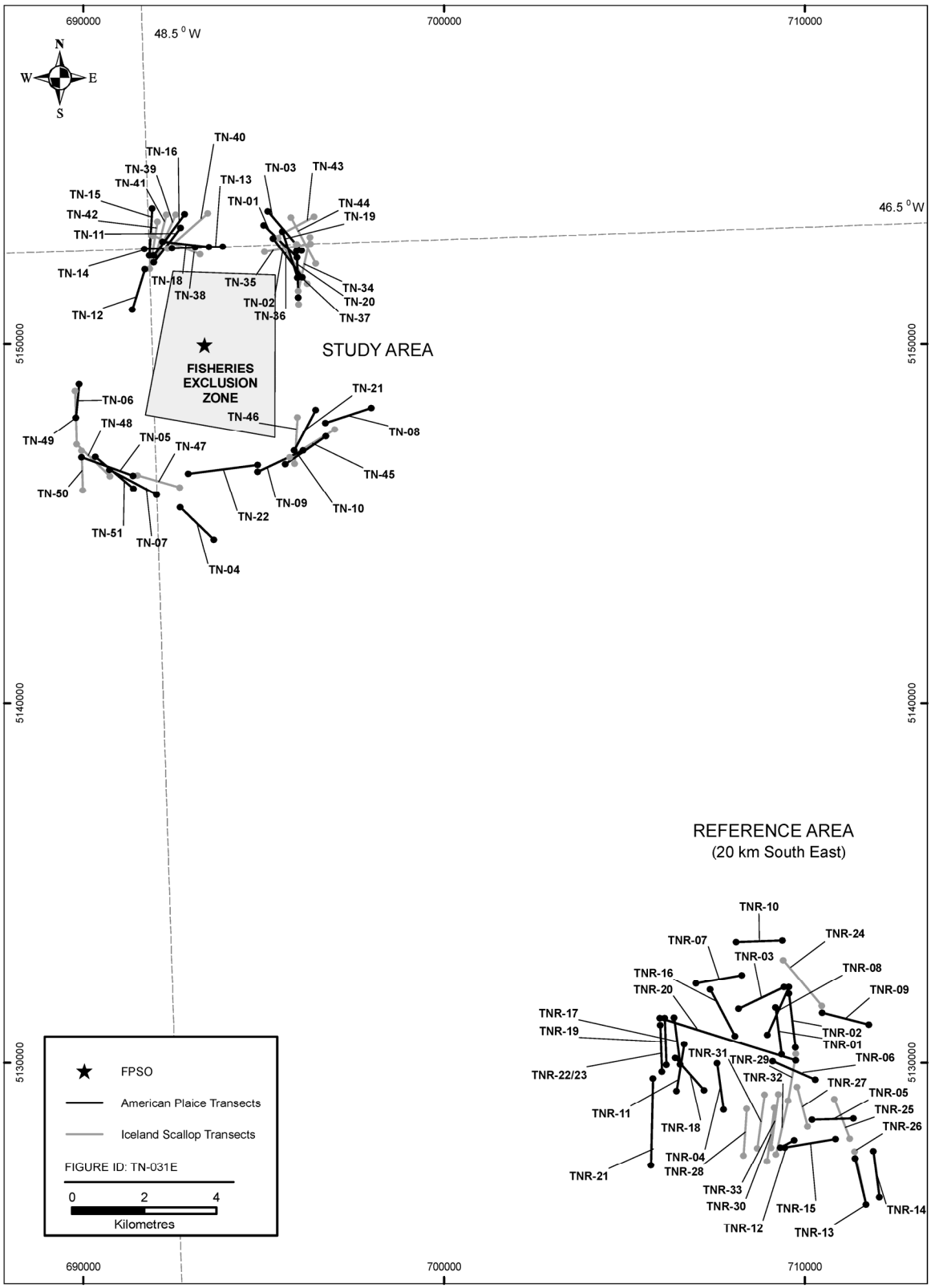


Figure 1-14 Transect Locations for Scallop and Plaice (2002)

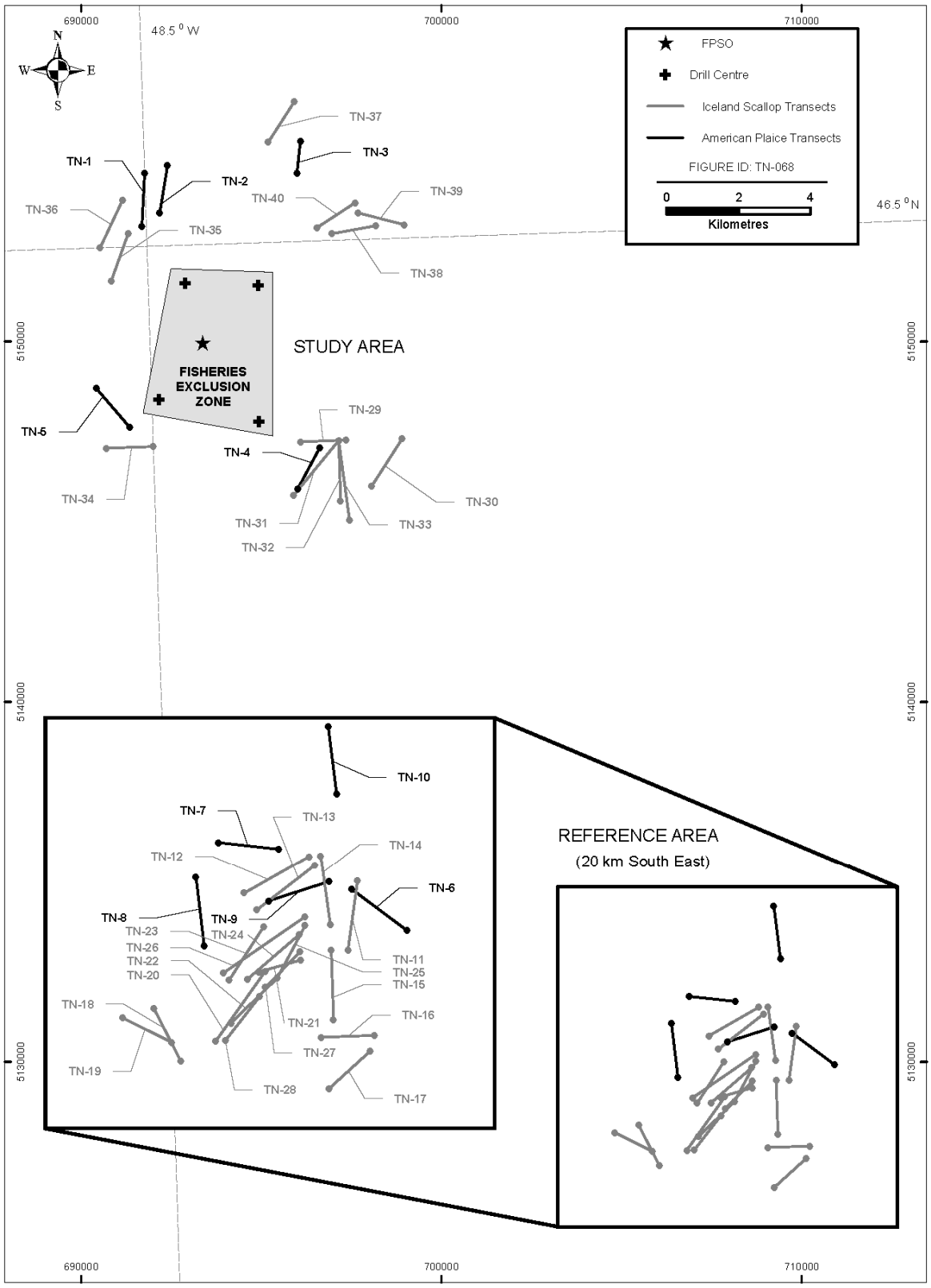


Figure 1-15 Transect Locations for Scallop and Plaice (2004)

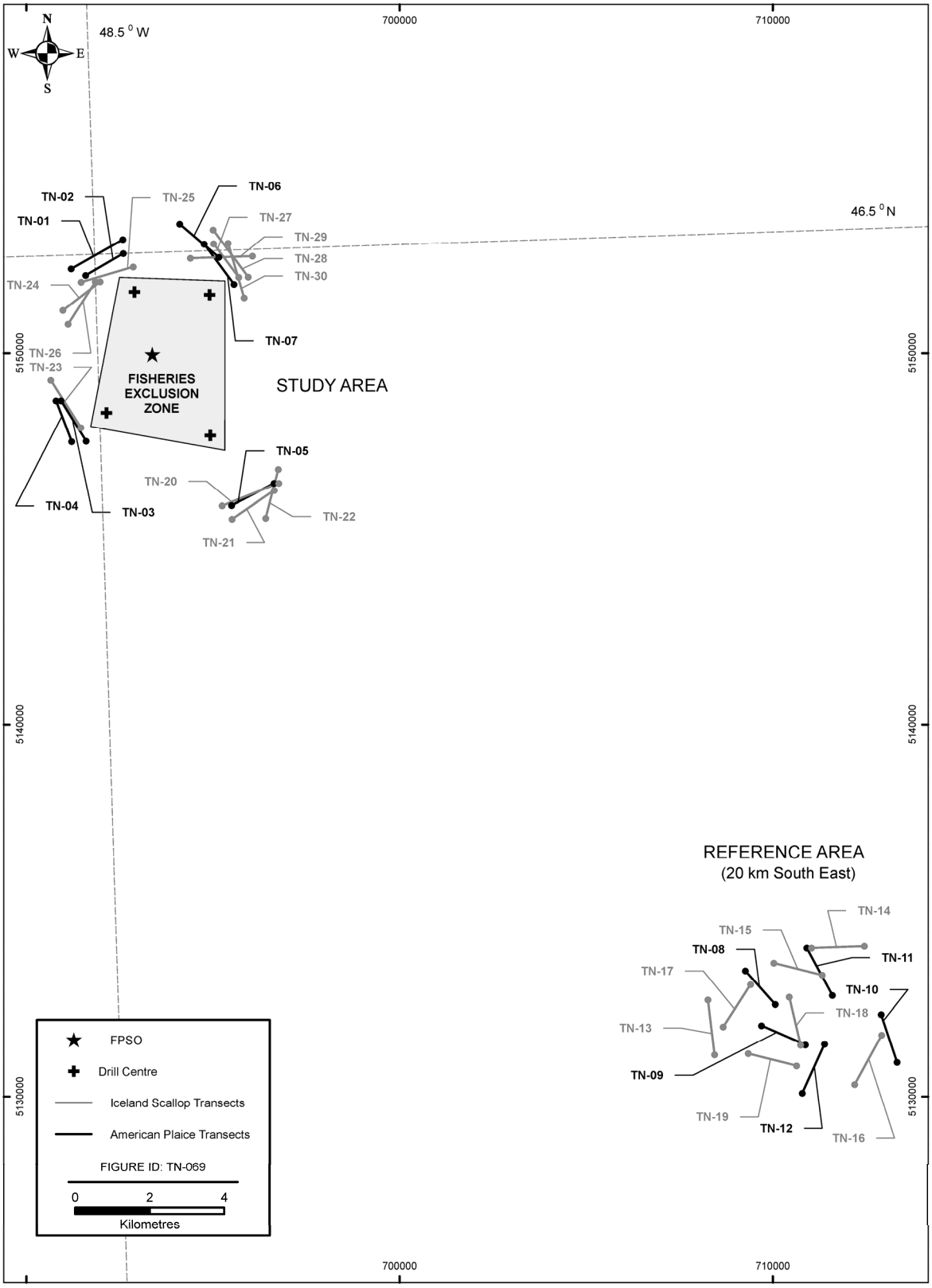


Figure 1-16 Transect Locations for Scallop and Plaice (2006)

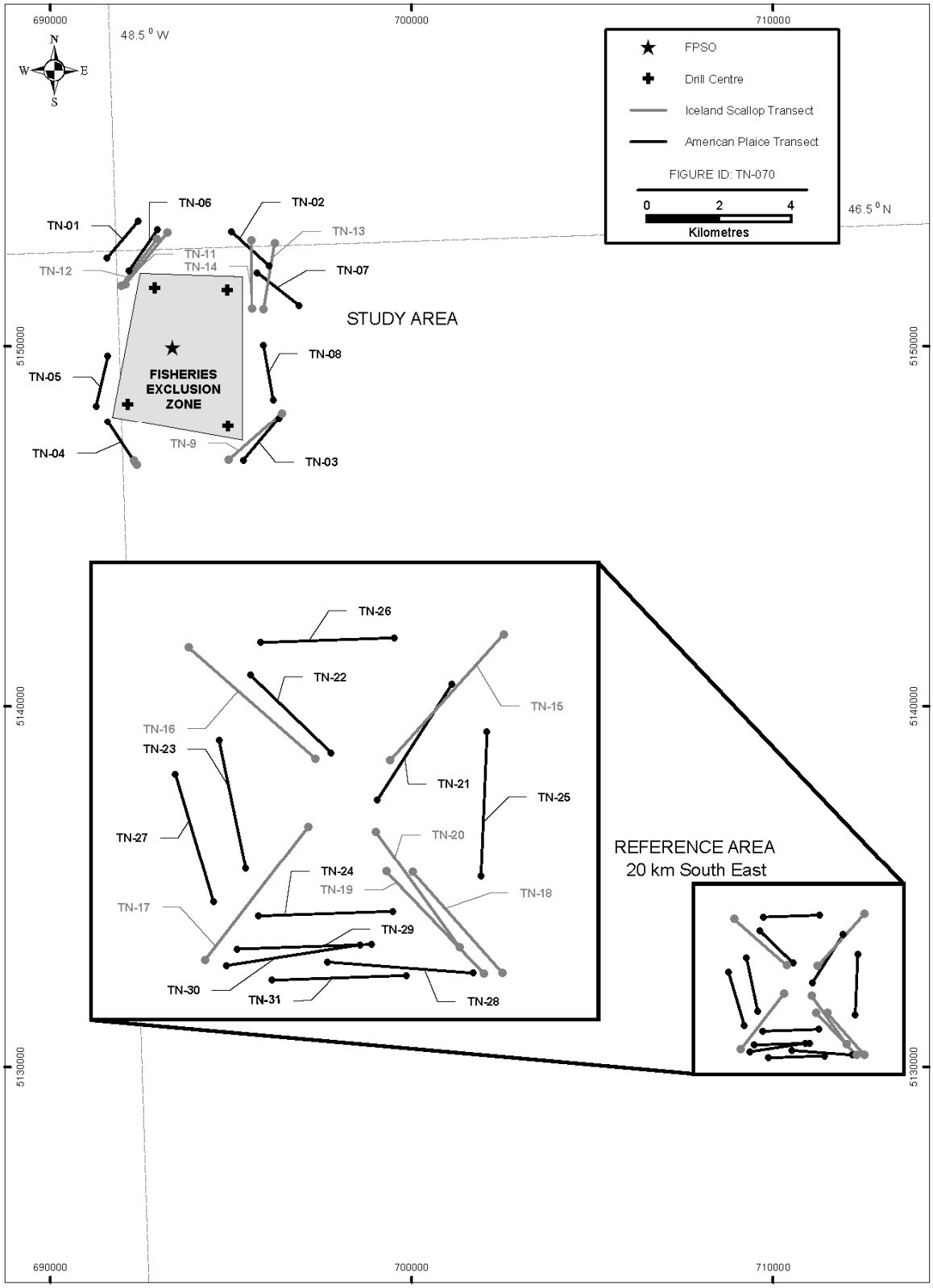


Figure 1-17 Transect Locations for Scallop and Plaice (2008)

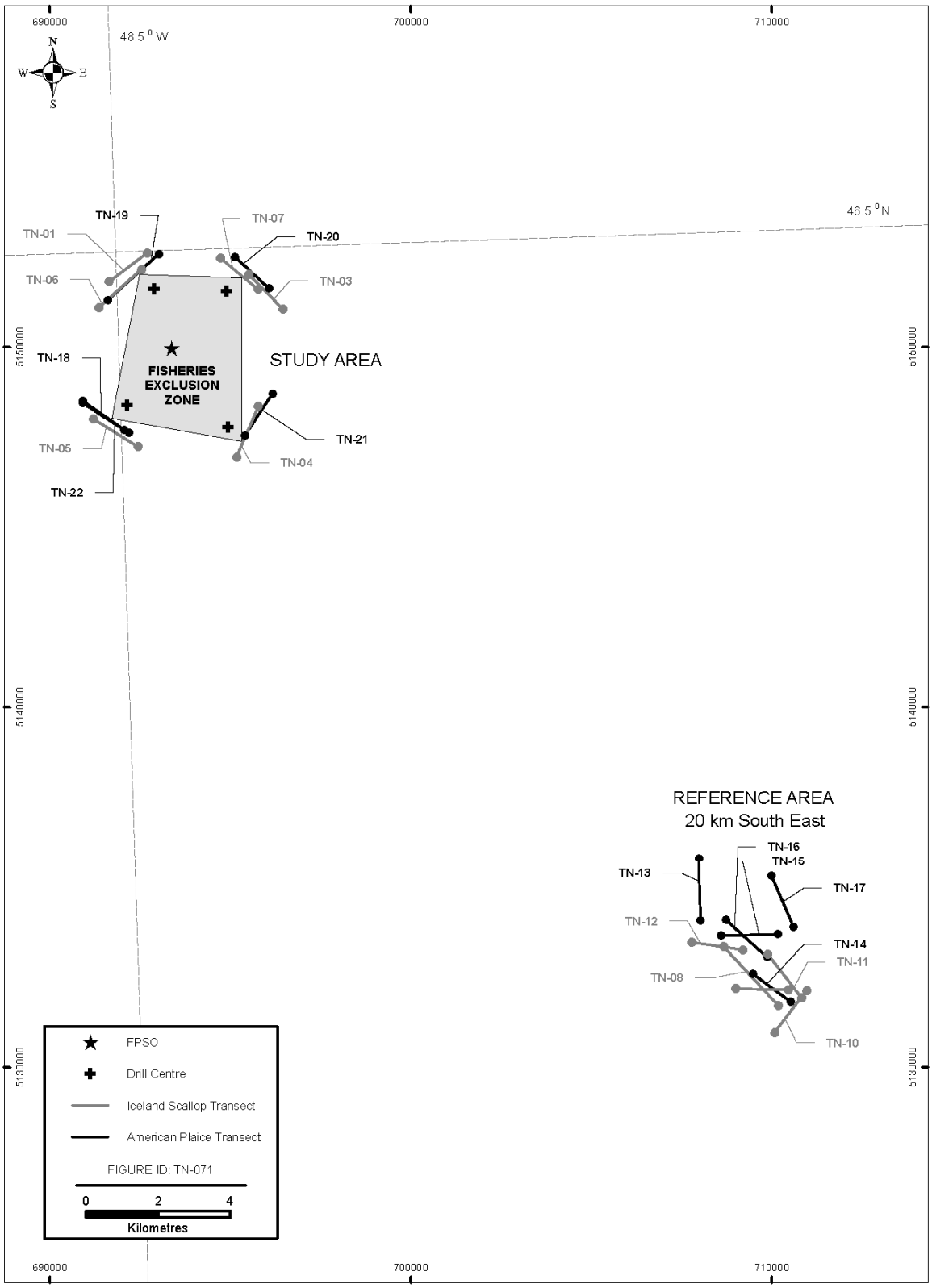


Figure 1-18 Transect Locations for Scallop and Plaice (2010)

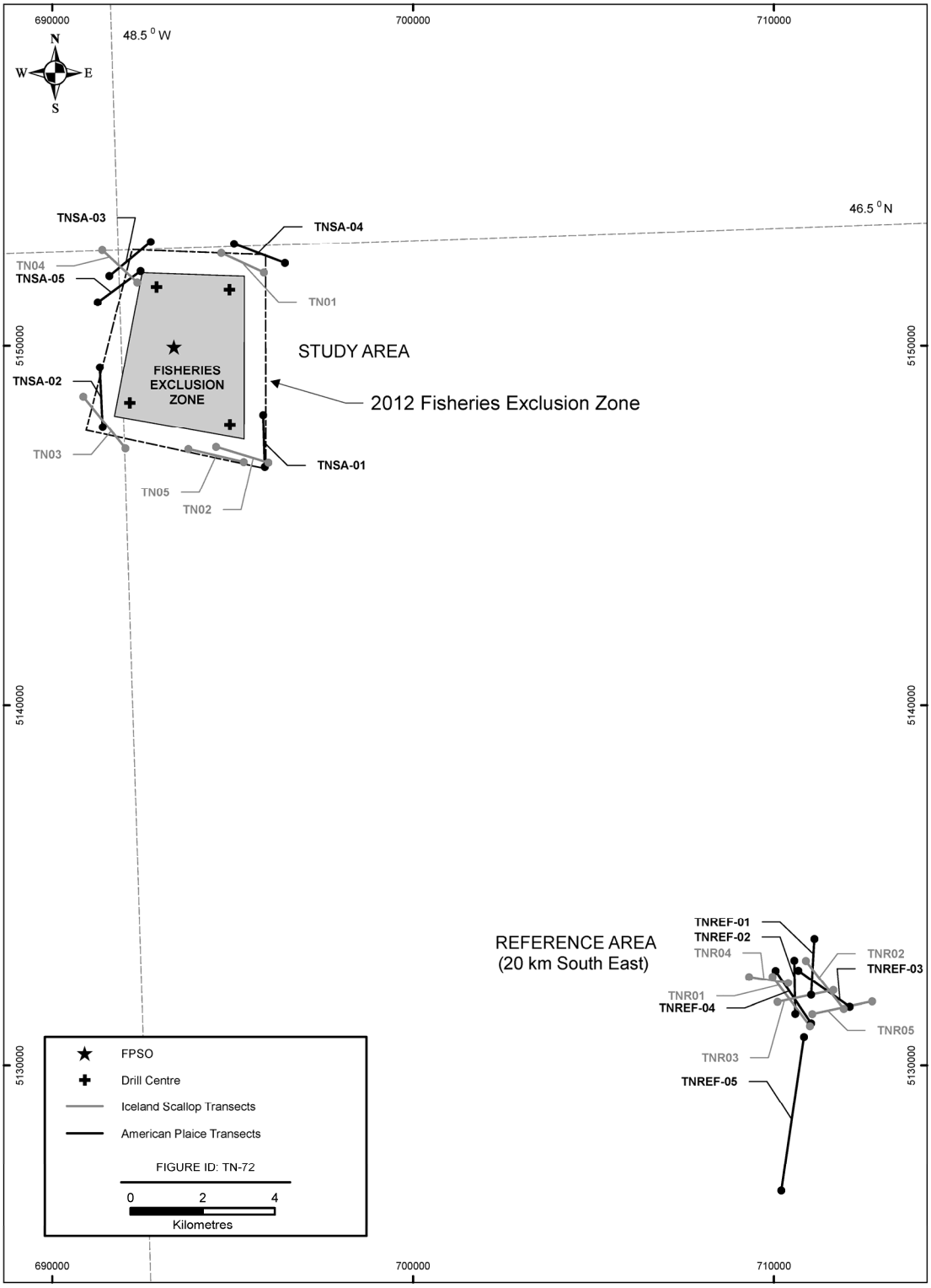


Figure 1-19 Transect Locations for Scallop and Plaice (2012)[7]

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

Table 1-2 Terra Nova Station Name Changes

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

Sample type	EEM Station Name	Baseline Station Name
	48(FEZ)	NW-SW-2
	49(FEZ)	NW-SW-1
	50(FEZ)	NW-O-1000
	51(FEZ)	NE-I-2000
	52(FEZ)	FE-I-4000
	53(FEZ)	SW-I-500
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 2012 (Volume 1)*, provides summary results, analysis and interpretation for the Terra Nova 2012 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. Since 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 2012.

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 2012 (Volume 2))*. Raw data and other information supporting *Volume 1* are also provided in *Volume 2*.

3.0 ACRONYMS

The following acronyms are used in this report. Acronyms for more detailed statistics are not provided below but are defined as they are used.

Acronym	Meaning
ANCOVA	Analysis of CoVariance
ANOVA	Analysis Of Variance
BACI	Before-After Control Impact
BA	Before-After
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CCME	Canadian Council of Ministers of the Environment
CI	Confidence Interval
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
FEZ	Fisheries Exclusion Zone
FPSO	Floating Production Offloading and Storage
IC50	50% inhibitory concentration); molar concentration of an agonist which produces 50% of the maximum possible inhibitory response to that agonist
LDL	Laboratory Detection Limit
MFO	Mixed Function Oxygenase
NE	North East
NMDS	Non-metric Multidimensional Scaling
NW	North West
PAH	Polycyclic Aromatic Hydrocarbons
PC	Principal Component
PCA	Principal Component Analysis
QA/QC	Quality Assurance/Quality Control
SD	Significant Difference
SE	South East
SW	South West

4.0 PROJECT-RELATED ACTIVITIES AND DISCHARGES

A number of site development activities occurred between 1997, when baseline field collection took place, and June 2012, when the collections for the eighth sampling year of the EEM program were performed. These activities were related to site development and operation, as described in the following sections[8].

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.

[8] Please note that the statistics present within this section pertain only to those operational activities that occurred prior to and including June 2012, when EEM sampling was performed. The discharge statistics do not reflect the production and drilling activities conducted beyond this period.

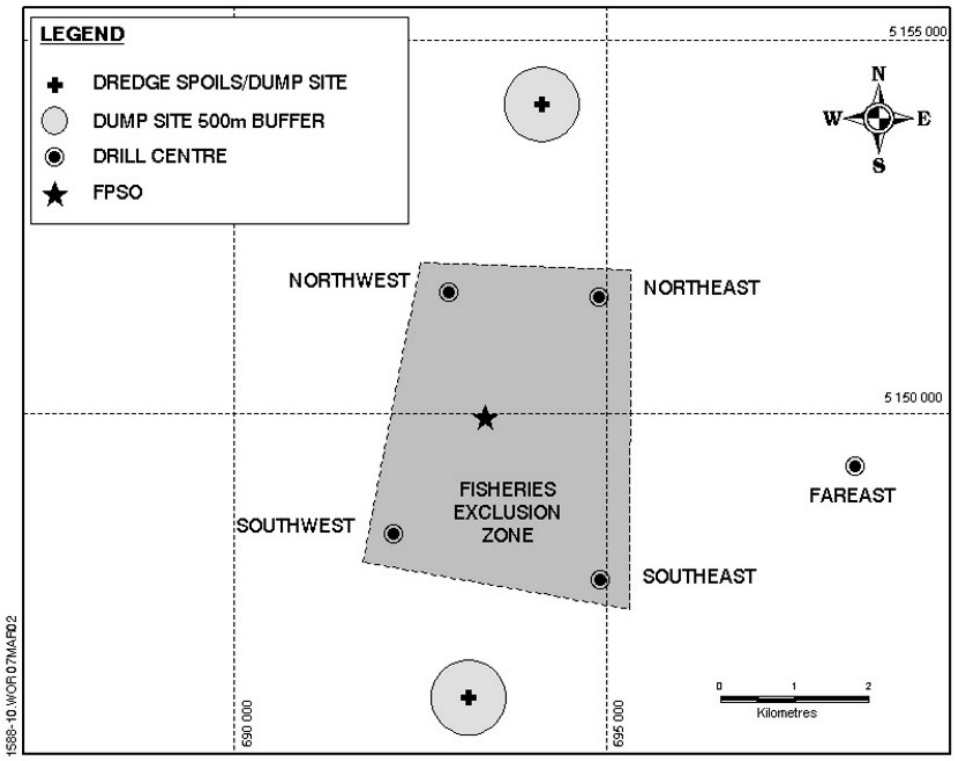


Figure 4-1 Drill Centre Locations and Dump Sites for Dredge Spoils

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 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 2012 were limited primarily to maintenance and repair activities for subsea equipment components, including subsea control module replacement, 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.

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 July 2012, 36 distinct wellbores and sidetracks have been drilled within the field. Since first oil in 2002, 30 wells in the NW, NE, SW and SE drill centres have been used for production activities. Of these 30 wells, 16 were oil producers, four were gas injectors and ten were water injectors. One of the four gas injectors and one of the ten water injectors have been abandoned.

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

1. water-based drillmuds;
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, 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. Drilling activities were conducted using water-based drill muds during the period of November 2010, after completion of the 2010 EEM program, to July 2012 (see Table 4-1 for details).

Table 4-1 Discharges of Water-based Drilling Fluid from November 2010 to July 2012

Year	Month	Well	Drill Centre	Discharges To Sea
				Fluid Volume (m^3)
2011	May	G-90 9	NE	860.2
2012	May	L-98 12	SW	555.5
2012	June	L-98 12	SW	2,528.6
November 2010 to July 2012 Total				**3,944.3**

Note: - Drilling discharge statistics refer only to discharges from since the last (2010) EEM program to the 2012 EEM program

From the beginning of drilling to July 2012, Suncor reported cumulative water-based discharges of 58,566 m^3. 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, 3,865 m^3 were discharged at the Far East (FE) drill centre and 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

Synthetic-based drill muds were used to facilitate the drilling of a single well during May and July of 2011. 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).

The single well drilled during 2011 with synthetic-based drill muds was drilling out of the NE drill centre (see Table 4-2 for details). No other synthetic-based drill mud drilling activities were conducted in the Terra Nova field during the period of November 2010 to July 2012.

Table 4-2 PureDrill IA35-LV Base Oil Fluid on Cuttings Discharged from November 2010 to July 2012

Year	Month	Well	Drill Centre	Discharge to Sea		
				Oil Volume (m^3)	Oil Weight (tonne)	Cuttings Weight (tonne)
2011	May	G-90 9	NE	35.91	29.62	493.78
2011	June	G-90 9	NE	27.70	22.85	314.85
2011	July	G-90 9	NE	0.00	0.00	0.00
November 2010 to July 2012 Total				**64**	**52**	**809**

Note: - Drilling discharge statistics refer only to discharges from since the last (2010) EEM program to the 2012 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 November 2010 to July 2012, Suncor reported cumulative synthetic-based mud-on-cuttings discharges of 52 tonnes, all of which were discharged at the NE drill centre. Since the beginning of drilling to October 2010, Suncor reported cumulative SBM-on-cuttings discharges of 6,324 tonnes: 1,749 tonnes were discharged at the SW drill centre, 521 tonnes were discharged at the NW drill centre, 2,077 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 and 184 tonnes were discharged at the drill site for the exploration well I-66 (PF8).

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.

No completion operations were conducted in the Terra Nova field during the period of November 2010 to July 2012.

From the beginning of drilling to July 2012, Suncor reported cumulative water-based completion fluid discharges of 43,485 m^3: 11,844 m^3 were discharged at the SW drill centre; 24,280 m^3 were discharged at the NE drill centre; 2,636 m^3 were discharged at the SE drill centre; and 4,725 m^3 were discharged at the NW drill centre.

4.3 PRODUCED WATER

The FPSO arrived at the Terra Nova oil field on August 4, 2001. Start-up of oil production occurred on January 20, 2002, with the opening of the HPE5 well from the SW drill centre at 1720 hours. Production was shut-down eight times between November 2010 and July 2012. Shut-down periods are listed in Table 4-3.

Table 4-3 Production Shut-Down Periods from October 2010 to July 2012

Year	Shut-Down Interval
2010	December 14 - 16
2011	August 6 - 7
	October 16 - November 7
	December 17 - 18
2012	January 2
	February 4 - 5
	May 6 -8
	June 9 - December 8

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 November 2010 to July 2012 are provided in Table 4-4.

Table 4-4 Produced Water Discharges from November 2010 to July 2012

Period	Monthly Average Effluent Oil Concentration (mg/L)	Total Monthly Effluent Flow (m^3/month)
November 2010	13.0	461,371
December 2010	11.4	335,836
January 2011	11.4	423,183
February 2011	15.4	348,320
March 2011	11.8	338,776
April 2011	7.7	361,971
May 2011	9.5	437,686
June 2011	13.2	369,316
July 2011	13.9	391,519
August 2011	23.6	277,262
September 2011	15.3	171,715
October 2011	23.0	121,703
November 2011	27.5	220,485
December 2011	23.2	356,131
January 2012	22.6	406,277
February 2012	20.2	399,076
March 2012	21.5	393,155
April 2012	16.0	420,715
May 2012	11.2	465,834
June 2012	17.5	135,866
July 2012	2012 Turnaround/ Off Station Program	

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 November 2010 to July 2011 and May to June 2012 was 355 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 November 2010 to July 2012.

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 November 2010 to July 2012 was 18,387 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 2012 EEM program was conducted from May 25 to June 1, 2012, using the offshore supply vessel *M/V Burin Sea.* 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). Sediment collection stations for the 2012 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

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 m^2 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 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). All samples were stored in pre-labelled 250-ml glass jars. In 2012, sediment samples collected for hydrocarbon, metals, ammonia and total inorganic and organic carbon analysis were stored at 4ºC and archive samples were stored at -20ºC. Because all these samples have been stored at -20ºC in previous

years, archive samples were used for analysis of those compounds in 2012[9]. Sediment samples collected for sulphide analysis were stored at 4 ºC, as in previous years. 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.

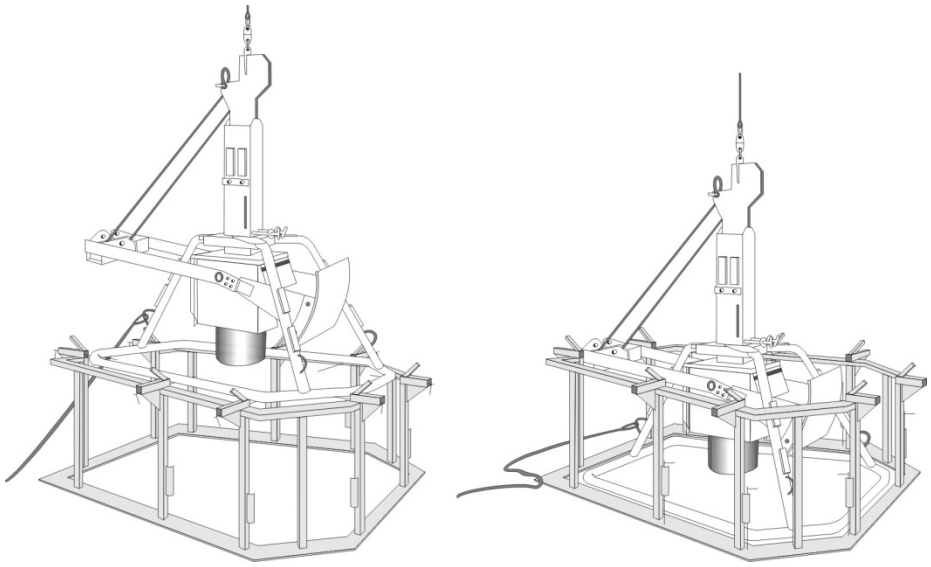
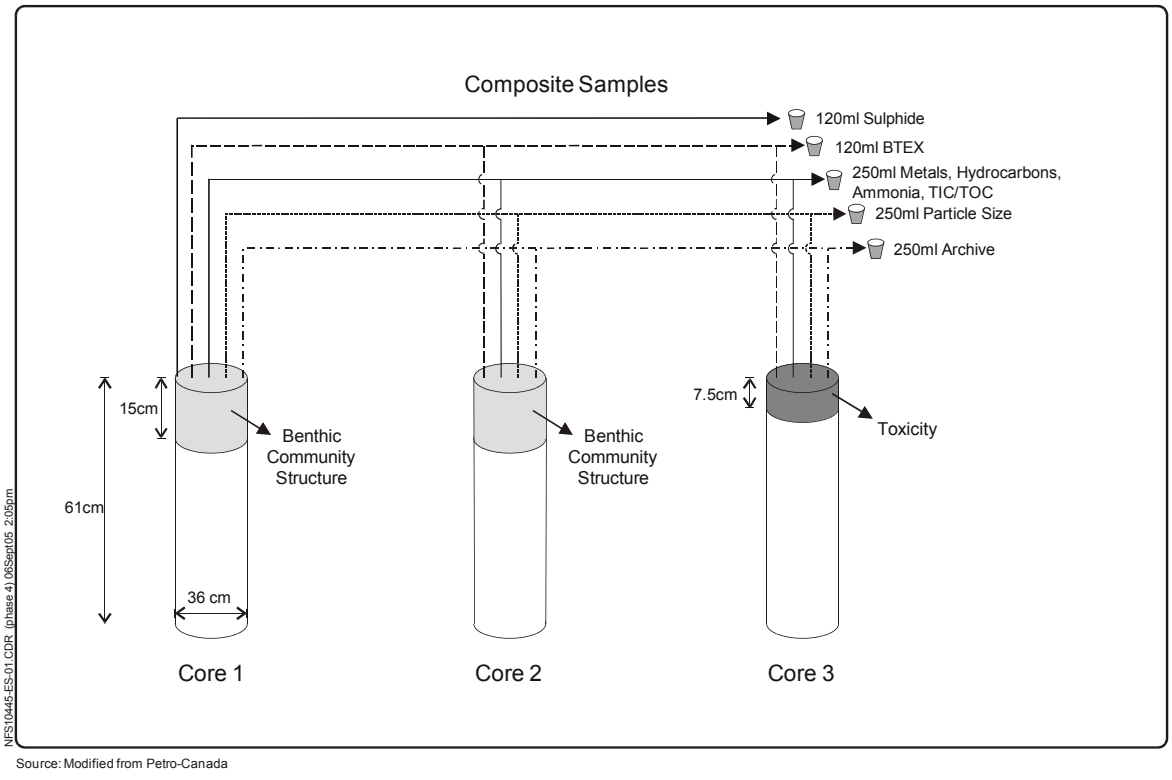


Figure 5-1 Sediment Corer Diagram

[9] There is no difference in collection methods between the chemistry samples and archive samples and the samples are interchangeable.

Figure 5-2 Sediment Corer



Source: Modified from Petro-Canada

Figure 5-3 Allocation of Samples from Cores

Sediment chemistry field blanks composed of clean sediment obtained from the analytical laboratory were collected at stations 4(SW), 18(NW) and 33(FEZ). Blank vials were opened as soon the core sampler from these three stations was brought on board the vessel and 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 18(NW), 20(NW), 28(FE), 36(FEZ) and 49(FEZ). Both field blanks and field duplicates were assigned randomly to stations.

Quality Assurance/Quality Control (QA/QC) protocols were followed for collection of samples to ensure sample integrity and prevent onboard contamination. Core samples were immediately covered with clean, plastic-lined metal covers and moved to a working area near the laboratory facility. 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 particle size, hydrocarbons, metals, sulphides, ammonia and total inorganic and organic carbon (Tables 5-2 and 5-3). Particle size analysis was conducted by Stantec Consulting Ltd. in St. John's, Newfoundland and Labrador. Remaining analyses were conducted by Maxxam Analytics in Halifax, Nova Scotia. Methods summaries from both these laboratories are provided in Appendix B-2.

Table 5-2 Particle Size Classification

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

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

Table 5-3 Sediment Chemistry Variables (1997 to 2012)

Variable	Method	Laboratory Detection Limit							Units
		1997	2000 &2001	2002	2004	2006	2008	2010 &2012	
Hydrocarbons									
Benzene	Calculated	0.025	0.025	0.025	0.025	0.03	0.03	0.03	mg/kg
Toluene	Calculated	0.025	0.025	0.025	0.025	0.03	0.03	0.03	mg/kg
Ethylbenzene	Calculated	0.025	0.025	0.025	0.025	0.03	0.03	0.03	mg/kg
Xylenes	Calculated	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	3	3	3	mg/kg
>C_{10}-C_{21}	GC/FID	15	0.25	0.25	0.25	0.3	0.3	0.3	mg/kg
>C_{21}-C_{32}	GC/FID	15	0.25	0.25	0.25	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	0.01	mg/kg
2-Chloronaphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
1-Methylnaphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
2-Methylnaphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Acenaphthene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Acenaphthylene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Anthracene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Benz[*a*]anthracene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Benzo[*a*]pyrene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Benzo[*b*]fluoranthene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Benzo[*ghi*]perylene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Benzo(j)fluoranthene*	GC-MS	NA	NA	NA	NA	NA	NA	NA/0.01	mg/kg
Benzo[*k*]fluoranthene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Chrysene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Dibenz[*a,h*]anthracene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Fluoranthene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Fluorene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Indeno[1,2,3-*cd*]pyrene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Naphthalene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Perylene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Phenanthrene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Pyrene	GC-MS	0.01	0.05	0.05	0.05	0.05	0.05	0.01	mg/kg
Carbon									
Total Carbon	LECO	NA	0.1	0.1	0.2	0.2	0.2	0.2	g/kg
Total Organic Carbon	LECO	NA	0.1	0.1	0.2	0.2	0.2	0.2	g/kg
Total Inorganic Carbon	By Difference	NA	0.1	0.1	0.2	0.2	0.2	0.2	g/kg
Metals (total)									
Aluminum	ICP-MS	10	10	10	10	10	10	10	mg/kg
Antimony	ICP-MS	2	2	2	2	2	2	2	mg/kg
Arsenic	ICP-MS	2	2	2	2	2	2	2	mg/kg
Barium	ICP-MS	5	5	5	5	5	5	5	mg/kg
Beryllium	ICP-MS	5	5	5	2	2	2	2	mg/kg
Cadmium	ICP-MS	0.3	0.05	0.05	0.05	0.05	0.05	0.05	mg/kg
Chromium	ICP-MS	2	2	2	2	2	2	2	mg/kg

Variable	Method	Laboratory Detection Limit							Units
		1997	2000 &2001	2002	2004	2006	2008	2010 &2012	
Cobalt	ICP-MS	1	1	1	1	1	1	1	mg/kg
Copper	ICP-MS	2	2	2	2	2	2	2	mg/kg
Iron	ICP-MS	20	20	20	50	50	50	50	mg/kg
Lead	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Lithium	ICP-MS	5	5	2	2	2	2	2	mg/kg
Manganese	ICP-MS	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	mg/kg
Molybdenum	ICP-MS	2	2	2	2	2	2	2	mg/kg
Nickel	ICP-MS	2	2	2	2	2	2	2	mg/kg
Selenium	ICP-MS	2	2	2	2	2	2	2	mg/kg
Sulphur	LECO	NA	NA	0.03	0.02	0.002	0.01	0.03	%(w)
Strontium	ICP-MS	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	mg/kg
Tin	ICP-MS	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	mg/kg
Vanadium	ICP-MS	2	2	2	2	2	2	2	mg/kg
Zinc	ICP-MS	2	2	2	5	5	5	5	mg/kg
Other									
Ammonia (as N)	COBAS	NA	NA	0.25	0.25	0.3	0.3	0.3	mg/kg
Sulphide	COBAS (SM4500-S2-D)	NA	NA	20	2	0.2	0.2	0.2	mg/kg
Moisture	Gravimetry	0.1	0.1	0.1	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 may vary from year to year because instruments are checked for precision and accuracy every year as part of QA/QC procedures.
- The carbon ranges $>C_{10}$-C_{13} and $>C_{13}$-C_{21} were extracted in 2002. For comparison with results for $>C_{10}$-C_{21} hydrocarbons from other years, values of $>C_{10}$-C_{13} and $>C_{13}$-C_{21} hydrocarbons for 2002 were added. Where values of $>C_{10}$-C_{13} hydrocarbons were less than laboratory detection limit (0.25 mg/kg) and values of $>C_{13}$-C_{21} hydrocarbons were greater than the laboratory detection limit (0.25 mg/kg), values of $>C_{10}$-C_{13} hydrocarbons were set to zero.
- NA = Not Analyzed.
- *Benzo(*j*)fluoranthene was not reported by the analytical laboratory until 2012.

Within the hydrocarbons, benzene, toluene, ethylbenzene and xylenes (BTEX) are aromatic organic compounds that are detected in the C_6-C_{10} range, commonly referred to as the gasoline range. $>C_{10}$-C_{21} is referred to as the diesel range and 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. Total petroleum hydrocarbons encompass all three ranges (C_6-C_{32}). Hydrocarbons in all ranges include aromatic, n-alkane (straight chain), isoalkane (branched chain) and cycloalkane (cyclic, non-aromatic chain) compounds. Polycyclic aromatic hydrocarbons (PAHs) are a diverse class of organic compounds that are composed of two or more fused aromatic benzene rings.

Gas chromatography is used to assess concentrations of hydrocarbons 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.

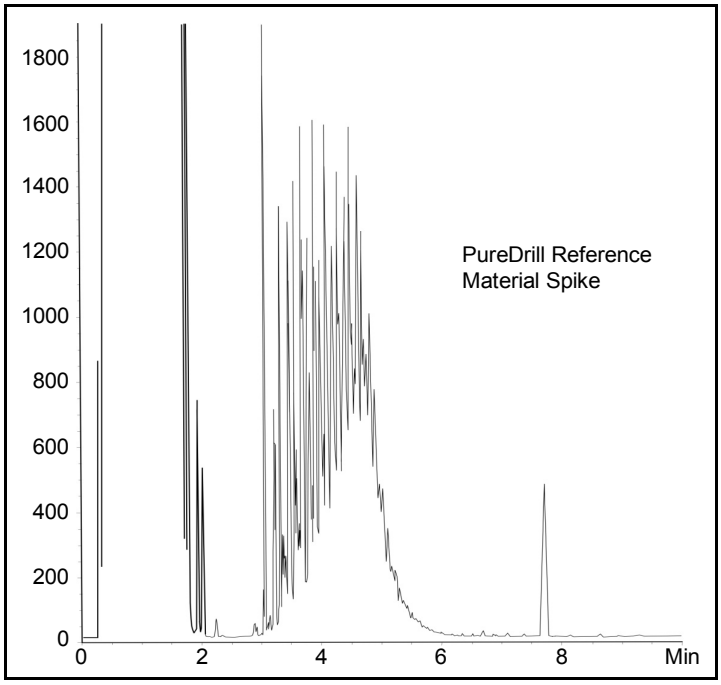


Figure 5-4 Gas Chromatogram Trace for PureDrill IA35-LV

5.1.2.2 Toxicity

Stantec Consulting Ltd. Science Laboratory 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 Environment Canada (1998) protocols using the marine amphipod *Rhepoxynius abronius* obtained from West Beach, Whidbey Island, Washington State (USA). Tests involved five replicate 1-L test chambers, with approximately 2 cm of sediment and approximately 800 mL of overlying water (Figure 5-5).

Figure 5-5 Amphipod Survival Test

Each test container was set up with 20 test organisms and maintained for ten days under appropriate test conditions, after which survival was recorded. A sixth 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 Azur solid phase diluent. The actual number of concentrations was dependent on the degree of reduction in bioluminescence observed. Negative (clean) and positive (toxic) controls were run concurrently with the test samples. Reduction of light after 15 minutes was used to measure toxicity. Data interpretation for 2004, 2006, 2008, 2010 and 2012 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 quality control check, some samples were retested outside the six week storage period[10]. 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 amphipod unavailability[11].

[10] Samples from stations 5SW, 6SE, 7SE, 9SE, 15NE, 13NE, 14NE, 17NE, 18NW, 23NW, 33FEZ, 37FEZ, 38FEZ, 39FEZ and 40FEZ were retested outside the six week storage period.

[11] Samples from stations 28FE, 8SE, 26FE, 25FE, 24FE, 27FE, 53FEZ, 42FEZ, 29FE, 45FEZ, 3SW, 41FEZ, 40FEZ, 9SE, 51FEZ, 38FEZ, 30FE, 32FE, 39FEZ, 31FE, 14NE, 12NE and 6SE were tested outside the six week storage period.

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[12] value.

Sample toxicity was assessed using standard toxicity testing statistical programs coupled with interpretation guidance and direction provided by Environment Canada. The amphipod survival test results for sediments 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 1SW and 6SE). 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. its 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.

[12] An IC50 (50% inhibitory concentration) is the molar concentration of an agonist that produces 50% of the maximum possible inhibitory response to that agonist.

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[13]). When this occurs, wet weight IC50s are calculated by hand using probit graphs.

5.1.2.3 Benthic Community Structure

All 2012 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 samples were sorted under a stereomicroscope at 6.4x magnification, with a final scan at 16x. After sorting, substrate from 10% of samples was re-examined by a different sorter to determine sorting efficiency. Efficiency levels of 99% were achieved (i.e., the first sorter recovered 99% 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.

[13] 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).

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 and 2012. 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 (C), toxicological (T) and biological (benthos; B) 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 2012 to Interim Sediment Quality Guidelines (Canadian Council of Ministers of the Environment (CCME) 2010) 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 in relation to drilling activity.

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 (>C10-C21 hydrocarbons and barium);
- particle size (% fines, sand and gravel) and total organic carbon;
- 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 total organic carbon content in sediments. Organic carbon, regardless of source, is typically associated with finer particles, as are metals and synthetic hydrocarbons.

Metals other than barium, several of which occur naturally at high concentrations in marine sediments, were primarily treated as indicators of the natural variance of barium concentrations that might be expected in the absence of drilling. However, concentrations of some metals could also increase in sediments as a result of project activity. A principal component analysis (PCA) of frequently detected metals was carried out to generate two "proxy" variables of sediment concentrations. The PCA was carried out on the correlation matrix of log-transformed sediment concentrations (see Appendix B-4 for details).

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 2012 data in order to understand the degree of the association with drilling activity in the current year. A scatterplot of the relationship between the response (sediment) variable and Min *d* was generated for visual inspection. 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.

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 3**, annual variations in Spearman rank correlation coefficients between responses variables and Min *d* were illustrated graphically.

Multiple rank regression was used in **Step 4** (see Appendix B-4 for details) to determine the relative influence of the FE and FEZ drill centres on sediment variables in 2012.

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 5** to compute the threshold distances for $>C_{10}$-C_{21} hydrocarbons and barium for the 2012 data. Threshold distances were previously computed for data from prior years using the same methods.

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)[14]. 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 were inspected visually (graphically) to assist in the interpretation of the repeated-measures regression results.

Values below Laboratory Detection Limit

When analyses were not performed on ranks, which treat values below laboratory detection limit as tied for the lowest rank, 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[15] for analyses and plots.

Of the metals, aluminum, iron, lead, manganese, strontium and vanadium were detected in all samples in every year. All these metals were included in PCA. Chromium was detected in all samples in every year except 2006, when it was not detected in two samples. These two chromium values were set to ½ the laboratory detection limit of 2 mg/kg for PCA[16].

Two ammonia concentrations less than the laboratory detection limit in 2002 were set to ½ the laboratory detection limit of 0.3 mg/kg[17] 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

[14] 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.
[15] 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.
[16] Uranium was also detected in all but two samples from 1997 to 2012, but at concentrations at or barely above the laboratory detection limit (i.e., variance was minimal). Therefore, uranium was excluded from PCA.
[17] 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.

if they were greater than the lower laboratory detection limits achieved from 2004 to 2010 (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, 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).

5.2.3 TOXICITY

5.2.3.1 Key Variables

Sediment toxicity variables were Microtox IC50 and 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 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 2012[18]. 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 5.2.2.1 for details). In 2008, an IC50 value could not be estimated for the sample from station 5(SW) beyond noting

[18] 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).

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 other IC50s between 98,500 and 197,000 mg wet/L, 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.

In **Step 1**, the Spearman rank correlation between Microtox and Amphipod survival was computed using the 2012 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 2012 data in order to understand the degree of the association with drilling activity in the current year. A scatterplot of the relationship between the toxicity response variables and Min *d* was also generated for visual inspection.

Multiple rank regression was used in **Step 4** (see Appendix B-4 for details) to determine the relative influence of the FE and FEZ drill centres on toxicity.

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*, and distance to the FE and the nearest FEZ drill centres, were computed in order to explore variations in the nature of the drilling effect. Amphipod survival was not compared among years because survival has been uniformly high and more than 98% of samples have been non-toxic.

In **Step 6**, repeated-measures regression was used to analyze the data from 48 stations that had been repeatedely sampled during EEM years, to further explore variations in the nature, strength and temporal variations in FE and FEZ distance gradients. 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. Data were rank-transformed for this step.

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 in relation to drilling activity. 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 543 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 2012 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 be observed richness relative to richness predicted by the *S-N* relationship, with an overall average of approximately 1. For example, a residual of 0.07918 (back-transformed adjusted richness value = 1.2) indicates that richness at that station was 20% greater than “average richness” expected based on total abundance at that station.

Non-metric Multidimensional Scaling (NMDS) 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 2012. 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 or positions along NMDS axes), which were considered "proxy" variables (i.e., NMDS 1, NMDS 2).

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 2012 data in order to understand the degree of the association with drilling activity in the current year. A scatterplot of the relationship between the response variable and Min *d* was also generated for visual inspection.

The influence of drilling activity on the benthic community variable could be anticipated to change over time in relation to variations in drilling activities. In **Step 3**, annual variations in Spearman rank correlation coefficients were illustrated graphically.

Multiple rank regression was used in **Step 4** (see Appendix B-4 for details) to determine the relative influence of the FE and FEZ drill centres on benthic community variables.

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 PC 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 for sediment physical and chemical characteristics from 1997 to 2012 are provided in Appendix B-2. Only those metals and organic compounds with at least one value above laboratory detection limit are reported in Appendix B-2. Table 5-4 provides summary statistics for frequently detected compounds in 2012. Raw data for 2012 are also provided in Appendix B-2.

As in prior years, sediments collected in 2012 were predominantly sand, organic carbon content was low, and all detectable metals for which there is a sediment quality guideline were at concentrations below their interim Sediment Quality Guideline (CCME 2010; Table 5-4).

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

Variable	Units	*n*	*n* < LDL	Median	Minimum	Maximum	ISQG
$>C_{10}$-C_{21}	mg/kg	53	4	1.3	<0.3	310	
$>C_{21}$-C_{32}	mg/kg	53	7	0.6	<0.3	3.1	
Aluminum	mg/kg	53	0	5900	3700	9000	
Barium	mg/kg	53	0	140	72	4900	
Cadmium	mg/kg	53	52	<0.05	<0.05	0.052	
Chromium	mg/kg	53	0	3.2	2.3	4.4	52.3
Copper	mg/kg	53	52	<2	<2	2.1	
Iron	mg/kg	53	0	1300	930	2900	
Lead	mg/kg	53	0	1.9	1.3	3.6	32
Lithium	mg/kg	53	52	<2	<2	2.1	
Manganese	mg/kg	53	0	32	18	100	
Mercury	mg/kg	53	51	<0.01	<0.01	0.018	
Strontium	mg/kg	53	0	38	22	440	
Sulphur	%	53	29	<0.03	<0.03	0.17	
Thalium	mg/kg	53	52	<0.1	<0.1	0.11	
Uranium	mg/kg	53	2	0.15	<0.1	0.26	
Vanadium	mg/kg	53	0	4.7	3	7.8	
Zinc	mg/kg	53	52	<5	<5	5.3	124
Inorganic Carbon	mg/kg	53	14	0.34	<0.2	12	
Organic Carbon	g/kg	53	0	0.83	0.26	2	
Total Carbon	g/kg	53	0	1.2	0.4	14	
Clay	%	53	0	0.39	0.19	0.66	
Gravel	%	53	0	5.7	0	18.6	
Sand	%	53	0	93.2	80	99.14	
Silt	%	53	0	0.57	0.08	1.75	
Ammonia	mg/kg	53	0	3.4	1.3	19	
Sulphide	mg/kg	53	19	0.25	<0.2	3.79	
Redox	mV	53	0	266	180	319	
Moisture	%	53	0	17	8	21	

Note: - LDL = Laboratory Detection Limit.

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

There was an increase in >C_{10}-C_{21} hydrocarbon concentrations from 2000 to 2006, with a decrease in concentration in recent years (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 other 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 and 1.30 mg/kg in both 2010 and 2012 (Appendix B-2). Maximum levels from 2002 to 2012 occurred at station 30(FE), located 0.14 km from the FE drill centre. The maximum >C_{10}-C_{21} hydrocarbon concentration (6,550 mg/kg) over all years occurred in 2004. All chromatograms for stations with >C_{10}-C_{21} hydrocarbon concentrations above the laboratory detection limit (49 of 53 stations in 2012) have showed a Unresolved Complex Mixture in the range of PureDrill IA35-LV (Appendix B-2; Suncor Energy 2001, 2003, 2005, 2007, 2009, 2011). In 2012, as in previous years, concentrations decreased rapidly with distance from drill centres (Figure 5-7).

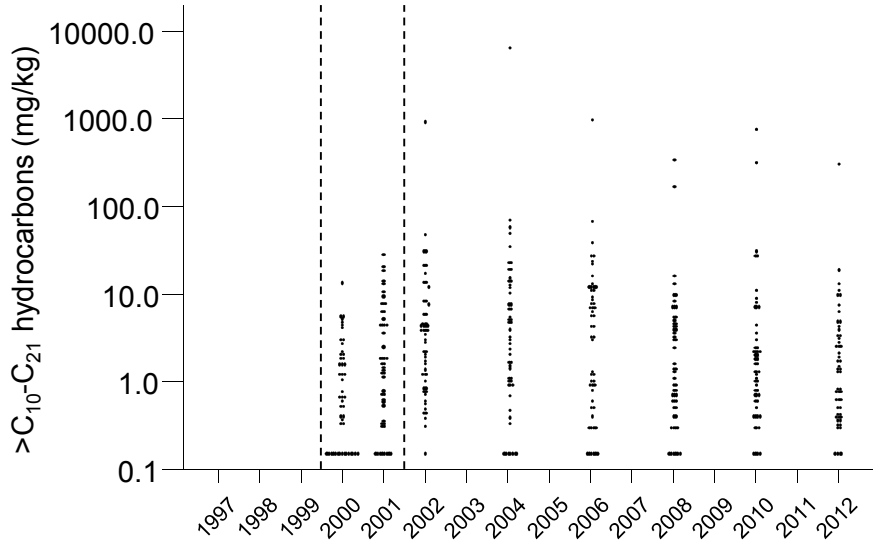


Figure 5-6 Annual Distributions for >C_{10}-C_{21} Hydrocarbon Concentrations (2000 to 2012)

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).

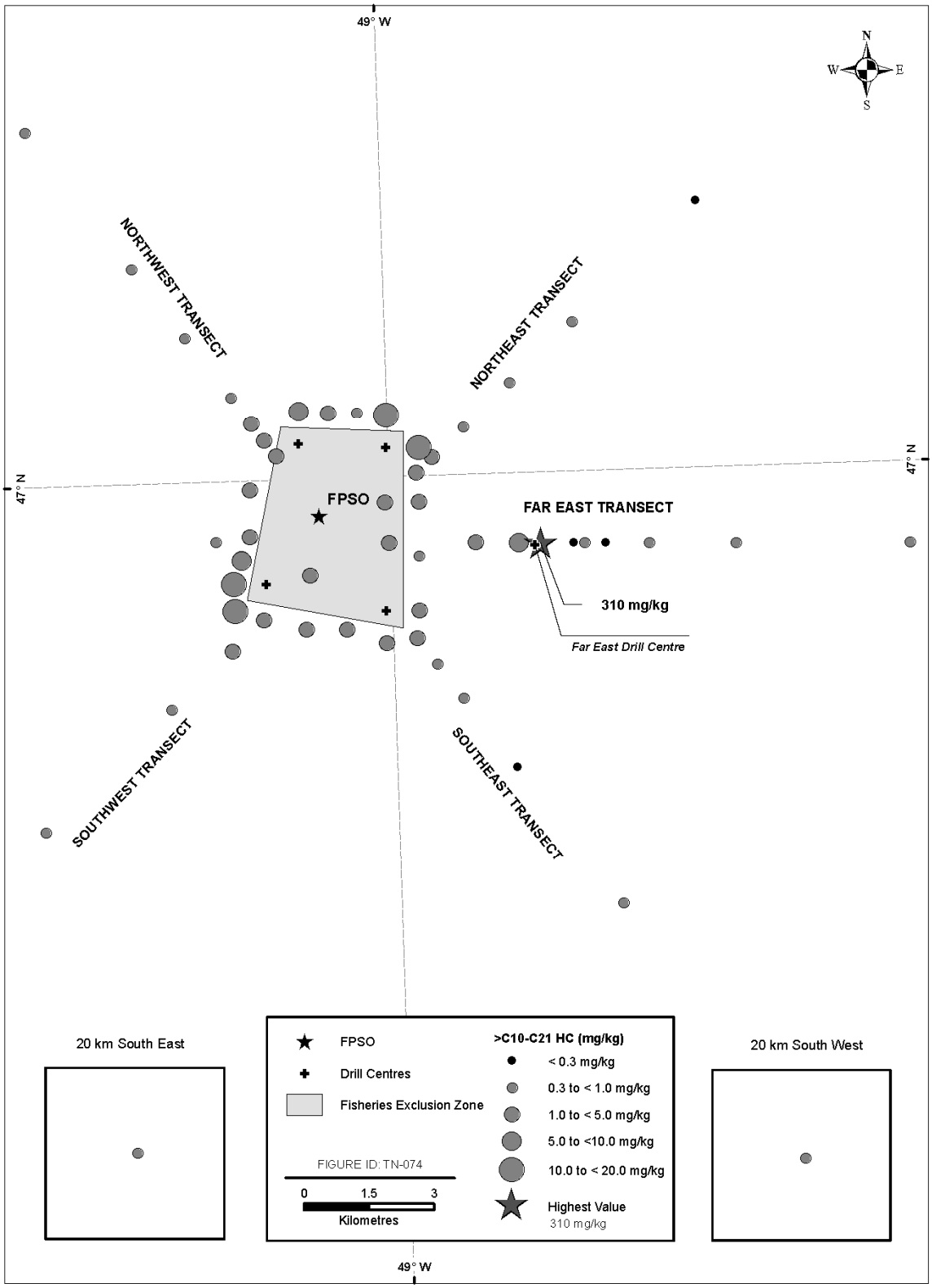


Figure 5-7 Spatial Distribution of >C_{10}-C_{21} Hydrocarbon Concentrations (2012)

Decreases of >C_{10}-C_{21} hydrocarbons with distance from the nearest drill centre (Min *d*) were significant in 2012 (Spearman rank: r_s = -0.78, Figure 5-8), as in previous years. In 2012, the Spearman rank value for Min *d* was greater than multiple R (R = 0.74, $p < 0.001$) for the multiple regression of >C_{10}-C_{21} hydrocarbons on distances from the FEZ and FE drill centres, or for the partial regressions of >C_{10}-C_{21} hydrocarbons on 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.

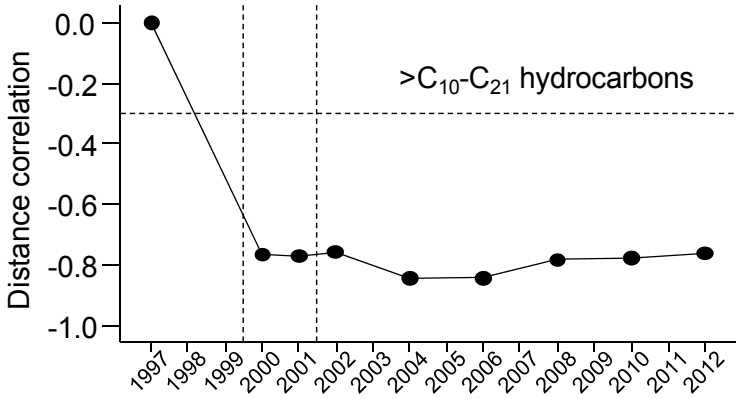


Figure 5-8 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for >C_{10}-C_{21} Hydrocarbons (1997 to 2012)

Notes: The horizontal dashed line indicates a Spearman rank correlation of |0.3|. Values below the line were generally significant at $p < 0.01$, depending on sample size in the given year. Distance correlations in 1997 are assumed to be zero. 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 5-5 Results of Rank-Rank Regression of >C_{10}-C_{21} Hydrocarbons on Distance Variables (2012)

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*** **	-0.02	**-0.78*** **

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

Adding a threshold in a hockey-stick model of >C_{10}-C_{21} hydrocarbon concentrations versus Min *d* reduced error variance relative to a bivariate regression ($p = 0.001$, Table 5-6). The fitted line in Figure 5-9 shows the hockey-stick model for 2012. In 2012, the estimated threshold distance (zone of influence) for >C_{10}-C_{21} hydrocarbons was 2.4 km, with a 95% CI of 1.7 to 4.6 km, similar to threshold distances and 95% CIs observed since 2008 (Table 5-6).

Table 5-6 Distance Relationships and Thresholds for >C_{10}-C_{21} Hydrocarbons (2000 to 2012)

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

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 2012.
- 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 and 2012.
- Not estimated = threshold was not estimated because $p > 0.05$ for adding the threshold.

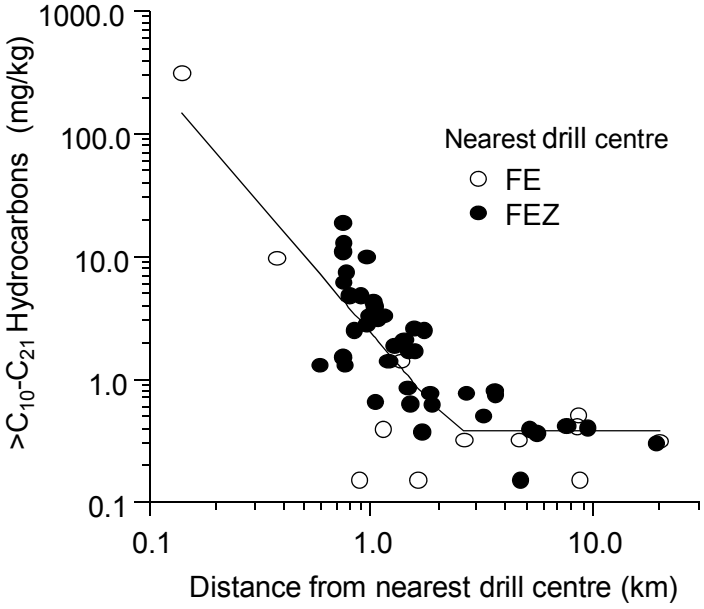


Figure 5-9 Distance Gradient for >C_{10}-C_{21} Hydrocarbons (2012)

The concentrations of >C_{10}-C_{21} hydrocarbons at stations nearest the FE drill centre were relatively low, except at stations 30(FE) and 31(FE) (Figure 5-9). Thus, any effects of the FE drill centre were largely dependent on concentrations at stations 30(FE) and 31(FE). The influence of the two stations was reduced in rank-rank regressions (as in Table 5-5). In contrast, there were some elevated >C_{10}-C_{21} hydrocarbon concentrations at several stations within 2 km of the FEZ drill centres, and a more continuous distance gradient for stations nearest the FEZ drill centres (Figure 5-9).

Results of repeated-measures regression are provided in Table 5-7. Appendix B-4 provides details on how the analysis is carried out and interpreted. Carry-over effects were highly significant for >C_{10}-C_{21} hydrocarbons (F = 8.1; Table 5-7), indicating persistent spatial differences over time. Since >C_{10}-C_{21} hydrocarbons were at non-detectable levels in baseline, carry-over effects cannot be related to baseline concentrations. Carry-over effects for >C_{10}-C_{21} hydrocarbons must, therefore, be persistent small-scale or localized 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 2012)

Effect	Test					
	Among Stations	**Within Stations**	**Before vs After NW, SE Drilling (2000 vs 2001)**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2012)**	**Linear Trend 2002 to 2012**	**Quadratic Trend 2002 to 2012**
FEZ *d*	**94.3*** **					
FE *d*	<0.1					
Error 1 (Carry-over)	**8.1*** **					
Year		**10.4*** **	6.2*	**12.9*** **	**24.1*** **	1.0
Year x FEZ *d*		0.1	6.0*	<0.1	1.2	0.4
Year x FE *d*		<0.1	0.6	11.1**	0.2	1.7

Notes: - *$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$ (in **bold**).
- n = 48 stations. Repeated-measures regression includes only those stations that were repeatedly sampled in all EEM years.
- Distance variables (X) and Y variables were transformed to ranks.
- See Appendix B-4 for description and interpretation of terms in the repeated-measures regression models.

The Within-Stations terms test for variations in distance regression intercepts (Year terms) or slopes (Year × FE *d* term, or Year x FEZ *d* term) among all years. Significant Year terms (i.e., intercepts) indicate that Y values on average varied significantly over time, and generally represent natural large-scale changes, and less so project effects. Significant variations in distance slopes (i.e., distance gradients) over time could represent either natural or project effects.

Overall Within-Stations terms test for *any* changes over time (= omnibus tests), many of which would not reflect project effects. The before-vs-after, linear-after and quadratic-after contrasts represent independent tests of more specific changes, since the '*Y*' tested are uncorrelated. The Linear and Quadratic Trend contrasts are equivalent to testing whether the slopes vary over time in a linear or quadratic fashion. The specific contrasts can be interpreted even if the overall within-stations

term test is or is not-significant. Here and in the sections that follow, the specific contrasts are interpreted in particular, while the within-stations contrasts are discussed if the specific contrasts are not significant.

The overall distance slope from the nearest FEZ drill centre was highly significant (F = 94.3, Table 5-7). Figure 5-10 shows that distance to the FEZ drill centre (with regression slopes of around -0.6) consistently had a greater influence on >C_{10}-C_{21} hydrocarbons than did distance to the FE drill centre (with regression slopes of ~ -0.1). Regression slopes for the FEZ drill centre varied among years (F = 6.0; Table 5-7), with a decrease in the slope from 2000 to 2001 (Figure 5-10). There were no significant linear or quadratic trends in FEZ regression slopes after 2001.

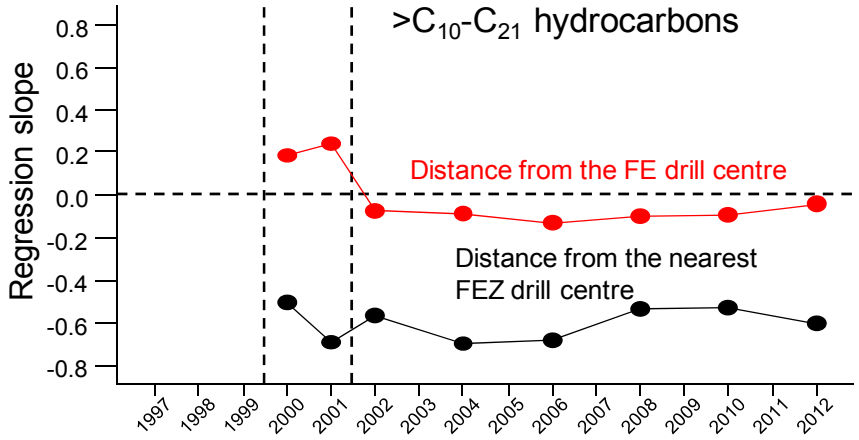


Figure 5-10 Annual Multiple Regression Distance Slopes for >C_{10}-C_{21} Hydrocarbons (2000 to 2012)

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).

FE regression slopes were not strong, but did change from before (2000 and 2001) to after (2002 to 2012) drilling at the FE drill centre (F = 11.1, Table 5-7), with slopes more negative in the post-drilling period. Because the distance regressions would have been near (or effectively) zero in the baseline period, the results of the repeated-measures regression, as well as the preceding analyses, provide evidence of drilling effects on >C_{10}-C_{21} hydrocarbon concentrations from both the FE and FEZ drill centres.

5.3.1.2 Barium

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 median levels ranging from 130 to 170 mg/kg from 2000 to 2012 (Appendix B-2). Maximum levels 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. 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)[19]. 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.

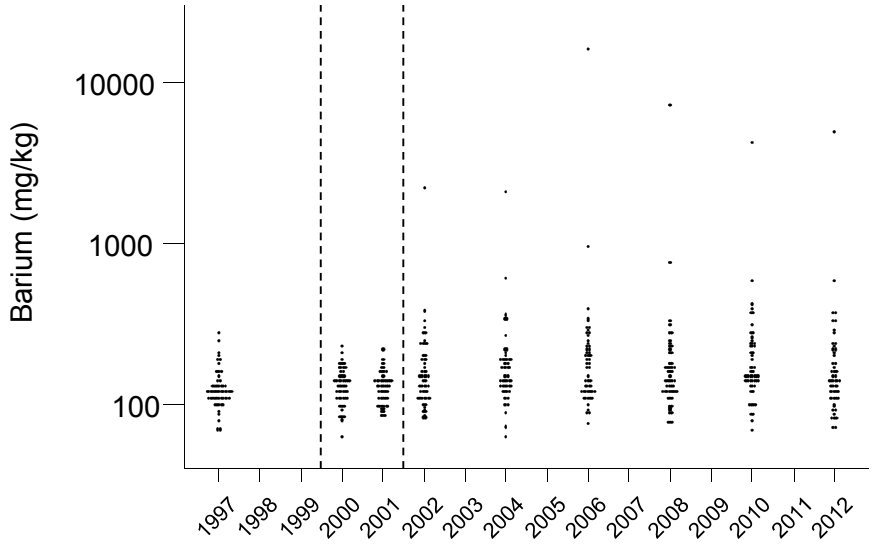


Figure 5-11 Annual Distributions for Barium Concentrations (1997 to 2012)

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).

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

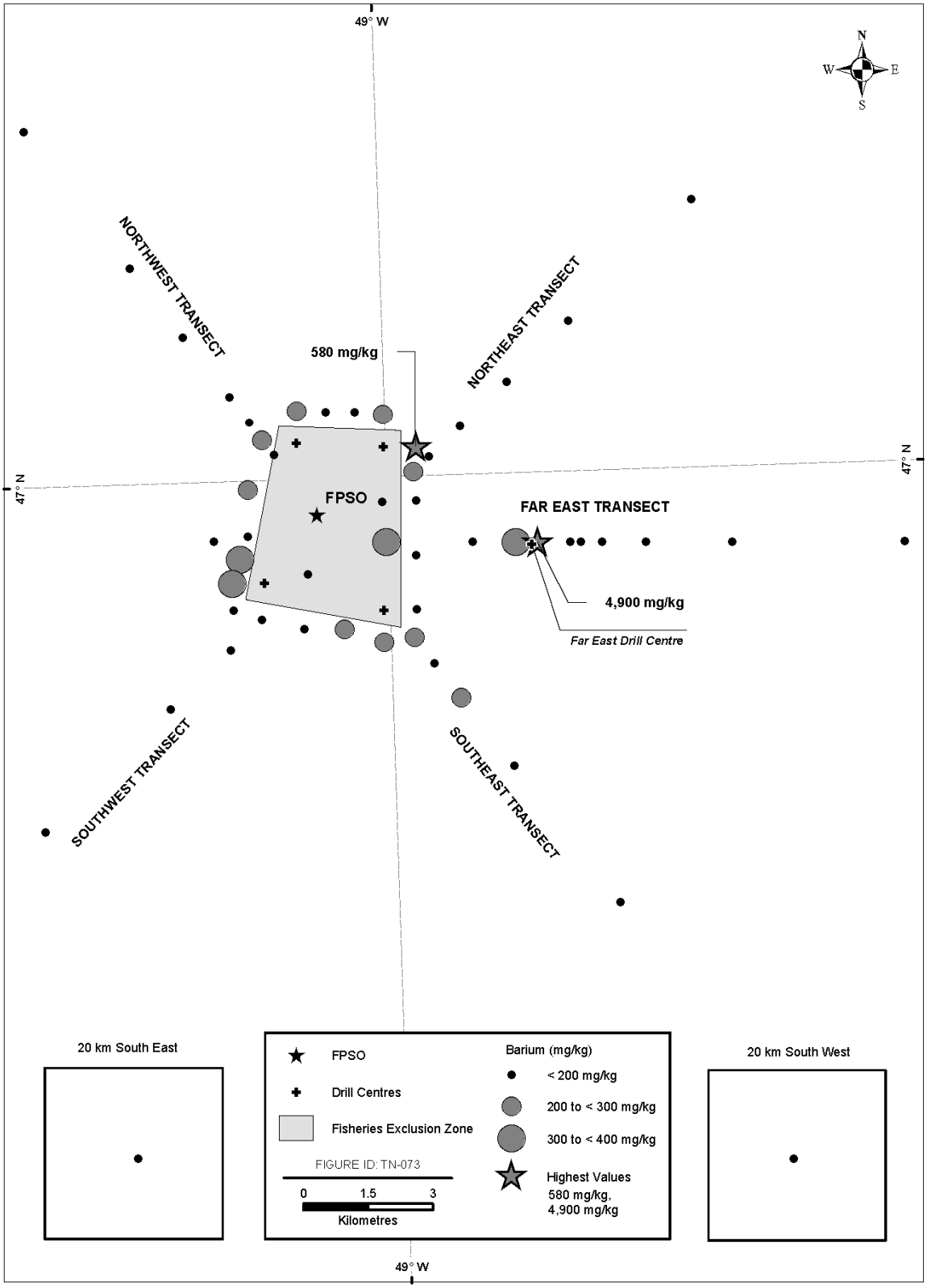


Figure 5-12 Spatial Distribution of Barium Concentrations (2012)

In 1997, barium concentrations decreased with distance from the nearest future drill centre (Min *d*), although that baseline distance gradient was weak, with a Spearman rank correlation of r_s = 0.261 (p > 0.05). Barium distance correlations progressively increased in strength from 2000 to 2006, and have decreased slightly in strength since then (Figure 5-13).

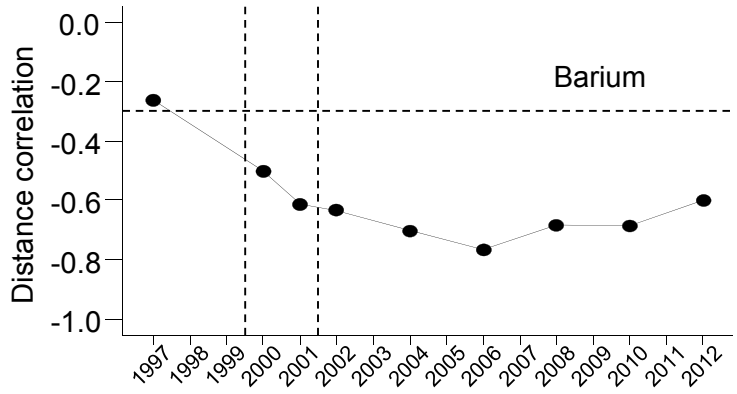


Figure 5-13 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Barium (1997 to 2012)

Notes: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values below the line 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).

In 2012, barium concentrations decreased significantly with Min *d* with the Spearman rank correlation of r_s = -0.60 (Figure 5-13). The negative correlation reflects higher concentrations of barium in sediments near drill centres. The Spearman rank value for Min *d* was greater than the multiple R (R = 0.57, p < 0.001) for the multiple regression of barium on distances from the FEZ and FE drill centres, or for the partial regressions 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 (2012)

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	
0.57* **	**-0.54*** **	-0.06	**-0.60*** **

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

The addition of a threshold to the relationship between barium concentration and Min *d* significantly reduced error variance ($p < 0.001$, Table 5-9). The estimated threshold distance for barium in 2012 was 1.1 km, with a 95% CI of 0.9 to 1.3 km (Figure 5-14). The threshold distance in 2012 was significantly shorter (closer to drill centres) than it was in 2010 when it was 2 km, but similar to what was observed from 2004 to 2008.

Table 5-9 Distance Relationships and Thresholds for Barium (1997 to 2012)

Year	*r* bivariate	*R* hockey-stick	*p* threshold	Threshold distance (km)	95% CI (km)
1997	-0.247	0.247	1	Not estimated	
2000	**-0.480*** **	**0.48**	1	Not estimated	
2001	**-0.567*** **	**0.593**	0.153	Not estimated	
2002	**-0.621*** **	**0.739**	**<0.001**	1.8	1.3 to 2.6
2004	**-0.679*** **	**0.822**	**<0.001**	1.2	1.0 to 1.5
2006	**-0.682*** **	**0.894**	**<0.001**	1.1	0.9 to 1.2
2008	**-0.631*** **	**0.868**	**<0.001**	1.0	0.9 to 1.2
2010	**-0.686*** **	**0.796**	**<0.001**	2.0	1.5 to 2.6
2012	**-0.577*** **	**0.802**	**<0.001**	1.1	0.9 to 1.3

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 2012. 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 and 2012.
- Not estimated = threshold was not estimated because $p > 0.05$ for adding the threshold.

Barium concentrations at stations nearest the FE drill centre were relatively low, except at stations 30(FE) and 31(FE) (Figure 5-14). Thus, any effects of the FE drill centre were largely dependent on concentrations at stations 30(FE) and 31(FE). The influence of the two stations was reduced in rank-rank regressions (as in Table 5-8). In contrast, there were some elevated barium concentrations at several stations within approximately 1 km of the FEZ drill centres, and a more continuous distance gradient for stations nearest the FEZ drill centres (Figure 5-14), as was observed for $>C_{10}$-C_{21} hydrocarbons.

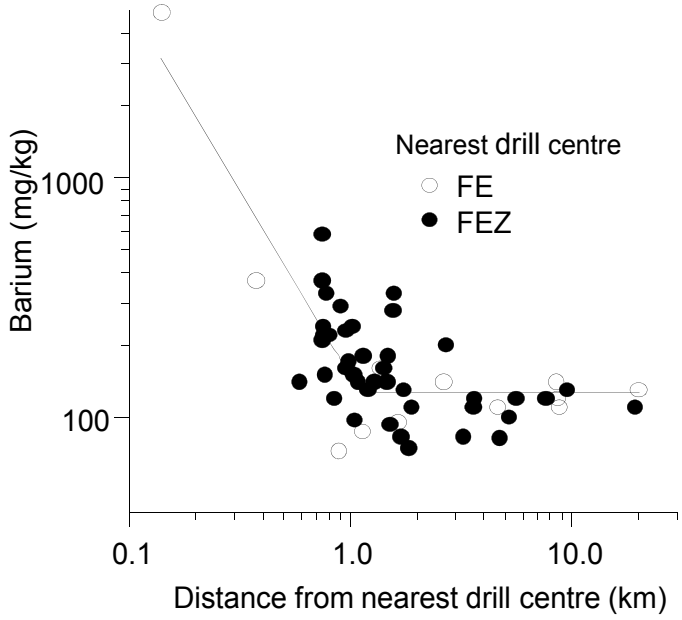


Figure 5-14 Distance Gradient for Barium (2012)

Carry-over effects were highly significant for barium (F = 12.3; Table 5-10), indicating persistent spatial differences over time. 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., some of the carry-over effects for barium were natural).

Table 5-10 Results (F Values) of Repeated-Measures Regressions Comparing Barium Concentrations Among EEM Years (2000 to 2012)

Effect	Test					
	Among Stations	**Within Stations**	**Before vs After NW, SE Drilling (2000 vs 2001)**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2012)**	**Linear Trend 2002 to 2012**	**Quadratic Trend 2002 to 2012**
FEZ *d*	25.1***					
FE *d*	1.2					
Error 1 (Carry-over)	12.3***					
Year		31.6***	84.8***	84.4***	5.8*	4.9*
Year x FEZ *d*		1.9	1.7	5.5*	0.6	1.0
Year x FE *d*		1.8	2.2	4.7*	<0.1	1.4

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

The overall multiple regression slopes for barium were stronger for the FEZ drill centres (F = 25.1) than they were for the FE drill centre (F = 1.2; Table 5-10, Figure 5-15). Both FE (F = 4.7) and FEZ (F = 5.5) regression slopes were more negative from 2002 to 2012 (Table 5-10, Figure 5-15).

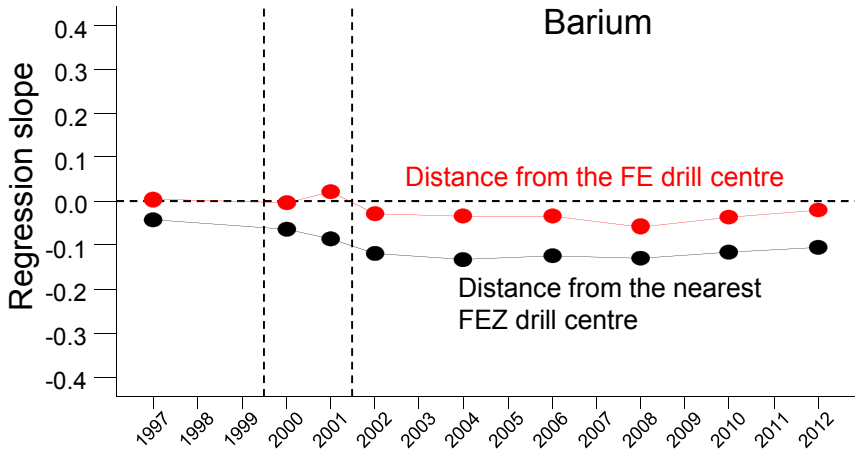


Figure 5-15 Annual Multiple Regression Distance Slopes for Barium (1997 to 2012)

Notes: 1997 regression slopes for barium were based on the 31 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

As noted above, sediments in 2012 were predominantly sand, with mean and median sand content of approximately 92% (Appendix B-2; Figure 5-16). Fines (silt + clay) content was low (0.4 to 2.2%; median = 1.0%). Gravel content varied widely, from 0% to approximately 19% (Appendix B-2; Figure 5-16).

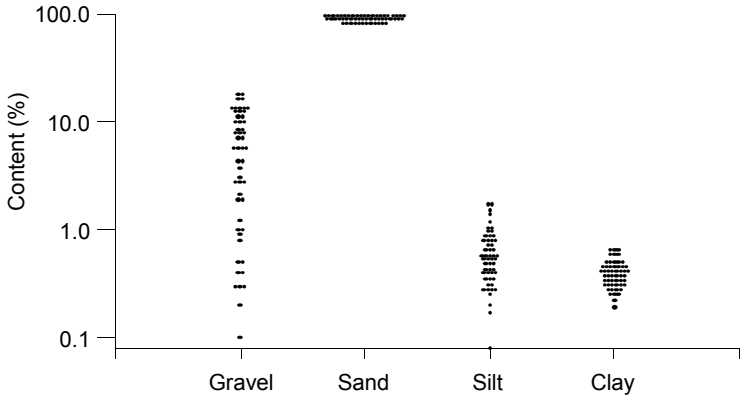


Figure 5-16 Distribution of Values for Four Particle Size Categories (2012)

Sand and gravel content were strongly negatively correlated because gravel (which includes pieces of shells) 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 (2012)

	% fines	**% sand**
% sand	-0.321*	
% gravel	0.251	**-0.995*****

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

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 10 to 20% of sediment grains (Figure 5-17).

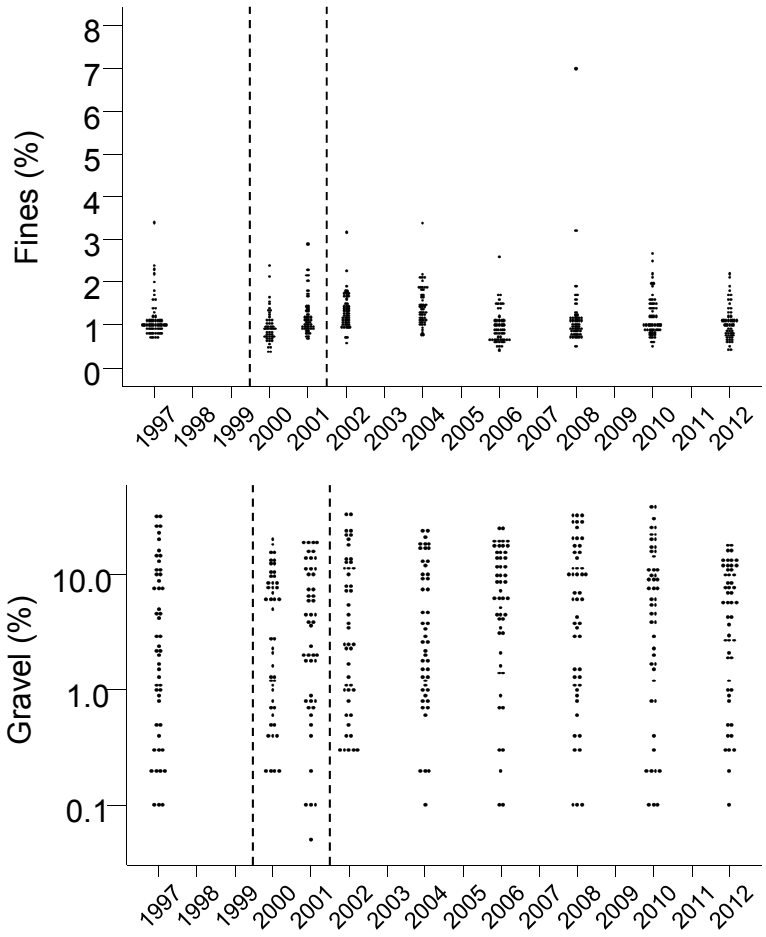


Figure 5-17 Annual Distributions for Fines and Gravel Content (1997 to 2012)

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).

Distance gradients for fines and gravel in 2012 are illustrated in Figure 5-18. In 2012, Spearman rank correlations were not significant for variations in fines and gravel with Min *d* and regardless of whether distances to the FE or FEZ drill centres was partialled out (Table 5-12). The weak decrease in fines with distance noted in 2012 was similar to that noted in baseline (Figure 5-19). In spite of this, the highest fines value in 2012 occurred at station 30(FE), located nearest a drill centre (Figure 5-18). Baseline levels for fines at station 30(FE) were 0.8%, compared to 2.2% in 2012, which could be weak evidence of an increase in fines at that one station. Distance correlations for fines content were significant (i.e., $r_S > |0.3|$) in 2000, 2001, 2006 and 2010. Distance correlations for gravel were never significant over the study period (Figure 5-19).

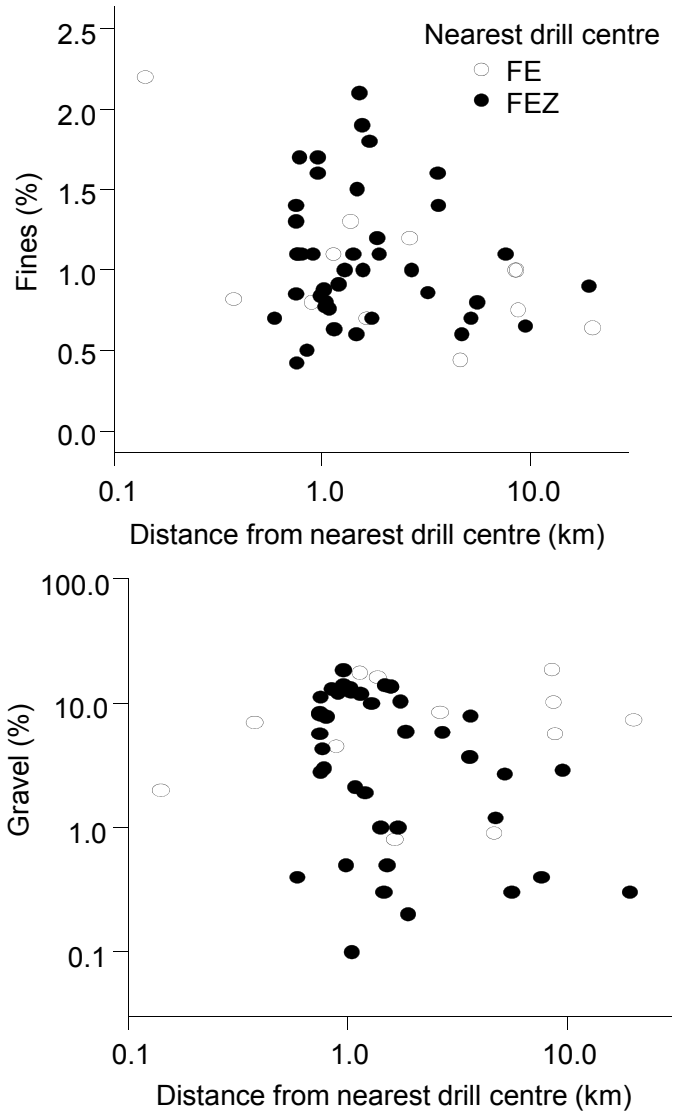


Figure 5-18 Distance Gradients for Fines and Gravel Content (2012)

Table 5-12 Results of Rank-Rank Regression of Fines and Gravel on Distance Variables (2012)

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	0.18	-0.15	-0.08	-0.19
Gravel	0.20	-0.14	-0.12	-0.20

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

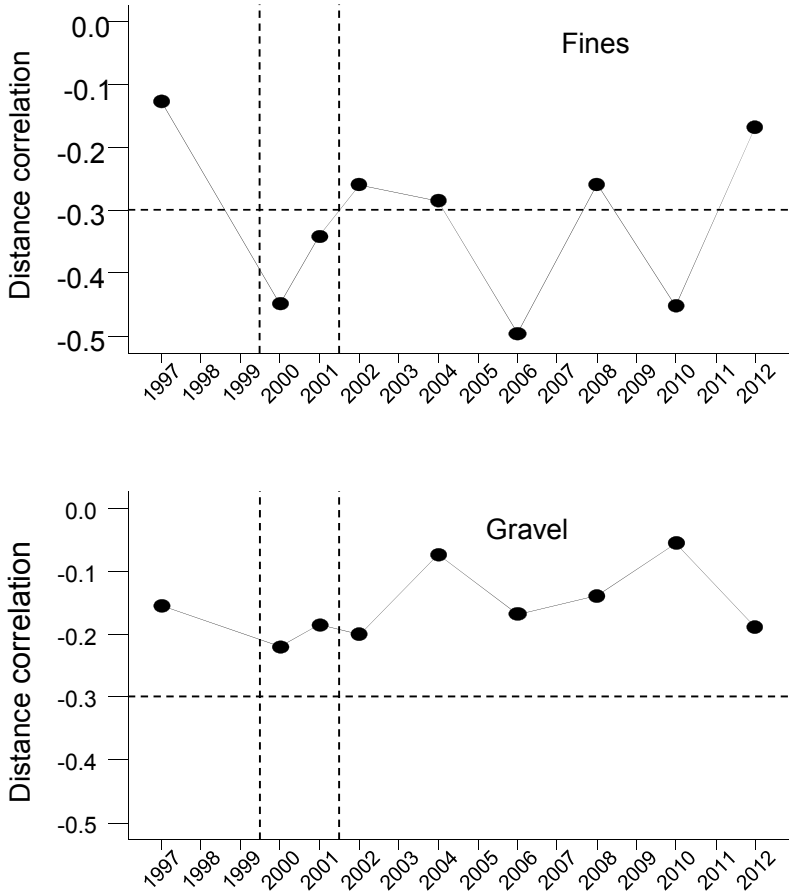


Figure 5-19 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Fines and Gravel Content (1997 to 2012)

Notes: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values below the line 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).

Table 5-13 provides results of repeated-measures regression analyses for sediment fines and gravel content. Carry-over effects were significant at $p < 0.001$ for both variables (see results for Error 1 in Table 5-13).

Table 5-13 Results (F Values) of Repeated-Measures Regressions Comparing Fines and Gravel Among EEM Years (2000 to 2012)

Effect	Test					
	Among Stations	**Within Stations**	**Before vs After NW, SE Drilling (2000 vs 2001)**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2012)**	**Linear Trend 2002 to 2012**	**Quadratic Trend 2002 to 2012**
Fines						
FEZ *d*	10.2**					
FE *d*	0.7					
Error 1 (Carry-over)	7.3***					
Year		2.6*	0.3	3.8	8.8**	0.4
Year x FEZ *d*		0.7	1.7	1.0	<0.1	0.5
Year x FE *d*		1.0	3.2	0.6	0.1	0.5
Gravel						
FEZ *d*	0.9					
FE *d*	0.6					
Error 1 (Carry-over)	16.7***					
Year		0.9	<0.1	0.2	0.2	<0.1
Year x FEZ *d*		0.5	0.7	<0.1	0.1	0.2
Year x FE *d*		0.5	0.9	<0.1	<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 transformed to ranks.

Temporal (year-to-year) variance was common for fines, as indicated by the significant 'Within-Stations Year' terms in Table 5-13 and changes in summary statistics in Figure 5-17. The overall FEZ distance gradient for fines content was also significant (F = 10.2; Table 5-13), 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 gradient did not change significantly over time (Table 5-13).

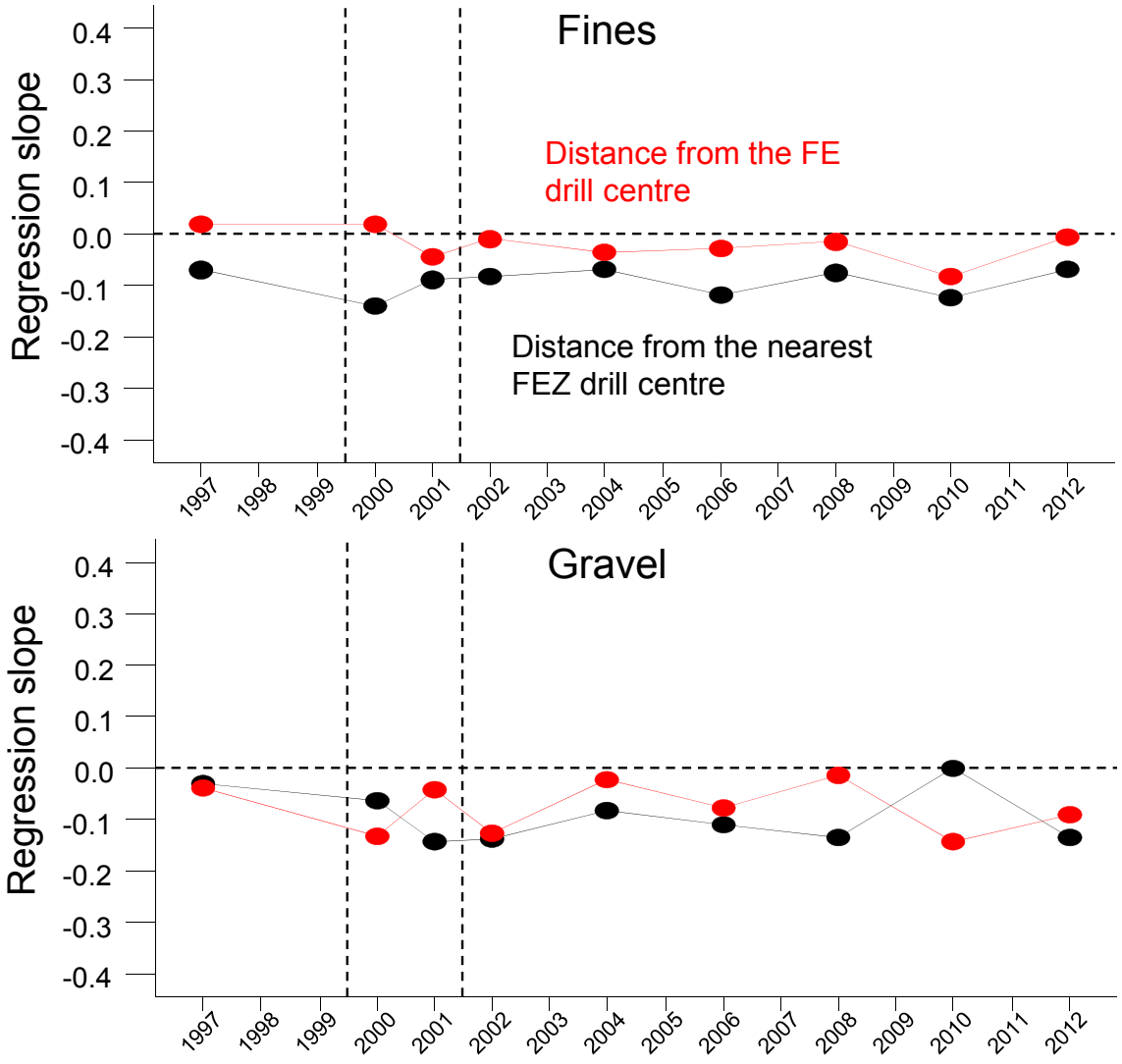


Figure 5-20 Annual Multiple Regression Distance Slopes for Fines and Gravel Content (1997 to 2012)

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

5.3.1.4 Organic Carbon Content

Sediment organic carbon content was low, ranging from 0.3 to 2 g/kg (Appendix B-2). The range in values of carbon content across sampling locations has remained consistent among years (Figure 5-21).

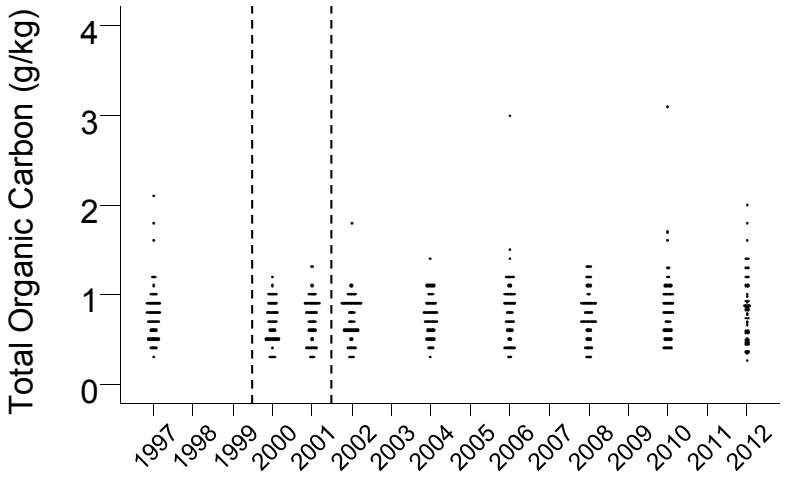


Figure 5-21 Annual Distributions for Total Organic Content (1997 to 2012)

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

The relationship between organic content and Min *d* was weakly significant in 2012 (Figure 5-22) with an r_s of -0.33 (Table 5-14). Distance relationships were negative and more strongly significant in 1997, 2000, 2001, 2006 and 2008 (Figure 5-23). The baseline (1997) correlation of approximately r_s = -0.4 was among the strongest distance correlation observed. In 2012, as in previous years, the partial correlation with distance from the FEZ drill centres was stronger than, and opposite to, the partial correlation with distance from the FE drill centre (r_s = -0.65 versus r_s = 0.29, Table 5-14) indicating a decrease in total organic content with distance from the centre of the development.

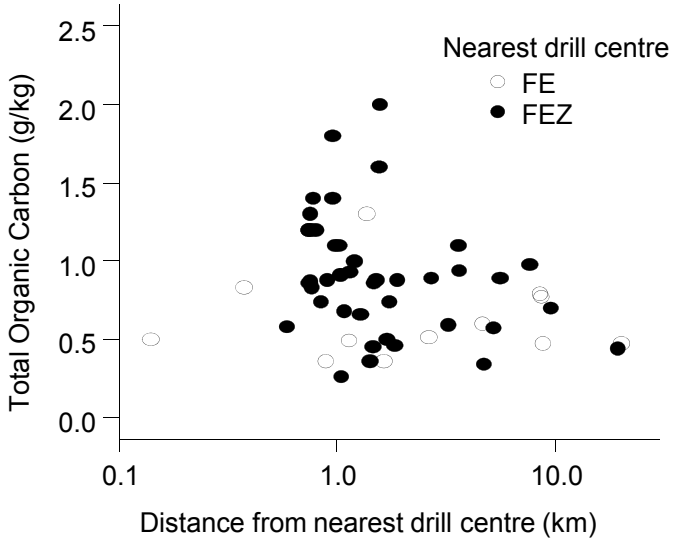


Figure 5-22 Distance Gradient for Total Organic Carbon Content (2012)

Table 5-14 Results of Rank-Rank Regression of Total Organic Carbon Content on Distance Variables (2012)

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	
Total Organic Carbon	**0.57*** **	**-0.65*** **	0.29*	-0.33*

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

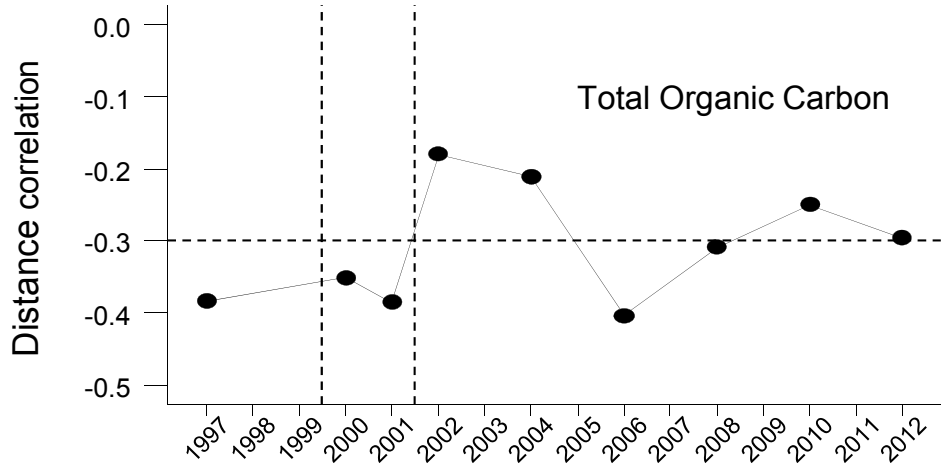


Figure 5-23 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) Total Organic Carbon Content (1997 to 2012)

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values below the line 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).

Carry-over effects were highly significant for organic carbon content ($F = 16.4$; Table 5-15), indicating persistent spatial differences over time. The overall FEZ distance gradient for total organic carbon in EEM years was also highly significant ($F = 19.8$ for Among Stations FEZ *d* term in Table 5-15), because organic carbon decreased with distance from the FEZ drill centres in all years, including baseline (Figure 5-24). The FEZ distance slope for 1997 (baseline) was as strong as in EEM years. There was significant, but modest, increase in the strength of the FEZ distance slopes ($F = 10.9$). Organic carbon content increased with increasing distance from the FE drill centre in EEM years and in 1997 (baseline) (Figure 5-24). The overall FE distance gradient was significant ($F = 7.3$), and there were no significant changes in that gradient over time ($p > 0.05$; Table 5-15).

Table 5-15 Results (F Values) of Repeated-Measures Regressions Comparing Total Organic Carbon Content Among EEM Years (2000 to 2012)

Effect	Test					
	Among Stations	Within Stations	Before vs After NW, SE Drilling (2000 vs 2001)	Before vs After FE Drilling (2000 and 2001 vs 2002 to 2012)	Linear Trend 2002 to 2012	Quadratic Trend 2002 to 2012
FEZ *d*	**19.8*** **					
FE *d*	7.3**					
Error 1 (Carry-over)	**16.4*** **					
Year		**7.3*** **	**35.5*** **	0.6	2.8	2.0
Year x FEZ *d*		2.1*	2.9	<0.1	10.9**	<0.1
Year x FE *d*		1.0	0.3	0.6	1.2	3.6

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 transformed to ranks.

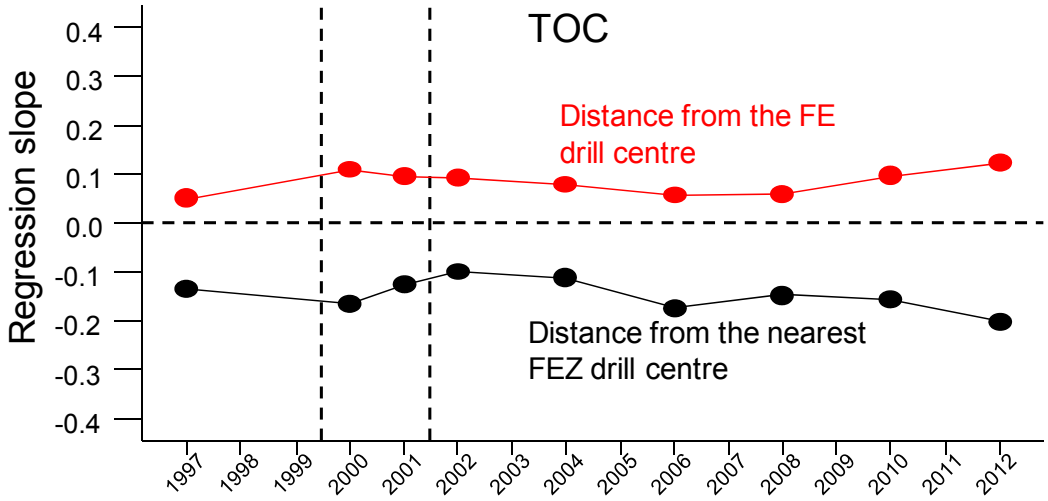


Figure 5-24 Annual Multiple Regression Distance Slopes for Total Organic Content (1997 to 2012)

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

5.3.1.5 Metals

A PCA of metals (other than 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, chromium, iron, lead, manganese, strontium and vanadium were detected at every station in all years. 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 5-16). Strontium was also weakly positively associated with Metals PC1. 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% of the total variance, and was strongly negatively correlated with strontium concentration (r_p = -0.63), 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 5-16 Pearson Correlations (r_p) Between Metal Concentrations and Principal Components Derived from those Concentrations (1997 to 2012)

Variable	Correlation (r_P) with Axis	
	Metals PC1	**Metals PC2**
Aluminum	**0.80**	-0.39
Chromium	**0.79**	0.19
Iron	**0.87**	0.42
Lead	**0.80**	-0.40
Manganese	**0.75**	0.59
Strontium	0.58	**-0.63**
Vanadium	**0.92**	0.05
Percent of Variance Explained	63.2	18.1

Notes:
- $|r_p| \geq 0.6$ in **bold.**
- Concentrations were log-transformed prior to deriving PC.
- n = 416 stations; 54 in 1997, 49 in 2000 and 2001, 53 in 2002, 52 in 2004, and 53 in 2006, 2008, 2010 and 2012.
- PC's were retained if they explained more than 10% of the total variation in the data.

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

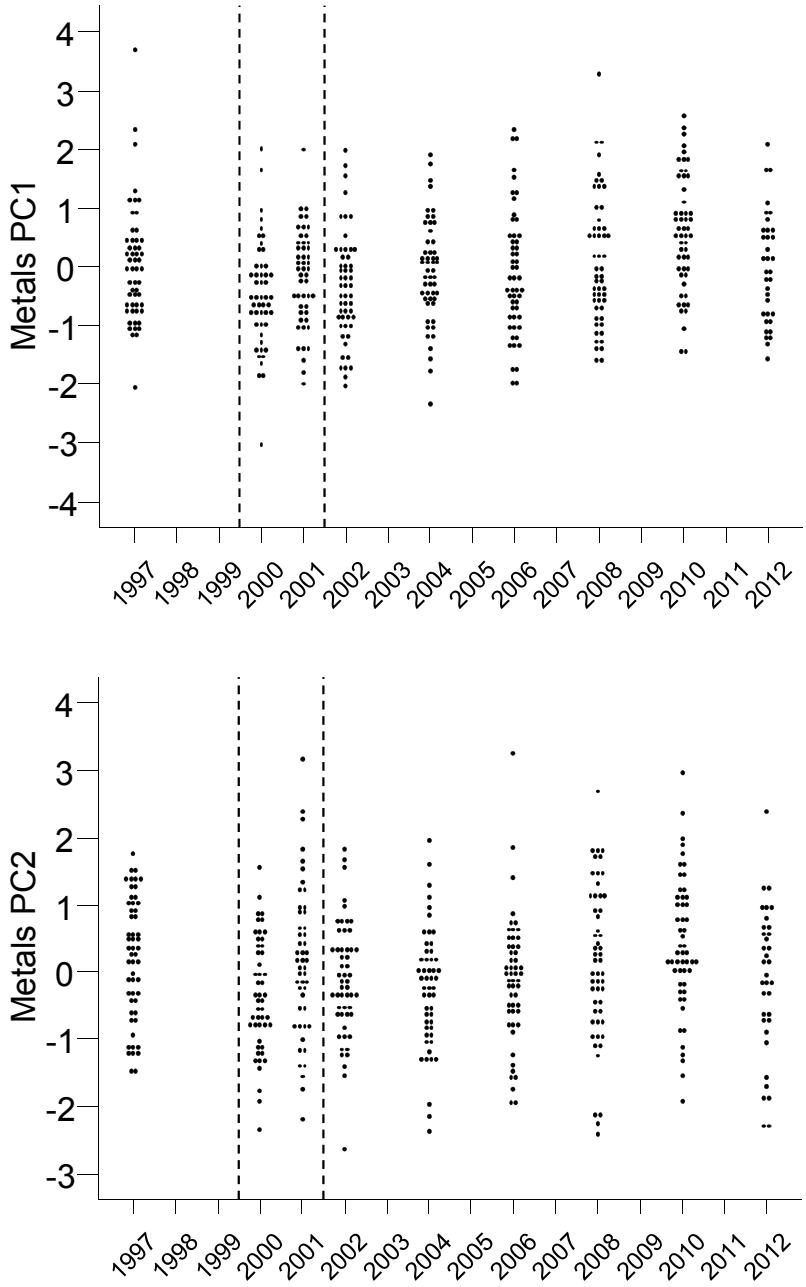


Figure 5-25 Annual Distributions for Metals PC1 and Metals PC2 (1997 to 2012)

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).

Distance relationships with Min *d* for Metals PC1 and PC2 were not strong in 2012 (Figure 5-26). Metals PC1 scores decreased with Min *d* in every year except 2012 (Figure 5-27). The strongest distance correlation occurred in 2001 (r_s ~-0.6; $p < 0.001$). Correlations in other EEM years varied around $r_s = -0.3$. Distance correlations for Metals PC2 scores (strontium concentrations relative to manganese and iron concentrations) were weaker than correlations for Metals PC1 from 2000 to 2002, and similar in strength in recent years.

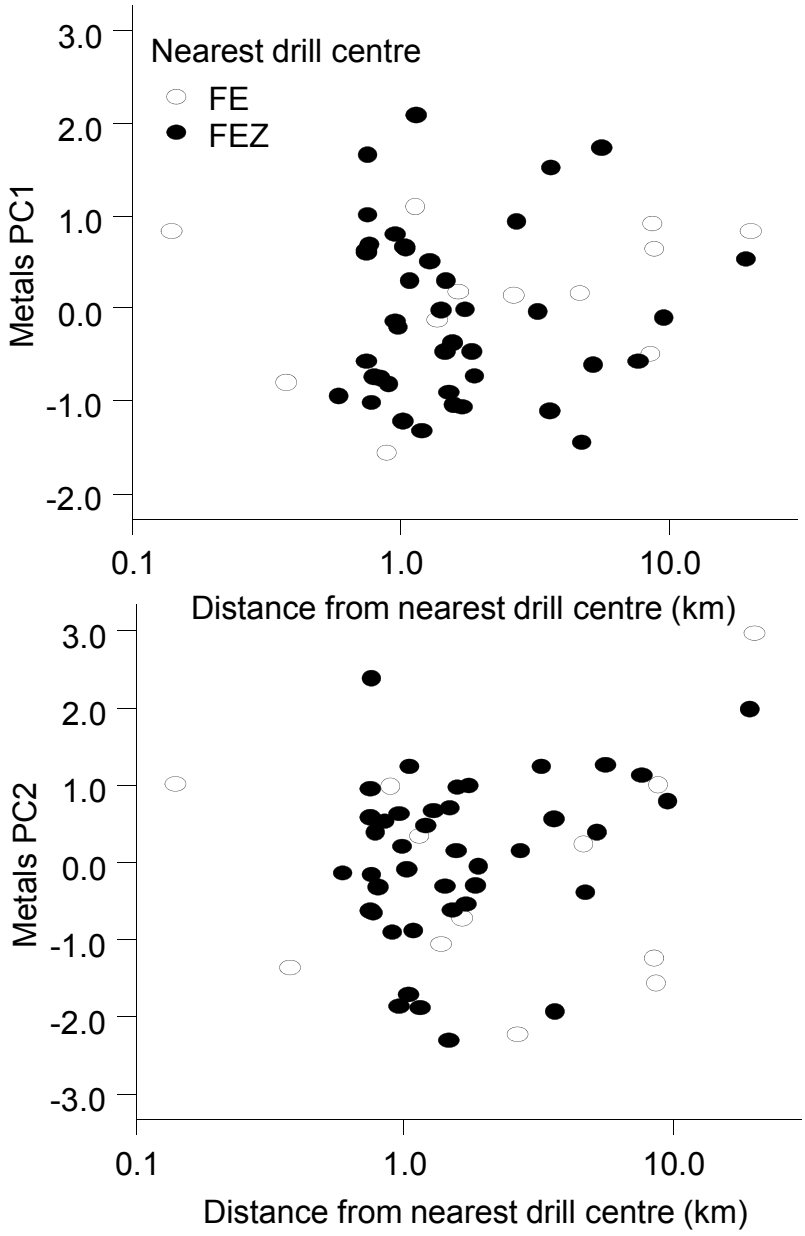


Figure 5-26 Distance Gradients for Metals PC1 and Metals PC2 (2012)

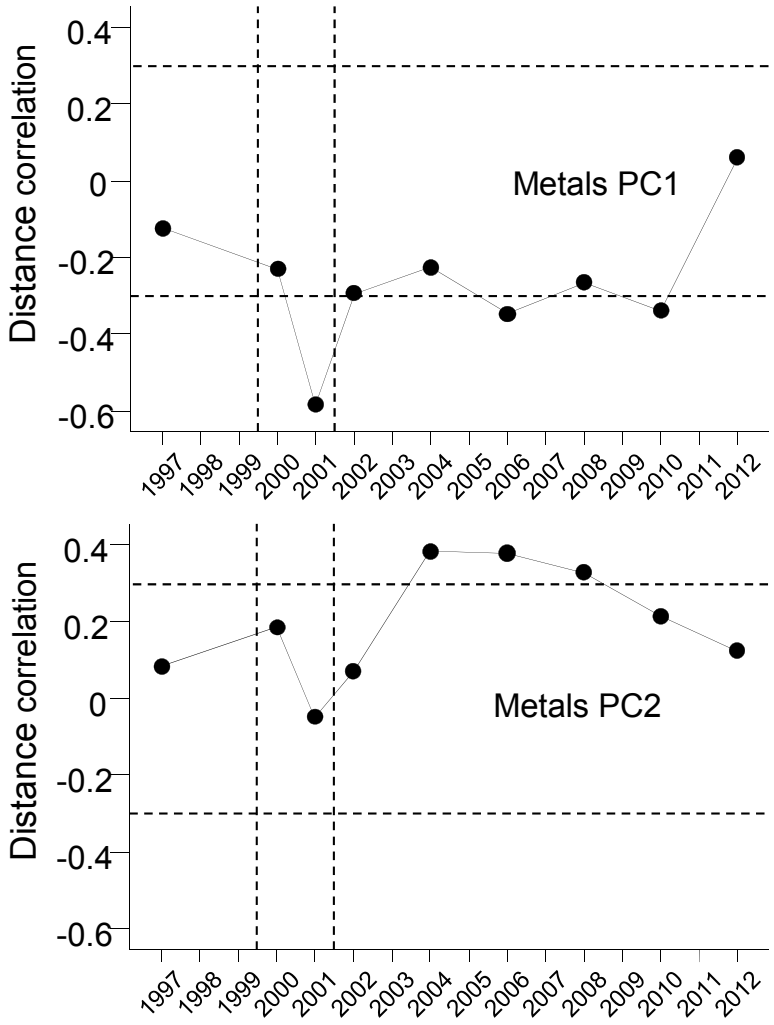


Figure 5-27 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Metals PC1 and Metals PC2 (1997 to 2012)

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values below the line 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).

Partial correlations of FEZ and FE distances with Metals PC1 or PC2 in 2012 were not significant (Table 5-17).

Table 5-17 Results of Rank-Rank Regression of Metals PC1 and PC2 on Distance Variables (2012)

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	0.09	0.09	0.02	0.07
Metals PC2	0.25	0.08	0.26	0.12

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

Metals PC1 scores had strong carry-over effects (F = 5.2; Table 5-18), indicating persistent spatial differences over time. Overall FEZ distance gradients were weakly significant (F = 4.8). FEZ distance gradients were weaker (less negative) after 2002 (F = 5.3; Figure 5-28). Overall FE distance gradients were not significant.

Table 5-18 Results (F Values) of Repeated-Measures Regressions Comparing Metals PC1 and Metals PC2 Among EEM Years (2000 to 2012)

Effect	Test					
	Among Stations	**Within Stations**	**Before vs After NW, SE Drilling (2000 vs 2001)**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2012)**	**Linear Trend 2002 to 2012**	**Quadratic Trend 2002 to 2012**
Metals PC1						
FEZ *d*	4.8*					
FE *d*	2.7					
Error 1 (Carry-over)	5.2***					
Year		2.8**	0.3	0.8	<0.1	3.2
Year x FEZ *d*		2.1	2.2	5.3*	1.4	3.0
Year x FE *d*		0.6	1.2	0.2	0.9	<0.1
Metals PC2						
FEZ *d*	2.3					
FE *d*	2.1					
Error 1 (Carry-over)	5.4***					
Year		2.3	12.2**	2.4	0.5	0.7
Year x FEZ *d*		1.0	7.1*	1.2	0.4	0.2
Year x FE *d*		1.2	<0.1	1.9	2.2	<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 transformed to ranks.

Metals PC2 scores also had strong carry-over effects (F = 5.4; Table 5-18). Overall FE and FEZ gradients were not significant. There was a difference in FEZ distance gradients between 2000 and 2001 (F = 7.1; Table 5-18), with slopes more strongly negative in 2001 (Figure 5-28).

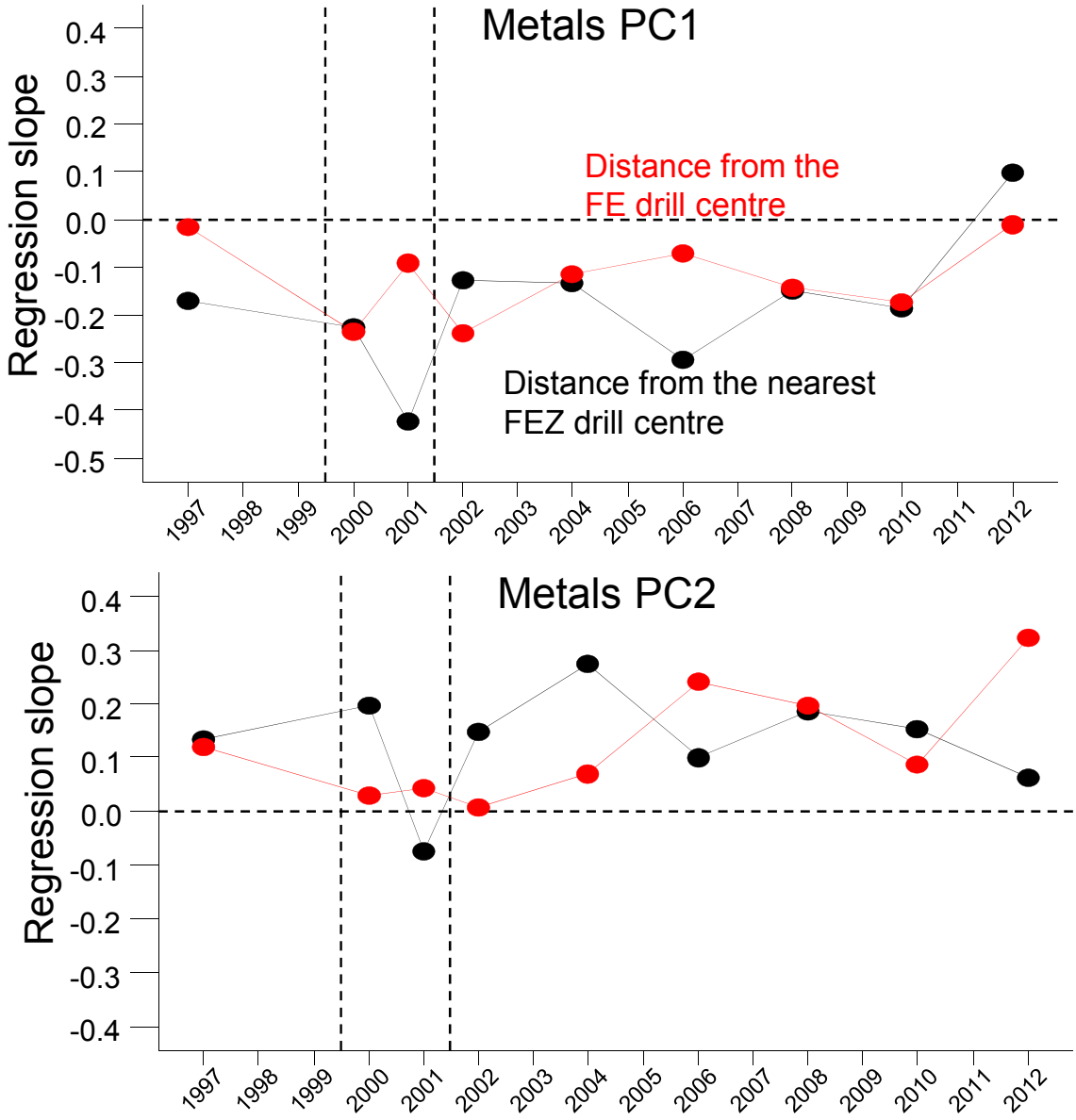


Figure 5-28 Annual Multiple Regression Distance Slopes for Metals PC1 and Metals PC2 (1997 to 2012)

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

5.3.1.6 Ammonia

Ammonia measurements started in 2001 for at Terra Nova. Concentrations were generally higher in 2001 than in subsequent years, when concentrations were generally less than 10 mg/kg (Figure 5-29).

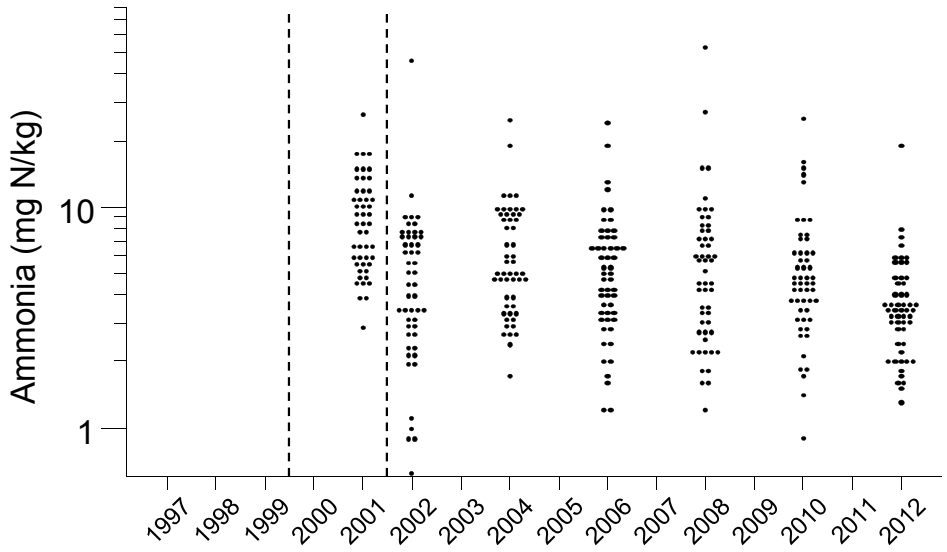


Figure 5-29 Annual Distributions for Ammonia Concentrations (1997 to 2012)

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

There was no significant change in ammonia concentrations with Min *d* in 2012 (Figure 5-30), similar to what was observed in all previous years except 2010 (Figure 5-31). The partial correlation for FEZ distances was weakly significant (Table 5-20).

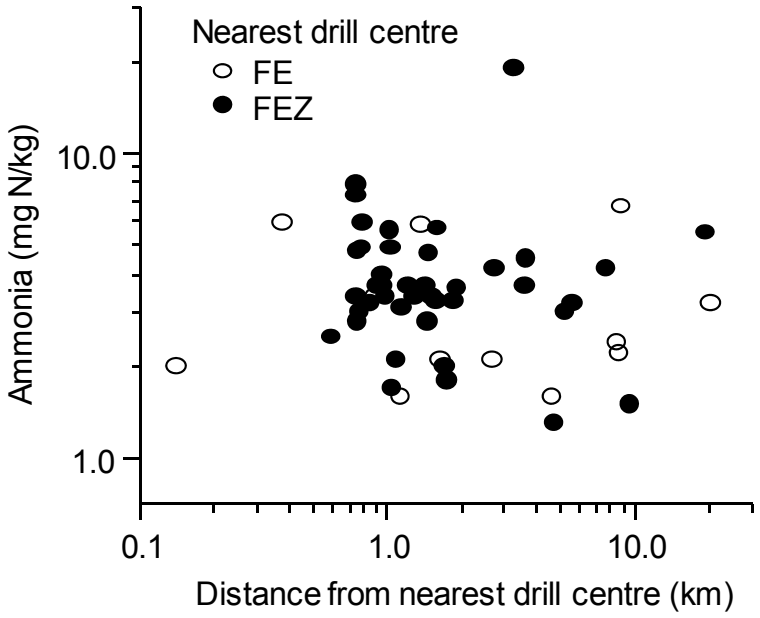


Figure 5-30 Distance Gradient for Ammonia (2012)

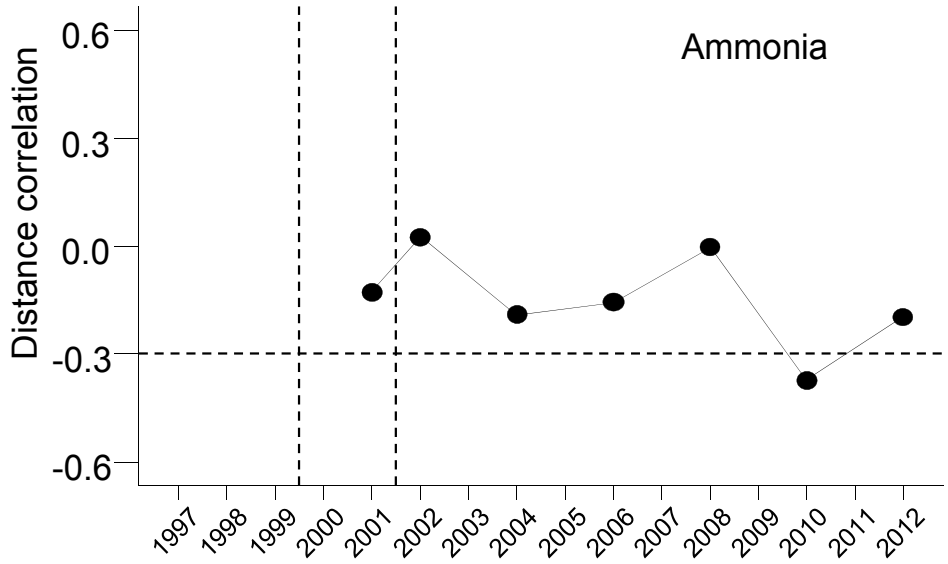


Figure 5-31 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Ammonia (1997 to 2012)

Notes: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values below the line 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).

Table 5-19 Results of Rank-Rank Regression of Ammonia on Distance Variables (2012)

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	0.26	-0.28*	0.11	-0.16

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

Carry-over effects for ammonia were significant ($F = 2$; Table 5-20). Ammonia concentrations were significantly lower after 2002 ($F = 5.1$, Table 5-20; Figure 5-29). FEZ distance gradients for ammonia were significant and negative, but with no change over time (all $F < 1$, Table 5-20, Figure 5-32). FE distance gradients were not significant and there was no evidence that ammonia distance gradients varied from before to after drilling began at the FE drill centre ($F = 0.2$).

Table 5-20 Results (F Values) of Repeated-Measures Regressions Comparing Ammonia Among EEM Years (2000 to 2012)

Effect	Test					
	Among Stations	**Within Stations**	**Before vs After NW, SE Drilling (2000 vs 2001)**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2012)**	**Linear Trend 2002 to 2012**	**Quadratic Trend 2002 to 2012**
FEZ *d*	10.6**					
FE *d*	2.8					
Error 1 (Carry-over)	2.0***					
Year		1.3		5.1*	1.3	<0.1
Year x FEZ *d*		0.6		1.0	0.3	<0.1
Year x FE *d*		0.1		0.2	<0.1	<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 transformed to ranks.

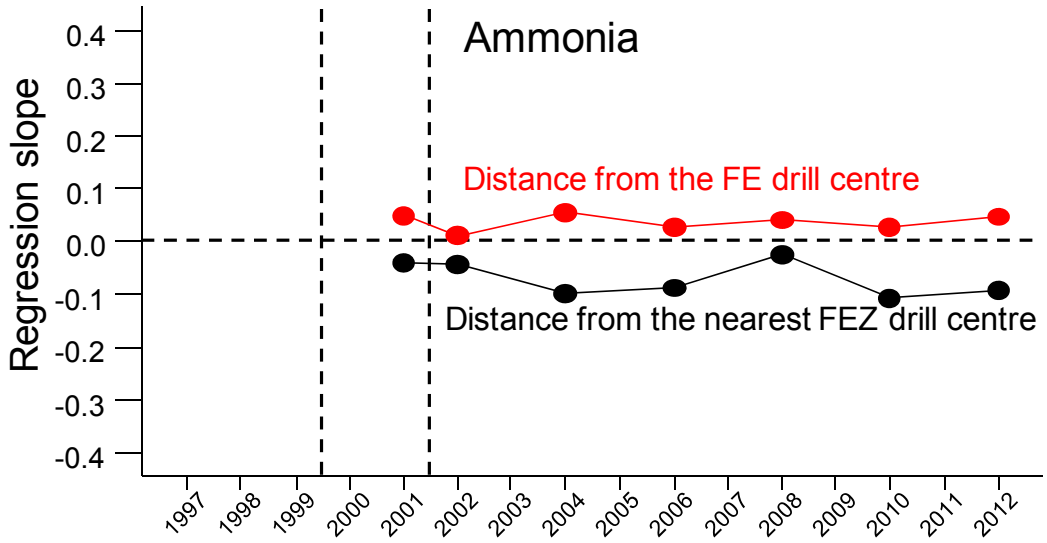


Figure 5-32 Annual Multiple Regression Distance Slopes for Ammonia (1997 to 2012)

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 was only measured at a subset of 29 stations in 1997, so analyses were restricted to EEM years. Redox decreased from 2001 to 2004, increased in 2006, decreased in 2008, then increased in 2010. The range of redox values in 2012 was similar to that noted in 2010 (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. Redox did not strongly, or significantly,

covary with Min *d* in 2012 (Figures 5-34 and 5-35). The relationship between redox and Min *d* has changed over time, and the only significant increases in redox with distance from drill centres occurred in 2000, 2002 and 2004 (Figure 5-35). 2012 distance relationships using partial regressions of distances to the FE and FEZ drill centres were similar to those obtained with Min *d* (Table 5-21). In 2012, all sediments were oxic (i.e., redox > 100 mV; Figure 5-33).

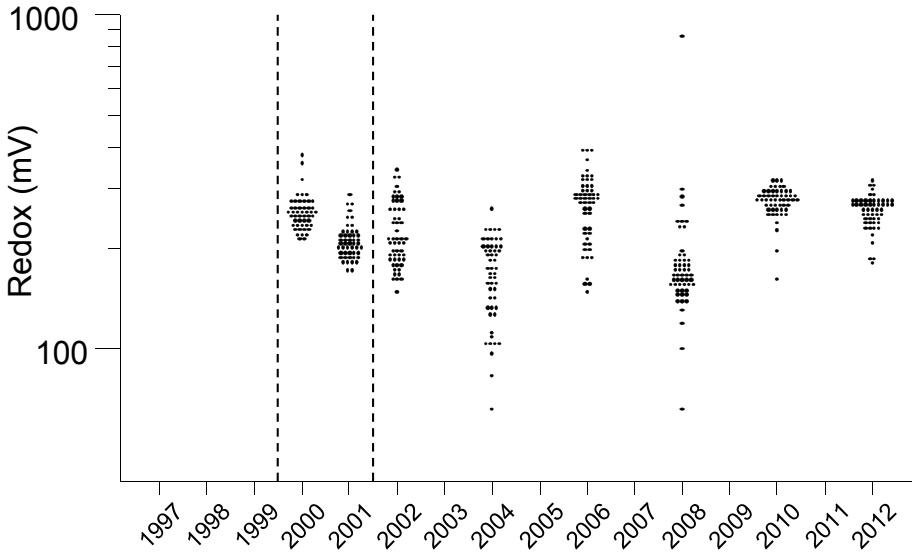


Figure 5-33 Annual Distributions for Redox (1997 to 2012)

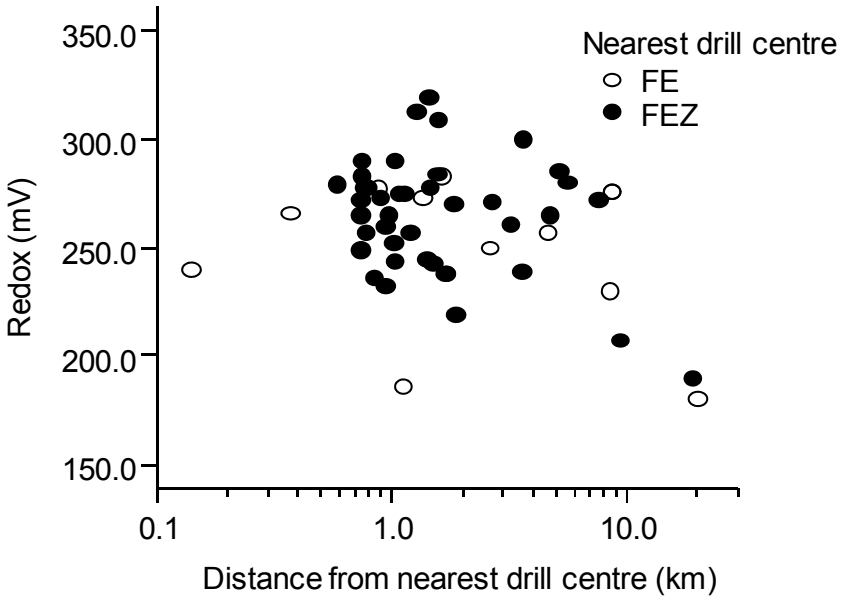


Figure 5-34 Distance Gradient for Redox (2012)

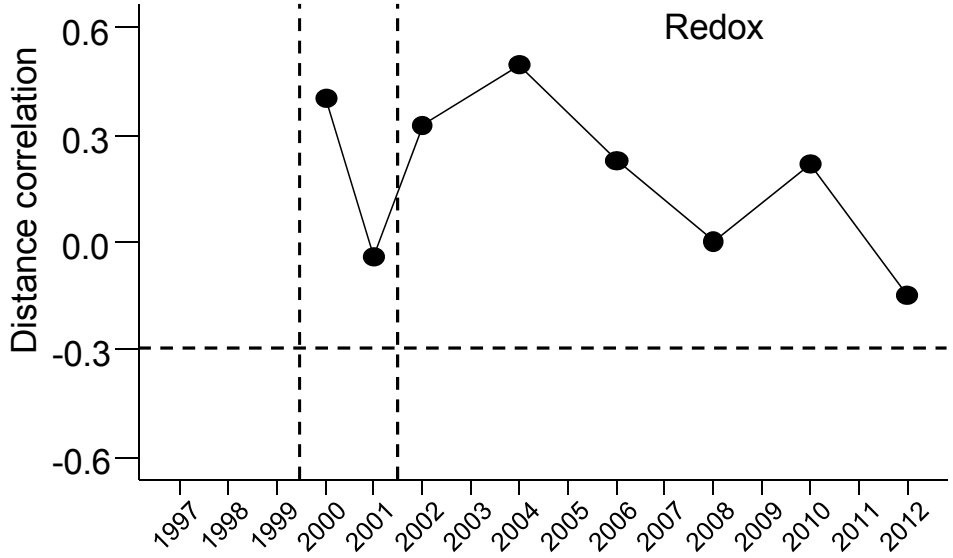


Figure 5-35 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Redox (1997 to 2012)

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values below the line 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).

Table 5-21 Results of Rank-Rank Regression of Redox on Distance Variables (2012)

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	0.39**	-0.24	-0.23	-0.22

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

Carry-over effects for redox were not significant ($F = 1.2$; Table 5-22). The overall distance gradient for redox from the FEZ drill centres was significant (positive; $F = 10.0$; Figure 5-36). The distance gradient was stronger in 2000 than in 2001 ($F = 7.0$), but was greatest in 2002, and has since decreased linearly ($F = 27.6$).The overall distance gradient from the FE drill centre was not significantly different from zero ($F = 0.8$), although there was variation in the gradient (slope) among years ($F = 4.1$). The FE distance gradient did not change from before to after drilling at the FE drill centre ($F < 0.1$).

Table 5-22 Results (F Values) of Repeated-Measures Regressions Comparing Redox Among EEM Years (2000 to 2012)

Effect	Test					
	Among Stations	Within Stations	Before vs After NW, SE Drilling (2000 vs 2001)	Before vs After FE Drilling (2000 and 2001 vs 2002 to 2012)	Linear Trend 2002 to 2012	Quadratic Trend 2002 to 2012
FEZ *d*	**10.0*** **					
FE *d*	0.8					
Error 1 (Carry-over)	1.2					
Year		**9.1*** **	**60.3*** **	3.8	**22.0*** **	9.1**
Year x FEZ *d*		**4.0*** **	7.0*	0.4	**27.6*** **	0.5
Year x FE *d*		**4.1*** **	3.5	<0.1	0.2	10.7**

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 transformed to ranks.

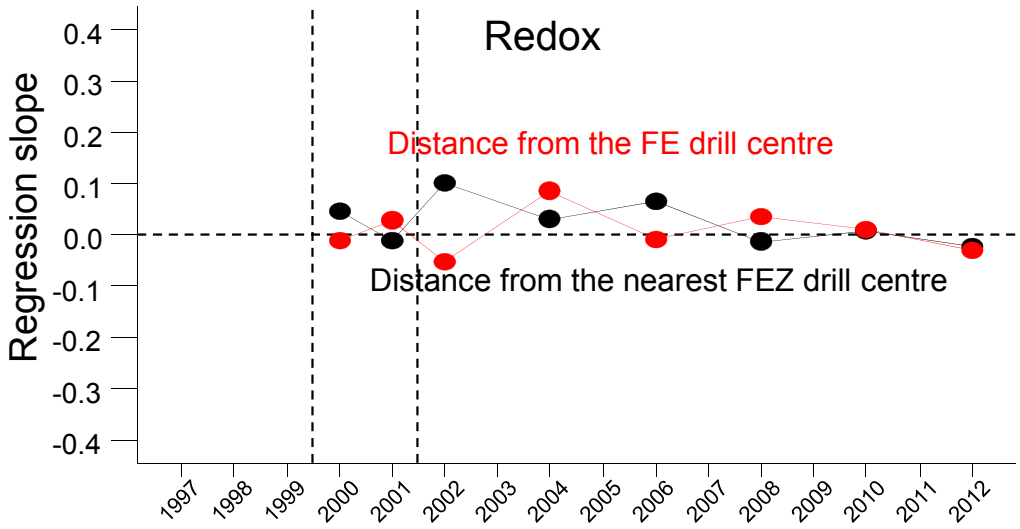


Figure 5-36 Annual Multiple Regression Distance Slopes for Redox (1997 to 2012)

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).

5.3.1.8 Suphur 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 has been below 10 mg/kg since 2006 (Figure 5-37).

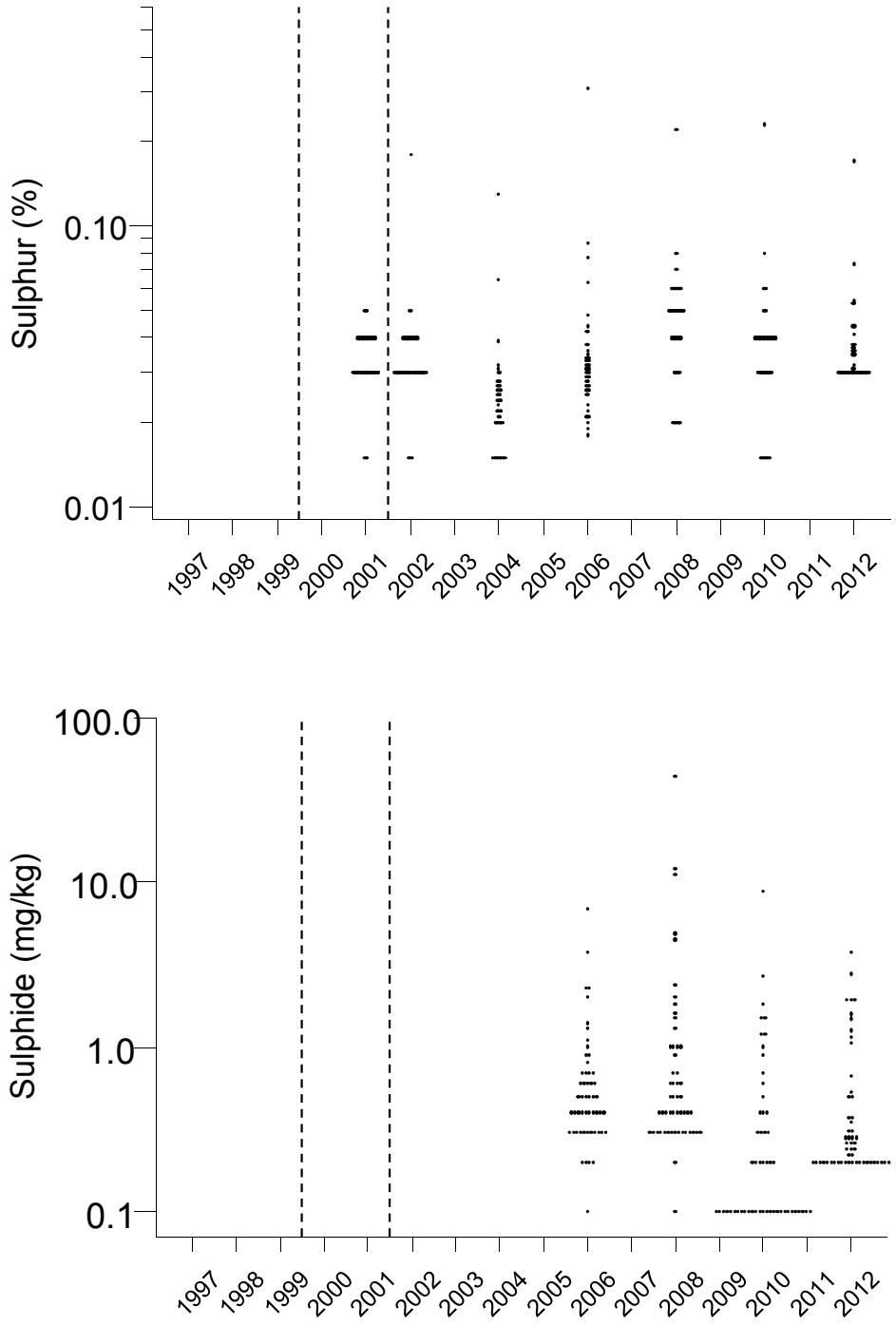


Figure 5-37 Annual Distributions of Concentrations for Sulphur (2001 to 2012) and Sulphide (2006 to 2012)

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).

Sulphur was weakly negatively correlated with Min *d* in 2012, with concentrations somewhat greater near drill centres, and greatest at station 30(FE), the station nearest a drill centre (Figure 5-38). Sulphur has had modestly strong distance relationships in most years since 2001 (Figure 5-39). The strength of the relationship has not changed appreciably since 2001. Distance from the FEZ drill centres has been a better predictor of sulphur concentrations than distance from the FE drill centre (Table 5-23). In spite of the high sulphur level noted at station 30(FE) in 2012, sulphur levels at all but four stations near the FE drill centre were below the laboratory detection limit.

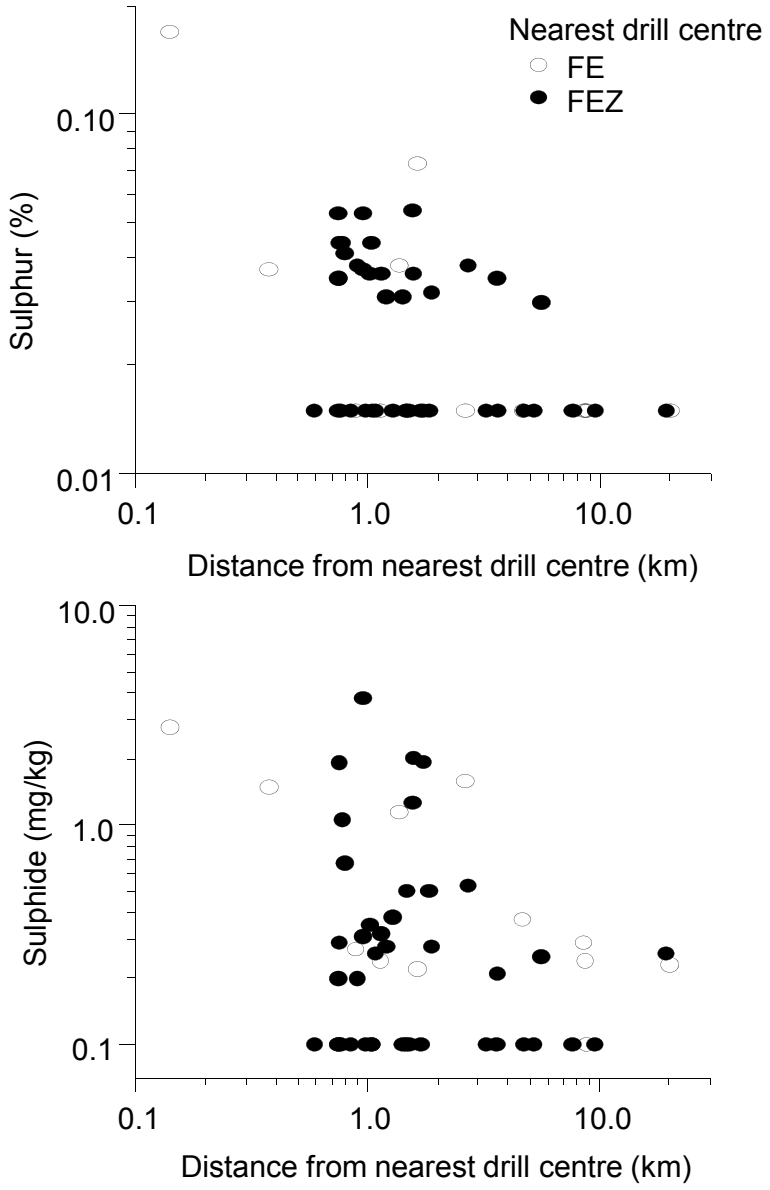


Figure 5-38 Distance Gradients for Sulphur and Sulphide (2012)

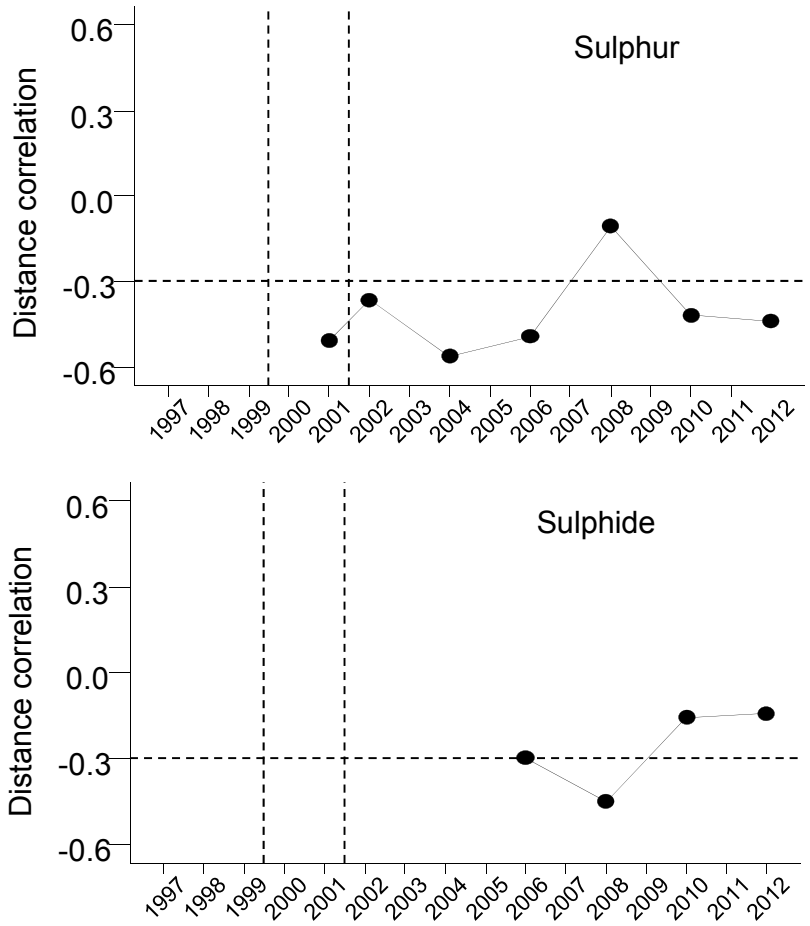


Figure 5-39 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Sulphur (2001 to 2012) and Sulphide (2006 to 2012)

Note: The horizontal dotted line indicates a Spearman rank correlation of |0.3|. Values below the line 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).

Table 5-23 Results of Rank-Rank Regression of Sulphur and Sulphide on Distance Variables (2012)

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	0.36**	-0.36**	-0.01	-0.44**
Sulphide	0.16	-0.02	-0.16	-0.24

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

Sulphide concentrations were less strongly associated with Min *d* than was sulphur concentrations in 2012 (Figure 5-38; Table 5-23) or other prior years (Figure 5-39).

Carry-over effects were significant for sulphur ($F = 6.5$, Table 5-24). There were significant variations in overall sulphur concentrations among years ($F = 10.3$), with a general increase in levels over time (Figure 5-4037, $F = 12.1$, Table 5-24). The overall distance slope from the FEZ drill centres was significant ($F = 9.5$), but distance slopes did not vary among years (all Year x FEZ *d* $F < 1.5$, Table 5-24, also see Figure 5-40). There were significant variations in FE distance slopes among years ($F = 2.4$), but those changes did not coincide with the onset of drilling at the FE drill centre ($F < 0.1$, Figure 5-40).

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

Table 5-24 Results (F Values) of Repeated-Measures Regressions Comparing Concentrations Among EEM Years for Sulphur (2001 to 2012)

Effect	Test					
	Among Stations	**Within Stations**	**Before vs After NW, SE Drilling (2000 vs 2001)**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2012)**	**Linear Trend 2002 to 2012**	**Quadratic Trend 2002 to 2012**
FEZ *d*	9.5***					
FE *d*	0.2					
Error 1 (Carry-over)	6.5***					
Year		10.3***		3.0	12.1**	2.1
Year x FEZ *d*		0.7		0.6	<0.1	1.3
Year x FE *d*		2.4*		<0.1	2.1	0.9

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.
- Distance variables (X) and Y variables were transformed to ranks.

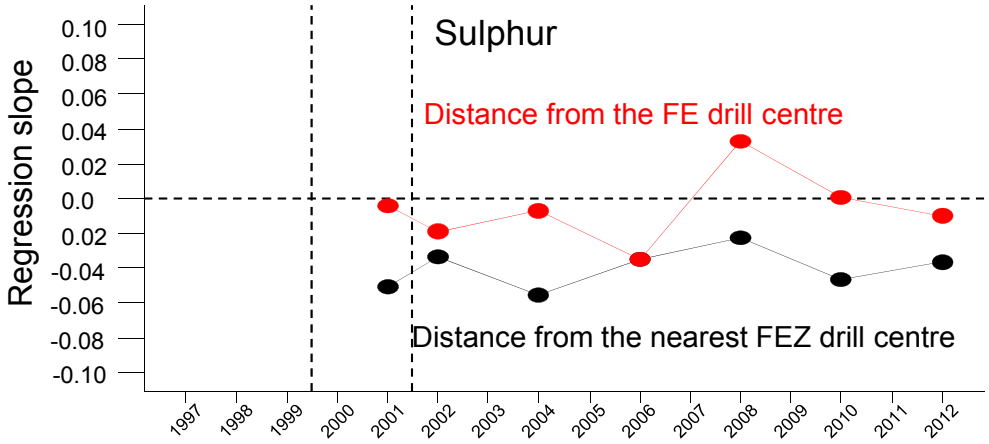


Figure 5-40 Annual Multiple Regression Distance Slopes for Sulphur (2001 to 2012)

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).

5.3.2 TOXICITY

5.3.2.1 Analysis of 2012 Data

Appendix B-5 provides Microtox IC50s and amphipod survival results from 1997 to 2012. In 2012, Microtox IC50s ranged from 2,773 to > 197,000 mg wet/L. IC50s were less than 197,000 mg wet/L (the highest concentration tested) in 18 (of 53) samples. IC50s less than 50,000 mg wet/L (the definition of toxic used in this report) occurred in 13 samples.

Amphipod survival ranged from 71 to 100%, with a median survival of 96%. The lowest survival occurred in sediments from station 52(FEZ), located 1.57 km from the SE drill centre, and only that sample was classified as toxic following Environment Canada (1998) interpretative guidance. The sediment sample from station 52(FEZ) was classified as toxic based on comparison to control sediments, but the sample was not toxic when compared to Reference sediments.

Relationships with Sediment Physical and Chemical Characteristics

Microtox IC50s and amphipod survival were uncorrelated ($r_s = 0.006$; $p >> 0.05$) over all 53 samples tested in 2012.

Microtox IC50s were negatively correlated with most sediment physical and chemical variables (Table 5-25), indicating that negative responses increased as values of those variables increased. Correlations in Table 5-25 are not necessarily indicative of direct negative effects of sediment physical and chemical characteristics on Microtox test organisms. IC50s were not significantly correlated with $>C_{10}$-C_{21} hydrocarbons. IC50s were significantly correlated with barium, but that correlation was weaker than correlations with many other variables (Table 5-25). In 2012, as in prior years, strontium was the strongest correlate of Microtox IC50s. Correlations between IC50s versus adjusted fines, sulphur, sulphide and ammonia, which can negatively affect Microtox test organisms, were significant.

Table 5-25 Spearman Rank Correlations (r_s) Between Toxicity Test Responses and Sediment Physical and Chemical Characteristics (2012)

Physical / Chemical Variable	Microtox IC50 (wet weight)	Amphipoda Survival
$>C_{10}$-C_{21}	-0.197	0.282*
Barium	-0.338*	0.185
Fines	-0.324*	0.085
Adjusted Fines	-0.358*	0.062
Gravel	-0.359*	-0.006
Total Organic Carbon	-0.318*	0.223
Metals PC1	0.081	0.052
Metals PC2	0.019	-0.193
Strontium	**-0.652*** **	0.108
Sulphur	-0.208	0.160
Sulphide	-0.444**	0.008
Ammonia	-0.297*	0.201
Redox	-0.117	0.108

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

Most correlations between amphipod survival and sediment physical and chemical variables were weak and non-significant (Table 5-25). The correlation between amphipod survival and $>C_{10}$-C_{21} hydrocarbons was stronger (r_S = 0.28) and weakly significant. The correlation, however, was positive, indicating higher survival in sediments with higher concentrations of hydrocarbons; a result that does not imply a negative effect of hydrocarbons on survival.

Distance Relationships

In 2012, Microtox IC50s were uncorrelated with distances from drill centres (Table 5-26). Instead, the lowest values (greatest toxicity) generally occurred at intermediate distances of approximately 1 to 2 km from nearest drill centres (Figure 5-41). That observation was also made in prior years (see Suncor Energy 2011).

Table 5-26 Results of Rank-Rank Regressions of Toxicity Test Responses on Distance Variables (2012)

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	0.15	0.24	0.10
Amphipod survival	0.25	-0.30	0.15	-0.13

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

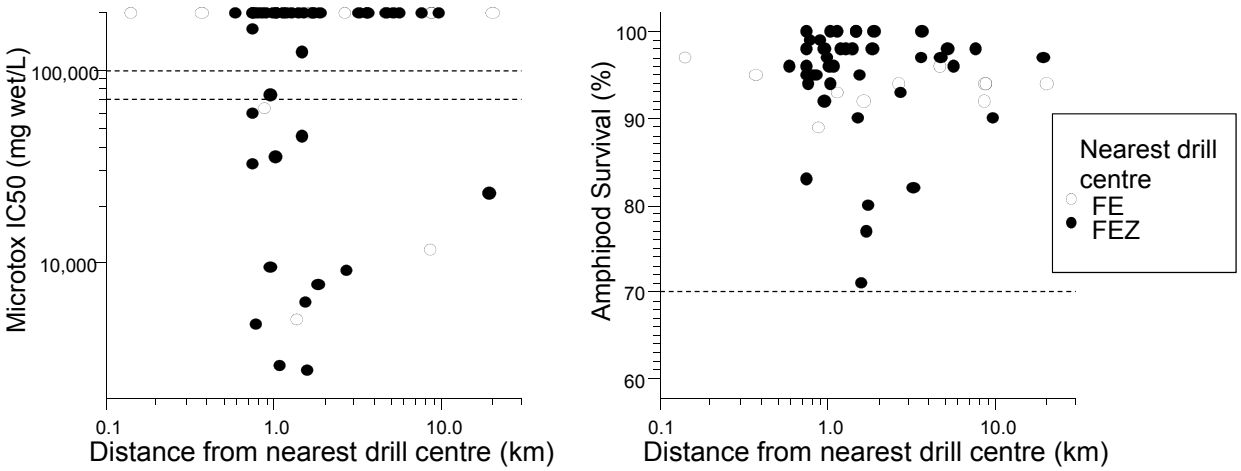


Figure 5-41 Distance Gradients for Toxicity Test Responses (2012)

Notes: The horizontal dashed lines in Figure 5-41 (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. Based on Environment Canada (2002) interpretative guidance, negative responses would also be considered evidence of toxicity.

In 2012, amphipod survival was uncorrelated with distances from drill centres (r_S = -0.134; Table 5-27) and survival of amphipods was greater than 70% in all sediments.

5.3.2.2 Comparison Among Years

Multi-year comparisons are not provided for amphipod survival because survival has been uniformly high and more than 98% of samples have been non-toxic.

Table 5-27 summarizes frequencies of Microtox IC50s less than 98,500 mg wet/L, the benchmark used to define negative responses, and values less than 50,000 mg wet/L, the benchmark used to define toxicity. In 1997, there were four samples with negative responses, one of which (from station 12(NE), 8.77 km from the FE drill centre) was toxic.

Table 5-27 Frequencies of Samples with Negative Microtox Responses (1997 to 2012)

Year	No. stations	Negative Responses (IC50 <98,500 mg wet/L)		Toxicity (IC50 <50,000 mg wet/L)	
		No. stations	%	No. stations	%
1997	54	4	7	1	2
2000	49	15	31	10	20
2001	49	19	39	13	27
2002	53	21	40	8	15
2004	52	10	19	10	19
2006	53	7	13	6	11
2008	53	10	19	9	17
2010	53	13	25	8	15
2012	53	14	26	13	25
Total (All years)	469	113	24	78	17
Total (EEM years)	415	109	26	77	19

Frequencies of negative responses and toxicity were greater in EEM years. Frequencies of negative responses decreased from 30 to 40% from 2000 to 2002, to approximately 20% in subsequent years. However, a decrease over time was less evident for toxicity (Table 5-27), as frequencies of toxicity were generally between 15 to 30% in EEM years, except for 2006 (11%). Negative responses occurred in 26% of samples, while toxicity occurred in 25% of samples in 2012.

A positive correlation between Microtox IC50 and Min *d* in EEM years could indicate that the increase in toxicity noted since baseline is related to project activity. However, in most EEM years, Microtox IC50s were not strongly (or significantly) positively correlated with Min *d* (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.

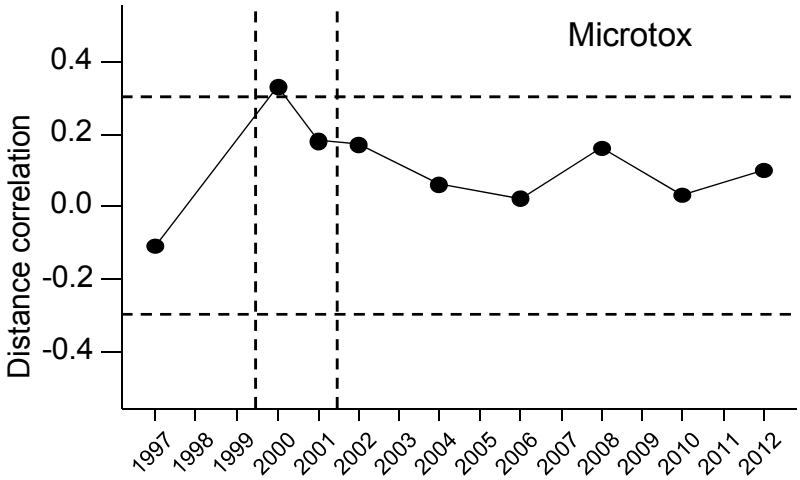


Figure 5-42 Spearman Rank Correlations with Distance from the Nearest Active Drill Centre (Min d) for Microtox (1997 to 2012)

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 $p < 0.01$, 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).

Repeated-measures regression on Microtox toxicity showed that carry-over effects were highly significant ($F = 10.3$, Table 5-28). Among-stations FE and FEZ distance gradients were not significant, while there were no significant variations among EEM years (Figure 5-43). There were no annual variations in distance gradients that were consistent with drilling-related activities (all $F < 1.7$). These various observations provide no evidence that increasing drilling operations have caused an increase in sediment toxicity in EEM years. These data do not provide strong evidence for a link between toxicity and drilling.

Table 5-28 Results (F Values) of Repeated-Measures Regressions Comparing Microtox Toxicity Among EEM Years (2000 to 2012)

Effect	Test					
	Among Stations	**Within Stations**	**Before vs After NW, SE Drilling (2000 vs 2001)**	**Before vs After FE Drilling (2000 and 2001 vs 2002 to 2012)**	**Linear Trend 2002 to 2012**	**Quadratic Trend 2002 to 2012**
FEZ *d*	2.2					
FE *d*	1.0					
Error 1 (Carry-over)	10.3***					
Year		0.7	1.2	1.6	<0.1	1.0
Year x FEZ *d*		0.5	1.4	1.5	<0.1	0.7
Year x FE *d*		0.4	<0.1	0.3	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 transformed to ranks.

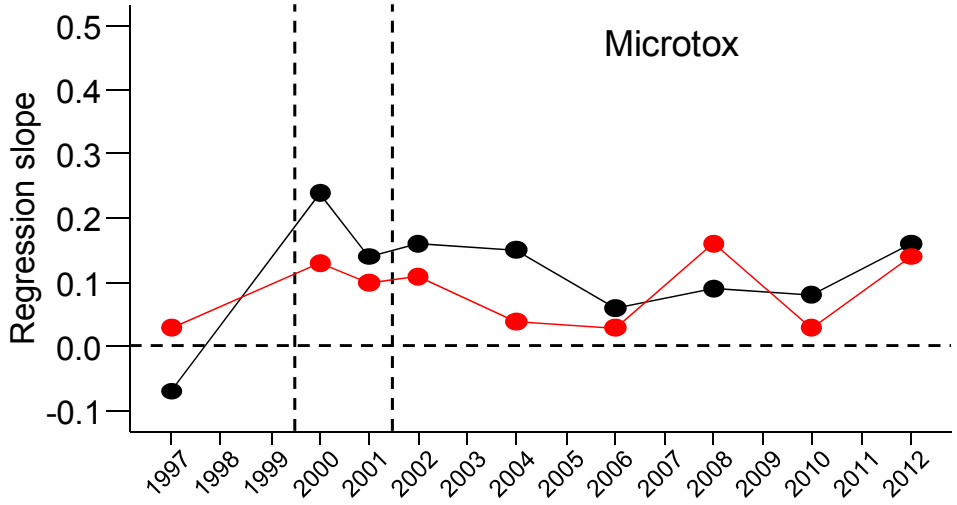


Figure 5-43 Annual Multiple Regression Distance Slopes for Microtox (2000 to 2012)

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 BENTHIC COMMUNITY STRUCTURE

5.3.3.1 Overview

Over the nine sample years (from 1997 to 2012), more than 650 individual kinds of invertebrates from over 180 families (excluding meiofauna such as oligochaetes, protodrilids, copepods, ostracods, nematodes, nemerteans) have been collected, sorted from sediments and identified (Table 5-29).

In 2012, over 32,000 individual benthic macro-invertebrates (i.e., excluding meiofauna) were collected in 106 samples from 53 stations (Table 5-29). Samples were dominated by polychaetes, which accounted for approximately 85% of total abundance in previous years, and 78% in 2012. Molluscs and crustaceans were the only other phyla accounting for more than 1% of total abundance in 2012 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 2012)

Taxon			2000 to 2010		2012	
Phylum or Subphylum	**Class or Order**	**Family**	**% of organisms**	**% of samples**	**% of organisms**	**% of samples**
Porifera			<1	20	<1	9
Cnidaria			0.4	70	0.5	74
Platyhelminthes			<1	1	0.0	0
Priapulida			0.1	9	0.0	0
Annelida	Polychaeta	Sub-total	85.2	100	77.8	100
		Ampharetidae	0.7	51	1.2	81
		Capitellidae	1.3	90	1.2	77
		Cirratulidae	14.9	100	7.0	100
		Dorvilleidae	0.5	53	0.8	51
		Glyceridae	0.8	62	1.1	58
		Maldanidae	1.4	72	1.7	72
		Nereidae	0.4	46	0.9	45
		Opheliidae	0.7	62	0.6	60
		Orbiniidae	1.3	72	1.4	70
		Paraonidae	2.9	88	3.4	91
		Pholoidae	3.5	88	2.0	79
		Phyllodocidae	3.5	99	3.2	98
		Polynoidae	0.9	83	0.8	87
		Sabellidae	2.5	88	4.9	83
		Spionidae	36.9	100	32.1	100
		Syllidae	11.7	100	12.4	100
		Terebellidae	0.5	54	1.1	68
Sipuncula			0.1	24	0.0	0
Mollusca	Polyplacophora		<1	1	0.0	0
	Bivalvia	Sub-total	2.3	100	3.6	100
		Hiatellidae	0.6	91	0.9	94
		Tellinidae	1.2	76	1.6	79
	Gastropoda	Sub-total	1.2	79	3.4	89
		Lepetidae	0.9	45	2.6	62
Crustacea	Amphipoda	Sub-total	4.2	98	5.9	100
		Ampeliscidae	0.4	35	0.6	36
		Corophiidae	0.1	10	0.6	66
		Oedicerotidae	0.6	75	0.5	72
		Phoxocephalidae	1.3	76	1.7	75
		Stenopleustidae	0.8	53	0.0	0
		Stenothoidae	0.0	0	0.9	74
	Cirripedia	Balanidae	2.1	56	3.1	64
	Cumacea	Sub-total	0.6	72	1.2	98
		Diastylidae	0.2	33	0.6	66
		Leuconidae	0.4	60	0.6	85
	Decapoda		0.1	23	<1	11
	Isopoda		0.2	39	0.4	58
	Tanaidacea	Sub-total	2.1	80	2.2	77
		Paratanaidae	1.8	59	2.2	77
Chelicerata	Pycnogonida	Nymphonidae	<1	2	0.0	0
Brachiopoda		Hemithyrididae	<1	<1	<1	4
Echinodermata		Sub-total	0.7	88	0.5	75
		Ophiuroidea	0.6	36	0.5	34
Hemichordata			0.2	18	1.0	60
Grand Total Count			265,849		32,558	

In 2012, as in previous years, invertebrate communities were dominated by three polychaete families: Spionidae, Syllidae and Cirratulidae (Table 5-29). These three families were collected at every station in every year and accounted for just over 50% of the total number of invertebrates collected in EEM samples in 2012.

Table 5-29 also provides relative abundances and occurrences for families accounting for at least 0.5% of total abundance from 2000 to 2010 and separately for 2012. Most of the other common families were also polychaetes. Tellinidae (mostly *Macoma*) and Hiatellidae (*Cyrtodaria* and *Hiatella*) were the dominant bivalve families (Table 5-30). Lepetidae (*Lepeta*) was the dominant gastropod family. Tanaidacea (Order) was the most abundant crustacean. Phoxocephalidae (*Phoxocephalus*) was the dominant amphipod family.

Table 5-30 Summary Statistics for Invertebrate Community Variables (2012)

Variable	Unit/Interpretation	Min	Max	Median	Mean	SD	CV
Summary Measures							
Total abundance (N)	No. organisms/station	119	1,602	405	602	426	71
Biomass (B)	g wet/station	14	1,021	186	231	172	74
Richness (S)	No. taxa/station	16	59	32	36	11	30
Adjusted Richness (S2)	Observed:Expected S	0.6	1.3	1.0	1.0	0.2	15
NMDS1	Spionidae dominance	-1.858	1.024	0.108	-0.145	0.809	
NMDS2	Cirratulidae dominance	-1.971	1.570	-0.352	-0.259	0.590	
Taxon Abundance							
Spionidae	No. organisms/station	3	713	119	197.2	195.9	99
Cirratulidae	No. organisms/station	1	205	26	43.3	42.8	99
Syllidae	No. organisms/station	5	154	75	76.4	37.5	49
Orbiniidae	No. organisms/station	0	52	5	8.5	12.5	146
Paraonidae	No. organisms/station	0	167	5	21.1	33.6	159
Phyllodocidae	No. organisms/station	0	64	17	19.8	15.0	76
Tellinidae	No. organisms/station	0	89	5	9.7	14.8	152
Amphipoda	No. organisms/station	3	216	22	36.2	39.2	108
Echinodermata	No. organisms/station	0	92	3	5.3	12.8	240

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).

In 2012, total abundance varied by more than 10-fold among stations (from 119 to 1,602 individual per station), with the standard deviations (SD) of abundances more than 70% of the mean for all major groups (Table 5-30). Coefficients of Variations (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%.

Biomass varied over 70-fold (approximately 14 to 1021 g wet/station) among stations, with a CV of 74% (Table 5-30).

Richness and adjusted richness varied less (i.e., had lower CVs) among stations than abundances and biomass (Table 5-30). In 2012, 15 to 59 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 2012 stations. Richness adjusted for abundance (adjusted richness) removed most of the positive correlation between raw richness and abundance. Biomass in 2012 was weakly positively correlated with richness (r_s = 0.302, Table 5-31) and abundance (r_s = 0.286).

Table 5-31 Spearman Rank Correlations (r_s) Among Primary Benthic Invertebrate Community Variables (2012)

Parameter	Total Abundance (N)	Biomass (B)	Richness (S)
Biomass (B)	0.286*		
Richness (S)	**0.867*** **	0.302*	
Adjusted Richness (S2)	-0.096	0.068	0.334**

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

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 and Phyllodocidae, which co-varied with Spionidae abundance, were also significantly positively correlated with total abundance, as was amphipod abundance. Echinoderm and Paraonidae abundances were more weakly positively correlated with total abundance.

Table 5-32 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Summary Measures versus Taxon Abundances (2012)

Taxon Abundance	Total Abundance (N)	Biomass (B)	Richness (S)	Adjusted Richness (S2)
Spionidae	**0.940*** **	0.242	**0.821*** **	-0.098
Cirratulidae	**0.518*** **	0.052	0.402**	-0.101
Syllidae	**0.568*** **	0.057	**0.514*** **	-0.040
Orbiniidae	-0.132	0.119	-0.152	-0.049
Paraonidae	0.262*	-0.179	0.236*	-0.121
Phyllodocidae	**0.833*** **	0.402**	**0.674*** **	-0.135
Tellinidae	**0.532*** **	0.347**	**0.501*** **	0.067
Amphipoda	**0.448*** **	0.052	**0.489*** **	0.146
Echinodermata	0.274*	0.031	**0.463*** **	0.359**

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

Biomass was weakly positively correlated with abundances of Phyllodocidae polychaetes and Tellinidae bivalves (Table 5-32).

As was the case for abundance, richness was positively and significantly correlated with abundances of all of the taxa listed in Table 5-32 except for Orbiniidae. These correlations were partly associated with the overall correlation between richness and total abundance, driven by the dominant polychaetes. Adjusting richness for total abundance reduced the strength of the correlation between adjusted richness and the dominant groups. The relationship between abundance of Echinodermata and richness remained significant despite adjusting for abundance (r_S = 0.359).

5.3.3.2 Abundance

Total abundance increased from 2000 to 2012 (Figure 5-44). Approximately 200 to 1,000 organisms per station were noted in 2000, whereas 200 to 1,800 organisms per station were noted in 2012. The range in values of total abundance increased from 2002 to 2008, and then decreased in 2010 and 2012 (Figure 5-44). 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).

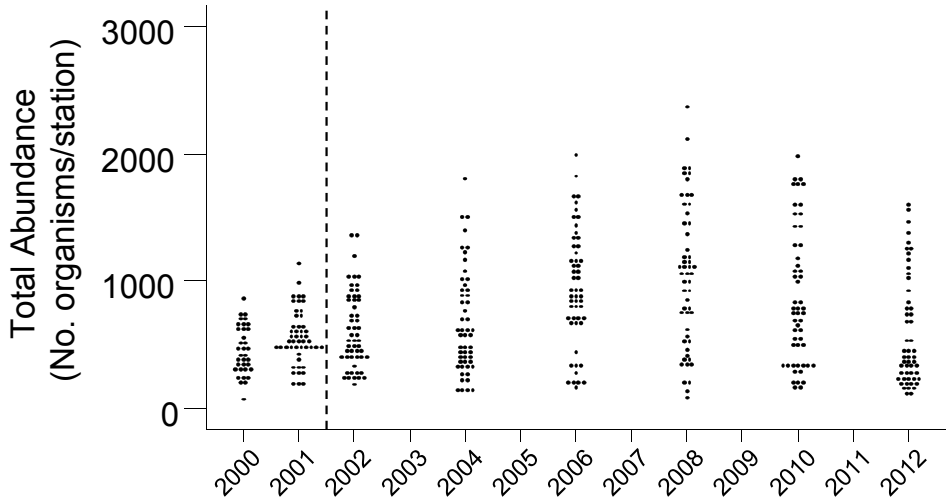


Figure 5-44 Annual Distributions for Total Abundance (2000 to 2012)

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

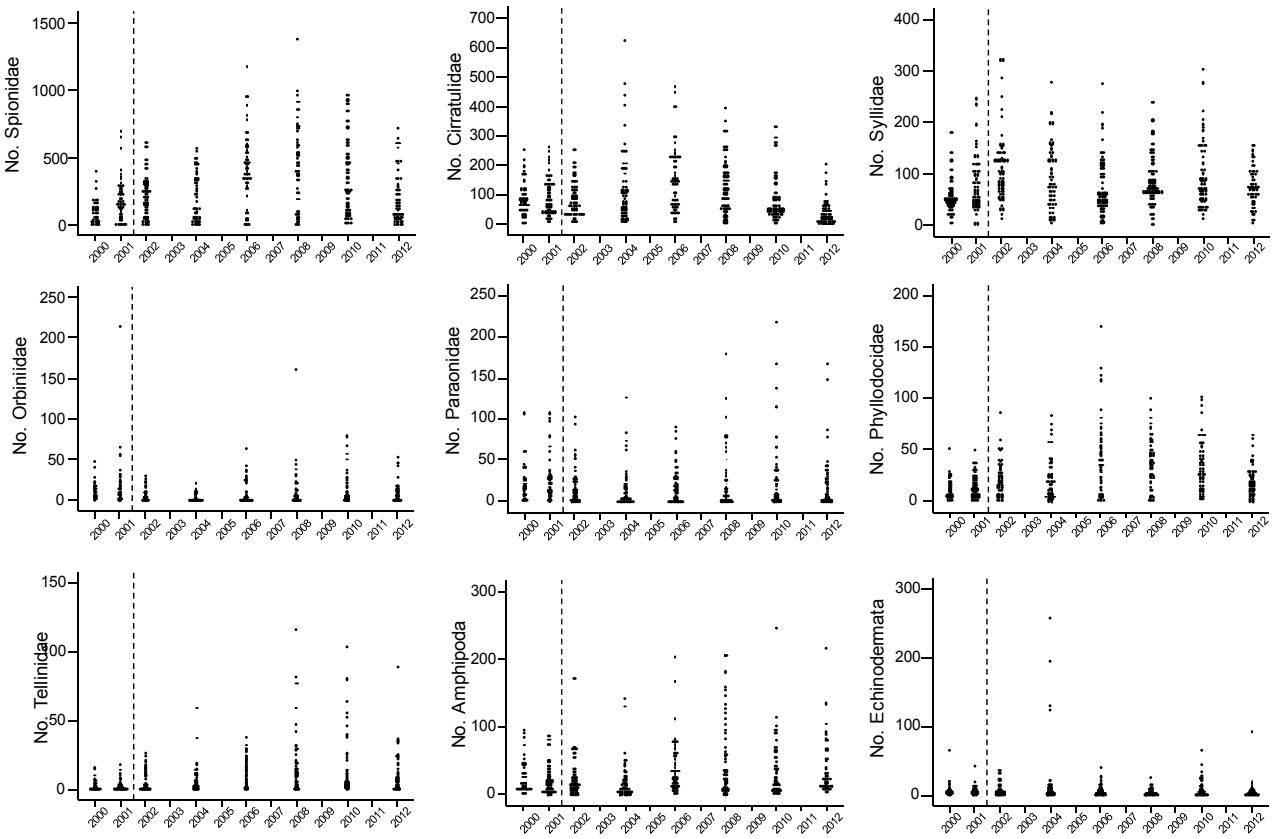


Figure 5-45 Annual Variations in Abundances of Major Taxonomic Groups (2000 to 2012)

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 uncorrelated with distances to drill centres in 2012 (see scatterplot in Figure 5-46). Distance correlations for total abundance have always been weakly negative, and were significantly related to distance (i.e., $r_s < -0.3$) only in 2004 (Figure 5-47). The distance correlation between abundance and distance to the nearest FEZ drill centre in 2012 was about as strong as the correlation between abundance and Min *d*, although neither were significant (Table 5-33).

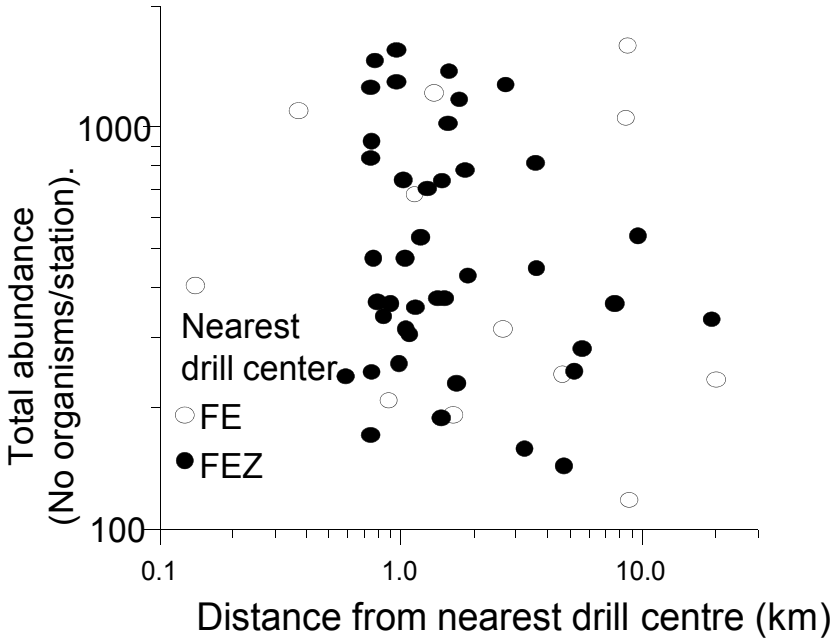


Figure 5-46 Distance Gradient for Total Abundance (2012)

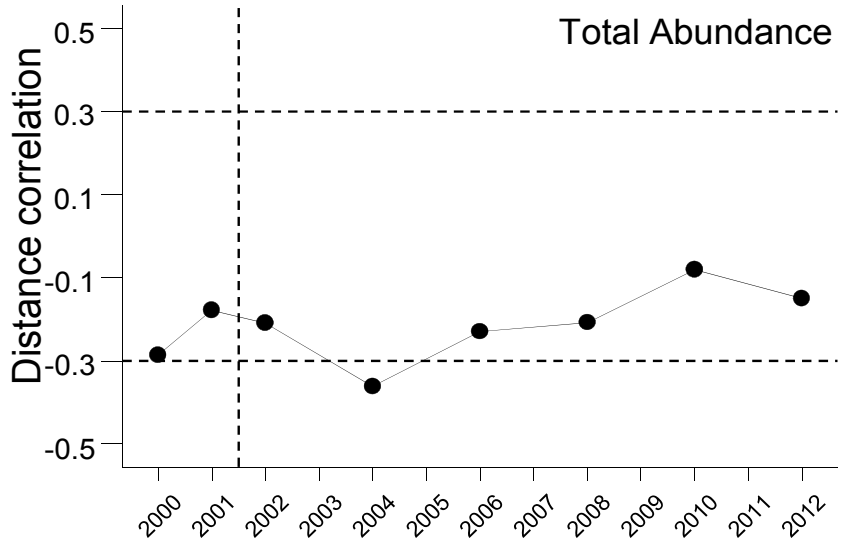


Figure 5-47 Annual Distance Correlations (r_s) for Total Abundance (2000 to 2012)

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

Table 5-33 Results of Rank-Rank Regression of Total Abundance on Distance Variables (2012)

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	0.14	-0.18	0.04	-0.15

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

Carry-over effects were highly significant for total abundance ($F = 8.8$; Table 5-34), indicating persistent spatial differences over time. The overall FEZ distance gradient was significant ($F = 5.2$). There was a general linear trend over time (increase) from 2002 to 2012 in abundance. FEZ and FE distance gradients did not vary over time (all $F \sim 1$; Table 5-34, and see also Figure 5-48).

Table 5-34 Results (F Values) of Repeated-Measures Regressions Comparing Total Abundance Among EEM Years (2001 to 2012)

Effect	Test				
	Among Stations	Within Stations	Before vs After FE Drilling (2001 vs 2002 to 2012)	Linear Trend 2002 to 2012	Quadratic Trend 2002 to 2012
FEZ *d*	5.2*				
FE *d*	0.1				
Error 1 (Carry-over)	8.8***				
Year		1.5	0.3	6.9*	0.1
Year x FEZ *d*		0.9	1.1	0.7	0.2
Year x FE *d*		1.1	1.6	1.8	0.4

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

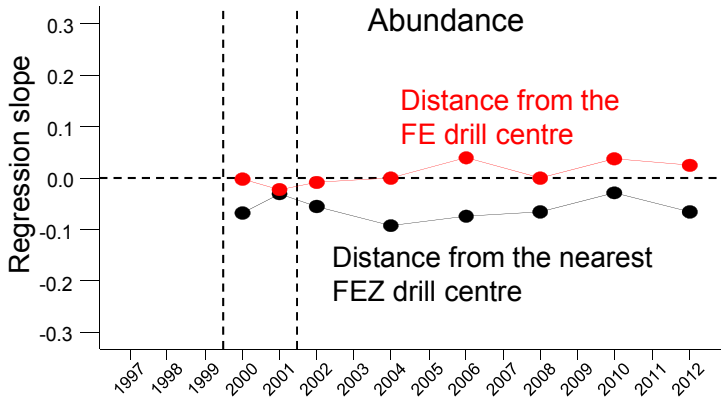


Figure 5-48 Annual Multiple Regression Distance Slopes for Total Abundance (2000 to 2012)

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), and with median biomass at just less than 200 g wet/station. Variations in biomass in 2012 were similar to variations observed in prior years, with the exception of two samples that had much higher biomass values than had been previously recorded. Higher biomass values were recorded at stations 46(FEZ) (0.8 km from the SW drill centre) and 20(NW) (3.59 km from the NW drill centre), with values of 755 g wet/station and 1021 g wet/station, respectively. *Balanus* were relatively abundant at both stations.

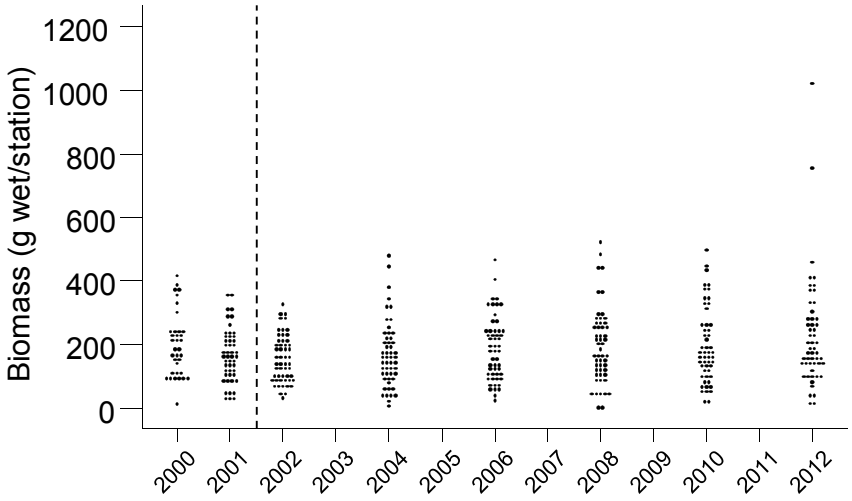


Figure 5-49 Annual Distributions for Biomass (2000 to 2012)

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

Biomass in 2012 was not significantly correlated with Min *d* (Figures 5-50 and 5-51) with a Spearman rank correlation of r_s = -0.09. Biomass has only been correlated with Min *d* in 2004 (Figure 5-50), when the relationship was significant and positive, indicating increasing biomass with increasing Min *d*. Multiple regression using FE and FEZ distances explained more variance in 2012 biomass values than did Min *d*, with biomass decreasing with distance from the nearest FEZ drill centre and increasing with distance from the FE drill centre (Table 5-35). Removal of the two relatively extreme biomass values did not change the nature of the correlation of biomass with Min *d* or the partial correlations with distances to the FE and FEZ drill centres, though the magnitude of the partial correlations were modestly weaker.

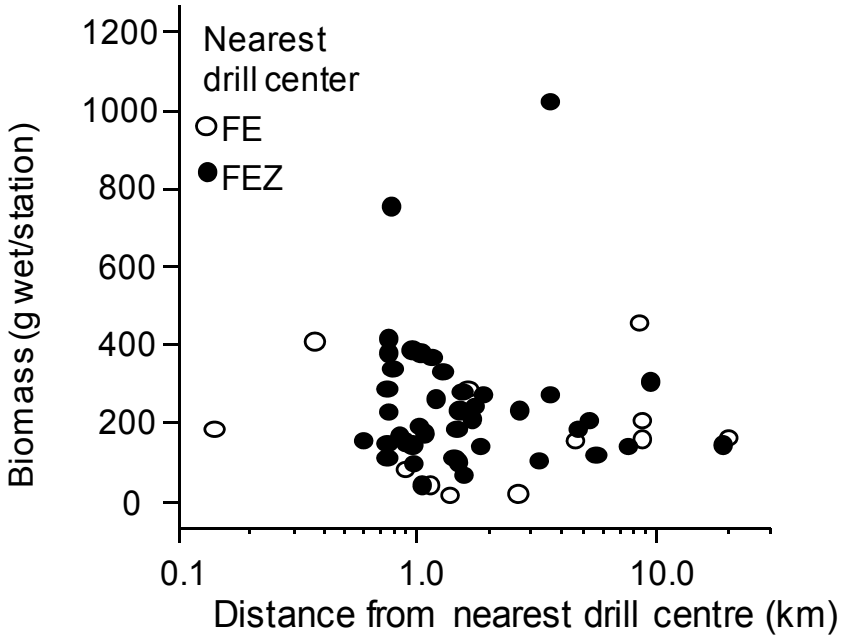


Figure 5-50 Distance Gradient for Biomass (2012)

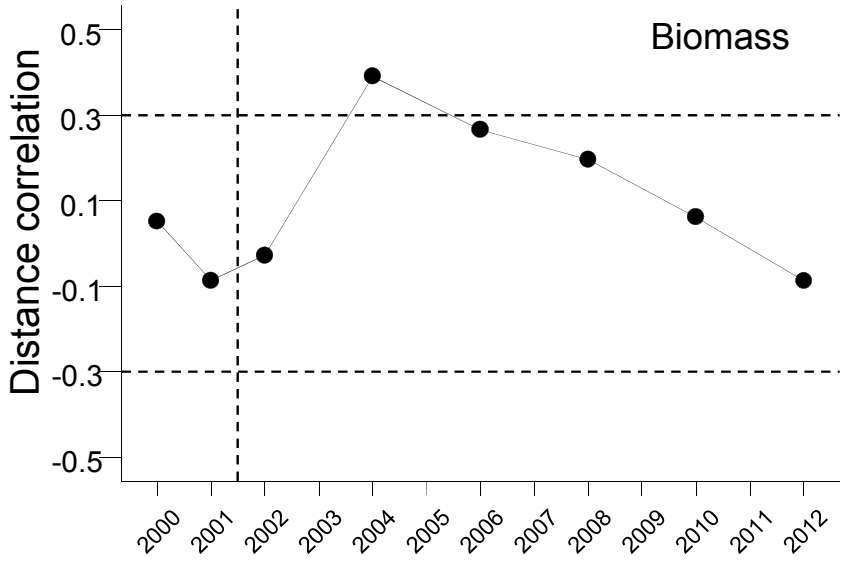


Figure 5-51 Annual Distance Correlations (r_s) for Biomass (2000 to 2012)

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

Table 5-35 Results of Rank-Rank Regression of Biomass dance on Distance Variables (2012)

Response Variable	Multiple R	Regression on distance from nearest FEZ and FE drill centres (Partial *r*)		Min *d* (r_s)
		FEZ *d* (FE *d* constant)	FE *d* (FEZ *d* constant	
Biomass	0.11	-0.27*	0.34*	-0.09

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

Carry-over effects were significant but relatively weak for biomass ($F = 1.9$, Table 5-36). The Among Stations FE distance gradients ($F = 32.8$) were strongly significant and positive, reflecting greater biomass with increasing distance from the FE drill centres (Figure 5-51; Table 5-36). There were significant annual variations in the FE distance gradients ($F = 2.3$), but there was no difference from before to after drilling at the FE drill centre ($F = 2.5$; Figure 5-52), and no linear or quadratic trends in distance gradients. The FE distance gradient was relatively strong in 2012 compared to prior years (Figure 5-52). As per previously, removal of the higher biomass values at stations 20(NW) and 46(FEZ) did not appreciably change the strength of the distance gradient in 2012.

Table 5-36 Results (F Values) of Repeated-Measures Regressions Comparing Biomass Among EEM Years (2001 to 2012)

Effect	Test				
	Among Stations	Within Stations	Before vs After FE Drilling (2001 vs 2002 to 2012)	Linear Trend 2002 to 2012	Quadratic Trend 2002 to 2012
FEZ *d*	1.7				
FE *d*	32.8***				
Error 1 (Carry-over)	1.9**				
Year		1.6	0.9	1.0	3.6
Year x FEZ *d*		0.9	<0.1	4.8*	<0.1
Year x FE *d*		2.3*	2.5	2.1	3.4

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

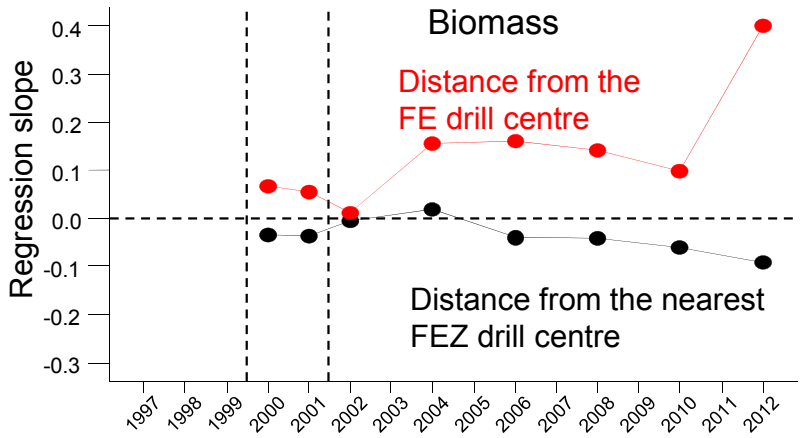


Figure 5-52 Annual Multiple Regression Distance Slopes for Biomass (2000 to 2012)

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

There was a minor linear trend in FEZ distance gradients ($F = 4.8$), with slopes generally becoming more negative over time from 2004 to 2012, and reflecting higher biomass near FEZ drill centres (Figure 5-52).

5.3.3.4 Richness

Approximately 15 to 60 taxa per station have been noted since sampling began in 2000 (Figure 5-53). Richness in 2012 did not vary significantly with Min *d* (Figure 5-54), similar to what was observed in prior years (Figure 5-55). Multiple regression likewise failed to demonstrate an influence of Min *d*, or distance to the FE or FEZ drill centres (Table 5-37).

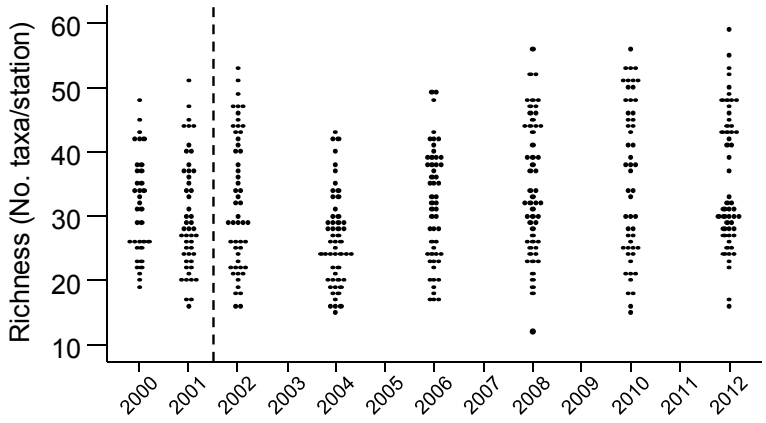


Figure 5-53 Annual Distributions for Richness (2000 to 2012)

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

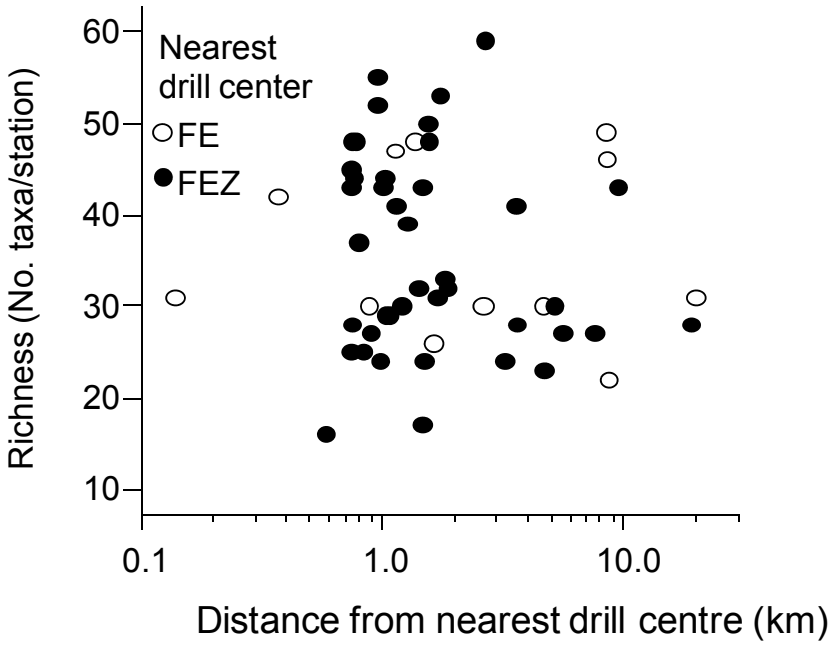


Figure 5-54 Distance Gradient for Richness (2012)

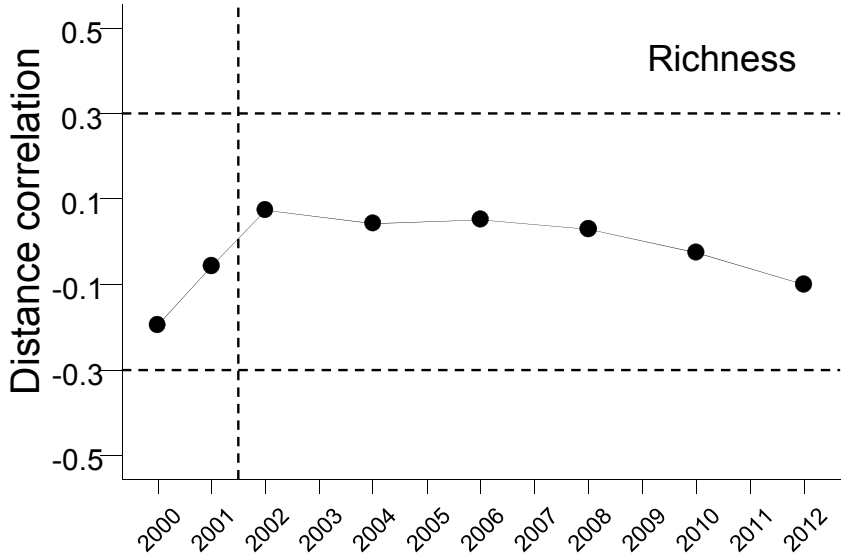


Figure 5-55 Annual Distance Correlations (r_s) for Richness (2000 to 2012)

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

Table 5-37 Results of Rank-Rank Regression of Richness on Distance Variables (2012)

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	0.13	-0.08	-0.07	-0.10

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

Carry-over effects were highly significant for richness with $F = 18.5$ ($p << 0.001$; Table 5-38). Mean richness over the sampling years varied linearly from 2002 to 2012 ($F = 4.2$), reflecting a modest increase in number of taxa over time. Regression slopes for distances to FE and FEZ drill centres were small and non-significant (Figure 5-56), and did not vary over time (all *F* values ~ 1 or less).

Table 5-38 Results (F Values) of Repeated-Measures Regressions Comparing Richness Among EEM Years (2001 to 2012)

Effect	Test				
	Among Stations	Within Stations	Before vs After FE Drilling (2001 vs 2002 to 2012)	Linear Trend 2002 to 2012	Quadratic Trend 2002 to 2012
FEZ *d*	<0.1				
FE *d*	0.1				
Error 1 (Carry-over)	18.5***				
Year		1.1	<0.1	4.2*	0.1
Year x FEZ *d*		0.7	<0.1	0.6	1.8
Year x FE *d*		0.4	1.0	0.4	0.3

Notes: - **p* ≤ 0.05; ***p* ≤ 0.01; ****p* ≤ 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 transformed to ranks.

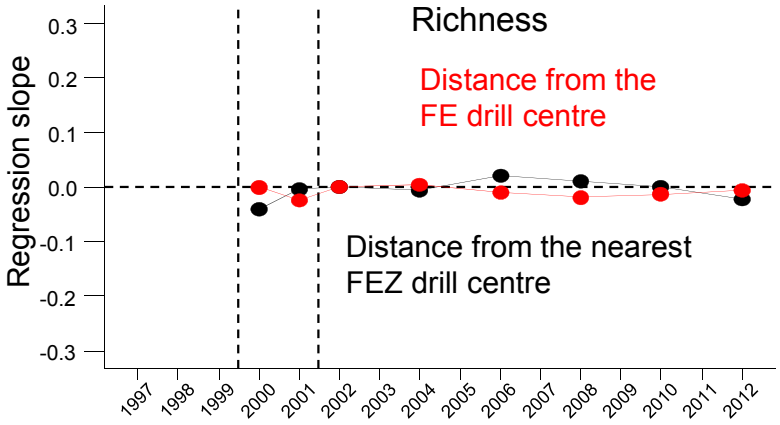


Figure 5-56 Annual Multiple Regression Distance Slopes for Richness (2000 to 2012)

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 0.6 and 1.7 in 2012, 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. The relationship between adjusted richness and Min *d* was weak and non-significant in 2012 (Figure 5-58). Distance gradients were stronger, positive and significant in 2004, 2006 and 2008, indicating greater richness with distance from drill centres in those years (Figure 5-59), compared to earlier or later periods. Multiple regression of adjusted richness on FE and FEZ distances for 2012 was not significant (Table 5-39).

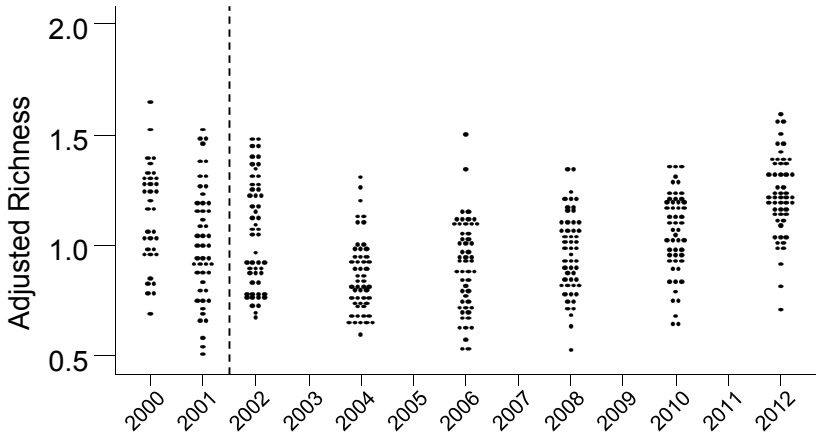


Figure 5-57 Annual Distributions for Adjusted Richness (2000 to 2012)

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

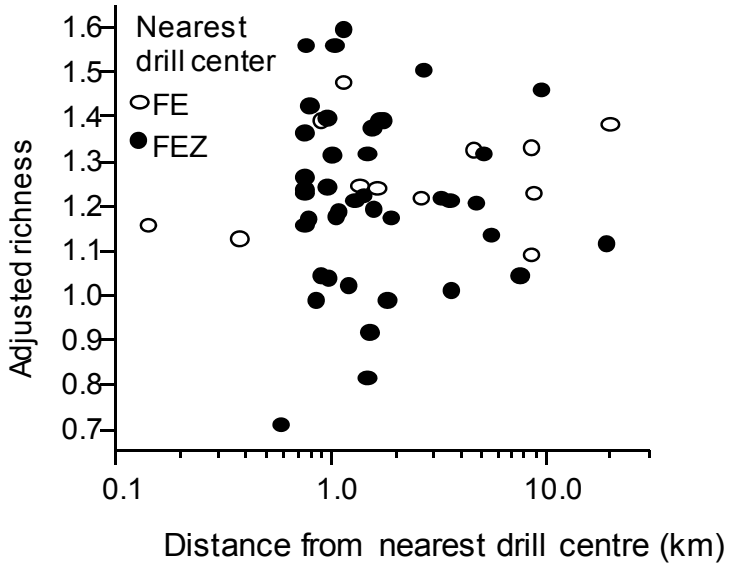


Figure 5-58 Distance Gradient for Adjusted Richness (2012)

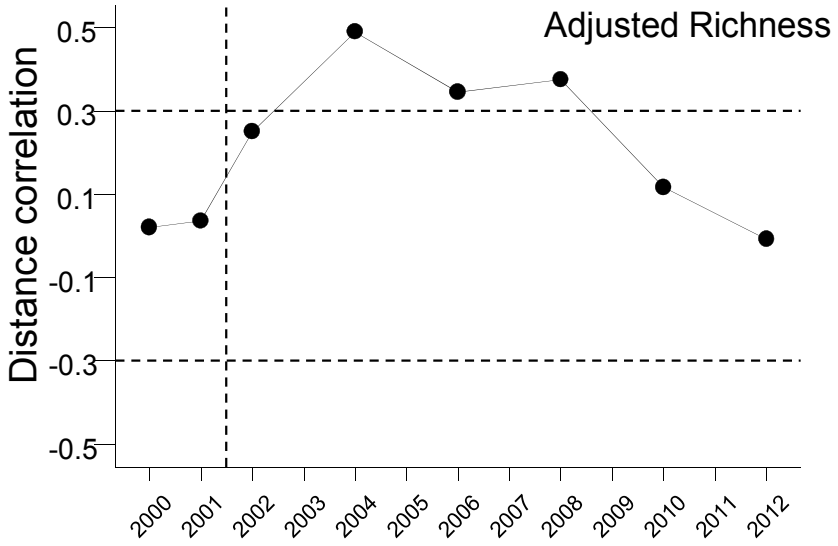


Figure 5-59 Annual Distance Correlations (r_s) for Adjusted Richness (2000 to 2012)

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

Table 5-39 Results of Rank-Rank Regression of Adjusted Richness on Distance Variables (2012)

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	0.13	0.07	-0.14	-0.01

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

Carry-over effects for adjusted richness were highly significant ($F = 6.1$, $p << 0.001$; Table 5-40). The overall FEZ distance gradient for adjusted richness values were significant ($F = 7.2$), with distance slopes varying among years ($F = 3.1$), including linearly and in a quadratic fashion from 2002 to 2012 (F values > 5 in both cases). Distance gradients were strongest (positive) in the period from 2004 to 2010, and weaker in 2001, 2002 and 2012 (Figure 5-60). FE distance gradients were not significant, and did not vary temporally (all F values ~ 1).

Table 5-40 Results (F Values) of Repeated-Measures Regressions Comparing Adjusted Richness Among EEM Years (2001 to 2012)

Effect	Test				
	Among Stations	Within Stations	Before vs After FE Drilling (2001 vs 2002 to 2012)	Linear Trend 2002 to 2012	Quadratic Trend 2002 to 2012
FEZ *d*	7.2*				
FE *d*	1.1				
Error 1 (Carry-over)	6.1***				
Year		3.2**	3.8	6.2*	5.3*
Year x FEZ *d*		3.1**	5.5*	5.2*	6.1*
Year x FE *d*		0.6	<0.1	1.4	1.4

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

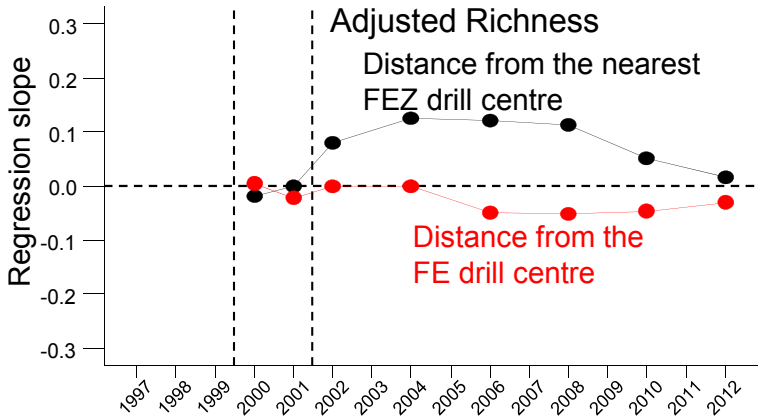


Figure 5-60 Annual Multiple Regression Distance Slopes for Adjusted Richness (2000 to 2012)

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

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 0.17. Stress values can range from 0 (perfect fit) to 1 (no fit). A stress coefficient of 0.17 indicates a reasonable two-dimensional fit to the pair-wise Bray-Curtis distances among the 402 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.

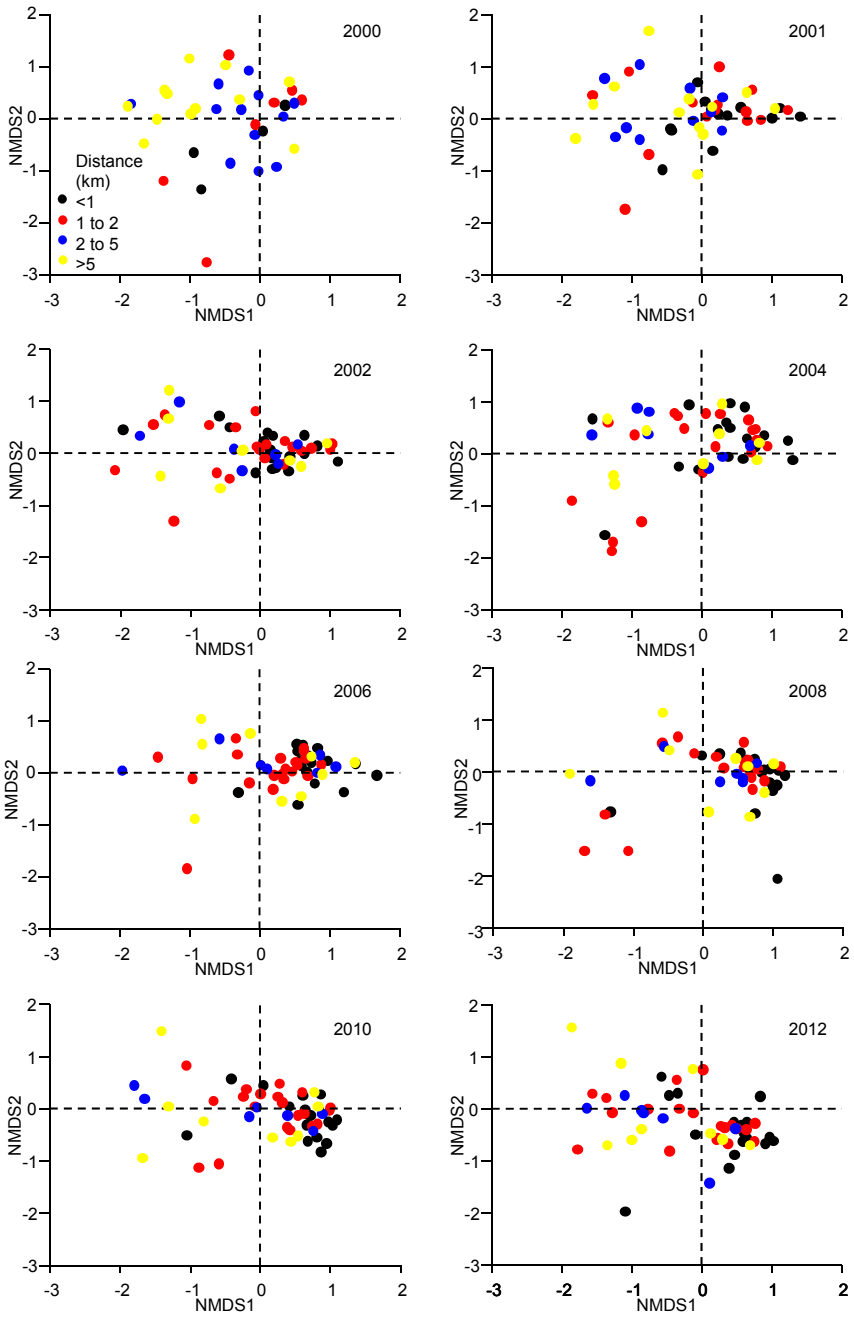


Figure 5-61 Non-Metric Multidimensional Scaling Plots Based on Relative Abundances of Invertebrate Taxa (2000 to 2012)

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 2012).

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 (Figure 5-62 (i.e., r_s with both NMDS axes approximately 0)).

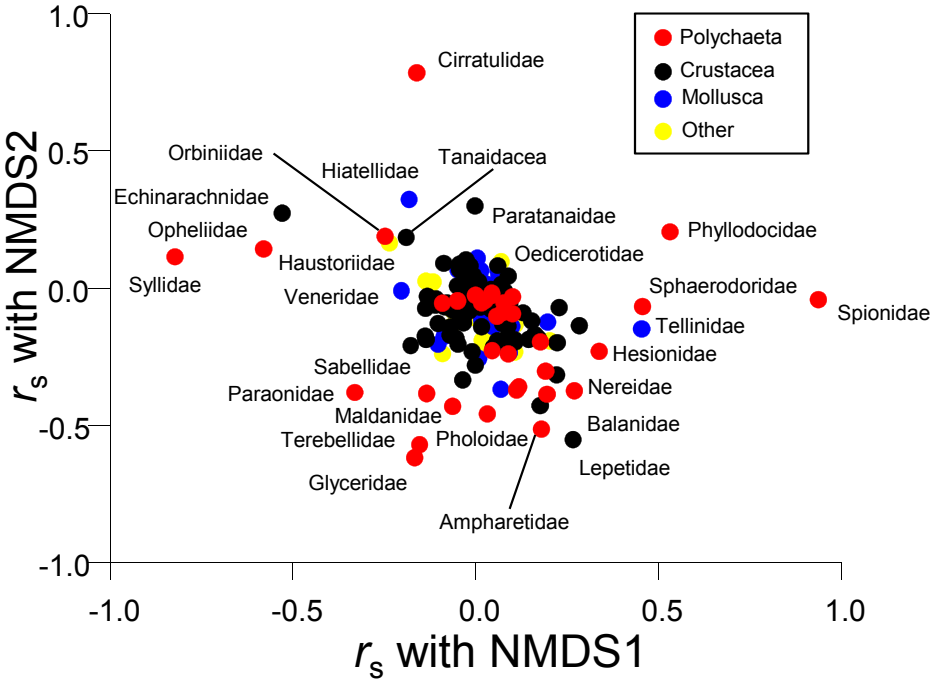


Figure 5-62 Spearman Rank Correlations (r_s) Between Family Relative (%) Abundances and Non-Metric Multidimensional Scaling Axes (2000 to 2012)

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 with NMDS1 scores, but that family accounted for a minor fraction of the total numbers in 2012 (approximately 0.4%).

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 were produced by communities that had higher abundance (r_s = 0.77) and a greater richness of fauna (r_s = 0.64). Larger negative NMDS2 scores were produced by communities with higher abundance (r_s = -0.42) and greater richness of fauna (r_s = -0.48).

Table 5-41 Spearman Rank Correlations (r_s) Between Benthic Invertebrate Community Summary Measures and NMDS Axis Scores (2012)

Summary Measure	NMDS1	NMDS2
Abundance	0.77***	-0.42**
Biomass	0.23	-0.16
Richness	0.64***	-0.48***
Adjusted Richness	-0.10	-0.19

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 2012 (Figure 5-63), reflecting higher abundances of Spionidae, Phyllodocidae and Tellinidae, and lower abundances of Orbiniidae and Paraonidae nearer drill centres. Variations in abundances of major taxa, in relation to Min *d* in 2012, are illustrated in Figure 5-64, showing that stations nearer drill centres tended to have higher abundances of Spionidae, Phylodocidae and Tellinidae, and lower numbers of Orbiniidae and Paraonidae. Numbers of Spionidae, Phyllodocidae and Tellinidae have typically varied negatively with Min *d* across all sampling years, while numbers of Orbiniidae and Paraonidae have varied more positively with Min *d* across all sampling years (Figure 5-65).

NMDS1 scores were also 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).

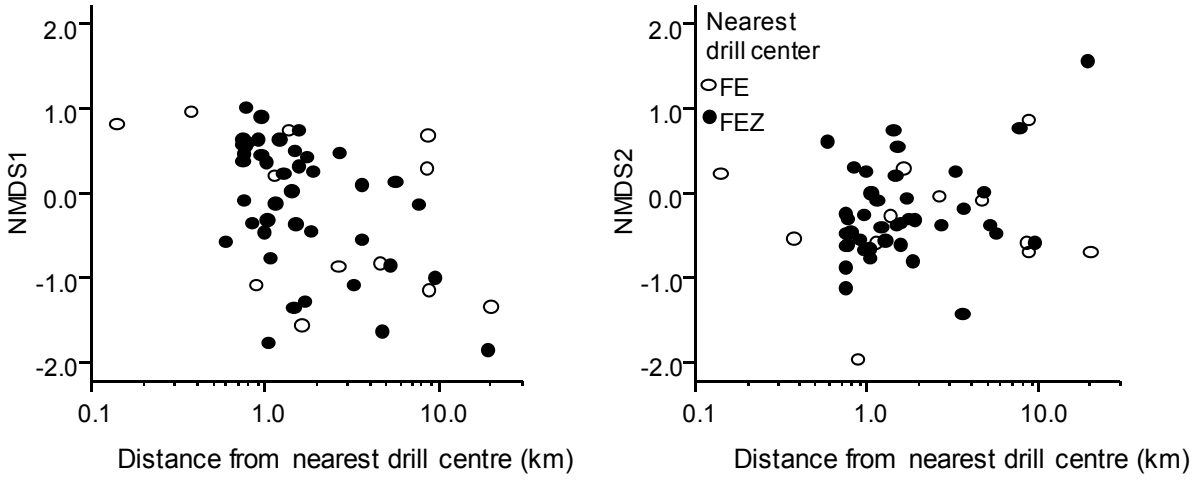


Figure 5-63 Distance Gradient for NMDS 1 and 2 (2012)

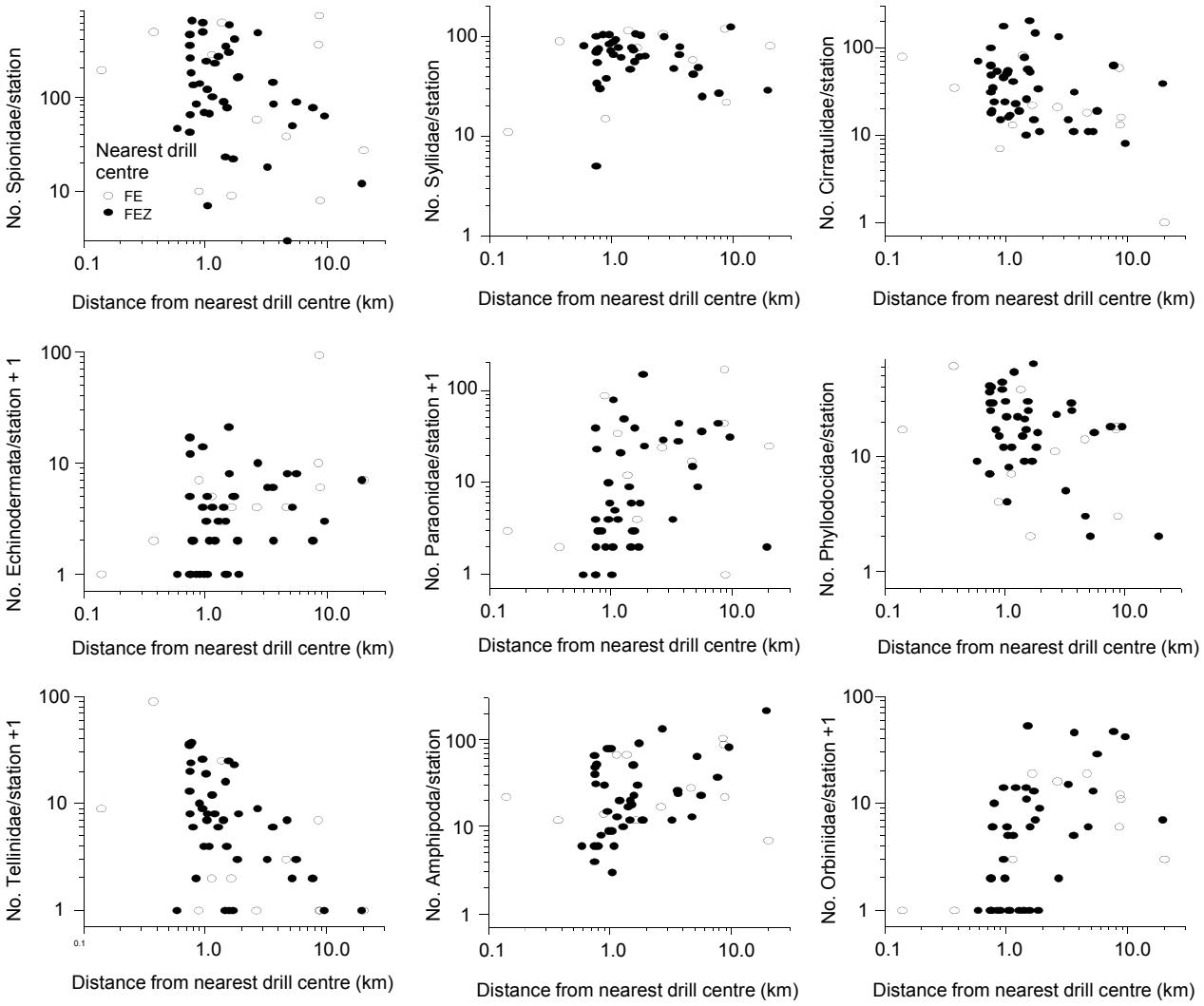


Figure 5-64 Distance Gradient for Major and Numerically Dominant Benthic Taxa (2012)

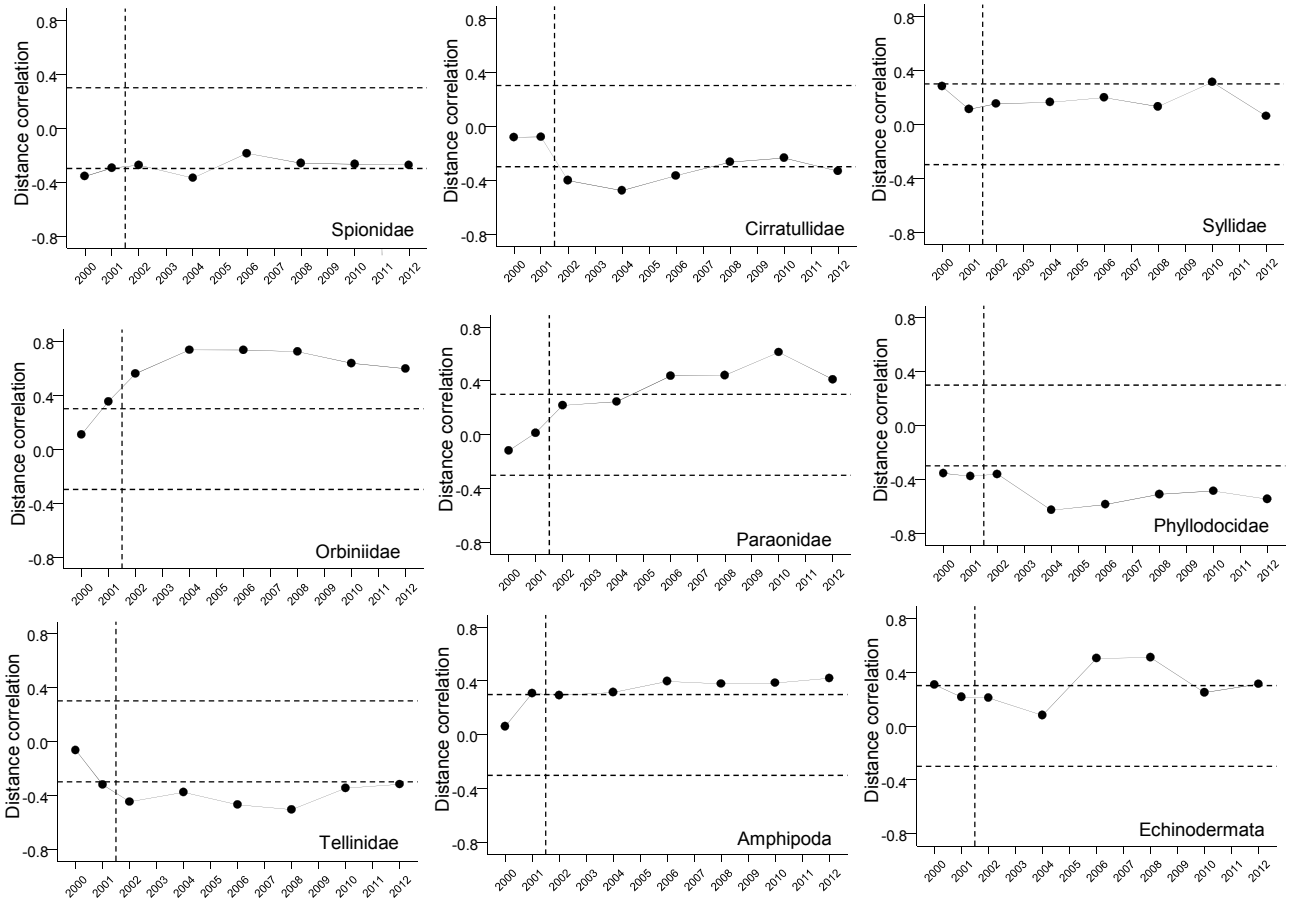


Figure 5-65 Annual Distance Correlations (r_s) for Major and Numerically Dominant Benthic Taxa (2000 to 2012)

As in previous years, threshold relationships were not apparent for NMDS1, but effects on the most affected taxa were apparent within 1 to 2 km of drill centres (Figure 5-64).

NMDS2 scores were uncorrelated with any distance measure in 2012 (Table 5-42). Distance to the FEZ drill centres was a stronger predictor of NMDS1 in 2012 than distance from the FE drill centre (Table 5-42), indicating greater influence from the FEZ drill centres than from the FE drill centre.

Table 5-42 Results of Rank-Rank Regression of NMDS 1 and 2 on Distance Variables (2012)

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	0.43**	-0.39**	-0.05	**-0.48*** **
NMDS2	0.20	0.12	-0.03	0.14

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

Across years, NMDS1 score correlations with Min *d* have generally been negative since 2000 and correlations have increased in strength since 2004 (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).

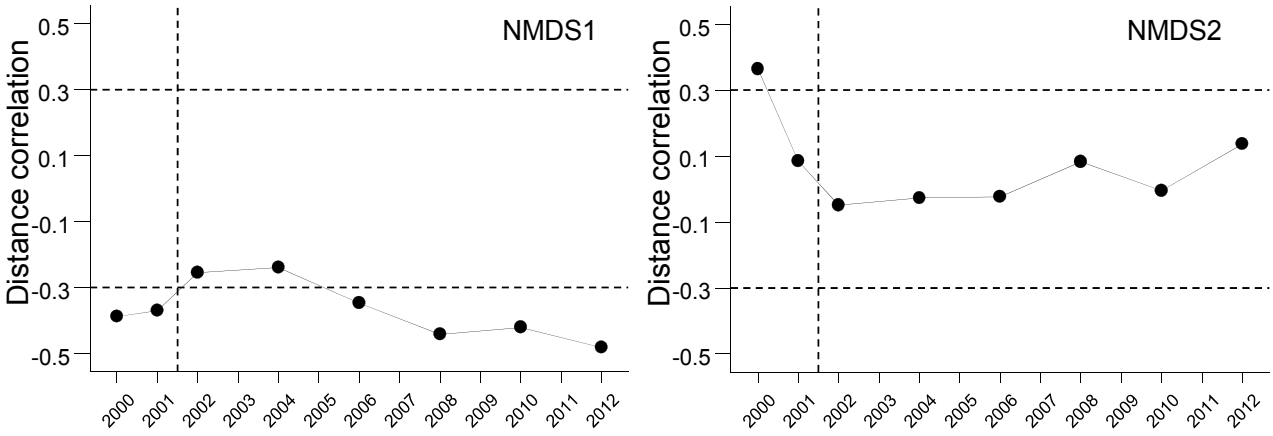


Figure 5-66 Annual Distance Correlations (r_s) for NMDS 1 and 2 (2000 to 2012)

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

Carry-over effects were highly significant for both NMDS1 and NMDS2 (Table 5-43). The overall FEZ distance gradient for NMDS1 scores (decreases with distance from FEZ drill centres) was significant ($F = 15.3$; Table 5-45), but gradients from the FEZ drill centres in repeated-measures regression did not significantly vary over time (i.e., distance regression slopes were approximately -0.2 through the data record) (Figure 5-67). The overall FE distance gradient for NMDS1 scores (increases with distance from the FE drill centre) was also significant ($F = 4.2$), with distance gradients becoming weaker over time since 2004 (i.e., regression slopes decreased in value from 2004 to present; Figure 5-67, $F = 4.4$ for the linear term), and potentially accounting for the strengthening relationship between NMDS1 and the overall distance measure: Min *d*.

Overall FE and FEZ distance gradients for NMDS2 scores were not significant. There was a weak quadratic effect ($F = 9.6$) for FEZ distance gradients, reflecting that they became negative in 2004 and 2006 and have trended towards more positive slopes in 2012 (Figure 5-67).

Table 5-43 Results (F Values) of Repeated-Measures Regressions Comparing NMDS 1 and 2 Among EEM Years (2001 to 2012)

Effect	Test				
	Among Stations	**Within Stations**	**Before vs After FE Drilling (2001 vs 2002 to 2012)**	**Linear Trend 2002 to 2012**	**Quadratic Trend 2002 to 2012**
NMDS 1					
FEZ *d*	15.3***				
FE *d*	4.2*				
Error 1 (Carry-over)	11.2***				
Year		3.4**	4.7*	5.0*	3.7
Year x FEZ *d*		0.2	<0.1	<0.1	<0.1
Year x FE *d*		2.1	2.8	4.4*	<0.1
NMDS 2					
FEZ *d*	<0.1				
FE *d*	0.8				
Error 1 (Carry-over)	12.3***				
Year		2.8*	0.3	6.9*	0.5
Year x FEZ *d*		2.5*	2.7	2.3	9.6**
Year x FE *d*		0.5	0.1	0.2	3.2

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

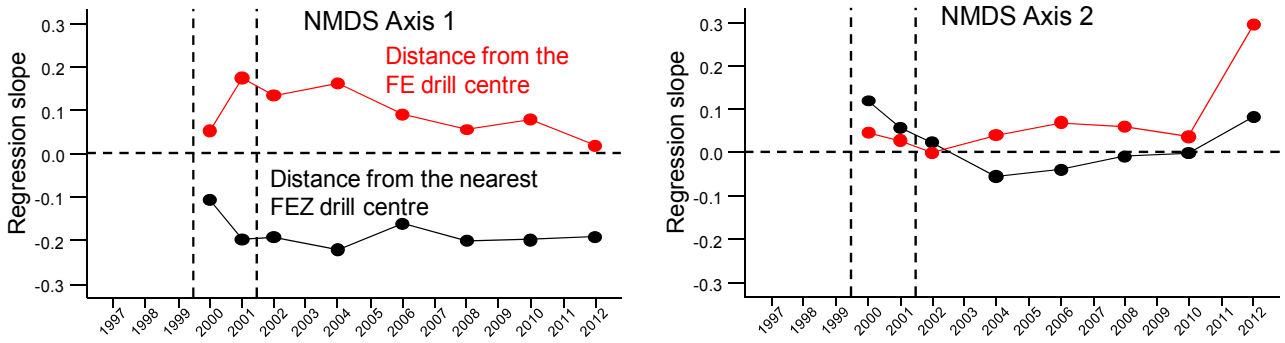


Figure 5-67 Annual Multiple Regression Distance Slopes for NMDS 1 and 2 (2000 to 2012)

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 total organic carbon were selected because they collectively described the physical configuration and organic content of the sediments, factors that fundamentally influence benthic community composition.
- Microtox IC50 was selected because it indicated both toxic and non-toxic sediments, whereas laboratory amphipod survival did not (only one sample was toxic to laboratory amphipods in 2012).
- 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, barium, $>C_{10}$-C_{21} hydrocarbons, total organic carbon, fines, gravel). The PCA was carried using all the data from 2000 to 2012 (i.e., 348 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 2012)

Variable	Correlation with Principal Component Axis		
	1	2	3
Min *d*	**-0.61**	-0.51	0.24
Abundance	**0.68**	-0.25	0.44
Biomass	-0.06	-0.05	**0.70**
Richness	0.51	**-0.77**	0.19
Adjusted Richness	**0.67**	0.26	0.53
NMDS1	-0.33	0.51	0.37
NMDS2	0.03	**-0.80**	-0.19
Microtox	-0.39	0.36	0.22
Barium	**0.72**	0.36	-0.29
$>C_{10}$-C_{21} Hydrocarbons	**0.68**	0.54	-0.14
Metals PC1	0.59	0.08	-0.10
Total Organic Carbon	**0.77**	0.03	0.31
Fines	**0.62**	0.01	-0.30
Gravel	0.57	-0.55	-0.07
Variance Explained	31.7	19.5	11.3

Note: - $|r_p| \geq 0.6$ in **bold.**

The first PCA axis scores were strongly negatively correlated with Min *d*, and strongly positively correlated with total abundance, taxa richness (adjusted), barium concentrations, $>C_{10}$-C_{21} hydrocarbon concentrations, total organic carbon content and percent fines.

The second PCA axis scores were strongly correlated with richness and NMDS2 scores. No other biological, physical, or chemical variables were strongly correlated ($r_p \geq |0.6|$) with the second axis.

The third PCA axis scores were strongly correlated with biomass. No other biological, physical, or chemical variables were strongly correlated with the third axis.

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. Microtox IC50 was retained because it was the only sediment toxicity test that produced variation in toxicity. Microtox did not correlate strongly with any of the PCA axes, indicating that it was either relatively invariant and/or did not covary with

other measures. Inclusion of Microtox in the next step is done to ensure that significant associations with benthic community measures, if they are present, are not missed. Percent of the sediment as gravel and fines are somewhat redundant with total organic carbon. Therefore, gravel and fines were excluded and total organic carbon was retained. Min *d* was excluded from this second step because it cannot be a causal variable, and because it is redundant with barium and $>C_{10}$-C_{21} hydrocarbons. Metals PC1 was not included because the PCA did not indicate a strong association with any benthic measure.

Total benthic abundances and taxa richness were significantly negatively correlated with Microtox, and significantly positively correlated with barium and total organic carbon (Figures 5-68 and 5-69). The positive relationships for abundance and richness with barium are unlikely, and may therefore have been driven by a common relationship with substrate texture, or total organic carbon. It is also unlikely that the negative relationship between total numbers (and richness) and Microtox reflects a causative relationship; greater toxicity should correspond with fewer organisms and fewer kinds of organisms, not greater numbers and greater diversity.

Biomass was not significantly correlated with selected measures of sediment quality or texture in 2012, nor in most other years (Figure 5-70). Biomass decreased significantly in relation to barium concentration in 2004 and the relationship was generally negative (though weak and not significant) in other years. Biomass did not covary significantly with concentrations of $>C_{10}$-C_{21} hydrocarbons (Figure 5-70). Therefore, the evidence for an influence of drilling muds on biomass is weak.

Adjusted richness has decreased significantly with $>C_{10}$-C_{21} hydrocarbon concentrations from 2004 to 2008, but relationships were not significant in most years (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 1000 mg/kg and 500 mg/kg, respectively. However, there were very few observations where sediments contained these high concentrations (generally only station 30(FE) sampled repeatedly over time).

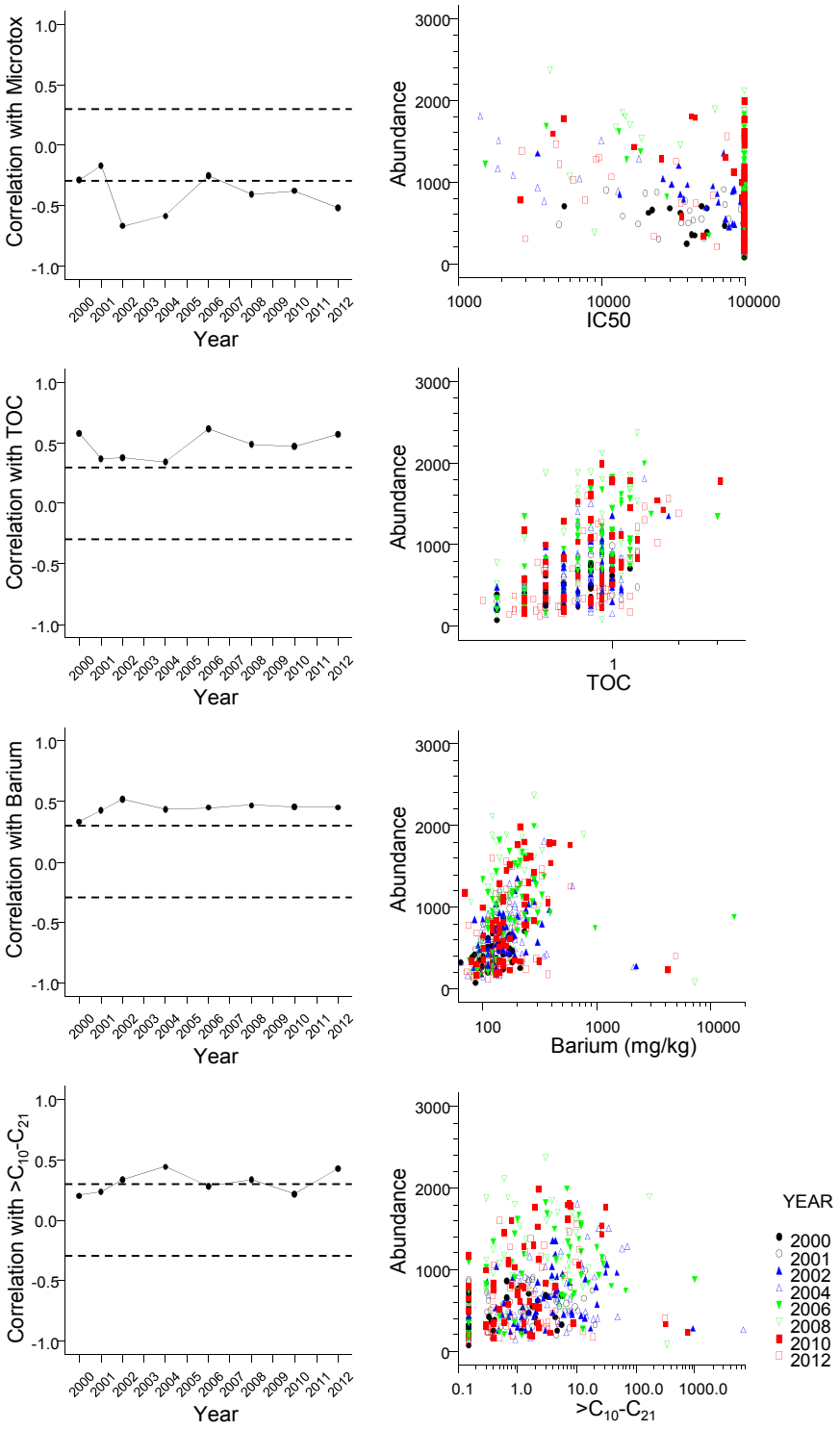


Figure 5-68 Correlations (r_s) Over Time and Scatterplots of Total Abundance in Relation to Microtox, Total Organic Carbon, Barium and $>C_{10}$-C_{21} Hydrocarbons

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

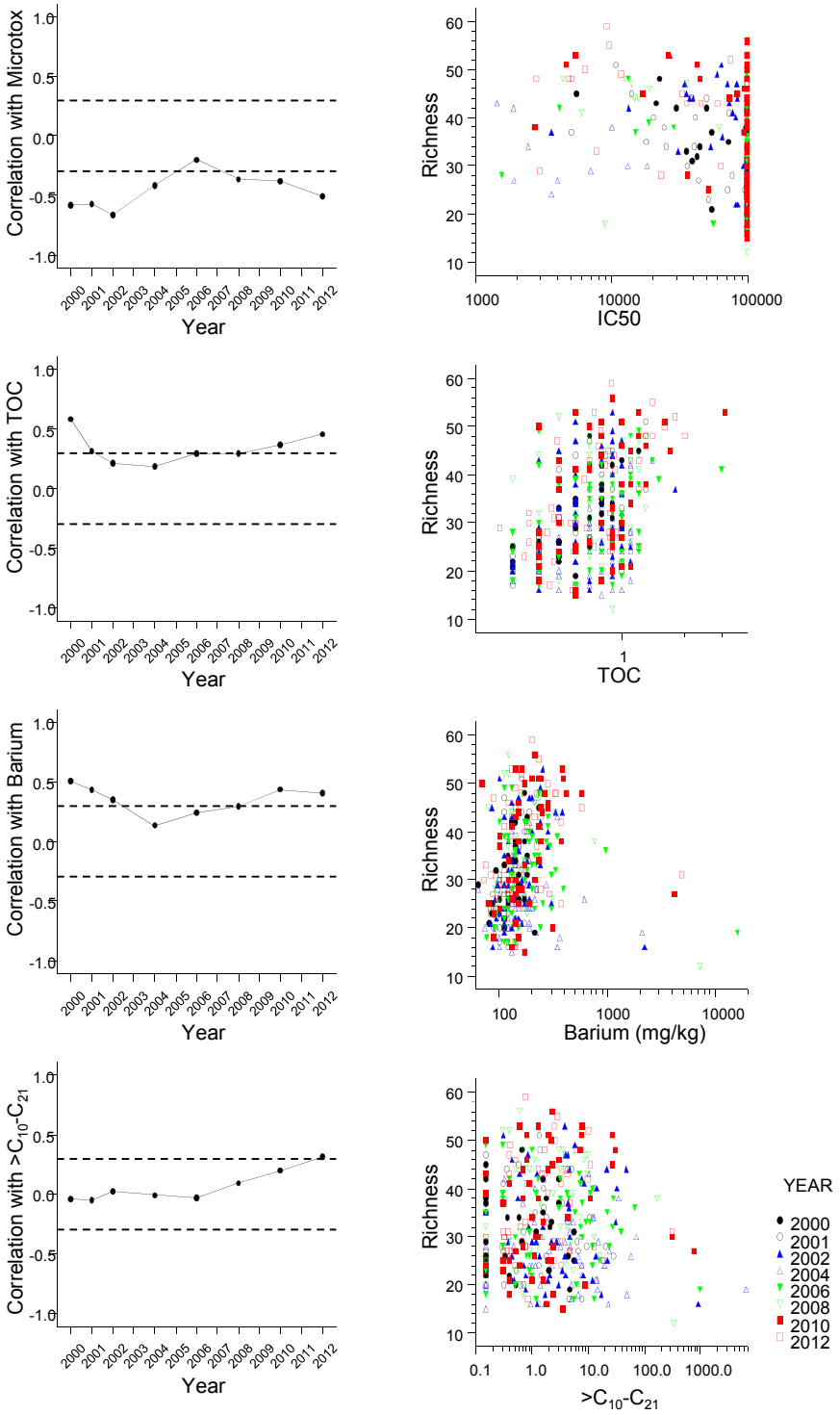


Figure 5-69 Correlations (r_s) Over Time and Scatterplots of Richness in Relation to Microtox, Total Organic Carbon, Barium and >C_{10}-C_{21} Hydrocarbons

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

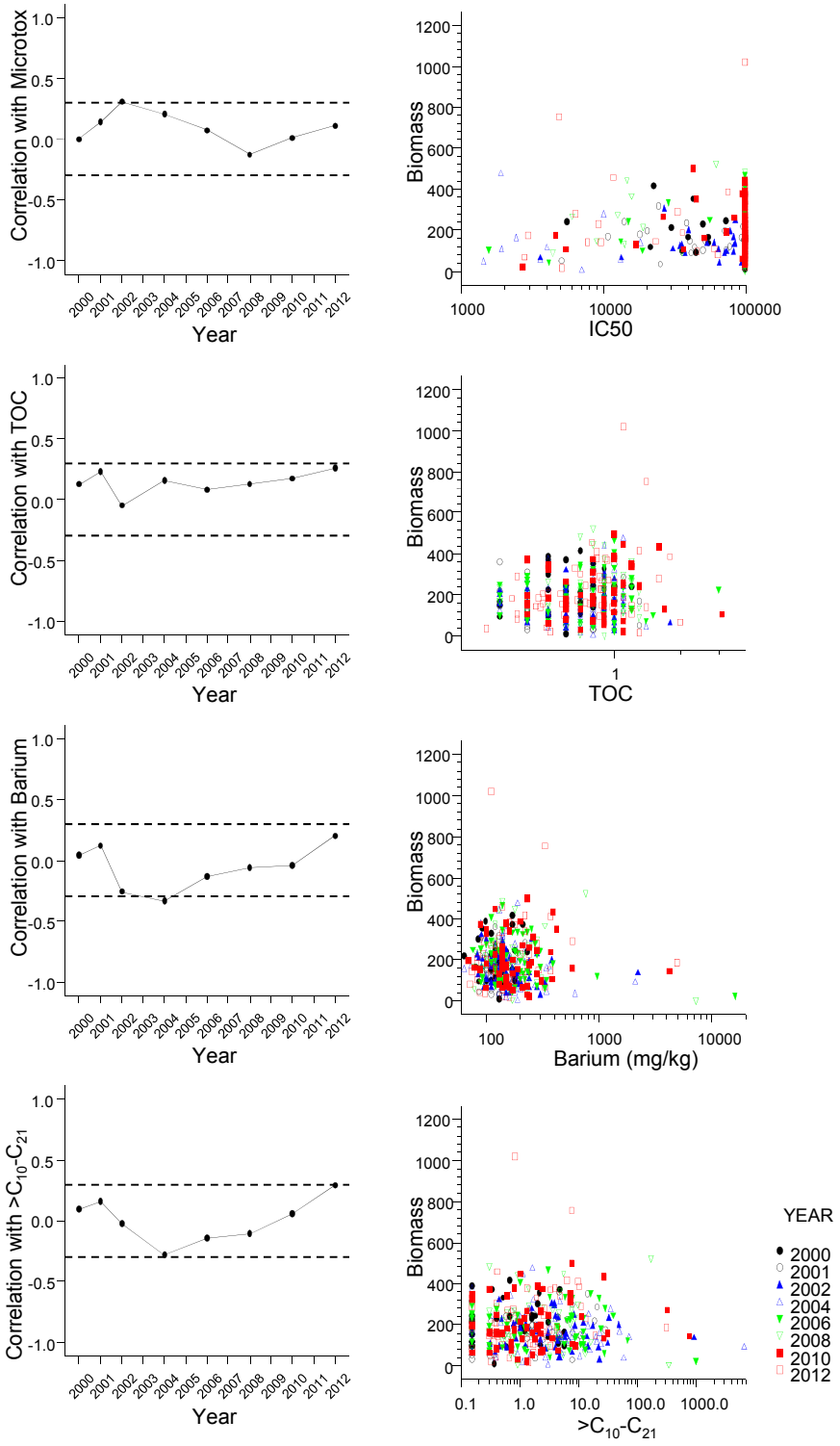


Figure 5-70 Correlations (r_s) Over Time and Scatterplots of Biomass in Relation to Microtox, Total Organic Carbon, Barium and >C_{10}-C_{21} Hydrocarbons

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

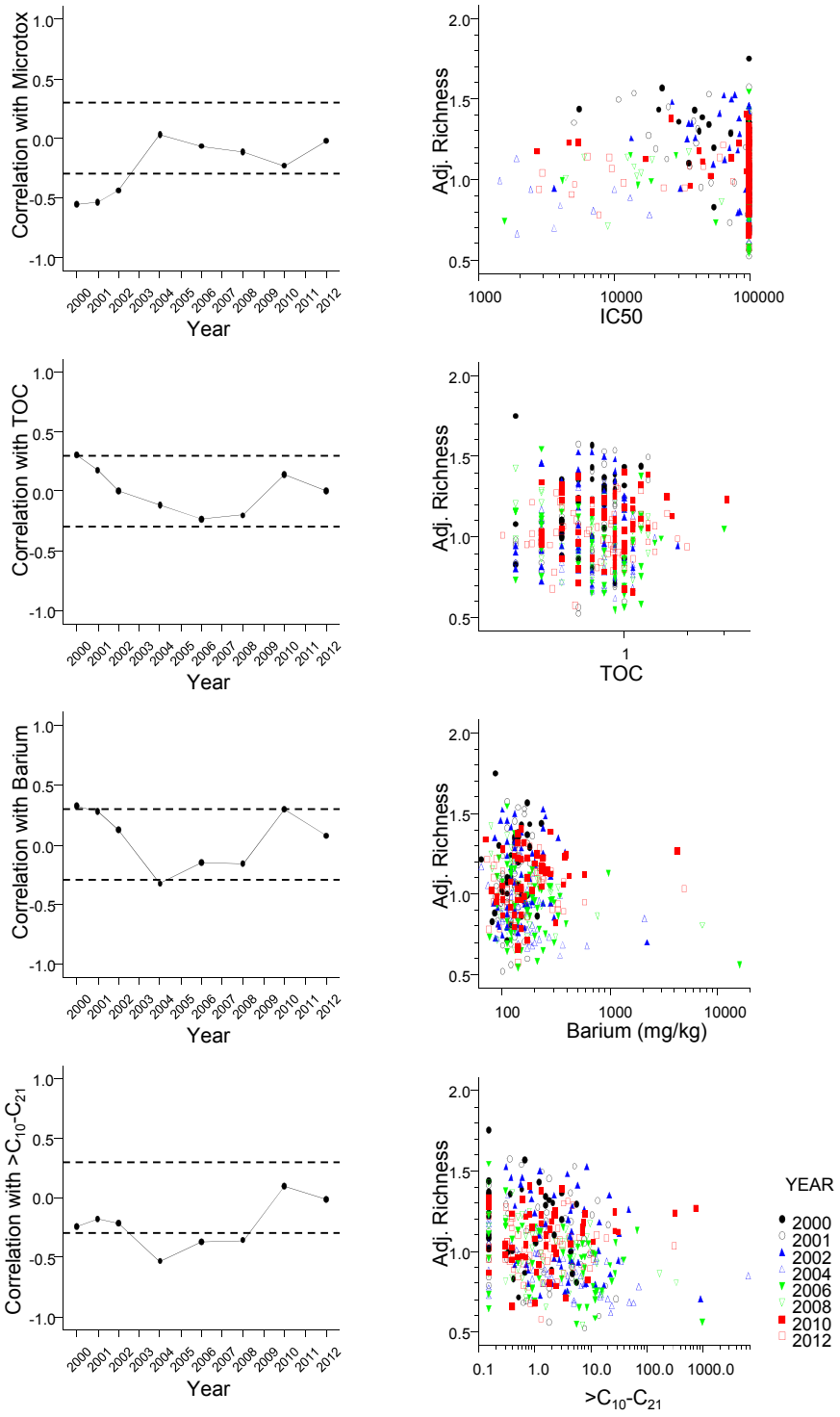


Figure 5-71 Correlations (r_s) Over Time and Scatterplots of Adjusted Richness in Relation to Microtox, Total Organic Carbon, Barium and >C_{10}-C_{21} Hydrocarbons

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

NMDS1 scores were significantly positively associated with total organic carbon, barium and >C_{10}-C_{21} hydrocarbon concentrations across all years (Figure 5-72). The relationship between NMDS1 scores total organic carbon, 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 total organic carbon 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[20].

NMDS2 scores were not significantly correlated with Microtox, total organic carbon, barium of >C_{10}-C_{21} hydrocarbons in 2012, and in most other years (Figure 5-73).

[20] Baseline data are unavailable for NMDS1.

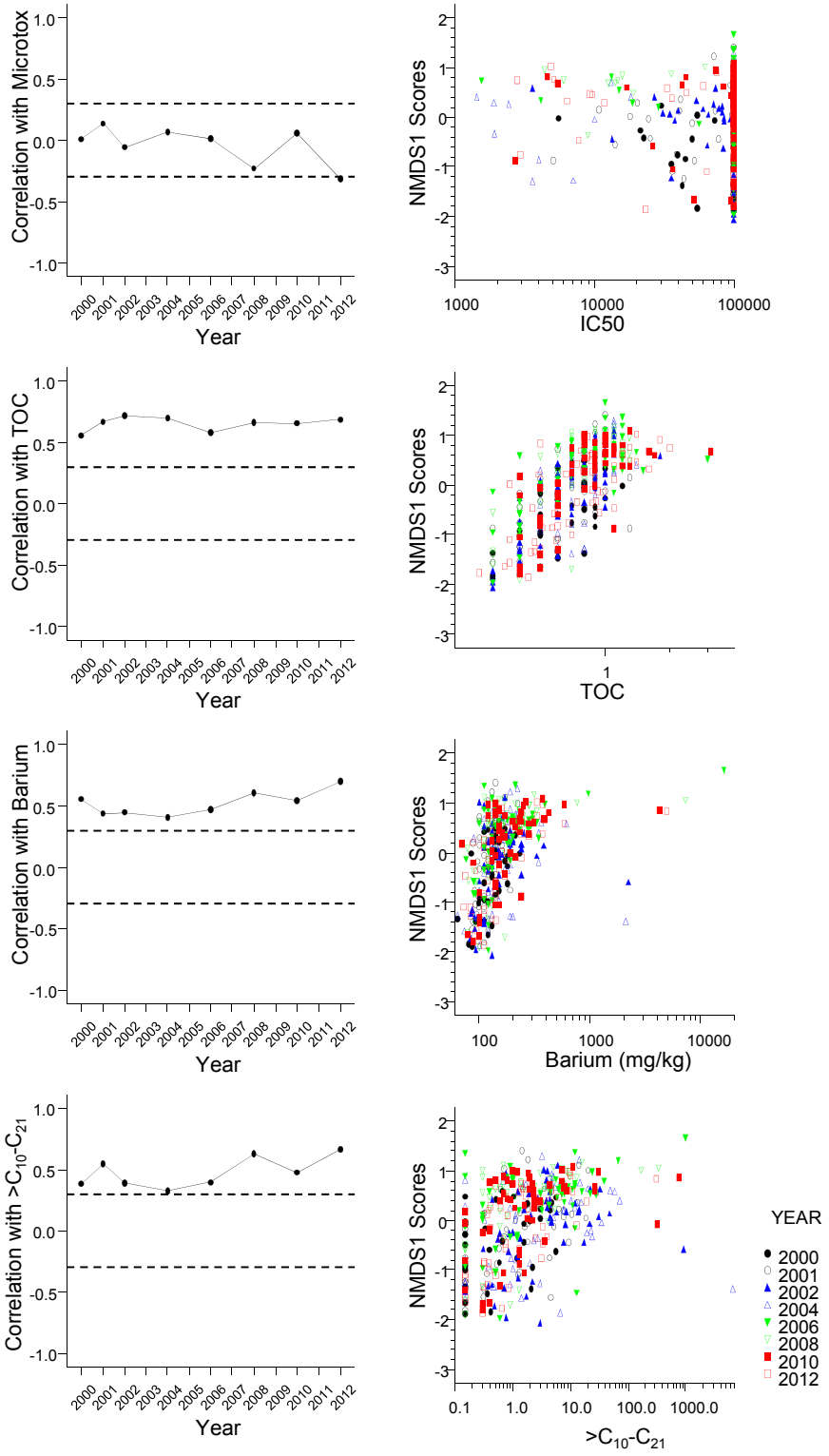


Figure 5-72 Correlations (r_s) Over Time and Scatterplots of NMDS1 Scores in Relation to Microtox, Total Organic Carbon, Barium and $>C_{10}$-C_{21} Hydrocarbons

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

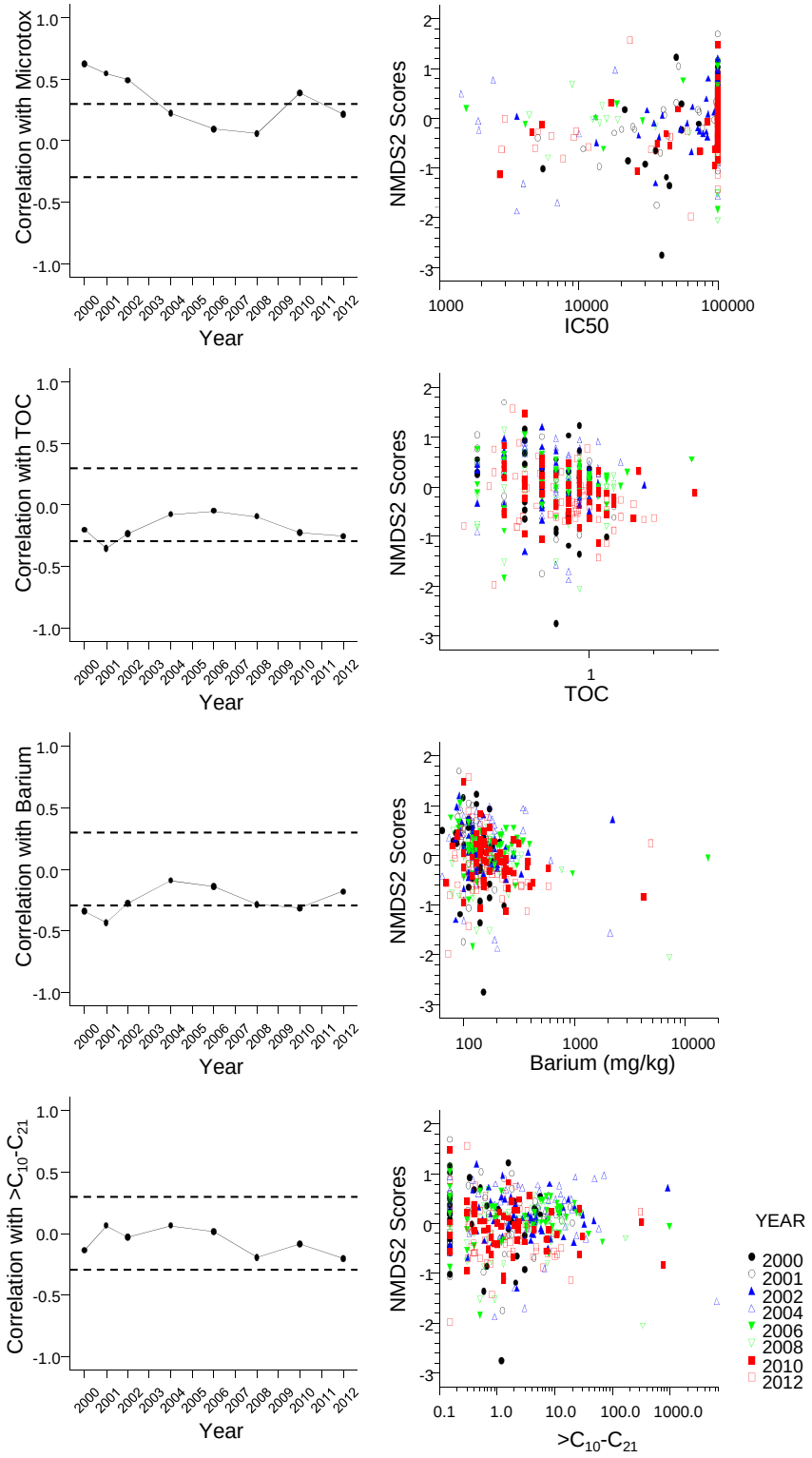


Figure 5-73 Correlations (r_s) Over Time and Scatterplots of NMDS2 Scores in Relation to Microtox, Total Organic Carbon, Barium and $>C_{10}$-C_{21} Hydrocarbons

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

5.4 SUMMARY OF FINDINGS

5.4.1 PHYSICAL AND CHEMICAL CHARACTERISTICS

In 2012, as in previous years, $>C_{10}$-C_{21} hydrocarbons and barium concentrations decreased significantly with distance from drill centres. In 2012, concentrations of $>C_{10}$-C_{21} hydrocarbons decreased to levels near laboratory detection limit (0.3 mg/kg) approximately 2.5 km from drill centres. Concentrations of barium decreased to background levels within approximately 1 km of drill centres. Estimated distances at which low concentrations were reached (i.e., threshold distances) for $>C_{10}$-C_{21} hydrocarbons have decreased from 4 to 5 km in 2004 and 2006 to approximately 2 to 3 km from 2008 to 2012. The estimated threshold distance for barium was shorter than it was in 2010, when it was 2 km, but it was similar to what was observed from 2004 to 2008. No threshold distances could be estimated for $>C_{10}$-C_{21} hydrocarbons prior to 2004; and no threshold distances could be estimated for barium prior to 2002, because the threshold relationships were not significant.

$>C_{10}$-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 and 1.30 mg/kg in 2010 and 2012. 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 2012, the maximum $>C_{10}$-C_{21} hydrocarbon concentrations (310 mg/kg) also occurred at station 30(FE).

Median barium concentrations increased from 120 mg/kg in baseline (1997) to concentrations ranging from 130 to 170 mg/kg from 2000 to 2012. Median concentrations in EEM years have been below the 95th percentile concentration (200 mg/kg) noted in baseline. Over all EEM years, the highest barium concentration (16,000 mg/kg) was noted in 2006 at station 30(FE), located 0.14 km from the FE drill centre. Barium concentration was also highest (4,900 mg/kg) at station 30(FE) in 2012.

In 2012, sulphur concentrations decreased significantly with distance from the FEZ drill centres, but did not decrease significantly with distance from the FE drill centre. The FEZ distance gradient for sulphur largely depended on some high concentrations (0.03 to 0.05%) at stations within 1 to 2 km of the FEZ drill centres.

Sulphur concentrations also decreased significantly with distance from drill centres in 2001, 2002, 2004, 2006 and 2010, with little change in the strength of distance relationships over time. In 2012, the highest sulphur concentration (0.17%) occurred at station 30(FE), and this was the only concentration exceeding 0.1%. Concentrations at most other stations near the FE drill centre were relatively low. The highest sulphur level over all EEM years was 0.31% and was noted at station 30(FE) in 2006. Median levels were highest in 2008 and 2010 (0.05 and 0.04%, respectively). Median levels in 2012 were below the laboratory detection limit of 0.03%.

Fines content in 2012 ranged from 0.4 to 2.2% (median = 1.0%). Fines content during baseline (1997) ranged from 0.7 to 3.4% (median = 1.0%). The highest fines content in 2012 occurred at station 30(FE). 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 sample year, including baseline (1997), and correlations with distance were significant in 2000, 2001, 2004, 2006 and 2010. Distance correlations were not significant for fines in 2012.

Other sediment physical and chemical variables were largely unaffected by project activities. Evidence for effects ranged from none to equivocal, with elevated levels observed at only a few stations near drill centres and/or in a few years.

5.4.2 TOXICITY

There has been little evidence for project effects on laboratory amphipods in EEM years and more than 98% of samples have been non-toxic. In 2012, only one sample was toxic to laboratory amphipods. Sediments for that sample were from station 52(FEZ), located 1.57 km from the SE drill centre. Amphipod survival in 2012 was uncorrelated with distance from drill centres and with most sediment physical and chemical characteristics. Survival of laboratory amphipods increased with $>C_{10}$-C_{21} hydrocarbons; a result that does not imply a negative effect of hydrocarbons on survival.

Microtox IC50s from laboratory toxicity tests were unrelated to distance from drill centres and to $>C_{10}$-C_{21} hydrocarbon concentrations in 2012, like most other EEM years. Negative Microtox responses were correlated with barium concentration but, as in previous years, these correlations were weaker than correlations with other variables (e.g., strontium concentrations). Negative effects on Microtox were observed at four stations in 1997 versus 10 to 20 stations in EEM years. Sediments from 13 stations were toxic in 2012.

5.4.3 BENTHIC COMMUNITY STRUCTURE

Total abundance, biomass, richness, adjusted richness and NMDS2 scores were uncorrelated with distances to the nearest drill centre in 2012, as in most previous years. There was an overall decrease in abundance with distance from the FEZ drill centres from 2001[21] to 2012, but that gradient did not change over time. There were changes in the FE distance gradient for biomass, but those changes did not coincide with the onset of drilling at that drill centre. The distant gradient from the FEZ drill centres was relatively weak but increased in strength from 2004 to 2012, reflecting higher biomass near FEZ drill centres.

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 were also correlated with NMDS1 scores.

NMDS1 scores were strongly negatively associated with distance to the nearest drill centre in 2012, reflecting higher abundances of Spionidae, Phyllodocidae and Tellinidae, and lower abundances of Orbiniidae and Paraonidae nearer drill centres. NMDS1 scores were also relatively high at stations 30(FE) and 31(FE), the two stations nearest a drill centre[22]. None of the other indices were visibly affected at stations 30(FE) and 31(FE) in 2012.

Across years, NMDS1 scores have generally been negatively correlated with distance to the nearest drill centre, with correlations stronger since 2004. 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 1 to 2 km of drill centres.

[21] 1997 data are unavailable for benthic community indices and 2001 data were excluded from repeated-measures regression because many samples were sieved using the Wash method.

[22] High scores reflect relatively high abundances of Spionidae, Phyllodocidae and Tellinidae and lower abundance of spionids, phyllodocids and tellinids, lower abundances of Orbinidae and Paraonidae.

5.4.3.1 Integrated Assessment

Correlations between most indices of benthic community structure and >C_{10}-C_{21} hydrocarbon and barium concentrations, as measures of drilling discharge, total organic carbon content, as a measure of sediment texture, and Microtox toxicity were weak or absent, not consistent across years, or did not indicate a project effect. Scatter plots of data for all years indicated potential negative effects for some indices at barium concentrations in excess of approximately 1,000 mg/kg and >C_{10}-C_{21} concentrations in excess of approximately 500 mg/kg. However, these high concentrations have only ever occurred at one station (station 30(FE), located 0.14 km from the FE drill centre).

Conversely, NMDS1 scores were significantly positively associated with total organic carbon, barium and >C_{10}-C_{21} hydrocarbon concentrations in all years. The relationship between NMDS1 scores and barium and hydrocarbons reflects higher abundances of Spionidae and Phyllodocidae polychaetes and Tellinidae bivalves, and lower abundances or Orbiniidae and Paraonidae polychaetes and other more minor taxa in sediments with higher concentrations of total organic carbon, barium and hydrocarbons. 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. NMDS1 scores were uncorrelated with Microtox toxicity, supporting the argument that any effects on Microtox were unrelated to project activity.

6.0 WATER COMPONENT

6.1 FIELD COLLECTION

The water sampling component of the 2012 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 2012 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 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	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

Field blanks for PAHs and alkyl PAHs, total petroleum hydrocarbons and metals made up of distilled water were collected at stations W9 (Bottom), W12 (Surface), W13 (Surface) and W16 (Middle). Blank vials were opened as soon as water samples from these locations were brought on board 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 W3 (Surface), W7 (Surface), W12 (Bottom), W18 (Bottom) and W23 (Surface).

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 profiles.

QA/QC protocols were followed for collection of samples to ensure sample integrity and prevent onboard contamination. All instruments and work surfaces were washed with mild soap and water, disinfected with isopropyl alcohol, and then rinsed with distilled water before collections at each station. Sampling personnel were supplied with new latex gloves for each station. Processed samples were transferred to cold storage within one hour of collection.

6.2 LABORATORY ANALYSIS

Organic constituents in water samples were processed by RPC. Remaining constituents were processed by Maxxam Analytics. In accordance with Suncor Energy's revised Water Quality Program (Suncor Energy 2009), seawater samples were processed for additional constituents in 2012. A list of specific constituents

in 2012 and in previous years is provided in Table 6-2. Details on analytical methods in 2012 are provided in Appendix C-2.

Table 6-2 Water Chemistry Analytes (1997 to 2012)

Analytes	Method	Detection Limit								
		1997	2000	2001	2002	2004	2006 & 08	2010	2012	Units
Benzene	P&T GC/MS	NA	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	mg/L
Ethylbenzene	P&T GC/MS	NA	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	mg/L
C_6-C_{10} (Less BTEX)	Calculated	NA	0.25	0.25	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	mg/L
>C_{10}-C_{13}	GC/FID	NA	NA	NA	0.05	NA	NA	NA	NA	mg/L
>C_{13}-C_{21}	GC/FID	NA	NA	NA	0.05	NA	NA	NA	NA	mg/L
>C_{10}-C_{16}	GC/FID	NA	NA	NA	0.05	NA	NA	NA	0.05	mg/L
>C_{16}-C_{21}	GC/FIC	NA	NA	NA	0.05	NA	NA	NA	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	mg/L
C_6-C_{32}	Calculated	NA	0.2	0.2	0.2	0.2	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	mg/L
Vegetable Oil & Grease	IR	1	NA	NA	NA	NA	NA	NA	NA	mg/L
Mineral Oil & Grease	IR	1	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	0.01	µg/L
2-Chloronaphthalene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.05	0.05	0.01	µg/L
1-Methylnaphthalene	GC/FID	0.01	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	µg/L
Acenaphthene	GC/FID	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	µg/L
Anthracene	GC/FID	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	µg/L
Benzo[*a*]pyrene	GC/FID	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	µg/L
Benzo[*b*]fluoranthene	GC/FID	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	µg/L
Benzo[*k*]fluoranthene	GC/FID	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	µg/L
Dibenz[*a,h*]anthracene	GC/FID	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	µg/L
Fluorene	GC/FID	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	µg/L
Naphthalene	GC/FID	0.05	0.2	0.2	0.2	0.2	0.2	0.2	0.05	µg/L
Perylene	GC/FID	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	µg/L
Phenanthrene	GC/FID	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	µg/L
Biphenyl	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.05	µg/L
C1-Naphthalenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	µg/L
C2-Naphthalenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	µg/L
C3-Naphthalenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	µg/L
C1-Phenanthrenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	µg/L
C2-Phenanthrenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	µg/L
C3-Phenanthrenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	µg/L
Dibenzothiophene	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	µg/L

Analytes	Method	Detection Limit								
		1997	2000	2001	2002	2004	2006 & 08	2010	2012	Units
C1-Dibenzothiophenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	µg/L
C2-Dibenzothiophenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	µg/L
C3-Dibenzothiophenes	GC/FID	NA	NA	NA	NA	NA	NA	NA	0.1	µg/L
Aluminum	ICP-MS	NA	NA	NA	NA	NA	NA	NA	10	µg/L
Antimony	ICP-MS	NA	NA	NA	NA	NA	NA	NA	0.5	µg/L
Arsenic	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	µg/L
Barium	ICP-MS	NA	NA	50	NA	NA	NA	NA	1	µg/L
Beryllium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	µg/L
Bismuth	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	µg/L
Boron	ICP-MS	NA	NA	NA	NA	NA	NA	NA	50	µg/L
Cadmium	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.05	µg/L
Calcium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	mg/L
Chromium	ICP-MS	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	µg/L
Copper	ICP-MS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.5	µg/L
Iron	ICP-MS	1	1	1	1	1	1	1	2	µg/L
Lead	ICP-MS	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	µg/L
Magnesium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	mg/L
Manganese	ICP-MS	1	1	1	1	1	1	1	0.5	µg/L
Mercury	CVAAS	0.05	0.05	0.05	0.05	0.05	0.01	0.013	0.013	µg/L
Molybdenum	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	µg/L
Nickel	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.2	µg/L
Phosphorous	ICP-MS	NA	NA	NA	NA	NA	NA	NA	50	µg/L
Potassium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	mg/L
Selenium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	0.5	µg/L
Silicon	ICP-MS	NA	NA	NA	NA	NA	NA	NA	100	µg/L
Silver	ICP-MS	NA	NA	NA	NA	NA	NA	NA	0.05	µg/L
Sodium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1	mg/L
Strontium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	10	µg/L
Sulphur	ICP-MS	NA	NA	NA	NA	NA	NA	NA	20	mg/L
Thallium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	0.10	µg/L
Tin	ICP-MS	NA	NA	NA	NA	NA	NA	NA	1.0	µg/L
Titanium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	10	µg/L
Uranium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	0.05	µg/L
Vanadium	ICP-MS	NA	NA	NA	NA	NA	NA	NA	10	µg/L
Zinc	ICP-MS	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	µg/L
Chlorophyll *a*	Fluorescence	NA	0.1	0.1	0.1	0.1	0.01	0.01	0.0004	µg/L
Total suspended solids	Grav.	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.05	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.

6.3 DATA ANALYSIS

6.3.1 PHYSICAL AND CHEMICAL CHARACTERISTICS FROM NISKIN BOTTLES

Analysis of 2012 physical and chemical characteristics from Niskin bottle samples include quantitative analysis of analytes that were detected in 60% or more of samples and qualitative examination of analytes that occurred in 20% to 59% of samples. Remaining analytes are briefly discussed. The 2012 assessment also includes an examination of extreme high or low values in 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 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, in 2012, 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-2). The SW and SE Reference Areas sampled in previous years were again sampled in 2012.

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.

Seven comparisons were tested on these frequently detected analytes using ANOVA (Analysis Of Variance) with Depth and Area as factors:

- Differences in concentration between the Study Areas and the Reference Areas (SR);
- Differences in concentrations between the Study Areas (BS);
- Differences in concentration between the Reference Areas (BR);
- Differences between stations inside the FEZ and the Reference Areas (IFEZ *vs* R);
- Differences between stations outside the FEZ and the Reference Areas (OFEZ *vs* R);
- Differences in depth gradients, overall (Depth); and
- Differences in depth gradients among Areas (AD).

Analytes with values less than 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, stations outside the FEZ and in the combined Reference Areas were qualitatively compared.

Finally, the concentrations of produced water constituents were compared to concentrations at Reference Area stations to generate an estimate of expected enrichment, or depletion, on release resulting from produced water. Individual stations were then examined for produced water constituents with expected concentrations on release of more than, or less than, 10 X seawater concentrations. The concentration of produced water constituents was obtained from a produced water chemical characterization performed on samples collected on April 6, 2012.

Multi-year comparisons examined changes in median levels of arsenic, iron and total suspended solids across years in the combined Study Areas (as there was just one Study Area in previous years) and the combined Reference Areas. Data from 1997 were excluded from multi-year comparisons because samples were not collected in defined Study and Reference Areas in that year.

6.3.2 PIGMENTS AND TEMPERATURE PROFILES

Temperature and chlorophyll *a* concentration versus depth from the CTD recorder in 2012 were plotted for a visual inspection of the data. Chlorophyll *a* values from the CTD recorder were then grouped into the following depth classes: 5 to 30 m (surface), 31 to 60 m (middle) and 61 to 100 m (bottom) to approximate depths sampled with Niskin Bottles (see Section 6.1). CTD data from the first 5 m of the water column were excluded because erroneous results are common at those shallow depths.

Boxplots of chlorophyll *a* values from Niskin bottles and the CTD recorder were generated, and stations inside the FEZ, outside the FEZ and in the two Reference Areas were compared quantitatively in ANOVA as described in Section 6.3.1. Niskin bottle data were $\log_{10}$ transformed for analysis. Data transformation was not required for CTD data.

Multi-year comparisons examined changes in median temperature and chlorophyll *a* at three sampling depths across years in the combined Study Areas (as there was just one Study Area in previous years) and the combined Reference Areas. Data from 1997 were excluded from multi-year comparisons because data were not

collected in defined Study and Reference Areas, and pigment analysis was not performed on Niskin bottle samples in 1997.

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 2012 are provided in Appendix C-2. Arsenic, barium, boron, chromium, lithium, molybdenum, strontium, uranium, calcium, magnesium, potassium, sodium and sulphur were detected in all samples. Total suspended solids, iron and cadmium were detected in 93%, 65% and 60% of samples, respectively. These variables were analyzed quantitatively. Copper, lead, manganese, mercury[23], silicon and zinc were detected in approximately 20% to 59% of samples and were examined qualitatively.

Remaining constituents were rarely or never detected. Nickel was detected in 15% of samples; in 5 (of 24) samples from the Reference Areas and 6 (of 48) samples from the Study Areas. Aluminum was detected in 14% of samples; in 2 (of 24) samples from the Reference Areas and 8 (of 48) samples from the Study Areas. Phosphorus was detected in 8% of samples; in 1 (of 24) sample from the Reference Areas and 5 (of 48) samples from the Study Areas. Cobalt was detected in one sample from the SE Reference Area. Tin and naphthalene[24] were each detected in one sample from the Study Areas.

6.4.1.1 Frequently Detected Variables

Boxplots of frequently detected variables are provided in Figure 6-2 and ANOVA results are provided in Table 6-3. Barium concentrations differed significantly between the Study and Reference Areas. Barium concentrations were higher in surface samples at stations inside and outside the FEZ compared to the Reference Areas (Figure 6-2, $p \leq 0.001$, Table 6-3). These differences were slight, with differences in median levels of approximately 1 to 2 µg/L between the Study and Reference Areas. The largest difference in barium concentrations occurred over depth, with barium levels higher in bottom samples in all Areas (Figure 6-2, Appendix C-2). Overall, the highest barium concentrations were noted in bottom samples in the SW Reference Area (Figure 6-2).

[23] The sample for mercury for station W12 (surface) was lost, giving 15 rather than 16 surface measurements for mercury in the Study Areas.
[24] The PAH and alkyl PAH sample for station W1 (middle) from the SW Reference Area was lost. Except for naphthalene, which was detected in one Study Area sample, no PAH or alkyl PAHs were detected in the remaining 70 samples.

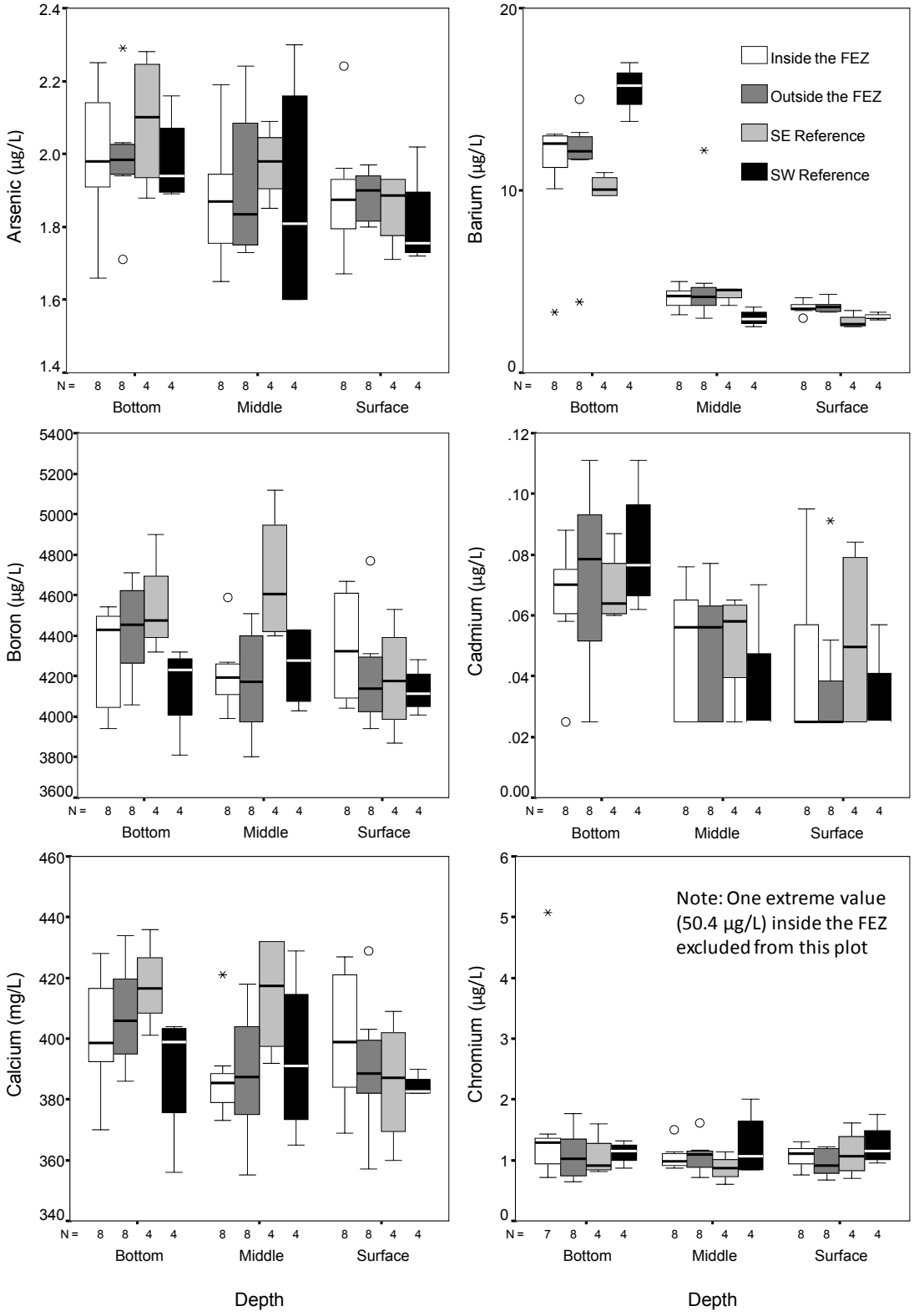


Figure 6-2 Boxplots of Frequently Detected Variables (2012)

Note: Values below detection limit for cadmium were set to ½ detection limit for plotting.

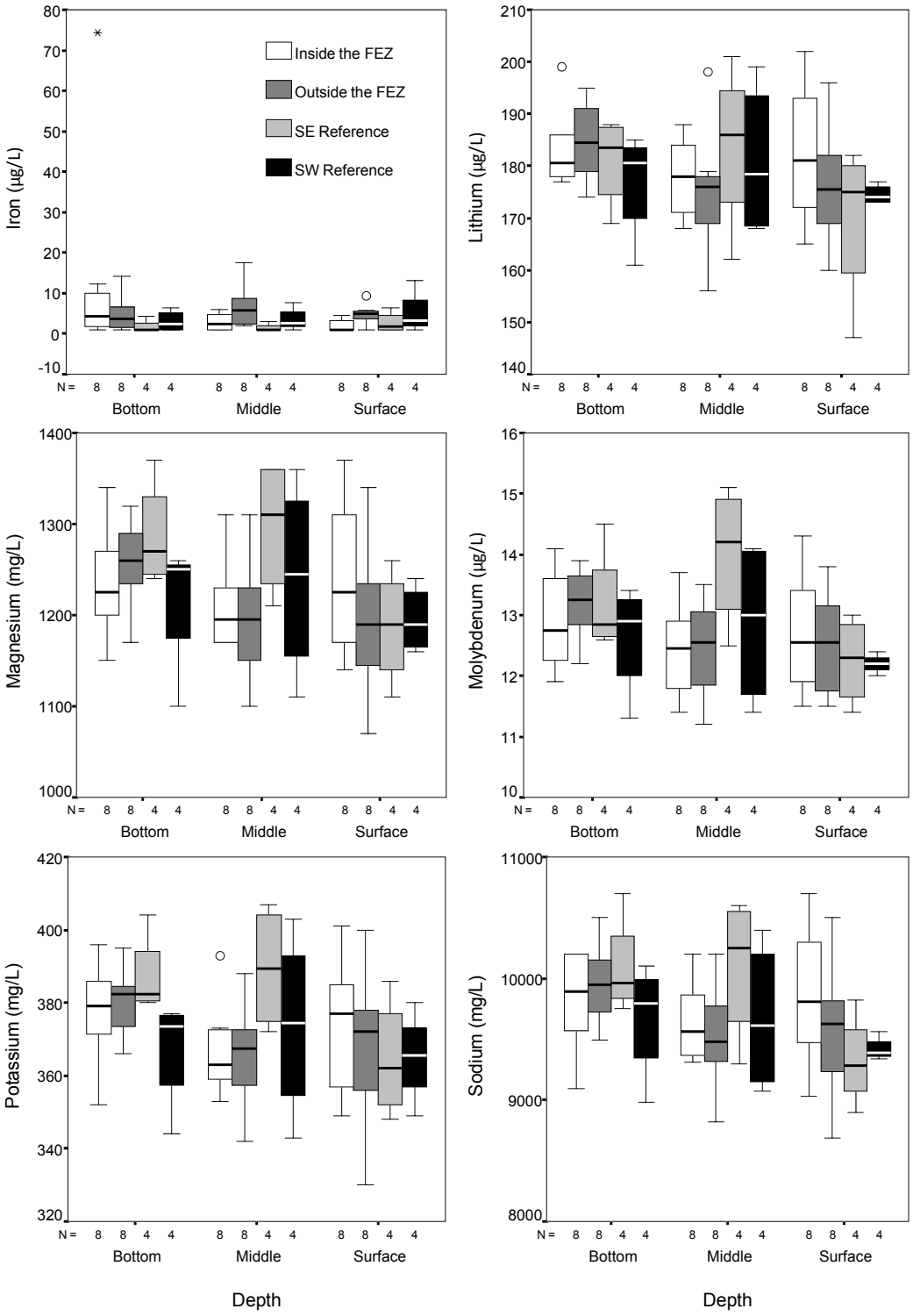


Figure 6-2 (cont.) Boxplots of Frequently Detected Variables (2012)

Note: Values below detection limit for iron were set to ½ detection limit for plotting.

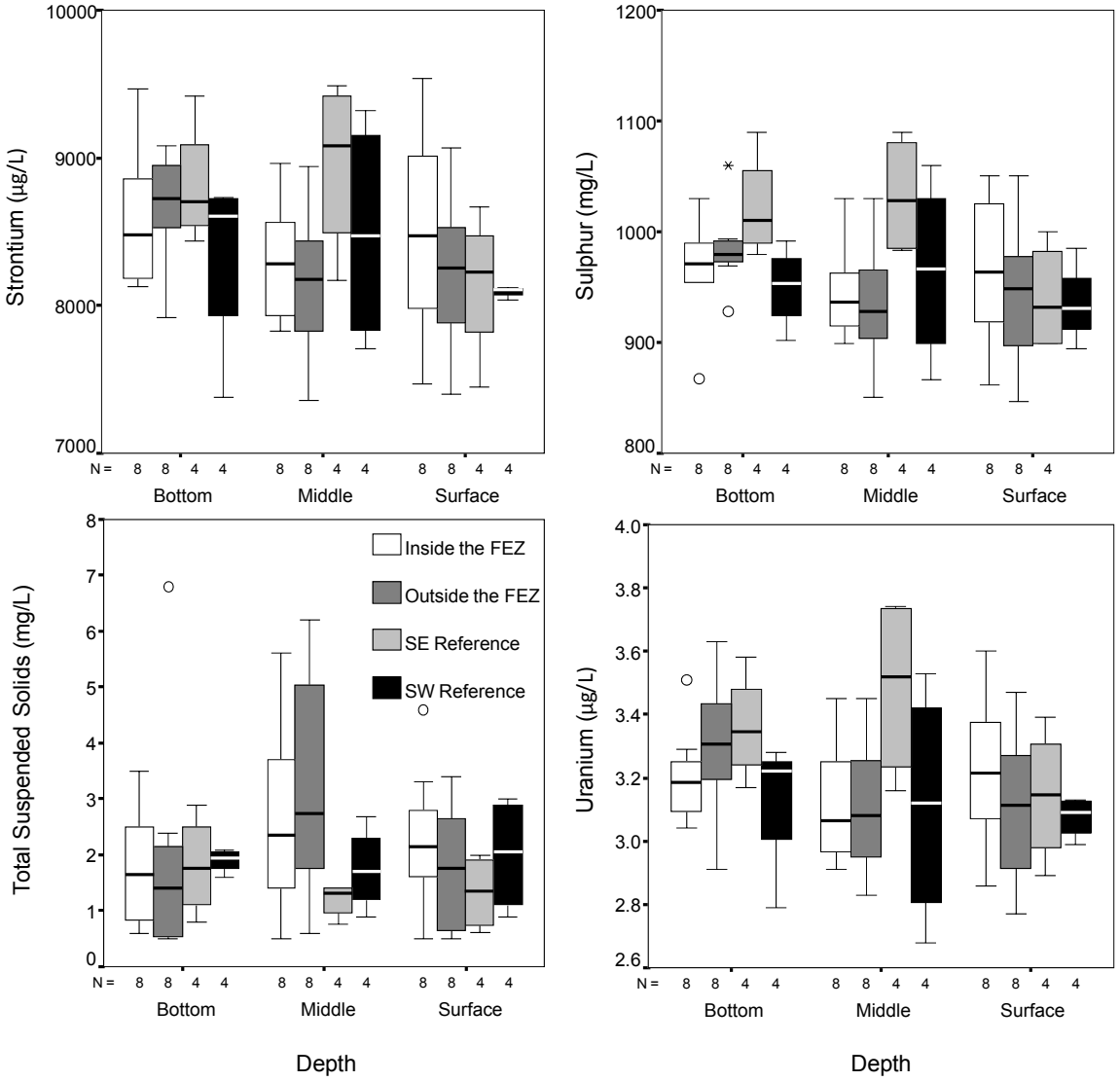


Figure 6-2 (cont.) Boxplots of Frequently Detected Variables (2012)

Note: Values below detection limit for total suspended solids were set to ½ detection limit for plotting.

Table 6-3 Results of ANOVA (p-values) Testing Differences Between Areas (2012)

Variable	*p*-values							
	Area	**Depth**	**AxD**	**SR**	**BR**	**BS**	**IFEZ vs R**	**OFEXvs R**
Arsenic	0.652	0.015	0.962	0.896	0.216	0.809	0.816	0.994
Barium	0.612	**<0.001**	0.035	0.292	0.650	0.489	0.569	0.209
	0.344	B		0.331	0.130	0.831	0.343	0.459
	0.116	M		0.140	0.068	0.444	0.357	0.100
	0.001	S		**<0.001**	0.120	0.713	**0.001**	**<0.001**
Boron	0.039	0.150	0.069	0.489	0.005	0.782	0.644	0.461
Chromium	0.277	0.433	0.409	0.585	0.424	0.088	0.185	0.696
Lithium	0.732	0.209	0.407	0.427	0.915	0.427	0.279	0.770
Molybenum	0.372	0.067	0.166	0.496	0.108	0.817	0.481	0.636
Strontium	0.376	0.078	0.293	0.610	0.125	0.491	0.923	0.432
Uranium	0.100	0.268	0.345	0.493	0.017	0.860	0.613	0.496
Calcium	0.213	0.072	0.202	0.763	0.038	0.843	0.871	0.719
Magnesium	0.355	0.095	0.225	0.387	0.151	0.513	0.672	0.283
Potassium	0.290	0.102	0.274	0.538	0.073	0.739	0.714	0.485
Sodium	0.503	0.048	0.189	0.874	0.185	0.461	0.613	0.816
Sulfur	0.098	0.105	0.235	0.197	0.033	0.742	0.339	0.200
Total suspended solids	0.469	0.852	0.554	0.272	0.285	0.674	0.246	0.457
Iron	0.013	0.986	0.412	0.041	0.118	0.032	0.481	0.005
Cadmium	0.846	**<0.001**	0.769	0.799	0.391	0.959	0.805	0.846

Notes: - Total suspended solids, iron and cadmium were rank transformed. Remaining variables were $\log_{10}$ transformed.
- 'Area' tests for differences among the four areas, overall.
- 'Depth' tests for depth differences, overall.
- 'SR' tests for differences between the two Reference Areas and the two Study Areas.
- 'BR' tests for differences between the two Reference Areas.
- 'BS' tests for differences between the two Study Areas.
- 'IFEZ *vs* R' tests for a difference between Study Area stations inside the FEZ and the average of the Reference Areas.
- 'OFEZ *vs* R' tests for a difference between Study Area stations outside the FEZ and the average of the Reference Areas.
- 'AxD' tests for differences in depth gradients among Areas.
- If AxD was statistically significant (as was the case for barium), additional tests were performed for each depth.
- Reported *p*-values for Area, Depth, BR, SR, BS, 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**.

Iron differed significantly between stations inside the FEZ and stations outside the FEZ ($p = 0.032$, Table 6-3), with levels generally higher at stations outside the FEZ (Figure 6-2; median iron concentration was 2.5 µg/L at stations inside the FEZ versus 4.85 µg/L at stations outside the FEZ). Iron concentrations also varied

significant between stations outside the FEZ and Reference stations ($p = 0.005$, Table 6-3). The median iron concentration in the Reference Areas was 1.7 µg/L and lower than the median concentration of 4.85 µg/L noted outside the FEZ. The effect of the one extreme iron value inside the FEZ (Figure 6-2) was reduced by rank transformation and the difference between stations inside the FEZ and Reference Stations was not significant (Table 6-3). That one extreme iron value is discussed further below in the context of potential input from produced water.

There were no differences between the Study and Reference Areas for any other variable. Removal of the one extreme (50.4 µg/L) or two extreme (50.4 µg/L and 5.07 µg/L, Figure 6-2) chromium values from ANOVA did not lead to significant differences between the Study and Reference Areas ($p = 0.53$ and $p = 0.99$, respectively).

Arsenic, barium, cadmium and sodium varied significant with depth ($p < 0.05$, Table 6-3), with values generally higher in bottom samples (Figure 6-2).

Boron, uranium, calcium and sulphur differed significantly between the two Reference Areas ($p < 0.05$, Table 6-3 and Figure 6-2). Barium in bottom samples also differed significantly ($p < 0.001$) between the two Reference Areas when the two extreme low barium values (see Figure 6-2) were removed from the dataset. The two samples in question increased within-area variance considerably (and differences among Areas are judged against within-area variance). None of the other contrasts for barium in bottom samples were significant with the two values removed.

6.4.1.2 Infrequently Detected Variables

Figure 6-3 provides percent occurrence of infrequently detected variables for stations inside the FEZ, stations outside the FEZ and the two Reference Areas (combined). In most cases, differences among Areas were not large or percent occurrence was higher in the Reference Areas (e.g., copper, Figure 6-3).

Mercury was detected more frequently in Study Area samples than in Reference Area samples. Mercury concentrations in the Study Areas were low, with a maximum concentration of 0.017 µg/L. The highest mercury concentration (0.02 µg/L) was recorded in the SW Reference Area (Appendix C-2).

Manganese was detected more frequently at stations located outside the FEZ (Figure 6-3). When detected, manganese concentrations at these stations were comparable to concentrations at stations inside the FEZ. When manganese was detected, concentrations in these two Areas ranged from 0.50 to 1.43 µg/L and from 0.56 to 1.57 µg/L, respectively. The range of concentrations above detection limit was greater in the Reference Areas (0.52 to 10.60 µg/L) (Appendix C-2).

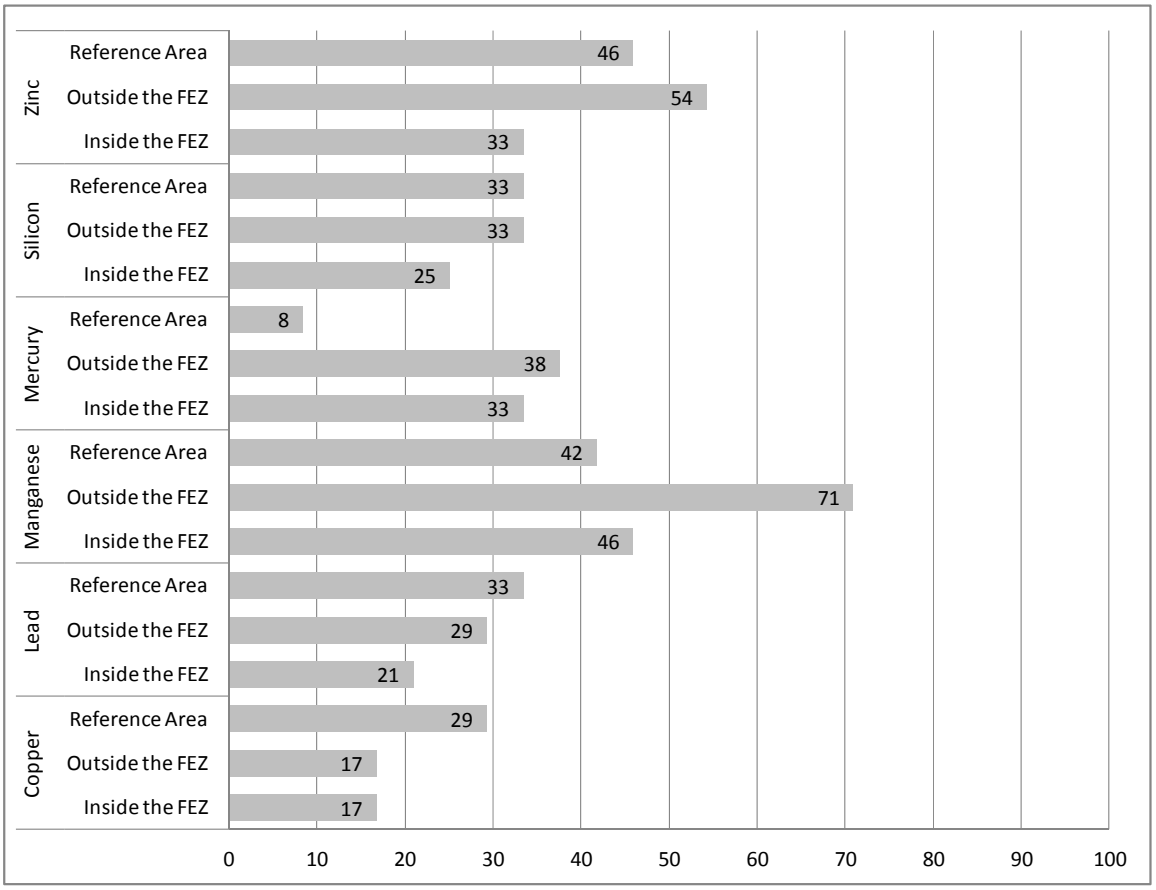


Figure 6-3 Percent Occurrence for Infrequently Detected Variables (2012)

Note: Percent Occurrence Represents Occurrence at Any Depth.

6.4.1.3 Produced Water Constituents

Concentrations of seawater constituents at Reference Area stations in 2012 for each of the three depths sampled and concentration of these constituents in produced water are provided in Table 6-4. Only those constituents detected in seawater samples and with produced water concentrations more than, or less than, 10 X that of seawater at Reference Area stations are shown.

Table 6-4 Concentration of Seawater Constituents at Reference Area Stations and in Produced Water (2012)

Depth	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[1] (µg/L)			
Bottom	Naphthalene	0	<0.05	<0.05	0.025	160	6400	0
	Iron	3	<2	6.4	1	2940	2940	0
	Manganese	3	<0.5	3.43	0.25	92	368	0
	Barium	8	9.7	17	12.4	260.5	21	0
	Lithium	8	161	188	181	2530	14	0
	Molybdenum	8	11.3	14.5	12.85	0.2	0	64
	Uranium	8	2.79	3.58	3.25	0.1	0	33
Middle	Naphthalene	0	<0.05	<0.05	0.025	160	6400	0
	Iron	4	<2	7.7	2.95	2940	997	0
	Manganese	3	<0.5	1.05	0.25	92	368	0
	Barium	8	2.5	4.6	3.65	260.5	71	0
	Lithium	8	162	201	186	2530	14	0
	Molybdenum	8	11.4	15.1	13.85	0.2	0	69
	Uranium	8	2.68	3.74	3.31	0.1	0	33
Surface	Naphthalene	0	<0.05	<0.05	0.025	160	6400	0
	Iron	5	<2	13.1	3.6	2940	817	0
	Manganese	4	<0.5	10.6	0.88	92	105	0
	Barium	8	2.5	3.4	3	260.5	87	0
	Lithium	8	147	182	174	2530	15	0
	Molybdenum	8	11.4	13	12.2	0.2	0	61
	Uranium	8	2.89	3.39	3.095	0.1	0	31

Notes: - [1]When the median of value was below the laboratory detection limit, the median was set to half the 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 X that of seawater at Reference Area stations are shown.

Table 6-4 indicates that naphthalene, iron, manganese, barium and lithium could be enriched in seawater samples as a result of produced water input; molybdenum and uranium could be depleted. Naphthalene was detected at mid-depth at Study Area station W19 at a level barely above the laboratory detection limit (0.06 µg/L versus a laboratory detection limit of 0.05 µg/L). A relatively high iron concentration was detected in the bottom sample (see outlier in Figure 6-2) collected at Study Area station W15. A relatively high concentration of barium was noted at the bottom at station W9 (Figure 6-2). Elevated levels of lithium were noted at Study Area stations W18 (mid-depth) and W19 (bottom) (Figure 6-2). Other than higher frequency of occurrence at stations outside the FEZ relative to stations inside the FEZ and in Reference Areas (see Section 6.4.1.2), elevated levels of manganese were not noted in the Study Areas. The highest manganese level (10.6 µg/L) occurred in the

SW Reference Area (Appendix C-2). Molybdenum and uranium were not visibly depleted at any station (Figure 6-2).

Table 6-5 provides distance and direction from the FPSO for stations where produced water constituents were potentially detected. Currents on May 30 and 31, just prior and during sampling, were predominantly toward the north, northwest, northeast and east, with little movement toward the south[25]. Therefore, the occurrence of produced water constituents to the south of the FPSO (stations W18 and W19) would not be consistent with current direction just prior to and during sampling; but occurrence to the northwest (station W9, where a relatively high barium level was detected) and, to a lesser extent, to the east (station W15, where a relatively high iron level was detected) could be.

Table 6-5 Stations Where Produced Water Constituents Potentially were Detected (2012)

Station	Sampling Date/Time	Distance from FPSO (km)	Direction from FPSO
W9	May 31/07:20 hrs	2.32	North-west
W15	May 31/14:13 hrs	0.25	East
W18	May 31/19:47 hrs	2.87	South-east
W19	May 31/15:45 hrs	0.26	South

Overall, evidence that produced water constituents were detected in seawater samples at Terra Nova in 2012 is weak given that only four stations showed relatively high concentrations of some of the constituents present in produced water, and that overall differences between the Study and Reference Areas for those constituents (Section 6.4.1.1), when they occurred, were slight.

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 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. The median level observed in the Study Area in 2012 was approximately equivalent to the median level observed in the Reference Areas in 2008.

[25] Current data at 45 m depth were provided by Oceans Ltd. and were collected approximately 5.5 km to the west of the FPSO.

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

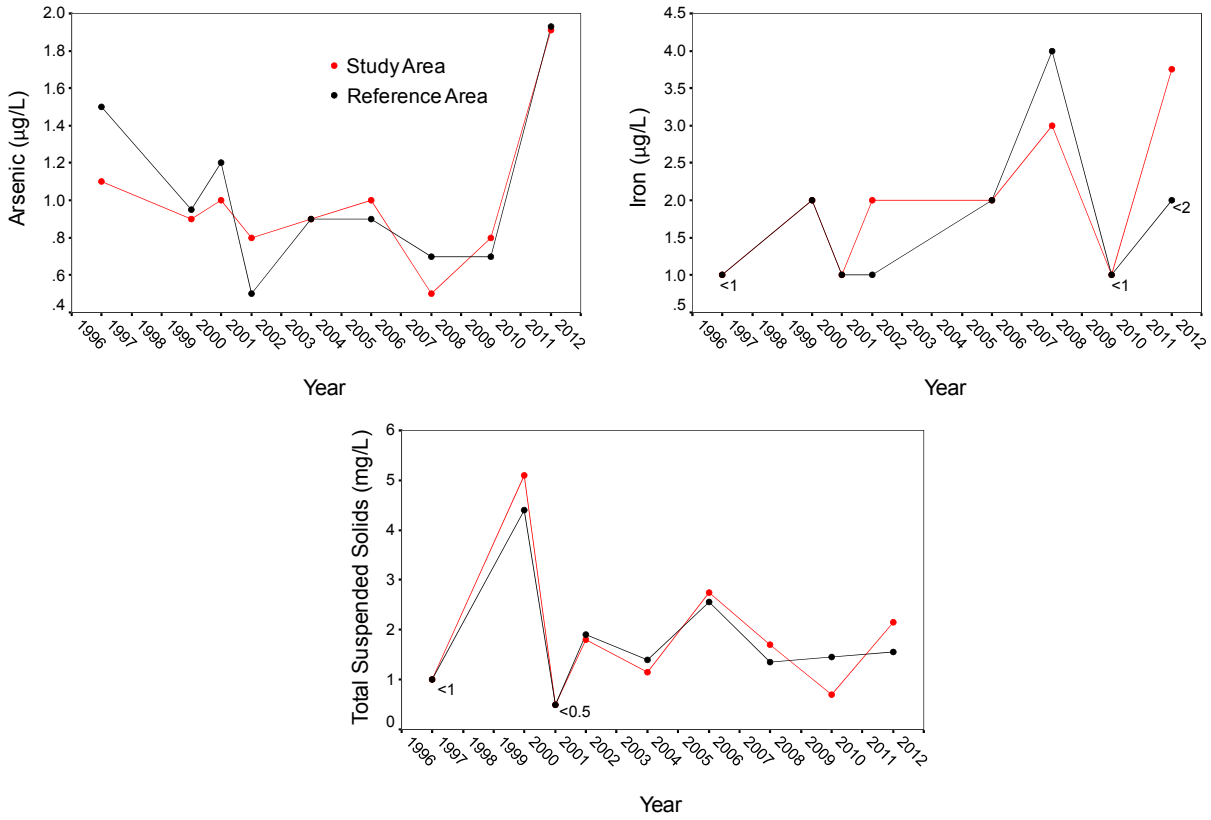


Figure 6-4 Median Arsenic, Iron and Total Suspended Solids Concentrations in Niskin Bottle Water Samples from the Reference and Study Areas (2000 to 2012)

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 2012, and depth profiles for individual water stations in 2012, are provided in Appendix C-3. Summary statistics for chlorophyll *a* and pheophytin *a* from Niskin bottle samples are provided in Appendix C-2. Pheophytin *a* was not detected in water samples in 2012.

Temperature at water stations sampled in 2012 ranged from a low of -1°C near bottom to 3 or 4°C near the surface. Thermoclines extended from approximately

30 to 70 m at stations inside the FEZ, from approximately 30 to 60 m at stations outside the FEZ, and from 40 to 60 m at Reference Area stations (Figure 6-5).

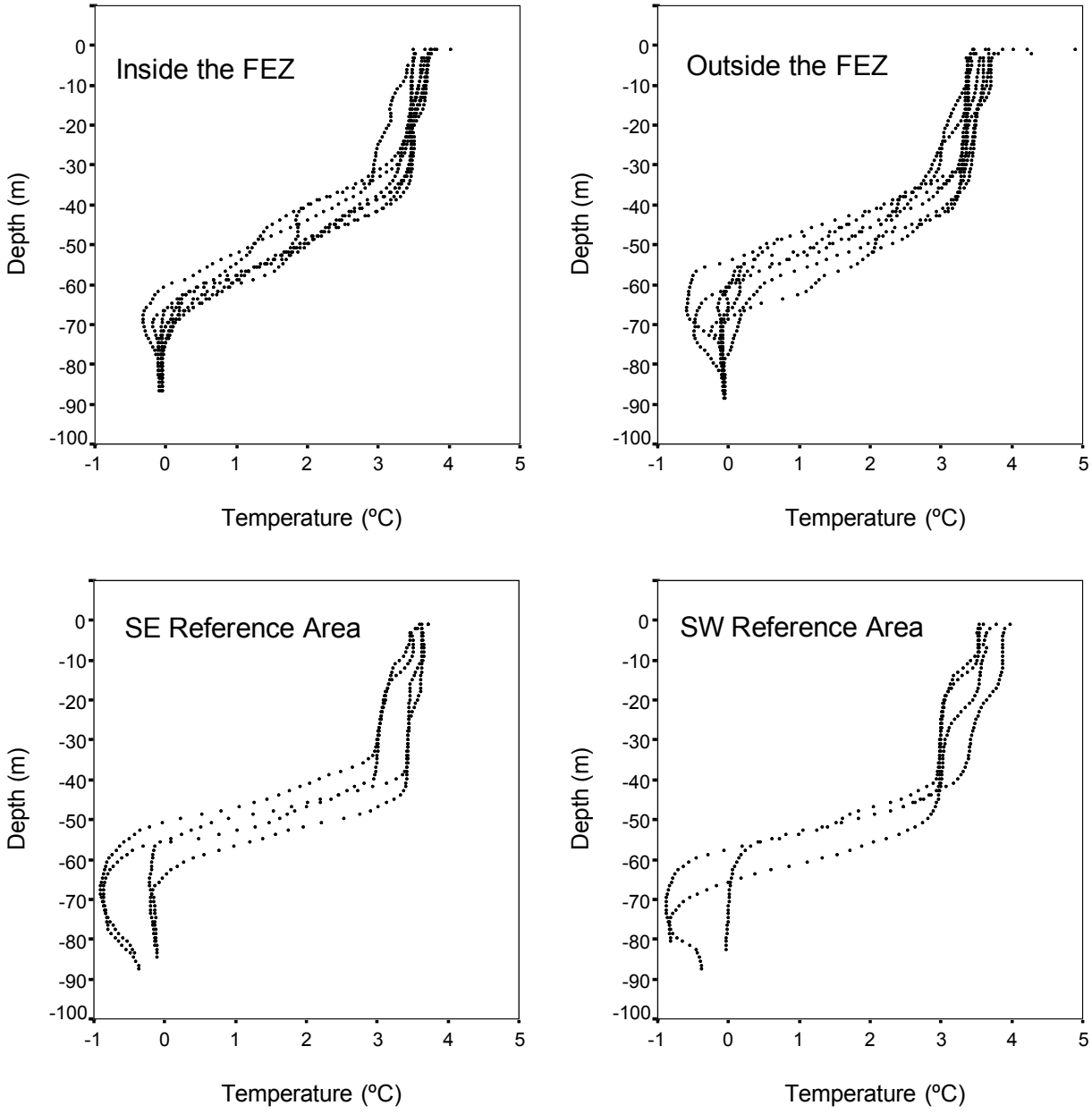


Figure 6-5 Temperature from CTD Casts versus Depth for Each Area (2012)

In 2012, chlorophyll *a* concentrations at water quality stations varied between approximately 3 and 4 μg/L with concentrations increasing with depth in all Areas (Figure 6-6).

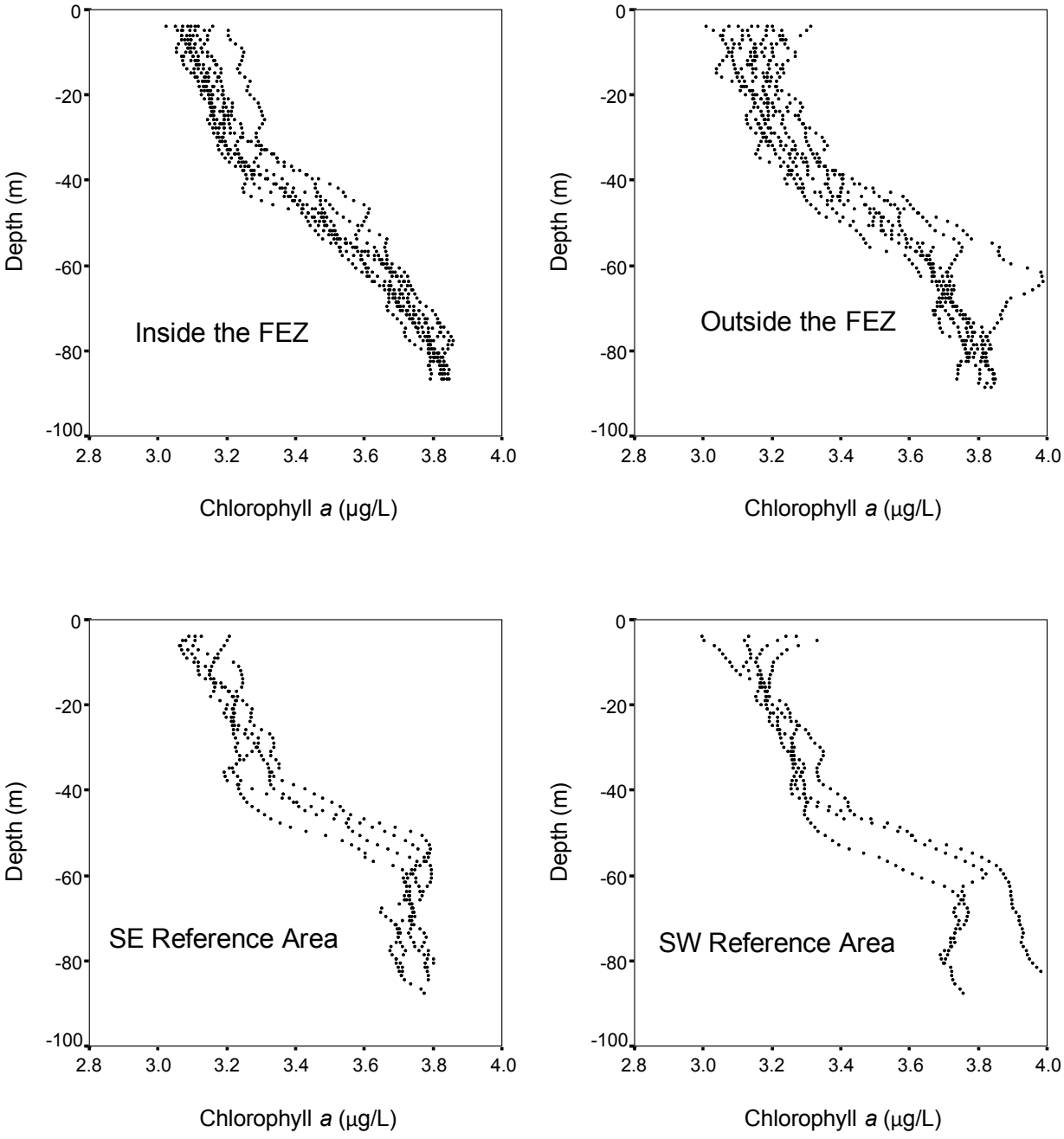


Figure 6-6 Chlorophyll a Concentrations from CTD Casts versus Depth for Each Area (2012)

Boxplots of chlorophyll *a* concentrations from Niskin bottles and CTD casts (the later 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.

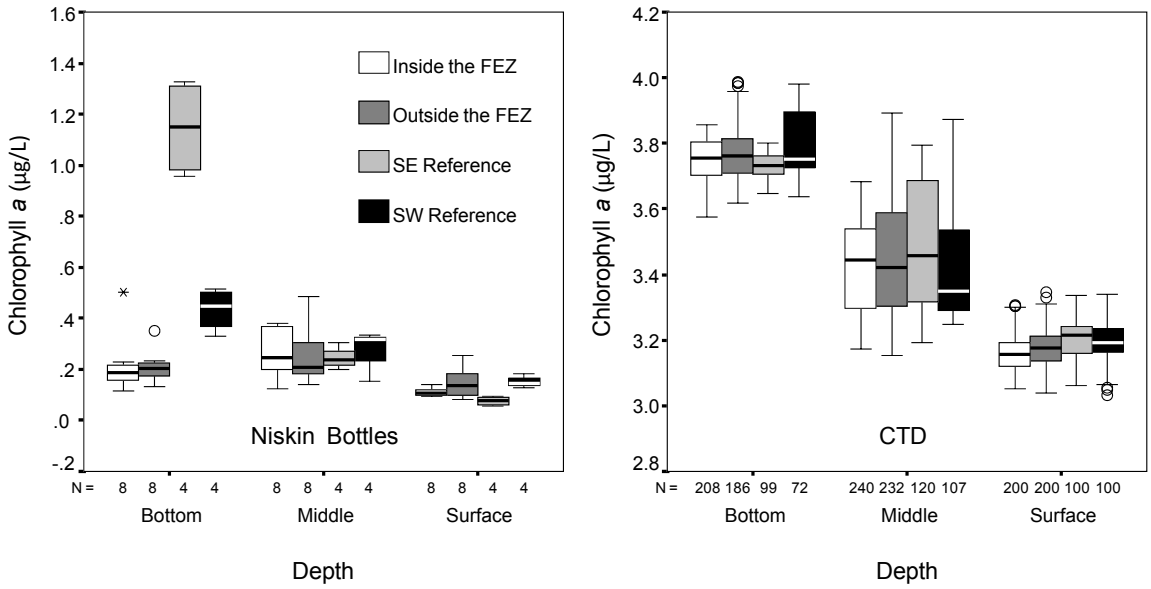


Figure 6-7 Boxplot of Chlorophyll a Concentrations from Niskin Bottles and CTD Casts (2012)

Both Niskin bottle and CTD data show increasing chlorophyll *a* concentration with depth (Figure 6-7), with this trend more apparent for the more extensive CTD dataset. The difference in absolute values between Niskin bottle data and CTD data has been discussed previously (see Suncor Energy 2005). Relative values have generally been consistent and the range of chlorophyll *a* values in 2012 spans approximately 1 µg/L in both instances. In 2012, there was more variability among Areas for bottom samples for Niskin bottle data than there was for CTD data, but a patchy distribution of chlorophyll *a* concentrations would reasonably explain that result for the more limited Niskin bottle dataset (also see variability among CTD casts within Areas in Figure 6-6).

Table 6-4 provides results of ANOVA testing for differences between Areas for chlorophyll *a* from Niskin bottles and the CTD recorder. As indicated by Figures 6-6 and 6-7, chlorophyll *a* concentration from Niskin bottles and CTD casts varied over depth and these relationships were significant ($p < 0.0001$ in all cases, Table 6-6). Differences in chlorophyll *a* concentrations between the Study Areas and the Reference Areas from Niskin samples taken at bottom depths were significant, as were differences between the two Reference Areas at those depths ($p < 0.0001$ in

both cases, Table 6-4). Chlorophyll *a* concentrations from Niskin samples taken at bottom depths were lower in the Study Areas than in the Reference Areas, and concentrations were lower in the SW Reference Area than in the SE Reference Area (Figure 6-7). Surface chlorophyll *a* concentration from Niskin bottle samples differed between the two Reference Areas (p = 0.002, Table 6-6), with concentrations higher in the SW Reference Area than in the SE Reference Area (Figure 6-7).

Table 6-6 Results of ANOVA (p-values) Testing Differences in Chlorophyll a concentrations Between Areas (2012)

Variable	*p*-values							
	Area	**Depth**	**AxD**	**SR**	**BR**	**BS**	**IFEZ vs R**	**OFEZ vs R**
Chlorophyll *a* from Niskin Bottles	**<0.001**	**<0.001**	**<0.001**	**<0.001**	0.645	0.545	**<0.001**	**<0.001**
	<0.001	B		**<0.001**	**<0.001**	0.858	**<0.001**	**<0.001**
	0.946	M		0.769	0.713	0.716	0.942	0.662
	0.006	S		0.234	0.002	0.139	0.774	0.082
Chlorophyll *a* from the CTD recorder	**0.001**	**<0.001**	**<0.001**	0.003	0.839	0.012	**<0.001**	0.168
	<0.001	B		0.349	**<0.001**	0.063	0.083	0.946
	0.012	M		0.221	0.009	0.138	0.071	0.744
	<0.001	S		**<0.001**	0.439	0.029	**<0.001**	**<0.001**

Notes:
- 'Area' tests for differences among the four areas, overall.
- 'Depth' tests for depth differences, overall.
- 'SR' tests for differences between the two Reference Areas and the two Study Areas.
- 'BR' tests for differences between the two Reference Areas.
- 'BS' tests for differences between the two Study Areas.
- 'IFEZ *vs* R' tests for a difference between Study Area stations inside the FEZ and the average of the Reference Areas.
- 'OFEZ *vs* R' tests for a difference between Study Area stations outside the FEZ and the average of the 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, BS, 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**.

Differences noted between Areas with Niskin bottle samples were not apparent with the larger CTD dataset, but surface chlorophyll *a* concentrations differed between the Study and Reference Areas (p < 0.0001, Table 6-6), with concentrations slightly higher in the Reference Areas (Figure 6-7). Surface chlorophyll *a* concentrations also differed between stations inside the FEZ and stations outside the FEZ (p = 0.03, Table 6-6), with concentrations slightly higher at stations outside the FEZ. Chlorophyll *a* concentrations differed between the two Reference Areas at mid-depth and at the bottom (p < 0.05, Table 6-6). At mid-depth, chlorophyll *a* concentrations were higher at stations in the SE Reference Area than at stations in the SW Reference Area. At the bottom, concentrations were higher at stations in the

SW Reference Area than at stations in the SE Reference Area (Figure 6-7). All differences between Areas were subtle and differences were significant because of the large sample size and consequent high statistical power and robustness of tests on the CTD data.

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.

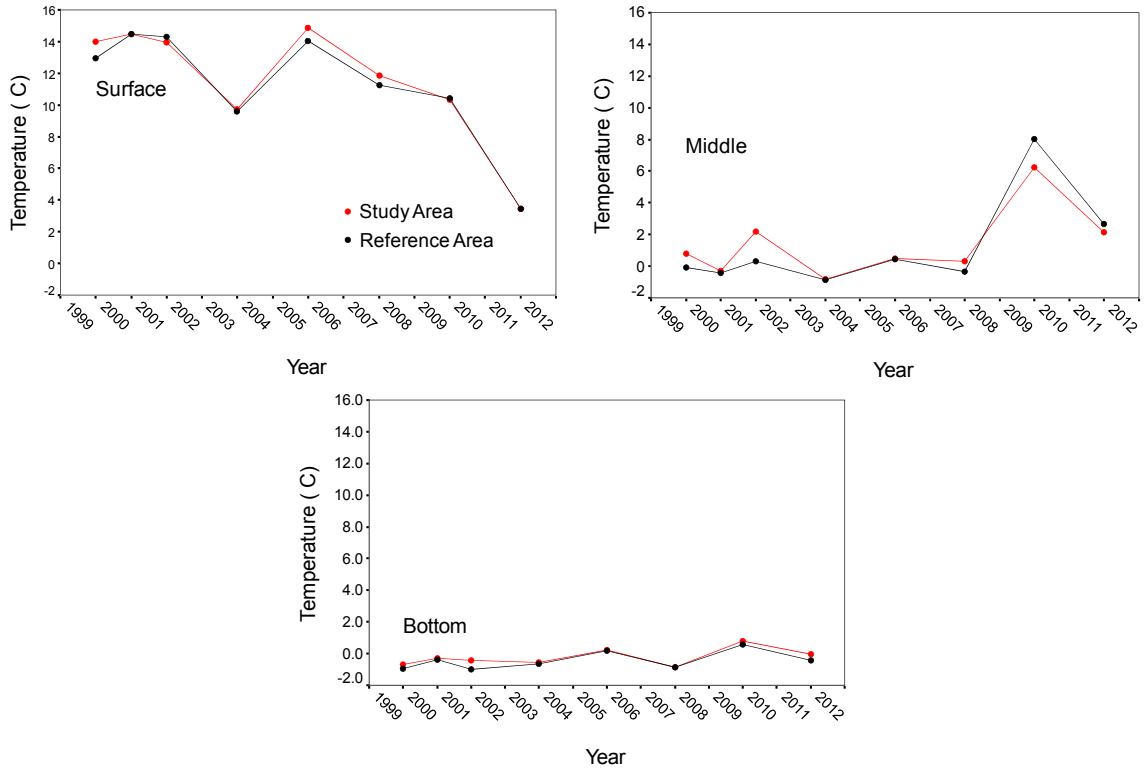


Figure 6-8 Median Temperature from CTD Casts in the Study and Reference Areas (2000 to 2012)

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.

Figures 6-9 and 6-10 show median chlorophyll *a* concentration at three sampling depths from CTD casts and from Niskin bottle samples, respectively. Median chlorophyll *a* concentration from CTD casts 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). Median chlorophyll *a*

concentration was higher in bottom samples in 2012 than in previous years, in all Areas, with concentrations slightly higher at this depth than at either the surface or mid-depth (Figure 6-6). Sampling in 2012 occurred in May. Sampling occurred from September to October in other years (Table 5-1, Section 5).

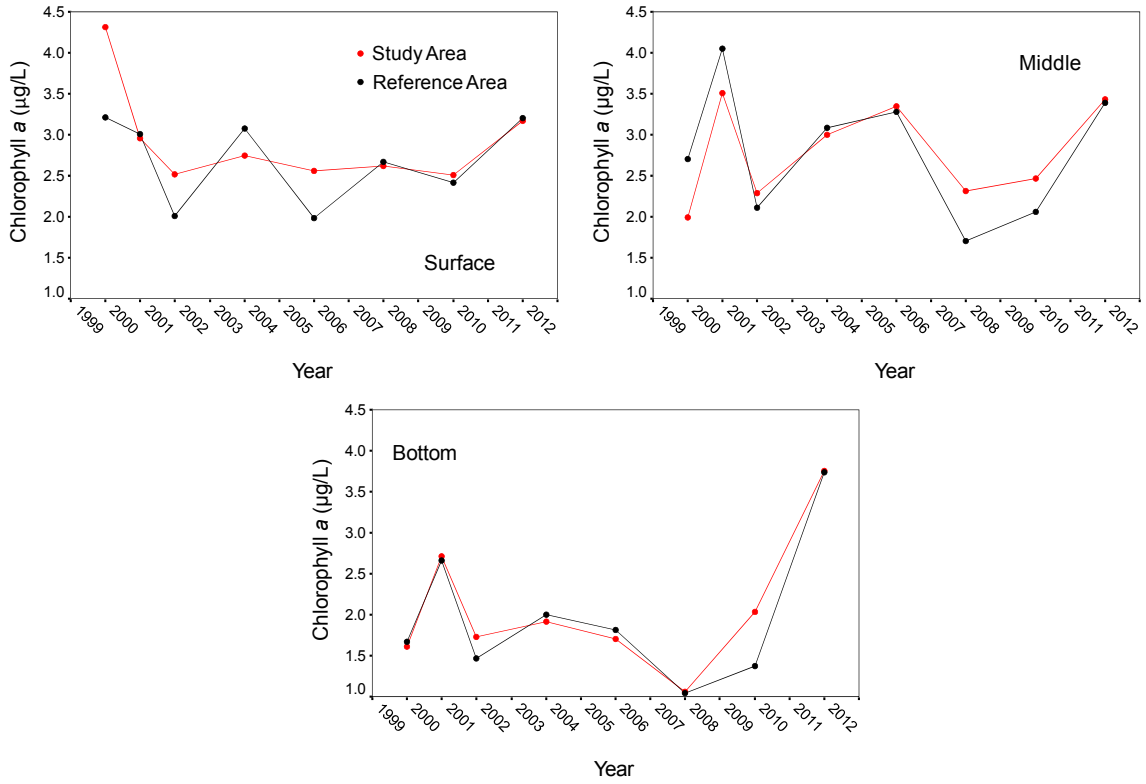


Figure 6-9 Median Chlorophyll a Concentration from CTD Casts in the Study and Reference Areas (2000 to 2012)

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.

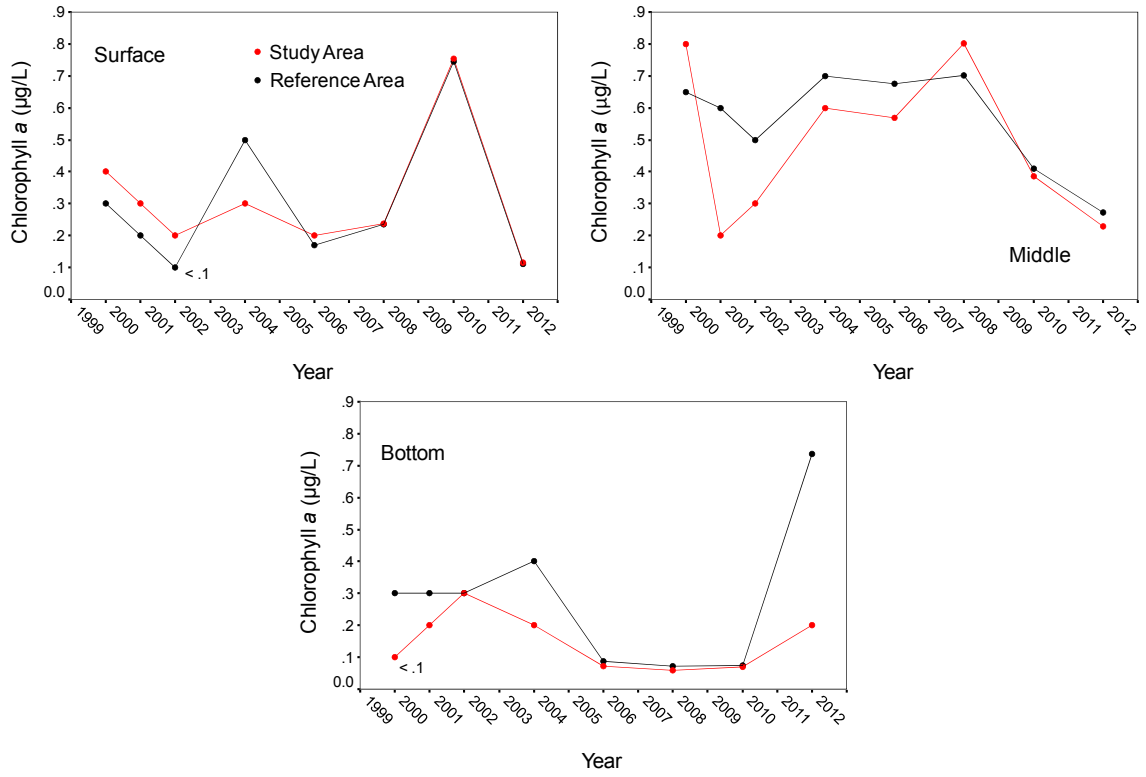


Figure 6-10 Median Chlorophyll a Concentration from Niskin Bottle Samples in the Study and Reference Areas (2000 to 2012)

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.

Like the more extensive CTD dataset, Niskin bottle data also show some consistency between the Study and the Reference Areas, particularly since 2006, and show higher bottom chlorophyll concentrations in the Reference Area in 2012 (Figure 6-10).

6.5 SUMMARY OF FINDINGS

In 2012, >C_{10}-C_{21} and >C_{21}-C_{32} hydrocarbons were not detected in any sample. A low level of naphthalene (0.06 µg/L versus a laboratory detection limit of 0.05 µg/L) was detected in one sample from the Study Areas, at mid-depth.

Arsenic, barium, boron, chromium, lithium, molybdenum, strontium, uranium, calcium, magnesium, potassium, sodium and sulphur were detected in all samples. Total suspended solids, iron and cadmium were detected in 93%, 65% and 60% of samples, respectively. These variables were analyzed quantitatively.

There were no significant differences in concentrations between the Study and Reference Areas for all variables except barium and iron. Barium concentrations were higher in surface samples in the Study Areas compared to the Reference Areas. These differences were slight, with differences in median levels of approximately 1 to 2 µg/L between the Study and Reference Areas. The largest difference in barium concentrations occurred over depth, with barium levels higher in bottom samples in all Areas (approximately 12 µg/L in bottom samples versus 3 to 4 µg/L at other depths).

Iron differed significantly between stations inside the FEZ, stations outside the FEZ and the Reference Areas and, with the exception of one high value at a station inside the FEZ, iron levels were generally higher at stations outside the FEZ than in the other Areas. Median levels of 2.5 and 1.7 µg/L were noted at stations inside the FEZ and in the Reference Areas, respectively, and a median level of 4.85 µg/L was noted at stations outside the FEZ.

Copper, lead, manganese, mercury, silicon and zinc were detected in less than 60% of samples and the frequency of occurrence (percent occurrence) of these metals in each Area was examined qualitatively. In most cases, the differences in percent occurrence between Areas was not large, and percent occurrence for copper was higher in the Reference Areas.

Mercury was detected more frequently in Study Area samples than in Reference Area samples (in approximately 35% versus 8% of samples), but concentrations were low. The highest mercury concentration in Study Area samples was 0.017 µg/L. The highest mercury concentration overall (0.02 µg/L) was detected in the Reference Areas.

Manganese was detected more frequently at stations outside the FEZ (in 71% of samples versus 46% of samples inside the FEZ and 42% of samples in the Reference Areas). The highest manganese concentration at stations outside the FEZ was 1.57 µg/L. The highest overall manganese concentration (10.6 µg/L) occurred 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. An elevated concentration of barium (a constituent of both produced water and drill muds) was noted at station W9. An elevated concentration of iron was noted at station W15.

An elevated concentration of lithium was noted at station W18. Elevated concentrations of naphthalene and lithium were noted at stations W19.

Concentrations of arsenic, iron and total suspended solids were examined across years. These were the only variables that occurred frequently in samples in all sampling 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. The median iron concentration observed in the Study Area in 2012 was approximately equivalent to the median concentration observed in the Reference Areas in 2008. Total suspended solids in the Study and Reference Areas have generally been similar.

In 2012, chlorophyll *a* concentrations from CTD casts varied between approximately 3 and 4 µg/L. Both Niskin bottle and CTD data showed increasing chlorophyll *a* concentration with depth. From the larger CTD dataset, surface chlorophyll *a* concentrations differed between the Study and Reference Areas, with concentrations higher in the Reference Areas. Surface chlorophyll *a* concentrations also differed between stations inside the FEZ and stations outside the FEZ, with concentration higher at stations outside the FEZ.

Chlorophyll *a* concentrations differed between the two Reference Areas at mid-depth and at the bottom. At mid-depth, chlorophyll *a* concentrations were higher at stations in the SE Reference Area. At the bottom, concentrations were higher at stations in the SW Reference Area. All differences between Areas were subtle (less than 0.2 µg/L) and differences were significant because of the large sample size and consequent high statistical power and robustness of tests on the CTD data.

Across years, median chlorophyll *a* concentration from CTD casts has generally followed the same pattern in the Study and Reference Areas, with concentrations slightly more variable at the surface in the Reference Areas. Median chlorophyll *a* concentration was higher in bottom samples in 2012 than in all previous years, in all Areas. Niskin bottle data supported this finding, but only for samples in the Reference Areas[26].

[26] A patchy distribution of chlorophyll would reasonably explain differences in general observations made with CTD data and the more limited Niskin bottle dataset.

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 Aqviq* from July 7 and July 8, 2012. 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 July 8, 2012

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). Sampling for the 2012 program was conducted under experimental fishing license issued by DFO. A total of 50 plaice and 603 scallop were collected in the Terra Nova Study Area in 2012. A total of 50 plaice and 527 scallop were collected in the Reference Area. Location of sampling transects are provided in Figures 1-22 and 1-23 (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. 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. Only those plaice larger than 250 mm in length were retained for 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, length, width and height.

Blood from plaice used in fish health analysis was drawn from a dorsal vessel near the tail and carefully dispensed into a tube containing an anticoagulant (EDTA) and gently mixed. Two blood smears were prepared for each fish within one hour of blood withdrawal 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. The first gill arch on the right of the fish was removed and placed in 10% buffered formalin for histological processing. Tissue samples of heart, spleen and head-kidney were removed and placed in Dietrich's fixative for histological processing, if required. Otoliths were removed for ageing. Throughout the dissection process, any internal parasites and/or abnormal tissues were recorded and preserved in Dietrich's fixative for subsequent identification.

The following QA/QC protocols were implemented for collection of samples to ensure sample integrity and prevent onboard contamination. 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. Processed samples to be frozen were transferred to a -20°C freezer within one hour of collection.

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. Scallop from these same transects 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 (2012)

Transect	Area	No. of Scallop	Body Burden Composites	Taste (Wt. g. of Scallop)
TN-01	Study (NE corner of FEZ)	118	TN-01 (20 scallop)	579
TN-02	Study (SE corner of FEZ)	103	TN-02 (20 scallop)	645
TN-05	Study (SE corner of FEZ)	50	TN-05 (20 scallop)	
TN-03	Study (SW corner of FEZ)	135	TN-03 (20 scallop)	677
TN-04	Study (NW corner of FEZ)	192	TN-04 (20 scallop)	910
Total	**Study**	**598**	**5**	**2,811**
TNR-01	Reference	121	TNR-01 (20 scallop)	568
TNR-02	Reference	108	TNR-02 (20 scallop)	509
TNR-03	Reference	83	TNR-03 (20 scallop)	365
TNR-04	Reference	116	TNR-04 (20 scallop)	545
TNR-05	Reference	99	TNR-05 (20 scallop)	438
Total	**Reference**	**527**	**5**	**2,425**

Note: - Study Area tissue for taste analyses was selected to generate relatively equal weights, as feasible, from the four corners of the FEZ.

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 this test, 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 (2012)

Transect	Area	Total No. Fish	Body Burden Composites	Taste (Wt. g. of Top Fillets)	Health (No. of Fish)
TNSA-01	Study (SE corner of FEZ)	10	TNSA-01 (10 fish)	524	10
TNSA-02	Study (SW corner of FEZ)	10	TNSA-02 (10 fish)	531	10
TNSA-03	Study (NW corner of FEZ)	10	TNSA-03 (10 fish)	529	10
TNSA-05	Study (NW corner of FEZ)	10	TNSA-05 (10 fish)		10
TNSA-04	Study (NE corner of FEZ)	10	TNSA-04 (10 fish)	529	10
Total	**Study**	**50**	**5**	**2,109**	**50**
TNREF-01	Reference	10	TNREF-01 (10 fish)	497	10
TNREF-02	Reference	10	TNREF-02 (10 fish)	506	10
TNREF-03	Reference	10	TNREF-03 (10 fish)	505	10
TNREF-04	Reference	10	TNREF-04 (10 fish)	510	10
TNREF-05	Reference	10	TNREF-05 (10 fish)	481	10
Total	**Reference**	**50**	**5**	**2,499**	**50**

Notes: - 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 Halifax, 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 2012)

Variables	Method	Laboratory Detection Limit						Units
		1997	2000	2001	2002	2004/06	2008/10/12	
$>C_{10}$-C_{21}	GC/FID	15	15	15	15	15	15	mg/kg
$>C_{21}$-C_{32}	GC/FID	15	15	15	15	15	15	mg/kg
$>C_{10}$-C_{32}	Calculated	30	30	30	30	30	30	mg/kg
1-Chloronaphthalene	GC/MS	NA	NA	NA	NA	0.05	0.05	mg/kg
2-Chloronaphthalene	GC/MS	NA	NA	NA	NA	0.05	0.05	mg/kg
1-Methylnaphthalene	GC/MS	0.01	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	mg/kg
Acenaphthene	GC/MS	0.01	0.05	0.05	0.05	0.05	0.05	mg/kg

Variables	Method	Laboratory Detection Limit						Units
		1997	2000	2001	2002	2004/06	2008/10/12	
Acenaphthylene	GC/MS	0.01	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	mg/kg
Benz[*a*]anthracene	GC/MS	0.01	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	mg/kg
Benzo[*b*]fluoranthene	GC/MS	0.01	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	mg/kg
Benzo(j)fluoranthene*	GC/MS	NA	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	mg/kg
Chrysene	GC/MS	0.01	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	mg/kg
Fluoranthene	GC/MS	0.01	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	mg/kg
Indeno[1,2,3-*cd*]pyrene	GC/MS	0.01	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	mg/kg
Perylene	GC/MS	0.01	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	mg/kg
Pyrene	GC/MS	0.01	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	mg/kg
Antimony	ICP-MS	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	mg/kg
Barium	ICP-MS	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	mg/kg
Boron	ICP-MS	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	mg/kg
Chromium	ICP-MS	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	mg/kg
Copper	ICP-MS	0.5	0.5	0.5	0.5	0.5	0.5	mg/kg
Iron	ICP-MS	5	5	5	5	15	15	mg/kg
Lead	ICP-MS	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	mg/kg
Manganese	ICP-MS	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	mg/kg
Molybdenum	ICP-MS	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	mg/kg
Selenium	ICP-MS	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	mg/kg
Strontium	ICP-MS	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	mg/kg
Tin	ICP-MS	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	mg/kg
Vanadium	ICP-MS	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	mg/kg
Lipids	AOAC922.06	0.1	0.1	0.1	0.5	0.5	0.5	%
Moisture	Gravimetry	0.1	0.1	0.1	0.1	0.1	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[27].
- NA = Not Analyzed.
- * Benzo(*j*)fluoranthene was not reported by the analytical laboratory until 2012.

[27] 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.

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 and triangle and hedonic scaling test procedures. 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 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

7.2.4.1 Haematology

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

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

7.2.4.2 MFO Assay

MFO induction was assessed in liver samples of plaice as 7-ethoxyresorufin O-deethylase (EROD) activity according to the method of Porter et al. (1989) modified for use on microplates.

Sample Preparation

Liver samples were thawed on ice within four weeks of storage at -65°C and homogenized in four volumes of 50 mM Tris buffer, pH 7.5 (1 g liver to 4 mL buffer) using at least 10 passes of a glass Ten Broek hand homogenizer. Homogenates were centrifuged at 9,000 g for 15 minutes at 4°C and the post-mitochondrial supernatant (S9 fraction) frozen in triplicate at -65°C until assayed. All liver samples were held and processed under the same storage and assay conditions. Assays were carried out within eight weeks of storage of S9 fractions.

EROD Assay

The enzymatic conversion of 7-ethoxyresorufin to resorufin was measured at an excitation wavelength of 544 nm and an emission wavelength of 590 nm at 27°C using a FluoStar Optima multi-mode microplate reader. The reaction mixture in each well, final volume of 340 µL, contained 50 mM Tris buffer, pH 7.5, 2 µM ethoxyresorufin (Sigma) dissolved in dimethyl sulphoxide, 0.15 mM NADPH and 6.7 µl of S9 protein (diluted 10 times in accordance with linearity considerations). All samples and five concentrations of resorufin (from 2.89 to 23.45 pmol/mL) were run in triplicate. An external positive control (from a pool of fish liver homogenates) was also run in triplicate with each batch of samples to ensure consistency of measurements. Protein concentration of each S9 sample was determined using the Lowry protein method (Lowry et al. 1951) with bovine serum albumin as standard. The rate of enzyme activity in pmol/min/mg protein was obtained from the regression of fluorescence readings against concentrations of resorufin.

7.2.4.3 Bile Metabolite Measurement

PAH metabolites were assessed in fish bile by fixed wavelength fluorescence detection according to the method described by Aas et al. (1998, 2000a). To avoid quenching of the fluorescence signal, bile samples were diluted 1:1600 times in water/HPLC grade methanol (50/50 v/v) (Ariese et al. 1993). Fluorescent readings of the diluted samples were performed at the excitation/emission wavelength pair 290/335 nm for the detection of naphthalene-type metabolites (2- to 3-ring PAHs; note the term naphthalene type metabolites also measures 3-ring compounds such as phenanthrene to some extent), 341/383 nm for the detection of pyrene-type metabolites (4-ring PAHs) and 380/430 nm for the detection of benzo(*a*)pyrene-type metabolites (5- to 6-ring PAHs) according to the reports of Krahn et al. (1987) and Lin et al. (1996). Results were expressed both as fluorescence readings and

fluorescence readings normalized to bile protein concentration in order to allow for differences in feeding status between groups (Lin et al. 1996). Proteins were measured according to the method of Lowry et al. (1951).

7.2.4.4 Histopathology

Fixed liver and gill samples were processed by standard histological methods (Lynch et al. 1969) using a Tissue-Tek® Vacuum Infiltration Processor. A graded ethyl alcohol series of 70%, 80%, 95% and two changes of 100% were used for dehydration of the samples. The tissues were then cleared in four changes of xylene and impregnated with three changes of molten embedding media, Tissue Prep 2™. The processed tissues were embedded in steel moulds using molten embedding media, and topped with labelled embedding rings. After cooling, the hardened blocks of embedded tissues were removed from their base moulds. The blocks were then trimmed of excess wax. Sections were cut at 6 µm on a Leitz microtome, floated on a 47°C water bath, and then picked up on labelled microscope slides. After air drying, slides were fixed at 60°C for approximately two hours to remove most of the embedding media and allow the tissue to adhere properly to the slide. Sections were stained using Mayers Haematoxylin and Eosin method (Luna 1968). Cover slips were applied using Entellan® and the slides were left to air dry and harden overnight.

Histological examination of each tissue was conducted by the same investigator. One slide with four to six sections was examined per fish. If an abnormality was found in a section, the other sections were checked for the same abnormality. To minimize interpretive bias, a "blind" system in which the examiner is not aware of the site of capture of the specimen was used. This is accomplished by using a "pathology" number on the slide label generated from a random number Table matched with the actual specimen number.

Liver

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

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

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

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

Macrophage aggregation was recorded on a relative scale from 0 to 7 and prevalence was calculated for fish showing a proliferation of macrophage aggregates (considered here as 4 or higher on the scale). Inflammatory response was rated on a scale of 0 to 3 (0-absent, 2-moderate and 3-heavy).

The percentage of fish affected by each type of lesion or prevalence of lesions was then calculated.

Gill

Each gill sample was examined microscopically, first under low power (20x) for a general overview of the entire section and to record any abnormalities or parasites present. Four filaments, or primary lamellae, sectioned at a correct angle (with the central venous sinus visible in at least two-thirds of the filament and with secondary lamellae of equal length on both sides) were selected and examined under 250x magnification for the presence of gill lesions associated with chemical toxicity (Mallat 1985). This included observations for epithelial lifting (separation of the epithelial layer from the basement membrane), telangiectasis (dilatation of blood vessel at the tip of the secondary lamellae), lamellar hyperplasia (thickening of the epithelium due to an increase in the number of epithelial cells) and fusion (fusion of two or more adjacent secondary lamellae) or oedeman (swelling within cells).

A semi-quantitative examination was carried out for the various lesions (with the exception of oedema), where the total number of secondary lamellae as well as the lamellae presenting the lesions was counted on each selected filament as follows:

- basal hyperplasia was recorded when an increase in thickness of the epithelium near the base of the lamellae reached at least one-third of the total length of the lamellae;
- distal hyperplasia was recorded when there were more than two cell layers all around the two sides of the secondary lamellae; and
- tip hyperplasia was recorded when there were more than three cell layers on at least two-thirds of the area around the secondary lamellar tip.

Results of the lamellar counts for each fish were expressed as the percentage of secondary lamellae presenting the lesion in relation to the total number of lamellae counted.

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

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

QA/QC procedures on histology and other health analyses 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 20 scallop selected for body burden analysis were representative of the larger subset of scallop sampled.

7.3.1.1 Scallop

Quantitative analyses of biological characteristics for scallop were performed on 2012 samples. Summary statistics from previous years are provided in Appendix D-4 for qualitative comparisons with 2012 data. Analyses of scallop biological characteristics in 2012 included comparisons of sex ratios, size and shape among transects within Areas and between Areas. Size and shape were also qualitatively compared between the sexes. These analyses included all 1,125 scallop from the 10 transects sampled in 2012.

Sex ratios (frequencies of the two sexes) were compared among transects within Areas and between Areas, using log-likelihood ratio or *G* tests[28] (Sokal and Rohlf 1981).

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

Size variables included shell length, width and height (one-dimensional measures), tissue weight (adductor muscle weight + viscera weight + gonad weight[29]) 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.

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

Analyses of plaice biological characteristics were performed predominantly to support fish health indicator assessment (see Section 7.3.4). For plaice, the same fish used in fish health assessment were used in body burden analysis and all fish sampled were used (see Table 7-3). Therefore, an analysis of the subset of animals used in these analyses versus animals sampled, as is done for scallop, is not required.

Maturity stages of male and female fish were defined according to procedures used by DFO (Appendix D-3, Annex A) and results were expressed as frequencies (percentages) of maturity stages. The frequency of maturity stages in each sampling Area was compared using the Fisher Exact Test.

Size and condition of plaice were analyzed separately for each sex. Plaice length, total body weight, liver and gonad weight, age and condition indices in the Study and Reference Areas were compared using the Unpaired t-test or the Mann-Whitney Rank Sum test, when the groups were not normally distributed.

[29] One male from the Study Area and one male and one female from the Reference Area had gonad weight less than 2 g. These were set to 1 g for analysis.

[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).

[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.

Fish condition was assessed by calculating the following indices (after Dutil et al. 1995):

- Fulton's condition factor: 100 x total body weight[32]/(length cubed);
- hepato-somatic index: 100 x liver weight/total weight; and
- gonado-somatic index: 100 x gonad weight/total weight.

Since these indices assume that body weight is proportional to the cube of length, and that 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 ANCOVA (Analysis of CoVariance). When ANCOVA revealed parallel slopes between Areas, comparisons were made on adjusted means to detect differences between Areas.

Comparisons between Areas with a *p* equal or less than 0.05 were considered to be statistically significant.

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.

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 and 2012). The PCA for muscle included six metals detected in all muscle samples. The PCA for viscera included 12 metals detected in every viscera sample, and mercury, which was not detected in one Study Area sample in 2010. The mercury concentration for that sample was set at 0.005 mg/kg (1/2 of the laboratory detection limit). Concentrations were $\log_{10}$ transformed prior to conducting the PCA.

Metals PC scores and fat concentrations were compared among the nine 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

[32] Gutted weight has been used in the past to calculate condition indices. However, in 2012, the value recorded in the field for gutted weight for the first 30 fish sampled was carcass weight, without skin and bones. Therefore, fish condition in 2012 was calculated on the basis of total body weight.

Linear contrast tested for a monotonic (progressive) increase or decrease (simple trend) in body burden variable values over the eight 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[33].

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 2010, detection limits were increased to 0.5% and there were six (of 40) values for adductor muscle less than 0.5%. For the two-way ANOVA comparing Years and Areas, all values less than 0.5% were set at 0.4%. In contrast, fat levels in viscera were never below recent detection limits of 0.5%.

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 and 2012. 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.

[33] A "bottom-up" approach should be used to interpret the results of the Year x Area ANOVA. If the overall Year x Area interaction or an interaction contrast is significant, Year and Area terms should be interpreted with caution unless they are much more significant (lower *p*) than the interactions.

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 every liver composite sample from 2001 to 2012, with one exception. 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.

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 and 2010 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

Log_{10} transformed MFO enzyme activity, bile metabolites (fluorescence readings and fluorescence readings normalized to bile protein), rating of gill oedeman and arcsine square-root transformed percentages of gill lesions in the Study and Reference Area were compared using the Unpaired t-test or the Mann-Whitney Rank Sum test, when the groups were not normally distributed. The prevalence of liver lesions was analyzed by the Fisher Exact Test.

Comparisons between Areas with a *p* equal or less than 0.05 were considered to be statistically significant.

7.4 RESULTS

7.4.1 BIOLOGICAL CHARACTERISTICS

7.4.1.1 Scallop

In 2012, a total of 1,125 scallop were collected in five Reference Area transects and five Study Area transects. 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 (2012)

Sex	Area	Statistic	Dimensions (mm)			Weights (g)					
			Length	Width	Height	Total	Shell	Tissue	Adductor	Gonad	Viscera
Female	Reference	*n*	291	291	291	291	291	291	291	291	291
		Mean	72.5	68.2	21.9	53.4	21.7	31.7	9.0	6.2	16.6
		SD	5.9	5.9	2.3	12.8	9.2	6.2	2.3	1.8	3.7
	Study	*n*	349	349	349	349	349	349	349	349	349
		Mean	73.3	68.3	23.4	58.3	26.6	31.6	8.9	6.5	16.2
		SD	5.7	5.6	2.4	12.6	11.2	7.2	3.1	2.5	4.0
Male	Reference	*n*	236	236	236	236	236	236	235	236	236
		Mean	70.5	66.4	21.5	49.6	19.7	29.9	8.3	6.0	15.6
		SD	6.1	6.1	2.3	11.6	8.4	6.3	2.3	1.7	3.6
	Study	*n*	249	249	249	249	249	249	249	249	249
		Mean	71.6	66.5	23.1	54.9	23.9	31.0	8.4	6.7	15.8
		SD	5.5	5.6	3.3	12.5	10.3	7.5	2.8	2.7	4.1

Sex Ratios

In 2012, female scallop outnumbered males in catches from both the Reference and Study Areas, with an overall female:male sex ratio of 57:43 (Table 7-6). Females also outnumbered males in all 10 transects. Therefore, sex ratios were skewed towards females even at small spatial scales (i.e., within transects). Variations in sex ratios between the Reference and Study Area were not significant (p = 0.269). Variations among transects within and across Areas were also not significant regardless of whether all scallop, or only scallop used in body burden analysis were considered (all p > 0.05; Table 7-7).

Table 7-6 Sex Ratios of Scallop in Transects (2012)

Area	Transect	Female		Male		Total
		No.	%	No.	%	
Reference	TN-R01	64	53	57	47	121
	TN-R02	58	54	50	46	108
	TN-R03	49	59	34	41	83
	TN-R04	59	51	57	49	116
	TN-R05	61	62	38	38	99
Reference Total		291	55	236	45	527
Study	TN-01	72	61	46	39	118
	TN-02	54	52	49	48	103
	TN-03	70	52	65	48	135
	TN-04	122	64	70	36	192
	TN-05	31	62	19	38	50
Study Total		349	58	249	42	598
Total		640	57	485	43	1125

Table 7-7 Results of G Tests Comparing Scallop Sex Ratios Among Transects (2012)

Source	df	Whole Data Set		Body Burden Data Set	
		G	*p*	G	*p*
Transects	9	11.101	0.269	14.16	0.117
Areas	1	1.128	0.288	0.419	0.520
Study	4	6.572	0.160	5.077	0.280
Reference	4	3.401	0.493	8.317	0.081
Among Transects within Areas	8	9.973	0.267	13.741	0.089

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

Size and Shape

PCA of log_{10} transformed values of one-dimensional shell size variables (length, width and height) and three-dimensional variables (shell and tissue weight) indicated that, 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.

Table 7-8 Correlations (r) Between Scallop Size Variables and Principal Components (PCs) Derived from those Variables (2012)

Variable	Correlation (r_P) with:		
	PC1	**PC2**	**PC3**
Length	**0.92**	0.06	0.13
Width	**0.91**	0.07	0.12
Height	**0.83**	0.20	-0.02
Shell Weight	**0.63**	**0.68**	-0.16
Muscle Weight	**0.66**	**-0.57**	0.28
Viscera Weight	**0.80**	-0.15	0.14
Gonad Weight	**0.58**	-0.38	**-0.72**
Percent of Variance Explained	59.6	14.3	9.6

Notes: - $|r| \geq 0.5$ in bold.
- n = 1125 scallop.

PC2 was positively correlated with shell weight and negatively correlated with tissue weight (Table 7-8). Higher PC2 scores therefore indicate greater shell:tissue weight ratios. PC3 was negatively correlated with gonad weight. Lower PC3 scores indicate greater gonad weight.

Female scallop were generally larger, as indicated by larger PC1 scores (Figure 7-3). For both sexes, scores on PC1, PC2 and PC3 did not differ significantly between Areas (all $p > 0.05$, Table 7-9). Scores on PC2 and PC3 varied significantly among transects within Areas for both sexes (all $p < 0.001$; Table 7-9). The analysis on the subset of scallops used for body burden analysis produced the same conclusions (i.e., that in spite of differences among transects within Areas in some cases, there were no differences in size and shape of scallop between the Reference Area and the Study Area (Table 7-9)).

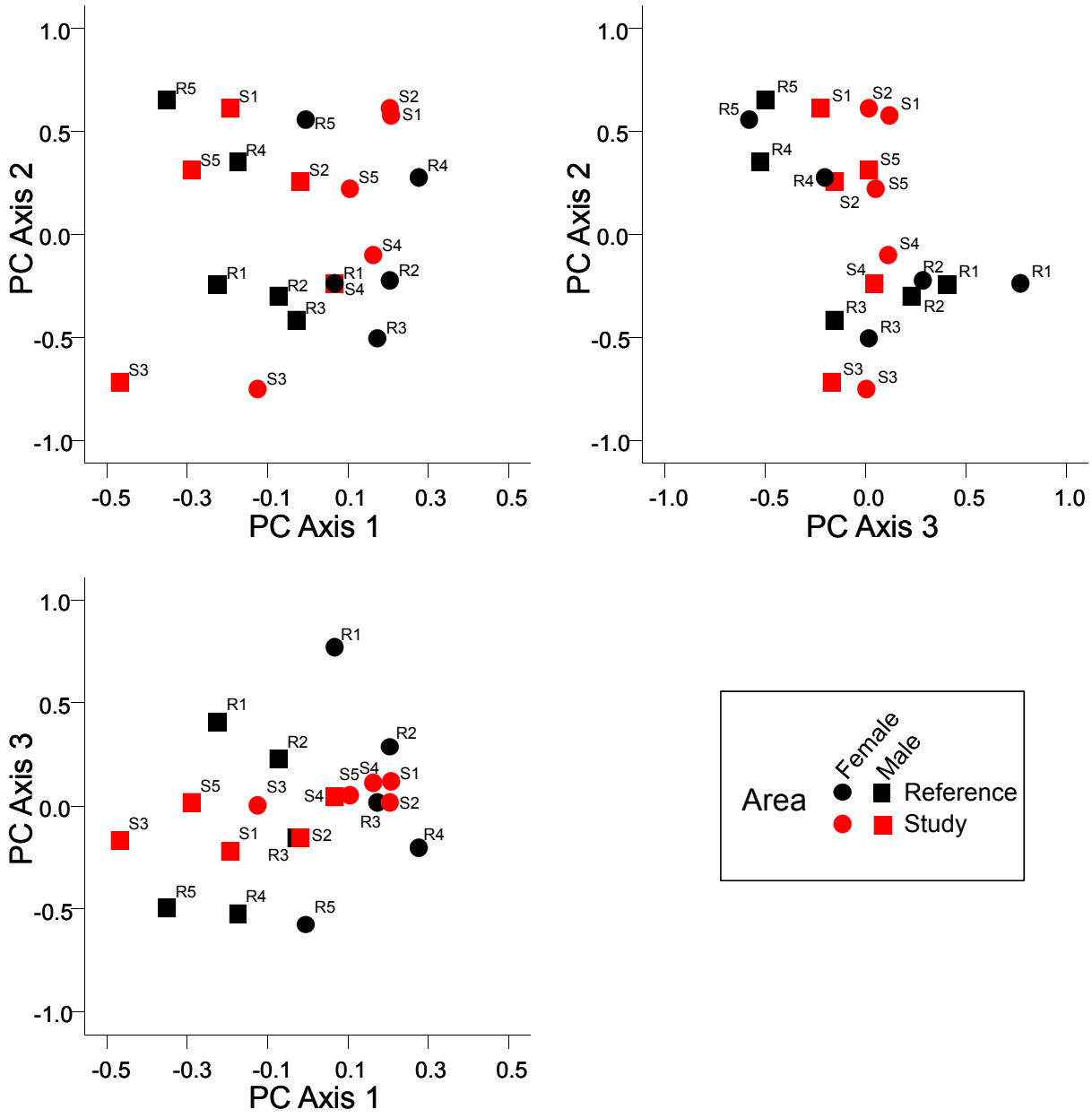


Figure 7-3 Mean Scallop Size and Shape Principal Component (PC) Scores (2012)

Notes: S denotes Study, R denotes Reference and numbers 1 through 5 denote the transect number

Table 7-9 Results of Nested ANOVA Comparing Scallop Size and Shape Principal Components (PCs) Among Transects Within Areas and Between Areas (2012)

Variable	Source	Female		Male	
		df	*p*	df	*p*
Whole Data Set					
PC Axis 1	Area	1	0.716	1	0.947
	Transect within Area	8	0.380	8	0.081
	Error	630		474*	
PC Axis 2	Area	1	0.687	1	0.921
	Transect within Area	8	0.000	8	0.000
	Error	630		474*	
PC Axis 3	Area	1	0.991	1	0.962
	Transect within Area	8	0.000	8	0.000
	Error	630		474*	
Body Burden Data Set					
PC Axis 1	Area	1	0.854	1	0.229
	Transect within Area	8	0.096	8	0.042
	Error	96		83*	
PC Axis 2	Area	1	0.552	1	0.770
	Transect within Area	8	0.002	8	**<0.001**
	Error	96		83*	
PC Axis 3	Area	1	0.564	1	0.814
	Transect within Area	8	0.006	8	0.145
	Error	96		83*	

Note: - $p \leq 0.001$ in **bold.**
- Muscle weight was missing for one male.

7.4.1.2 Plaice

Sex Ratios and Maturity Stages

Thirty-six females and 14 males were collected in the Study Area, and 45 females and five males were collected in the Reference Area. Females outnumbered males in both Areas, but the female:male sex ratio were significantly different between the two Areas ($p = 0.040$; Fisher Exact Test), with a lower female:male ratio in the Study Area.

The number of males collected in the Reference Area was low ($n = 5$) and no maturity stage was recorded for one fish. The four fish with recorded maturity stage were mature. In the Study Area, 8 of 14 (57%) males were mature and six were immature (43%) (Table 7-10). No significant differences in frequencies of various maturity stages were observed between the two Areas for male fish (Table 7-10, Fisher Exact Test). However, these results should be interpreted with caution as sample size is very small for comparison.

Table 7-10 Frequencies (%) of Maturity Stages of Male Plaice (2012)

Area	N	Immature M-100 [a]	Spent in the previous year M-110 [a]	Maturing to spawn this year M-140 [a]	Partly spent M-150 [a]	Spent this year M-160+M-170 [a]
Reference	4*	0	0	75.0	0	25.0
Study	14	42.9	21.4	21.4	0	14.3
p [b]		0.245	1.000	0.083	1.000	1.000

Note: - [a] Maturity stages were defined according to procedures used by DFO (Appendix D-3, Annex A).
- [b] *p* obtained with the Fisher Exact Test.
- * A fifth fish was collected but no maturity stage was recorded.

There were significant differences between the two Areas in the frequencies of immature females ($p = 0.002$), females maturing to spawn ($p = 0.041$) and spent females ($p < 0.001$) (Fisher Exact Test), with more immature females and females maturing to spawn and less spent females in the Study Area (Table 7-11).

Table 7-11 Frequencies (%) of Maturity Stages of Female Plaice (2012)

Area	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	45	2.2	4.4	2.2	4.4	86.7
Study	36	27.8	13.9	16.7	5.6	36.1
p [b]		0.002	0.232	0.041	1.000	<0.001

Note: - [a] Maturity stages were defined according to procedures used by DFO (Appendix D-3, Annex A).
- [b] *p* obtained with the Fisher 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 7-12. The complete data set is provided in Appendix D-3 (Annex B).

The Gonado-somatic Index was significantly different ($p = 0.036$) between Area, with a higher mean in males from the Study Area. Otherwise, there were no significant differences between Areas. Again, these results have to be interpreted cautiously because the samples sizes were very small for comparison.

Table 7-12 Biological Characteristics and Condition Indices of Male Plaice (all Maturity Stages Pooled) (2012)

Parameter	Reference Area	Study Area	*p* [d]
Fish number	5	14	
Length (cm)	35.1 ± 2.8	35.3 ± 3.2	0.884
Total body weight (g)	380.4 ± 85.6	374 ± 73.7	0.883
Liver weight (g)	4.4 ± 2.6	5.1 ± 2.3	0.535
Gonad weight (g)	3.5 ± 1.0	5.4 ± 2.1	0.087
Age (year)	9.0 ± 2.6	8.4 ± 1.4	0.495
Fulton's condition factor [a]	0.871 ± 0.061	0.851 ± 0.107	0.705
Hepato-somatic index [b]	1.087 ± 0.448	1.381 ± 0.532	0.287
Gonado-somatic index [c]	0.838 ± 0.609	1.452 ± 0.485	0.036

Note: - All data are expressed as mean of raw values ± standard deviation.
- [a] Calculated as 100 x total body weight/length^3.
- [b] Calculated as 100 x liver weight/total body weight.
- [c] Calculated as 100 x gonad weight/total body weight.
- [d] *p* obtained with the Unpaired t-test or Mann-Whitney Rank Sum test.

Adjusted means obtained by ANCOVA are provided in Table 7-13. There were no significant differences between Areas for total weight relative to length ($p = 0.467$), liver weight relative to total weight ($p = 0.467$) or gonad weight relative total weight ($p = 0.121$).

Table 7-13 Adjusted Means of Male Plaice (all Maturity Stages Pooled) (2012)

Variable	Covariate	Adjusted Means		*p* [a]
		Reference Area	Study Area	
Total weight	Length	384.4	373	0.467
Liver weight	Total weight	4.333	5.167	0.467
Gonad weight	Total weight	3.64	5.389	0.121

Note: - Adjusted means are predictive mean variable at overall mean covariate.
- [a] *p* obtained after ANCOVA analysis of log-log regression of variable on covariate.

Females

Information on biological characteristics and condition of female fish (all maturity stages pooled) from the Reference and Study Areas are summarized in Table 7-14. The complete data set is provided in Appendix D-3 (Annex B).

Table 7-14 Biological Characteristics and Condition Indices of Female Plaice (All Maturity Stages Pooled) (2012)

Parameter	Reference Area	Study Area	p [d]
Fish number	45	36	
Length (cm)	41.5 ± 3.4	40.6 ± 4.7	0.322
Total body weight (g)	659.9 ± 189.9	657.4 ± 269.1	0.482
Liver weight (g)	7.4 ± 3.4	8.6 ± 4.3	0.237
Gonad weight (g)	22.6 ± 12.6	22.8 ± 16.7	0.565
Age (year)	9.9 ± 1.3	9.5 ± 1.8	0.163
Fulton's condition factor [a]	0.765 ± 0.134	0.822 ± 0.086	0.011
Hepato-somatic index [b]	1.104 ± 0.348	1.328 ± 0.575	0.076
Gonado-somatic index [c]	3.224 ± 1.365	3.289 ± 2.068	0.260

Note: - All data are expressed as mean of raw values ± standard deviation.
- [a] Calculated as 100 x total body weight/length^3.
- [b] Calculated as 100 x liver weight/total body weight.
- [c] Calculated as 100 x gonad weight/total body weight.
- [d] p obtained with the Unpaired t-test or Mann-Whitney Rank Sum test.

Fulton's condition factor was significantly different (p = 0.011) between Areas, with a higher mean observed in fish from the Study Area. Otherwise, there were no significant differences between Areas.

Adjusted means obtained by ANCOVA are provided in Table 7-15. Liver and gonad weight relative to total weight did not differ significantly between the two Areas (p = 0.220 and p = 0.436, respectively). However, total weight relative to length differed between Areas (p = 0.006), with higher total weight relative to length in fish from the Study Area.

Table 7-15 Adjusted Means of Female Plaice (all Maturity Stages Pooled) (2012)

Variable	Covariate	Adjusted Means		p [a]
		Reference Area	Study Area	
Total weight	Length	638.4	684.3	**0.006**
Liver weight	Total weight	7.392	8.099	0.22
Gonad weight	Total weight	22.55	21.33	0.436

Note: - Adjusted means are predictive mean variable at overall mean covariate.
- [a] p obtained after ANCOVA analysis of log-log regression of variable on covariate.

Because significant differences were observed in the prevalence of female maturity stages between the two Areas, comparisons were also carried out on the maturity stage that was the most prevalent in both Areas (i.e., spent females).

As was the case for all females, Fulton's condition factor differed significantly between Area for spent females (p = 0.009), with spent females from the Study Area exhibiting a higher index than spent females from the Reference Area (Table 7-16).

Table 7-16 Biological Characteristics and Condition Indices of Spent Female Plaice (2012)

Parameter	Reference Area	Study Area	p [d]
Fish number	39	13	
Length (cm)	41.7 ± 3.3	41.8 ± 5.4	0.688
Total body weight (g)	672.3 ± 194.6	738.3 ± 319.9	0.916
Gutted body weight (g)	581.6 ± 161.4	652.5 ± 287.5	0.846
Liver weight (g)	7.5 ± 3.4	8.0 ± 5.0	0.991
Gonad weight (g)	23.8 ± 11.8	21.8 ± 13.4	0.617
Age (year)	9.9 ± 1.4	10.0 ± 1.6	0.810
Fulton's condition factor [a]	0.786 ± 0.064	0.840 ± 0.052	**0.009**
Hepato-somatic index [b]	1.110 ± 0.363	1.071 ± 0.447	0.749
Gonado-somatic index [c]	3.388 ± 1.245	2.763 ± 0.635	0.090

Note: - All data are expressed as mean of raw values ± standard deviation.
- [a] Calculated as 100 x total body weight/length^3.
- [b] Calculated as 100 x liver weight/total body weight.
- [c] Calculated as 100 x gonad weight/total body weight.
- [d] p obtained with the Unpaired t-test or Mann-Whitney Rank Sum test.

Adjusted means for spent females obtained by ANCOVA are provided in Table 7-17. Total body weight relative to length and gonad weight relative to body weight differed significantly between the two Areas (p = 0.010 and p = 0.011, respectively), with fish from the Study Area exhibiting a higher adjusted mean for total weight and a lower adjusted mean for gonad weight than fish from the Reference Area.

Table 7-17 Adjusted Means of Spent Female Plaice (2012)

Variable	Covariate	Adjusted Means		p [a]
		Reference Area	Study Area	
Total weight	Length	674.6	731.5	**0.01**
Liver weight	Total weight	7.743	7.385	0.67
Gonad weight	Total weight	24.59	19.54	**0.011**

Note: - [a] Adjusted means are predictive mean variable at overall mean covariate. They were obtained using the anti-Log_{10} transformation using the Log_{10} adjusted means from the ANCOVA analysis.
- [b] p were obtained using Log_{10} transformed data due to lack of homogeneity of variances/homogeneity of slopes.

7.4.2 BODY BURDEN

7.4.2.1 Scallop

Metals and Fat

In 2012, like in prior years, arsenic, boron, cadmium, mercury, strontium and zinc were detected in most scallop adductor muscle samples (Appendix D-2). Strontium concentration was below detection limit (1.5 mg/kg) in one Reference Area and in three 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 all scallop viscera samples in the Reference and Study Areas in 2012. 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 2012, $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbons were detected in four viscera samples from the Study Area and barium was detected in all Study Area viscera samples. $>C_{21}$-C_{32} hydrocarbons in viscera resulted from a laboratory artefact called tailing (where high $>C_{10}$-C_{21} hydrocarbon levels result in measurable levels in the $>C_{21}$-C_{32} range, even if levels of the latter hydrocarbons are not elevated) (J. Kiceniuk, 2012 pers. comm.). Hydrocarbons were not detected in any Reference Area samples, but barium was detected in one Reference Area viscera sample (Appendix D-2).

There were two muscle Principal Components (PCs) that each accounted for more than 10% of the total variance in analyte concentration (Table 7-18). 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 positively correlated with concentrations of mercury (Table 7-16), indicating that concentrations of mercury tended to vary independently of concentrations of other metals. The PC analyses here justify further examination of muscle PC1 scores, as a measure of total metals concentrations in muscle, and of mercury concentrations.

Table 7-18 Correlations (r) Between Concentrations of Metals in Scallop Tissue and Principal Components Derived from those Concentrations (1997 to 2012)

Variable	Correlation (*r*) with:					
	Muscle		Viscera			
	PC1	PC2	PC1	PC2	PC3	PC4
Aluminum			-0.12	**-0.94**	0.04	0.16
Arsenic	**0.63**	-0.50	**0.73**	-0.10	-0.41	0.13
Boron	0.58	-0.33	0.35	0.05	0.49	-0.28
Cadmium	0.55	0.10	**0.64**	0.01	0.33	-0.37
Copper			**0.70**	0.19	-0.01	0.50
Iron			0.14	**-0.94**	0.03	0.03
Manganese			0.39	-0.48	0.26	0.49
Mercury	0.20	**0.84**	0.41	0.24	-0.58	0.21
Nickel			0.37	0.26	0.49	0.57
Selenium			**0.83**	0.03	0.04	-0.25
Strontium	**0.70**	0.23	0.22	-0.55	0.15	-0.27
Uranium			0.54	-0.33	-0.54	-0.21
Zinc	**0.85**	0.15	**0.78**	0.25	0.13	-0.25
Percent of Variance Explained	38.2	19.2	28.4	20.3	11.5	10.5

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

There were four viscera PCs that each accounted for more than 10% of the total variance in analyte concentrations (Table 7-18). Concentrations of metals in viscera, except aluminum, 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, and none of the metals concentrations was strongly associated with scores on either viscera PC3 or PC4. Viscera PC3 and PC4 are, therefore, not examined in analyses below.

Scallop muscle PC1 (i.e., metals concentrations) varied significantly over time (Year term $p < 0.001$; Table 7-19). Muscle PC1 scores were somewhat lower before drilling (BA Term $p = 0.002$), but this difference as well as change over time in EEM years (EEM Linear Contrast $p < 0.001$) occurred in both Areas (BACI Contrast $p = 0.98$, EEM Linear x Area $p = 0.39$, also see Figure 7-4). Metal PC1 scores have generally been lower in the Study Area compared to the Reference Area (Area Term $p = 0.001$, Figure 7-4).

Table 7-19 Results of Two-Way ANOVA Comparing Metal and Fat Concentrations in Scallop Adductor Muscle Among Years and Between Areas (1997 to 2012)

Source	df	*p*		
		PC1	Mercury	Fat
Year	8	**<0.001**	**<0.001**	**<0.001**
BA	1	0.002	**<0.001**	0.068
EEM Linear	1	**<0.001**	**<0.001**	**<0.001**
Area (CI)	1	**0.001**	**<0.001**	0.456
Year*Area	8	0.150	0.019	0.097
BACI	1	0.983	0.362	0.283
EEM Linear*Area	1	0.394	0.028	0.914
Error	72			

Notes: - $p \leq 0.001$ in **bold.**
- n = 90 composite samples.

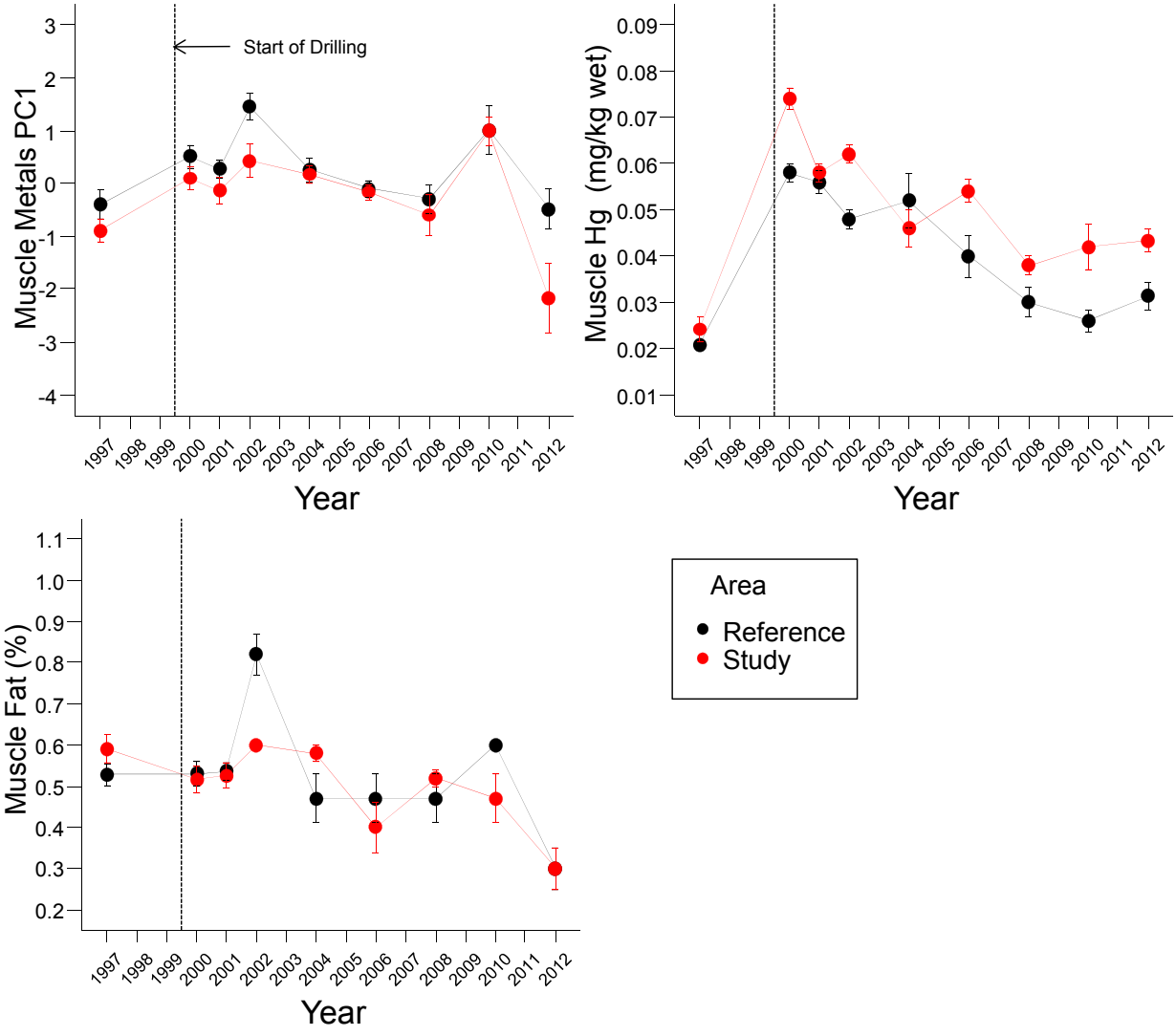


Figure 7-4 Area Mean (± 1 Standard Error (SE)) Metal and Fat Concentrations in Scallop Adductor Muscle (1997 to 2012)

Mercury concentrations also varied significantly over time (Year Term $p < 0.001$, Table 7-19). Concentrations were lower before drilling began (BA Term $p < 0.001$), but again this difference occurred in both Areas (BACI Contrast $p = 0.362$). Mercury concentrations have generally been higher in the Study Area in most years (Area Term $p < 0.001$), including baseline (Figure 7-4). Mercury levels have decreased in EEM years (EEM Linear Term $p < 0.001$, Figure 7-4), the decrease being somewhat less in the Study Area than the reference area (EEM Linear x Area Contrast $p = 0.028$, Figure 7-4).

Fat content in muscle varied among years (Year Term $p < 0.001$, Table 7-19), but not between Areas (Area Term $p = 0.456$) and has generally decreased in EEM years (EEM Linear Term $p < 0.001$, Figure 7-4).

Viscera metals PC1 scores differed between the Study and Reference Areas (Area Term $p < 0.001$, Table 7-20) and among years (Year Term $p = 0.001$), but with no difference between Areas from before to after drilling (BACI contrast $p = 0.087$, Table 7-20). Viscera metals PC1 scores were greater in the Study Area than in the Reference Area in every year including baseline, except for 2008 (Figure 7-5). Annual Reference Area means were relatively constant over time, whereas Study Area means were more variable (Year x Area Contrast $p = 0.003$, Figure 7-5). 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 Contrast $p = 0.007$, Figure 7-5).

Table 7-20 Results of Two-Way ANOVA Comparing Metal and Fat Concentrations in Scallop Viscera among Years and Between Areas (1997 to 2012)

Source	df	*p*		
		PC1	PC2	Fat
Year	8	**0.001**	**<0.001**	**<0.001**
BA	1	0.572	0.753	**<0.001**
EEM Linear	1	**<0.001**	**0.001**	0.005
Area (CI)	1	**<0.001**	0.013	0.116
Year x Area	8	0.003	0.041	**<0.001**
BACI	1	0.087	0.057	0.562
EEM Linear x Area	1	0.007	0.359	0.038
Error	72			

Notes: - $p \leq 0.001$ in **bold.**
- $n = 90$ composite samples.

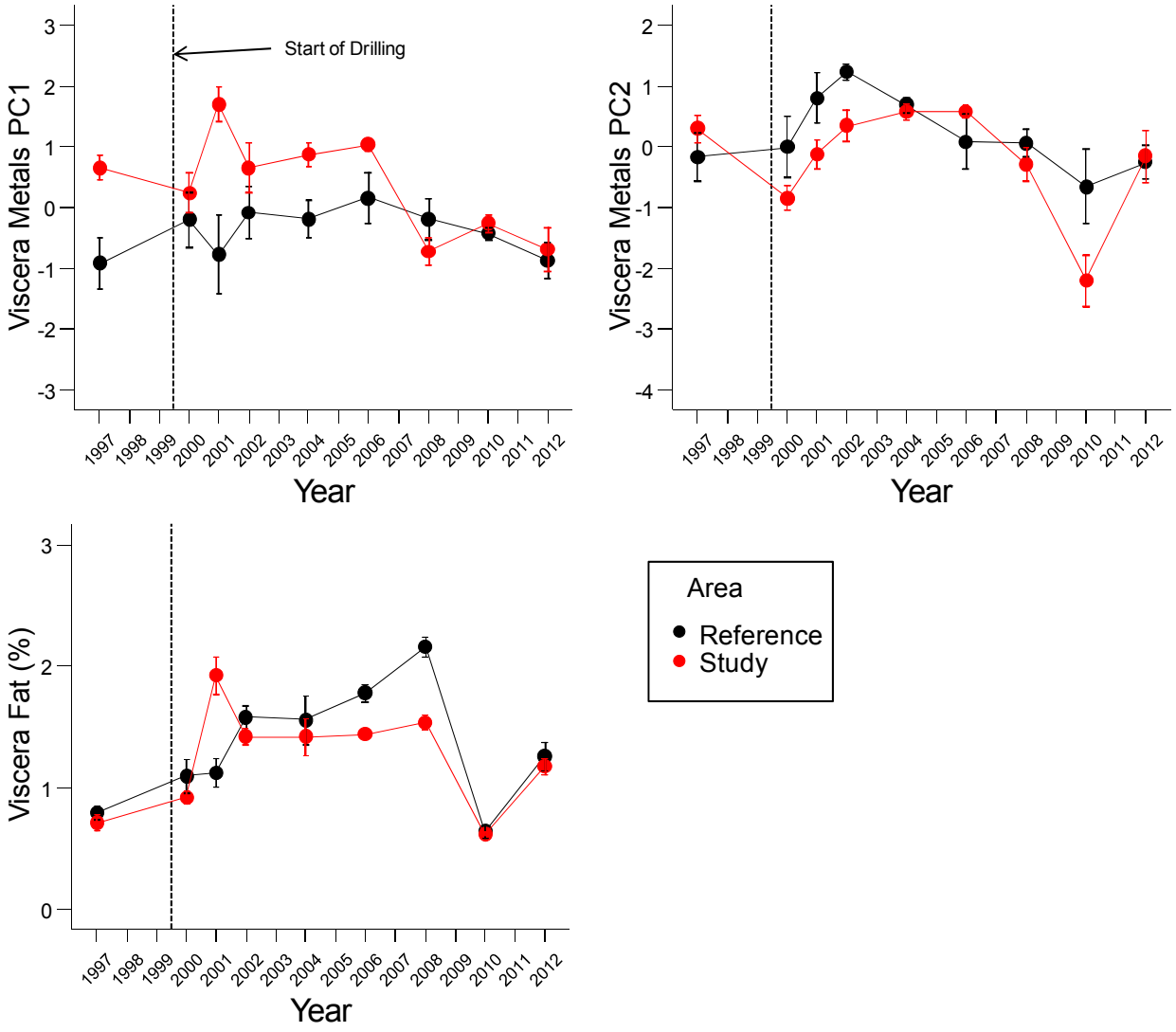


Figure 7-5 Area Mean (± 1 SE) Metal and Fat Concentrations in Scallop Viscera (1997 to 2012)

Viscera PC2 scores (negatively correlated with metals that occurred in high concentration in sediments) differed significantly over time (Year Term $p < 0.001$, Table 7-20). In both Areas, viscera PC2 scores generally decreased in EEM years (EEM Linear Term $p = 0.001$). Viscera PC2 scores in the Study Area relative to the Reference Area differed significantly over time (Year x Area Term $p = 0.013$, also note the nearly significant BACI Term). Viscera PC2 scores were greater in the Study Area than in the Reference Area in 1997, but scores were lower in the Study Area in most (five of eight) EEM years. Scores in 2012 were similar in both Areas (Figure 7-5).

In 2001, Study Area viscera fat content was greater than Reference Area fat content, whereas in all other years, Study Area fat content was similar to or lower than Reference Area fat content (Figure 7-5). The Year x Area interaction in Table 7-20 was significant partly because of the high value in the Study Area in 2001 versus other years. However, differences between Areas also varied in other years, from approximately 0 in 2010 and 2012 to approximately 50% in 2008. Fat content in scallop viscera varied between about 1 and 2%.

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 7-6). $>C_{10}$-C_{21} hydrocarbons were not detected in the Study Area in 1997 (baseline). 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 or 2012.

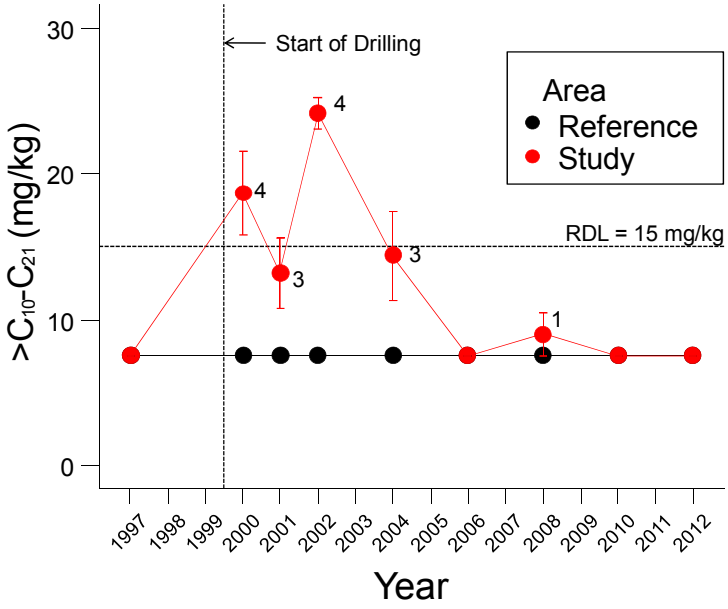


Figure 7-6 Frequencies of Detection and Area Means for $>C_{10}$-C_{21} Hydrocarbon Concentrations in Scallop Adductor Muscle (1997 to 2012)

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 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 in 2012 (1.6 mg/kg). Over the years, the Reference Area maximum was 2 mg/kg and the Study Area maximum was 5.8 mg/kg.

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 7-7). $>C_{10}$-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. Study Area means were well above the laboratory detection limit in earlier EEM years, decreased to near the detection limit in 2008, were below the detection limit in 2010, and were just at the detection limit in 2012. Chromatograms from Study Area samples with detectable hydrocarbon concentrations have resembled the profile of PureDrill IA35-LV. Therefore, contamination of scallop viscera from hydrocarbons in synthetic-based drill muds occurred but has been decreasing over time.

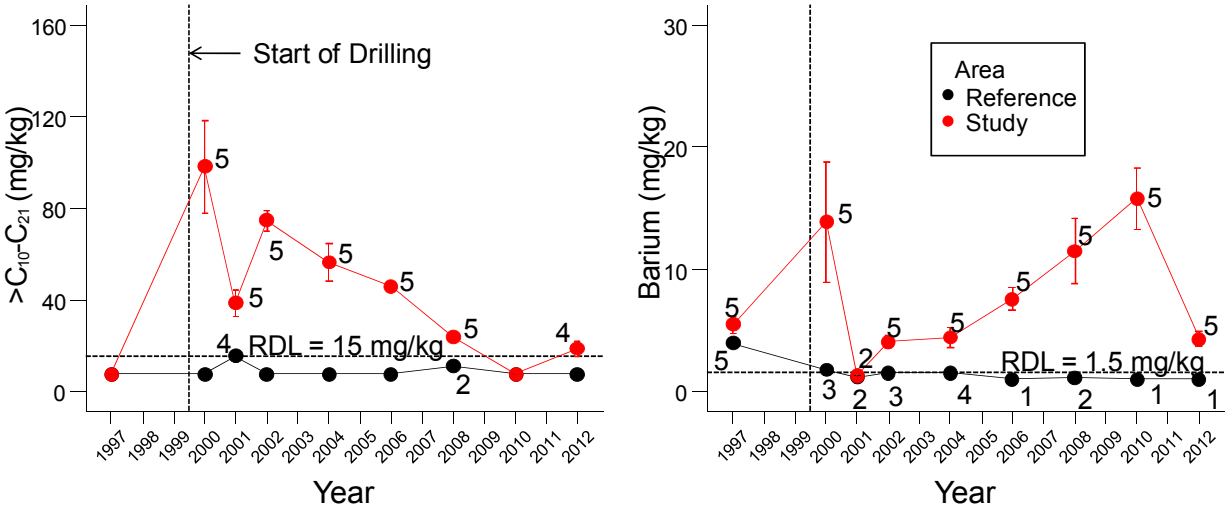


Figure 7-7 Frequencies of Detection and Area Meands of $>C_{10}$-C_{21} Hydrocarbon and Barium Concentrations in Scallop Viscera (1997 to 2012)

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 detection limit for the purpose of estimating means and SEs.

Barium has been detected more frequently and at higher concentrations in Study Area viscera samples than in Reference Area samples in EEM years (Figure 7-7). In 1997, barium was detected in all five Reference Area samples. Frequencies of detection and median concentrations subsequently decreased. 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. The concentration of barium decreased in 2012. 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 60 plaice fillet samples from 2000 to 2012 (Appendix D-2).

Arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc were detected in all 40 plaice liver composite samples in 2001, 2002, 2004, 2006 and 2010[34]. In 2008, manganese and selenium were not detected in one Reference Area sample with elevated laboratory detection limits (5 mg/kg). That sample was excluded from further analyses. Arsenic, cadmium, copper, selenium and zinc were detected in all 10 samples in 2012; iron was not detected in one Study Area sample; manganese was not detected in two samples from the Study Area; and mercury was not detected in two Study Area samples (Appendix D-2).

$>C_{10}$-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 2012 (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 2012 was approximately 1 to 2%. Fat content in composite liver samples was higher (approximately 10%) (Appendix D-2).

[34] 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 benzo(*j*)fluoranthese were detected in one plaice liver sample in 2012 (composite sample TNSA-02, Appendix D-2). However, a fluid leak onto the sample processing area was noted on the day that the sample in question was processed. The leak was fixed and a sample of the fluid was collected and processed for chemistry. Examination of chromatograms for the hydraulic fluid and the contaminated tissues indicated a good match between compounds in tissue and compounds in the fluid (J. Kiceniuk pers. comm.; Maxxam Analytics, pers. comm.). Therefore, tissue contamination with benzo(*j*)fluoranthene for the one liver sample in 2012 likely resulted from contamination onboard the sampling vessel.

Metals and Fat

Concentrations of arsenic, zinc and fat in plaice fillets varied significantly among EEM years (all Year Terms $p < 0.001$, Table 7-21). However, those differences were similar in both Areas (all Area Terms and Year x Area Contrasts $p > 0.05$). There was a net increase in arsenic concentrations in plaice filets over time in EEM years in both Area (EEM Linear Term $p < 0.001$, Figure 7-8), while zinc concentrations decreased, again in both Areas (EEM Linear Term $p = 0.003$, Figure 7-8). Those relationships spanned a narrow range of concentrations and were significant primarily because variance within Areas within years was minimal. Fat content in plaice fillets decreased over the study period (Year and EEM Linear Terms $p < 0.001$, Figure 7-21), in both the Reference and Study Areas. Mercury concentrations have been between 0.05 and 0.1 mg/kg (wet wt) over the period of study (Figure 7-8), and there have been no significant variations in mercury concentrations among years, or between Study and Reference Areas (Table 7-21).

Table 7-21 Results of Two-Way ANOVA Comparing Metal and Fat Concentrations in Plaice Fillets among Years and Between Areas (2001 to 2012)

Source	df	*p*			
		Arsenic	**Mercury**	**Zinc**	**Fat**
Year	6	**<0.001**	0.099	**<0.001**	**<0.001**
EEM Linear	1	**<0.001**	0.152	0.003	**<0.001**
Area	1	0.784	0.405	0.993	0.280
Year x Area	6	0.199	0.100	0.957	0.089
EEM Linear x Area	1	0.143	0.466	0.932	0.435
Error	56				

Notes: - $p \leq 0.001$ in **bold.**
- $n = 70$ composite samples.

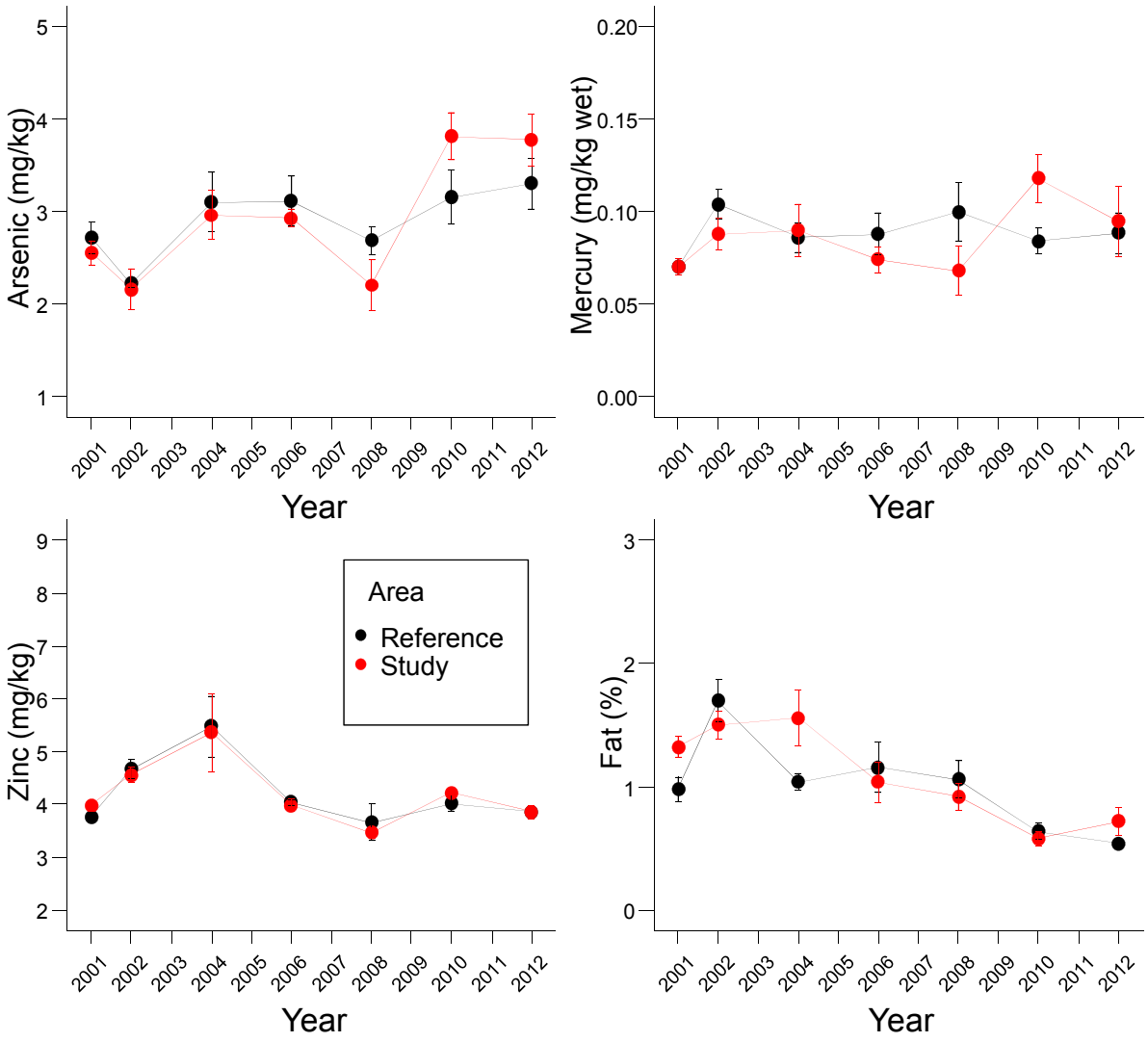


Figure 7-8 Area Mean (± 1 SE) Metal and Fat Concentrations in Plaice Fillets (2001 to 2012)

Mean concentrations of arsenic, mercury and zinc in fillet samples from individual plaice in 2000 were similar to means in subsequent years and did not differ substantially between Areas (Table 7-22). Fat content was not measured in 2000 fillet samples.

Table 7-22 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

Concentrations of the eight metals detected in all 69 plaice liver composites included in data analyses were positively correlated with liver PC1 derived from those concentrations (Table 7-23). Therefore, plaice liver PC1 was a summary measure of total metal concentrations. Plaice liver PC2 was negatively correlated with manganese concentrations, and weakly correlated with the other metals. The second liver PC, therefore, primarily reflected variations in concentrations of manganese that were independent of variations in concentration of the other metals. The PCA justified further analysis of PC1 as a measure of overall metals concentrations, and of manganese because it varied somewhat independently of the other metals.

Table 7-23 Correlations (r) Between Concentrations of Metals in Plaice Liver and Principal Components Derived from those Concentrations (2001 to 2012)

Variable	Correlation (*r*) with:	
	PC1	PC2
Arsenic	**0.80**	0.40
Cadmium	**0.80**	0.20
Copper	**0.84**	0.29
Iron	**0.91**	0.01
Manganese	0.54	**-0.71**
Mercury	**0.66**	-0.44
Selenium	**0.81**	-0.24
Zinc	**0.91**	0.16
Percent of Variance Explained	62.7	13.3

Notes: - $|r| \geq 0.6$ in **bold.**
- n = 69 composite samples.

Plaice liver PC1 scores differed significantly among years (Year Term $p < 0.001$, Table 7-24) but not between Areas (Area Term $p = 0.766$). There was a significant decrease over time in scores (EEM Linear Term $p < 0.001$, Figure 7-9) common to both Areas (EEM Linear x Area Contrast $p = 0.352$).

Table 7-24 Results of Two-Way ANOVA Comparing Metal Concentrations in Plaice Liver among Years and Between Areas (2001 to 2012)

Source	PC1		Manganese		Fat	
	df	*p*	df	*p*	df	*p*
Year	6	**<0.001**	6	**<0.001**	4	**<0.001**
EEM Linear	1	**<0.001**	1	**<0.001**	1	**<0.001**
Area	1	0.766	1	0.872	1	0.933
Year x Area	6	0.108	6	0.084	4	0.789
EEM Linear x Area	1	0.352	1	0.076	1	0.248
Error	55		55		40	

Notes: - $p \leq 0.001$ in **bold.**
- n = 69 composite samples from 2001 to 2012 for metals.
- n = 50 composite samples from 2004 to 2012 for fat.

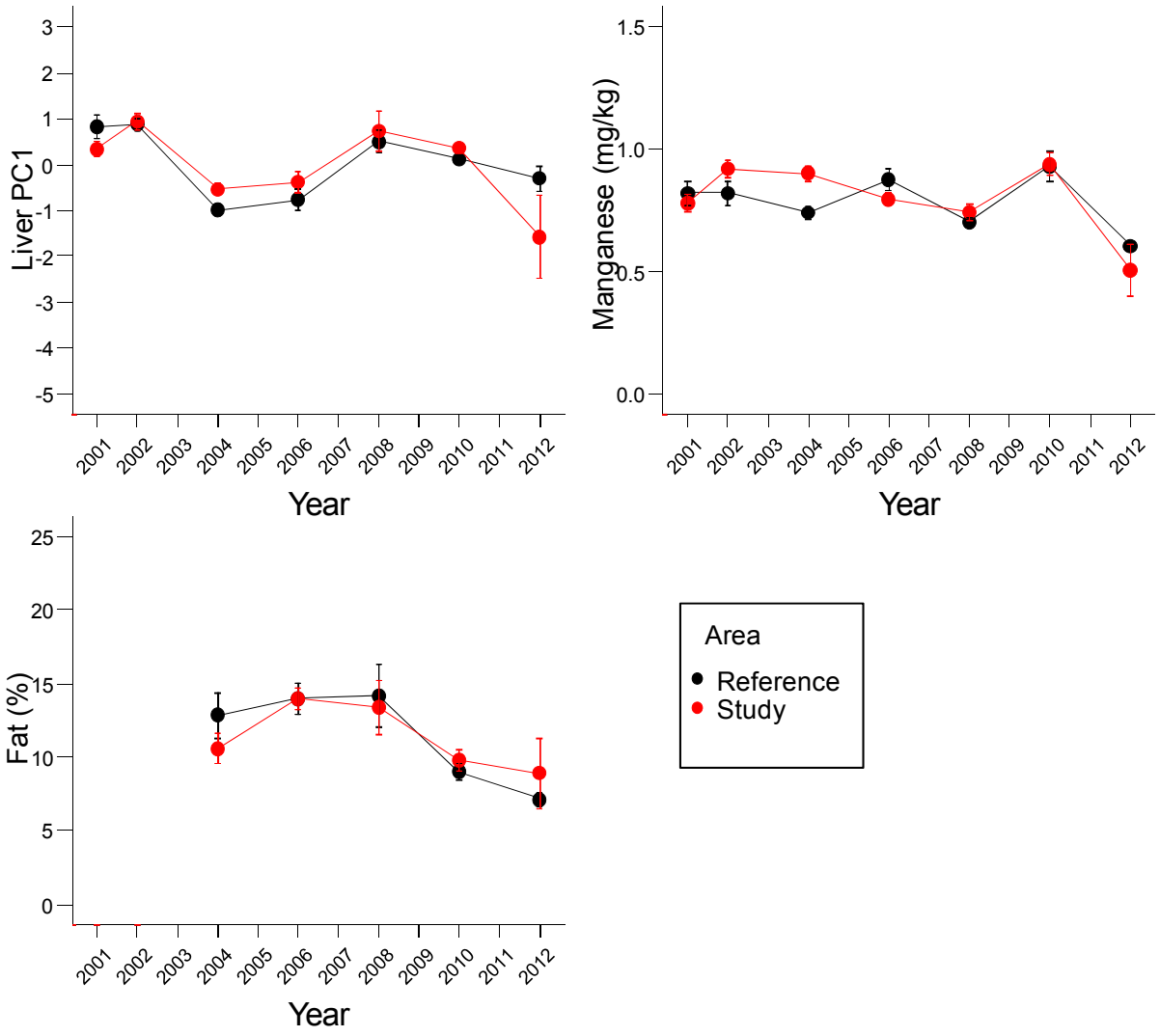


Figure 7-9 Area Mean (± 1 SE) Metal (2001 to 2012) and Fat (2004 to 2012) Concentrations in Plaice Livers

Manganese concentrations varied among years, with a significant decrease over time (Year and EEM Linear Terms $p < 0.001$, Table 7-24) common to both Reference and Study Areas (EEM Linear x Area Term $p = 0.076$).

Fat concentrations varied among years, with a significant decrease in fat content over time (Year and EEM Linear Terms $p < 0.001$, Table 7-24, Figure 7-9) common to both Reference Area and Study Area fish (EEM Linear x Area Contrast $p = 0.248$). Annual means for both Areas from 2004 to 2012 were approximately 7 to 15%, similar to values for the single Area composites analyzed in 2001 and 2002 (Table 7-25).

Table 7-25 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 (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 7-26). Compounds in the >C_{21}-C_{32} range were detected in all composites in those two years. In 2006, 2008, 2010 and 2012, compounds in the >C_{10}-C_{21} and >C21-C32 hydrocarbon range were detected in all liver composite. Median and maximum hydrocarbon concentrations were generally similar in the Reference and Study Areas (Table 7-26).

Table 7-26 Hydrocarbon Concentrations in Plaice Liver (2002 to 2012)

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
>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

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 70 to 80 mg/kg, with concentrations less than detection limit, for other samples.
- [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 38 and 48 mg/kg, and concentrations less than detection limit, for the other two samples. The median and maximum were based on the three samples with concentrations greater than detection limit.
- LDL = Laboratory Detection Limit.

Since 2002, hydrocarbons 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. That sample was from composite TNSA-02 and the Unresolved Complex Mixture in the chromatogram for this composite was similar to the Unresolved Complex Mixture for the hydraulic fluid that contaminated that sample (see 5th paragraph in Section 7.4.3.2 (page 33)). Otherwise, hydrocarbon peaks observed on chromatograms for liver (Appendix D-2; also see Suncor Energy 2003, 2005, 2007, 2009 and 2011 for chromatograms for 2002, 2004, 2006, 2008 and 2010 samples, respectively) were consistent with those expected for natural compounds (J. Kiceniuk, 2013 pers. comm.) and similar compounds have consistently been observed in plaice liver at the nearby White Rose site (Husky Energy 2011). In 2012, one sample (liver composite TNSA-03) from the Terra Nova Study Area was analyzed further by mass spectroscopy[35]. Based on this additional analysis, Maxxam Analytics reports that there was no indication of petrogenic hydrocarbons in the sample (see Appendix D-2 for results of additional analysis on liver).

[35] Only one sample had sufficient tissue remaining after the first analysis to undertake an additional analysis.

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 only 9 out of 24 samples. These results are not significant at $\alpha = 0.05$ (Appendix D-5).

ANOVA statistics for hedonic scaling are provided in Table 7-27 and a frequency histogram of results is provided in Figure 7-10. These results show no significant taste difference between Areas.

Table 7-27 Analysis of Variance for 2012 Taste Evaluation by Hedonic Scaling of Scallop

Source of Variation	SS	df	MS	F	*p*
Between Groups	0.52	1	0.52	0.30	0.59
Within Groups	79.46	46	1.73		
Total	79.98	47			

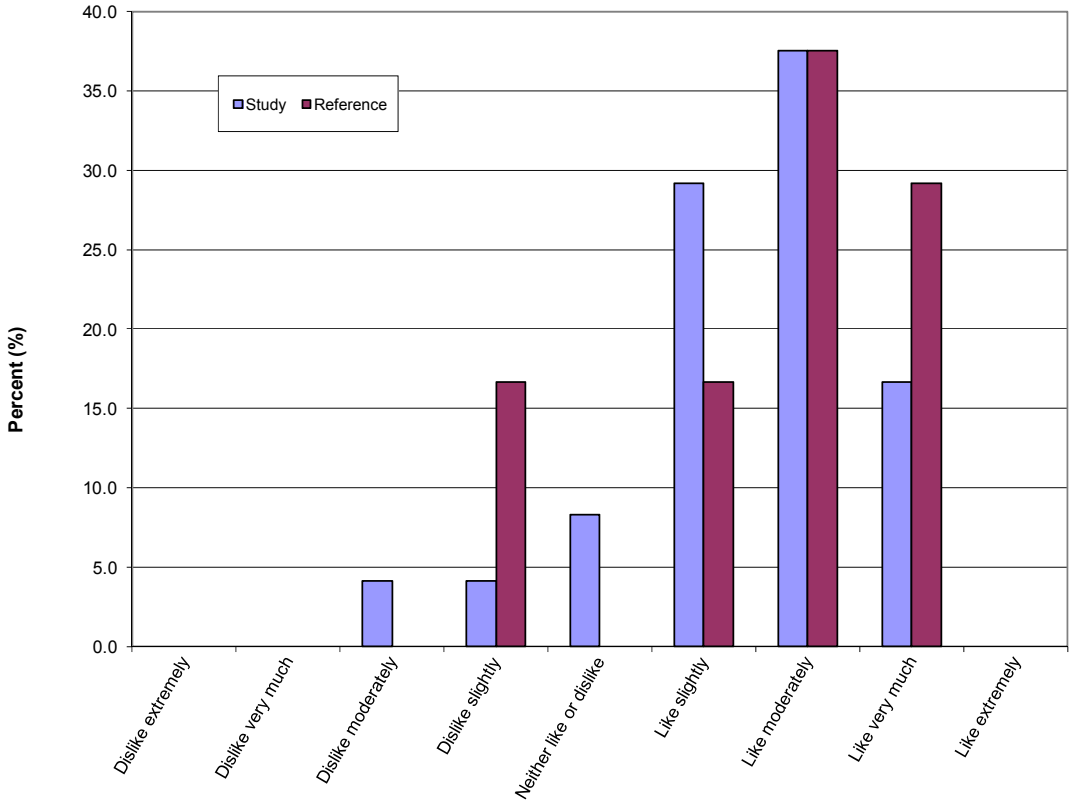


Figure 7-10 Scallops Frequency Histogram for Hedonic Scaling Taste Evaluation (2012)

From ancillary comments (Tables 7-28 and 7-29; Appendix D-5), there were no consistent comments identifying abnormal or foreign odour or taste.

Table 7-28 Summary of Comments from the Triangle Test for Scallop (2012)

Reference Area (RA)	Study Area (SA)
Correctly identified as odd sample	**Correctly identified as odd sample**
996 (RA) has a stronger taste, others bland	Very similar, little stronger flavour
525 (RA) a little less sweet scallop taste	Couldn't really tell the difference between any of them
525 9RA) had a stronger/sweeter seafood taste and was preferred over the other two samples	Sample 871 (SA) has a preferred flavour as compared to the other two samples
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
339 (SA) was less flavourable	Did not like. Not sweet. Slight odour on 684 (SA)
515 (RA) sweeter	525 (RA) and 626 (SA) have a milder taste
132 (RA) sweeter, more succulent. 139 (RA), 871 (SA) slightly stale	Very difficult to taste any difference. I identified the odd one by the slight difference in odour
871 (SA)/132 (RA) smell and taste a little sweeter than 139 (RA) , which has a fishier odour	Stronger odour from 396 (SA)
All quite flavourful. 139 (RA) a little less but no off odour or flavours noted	

Table 7-29 Summary of Comments from the Hedonic Scaling Test for Scallop (2012)

Preferred Reference Area (RA)	Preferred Study Area (SA)
I could not detect any difference in taste or odour	I could not detect any difference in taste or odour
Stronger odour and flavour on 393 (SA)	Very little difference in both samples
There was more flavour on sample 883 (RA)	Slight odour on 149 (RA)
Very little difference in both samples	209 (SA) sweet; 523 (RA) odour
149 (RA) has a better flavour	523 (RA) OK, but noticeable loss of fresh, sweet, natural flavour. 209 (SA) sweet, succulent, characteristic of fresh, high-quality scallop
149 (RA) has the better overall taste/odour	Not much difference
Lots of grit makes it hard to determine if I like it	Not much difference in the two of them
Not much difference. 149 (RA) seemed sweeter	
No significant difference in flavour of the two samples	
523 (RA) has a sweeter, juicier taste and that is why I preferred it	

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 11 out of 24 samples. These results were not significant at α = 0.05 (Appendix D-5).

ANOVA statistics for hedonic scaling are provided in Table 7-30 and a frequency histogram of results is provided in Figure 7-11. These results show no significant taste difference between Areas.

Table 7-30 Analysis of Variance for 2012 Taste Evaluation by Hedonic Scaling of Plaice

Source of Variation	SS	df	MS	F	*p*
Between Groups	0.02	1	0.02	0.01	0.92
Within Groups	99.46	46	2.16		
Total	99.48	47			

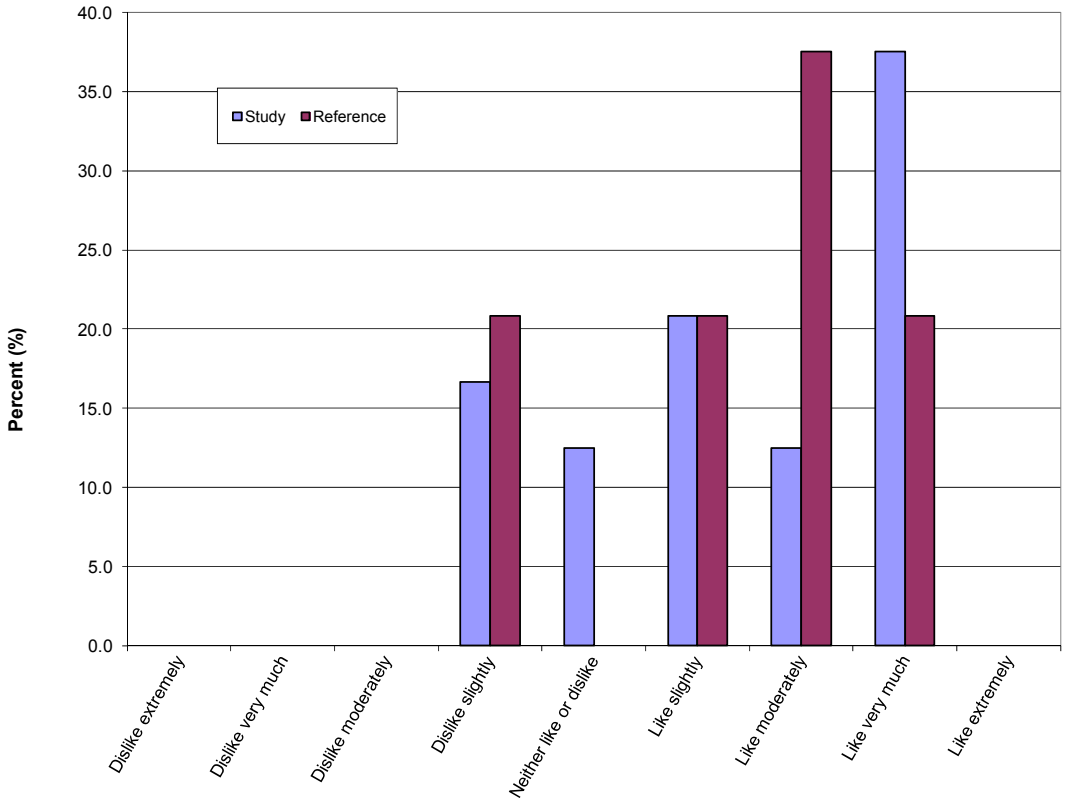


Figure 7-11 Plaice Frequency Histogram for Hedonic Scaling Taste Evaluation (2012)

Ancillary comments from panellists for both tests are summarized in Tables 7-31 and 7-32 and presented in full in Appendix D-5. There were no consistent comments identifying abnormal or foreign odour or taste.

Table 7-31 Summary of Comments from the Triangle Test for Plaice (2012)

Reference Area (RA)	Study Area (SA)
Correctly identified as odd sample	**Correctly identified as odd sample**
Stronger odour and flavour	Clear difference in taste but no difference in smell
110 (RA) smells and tastes less fishy	167 (SA) tasted mild. I quite liked it
Slight different taste in # 826 (RA). 532 (SA) and 893 (SA) tasted similar	551 (SA) was better from a taste perspective. No detectable difference in odour
532 (SA) and 893 (SA) were blander in taste	
Very similar. 826 (RA) has a little more flavour	
Incorrectly identified as odd sample	**Incorrectly identified as odd sample**
Had a stronger flavour, others more bland	Not much difference
Not much of a detectable difference in odour. Sample 601 (RA) did not taste good compared to samples 183 (RA) and 167 (SA)	Very little detectable difference
Stale flavor, an odour difference	Sample 893 (SA) has a more defined flavour
Did not like	532 (SA) and 826 (RA) bland, similar in flavour. 893 (SA) - stronger fishy taste

Table 7-32 Summary of Comments from Hedonic Scaling Tests for Plaice (2012)

Preferred Reference Area (RA)	Preferred Study Area (SA)
257 (SA) smelled a little more fishy	Very similar taste. I like 257 (SA) a little more but not a lot of difference
I don't really taste any difference in the two samples	257 (SA) smelled a little more fishy
237 (RA) has a more desirable flavour, not as fishy	I don't really taste any difference in the two samples
342 (SA) was bland; little to no flavour. 237 (RA) had a sweet taste	Slightly stronger odour on 940 (RA). Flavour of both rather stale tasting
342 (SA) slightly blander, but still very good	Odour and taste was superior for 257 (SA)
237 (RA) was more enjoyable	342 (SA) slightly blander, but still very good
Not much difference in two samples	Seem to be a nice flavour on Sample 342 (SA)
More of a "fishy" taste on 952 (SA)	342 (SA) has a "sweeter" seafood taste. 237 (RA) was bland
986 (SA) had an 'off' aftertaste; 879 (RA) tasted more fresh	712 (RA) - mild/pleasant flavour - OK. 952 (SA) - slightly sweeter
Sample 879 (RA) has a flavoury lingering taste. Sample 986 (SA) was slightly flat in flavour	Not much difference in two samples
Preferred taste of 879 (RA) and there was a slight odour on 986 (SA) and taste was slightly less desirable	I preferred 952 (SA) over the 712 (RA) due to it having more flavour. The odour of 952 (SA) was also nicer
	879 (RA) had a slightly more fishy flavour
	879 (RA) - less flavourable, slightly stale tasting

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

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) and results for each gender (all maturity stages pooled) are summarized in Figures 7-12 and 7-13.

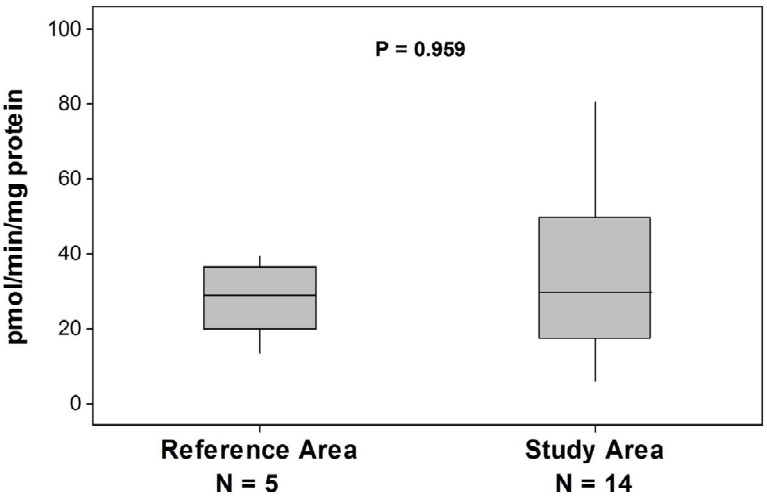


Figure 7-12 EROD Activity in the Liver of Male Plaice (All Maturity Stages)

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 obtained with the Unpaired t- test on log-transformed data.

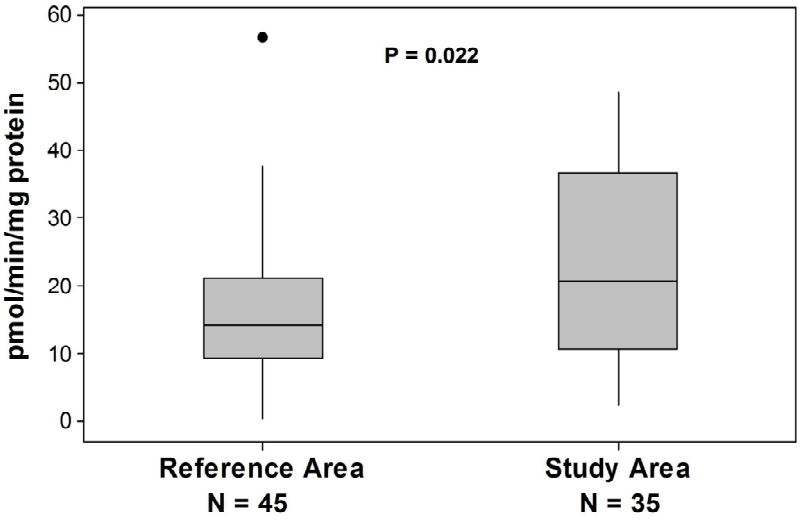


Figure 7-13 EROD Activity in the Liver of Female Plaice (All Maturity Stages Combined)

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 obtained with the Unpaired t- test on log-transformed data.

There was no significant difference in enzyme levels in males between the two Areas (p = 0.959; Unpaired t-test) (Figure 7-12).

For females, a significant inter-area difference in EROD enzyme levels was observed (p = 0.022; Mann-Whitney Rank Sum test on log-transformed data), with activity 1.5 fold higher in females from the Study Area (Figure 7-13).

Since maturity stage can probably 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 (Figure 7-14).

There was no significant difference in enzyme levels between the two Areas (p = 0.22; Mann-Whitney Rank Sum test on log-transformed data) for the spent females.

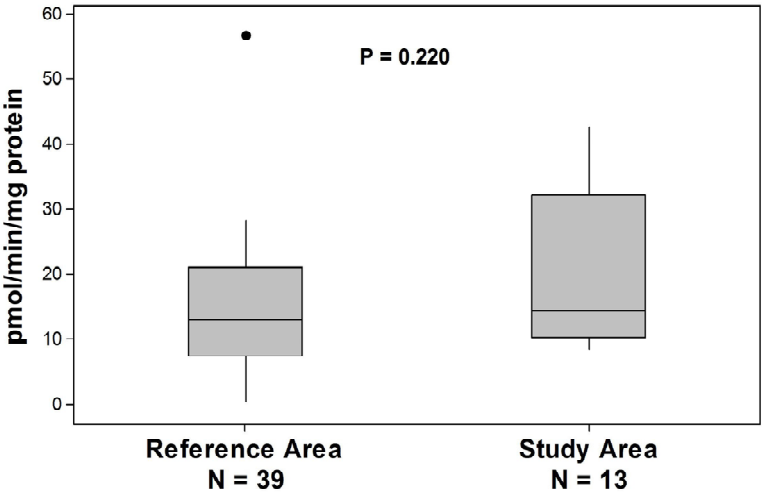


Figure 7-14 EROD Activity in the Liver of Spent Female Plaice

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 obtained with the Unpaired t- test on log-transformed data.

7.4.4.4 Bile Metabolites

PAH-type metabolites (2- to 3- ring naphthalene type, 4-ring pyrene type and 5- to 6-ring benzo(*a*)pyrene type) were measured in the bile of plaice, when bile volume permitted. Results for males are summarized in Tables 7-33 (relative fluorescence units) and 7-34 (units standardized to protein). The complete data set is provided in the Appendix D-3 (Annex D).

Table 7-33 Bile Fluorescence for Three Types of PAH-Metabolites in Male Plaice (2012)

Parameter	Reference Area N = 4	Study Area N = 12	*p*
Naphthalene - 290/335nm	20.19 ± 9.01	31.0 ± 15.06	0.218
Pyrene - 341/383nm	2.07 ± 1.15	3.16 ± 1.25	0.147
Benzo(*a*)pyrene - 380/430nm	1.878 ± 0.735	2.640 ± 0.764	0.104

Note: - Relative fluorescence units upon dilution of bile 1:1600 in water/HPLC methanol (50/50v/v).

Table 7-34 Bile Fluorescence Standardised to Protein for Three Types of PAH Metabolites in Male Plaice (2012)

Parameter	Reference Area N = 4	Study Area N = 12	*p*
Naphthalene - 290/335nm	4.12 ± 1.20	4.44 ± 1.04	0.618
Pyrene - 341/383nm	0.419 ± 0.199	0.473 ±0.129	0.531
Benzo(*a*)pyrene - 380/430nm	0.387 ± 0.099	0.406 ± 0.097	0.748

Note: - Relative fluorescence units upon dilution of bile 1:1600 in water/HPLC methanol (50/50v/v) standardised to protein.

Mean levels of the various PAH-type metabolites in males were similar between the two Areas, with and without protein standardization.

Results for females are summarized in Tables 7-35 (relative fluorescence units) and 7-36 (units standardized to protein). The complete data set is provided in the Appendix D-3 (Annex D).

Table 7-35 Bile Fluorescence for Three Types of PAH-Metabolites in Female Plaice (2012)

Parameter	Reference Area N = 41	Study Area N = 33	*p*
Naphthalene - 290/335nm	41.6 ± 42.9	50.7 ± 42.1	0.363
Pyrene - 341/383nm	3.18 ± 2.67	3.60 ± 2.81	0.507
Benzo(*a*)pyrene - 380/430nm	2.71 ± 2.01	2.82 ± 1.87	0.795

Note: - Relative fluorescence units upon dilution of bile 1:1600 in water/HPLC methanol (50/50v/v).

Table 7-36 Bile Fluorescence Standardised to Protein for Three Types of PAH Metabolites in Female Plaice (2012)

Parameter	Reference Area N = 41	Study Area N = 33	*p*
Naphthalene - 290/335nm	41.6 ± 42.9	50.7 ± 42.1	0.363
Pyrene - 341/383nm	3.18 ± 2.67	3.60 ± 2.81	0.507
Benzo(*a*)pyrene - 380/430nm	2.71 ± 2.01	2.82 ± 1.87	0.795

Note: - Relative fluorescence units upon dilution of bile 1:1600 in water/HPLC methanol (50/50v/v) standardised to protein.

Mean levels of the various PAH-type metabolites in females were also similar between the two Areas, with and without protein standardization.

7.4.4.5 Histopathology

Liver Histopathology

A total of 100 livers were examined, 50 from the Study Area and 50 from the Reference Area. Results are summarized in Table 7-37. The complete data set is provided in Appendix D-3 (Annex E). Representative photographs of normal liver, as well as a number of histological changes are included in Appendix D-3 (Annex F).

Table 7-37 Number of Plaice with Specific Types of Hepatic Lesions and Prevalence of Lesions (2012)

Lesions	Reference Area (N = 50)		Study Area (N = 50)	
	Fish affected	Prevalence % [a]	Fish affected	Prevalence % [a]
Nuclear pleomorphism	0	0	0	0
Megalocytic hepatosis	0	0	0	0
Fibrillar inclusions	0	0	0	0
Bile duct hyperplasia	1	2	0	0
Eosinophilic foci	0	0	0	0
Basophilic foci	0	0	0	0
Clear cell foci	0	0	0	0
Carcinoma	0	0	0	0
Cholangioma	0	0	0	0
Cholangiofibrosis	0	0	0	0
Proliferation of macrophage aggregation [b]	0	0	0	0
Hydropic vacuolation	0	0	0	0
Inflammatory response [c]	5	10	2	4
Hepatocellular vacuolation	12	24	9	18
Parasitic infestation of biliary system	32	64	21	42
Golden rings	1	2	0	0

Note: - [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.

Except for one fish from the Reference Area exhibiting bile duct hyperplasia, there were no other cases of lesions that have been commonly associated with chemical toxicity. Bile duct hyperplasia is characterized by an increased number of bile ducts with the ducts displaying various sizes and shapes (Appendix D-3, Annex F, Photo 2).

With respect to other lesions, the following were detected:

- Inflammatory response was observed in 10% of fish from the Reference Area and 4% of fish from the Study Area. In all cases, the inflammation was localized in a single small area of the section. The response was rated as mild in four fish from the Reference Area and one fish from the Study Area, moderate in one fish from the Study Area and severe (Appendix D-3, Annex F, Photo 3) in one fish from the Reference Area.
- Golden rings were detected around bile ducts in one fish from the Reference Area (Appendix D-3, Annex F, Photo 4).
- A patchy distribution of hepatocellular vacuolation, not associated with degenerative changes, was observed in 24% of fish from the Reference Area and in 18% of fish from the Study Area.

- An infestation of the biliary system with a myxosporean parasite, possibly *Myxidium* sp., was also observed in 64% of fish from the Reference Area and in 42% of fish from the Study Area. The infestation did not appear to result in any other pathological changes in hepatic tissues.

Overall, there were no significant differences in any of the hepatic indices examined between fish from the Study and Reference Areas (using Fisher Exact Test), except for the parasitic infestation, which was more prevalent in fish from the Reference Area (p = 0.045; Fisher Exact Test).

Gill Histopathology

Accurate histopathology counts were not possible for five fish from the Reference Area and four fish from the Study Area. Detailed histopathological studies were thus carried out on gill tissues of 91 fish.

There were no cases of epithelial lifting and the percentages of lamellae affected by the other lesions per fish were very low; all were less than 2.5%, except for one fish from the Study Area that had 5% of lamellae exhibiting tip hyperplasia (Appendix D-3, Annex F, Photo 5). A representative photograph of secondary lamellae without lesions (Photo 6) is also included in Appendix D-3 (Annex F).

Percentages of secondary lamellae affected by each type of lesion per Area are provided in Table 7-38. There were no significant differences between the Study and Reference Areas for any of the gill indices measured.

Table 7-38 Percentages of Lesions and Rating of Oedema Condition in the Gill Tissues of Plaice (2012)

Parameter	Reference Area N = 45	Study Area N = 46	p [c]
Epithelial lifting [a]	0	0	1.000
Basal hyperplasia [a]	0.0012 ± 0.0040	0.0007 ± 0.0020	0.582
Distal hyperplasia [a]	0.0005 ± 0.0013	0.0013 ± 0.0026	0.161
Tip hyperplasia [a]	0.0015 ± 0.0029	0.0020 ± 0.0075	0.344
Fusion [a]	0.0006 ± 0.0024	0.0002 ± 0.0009	0.655
Telangiectasis [a]	0	0.0001 ± 0.0002	0.333
Oedema condition [b]	0.911 ± 0.925	0.565 ± 0.655	0.087

Note: - All data are means ± standard deviations.
- [a] Mean percentage of lamellae presenting the lesion.
- [b] Mean of rating on a relative 0-3 scale.
- [c] p obtained with the Mann-Whitney Rank Sum test on arcsine square root-transformed percentages of the lesions or on ranking of oedema.

7.5 SUMMARY OF FINDINGS

7.5.1 BIOLOGICAL CHARACTERISTICS

In 2012, a total of 1,125 scallop were collected in Reference and Study Areas. Overall female:male ratios were approximately 60:40 and females outnumbered males in all transects, with no difference in sex ratio between the Study and Reference Areas. Females were generally larger than males and there were no differences in the size or shape of scallop between the Reference and Study Areas. Those results held for the subset (*n* = 199) of scallop used in body burden analysis.

A total of 19 male and 81 female plaice were collected in the Reference and Study Areas. Sex ratios differed between Areas, with a lower female:male sex ratio in the Study Area (approximately 70:30 in the Study Area versus approximately 90:10 in the Reference Area). No differences in maturity stage between the Areas were noted for males. For females, there were more immature females and females maturing to spawn and less spent females in the Study Area.

Size, age and fish condition for both males and females were similar between Areas in most cases. For males, the Gonado-somatic Index was higher in fish from the Study Area. However, that difference was not apparent in a comparison of gonad weight relative to total weight. For females, Fulton's condition factor and total weight relative to length were higher in fish from the Study Area.

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 2012. Aluminum, arsenic, boron, cadmium, copper, iron, manganese, mercury, nickel, strontium, uranium and zinc were detected in most viscera samples from 1997 to 2012. 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 in EEM years, overall, than in baseline (1997). Changes in metals concentration over time in EEM years were similar between Areas, with a decrease in metals concentration in 2012 to levels equivalent to or lower than baseline levels. In most years, including 2012, overall metal concentrations were lower in the Study Area than in the Reference Area.

Mercury concentration in muscle (examined separately from other metals) also differed significantly among years, with concentrations lower during baseline in both the Reference and Study Areas. Mercury levels have been higher in the Study Area than in the Reference Area in most years, including baseline, and levels have declined in EEM years, in both Areas.

Fat content in muscle varied among years, but not between Areas and has generally decreased in EEM years.

Overall metals concentration in scallop viscera (viscera PC1 scores) differed among years and concentrations generally 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 in 2010 and 2012. In 2012, Study Area metals concentrations were lower than concentrations measured during baseline and Reference Area concentrations were approximately equivalent to baseline concentrations.

Viscera PC2 scores (predominantly and negatively correlated with concentrations of aluminum and iron) decreased over time, indicating an increase in aluminum and iron in viscera. Viscera PC2 scores were greater in the Study Area than in the Reference Area in 1997, but scores were lower in the Study Area in most EEM years. In 2012, viscera PC2 scores were similar in the Reference and Study Areas and comparable to levels observed during baseline.

Fat content in scallop viscera has varied between 1 and 2% among 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 of hydrocarbons have been similar to profiles for 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 and 2012.

>C_{10}-C_{21} hydrocarbons resembling the drill mud PureDril 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, decreased to near the detection limit in 2008, were below the detection limit in 2010, and were just at the detection limit in 2012.

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 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 samples analyzed since 2000. Fillet samples were not analyzed in 1997. Arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc were detected in most plaice liver composites analyzed from 2001 to 2012. In 2008, manganese and selenium were not detected in one Reference Area liver sample with elevated laboratory detection limits (5 mg/kg). In 2012, iron was not detected in one Study Area liver sample; manganese was not detected in two Study Area liver samples; and mercury was not detected in two Study Area liver samples.

Concentrations of arsenic, zinc and fat in plaice fillets varied among years, but not between Areas. There was a net increase in arsenic concentration in plaice fillets in both Areas, and zinc and fat concentrations decreased, again in both Areas. Mercury concentrations have been between 0.05 and 0.01 mg/kg (wet wt) and there have been no significant differences in mercury concentration among years, or between Areas.

Overall metals concentrations in plaice liver (liver PC1 scores) differed among years, but not between Areas. There was a linear decrease in overall metals concentrations in both Areas in EEM years.

Manganese concentration in plaice 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.

$>C_{10}$-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} 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 2012, but none of these compounds had profiles that matched that of PureDrill IA35-LV. As in previous years, an additional mass spectroscopy test on a liver sample from the Study Area revealed that compounds in this sample 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 male or spent female plaice. With all maturity stages pooled, MFO enzyme activity was 1.5 times higher for Study Area females than for Reference Area females.

There was no difference between Areas in the level PAH-type metabolites in the bile of either male or female plaice.

Except for one fish from the Reference Area exhibiting bile duct hyperplasia, there were no other cases of liver lesions that have been commonly associated with chemical toxicity.

The frequency of microstructural changes in gills was low in both Areas and no inter-area differences were observed. Microstructural changes in gills that could be pathological in nature, such as severe lamellar hyperplasia and oedema and/or extensive fusion or telangiectasis, were absent in the two 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 2012 and all previous years. Gravel content varied from 0% to approximately 20%. Fines (silt + clay) content was low (median and maximum fines content were 1% and 2.2% in 2012, respectively). Sediment total organic carbon content was also low (0.03 to 0.2%). Total organic carbon content values of 1% are considered typical of marine sediments (CCME 2002), although this value may be more applicable to nearshore rather than offshore sediments.

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 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 2012, 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 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 2012 (i.e., the estimated zone of influence) was approximately 2.5 km, similar to threshold distances noted since 2008. Threshold distances of approximately 4 to 5 km for $>C_{10}$-C_{21} hydrocarbons were noted in 2004 and 2006. Therefore, threshold distances for $>C_{10}$-C_{21} hydrocarbons have decreased in recent

years. Barium concentrations decreased to background levels within approximately 1 km from drill centres in 2012, similar to threshold distances noted from 2004 to 2008, but less than the 2 km threshold noted in 2010.

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 2012, maximum $>C_{10}$-C_{21} hydrocarbon and barium concentrations were 310 and 4,900 mg/kg, respectively, and again occurred at station 30(FE). Highest median levels, over the whole field, were noted in 2006 for both $>C_{10}$-C_{21} hydrocarbons and barium (4.3 mg/kg and 170 mg/kg, respectively). Median levels in 2012 were 1.3 mg/kg and 140 mg/kg, respectively, similar to levels noted in 2008 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[36].

There has been evidence of project effects on sulphur in EEM years, with elevated levels near drill centres. In 2012, sulphur concentrations decreased significantly with distance from the FEZ drill centres but did not decrease significantly with distance from the FE drill centre. The FEZ distance gradient for sulphur largely depended on a few high concentrations (0.05 to 0.05%) at stations within 1 to 2 km of the FEZ drill centres. Sulphur concentrations also decreased significantly with distance from drill centres in 2001, 2002, 2004, 2006 and 2010, with little change in the strength of the distance relationships over time.

In 2012, the highest sulphur concentration (0.17%) occurred at station 30(FE), 0.14 km from the FE drill centre, and this was the only concentration exceeding 0.1%. Concentrations at other stations near the FE drill centre were low. The highest sulphur level over all EEM years was 0.31% at station 30(FE) in 2006. Median levels were highest in 2008 and 2010 (0.05 and 0.04%, respectively). Median levels in 2012 were below the laboratory detection limit of 0.03%. Overall, these data provide some indication that project effects on sulphur concentrations in sediments have decreased in 2012 relative to prior EEM years.

[36] A total of 141 tonnes of oil-on-cuttings and 3,944 m^3 of water-based muds were discharged at Terra Nova from 2007 to June 2012, when collections for the 2012 EEM program took place (Suncor Energy 2011 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 2011).

Sulphur (barium sulphate) is an important component of drill muds. Therefore, sulphur contamination would be expected where barium contamination occurs. However, elemental sulphur accounts for only 15% of the weight of barium sulphate, whereas barium accounts for 60%[37]. Therefore, contamination by sulphur, a lesser constituent of barium sulphate, should be of lesser magnitude than barium contamination.

Evidence of project effects on sediment fines content was weaker in 2012 than in other EEM years, as was the case for $>C_{10}$-C_{21}, barium and, to a lesser extent, sulphur concentrations. Fines content decreased with distance from drill centres in all years including baseline (1997). However, distance gradients were stronger in 2000, 2001, 2004, 2006 and 2010, suggesting project effects on fines in EEM years. In 2012, fines distance gradients were not significant and were similar to those noted in baseline. Fines content in 2012 ranged from 0.4 to 2.2% (median = 1.0%), with the highest fines level noted at station 30(FE) nearest a drill centre. Fines content during baseline (1997) ranged from 0.7 to 3.4% (median = 1.0%). Evidence of project effects on sediment fines content has always been weak, with only a few stations near drill centre showing increases in fines content.

Metals PC1 scores (a summary measure of the concentration of metals other than barium) were not significantly related to distance to drill centres in 2012 and scores were not visibly elevated at the station nearest a drill centre (station 30(FE)). Metals PC1 scores were only relatively strongly related to distance to drill centres in 2001 but, in general, there has been little evidence of project effects on metals other than barium.

In 2012, distance gradients for sulphide, ammonia and redox were not significant and levels noted at station 30(FE) were within the range noted at other stations. Total organic carbon content decreased with distance to drill centres in 2012, but a decrease in total organic carbon concentration with distance from drill centres was also noted in baseline, and the distance relationship was not stronger in 2012 than it was in baseline.

Overall, other than effects on $>C_{10}$-C_{21} hydrocarbons and barium and, to a lesser extent, sulphur, physical and chemical characteristics of sediments were largely unaffected by project activities. Evidence for effects ranged from none to equivocal

[37] The atomic weights of barium, sulphur and oxygen are approximately 137, 32 and 16, respectively. The molecular weight of barite ($BaSO_4$) will be 137 + 32 + 64 = 233. Barium will constitute 59% of barite by weight and sulphur will constitute 14% of barite by weight.

(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 (e.g., percent fines and total organic carbon) persisted through EEM years, often with little or no change in strength.

8.1.2 TOXICITY

Toxicity to luminescent bacteria (Microtox) was observed at 4 of 54 stations in 1997. It was observed at 10 to 20 of approximately 50 stations in EEM years. Thirteen (13) of 53 samples were toxic in 2012. Negative Microtox responses were not correlated with distance from drill centres or to $>C_{10}$-C_{21} hydrocarbon concentrations. Instead, effects on Microtox were greater at intermediate distances (1 to 2 km) from drill centres. As in previous years, Microtox responses were correlated with barium concentration in 2012, but the correlation was weaker than correlations with many other variables. Beyond this, the timing of Microtox toxicity at specific stations during EEM years generally did not coincide with the onset of drilling at the FEZ or FE drill centres for stations near these drill centres. In EEM years, toxicity has never occurred at stations 30(FE), the stations closest to a drill centre. Adverse Microtox responses were not associated with adverse effects on *in situ* benthic invertebrate communities. Instead, adverse Microtox responses were greater in sediments with higher overall numbers and variety of organisms (sediments with higher abundance and richness). Microtox responses were uncorrelated with the benthic index (NMDS1) that was most affected by project activity.

As in previous years, the strongest correlation with Microtox responses in 2012 was with sediment strontium content. Strontium effects were probably natural because sediment metals were largely unaffected by project activity (Section 8.1.1). Shell fragments are a biogenic source of strontium (e.g., Ueda et al. 1973). Decomposition of invertebrates may be greater in sediments where more shell fragments occur and this may negatively affect Microtox responses. Sediment sulphide concentration, an index of decomposition, was also higher in sediments where negative Microtox responses occurred and the relationship between Microtox and *in-situ* benthic invertebrates (more negative Microtox responses from sediments with higher abundance and richness) indicates that invertebrates, and hence dead invertebrates, were more abundant in these sediments.

Given all this, the evidence for project-effects on Microtox is weak, and the evidence that variations in Microtox responses were caused by variations in natural sediment characteristics is stronger.

There has been little evidence for project effects on laboratory amphipods in EEM years and more than 98% of samples have been non-toxic. One sample (of 53), from station 52(FEZ), was toxic to laboratory amphipods in 2012. Amphipod survival was not significantly correlated with distances from drill centres and most sediment physical or chemical characteristic. Amphipod survival was correlated with concentrations of $>C_{10}$-C_{21} hydrocarbons. The correlation, however, was positive indicating higher survival in sediments with higher concentrations of hydrocarbons; a result that does not imply a negative effect of hydrocarbons on survival.

8.1.3 BENTHIC INVERTEBRATE COMMUNITY STRUCTURE

Total abundance, biomass, richness, adjusted richness (a measure of diversity) and NMDS2 scores were uncorrelated with distances to the nearest drill centre in 2012, as in most previous years. There was an overall decrease in total abundance with distance from the FEZ drill centres from 2001[38] to 2012, but that gradient did not change over time. There were changes in the FE distance gradient for biomass (increases with distance from the FE drill centre), but those changes did not coincide with the onset of drilling at that drill centre. There was an increase in the FEZ distance gradients for biomass (decreases with distance from the FEZ drill centres) over time.

When they occurred, changes 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 numerous, taxa were also correlated with NMDS1 scores.

NMDS1 scores were strongly negatively associated with distance to the nearest drill centre in 2012, reflecting higher abundances of Spionidae, Phyllodocidae and Tellinidae, and lower abundances of Orbiniidae and Paraonidae nearer drill centres. NMDS1 scores were also relatively high at stations 30(FE) and 31(FE), the

[38] 1997 data are unavailable for benthic community indices, and 2000 data were not used in repeated-measures regression because many samples were sieved using the Wash method.

two stations nearest a drill centre[39]. None of the other indices were visibly affected at stations 30(FE) and 31(FE) in 2012.

Across years, NMDS1 scores have generally been negatively correlated with distance to the nearest drill centre (i.e., decreases with distance) and relationships have gained strength since 2004. 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 FEZ distance gradients have been negative and stronger than the FE distance gradients (which have been positive). The distance gradients from the FEZ drill centres did not change over time. Distance gradients from the FE drill centre have become weaker since 2004, potentially accounting for the strengthening relationship between NMDS1 and distance to the nearest drill centre (i.e., the overall distance measure).

Correlations between total abundance, biomass, richness, adjusted richness and NMDS2 scores and $>C_{10}$-C_{21} hydrocarbon and barium concentrations (as indicators of drilling discharge), total organic carbon content (correlated with sediment texture) and Microtox toxicity were weak or absent, not consistent across years, or did not indicate a project effect. However, scatter plots of data for all years indicated potential negative effects in some years and for some indices (predominantly total abundance and biomass) at barium concentrations in excess of approximately 1,000 mg/kg and $>C_{10}$-C_{21} concentrations in excess of approximately 500 mg/kg. These high concentrations have only ever occurred at one station (station 30(FE), located 0.14 km from the FE drill centre). Therefore, any conclusion about a threshold for negative effects needs to be made with caution. In 2012, negative effects on total abundance, biomass, richness, adjusted richness and NMDS2 at the highest barium and $>C_{10}$-C_{12} hydrocarbon concentrations (4,900 mg/kg and 310 mg/kg, respectively) were not apparent.

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

[39] High scores reflect relatively high abundances of Spionidae, Phyllodocidae and Tellinidae and lower abundance of spionids, phyllodocids and tellinids, lower abundances of Orbinidae and Paraonidae.

The association between NMDS1 scores and total organic carbon has generally been stronger than the association with the two drill mud indicators. 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. The lines of evidence to indicate that NMDS1 has 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, a strengthening of the overall distance gradient in EEM years and relatively high NMDS1 scores at the two stations nearest to a drill centre.

The relationship between NMDS1 scores and barium could have been related to a common relationship with substrate texture, in spite of the fact that sediment barium concentrations were affected by project activity. Singsaas et al. (2008; see also accompanying papers in *Integrated Environmental Assessment and Management*, Vol. 4, No. 2) summarize a risk-based approach for assessing the effects of water-based mud discharges in the North Sea. Issues considered were toxic compounds, suspended solids, burial of biota and alteration of sediment structure (i.e., particle size). Barium and barite are basically toxicologically inert and are largely present in water-based 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 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 2012, when Orbiniidae and Paraonidae were not found in samples, these samples 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 (e.g., Daan et al. 1994; Olsgård and Gray 1995; Daan and Mulder 1996; Montagna and Harper 1996; Peterson et al. 1996; Bakke and Nilssen 2005). 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 Clark 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

From 2002 to 2010, PAHs were generally detected more frequently, although sporadically and in trace amounts, in water column 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. This is a reduction in occurrence from previous years and compares to the one occurrence of a PAH noted in water samples in the baseline year (1997). The highest occurrence of PAHs in water samples was in 2006, with 56% of samples from the Study Area and 13% of samples from the Reference Areas containing trace amounts of PAHs.

Arsenic has been detected in all seawater samples from 1997 to 2012. 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 2009), seawater samples were processed for additional constituents in 2012. As a result, barium, boron, cadmium, calcium, chromium, lithium, magnesium, molybdenum, potassium, sodium, strontium, sulphur and uranium were also frequently detected in 2012 samples. Of these, only barium and iron differed significantly in concentration between Study Area and Reference Area stations.

In 2012, Study Area stations were located both inside and outside the FEZ. Barium concentrations were higher in surface samples at Study Area stations compared to Reference Area stations. These differences were slight, with the median level higher by approximately 1 to 2 µg/L for Study Area stations. The largest difference in barium concentrations occurred over depth, with barium levels higher by approximately 5 to 10 µg/L in bottom samples compared to other depths, in all Areas. Overall, the highest barium concentrations (median = 16 µg/L) occurred in bottom samples in the SW Reference Area. Barium was not measured in most previous years, including baseline. Barium was measured in 2001 at a laboratory detection limit of 50 µg/L and all values in that year were below the laboratory detection limit.

Iron concentrations varied significantly between stations outside the FEZ and Reference Area stations. The median iron concentration at stations outside the FEZ was 4.85 μg/L versus a median of 1.7 μg/L at Reference Area stations. Iron concentrations also varied significantly between stations inside the FEZ (median = 2.5 μg/L) and stations outside the FEZ. Across years, the median iron concentration was higher at Study Area stations than at Reference Area stations in 2002 and 2012; and the median iron concentration was higher at Reference Area stations in 2008. The median concentration at Reference Area stations noted in 2008 (4 μg/L) was comparable to the overall median (3.75 μg/L, stations inside and outside the FEZ combined) noted at Study Area stations in 2012.

A greater number of constituents differed significantly in concentration between the two Reference Areas than they did between the Study and Reference Areas. Boron, uranium, calcium and sulphur differed significantly between the two Reference Areas, and barium concentrations in bottom samples also differed significantly.

In 2012, the occurrence of high values of known produced water constituents was examined for individual Study Area samples to determine if there could be an association between high values and release of produced water. Concentrations of naphthalene, iron, manganese, barium and lithium are relatively high in Terra Nova produced water. Of these constituents, relatively high values were noted in individual seawater samples for iron (74 μg/L, station W15, bottom sample), barium (15 μg/L, station W9, bottom sample) and lithium (198 μg/L and 199 ug/L, stations W18 (mid-depth) and W19 (bottom), respectively), and that one sample with a trace amount of naphthalene was also from a Study Area sample (W19, mid-depth sample). Manganese was more frequently detected at stations outside the FEZ than at stations either inside the FEZ or in Reference Areas, although the maximum level (10.6 μg/L) occurred at station W1 in the SW Reference Area.

Given the sporadic occurrence of relatively high values for these constituents (in 4 of 48 Study Area samples), the evidence that these were related to release of produced water is weak. An examination of current direction prior to and during sampling did not lend strong support to the argument that constituents originated from the Terra Nova FPSO. The analysis of water chemistry at all stations described above and showing higher surface barium concentrations in the Study Area and higher iron concentrations outside the FEZ than in the Reference Areas could support the argument. However, the input of barium from produced water and drill muds is confounded and, as noted above, iron levels noted in the Study Area in 2012 were comparable to levels observed in the Reference Areas in 2008.

Overall, analyses indicate that seawater physical and chemical characteristics at Study Area stations and Reference Area stations are similar. In most cases, differences between Study and Reference Area stations were not significant. Where they were, differences were slight and an association with the Terra Nova development was not evident. Differences between the two Reference Areas were more frequent than differences between the Study and Reference Areas. The sporadic occurrence of trace amounts of PAHs in seawater samples was reduced in 2012 compared to many other EEM years, 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 (Neff et al. 2011 and references therein).

8.2.2 PHYTOPLANKTON PIGMENTS

Chlorophyll *a* concentration from Niskin bottle samples and CTD casts, and pheophytin *a* concentrations from Niskin bottle samples have been used as indicators of algal biomass in the Terra Nova EEM program. In 2012, pheophytin *a* was not detected in any seawater samples, most probably because sampling occurred earlier in the year (May in 2012 versus September to October in other years).

Chlorophyll *a* concentrations from CTD casts varied between approximately 3 and 4 µg/L in 2012. Both Niskin bottle and CTD data showed increasing chlorophyll *a* concentration with depth. From the larger CTD dataset[40], surface chlorophyll *a* concentrations differed between the Study and Reference Areas, with concentrations higher in the Reference Areas. Surface chlorophyll *a* concentrations also differed between stations inside the FEZ and stations outside the FEZ, with concentration higher at stations outside the FEZ.

Chlorophyll *a* concentrations from CTD data differed between the two Reference Areas at mid-depth and at the bottom. At mid-depth, chlorophyll *a* concentrations were higher at stations in the SE Reference Area. At the bottom, concentrations were higher at stations in the SW Reference Area. All differences between Areas were subtle (less than 0.2 µg/L) and differences were significant because of the large sample size and consequent high statistical power and robustness of tests on the CTD data.

[40] The discussion text focuses predominantly on results from the extensive CTD dataset.

Across years, median chlorophyll *a* concentration from CTD casts has generally followed the same pattern in the Study and Reference Areas. Median chlorophyll *a* concentration was higher in bottom samples in 2012 than in all previous years, in all Areas. Niskin bottle data supported this finding, but only for samples in the Reference Areas[41].

Overall, there is little indication that Terra Nova is affecting chlorophyll *a* concentration near the development. In 2012, variation in chlorophyll *a* among Areas was slight. Any nutrient enrichment from produced water (Rivkin et al. 2000) would be expected to increase phytoplankton production near the FPSO. In 2012, chlorophyll *a* concentrations were slightly higher in the Reference Areas, although there were differences between the two Reference Areas that were as 'large' as differences between the Study and Reference Areas. Based on these data, variations in chlorophyll *a* noted in the Study and Reference Areas were likely natural.

That chlorophyll *a* concentration was higher in bottom samples than at mid-depth or at the surface in all Areas in 2012 is an interesting finding and could indicate that there is a deep chlorophyll maximum on some parts of the Grand Banks in Spring. Evidence that this occurs locally could not be found but deep chlorophyll maxima have been noted elsewhere (e.g., Estrada et al. 1993; McManus and Dawson 1994). Temperature profiles indicate colder temperature at depth with a well-defined thermocline, which does not suggest downwelling as a potential explanation for higher chlorophyll *a* concentrations in deeper water.

8.3 COMMERCIAL FISH COMPONENT

8.3.1 BIOLOGICAL CHARACTERISTICS

8.3.1.1 Scallop

Female scallop have always been more abundant and larger than males in Terra Nova samples. In 2012, the female:male sex ratio was approximately 60:40, with no difference in sex ratio, size or shape between the Study and Reference Areas. These results held for the subset of scallop used in body burden analysis.

[41] A patchy distribution of chlorophyll would reasonably explain differences in general observations made with CTD data and the more limited Niskin bottle dataset.

8.3.1.2 Plaice

Plaice sex ratios differed between Areas in 2012, with a lower female:male sex ratio in the Study Area (approximately 70:30 in the Study Area versus approximately 90:10 in the Reference Area). No difference in maturity stages between Areas were noted for males. For females, there were more immature and maturing females and less spent females in the Study Area.

Size, age and fish condition for both males and females were similar between Areas in most cases. For males, the gonado-somatic index was higher in fish from the Study Area. For females, Fulton's condition factor and total weight relative to length were higher in fish from the Study Area.

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 and chromatogram profiles of hydrocarbons have been similar to profiles for 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 and 2012.

>C_{10}-C_{21} hydrocarbons resembling the drill mud PureDril IA35-LV have been noted in Study Area scallop viscera since drilling began. Study Area means were well above the laboratory detection limit (15 mg/kg) in earlier EEM years, decreased to near the detection limit in 2008, were below the detection limit in 2010, and were just at the detection limit in 2012.

Barium, a constituent of both synthetic- and water-based drill muds, was detected 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 in 2012 (1.6 mg/kg).

Over the years, the Reference Area maximum 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 viscera of Study Area scallop progressively increased. The concentration of barium decreased in 2012 to levels similar to baseline levels.

Concentrations of arsenic, boron, cadmium, strontium and zinc in scallop adductor muscle were frequently or always above laboratory detection limit in all sampling years. 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 2012 were similar to or lower than levels noted in baseline. In most years, including 2012, overall metal concentrations in scallop adductor muscle were lower in the Study Area than in the Reference Area.

Mercury concentration in muscle (examined separately) also differed significantly among years, with similar changes in both Areas. Mercury levels have been higher in the Study Area than in the Reference Area in most years, including baseline, and levels have declined in EEM years, in both Areas.

Concentrations of aluminum, arsenic, boron, cadmium, copper, iron, manganese, mercury, nickel, selenium, strontium, uranium and zinc were frequently or always above laboratory detection limit in scallop viscera in all sampling years. 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. Both these metals are found in very high concentration in sediments. Therefore, metals PC2 can be considered a measure of metals concentration in ingested sediments.

The concentration of most metals in scallop viscera differed among years and concentrations generally 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 in 2010 and 2012. In 2012, Study Area metals concentrations were lower than concentrations measured during baseline and Reference Area concentrations were approximately equivalent to baseline concentrations.

Concentrations of aluminum and iron, as determined by metals PC2, increased over time. Concentrations were lower in the Study Area than in the Reference Area in 1997, but concentrations were higher in the Study Area in most EEM years. In 2012, concentrations were similar in the Reference and Study Areas and comparable to levels observed during baseline.

As in previous years, results of body burden analysis on scallop tissue indicate tissue contamination with $>C_{10}$-C_{21} hydrocarbons and barium, two important constituents of drill muds. Hydrocarbons and barium in viscera probably originated from ingested sediment that was later egested since these chemicals were more rarely detected in muscle tissue. Data from 2012 and recent EEM years indicate a decrease in contamination since 2006. In 2012 and in prior years, there was little evidence of tissue contamination with metals other than barium. Changes in the concentration of metals other than barium have either been common to both the Study and Reference Areas, or differences have remained consistent since baseline.

$>C_{10}$-C_{21} in scallop tissue would originate from the drill mud PureDrill IA35-LV, a low toxicity synthetic-base drill mud (Appendix A). 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 (Neff et al., 2000). Neff et al. (2000) describes two studies where bivalves were exposed to synthetic-based fluids under laboratory conditions. In both cases, bivalves rapidly accumulated the fluid in tissue, but equally rapidly released the chemicals when returned to clean water, suggesting retention of the chemical in gills and digestive track, 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. For fish, Rushing et al. (1991) hypothesized that the greater molecular size of synthetic-based fluids 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 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 muds.

Barium noted in scallop tissue at Terra Nova would probably originate from barite and bentonite used in drill muds, although barium is found naturally in marine sediments. The effect of barite and bentonite 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) 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} hydrocarbons have only been detected in one plaice fillet sample, from a single Study Area fish in 2000. The chromatogram for that fish did not match that of PureDrill IA35-LV. Since 2002, compounds in the $>C_{10}$-C_{21} and $>C_{21}$-C_{32} hydrocarbon range have routinely been detected, in approximately equal amounts, in liver samples from Study and Reference Area plaice, but hydrocarbon profiles have not matched that of PureDrill IA35-LV. Instead, hydrocarbon peaks observed on chromatograms for liver were consistent with those expected for natural compounds (J. Kiceniuk, 2013, pers. comm.) and similar compounds have consistently been observed in plaice liver at the nearby White Rose site (Husky Energy 2013). As in previous years, an additional mass spectroscopy test on a liver sample from the Study Area confirmed that compounds in this sample were not petrogenic in origin.

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[42]. Arsenic, cadmium, copper, iron, manganese, mercury, selenium and zinc were detected in most plaice liver composites. 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.

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

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 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.

8.3.4.2 Haematology

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

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

8.3.4.3 Mixed Function Oxygenase Activity

There were no significant differences in MFO enzyme levels between the Study and Reference Areas for male plaice.

For females, and when considering all maturity stages, a slight but significant difference between the Study and Reference Area was observed in MFO enzyme levels, with enzyme activity 1.50-fold higher in females from the Study Area. Similar results have been noted in the past and enzyme activity has not increased over time. Enzyme activity was 1.35-fold higher for Study Area females in 2006, and it was 1.50, 1.66, and 1.50-fold higher for Study Area males in 2006, 2008 and 2010, respectively.

In 2012, there was no significant difference in the enzyme activity between the two Areas for spent females. This indicates that the difference observed when all maturity stages were considered could be due to the presence of immature females found in the Study Area. Immature fish of various species have been reported to have higher EROD activity than mature female fish (e.g., Whyte et al. 2000). A trend towards higher levels of EROD in immature female American plaice has also been observed in other surveys on the Grand Banks.

In addition to differences in maturity status, differences in MFO activity could be due to feeding differences. Some laboratory studies have shown that diet can modulate enzyme levels (Andersson et al. 1985; DiGiulio et al. 1993; Liao et al. 2011).

The increase in MFO enzyme activity observed in fish from the Study Area also could be due to exposure to low levels of contaminants related to platform discharges (e.g., produced water, sewage or grey-water) or vessel activity near the platform. Induction of MFO in fish has been established as a sensitive biological indicator of hydrocarbon pollution of aquatic biotopes (e.g., Payne et al. 1987; Whyte et al. 2000).

Overall, the slight enzyme induction observed in plaice could be due to natural variability such as feeding and reproductive status, but a role for low level contaminants cannot be ruled out.

8.3.4.4 Bile Metabolites

Analysis of PAH metabolites in fish bile has been shown to be a useful method for detection of recent PAH contamination (Krahn et al. 1986a, 1986b; Hellou and Payne 1987; Ariese et al. 1993; Krahn et al. 1993; Lin et al. 1996; Aas and Klungsoyr 1998; Escartin and Porte 1999; Aas et al. 2000a, 2000b; Gagnon and Holdway 2000, 2002).

PAH-type metabolites (2- to 3- ring naphthalene type, 4-ring pyrene type and 5- to 6-ring benzo(*a*)pyrene type) were measured in the bile of male and female plaice from the Study and Reference Areas in 2012, when bile volume permitted. Mean differences of relative fluorescence units and of units standardized to protein at pair wavelengths of the metabolite-types were similar between the Reference and Study Areas for each gender. These results indicate that there were no differences in recent exposure of fish to PAHs between the two Areas.

8.3.4.5 Histopathology

Other than one case of bile duct hyperplasia observed in the Reference Area, there were no other cases of liver lesions that have been associated with chemical toxicity.

A few other hepatic conditions, not specifically associated with contamination, were also noted. Golden rings around bile ducts were detected in one fish from the Reference Area. Small focal inflammatory responses were observed in 10% of fish from the Reference Area and 4% of fish from the Study Area. The condition was mild in most cases, although a moderate response was recorded in one fish from the Study Area and a more severe response in one fish from the Reference Area. Inflammatory responses are known to appear following viral, bacterial, or parasitic infections as well as tissue damage (e.g., Feist et al. 2004). However, a level of inflammation can also be associated with normal tissue repair and maintenance processes.

As noted in previous years, a “patchy distribution” of hepatocellular vacuolation, not associated with degenerative changes, was observed in a similar proportion of fish from the Study (18%) and Reference (24%) Areas, and is likely linked to gonadal maturation (Timashova 1981; Bodammer and Murchelano 1990; Couillard et al. 1997). Also, an infestation of the biliary system with a myxosporean parasite, which did not appear to result in any other pathological changes in hepatic tissues, was noted in fish from both Areas. However, the prevalence of the infestation was significantly higher in fish from the Reference Area.

The observations on golden rings, inflammatory responses, hepatocellular vacuolation and parasitism are of value in relation to providing general information on their presence in the area. However, it is important to note from an EEM perspective that a large number of liver lesions associated with chemical toxicity were absent in the Study Area.

For gill microstructures, the percentages of secondary lamellae affected by various lesions were very low in both Areas and no inter-area significant differences were observed.

Altogether, microstructural changes in gills that could be pathological in nature such as severe lamellar hyperplasia and oedema and/or extensive fusion or telangiectasis (e.g., Mallat 1985) were absent in the two Areas.

As in previous years, the results of the fish health survey carried out in 2012 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 2012 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 do indicate that there should be change in sediment physical and chemical characteristics and benthic community structure with distance from the discharge point.

There was clear evidence that barium and hydrocarbons in the $>C_{10}$-C_{21} range were elevated near drill centres in 2012, as in previous EEM years. There was also evidence of project effects on sulphur and, to a lesser extent, on sediment fines content, as in previous years. Sediment contamination with $>C_{10}$-C_{21}, barium and sulphur was reduced and evidence for an effect on fines was weaker in 2012 compared to previous EEM years.

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 barium decreased to background levels within approximately 1 km from drill centres; concentrations of >C_{10}-C_{21} hydrocarbons decreased to levels near the laboratory detection limit (0.3 mg/kg) within approximately 2.5 km from drill centres. Elevated concentrations of sulphur occurred within 1 to 2 km of drill centres. Evidence of project effects on fines was weak and elevated concentrations occurred only in the immediate vicinity of 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 2012 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 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 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

The '2000 versus 2001' contrast in repeated-measures regression was of value in earlier years (particularly in 2001). However the importance of that contrast is now low, relative to the linear and quadratic trends contrasts (i.e., trends over longer time periods). The 'before versus after drilling' at the FE drill centre contrast remains useful because years prior 2002 are 'baseline' for the FE drill centre. To better focus analyses on relevant repeated-measures terms, the '2000 versus 2001' contrast in repeated-measures regression should be eliminated.

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.

Estimates of chlorophyll *a* concentrations from Niksin bottles have been qualitatively similar to estimates from CTD casts. Given that CTD data are much more extensive than Niskin bottle data, the CTD dataset should be used preferentially to assess effects on chlorophyll *a* at Terra Nova. In 2012, the Niskin bottle data was useful in confirming that chlorophyll *a* concentrations were indeed greater at depth (an unexpected result). Therefore, measurement of chlorophyll *a* concentration from Niskin bottles should continue, but only to support the larger CTD dataset.

For the commercial fish component of the program, differences in plaice MFO activity should continue to be examined to assess if the noted patterns continue, accentuate, or are accompanied by differences in other indices of fish health.

In 2012, 754 kg of cod were caught as by-catch while trawling for plaice. Survival after processing (counting and weighing) is low. Because these fish are not required for the EEM program, it is recommended that counting and weighing of non-SARA by-catch species be discontinued in future programs. By-catch was reported in EEM reports prior to the 2010 program, but this has now been discontinued because of changes to fishing gear and vessels (i.e., catch is not comparable across years, nor is it an objective of the EEM program to examine catch or catch rates).

Similarly, all scallop caught in the scallop dredge are retained even if sufficient tissue has been collected for chemistry and taste tests. It is recommended that, allowing for a margin of error, collections be restricted to the number/weight of animals required for analysis. Remaining scallop should be returned to sea.

9.0 REFERENCES

9.1 PERSONAL COMMUNICATIONS

Kiceniuk, J. Environmental Scientist, D'Escousse, Nova Scotia. Personal Communication in 2011, 2012 and 2013.

Maxxam Analytics Halifax, NS. Personal Communication in 2005.

9.2 LITERATURE CITED

Aas, E., J. Beyer and A. Goksoyr. 2000a. Fixed wavelength fluorescence (FF) of bile as a monitoring tool for polyaromatic hydrocarbon exposure in fish: an evaluation of compound specificity, inner filter effect and signal interpretation. *Biomarkers*, 5 (1): 9-23.

Aas, E., T. Baussant, L. Balk, B. Liewenborg and O.K Anderson. 2000b. PAH metabolites in bile, cytochrome P4501A and DNA adducts as environmental risk parameters for chronic oil exposure: a laboratory experiment with Atlantic cod. *Aquat. Toxicol.*, 52(2): 241-258.

Aas, E., G. Jonsson, R. Sundt, S. Westerlund and S. Sanni. 2002. PAH metabolites and metals in bile from cod caged in the North Sea serve as indicators of pollution. *ICES Council Meeting Documents*.

Aas, E. and J. Klungsoyr. 1998. PAH metabolites in Bile and EROD activity in North Sea fish. *Mar. Environ. Res.*, 46(1-5): 229-232.

Andersson, T., U. Koivusaari. and L. Forlin. 1985. Xenobiotic biotransformation in the rainbow trout liver and kidney during starvation. *Compar. Biochem. Physiol.*, 82C: 221-225.

Ariese, F., S.J. Kok, M. Verkaik, C. Gooijer, N.H. Velthorst and J.W. Hofstraat. 1993. Synchronous fluorescence spectrophotometry of fish bile: a rapid screening method for the biomonitoring of PAH exposure. *Aquat. Toxicol.*, 26: 273-286.

Armsworthy, S.L., P.J. Cranford, K. Lee and T. King. 2005. Chronic effects of synthetic drilling muds on sea scallops (*Placopecten magellanicus*). In: S.L. Armsworth, P.J. Cranford and K. Lee (eds.). *Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Technologies*, Battelle Press, Columbus, OH.

Bakke, T. and I. Nilssen. 2005. Harmonised monitoring of offshore drilling waste effects in Norway. Pp. 433-448. In: In: S.L. Armsworth, P.J. Cranford and K. Lee (eds.). *Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Technologies*, Battelle Press, Columbus, OH.

Barlow, M.J. and P.F. Kingston. 2001. Observations on the effects of barite on the gill tissues of the suspension feeder *Cerastoderma edule* (Linne) and the deposit feeder *Macoma balthica* (Linne). *Mar. Poll. Bull.*, 42(1): 71-76.

Barton, B.A., J.D. Morgan and M.M. Vijayan. 2002. Physiological and condition-related indicators of environmental stress in fish. Pp. 111-148. In: M. Adams (ed.). *Biological Indicators of Aquatic Ecosystem Stress*, Bethesda, MD.

Blazer, V.S., J.W. Fournie, J.C. Wolf and M.J. Wolfe. 2006. Diagnostic criteria for proliferative hepatic lesions in brown bulhead *Ameiurus nebulosus*. *Diseases Aquat. Organ.*, 72(1): 19-30.

Bodammer, J.E. and R.A. Murchelano. 1990. Cytological study of vacuolated cells and other aberrant hepatocytes in winter flounder from Boston Harbour. *J. Nat. Cancer Inst.*, 50: 6744-6756.

Boorman, G.A., S. Botts, T.E. Bunton, J.W. Fournie, J.C. Harshbarger, W.E. Hawkins, D.E. Hinton, M.P. Jokinen, M.S. Okihiro. and M.J. Wolfe. 1997. Diagnostic criteria for degenerative, inflammatory, proliferative nonneoplastic and neoplastic liver lesions in medaka (*Oryzias latipes*): Consensus of a national toxicology program pathology working group. *Toxic. Pathol.*, 25(2): 202-210.

Canadian Newfoundland Offshore Petroleum Board. 1997. *Decision 97.02. Application for Approval. Terra Nova Canada - Newfoundland Benefits Plan*. Terra Nova Development Plan. 75 pp.

Calabrese. E.J and L.A. Baldwin. 2001. The frequency of U-shaped dose responses in the toxicolgical literature. *Toxic. Sci.*, 62: 330-338.

CCME (Canadian Council of Ministers of the Environment). 2002. *Canadian Sediment Quality Guidelines for the Protection of Aquatic Life*. www.ccme.ca/assets/pdf/sedqg_summary_table.pdf.

CCME (Canadian Council of Ministers of the Environment). 2010. Interim Sediment Quality Guidelines.

Chapman, P.M. 1992. Pollution status of North Sea sediments: An international integrative study. *Mar. Ecol. Prog. Ser.*, 91: 313-322.

Chapman, P.M., R.N. Dexter and E.R. Long. 1987. Synoptic measures of sediment contamination, toxicity and infaunal community structure (the Sediment Quality Triad) in San Francisco Bay. *Mar. Ecol. Prog. Ser.*, 37: 75-96.

Clarke, K.R. 1993. Nonparametric multivariate analyses of changes in community structure. *Austral. J. Ecol.*, 18: 117-143.

Couillard, C.M., P.V. Hodson, and M. Castonguay. 1997. Correlations between pathological changes and chemical contamination in American eels, Anguilla rostrata, from the St. Lawrence River. *Can. J. Fish. Aquat. Sci.*, 54: 1916-1927.

Cranford, P.J., S.L. Armsworthy, S. McGee, T. King and K. Lee. 2005. Scallops as sentinel organisms for offshore environmental effects monitoring. In: SL. Armsworth, P.J. Cranford and K. Lee (eds.). 2004. *Offshore Oil and Gas Environmental Effects Monitoring: Approaches and Technologies*. Battelle Press, Columbus, OH.

Cranford, P.J. and D. Gordon. 1992. The influence of dilute clay suspensions on the sea scallop (*Placopecten magellanicus*) feeding activity and tissue growth. *Neth. J. Sea Res.*, 30: 107-120.

Daan, R. and M. Mulder. 1996. On the short-term and long-term impacts of drilling activities in the Dutch sector of the North Sea. *ICES J. Mar. Sci.*, 53: 1036-1044.

Daan, R., M. Mulder and A.V. Leeuwen. 1994. Differential sensitivity of macrozoobenthic species to discharges of oil drill cuttings in the North Sea. *Neth. J. Sea Res.*, 33(1): 113-127.

DiGiulio, R.T., C. Habig and E.P. Gallagher. 1993. Effects of Black Rock Harbor sediments on indices of biotransformation, oxidative stress, and DNA integrity in channel catfish and brown bullhead. *Mar. Environ. Res.*, 39: 175-179.

Dutil, J.D., Y. Lambert, G.A. Chouinard. and A. Frechet. 1995. Fish condition: What should we measure in cod (*Gadus morhua*)?. *DFO Atl. Fish. Res. Doc.*, 95/11: 16 pp.

Ellis, A.E. 1976. Leucocytes and related cells in the plaice *Pleuronectes platessa*. *J. Fish. Biol.*, 8: 143-156.

Environment Canada. 1992. Biological Test Method: *Toxicity Test using Luminescent Bacteria Photobacterium phosphoreum*. Report EPS 1/RM/24. Environment Canada, Environmental Protection Service, Ottawa, ON.

Environment Canada. 1998. *Reference Method for Determining Acute Lethality of Sediment to Marine or Estuarine Amphipods*. Report EPS 1/RM/34. Environment Canada Environmental Protection Service, Ottawa, ON.

Environment Canada. 2002. Biological Test Method: Reference Method for Determining the Toxicity of Sediment Using Luminescent Bacteria in a Solid-Phase Test. Report EPS 1/RM/42.

Escartin, E. and C. Porte. 1999. Assessment of PAH pollution in coastal areas from the NW mediterranean through the analysis of fish bile. *Mar. Poll. Bull.*, 38 (12): 1200-1206.

Estrada, M., C. Marrasé, M. Latasa, E. Berdalet, M. Delgado and T. Riera, 1993. Variability of deep chlorophyll maximum characteristics in the Northwestern Mediterranean. *Mar. Ecol. Prog. Ser.*, 92: 289-300.

Feist, S.W., Lang, T., Stentiford, G.D. and A. Kohler. 2004. Biological effects of contaminants: use of liver pathology of the European flatfish dab (*Limanda limanda*) and flounder (*Platichthys flesus*) for monitoring. *ICES Tech. Mar. Environ. Sci.*, No 38, ICES, Copenhagen.

Gagnon, R.M. and D.A. Holdway. 2000. EROD induction and biliary metabolite excretion following exposure to the water accommodated fraction of crude oil and to chemically dispersed crude oil. *Arch. Environ. Contam. Toxicol.*, 38 (1): 70-77.

Gagnon, R.M. and D.A. Holdway. 2002. EROD activity, serum SDH and PAH biliary metabolites in sand flathead (*Platycephalus bassensis*) collected in Port Phillip Bay, Australia. *Mar. Poll. Bull.*, 44: 230-237.

GESAMP. 1993. Impact of Oil and Related Chemicals and Wastes on the Marine Environment. Reports and Studies. GESAMP No. 50: 180 pp.

Goede R.W. and B.A. Barton. 1990. Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. Pp. 93-108. In: S.M. Adams (ed.). *Biological Indicators of Stress in Fish*, American Fisheries Symposium 8, Bethesda, MD.

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

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

Hellou, J. and J.F. Payne. 1987. Assessment of contamination of fish by water-soluble fractions of petroleum: A role for bile metabolites. *Envron. Toxicol. Chem.*, 6: 857-862.

Husky Energy. 2013. *White Rose Environmental Effects Monitoring Program 2012*. Report prepared by Stantec Consulting Ltd. for Husky Energy, St. John's, NL.

ICES (International Council for the Exploration of the Sea). 2004. Biological of contaminants: Use of liver pathology of the European flatfish dab (*Limanda limanda*) and flounder (*Platichthys flesus*) for monitoring. By S.W. Feist, T. Lang, G.D. Stentiford and A. Kohler. *ICES Tech. Mar. Environ. Sci.*, No. 38, 42 pp.

Kennicutt, M.C., R.H. Green, P. Montagna and P.F. Roscigno. 1996. Gulf of Mexico Offshore Operations Monitoring Experiment (GOOMEX), Phase I: Sublethal responses to contaminant exposure – introduction and overview. *Can. J. Fish. Aquat. Sci.*, 53: 2540-2553.

Kilgour, B.W., K.R. Munkittrick, C.B. Portt, K. Hedley, J. Culp, S. Dixit, G. Pastershank. 2005. Biological criteria for municipal wastewater effluent monitoring programs. *Water Qual. Res. J. Can.*, 40: 374-387.

Kilgour, B.W., K.M. Somers and D.R. Barton. 2004. A comparison of the sensitivity of stream benthic community indices to effects associated with mines, pulp and paper mills and urbanization. *Environ. Toxicol. Chem.*, 23: 212-221.

Krahn, M.M., M.S. Myers, D.G. Burrows and D.C. Malins. 1986a. Associations between metabolites of aromatics compounds in bile and occurrence of hepatic lesions in English sole (*Parophrys vetulus*) from Puget Sound, Washington. *Arch. of Environ. Contam. Toxicol.*, 15: 61-67.

Krahn, M.M., L.J. Kittle and W.D. Macleod. 1986b. Evidence for exposure of fish to oil spilled into the Columbia River. *Marine Environ. Res.*, 20:291-298.

Krahn, M.M., D.G. Burrows, W.D. MacLeod and D.C Malins, Jr. 1987. Determination of individual metabolites of aromatic compounds in hydrolyzed bile of English sole (*Parophrs vetulus*) from polluted sites in Puget Sound. *Arch. Environ. Contam. Toxicol.*, 16: 512-522

Krahn, M.M., G.M. Ylitalo, J. Buzitis, S.-L. Chan and U. Varanasi. 1993. A review of rapid high performance liquid chromatography methods that screen for aromatic compounds in environmental samples. *J. Chromatogr.*, 642:15-32.

Larmond, E. 1977. *Laboratory Methods for Sensory Evaluation of Food*. Department of Agriculture. Research Branch. Ottawa, ON. 73 pp.

Liao, T., F. Yang, Y. Hui, W. Cheng, G. Xiong, S. Jin, J. Wang and Y. Xu. 2011. Multi-endpoints toxicities on Chinese rare minnow (*Gobiocypris rarus*) fed with different diets. *Environ. Toxicol. Pharmacol.*, 31(1): 70-78.

Lin, E.L.C., S.M. Cormier and J.A. Torsella. 1996. Fish biliary polycyclic aromatic hydrocarbon metabolites estimated by fixed-wavelength fluorescence: comparison with HPLCfluorescence detection. *Ecotoxic. Environ. Saf.*, 35: 16-23.

Long, E.R., C.B. Hong and C.G. Severn. 2001. Relationships between acute sediment toxicity in laboratory tests and abundance and diversity of benthic infauna in marine sediments: a review. *Environ. Toxic. Chem.*, 20: 46-60.

Lowry, O.H., N.J. Rosebrough, A.L. Fan and R.J. Randall. 1951. Protein measurement with the folin phenol reagent. *J. Biol. Chem.*, 193: 265-275.

Luna, F.G. 1968*. Manual of Histological Staining Methods of the Armed Forces Institute of Pathology*. McGraw-Hill, New York, NY. 258 pp.

Lynch, M., S. Raphael, L. Mellor, P. Spare and M. Inwood. 1969. *Medical Laboratory Technology and Clinical Pathology*. Saunders Company. 1359 pp.

Mallatt, J. 1985. Fish gill structure changes induced by toxicants and other irritants: a statistical review. *Can. J. Fish. Aquat. Sci.*, 42: 630-648.

McManus, G.B. and R. Dawson, 1994. Phytoplankton pigments in the deep chlorophyll maximum of the Caribbean Sea and the western tropical Atlantic Ocean. *Mar. Ecol. Prog. Ser.*, 113: 199-206.

Montagna P. and D.E. Harper, Jr. 1996. Benthic infaunal long-term response to offshore production platforms in the Gulf of Mexico. *Can. J. Fish. Aquat. Sci.*, 53(11): 2567-2588.

Morgan, M.J. 2003. A preliminary examination of variability in condition of American plaice in NAFO divisions 3NLO. *NAFO SCR Doc.*, 03/11: 14 pp.

Myers, M.S., L.D. Rhodes and B.B. McCain. 1987. Pathologic anatomy and patterns of occurrence of hepatic neoplasms, putative preneoplastic pesions, and other idiopathic hepatic conditions in english sole (*Parophrys vetulus*) from Puget Sound, Washington. *J. Nat. Cancer Inst.*, 78 (2): 333-363.

National Energy Board, Canada-Newfoundland and Labrador Offshore Petroleum Board (and Canada-Nova Scotia Offshore Petroleum Board. 2010. *Offshore Waste Treatment Guidelines*). vi + 28 pp.

Neff, J.M. 2008. Estimation of bioavailbility of metals in drilling mid barite. *Integrat. Environ. Assess. Mgmt.*, 4(2): 184-193.

Neff, J.M., S. McKelvie and R.C. Ayers. 2000. *Environmental Impacts of Synthetic Based Drilling Fluids*. US Department of Interior Minerals Management Services, Gulf of Mexico OCS Region. http://www.gomr.mms.gov/PI/PDFImages/ESPIS/3/3175.pdf

Neff, J., K. Lee and E.M. DeBlois. 2011. Produced water: Overview of composition, fates and effects. In: K. Lee and J. Neff (eds.). *Produced Water: Environmental Risks and Advances in Mitigation Technologies*, Springer (New York), 607 pp.

Newman, M.C. and W.H. Clements. 2008. *Ecotoxicology: A Comprehensive Treatment*. Taylor & Francis Group, Boca Raton, FL. 852 pp.

Olsgård, F. and J.S. Gray. 1995. A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. *Mar. Ecol. Prog. Ser.*, 122: 277-306.

Payne, J. F., L.L. Fancey, A.D. Rahimtula and E.L. Porter. 1987. Review and perspective on the use of mixed-function oxygenase enzymes in biological monitoring. *Comp. Pharmacol. Physiol.*, 86C(2): 233-245.

Peterson, C.H., M.C. Kennicutt, R.H. Green, P. Montagna, D.E. Harper Jr., E.N. Powell, and P.F. Roscigno. 1996. Ecological consequences of environmental perturbations associated with offshore hydrocarbon production: A perspective on long-term exposures in the Gulf of Mexico. *Can. J. Fish. Aquat. Sci.*, 53(11): 2637-2654.

Platt, WR. 1969. *Color Atlas and Textbook or Hematology*. Lippincott Company, Philadelphia, PA. 445 pp.

Porter, E.L., J.F. Payne, J. Kiceniuk, L. Fancey, and W. Melvin. 1989. Assessment of the potential for mixed-function oxygenase enzyme introduction in the extrahepatic tissues of cunners during reproduction. *Mar. Environ. Res.*, 28: 117-121.

Rivkin, R.B., R. Tian, M.R. Anderson, J.F. Payne and D. Deibel. 2000. Ecosystem level effects of offshore platform discharges – identification, assessment and modeling. In: Penney, K.C., K.A. Coady, M.H. Murdoch, W.R. Parker and A.J. Niimi (eds.). *Proceedings of the 27th Annual Aquatic Toxicity Workshop*: October 1-4, 2000, St. John's, Newfoundland. *Can. Tech. Rep. Fish. Aquat. Sci.*, 2331: 3-12.

Rushing, J.H., M.A. Churan and F.V. Jones. 1991. Bioaccumulation from mineral oil-wet and synthetic liquid-wet cuttings in an estuarine fish, *Fundulus grandis*. *SPE Health, Safety and Environment in Oil and Gas Exploration and Production Conference*, 11-14 November 1991, The Hague, Netherlands.

Seaconsult. 1998. *Distribution of Well Cuttings and Produced Water for the Terra Nova Development*. Prepared for Terra Nova Alliance, St. John's, NL by Seaconsult Marine Research Ltd., Vancouver, BC. 40 pp. + App.

Singsaas, I., H. Rye, T.K. Frost, M.G.D. Smit, E. Garpestad, I. Skare, K. Bakke, L.F. Veiga, M. Buffagni, O-A Follum, S. Johnsen, U-E Moltu and M. Reed. 2008. Development of a risk-based environmental management tool for drilling discharges: Summary of a four-year project. *Integr. Environ. Assess. Mgmt.*, 4(2): 171-176.

Smit, M.G.D., K.I.E. Holthaus, H.C. Trannum, J.M. Neff, G. Kjeilen-Eilersten, R.G. Jak, I. Singsaas, M.A. Huijbregts and A.J. Hendriks. 2008. Species sensitivity distributions for suspended clays, sediment burial, and grain size change in the marine environment. *Environ. Toxic. Chem.*, 27(4): 1006-1012.

Sokal, R.R. and F.J. Rohlf. 1981. *Biometry*. Second Edition. W.H. Freeman and Company, New York, NY. 859 pp.

Suncor Energy. 1996. *Development Application: Terra Nova Development. Environmental Impact Statement*. St. John's, NL.

Suncor Energy. 1997. *Development Application: Terra Nova Development. Environmental Impact Statement – Addendum*. Prepared by Jacques Whitford Environment Limited for Suncor Energy. St. John's, NL.

Suncor Energy. 1998a. *Terra Nova Baseline Characterization Data Report*. Prepared by Jacques Whitford Environment Limited for Suncor Energy, St. John's, NL. 17 pp + Appendices.

Suncor Energy. 1998b. *Environmental Effects Monitoring Program. Document No. TM-IM-EV02-X00-001)*. Prepared by Jacques Whitford Environment Limited for Suncor Energy, St. John's, NL. 99 pp. + Appendices.

Suncor Energy. 2001. *2000 Terra Nova Environmental Effects Monitoring Program*. Prepared by Jacques Whitford Environment Limited for Suncor Energy, St. John's, NL. 147 pp. + Appendices.

Suncor Energy. 2002. *2001 Terra Nova Environmental Effects Monitoring Program*. Prepared by Jacques Whitford Environment Limited for Suncor Energy, St. John's, NL. 194 pp. + Appendices.

Suncor Energy. 2003. *2002 Terra Nova Environmental Effects Monitoring Program*. Prepared by Jacques Whitford Environment Limited for Suncor Energy, St. John's, NL. 235 pp. + Appendices.

Suncor Energy. 2005. *2004 Terra Nova Environmental Effects Monitoring Program*. Prepared by Jacques Whitford Environment Limited for Suncor Energy, St. John's, NL.

Suncor Energy. 2007. *2006 Terra Nova Environmental Effects Monitoring Program*. Prepared by Jacques Whitford Limited for Suncor Energy, St. John's, NL.

Suncor Energy. 2009. *2008 Terra Nova Environmental Effects Monitoring Program*. Prepared by Jacques Whitford Stantec Ltd. for Suncor Energy, St. John's, NL.

Suncor Energy. 2011. *2010 Terra Nova Environmental Effects Monitoring Program*. Prepared by Jacques Whitford Stantec Ltd. for Suncor Energy, St. John's, NL.

Timashova, L.V. 1981. Seasonal changes in the structure of the liver of the plaice, *Pleuronectes platessa*. *J. Ichthyol.*, 21: 145-151.

Ueda, T., Y. Suzuki and R. Nakamura R. 1973. Accumulation of Sr in marine organism – I strontium and calcium contents, CR and OR values in marine organisms. *Bull. Jap. Sci. Fish.*, 39: 1253-1262.

Wang, Y.-G. and M. Zhu. 2006. Rank-based regression for analysis of repeated measures. *Biometrika*, 93: 459-464.

Warwick, R.M. and K.R. Clarke. 1991. A comparison of some methods for analyzing changes in benthic community structure. *J. Mar. Biol. Assoc. UK*, 71: 225-244.

Warwick, R.M. and K.R. Clarke. 1993. Increased variability as a symptom of stress in marine communities. *J. Exp. Mar. Biol. Ecol.*, 172: 215-226.

Whyte, J.J., Jung, R.E., Schmitt, C.J. and D.E. Tillitt. 2000. Ethoxyresorufin-O-deethylase (EROD) activity in fish as a biomarker of chemical exposure. *Critical Rev. Toxic.*, 30(4): 347-570.